A Demonstration Unit for Human Centric Lighting

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2017

MASTER THESIS

Human Centric Lighting

A Portable Demonstration Unit

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Published by

Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

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Division of Product Development, Department of Design Sciences
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Abstract

The modern human being is exposed to different kinds of light during a normal day, both natural light and adjusted lighting. The idea that light affects us is uncontested, and so affecting the light in turn becomes a question of well-being. It is often thought that abundant and strong lighting is good lighting, but this is far from always accurate. Moreover, the light from a regular lightbulb is in this case often assumed as the perfect light, which is seldom the case since, among other things, it differs from natural light.

The light bulb, and its lighting possibilities, spawned from a strictly technical solution to a rather straightforward problem – being able to see well enough to work, read, write, draw, etc. Today, however, we are capable of creating a light based on people's needs, using technology to benefit the human mind and not the other way around.

Good lighting can be adapted in more ways than just an on/off-button; being able to adjust intensity with a dimmer is a suitable first step. The next step would be to vary the composition of the light, allowing different colour tints to be amplified. A favourable light environment brings many benefits that, when it comes to life cycle assessment, often play a larger part than focus on energy consumption.

Future by Lund (FBL) located at Ideon Innovation, has, along with a number of other organisations, been involved in projects involving dynamic light. Several installations with beneficial lighting have been mounted in schools, care homes, healthcare establishments and offices, providing a salubrious indoor environment for the people involved. Now they were looking to further extend the concept with fixtures designed specifically to be temporary, resulting in this master thesis. The project's development gave rise to a concept of two different designs, each with two different possible installation methods.

Keywords: Human Centric Lighting (HCL), dynamic light, circadian rhythm, melatonin, colour composition, demo lights

Sammanfattning

Den moderna människan vistas i olika typer av ljus under en normal dag, både naturligt och anpassat ljus. Att ljus påverkar oss är oomtvistat, och att vi i tur kan påverka ljuset blir därför en faktor för välbefinnande. Idag är det ofta som rikligt och starkt ljus anses vara ett bra ljus, men detta stämmer långt ifrån alltid. Dessutom utgår man ofta från att ljuset från en glödlampa är det perfekta ljuset, så är dock sällan fallet då det bland annat skiljer sig från naturligt ljus.

Ljuset från en glödlampa togs fram utifrån en teknisk lösning på ett relativt grundläggande och elementärt problem – att kunna se tillräckligt bra för att jobba, läsa, skriva, eller rita inomhus. Idag har vi emellertid möjlighet att skapa ett ljus utifrån våra behov, att använda tekniken till människans fördel och inte tvärtom.

Ett bra ljus kan anpassas på flera olika sätt än en på/av-funktion; att kunna ställa in ljusintentiteten med en dimmer är ett lämpligt första steg. Nästa steg är att kunna variera ljustets sammansättning genom att låta olika färgtoner förstärkas. Med en god ljusmiljö uppnås många positiva effekter, som vid bedömning av livscykelkostnader ofta är av större vikt än ett fokus på energiförbrukningen.

Future by Lund (FBL) vid Ideon Innovation har, i samarbete med ett antal andra organisationer, varit involverade i projekt inom just dynamiskt ljus. Ett flertal demonstrationsmiljöer med hälsofrämjande ljus har installerats inom skolor, äldrevården, sjukvården och kontor, och därmed försett de involverade med en god inomhusmiljö. Nu önskade de vidareutveckla konceptet till att även innefatta armaturer som är speciellt framtagna för att vara tillfälliga, vilket är vad detta examensarbetet gick ut på. Konceptet som projektet i slutändan gav upphov till innehåller två utformningar, vardera med två olika installationsmetoder tillgängliga.

Nyckelord: Human Centric Lighting (HCL), dynamiskt ljus, dygnsrytm, melatonin, färgkomposition, demobelysning

Preface

There are some people who deserve a special mention here, because without them this report would just be a blank document with a logo on top:

Thank you to my supervisor and co-supervisor, Axel Nordin and Fredrik Malmberg, who have both been tremendously helpful and also put up with my incessant (and sometimes dumb) questions.

Thank you to Hillevi Hemphälä for an educational seminar and for trying to find time for an interview when your schedule was so full.

Thank you, Alexander Weiland for helping me with my prototype even though you don't work in lighting anymore and had to help me on your time off.

Thank you, coordinator Cilla Perlhagen for being helpful and supportive when things took an unexpected turn right at the start. Oh, and for, you know, coordinating.

Thank you, Kristina Hansen for offering me a perspective from the healthcare industry in my focus group.

Thank you to Michael Moscrop, my cohabitant and partner in crime, for not just putting up with me but also offering help when things got stressful. I know I can be a pain.

Thank you also to Olaf Diegel, Hanway Tran, Kristian Axelsson, and the Workshop guys in IKDC and A-huset.

Lastly, thank you to my family for supporting me, and for spending Christmas with this grumpy face.

Lund, January 2018

Cornelia Cronström

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List of acronyms and abbreviations

FBL	Future by Lund
HCL	human centric lighting
HR	human resources
LED	light-emitting diode
MDF	medium-density fibreboard
MVP	minimum viable product
PoE	power over ethernet
Ra	colour rendering index
RGB	red-green-blue
ROI	return on investment

1 Introduction

This chapter presents the background and essential features of the degree project.

1.1 Background

1.1.1 **Human Centric Lighting**

Research indicates that blue light with a wavelength peak at 470 nm increases our levels of the hormone cortisol, resulting in a stimulating effect. There have also been indications that patients with Parkinson's disease tend to navigate better in green light at around 530 nm. Moreover, there is strong suggestion that the various wavelengths from the sun affect us differently, and can be advantageous if exposed to at different times of the day. [1]

The demonstrations supplied indirectly by FBL, described in the abstract above, provide a sense of where and what we can reach with today's technology, but may also serve as inspiration to the potential that exists in the future of lighting.

Dynamic lighting is still breaking into the market, and the main reservations about acquiring it usually revolve around budget and costs. [2] It is perhaps understandable that facility managers and the like are sometimes sceptical to an investment that is difficult to calculate, and that doesn't offer a clear holistic view of the benefits versus drawbacks.

However, an installation may not be as costly as one might initially assume. The demo-trials have suggested that dynamic light brings a variety of health benefits, ranging from residential homes having fewer accidents, to workers experiencing a higher level of overall efficiency and needing fewer total days of sick leave. Moreover, converting to HCL at a time when renovations are already due, appears to only increase installation cost by a fraction. [2]

1.1.2 **Future by Lund**

FBL is a platform for innovations regarding sustainable and smart development in cities and towns. It is based in Lund and consists of several projects relevant to issues in a global perspective, often in cooperation with Lund municipality (Lunds kommun). Projects include new solutions within public transport, business models for renewable energy, and optimising public spaces, to name a few. [3]

1.2 Objective

The purpose of this degree project was to design a portable Human Centric Lighting solution, one that can be installed with ease and mediate the experience of dynamic lighting. The idea being that more potential users of HCL may sign up for a trial period if the installation wasn't too elaborate or didn't take too much time, as well as perhaps not being too costly. A demo installation would allow people to test dynamic lighting in their facility and delay any decision making until later. The solution would be aimed at facility managers or Human Resources (HR) – responsible parties of buildings and offices – who have not yet decided to try HCL either because of ambivalence or because they simply haven't known about it. The *users*, however, would be the people housed in the building: Workers, patients, students, teachers etc.

A lighting system consists of three main parts at this time: The "button", the "computer" and the "lamp" – that is, a panel or remote control enabling the user to manipulate the light; a driver and what other equipment may be needed to communicate with the light; and a fixture. [1] Not all three of these components had to be designed, but the resulting product had to be developed with this structure taken into account.

A bonus would be if the product developed could communicate a notable difference between dynamic Light Emitting Diode (LED) lighting and old fashioned incandescent light, either expressed in the design language of the aesthetics, or in the interface somehow. Often when HCL is being used no visible difference is noticed until a traditional light bulb, with its yellow light, is turned on for comparison.

The objectives of the project originally put forward in the goal specification were the following:

- An understanding of the structure and function of the HCL system.
- Examine the target group's behaviour and needs.
- Determine the requirements for a portable lighting solution.
- Generate portable solutions which are elegantly compatible with designed light cover and integral with current working/studying atmosphere.
- Investigate different material alternatives for HCL, as well as doing a cost analysis.

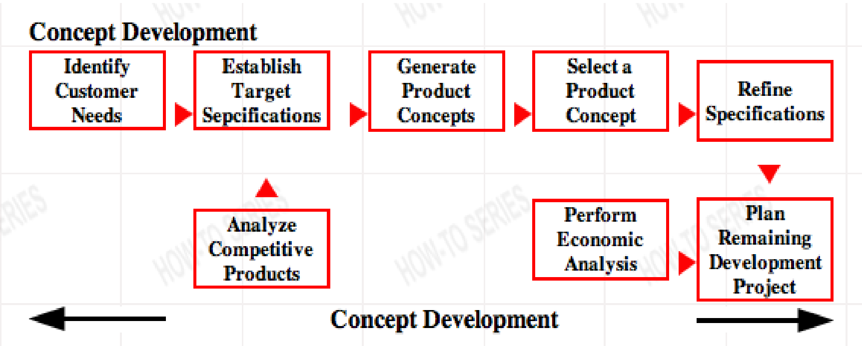
This degree project left a lot of freedom and flexibility, with the option to tailor the assignment based on what was plausible and what ideas came up. Certain aspects were altered along the way. For example, due to a change in circumstances after the goal specification was written, less focus was going to be put on the practical details such as cost analysis and material options, and more spent on the general design and aesthetics.

Other delimitations of the project were:

- Less customer research in the early stages:
  A judgement call was made that surveys or large-scale interviews would not fetch a lot of useful information, since HCL and dynamic lighting were still relatively new and unknown to the public, and people don't necessarily take notice of what light fixtures they have at work or in school.
- Although reflections on environmental aspects were present during the project, as they probably are in the mind of every designer today, the demo product had fairly specific demands of being easily mounted. As a result of this, functional demands were prioritised over environmental considerations.
- Some detailed analyses were made, such as calculating battery weight and attaching LED lights to an RGB-controller, but the initial aim of the project was not to consider the physics so much but rather to centre on the overall functional design and what could be provided aesthetically.

1.3 Method

The principles for developing the concept, as described in the goal specification, were to follow the approach proposed in *Product Design and Development* by Ulrich & Eppinger, with certain modifications. [4, Exhibit 2-3]



First, customer needs are identified and then translated into target specifications. In a sense the target specifications represent the hopes of the development team, and are later refined during the process. After this, concepts are generated through, for example, exploration and brainstorming. Concepts are then selected, which can be done in several steps, and tested to see if the initial needs are met, in order to refine the specifications and move on to the rest of the project.

1.4 Chapter run-through

1.4.1 **Chapter 1 - Introduction**

Chapter 1 includes a description of the methods used in this degree project, as well as a peek into the background of the organisation FBL and the concept of HCL. It also describes the initial objective of this Master Thesis project

1.4.2 **Chapter 2 – Problem analysis**

The second chapter describes in detail the issues that formed the basis of the degree project, and moves on to investigate and research the situation on a deeper scale. A vital part in establishing the requirements for the design process.

1.4.3 **Chapter 3 – Execution**

The work takes off properly with two cycles of concept generating, as well as concept evaluation, selection and prototyping.

1.4.4 **Chapter 4 – Additional Research**

This chapter takes us through new ideas and information that arose towards the end of the project, for example through a focus group/group interview being held with the prototypes and a small presentation.

1.4.5 **Chapter 5 – The Final Result**

The information retrieved in chapter 4 is taken into account and the final adjustments are made.

1.4.6 Chapter 6 – Discussion and Reflections

In the sixth chapter the outcome of the thesis work is discussed, entertaining thoughts on what might have been different under other circumstances, as well as what could have been done better.

2 Problem analysis

Before generating solution concepts, both aesthetic and functional ones, a significant amount of research was needed. This step was nearly as big as, if not bigger than, the execution phase.

2.1 Research methods

Background research consisted of many different actions. Current solutions and components were investigated, material from relevant past courses were repeated, information on the subject of HCL was gathered, etc. Because dynamic lighting still seemed to be relatively unknown to the public (which later research would confirm), the decision was made not to conduct customer research in the form of surveys or large-scale interviews this early on in the process. Instead, the main tools used were observations and face-to-face interviews with people working in related fields.

2.2 Theory

Because of the variation in the sunlight over the course of the day, natural daylight regulates our circadian rhythm which in turn plays a vital role in our health and energy levels. The circadian clock is an important part of human biology, so much so that the 2017 Nobel Prize winners in Physiology/Medicine was awarded for research on it. Despite the importance of sunlight, a large part of the population spends about 90 % of their time indoors and therefore miss out on the possible benefits of this process, potentially leading to drawbacks such as lethargy and sleep deprivation. [5;6]

It may not be easily noticeable, but daylight is of a colder, bluer colour temperature in the morning (NB, *Perceived* as colder but actually a higher colour temperature in numerical value) and a warmer-feeling, redder, more cosy hue in the later parts of the day. Human beings, not to mention other animals on the planet, have evolved around this daily cycle and adapted their body clock to it, meaning that the properties of the light affect our alertness and hormone levels. This is why, for example, it is not recommended to spend too much time on our mobile phones at night, as the light emitted from the screen is normally of a blue tint, inhibiting our production of melatonin (sleep hormone) and disrupting our sleep pattern. Furthermore, there are studies indicating that exposure to more than two hours of blue light every evening increases the risk of depression. This risk is thought to increase with wider screens and proximity to the eyes. [5;7]

Dynamic lighting refers to the ability to change the indoor light to your preferences, namely to mimic the cycle of the sun's light by making it more intense and blue in the morning and closer to the red part of the spectrum towards the evening. This is achieved using software and a driver to control the colour and intensity of the light. Spending the day in this tailored light will block melatonin production in the morning, improving alertness, and allow a gradual enhancement of the same during the afternoon and evening, increasing the chances of a good night's sleep. It can also lead to other health benefits over time. [5]

We may not always think about it, but Europe, and the Nordic countries in particular, are located very far to the north on this globe. At 55° latitude, which runs through the south of Sweden and is relatively "southern" for Scandinavia, the south hemisphere equivalent barely encounters any landmass. By comparison, the 65th parallel north passes just north of Skellefteå and through the Finnish town Oulu, while its south hemisphere equal crosses the Antarctic peninsula. Looking at these coordinates on a map shows just how far away from the equator Sweden and its Nordic neighbours really are. [8]

So even though the climate here may be warmer than on the Antarctic peninsula, the hours of sunlight received during the winter months are exiguous. This lack of light, as well as the interchange between bright summers and dark winters, can have an impact on health and disease. For example, type 1 diabetes is more common in Sweden and Finland than in mainland Europe where the daylight distribution is more even. In fact, on record this type of diabetes is more prevalent in these two countries than anywhere else in the world. [5]

Good indoor lighting is, therefore, not just about imitating the variation of outdoor light, but also about providing the amount humans need when the season fails to or when a lot of time is spent indoors. Other aspects closely connected with HCL are Visual Ergonomics – looking at how artificial light may affect us through flicker and glare – and Measurability – which methods are best for measuring both indoor and outdoor light. Good indoor lighting has little to no flicker, doesn't cause glare or strong contrasts (see section 4.2.1.), and has a Colour Rendering Index (Ra) as close to 100 as possible. The lowest index found is 80, as lights with an Ra lower than that are not allowed on the market. Intense light increases alertness but if too intense it will cause headaches. [9-11]

Dynamic lighting is usually set up using LED lights. LEDs have been in production since the early 60s, and their light comes from electrons emitting energy in the form of photons. Aside from lamps and screens, the diodes can also be used as transmitting elements in remote controls. They have a range of benefits, such as low energy consumption, longer life than incandescent lights, very little heat radiation, and a wide colour spectrum. They do come with disadvantages as well, though. Voltage sensitivity, for example, meaning that changing the voltage reduces the lifetime significantly, and the price per lumen is relatively high. Moreover, using them in outside applications such as traffic lights means they will not melt snow that may land on them in winter, because of the low heat. [12]

2.3 FBL contact

One of the biggest sources of information and product demands was the co-supervisor Fredrik at FBL, demo coordinator of these lighting projects. A lot of intelligence for shaping the consumer needs was drawn directly from him.

Fredrik explained that one big reason why people were sceptical to acquiring dynamic lighting was because an investment was hard to calculate when it came to balancing the books. They fear a costly and complicated installation with little visible result. They also sometimes imagine that setting up the light curve along with the driver and control panel requires an expert programmer, making an installation even more intricate. As it happens, the physical installation may take a little time but according to [2] the software part is easier than one might think. So instead of two installers, it would be perfectly possible to have just one who is a little bit specialised in HCL. This training would not need to be extensive, but even installers like these are few and far between at the moment.

[2] likened the scepticism with when the automobile was invented. People were hesitant toward such a new concept. They didn’t want cars, they wanted faster horses. In a similar manner today, people don’t always want to step outside their comfort zone, but just want the existing solution to be improved. For this reason, sometimes an installation will be made while keeping the old lighting fixtures, if possible. That way, the users can switch between their old incandescent lighting and the new more natural lighting. After trying the dynamic lighting, the consumers always turn to using it all the time and almost never switch back to the old lighting. The exception was one case where they changed back because of a faulty fixture in the new installation, but after this was rectified the new lighting was used again. [2]

Based on this information, it seemed to come down to designing a solution that was temporary but still offered the same quality of light and functions as the current solution, so the users don’t feel like they’re downgrading from the more permanent choice. It would be beneficial if the installation was easy and/or quick, in order to eliminate ambivalence around an elaborate installation, and since the solution would be temporary it would be a plus if it didn’t leave any damage or major changes when it was taken out, such as opening a wall to draw new cables.

To set up the dynamic light, a driver is needed, as well as the lamp itself, and a remote control or control panel. [2] An example of a driver they keep at the office of FBL was about 400 cm^3 in volume and weighed 212 g. At the moment, everything was connected with cables, even the control panel fixed mid-height on the wall by the door.

A look above the acoustic ceiling showed that there was lots of room to manoeuvre in the "void" and that indeed power sockets could be drawn and placed there for closer proximity to the lights.

The offices at FBL was also one of many places where dynamic light could be observed, the different colour temperatures and intensities could be noted and comparisons to traditional lighting could be made. It is hard to explain in words, or indeed pictures, the difference between incandescent light from light bulbs, or fluorescent light tubes, and HCL from LEDs. There is, however, a distinct change when switching between the two. Traditional lighting suddenly feels very yellow, while the LED light feels more neutral, natural and less invasive. Without that deliberate comparison, though, HCL can go unnoticed if you don't know it's there.

3 Execution

This chapter describes the active part of the design process, from when the requirements were established, to concept generating, concept selection and the making of prototypes.

3.1 Concept generating.

The needs and demands from the investigation could now be defined, as seen in table 3.1. Each function was assigned a letter based on whether it was the main function, desirable, or even crucial to the project. There was some speculation as to whether 'Emit dynamic light' should have been the main function, as this is the task FBL have taken upon themselves to provide. In the end, 'Temporary installation' was picked as the main function since it is the basis of this project, and the function of mediating dynamic light was labelled crucial instead.

Table 3.1 Function Needs.

Description	***Main/Crucial/Desirable function***
Temporary installation	Main
Same or equivalent as permanent installation	Desirable
Emit dynamic light	Crucial
Easy installation	Desirable
Quick installation	Desirable
Cause no permanent damage or structural changes	Desirable
Applicable in any type of room	Desirable

Idea generation began with a lot of rough sketches. Some inspiration was drawn from personal experience, as well as observing lights and lamps from surroundings.

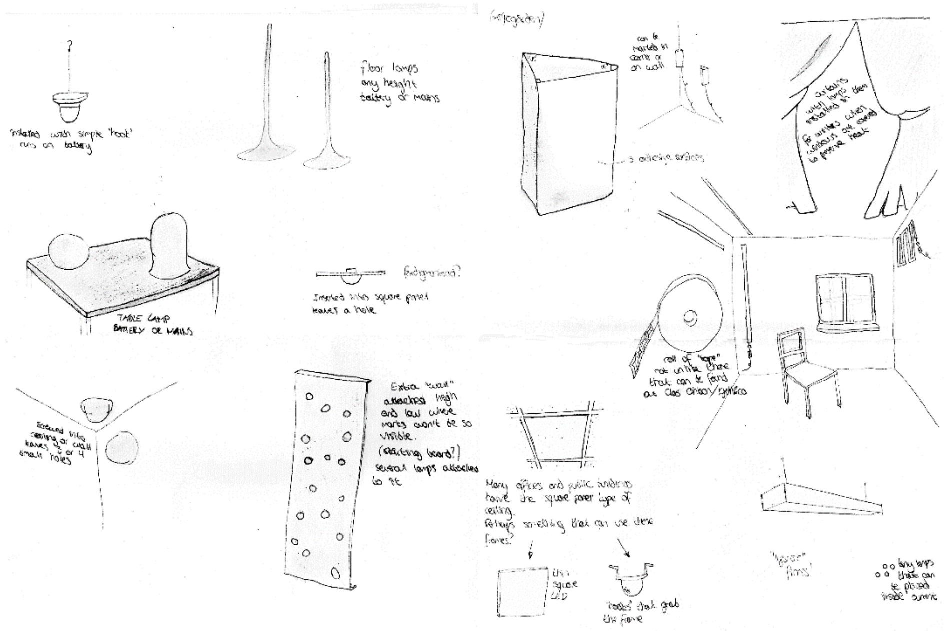


Figure 3-1 Extract of sketches during concept generation. Image has been heavily edited to enhance contrast and visibility.

Concept generation was done in two cycles. The first cycle consisted mainly of internal searching, brainstorming, with plenty of sketching paper. After the first cycle, sketches were organized and combined to go through evaluation and feedback from the supervisors and contacts involved at Ideon. Then followed a second cycle of concept generation where the ideas that had received positive feedback were developed further and a few new concepts brought in. Thus using both an external search and reflection.

After further discussions the concepts were narrowed down to just a handful, based on their fulfillment of the function needs.

3.1.1 **Concept A**

A hanging lamp that runs on battery and installed with a simple hook in the ceiling. The only mark left after removal is the small hole of the hook.

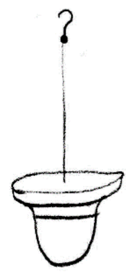


Figure 3-2 Concept A

3.1.2 **Concept B**

A tall extra “wall segment” that attaches high and low on the existing wall, perhaps using the skirting board along the floor, so that marks from installing it won’t be so visible. Several individual lamps will be attached to it and cables and suchlike won’t be visible behind it.

In the second cycle of concept generation this design was evolved to imitate a picture or a painting. It could be a large screen leaning on the wall or a smaller one to hang up, working as decoration as well as lighting.

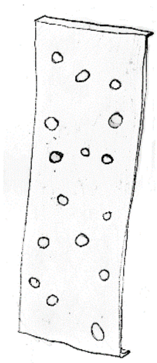


Figure 3-3 Concept

3.1.3 **Concept C**

A lamp already inserted into one of the square 60x60 ceiling panel that a lot of offices use. This *would* leave a hole in the panel itself but if the fixture came already mounted on a panel, and was removed together with it after, this would not make much difference.

A fixture that uses the framework of drop ceilings to attach, perhaps with some sort of hooks. Battery powered. A rather vague idea from the first concept generation cycle.

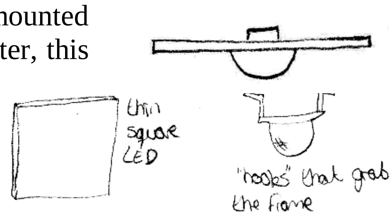


Figure 3-4 Predecessors to concept C

These two concepts were combined in the second concept generation cycle to create a thin square battery-powered LED panel that is just simply placed in one of the existing ceiling slots.

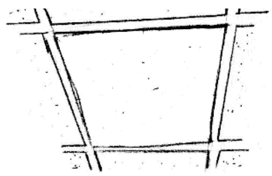


Figure 3-5 Concept C

3.1.4 **Concept D**

A strip on a roll of “tape” that can be attached anywhere with glue, much like cellotape. This allows for flexibility in placement and is also very bendable, allowing it to be placed in awkward spots. However, the need for a driver and software to make the light dynamic may counteract this flexibility somewhat.

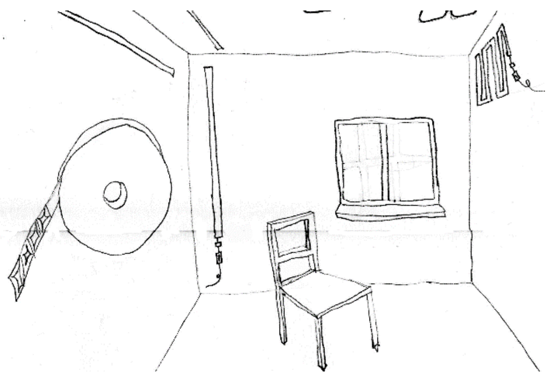


Figure 3-6 Concept D

3.2 Concept screening and selection.

In the *Product Design and Development* literature, many methods of picking a concept are presented, such as intuition, multivoting, web-based surveys and prototype testing. [4, chapter 8] This project combined the methods of intuition and external decision with a decision matrix. First, a concept screening was made according to table 2.2 below. After this, the ideas were discussed with contacts, mainly the supervisor at the organisation, to come to a final decision together.

The decision matrix used was one where the concepts are compared to the standard current solution in each of the functions desired, and given a plus if better, zero if equivalent, and minus if worse. The columns are then added up. Giving one point for a plus and removing one point for a minus, thus receiving a score. Concept C would only be fitted in rooms with an acoustic ceiling as it is based on the 60 by 60 framework found there, however current non-portable installations are already fitted in these [1;7] and Concept C was therefore given a zero in the applicability function.

Table 3.2 Concept Screening.

Description	***Concept A***	***Concept B***	***Concept C***	***Concept D***
Temporary installation	+	+	+	+
Same or equivalent as permanent installation	0	0	0	-
Emit dynamic light	0	0	0	0
Easy installation	+	+	+	+
Quick installation	+	+	+	+
Cause no permanent damage or structural changes	-	+	+	0
Applicable in any type of room	+	+	0	+
Net score	3	5	4	3
Develop	No	Combine	Combine	No

Concept D was given a minus in the second function, as the placement of the strip and the thinness of it may or may not limit the quality and amount of light emitted. It was also given a zero in the permanent damage category, as there is no telling this early on if removing the strip with the glue could damage furniture, walls, ceilings or wallpaper. The glue would likely have to be made quite strong in order to support the driver as well as the lights, depending on what the design would come to be, and this damage would be quite visible as opposed to hidden behind a drop ceiling. However, the damage was estimated to be relatively small and Concept D was given a zero instead of a minus.

Concept A was given a minus in the permanent damage category, as removing it would leave a hook, or even a hole, in the ceiling. It would probably not be a big hole, or a big deal, but it would be visible. All concepts were given a zero in dynamic light as there would be no point in developing the product if the light could not have been made dynamic in the first place. They were also all given a plus in the temporary category, since all four concepts were more temporary than current installations.

Before making the final decision, the concepts were discussed with some external parties and then brought to the contact at FBL for external opinion. There the choice was made, based on the received external feedback, the concept screening above, and a bit of intuition, to develop both concept B and C as a complement to one another.

3.3 Sketching, further defining and prototyping

Now followed a time of further developing the chosen concepts. The main product was going to be a wireless 60 by 60 ceiling panel that could simply be placed in the frame of a standard acoustic ceiling, with the complement of a light that could be hanged on the wall in a painting-like manner. The wall fixture would play a more aesthetic part and would also work in rooms that didn’t have drop ceilings. Both units would come pre-installed with the light curve and a battery powered control panel to fix on the wall.

The ceiling panel was the product with the most restrictions, and investigation was needed to determine if it was plausible with regards to weight and battery power.

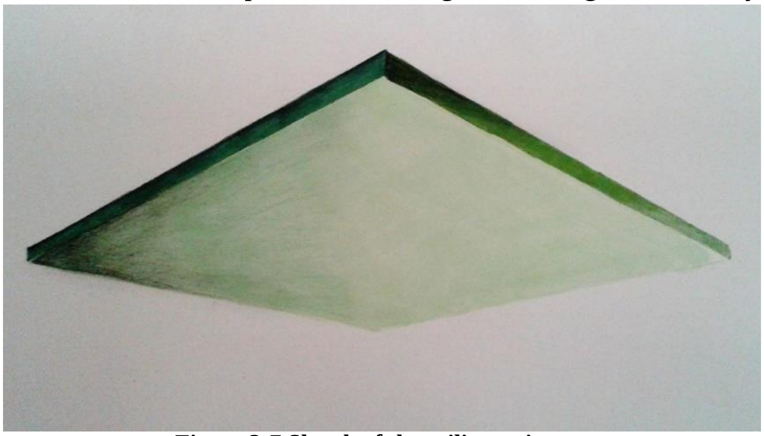


Figure 3-7 Sketch of the ceiling unit

According to Saint-Gobain Ecophon, one of the biggest manufacturers and distributors of acoustic ceilings in Sweden, the majority of their ceilings have a maximum recommended load of 83 Newtons (8.45 kg) in the case of a load distributed over 0.36 m². This recommendation it calculated with a multiple safety margin and can be exceeded a little bit if, for example, dynamic load is avoided, individual loads are separated by more than 1 meter, hangers are located more closely together etc, but it is a good number to try and stay within. [13]

The biggest part factoring into the weight of the lamp would be the battery. Assume we want a battery to last a month, and 9 hours a day, this would make

$T = 9 \cdot 30 \cdot \frac{5}{7} = 192.8571$ working hours in a month, not counting bank holidays. Now let's think that we want one lamp unit to emit 500 lumens, and that the power of the whole LED+driver system has a light efficiency of 70 lumen/W. This gives us

$$\frac{500}{70} = 7.1429\ W$$

per unit. Hence $192.8571 \times 7.1429 = 1377.559\ Wh$ for one lamp unit and one month. Now let's look at the possible energy densities for batteries out there. Like many other fields, battery technology is constantly improving and evolving, meaning that you won't necessarily acquire consistent information from different sources.

Smartphone batteries are, according to one source, supposed to have a specific energy of 229 Wh/kg. Other sources state that Lithium-ion batteries (which is often what smartphones use) have between 100 and 243 Wh/kg specific energy, with the 18650-type offering 181.8-265.3 Wh/h. Lecture material from an electronics course at the Lund Institute of Technology states that Lithium-ion batteries can have a specific energy of up to 250 Wh/kg, with new technology emerging where Li-ion batteries will reach 250-330 Wh/kg, Li-metal will have 160-380 Wh/kg, and Zinc-Air batteries reaching an impressive 320-530 Wh/kg. This particular lecture being a couple of years old, it is entirely possible that existing technology has moved closer to those numbers. [14-16]

The capacities and specifications found on the internet often refer to cutting edge, and not necessarily the technology that can be easily obtained on the current market. Nevertheless, given these sources it seems reasonable that a battery with a specific energy of 220 watt-hours per kilogram would be obtainable. This gives us the battery mass of $\frac{1377.559}{220} = 6.2616$ kg. Rounded up to 6.3 kg.

In 2013, the technology giant Philips “broke the 200 lumens/watt barrier” by developing the so called TLED prototype. It was, by their books, the most energy efficient existing lighting technology at the time. On the more modest side, their RL tube emits 100-110 lumens/W and their “regular” LED bulb gives 76 lm/W. [16] It is therefore conceivable that a LED+driver system with 75 lm/W could be obtained without too much hardship, and perhaps an even better one in the future.

This would give us a battery weight of

$$\frac{500}{75} \times \frac{192.8571}{220} = 5.8442\ kg$$

Rounded down to 5.8 kg.

A driver’s weight varies depending on material and function but the one kept at FBL for measure weighs 212 grams. [1] To add a bit of a margin 300 g is estimated.

A module for wireless communication weighs almost nothing and is practically negligible in the weight calculations. One example is a Zigbee product from Digi International which weighs 6.8 grams. [18]

For the lamp unit to stay within the recommended margin, the shell, wires, diodes and potential opalized disc need to weigh a maximum of 2.3 kg.

The wall mounted unit did not have the same weight restrictions as the ceiling mounted one. It was meant to have a more aesthetic touch, and the idea was that the user could choose the look they wanted. It was, in this part of the process, also meant to be wireless, with the option of being small and hanging on the wall or large and leaned towards it. This way it would be like an actual painting or artwork.

Figure 3-8 Example of wall mounted unit

Developing two complementing concepts, one which may come in different looks, provides the consumer with a choice. Having a choice is normally good, but there needs to be structure in order to avoid confusion and even frustration. Perhaps the best system for providing these lights is through some form of subscription. The consumer can sign up for a six-month trial, the trial period being the actual product, and recommendations are provided along with the choice of which fixtures to acquire. This would also eliminate the issue of having to change the batteries, as new lamps with fresh batteries can be brought in every month and the old ones taken

Figure 3-9 Crude cardboard model of the ceiling fixture

away for charging, minimizing efforts for the user. It would be in line with having the daylight curve pre-installed.

Prototypes were constructed in this step as well, mainly to be able to use them in a focus group later on, see chapter 4. First, simple models were made in cardboard, just to get a feel for the intended product and a sense of what the later prototypes would need. Later, more advanced prototypes were built, where the aim was to create a Minimum Viable Product (MVP), in short, a prototype just close enough to the real product to show the rough features and be able to receive feedback. This was suggested by the supervisor at FBL, who made the judgement that making a perfect lamp was an unreasonable task.

Figure 3-10 Cardboard model of wall mounted lamp

To this end, the prototypes were not fitted with a driver or dynamic light, but just made to show the look and the principle of the imagined concept. LED-strips with white light were soldered with a receiver for a remote control and attached to a 12V AGM battery. For the ceiling mounted unit a steel frame was made to represent the framework, and the skeleton of an existing lamp was acquired. The LED-strip was fitted inside this skeleton, with an opalized plate to scatter the light evenly. For the wall mounted unit a shell was made by vacuum forming acrylic, and painting it from the inside to make it less transparent. To make this shell, a mould had to be made in MDF and then the acrylic was forced into position around it, before removing the MDF mould. The LED-strip was attached inside this shell along the edges, and the receiver and battery were placed near the edges as well.

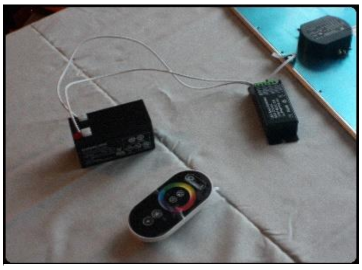


Figure 3-11 Battery (left) attached to a receiver, in turn attached to the LED-strip.

Figure 3-12 Prototype of wall mounted lamp

Figure 3-13 Prototype of ceiling mounted lamp

Figure 3-14 Steel frame 60 x 60

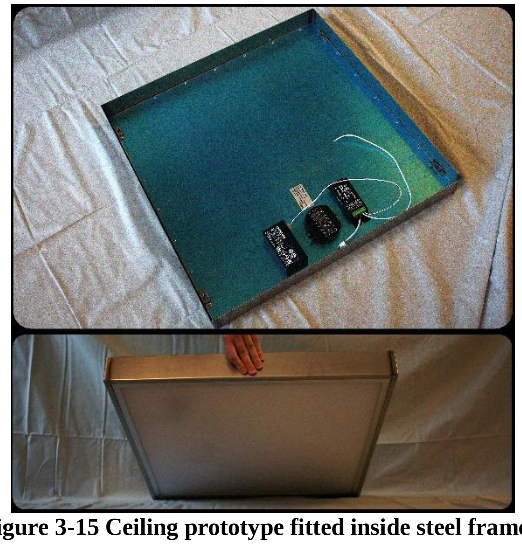


Figure 3-15 Ceiling prototype fitted inside steel frame

4 Additional Research

This chapter describes, in detail, the information extracted from a focus group held towards the end of the project. There is also a recap of an interview held with an expert in Visual Ergonomics.

4.1 Focus group

When the execution phase was nearing its end, and the prototypes were almost complete, a focus group was held. Despite being a relatively small focus group, a lot of useful information and observations were extracted from it. The group consisted of five participants of varying ages, two of which worked for large companies in the private sector. Another two worked in the public sector, one in a government office and the other being a Doctor of Medicine, and one participant was self-employed. This provided a rather diverse perspective.

The session started by gauging what the participants knew about HCL and dynamic lighting already, and what they thought it may involve. This was followed by a short presentation on the concept and theory of HCL, and then by a not so short discussion about the participants' reactions and feelings about the concept. First before and then after introducing the solution and prototypes of this project.

4.1.1 Previous knowledge on Human Centric Lighting

As it turned out, none of the participants had heard of HCL before, at least not in name. One of them, who works in healthcare, had heard a lot of talk about "improving the lights" at their workplace. This might not refer to dynamic light or HCL, but indicates that there may be an interest in lighting and fixtures on an individual plane, at least in the public sector.

A couple of the participants said they would guess that HCL was user centric, as in adapted to the convenience of a human as opposed to the architecture. They knew, for example, that people were aware of the problems with lack of daylight and thought it may have something to do with winter or darkness, but not human biology.

One person described how they were using a programme called F.Lux on their work computer, a software that adjusts the screen's colour temperature according to the time of day as a reminder not to stay up late at night. Another participant said they would have guessed that HCL was about mood lighting to put people in a happy mood, but only short term through being aesthetically pleasing. A "pure marketing ploy".

Having said all this, once HCL had been properly introduced there was a lot of interest in and questions about it. Is it meant for a room or a whole building? Can private people acquire it? Are they ceiling or wall lights? Is it always indoors? The participants seemed to find the topic very intriguing.

4.1.2 Thoughts and reactions

The session moved on to talk about potential problems with the lighting concept, what reasons one might have not to invest in an installation, and what might be done to persuade people to try it. One interesting question that arose was whether there are in fact bad cases of HCL, if a situation can exist where installing it makes things worse or, at the very least, is a complete waste of money.

Most participants seemed to agree that not being able to show Return On Investment (ROI) would be a drawback in choosing whether to change the lighting fixtures, but not necessarily a deal breaker. An idea brought up by one person was that an installation could be made in one out of several rooms in, for instance, a care home. If the users liked the room with the new light they would likely spend more time in it, and this would be more prudent than "jumping the cliff" and installing the fixtures in all rooms.

An interesting factor brought up by two of the participants (who, incidentally, both work in the private sector) was that companies who make money on intellectual property, such as software or technology, spend a lot of money and time on ergonomics. They want their employees to stay sharp because that is when they are inspired. Of course, the image of the company is also important. They want people to say "I want to work there" and talk about it with their friends, and they realise that this is hard to calculate in numbers. A significant part of the budget is therefore spent on making the work environment better, and some companies might even try out new concepts even if there isn't much evidence to confirm that it works, or even if it isn't very good for the environment. There is room for experiments. On the other side of the coin, if they try a new concept, make an evaluation, and the employees claim that they don't notice a difference, they would most likely discard the concept even if there **is** evidence out there to support it.

Conversely, it was added, businesses with a high turnover of staff, such as fast food restaurants, would not be interested at all in setting up more ergonomic lighting fixtures, or any other improvements to the indoor environment. In fact, it was added that these types of establishments sometimes deliberately design the lighting and the environment to be unpleasant, to make customers move on quicker.

When it comes to the public sector, two of the people claimed that they would invest in dynamic lighting if it was the same price or cheaper than acquiring other new fixtures, in the hypothetical scenario that they were facility managers. The rest of the participants said that they would probably try it if it was a solid concept, not a fad, or if HCL became a big term that everyone had heard about. One of them said they would be concerned about environmental questions as well. The consistent message here seemed to be that to break into the public sector you'd need to "get the word out" about HCL, as the public sector often must be more careful about its investments.

4.1.3 The Verdict

Arguably, the most useful observations were derived when the project's solution concept was described and the prototypes were brought out. Some liked the idea of battery powered lamp fixtures, while others were very negative to it. They said it was a "no go" with the battery change, seeing how the battery would need to be changed once a month. It was perhaps okay for a trial period, but definitely not for a more long-term investment.

The concept of using Power over Ethernet-cables (PoE) was presented as well, and those who didn't like the battery idea were much more positive towards this one. Some companies already have PoE set up in their drop ceilings and plugging in a lamp using this system would therefore not require any additional preparations. Indeed, connecting light fittings to PoE would instantly connect them to the communication network of the entire building, making it possible to reach them wirelessly with a control panel or a remote without having to install a separate wireless system on them.

One participant said that where they work the acoustic ceilings do not have PoE already, only regular 230V outlets. There was, however, a cable runner at waist height in almost every room aimed for ethernet or PoE cables.

The whole group liked the idea of a trial period being handled like a subscription. Because there were some who still liked the wireless battery concept, this way when you "subscribe" to dynamic lighting you could choose the connection type that suited your building best. Moreover, the aim to make the wall mounted lamp aesthetically pleasing, and serve also as decoration like a picture or painting, was popular and with a subscription one could choose the style and look. The majority of the group preferred being able to connect the wall fixture to the wall over using battery, though it would depend a little bit on the design of it. One participant wondered if it couldn't be possible to charge the battery themselves using a USB cable.

One of the focus group's participants mentioned the idea of being able to connect the fixture to a circuit track, a system that many shops and public places use where an object is fitted into a groove on a track and automatically gets power once it's fitted. They didn't know if it could be combined with a drop ceiling, or what additional efforts would have to be made to communicate with the lamp, but claimed that if possible it would be a very simple connection method.

Everyone agreed that if several options were to be offered in a subscription it would be wise to have one that was the standard, that way customers would not have the burden of choosing but still be offered alternatives if they inquired about it. Most of the group were of the opinion that the regular 230V socket connection should be the standard one, since people are familiar with it.

4.1.4 **Discussion**

The focus group brought a lot of information and was a great reminder of how useful it can be to gather some outside perspective. It confirmed that even though HCL may be on the rise, the term is still fairly unknown. People are, however, familiar with the concept of lighting being used to our advantage and, perhaps more importantly, there is an interest in it. It was also confirmed that money was one of the factors in deciding whether or not to try a new type of lighting, but also added that it depends a lot on the building and the company in question.

Looking at not just private versus public sector, but also the type of private company and what they aim for, was an interesting new take. So far FBL have first and foremost targeted the public sector, with a couple of exceptions. [1] Most participants agreed that if they were facility managers of a building in the public sector, they would be less likely to invest in a costly installation than if they were in the private sector, especially when the ROI is unclear. They would be more open to it if it became a well-known concept and a term everyone recognised. Are FBL targeting the wrong people? Perhaps the key is to first break into the private market among businesses who deal in intellectual property, and then target the public sector when more people know what they would be buying.

The focus group session made it clear that an HCL trial period needed to offer more than just battery powered solutions. The idea of a subscription had been touched on before. It seems a good service will offer one main solution, with the option to actively change it if one pleases. If the standard solution was to be the battery powered lamp, the subscription could involve a delivery of a set of new lamps every month, as well as retrieval of the old ones. The important factor being that it should be easy and convenient for the users. A trial period would be a six-month subscription where, for example, the client pays a subscription fee and the company providing the lighting is responsible for all involving factors such as delivery and maintenance. Although based on the discussions in the focus group it may be wiser to offer a free trial period if the client is in the public sector, to make the concept more attractive.

The fact that some offices have PoE access readily available in the acoustic ceiling, and others have the option of running it along the wall, can perhaps be used to an advantage. PoE has become more and more prevalent in many technological fields, and brings advantages such as time savings, cost savings, flexibility and safety. Running a PoE cable might still be easier than using the regular power output as you don’t have to set up a wireless connection separately, it works as a sort of 2-in-1 connection. If the settings are already pre-programmed, as has been discussed previously, the installation would only involve drawing a PoE cable above the ceiling and plugging in. [18-20]

If the ceiling light was to be powered through standard 230V output, the setup would be the following: Power connection to lamp and driver, a module for wireless communication (such as ZigBee [18]) between driver and control panel, and the control panel itself could easily be powered with battery and placed anywhere on the wall. Again, this would not be a terribly complex installation provided that the settings are pre-programmed and the user only needs to execute one command, such as punching in the current time.

The proposal to use a circuit track was an interesting suggestion, however perhaps a little difficult to implement along with drop ceilings. Because of the wide shape and location of the ceiling lamp, a track would need to be positioned above the ceiling tiles and an extra arm or similar would need to be attached to the product to connect. However, it is possible that using this method would redistribute some of the weight away from the framework the lamp is resting on, a thought perhaps worth entertaining later down the line.

The wall light offers more flexibility because of its position, and the focus group seemed to prefer a standard power output for this one since walls often have regular wall sockets anyway. PoE for the wall light seemed less relevant at the focus group for this reason. Since different choices were going to be offered for the more aesthetic wall lighting anyway, perhaps the best solution here would be to keep the smaller ones battery powered, and supply the larger ones with regular power plugs.

4.2 Visual Ergonomics

4.2.1 **The interview**

Lund University houses one of the worlds few experts in Visual Ergonomics. Hillevi Hemphälä has a PhD on the subject, and works at the Division of Ergonomics and Aerosol Technology at the Lund Institute of Technology, as well as having several other projects on the go. Visual ergonomics looks at how to best shape a working environment to avoid disturbances that might impede performance and cause health issues. The main focus is on flicker and glare, both of which may be present without being visible to the naked eye. [11]

Flicker is down to the manufacturers of the lamps, and is best avoided in the step of buying the lamp. Glare revolves more around the placement of lamps in the room, and the contrast our eyes must endure between brightness, darkness, reflections, colours and so on. A bad working environment in these two aspects can cause headaches, and if the body subconsciously adjusts its position to see better it can put strain on the muscles and lead to musculoskeletal problems [9]

Visual Ergonomics is an area closely linked to HCL, and although this master thesis centres around dynamic light and the circadian rhythm, acquiring some insight into a related subject seemed like a good idea regardless of whether it led to changes in the design or not. An open seminar was attended and later on followed by a one-on-one interview.

Hillevi emphasised that it is important to try to avoid sharp contrasts in a room when working, and instead try to achieve soft gradients. This to try and imitate the lighting environment we experience when we're outdoors, in nature there aren't many sharp contrasts when we look around. One way to achieve this is to place a prismatic raster inside the lamp, which redistributes the light rays and mediates an even light. Placing several weaker lights instead of one strong might also help, but not too much because we still need some shadows in a room or our eyes may get confused. [11]

If a lamp is placed in the ceiling it should not be too far forward from where we are sitting as the direct light may disturb our eyes, and not too far behind us either as this may cast shadows on the area we are looking at. The optimal placement would be right above us, a little bit to the left if we're right handed and vice versa. If a lamp is mounted on the wall, the higher the better as the part of our eye most affected by light is on the lower part of the retina. [11]

A ceiling light that shines straight down is better if the rays have a 45° cut-off angle, instead of scattering everywhere. That is, the shine from the lamp narrows down as it moves closer to the floor. It is also a good idea to avoid shiny and glossy surfaces, as they reflect light, and try to stick to matte ones. On top of this, contrast in colour, such as having a white desk and a black computer screen, can be detrimental to our vision and it is better to try to keep softer beige and brown colours. [9]

A good lighting method, if at all possible, is to light up the ceiling and walls. That way, the light does not hit anybody's eyes directly but the room is still lit up. In the case of the wall lamp in this project, allowing light to come out through the top and sides, hence illuminating the wall and the ceiling a little, might be a good addition. The ceiling light might be dropped down a smidge so that it comes out of the frame a little bit and illuminates the ceiling from its sides. [11]

All these guidelines are for visually demanding work, different rules apply for other activities like eating or socialising. In these cases, more light, like sunshine, is preferable because we do need light to function properly. Hillevi recommends eating breakfast by a window if the day ahead is filled with visually demanding indoor work. [9]

When it comes to checking the flicker in lamps, a nifty tool is the camera in your phone. Holding the shutter close to the light source will reveal interference on the preview screen in the form of moving stripes, if the light flickers. This method will not work if the frequency of the flicker is exactly the same as that of the camera, and in shops it would obviously have to be tried on a display specimen. Either way, it is a handy tool to have. [9]

4.2.2 **Discussion**

This degree project focuses on dynamic lighting and the aim of the process is quite clear without introducing demands from other fields in the industry. Attending the seminar made it evident that there are areas where Visual Ergonomics even clashes with certain aspects of HCL, as HCL covers many aspects of human wellbeing while Visual Ergonomics specialises more in visually demanding activities. There was, for instance, an example in the seminar of streetlights being replaced with more energy efficient white LED-lights. The advantage of this was that crime on that street diminished and people felt safer, on account of the light being more "awakening" and feeling less private. The drawback was that the contrast increased since the light didn't reach as far but was more concentrated around the light source, causing glare when standing nearby. Usually a compromise has to be met in cases like these. [9]

Nevertheless, some recommendations could perhaps be kept in mind without compromising the project too much. A prismatic raster could be placed in the wall fittings and a PoE- or standard output powered ceiling lamp as discussed in the focus group above. Perhaps even in the wireless ceiling fixture, although that would add weight to it and more calculations would have to be made.

Flicker could definitely be considered when choosing diodes and drivers for the finished product, although the lamps will not be exchanged in the prototypes as they are created as an MVP and are only meant to demonstrate the function. To avoid adding extra contrast and reflections, the shell surrounding the lamp could be made uniform in colour and a glossy finish or shiny metals could be avoided. The wall fixture could perhaps emit light from the top and sides of its frame, and customers subscribing to the trial period could be given recommendations on where to place both the ceiling and the wall fixtures.

Perhaps the ceiling lamp could even be dropped down a little bit as mentioned, adding more volume as well, though if that choice is made some additional investigation will be necessary.

5 The Final Result

This chapter describes the final configuration chosen for the solution in this degree project.

After taking the additional research into consideration, the solution was altered somewhat to include more flexibility. The solution itself would be a six-month subscription to a trial period of HCL, offering alternatives to the wireless battery-run modules and enabling the consumer to tailor their product package. As discussed in the focus group, the client would be presented with a standard kit to remove the risk of ambivalence, and the offered the choice to make changes based on the available alternatives. If the battery powered modules were chosen, the subscription would also include regular delivery of new fixtures and removal of old ones, eliminating the responsibility of charging the batteries as discussed above.

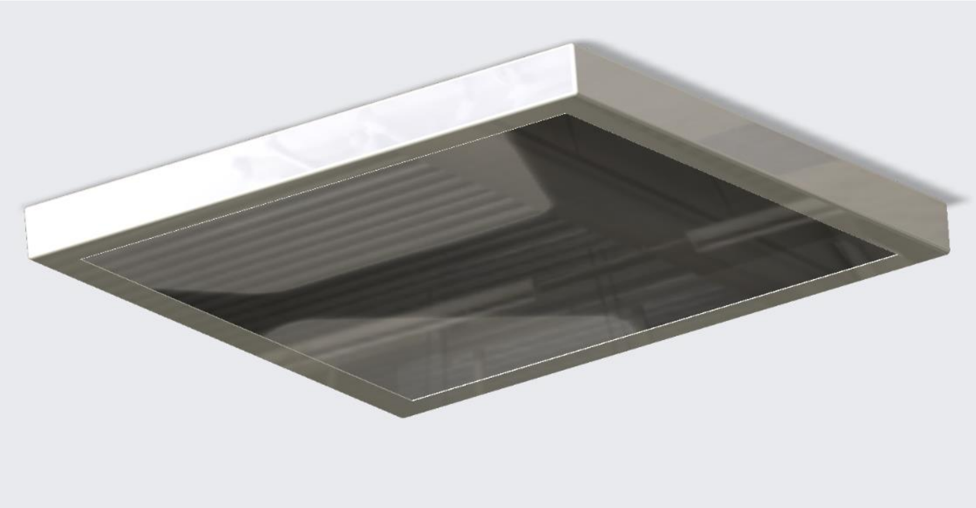


Figure 5-1 CAD-model of the ceiling fixture

Figure 5-2 Rendered image of the ceiling fixture in place

The standard presented ceiling module would be the wireless variety, with an option to swap it for a PoE driven alternative, since that received a lot of positivity in the focus group. A prismatic raster, as discussed in the Visual Ergonomics interview, would be placed in the PoE driven variety to redistribute the light, but not in the battery powered one as that would affect the safety margin on the weight. However, the flexibility offered with the battery option means that the lamp can easily be moved and placed in positions that don’t produce glare.

Figure 5-3 CAD-model of wall fixture, large variety

The standard wall mounted module presented would be connected to a standard power output, the preferred power source in the additional research, with the option available to instead choose the wireless design. For the wall there would also be the option to choose the size. All of the fixtures would come pre-programmed with the dynamic light curve and a wireless control panel.

Figure 5-4 Example of a control panel used with the lighting installation

The choice presented would have the following structure:

- Ceiling mounted
  - Battery run
  - PoE run
- Wall mounted
  - 230V standard plug
    - Large
    - Small
  - Battery run
    - Large
    - Small

If no particular choice is made, default choice would be the battery run ceiling fixture with the 230V wall fixture. Should the location not have acoustic ceiling, default would be the 230V wall fixture.

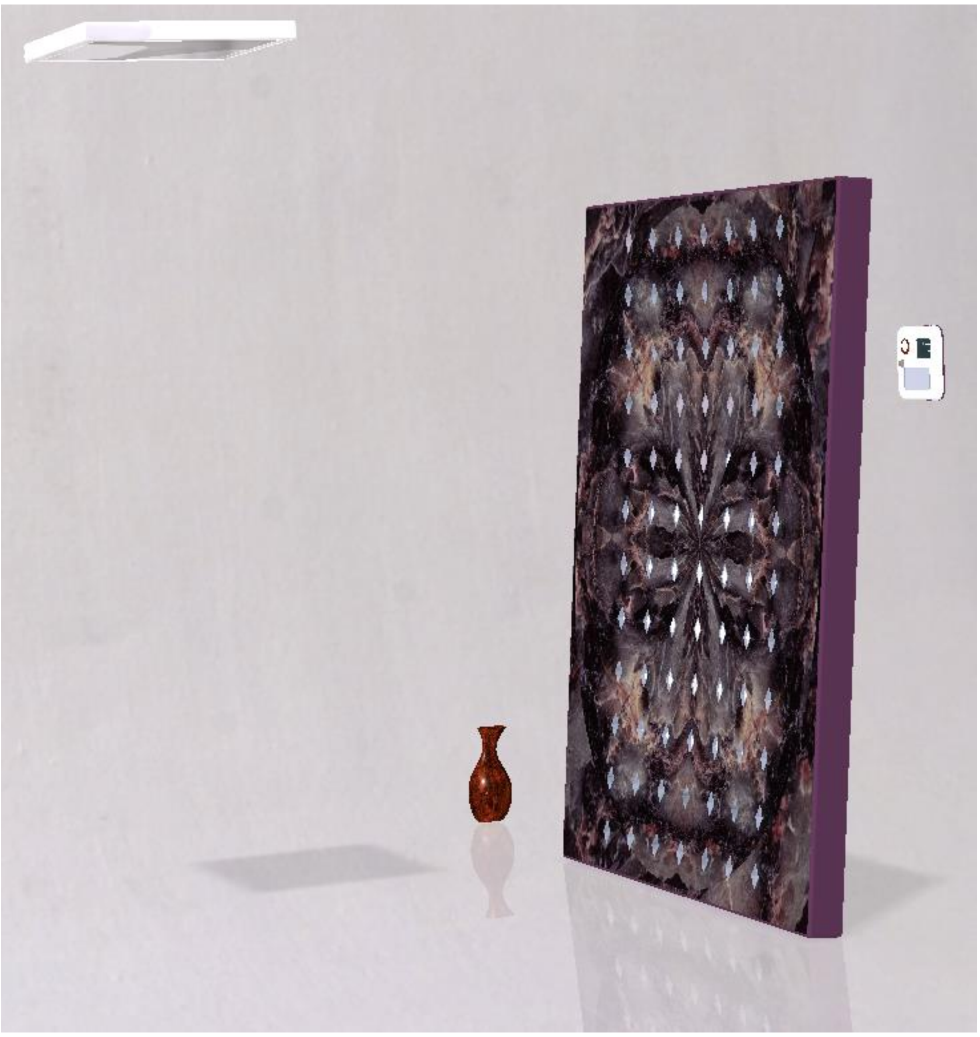


Figure 5-5 CAD-scene with the different components

5.1 Discussion

The weight limit on the wireless ceiling fixture puts demands on the material it is made of. Lamp fixtures like these in the industry, and certainly the shell used for the prototype in this project, are often made of metal to direct heat away from the LEDs. Although LEDs emit less heat than their predecessors they can still overheat, and need some kind of refrigerant. The fixture could be made in sheet aluminium, a fairly low-density metal with high thermal conductivity. If a lighter material is used, a heat sink would have to be incorporated. [22] Alternatively, the surface where the

LED-strip is attached could still be made of metal to divert heat, perhaps in combination with a thermal paste.

If a client chooses the PoE-connected ceiling fixture but doesn't have PoE already incorporated into their drop ceilings, it can still be installed quite easily. The device is connected to a PoE switch, which provides all connected devices with network access, in the image below the device is a camera. [19]

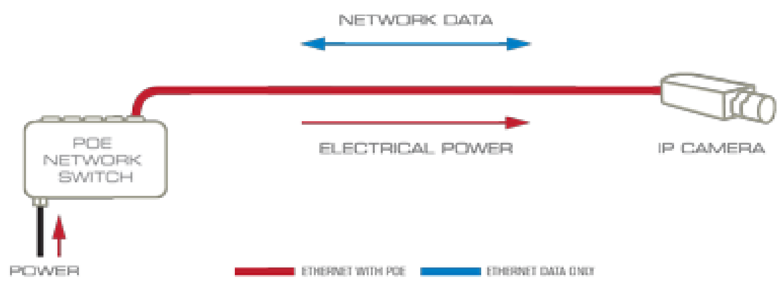


Figure 5-5 PoE connected with a switch. Image taken from veracityglobal.com

In the case of buildings without a PoE network, a midspan (PoE-injector) is used, merging power and network into one. See image below.

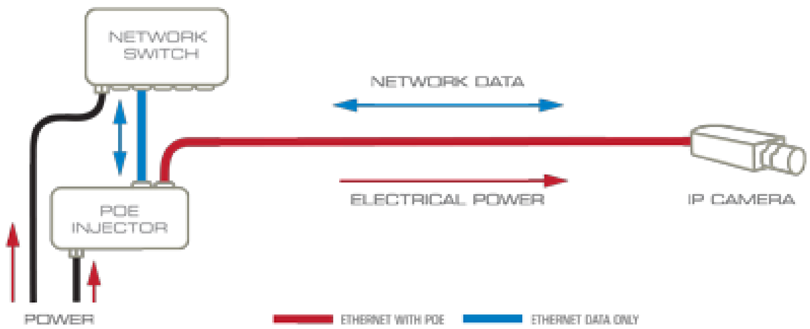


Figure 5-6 Connecting PoE from separate power and network sources. Image taken from veracityglobal.com

One major advantage PoE brings is that no qualified electrician is needed to install the devices, making it a simple task. However, if a large number of lamps are to be fitted in a room, meaning a large number of PoE cables need to be drawn above the ceiling, that may be a more elaborate task.

6 Discussion and Reflections

It would have been interesting to take a closer look at the environmental impact of the designed products. This was not defined in the aim of the project, but sustainability is quite a frequent subject in FBL:s many projects [3], and a common denominator when talking about the future of lighting. Of course, the use of LED lights carries a certain environmental benefit due to its energy efficiency, but the production of new items always comes with a carbon footprint. Moreover, exchanging standard power outlets (which could in theory be green electricity) for batteries changes the conditions for how to achieve sustainability.

The battery market today is dominated by lithium batteries, because of their superiority in energy and performance in comparison to their size, but they do bring environmental consequences. The world has limited lithium resources, and it is uncertain if they could sustain the increasing need that would appear in our ever-evolving day to day life. [23]

Lithium is also very difficult to extract for recycling from today's batteries, which are also partly composed of non-organic material, and contain other elements even more scarce than lithium and requiring a large amount of energy to recycle. Furthermore, recycling them emits toxic gases. [23]

However, research and development is always on the go in technology. In 2015, for example, researchers at Uppsala University started to investigate a greener alternative to lithium batteries based on recycling and renewable, organic materials. The components, made from resources such as pine resin and alfalfa sprouts, could be recycled with safe substances like ethanol and water, and lithium from an old battery could also be used to create a new battery with these organic materials. [23] It is unclear, though, whether new batteries like these could evolve in terms of specific energy (as has been relevant in this project) and power, as other batteries on the market are.

For the fixtures that are not battery operated, it would have been great to look at how to optimise them environmentally. For example, how to maximise the lifetime of the items before new ones would have to be manufactured.

The battery adds a significant amount of weight to the product which, as seen in the focus group chapter, makes it less attractive to some. The option of reducing the battery life and allowing clients to charge the batteries themselves was discussed, but later dismissed as it would not be in line with keeping circumstances simple for the users. As batteries evolve along with technology, perhaps they will be made lighter and more efficient, making the battery powered option a much more relevant product.

Given more time, and perhaps the opportunity to revise and explore electrical matters further, a more in-depth analysis could have been made. For example, a calculation of the exact power needed to support all the components of the light fixtures, or a detailed description of the wiring required. Instead, assumptions had to be made based on statements from other people and examples found online.

One thing I would change if the option presented itself is to have more customer research directly from those involved in deciding whether or not to try dynamic lighting, like facility managers, HR, or other decision makers. As it happens, it would turn out to be quite difficult to get hold of people like this, not least because the companies and buildings don't always know who would be the right person for this particular decision. Getting in touch with one person will sometimes get you referred to another, there is, obviously, no one in a company titled “HCL manager”. Not yet, in any case.

A great customer research scenario would have been to gather 15-20 facility managers and perform a survey or a long focus group session. However, 20 facility managers would represent hundreds and maybe more consumers, perhaps a little unrealistic. I suppose a good product should speak for itself without having to actively seek out so many potential customers at once.

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Appendix A Time plan

A.1 Project plan and outcome

The estimated timeline differed quite significantly from the timeline that transpired. At the start of the project the steps of the process were discussed with the main supervisor and a rough timeline was drawn up, including some breaks during the summer months, as can be seen in figure A-1.

Week		Notes
18	Project planning	
19	Background research: Gather info on HCL	What it is, how it works, etc
20	Background research: Repeat material Visit exhibition from LTH course on 18th May	19th May: Send update to supervisor
21	Background research: Investigate current solutions & components	
22	Background research: Customer research	Get as much information as possible from Survey Party 2nd June: Send update to supervisor
23		
24	More customer research	If this step involves doing surveys or interviews, an extra week is added
25	Specify requirements Establish main v desirable functions	23rd June: Send update to supervisor
26	Concept generating 1	
27	Concept evaluation + feedback	
28	Concept generating 2	14th July: Send update to supervisor
29		Preliminary
30		Preliminary
31	Concept selection	4th August: Send update to supervisor
32	Concept analysis	
33	Prototyping or other	
34		
35	Possibility of interviews/focus group/ surveys/FEM for concept analysis	1st September: Send update to supervisor
36	Prototyping or other	
37	Further analysis	15th September: Send update to supervisor
38	Write final report	A lot of the writing will be done in conjunction with the work.
39	Write & print final report	
40	Prepare presentation	6th October: Send update to supervisor
41	Critical review + Presentation	

Figure A-1 Assessed time plan agreed with supervisor

The calendar weeks can be seen in the leftmost column. This turned out to be a rather optimistic time plan, as the presentation took place in the beginning of January. One reason for this was underestimating the time needed for some topics. Another reason was that standard times for presentation at the division of Product Development take place twice a year, with the autumn/winter one being in January. When it became apparent that the project was taking more time than initially assessed, a spot was booked for the January presentations for convenience instead of planning a separate occasion.