Development of smart garden lighting

Chalmers University of Technology

Master's thesis in Product Development

EBBA EINARSSON

INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

This project is done at a company that develop and manufactures smart electrical components, for indoor purposes today. Due to the lack of smart outdoor fixtures, this company wanted to explore garden lighting and its possibilities. This project therefore investigates garden lighting and the main goal was to result in a design proposal and to create a prototype of a garden spotlight luminaire.

The report refers to a complete product development process for the development of smart / connected garden lighting. The process began with a research phase including a literature study on theoretical information and garden lighting in general. A customer needs analysis was made based on interviews and a survey to reach the user's behavior and what the garden luminaire needs to achieve. A market analysis was done through store visits, patent research, benchmark analysis, product testing and a disassembly session to understand what the user wants and what is on the market today.

Later, a product specification could be made and these requirements and functions were created to begin the concept generation process. The concept generation process was done through inspiration, creative concept generation and systematic concept generation. These concepts were reviewed and later evaluated through matrices, expert reviews and lists of pros and cons.

One concept was further developed in an iterative process to end up in a design proposal. This design was 3D printed and later tested and redesigned to meet expectations and be functional. The final concept could later be printed, assembled and polished to become the final prototype.

The result shows a functional design, with new innovative solutions to reach more customers' needs. The prototype can roughly show how the functions will work and how the lamp will behave in reality.

Acknowledgements

This report is the result of a 30-credit degree project carried out by Ebba Einarsson on the master of Product Development. Written at the Department of Industrial and Materials Science at Chalmers University of Technology and examined and supervised by Professor Lars Lindkvist. The work was carried out for a company with an assigned supervisor. The writer would like to thank supervisors, people involved from the company, and also participants in interviews and questionnaire.

Ebba Einarsson, Gothenburg, 05 2022

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Introduction

1.1 Background

This project is done at a company that manufactures smart electrical components for private owners. The company has thesis students every year in several departments. During this period, four groups did their degree projects in the mechanical engineering department and worked on various projects.

1.2 The problem

The main problem is that there are no available outdoor garden lighting developed of the company on the market. Since there is an increased need of outdoor lighting, a garden luminaire will be developed.

1.3 Purpose

The purpose of the degree is to be able to describe, discuss and arrive at a result. The purpose of the project is to develop smart / connected garden lighting with simple installation, and present design proposals as well as a prototype.

1.4 Objective

In order to be able to start the project and generate future relevant ideas, a period of searching for information is required to collect data as a basis for analysis. One of the main focuses is to generate a simple and flexible installation for the customer. Thereafter, concepts will be generated and eliminated based on different models. Finally, the definite alternatives will be designed in CAD, and a prototype will be made. Hopefully, the company can then further develop or benefit from this idea, process and prototype in other ways.

1.5 Limitations

The following aspects were not treated in this project, as the design of electric components such as circuit board, cables, plug for connection etc. Further aspects that

were not treated are choice of material, price/business case and the manufacturing process.

2
Methods

2.1 Project overview and its phases

The project was handed out with inspiration of a Front-end process as illustrated in figure 2.1. This due to the front-end process generally contains interrelated activities, as this project does [26]. The project began with a mission statement and identification of customer needs. Then make a target specification, generate product concepts, select them and test. Along these steps, benchmarks, competitive products and building models are influencing to execute a good prototype in the end. According to Ulrich, Eppinger and Yang (2020) the front-end process rarely proceed in purely sequential fashion, completing each activity before beginning the next. The front-end activities often overlap and iteration is often necessary [26]. This project is a good example of this type of method.

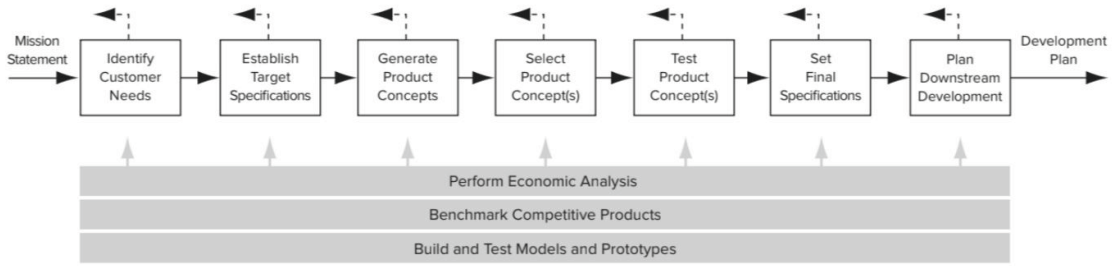

Figure 2.1: Front-end process

To provide an overview to understand how the project was distributed, an overview of the activities is presented below in figure 2.2. The project started with a research phase for a month to get the best basic knowledge to deliver a product through relevant methods.

Figure 2.2: Phases and report overview

2.2 Research phase

The project started with a research phase to understand the area and what needs the user will have, as in figure 2.3. This research was done by both literature studies, especially via the internet on websites. In order to develop a garden lighting product, it was important to find what the garden owners want in a luminaire like this, therefore a user needs analysis needed to be done. This was done with both a qualitative method such as interviews and a quantitative method through a survey. A market analysis was needed to gain knowledge of which products are available in the area of smart garden luminaires. Later, a benchmark analysis was made through internet research, and products were purchased to be disassembled and tested.

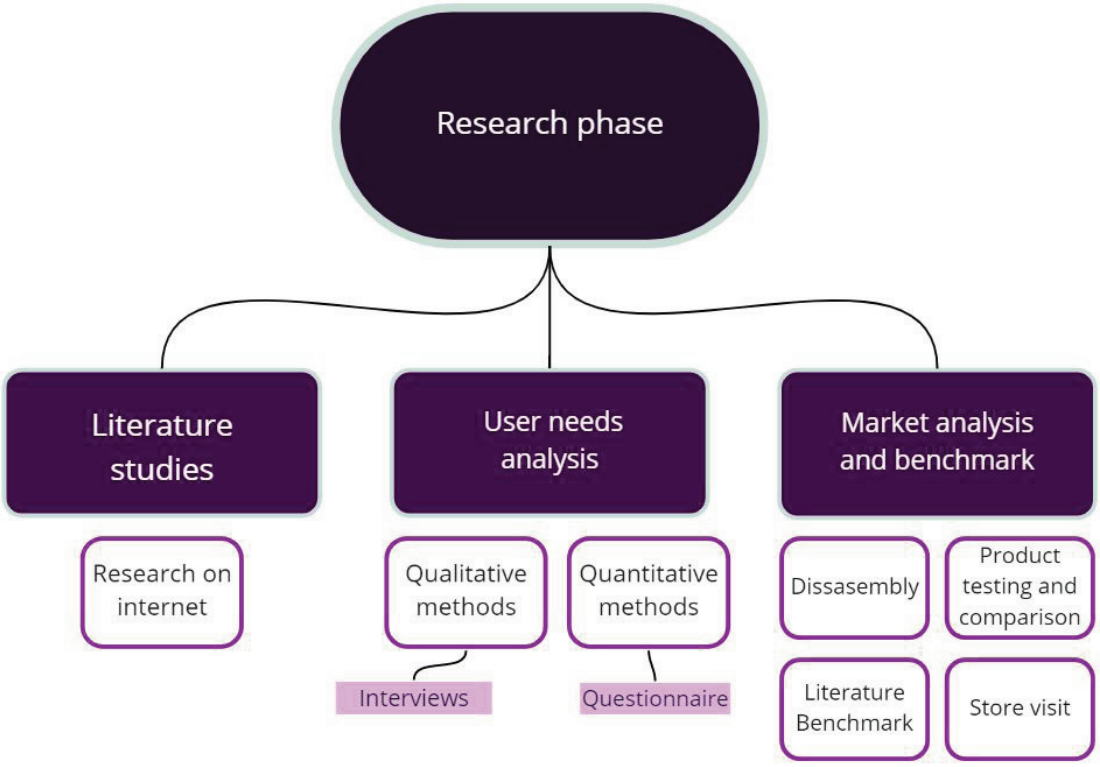

Figure 2.3: Research methods

2.3 Product Specification and user needs

This project aims to deliver a garden luminaire through a well-developed process. All information obtained from the survey and the interviews has been analyzed, in order to obtain the right needs and requirements. As Ulrich, Eppinger and Yang (2020), one of the first phases is to identifying customer needs and then establish a target specification as in figure 2.1.

The analysis of data was made trough four steps, listing, reducing and find patterns and organize the information provided, in order to find explicit demands / wishes,

problems and useful comments that could add value to the project in the future. This was done by searching for different patterns between statements and then organizing them into different groups of topics. Some answers from the interviews were highlighted as useful information for the project, such as things that are important to gain more knowledge about, or people to contact for further interviews. These specified comments were useful for creating the user needs list, which was later transferred to the requirements and wishes in the requirements list. This list also includes requirements and wishes from the company as well as various standards, etc. The demands must always be completely fulfilled as specified and wishes shall be fulfilled as well as possible, "the better, the better"[25].

To understand the function of the product, it was necessary to analyze the problem and create a functional analysis. The functional analysis includes both main functions and its sub-functions to get to know the product. These methods are shown in figure 2.4.

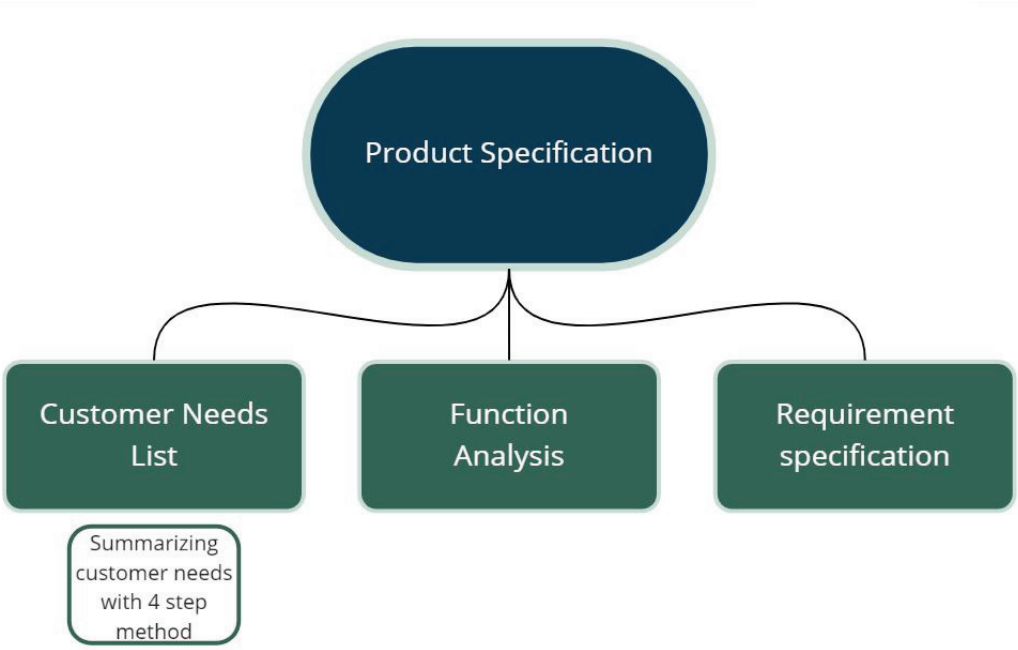

Figure 2.4: Product Specification

2.4 Concept Generation

2.4.1 Idea generation of concepts

The idea generation of concepts was done through different stages and methods as seen in figure 2.5. Idea generation via both systematic and creative methods. The systematic methods included a morphological matrix. The creative methods include brainstorming and a workshop. To get inspiration, some mood boards were created to increase creativity.

To generate concepts within this project, it was important to start taking inspiration. This was done both by existing components and by various moodboards. With this inspiration, a brainstorming was done, both ordinary and extreme. It was done by the project owner and later a workshop was done with the company to create concepts together.

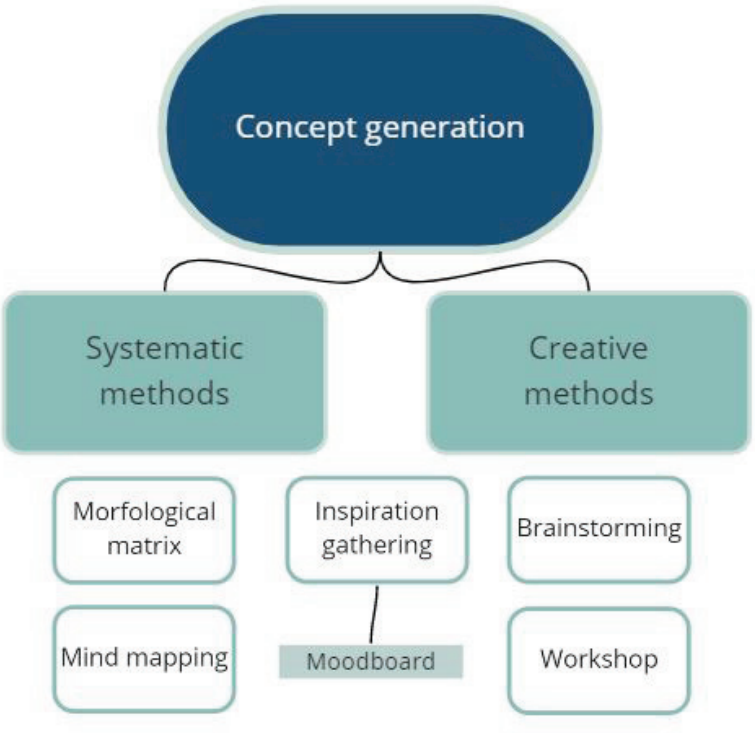

Figure 2.5: Concept Generation

2.5 Screening and evaluation

To eliminate some of the concepts to move forward with, a screening and evaluation process was needed, which is shown in figure 2.6. With lessons learned from Almefelt L [24] and [26], the systematic elimination process was made consistent in matrices. As Ulrich, Eppinger and Yang (2020), "the concpet selection is the activity in which various product concepts are analyzed and sequentially eliminated to identify the most promising concept(s)". First, an elimination matrix was made to eliminate concepts that did not meet the overall important requirements. Later, the final concepts were compared according to their requirements in three Pugh matrices. The concepts were also revised by people in the company, in order to more easily eliminate the inferior concepts.

There were several decisions that affected the concepts that needed to be worked out. To make these decisions, a list of pros and cons was made. These were based on both interviews and secondary research. The interviews were conducted through shorter semi-structured interviews of competitors. The competitors' way of thinking

was useful for gaining knowledge about the market, etc. Semi-structured interviews were also conducted with some salespeople from the company to gain competence about what they believe in.

Some of these steps also included expert review, by engineers in the company, but also competitors and a lighting expert.

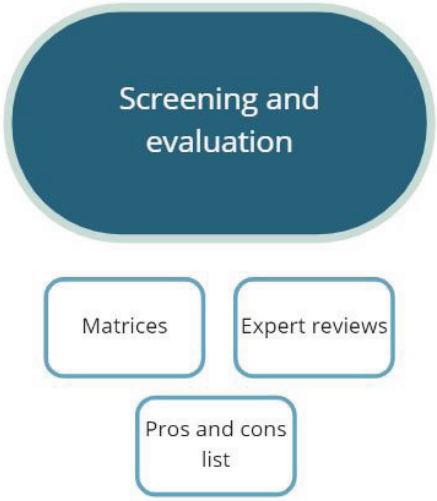

Figure 2.6: Screening and evaluation

2.6 Concept Development

This process was somehow iterative, due to the fact that many changes were made and the functions were also developed from the basic concept. Some inspiration was taken from the previous process, the concept generation phase.

The final concept was designed in CAD, in Solidworks.The company had also several design guidelines to follow, to make a product that would fit in their portfolio along with the other projects. During this process, some engineers from the company came up with some input to improve the design. When the final CAD design was developed, the model could later be 3D printed for testing. When printed, the people from the company could hold the product in their hands and see the model in real life, which led to many discussions and development opportunities. Then the process went iterative again, and CAD needed to be improved to print better 3D models. This process is shown in figure 2.7.

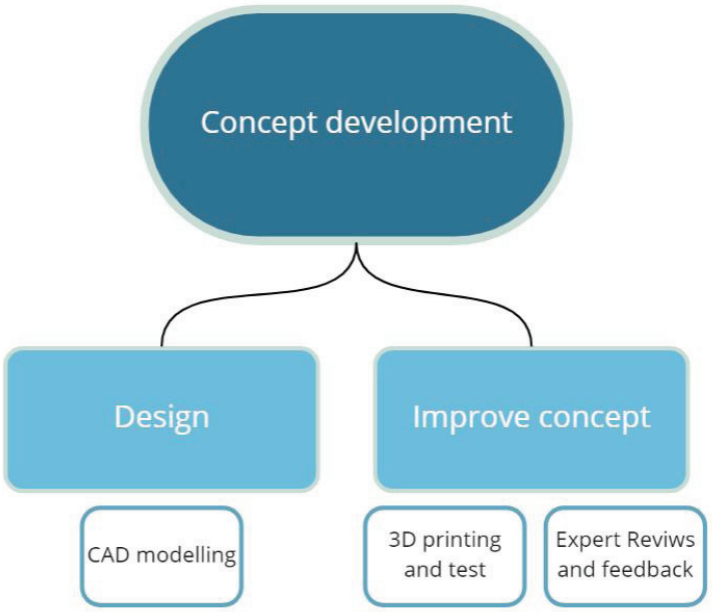

Figure 2.7: Concept Development

2.7 Validation and final concept

This phase included the design of the final concept and the prototype as seen in figure 2.8. The validation was about the user test and the prototype design was done through practical work.

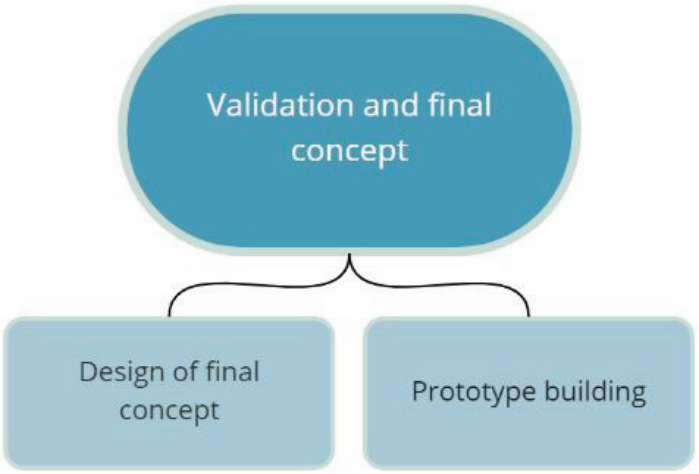

Figure 2.8: Validation and final concept

3
Research phase

This chapter involves literature studies, a customer needs analysis, market and benchmark analysis.

3.1 Literature studies

The first research is done through literature studies by searching the internet.

3.1.1 Garden Lighting

Through the years, it has become very popular to light up gardens [1]. Partly due to an increased awareness that good lighting affects the experience of the environment, but also because large parts of the year are dark and people want illuminated homes. With small contrasts of light, the beautiful parts of the garden can be noticed and inspire others [2]. The use of the garden will increase, which also leads to extra security and a feeling of security in the dark [3]. However, there are other types of lighting to install in the home, such as general lighting, function lighting and decorative lighting, which are also growing in interest among people [4].

As earlier mentioned, due to [11] landscape lighting has three basic goals, such as safety, security and aesthetics. If the night environments avoid security damage due to the lighting giving a clear view of any obstacles such as steps and water, etc. Security is about avoiding intrusion by intruders and the light can be a deterrent for an intruder and it adds the feeling of protection. Aesthetics is about allowing enjoyment of the environment. It can psychologically enlarge the interior space by visually merging it with the landscape and providing activities [11].

3.1.1.1 Trees and how to light them up

Most garden owners have many trees in their gardens, both small and large, short and tall. Among Swedish gardeners, they often use trees such as dogwood, maples, cypresses, cherries, magnolias, birches, crepe myrtle and many more. There are often fruit trees, herbs, vegetables and flowers in abundance also due to Visit Sweden [12].

The garden lighting company Lightson has made a guide for garden owners for which beam scattering and effect suits each tree size. As shown in the figure 3.1 most of the smaller trees and plants need less power such as 1-5 watts, and a varying beam

angle. While the larger and taller trees need more power up to 12 watts. The wide trees need a wider beam angle such as 60 degrees, and the thinner and taller ones need a smaller beam angle, such as 15 degrees. In total, most popular and common plants and trees need a beam angle of about 25-30 degrees.

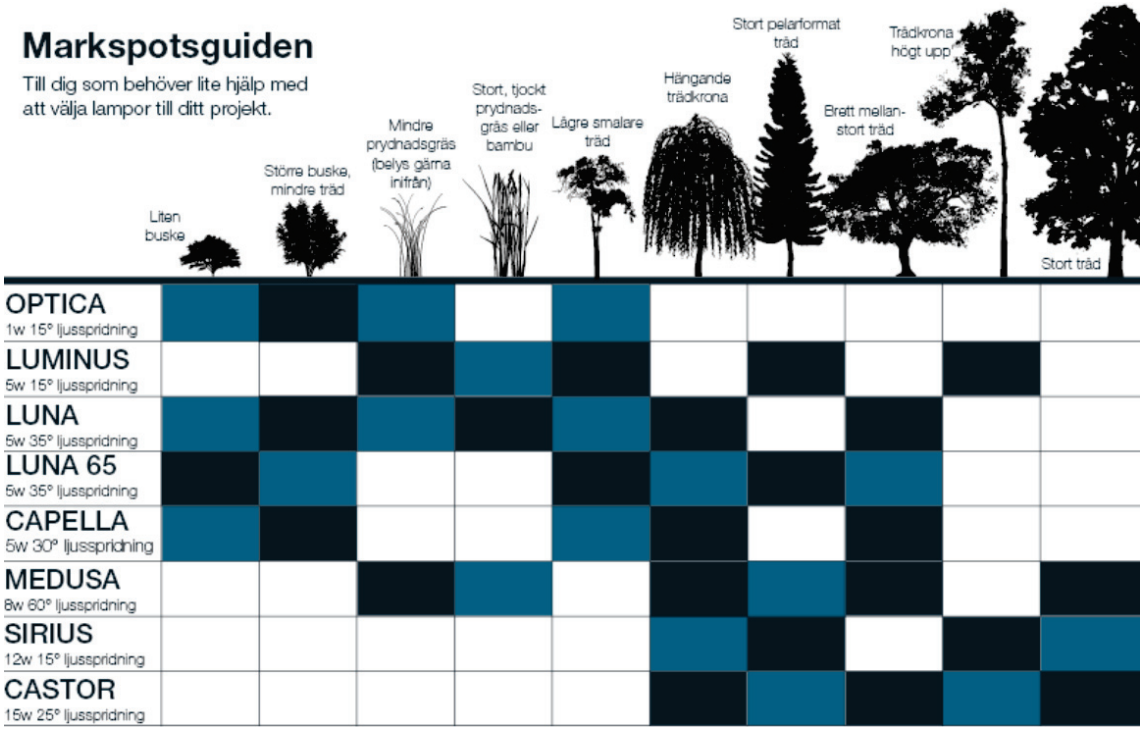

Figure 3.1: The beam angle suitable different types of garden trees and plants [21]

3.1.1.2 What does your eye want to see

According to "The landscape Lighting Book" by Moyer J (2013), it is described to design the garden from the eye. It is important to understand how the eye works to make the right decision about landscape lighting. The garden must be planned for eye response in dark environments. Contrasts between dark and light make the eye try to adapt to both brightnesses. The lighting expert must be careful when using dramatic changes in brightness to minimize eye problems. It is also necessary to consider the layered light entering the landscape to provide a balance of brightness, to enable the eye to move through the room without a continuous displacement of the iris opening [11].

3.1.2 Theoretical Information

3.1.2.1 Smart lighting

Connected lighting systems bring people, places and devices together by connecting LED lighting to smart control systems, networks and apps [5]. The LED lamp emits very little heat, as it instead converts large parts of the energy into light [6]. Why the use of LED lamps has increased in most cases depends on its energy efficiency,

cost, longevity and durability [7]. One type of LED is RGB diodes (red / green / blue) which can produce many color combinations and are sometimes used for decorative lighting and garden lighting.

Smart lighting is lighting that has more functions than lighting, such as being connected, on and off at a certain time, adapted to everyday life and controlled from apps. There are also features like astronomical timer, which makes it possible to activate scenarios based on the position of the sun.

3.1.2.2 IP Standard or the IP code

The international protection label classifies and provides a guideline for the degree of protection against intrusion, dust, accidental contact and water[14]. The first number in the IP combination means how secure the product is from solid particles. The second number tells you how resistant the product is to water.

Due to the Swedish Electrical Safety Agency, all products must have markings on the type plate and packaging if the product has IP21 or higher. Water may enter as long as it can come out when making an IP44 lamp, as long as the water does not end up on any live parts. No water is allowed in the manufacture of an IP65 lamp. The IP numbers consist of numbers shown below:

- IP 2X: Protect against solid objects greater than 12 mm
- IP 3X: Protect against solid objects greater than 2,5 mm
- IP 3X: Protect against solid objects greater than 1 mm
- IP 4X: Protect against solid objects less than 1 mm
- IP 5X: Solid objects safe
- IP 6X: Solid objects proof
- IP X1: Protect against dripping water
- IP X2: Protect against dripping water in 15 degrees
- IP X3: Protect against spraying water
- IP X4: Protect against 10 L/min spraying water
- IP X5: Protect against water jets
- IP X6: Protect against water jets 100 L/min in 100kPa
- IP X7: Waterproof 30 min in 1 m deep water

3.1.2.3 Current

In Sweden, the standard electrical voltage system is 230 volts AC (alternating current) and has a frequency of 50 Hz in a standard wall socket [14]. 230 volt systems are classified as low voltage systems, but it can be a huge danger to people in every way. High voltage systems are, for example, the cable systems for trains etc.

DC (direct current) is often used in much lower currents in products. This is because DC is the energy that can be stored in batteries. The alternating power can not be stored in batteries but can be generated by wind or water turbines, or other renewable energy sources, which is the main reason why most countries use it indoors. Direct current can be generated by renewable resources such as solar panels [16].

3.1.2.4 How garden lighting is installed

All garden lighting and other products to be used outdoors must be installed to an earth leakage circuit breaker. This product quickly shuts off the power in situations where a protection on the product would be damaged and direct the power to the user. It is also important to remember to have all equipment with a high IP standard and to have products that are made to be outdoors [14].

If there is a 230 volt system, the cables need to be buried in the ground, or protected in a safety cable due to the danger. Very low voltage systems such as 12- or 24-volt systems can be installed by anyone, but the 230-volt system needs an electrician to install due to the Swedish Electrical Safety Agency [14].

3.1.2.5 Energy label

Due to the European Commission [10], all lamps and luminaires shall produce with an energy label showing their energy efficiency on a scale from A (most efficient) to G (least efficient) as in figure 3.2. The earlier energy label is shown to the left in figure 3.2 and have a range from A+++ to D. Today, there are much stricter rules, which led to many products being presented at G-level.

Figure 3.2: Energy label
[10]

The energy label or energy efficiency class can be calculated as in figure 3.3. If the product is to have the very best classification, the product needs to produce more than 210 lumens per watt, which is now difficult to achieve.

Energy efficiency class	Total mains efficacy η_{TM} (lm/W)
A	$210 \leq \eta_{TM}$
B	$185 \leq \eta_{TM} < 210$
C	$160 \leq \eta_{TM} < 185$
D	$135 \leq \eta_{TM} < 160$
E	$110 \leq \eta_{TM} < 135$
F	$85 \leq \eta_{TM} < 110$
G	$\eta_{TM} < 85$

Figure 3.3: Energy Effectivity Classification [20]

3.1.2.6 Symbols and safety classifications

It takes about 25 product categories to become CE certified in order to be manufactured. The CE marking is on the left of the figure 3.4. The CE mark is a symbol that acts as a passport that gives free movement in the internal market. There are also some other classifications such as class one and two. Class one is in the middle of the figure 3.4 and means that the products need earth. The mark to the right in figure 3.4 is a class two marking that means that the product needs two layers of insulation.

Figure 3.4: Symbols and classifications

3.1.2.7 Kelvin

The color temperature is expressed in Kelvin (K) for light sources. It has to do with the effect of light and not with the heat, which it could do due to the temperature. The effect can be both warm white or cold white seen in figure 3.5. The smaller the temperature, the warmer and yellower the color of the lamps. Therefore, the higher the number of Kelvin, the whiter and colder the light. For example, a candle has

about 1500 K, light bulbs have about 2700 Kelvin and daily outdoor light is about 5500-7000 Kelvin 3.5. Warm white varies from 2200-3300 Kelvin and cold white goes from 3300-5500 Kelvin. Due to a lighting expert, different trees need different Kelvin to perform at their best.

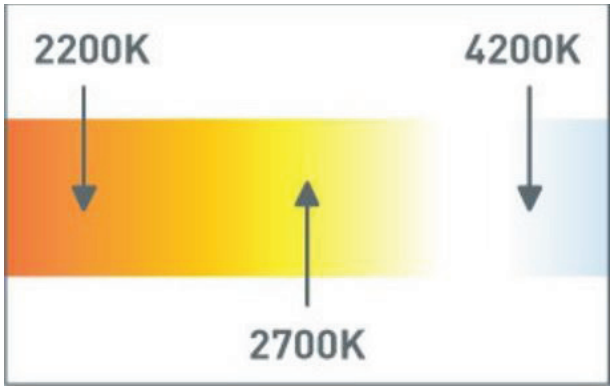

Figure 3.5: Kelvin Scale
[23]

3.1.2.8 Watt and Lumen

Effectively is measured in Watt (W). In earlier days the Watt number described the properties of the lamp and the relationship between power and light was proportional. But today the relationship is different and nowadays the Lumen scale is used to describe how much the luminaire generates. The lumen is the device for luminous flux. The more luminous flux, the more light the lamp will light.

3.1.2.9 Candela and beam angle

Candela indicates how bright a spotlight shines and the magnitude of the brightness can be used. The biggest difference from Lumen is that Candela takes the angle at which the light is emitted into account. Therefore, two lights with the same lumen, but different angles, will have different brightness.

If two light sources have different beam angles, they will be experienced differently. For example, if one lamp has a beam angle of 40 degrees and the other of 15 degrees, but they both have the same luminous flux, the 15 degree lamp will experience stronger light and higher Candela. The beam angle is the angle when at least half the brightness is available [17].

3.1.2.10 RGB and RGBW

The biggest difference between RGB and RGBW LED lights is that RGB has three in one LED ship and RGBW has four in one LED ship [19]. RGB has red, green and blue, and RGBW adds white. This is because a regular RGB store cannot produce a white tone. Another difference is that RGBW LED lights illuminate colored objects and skin tones at a higher level than RGB. This means that RGBW can also maintain a higher color rendering index.

Color rendering index (CRI) This can also be called Ra-index (rendering average). This scale varies from 0-100 where 100 is almost similar to the reference light source. The index is based on the first generation of LED lights as many of the users were disappointed with the quality of the light. The color did not work as it should, and therefore this scale was created to use an index of how a light source is balanced in terms of color [18]. The light bulb has the best RA index and the LED lights are on their way and today most perform above CRI 80.

3.2 Customer Needs Analysis

The first step in this research phase was to do some internet research to gain a basic knowledge. In order to reach the customers' interest and create a useful product, a customer needs analysis was performed. This section further describes this.

3.2.1 Interviews

Seven different semi-structured interviews were conducted to gain a better understanding and what requirements are needed. The first interview was done with some electricians, a lighting expert, salespeople from the company and competitors described in more detail below. To evaluate a customer needs list, these interview results were analyzed using a four-step method described in chapter two.

3.2.1.1 Electricians

An interview was done with an electrician to understand the structure of garden lamps and their installation. The installation is very important to minimize the risk of people being injured and that the luminaire works optimally. Due to the external environment, the installation becomes a little more difficult to handle.

The lessons learned from the interview is that they have a belief in a smart garden lighting in the future. One input for the project was to sell the garden equipment as a starter kit with different varieties.

Garden lighting is easiest to install with 12 or 24 volt systems, due to the complexity of installing 230 volt systems for outdoor environments in the field and safety issues. Regardless of the system, the cables must either be buried or placed in a good way so as not to disturb or break. Garden owners usually want to move and install their garden lighting on their own, which makes it impossible with a 230 volt system. There must be a good solution for the transformation system as the most used solutions today are difficult to handle as an electrician. It can install the transformation system separately from the plug, but still inside. The armature need at least IP67 standards to survive harsh weather conditions and layers of snow. Finally, it would be a good idea if the system could be connected to ground lighting.

3.2.1.2 Lighting Experts

A semi-structured interview with the lighting expert was conducted together with two experts from the company. The lighting expert had some general views on the project as below.

- Most garden lights are between 1-3 watts and rarely more than 300 lumens because it is dark outside.
- If you are having a lens, a prismatic lens as Deltaco can be used.
- Tunable white is good, as some trees and plants do better in cold vs warm light.
- Decklights feel old-fashioned.
- Adjustable beam angle can drop a bit when you want tunable white.
- The classic screw adjustment of the lamp angle often becomes poor after a while, much due to the rubber drying in between.
- Its not often you redirect the lamp.
- Spotlights are by far the most common outdoor lighting, followed by linear lighting.
- One idea is to be able to make a flexible IP-rated list (Led-linear).
- Believe that garden lighting will grow.
- Can neither say 24 nor 230, but 24 would have felt safer, avoided digging and easier.
- 24 volts can make the products smaller, even cost-effective to have a driver for several lamps.
- A common mistake is to use too bright light and get too strong contrasts.

The lighting expert also got some tips to the project, and these are listed below.

- About 300 lumens is enough
- Think of a tough climate and durable luminaires
- Remember the light image and that it is well dimmed (eg lower the lens, or have options for glare)
- Sell as a kit, eg 5 lamps with different fasteners.
- Start with a relatively narrow light angle, type 24 degrees with frosted glass (cheapest)
- Have options to be special and to sell (eg individual control, tunable white)
- Make the lamp as discreet as possible. Can be an idea to make the lamp dark green.
- Make the spot with a "cap" to direct light and dazzle (especially with frosted glass).
- Do not make a "cap" on the underside so that water and shit settle.
- Deltaco's size is a good reference for dimensions.
- How the light turns out is always most important
- Think about which material is the best in terms of price and sustainability, cost is important because it applies to private individuals who usually do not hire lighting designers, etc.
- If you are going to dilute the fastener in the ground, make the skewer like a cross or flat so that it does not twist.

- Do not chase lumens / watts as they do not have as clear "directions" for gardening
- Think of UV-sensitive plastic
- Have a built-in diffuser
- Can get a little frivolous with RGB, but can be good to give the alternative.

The lighting expert also sends some tips about good quality garden luminaires that can be useful to get inspiration from.

3.2.1.3 Salespersons at the company

A semi-structured interview was also conducted with some salespeople at the company. These salespeople have great skills from a background as an electrician. Some tips were summarized below.

- The biggest focus would be to take a bigger market, make a cheaper lamp more more value than competitors.
- The cost is very important.
- Being able to change Kelvin is relevant.
- Absolutely believe garden lighting is a growing market.
- RGB is nice when partying, but maybe not in garden daily.
- Think of simple installation with skewers, don't do any downpipe attachments because its ugly.

3.2.1.4 Competitive companies

Three semi-structured interviews were conducted with different competing companies. To summarize the answers from the first company, there was not particularly in demand on dimming but believes in adjustable spreading angle. They believed in 12V because there is a bigger market and its safer. There are also usually no problems with voltage drops, and the biggest problems are hiding the cables. Making a product in 230 volts feels more real, and people want to reconstruct its gardens to have a 230 volt system in it.

The other company contacted advised the author of this report to invest in 230 because of its robustness. The company now also sells mostly 230 systems, but some 12 v systems as well. There should be more luminaires in the garden and not have too much lumen. Many garden owners install themselves, even if it requires an electrician.

The last competitor did not use a 230 volt lighting system where it was difficult to hide the device. Many people have 24 volt systems in their deck but not in garden spotlights. It may be easier to extend 230 volt cables and not have the distance limit. Do not forget the seal. There will probably be a large market of dimmable and adjustable white features.

3.2.2 Questionnaire

A survey was conducted to reach what potential customers need and their preferences. The survey was divided into two parts by garden lighting owners and people who do not have garden lighting. The survey was shared on social media in groups for garden interest and home automation.

There were 115 responses in total and 52 percent were people between 40-60 years, 20 percent over 60 years, 26 percent between 25 and 40 and a small percent under 25 years. It was 36 percent men, 64 women and 1 percent others. 63 percent of them have garden lighting in their homes and most use outdoor lighting to illuminate trees, plants, land, steps and deck lighting and facade lighting. Some people had fence lighting, pole lighting and wall lighting. The most popular lighting was the headlight, the other popular were the light strips, solar cells and the bollard. The main purpose of using garden lighting was to make the garden beautiful and increase the coziness. 40 percent also wanted the garden lighting to increase safety and some of them wanted to draw attention to the garden and some wanted to light up the garden for their animals.

The main feature used in their garden lighting was the timer, and over 50 percent use it. About 35 percent use astronomical timers and motion sensors, and have light sources that can be mounted in different types of places. A quarter of them had dimmable lamps, more had adjustable white lighting than adjustable color function. The majority of the people who responded to the form used warm white light, but there are some answers to having cold white temperature. Those who had standard base luminaires for the garden mostly wanted an astronomical timer, motion sensor, dimmable light, mountable in different places and with adjustable white temperature. Eight people wanted adjustable RBGW colors and some wanted all the features.

Some parameters that are important for the garden lamp user were especially the design of the luminaire and how it fits into the garden and how it blends into the area. Electricity consumption and price were important factors, as was the brightness. The light angle, color and glare were important to 40 percent of the people, and the size, mounting rod and unit were important but smaller in proportion to the others.

One third of those who had garden lighting had a smart system as well and were very happy with it. Only one person was not happy with it because the twilight and dawn function did not work for them. 45 percent were 100 percent satisfied, 42 percent were 80 percent satisfied and the rest were moderately satisfied with the smart system. Most were particularly pleased with the timer function, the automation, the lighting system, the astronomical timer, no bugs, the pre-programmed functions and the whole system.

Some of the smart system users had certain features that struggled or factors that could be developed. One person wanted the system not to be dependent on sunlight,

and the other wanted more intelligence in the system. It was also mentioned that the system would support other lighting solutions from other manufacturers as well.

Half of the respondents had an interest in having a smart garden system in the future and wanted functions such as a connected system, dimmable lighting, astronomical and standard timer, motion sensor and adjustable temperature of the white light. More people wanted RGBW colors from non-users compared to garden owners. Some mentioned that they wanted high quality, control each luminaire separately and have an open API or similar. The other half was not interested in having smart garden systems, mainly because it was not necessary, no interest and just as expensive. Some also found it complicated to install and must have grease or other components that the person may not have. There were also environmental and ethical reasons behind the opinion.

Of the 30 percent who did not use garden lighting at home, 60 percent were still interested in having garden lighting systems in the future. This was mainly due to the beauty, coziness and increased security. The parameters that matter most were quite the same as for the garden owners. The design, the mix in the environment, the price, the brightness, the uniform light angle and the color. The device was more important than the energy consumption compared to the users' preferences. Four out of five people were also interested in a smart garden system.

Still, a third of those who did not have garden lighting were not interested in having it in the near future due to inaccessibility, lack of interest and unnecessary. There were also people who thought it was ugly and expensive, and damaged the environment. The majority of six people thought it was ethically wrong to have garden lighting in their garden.

3.3 Market Analysis and Benchmark

3.3.1 Visiting stores

To get an overview of what a product is on the market, some semi-structured interviews have been conducted in some stores in Gothenburg. Initially, a general overview was made to gain an understanding of the range of garden lamps that the store offered. All stores have different sizes, which means that they can offer different amounts of products.

The first store visited was NetonNet in Sisjön and the supply was above average, but still poor. They offered two different smart garden lamps from Deltaco and some Philips Hue luminaires but no garden material. The staff in the store said that they sell a larger amount of Deltaco than Philips, just because a smart bridge is needed to use Philips products. Customers did not ask much about smart garden lamp because it is still so new on the market. People who buy them either only buy

the light that is available or they have great insight into the market and have a lot of information before entering the store and do not have to ask for help. The garden products from the Philips range are only sold on the website, and they did not know why. They also sell very simple white candles, and the need for RGB colors is not that great, except at parties. The quality of the various brands was according to NetonNet's equivalent.

The other store was Inet in Sisjön, where they offered both Philips and Deltaco products, but no garden lamps.

The third store was Elgiganten where they had a rather unstructured store where the garden lighting was definitely not in focus, perhaps due to the season, they said. They did not get many questions about smart garden lighting, but the interest in smart indoor lighting was much greater. The smart outdoor lighting had just hit the market for the electricity giant in a year, but maybe it will explode, the employee said. They only offered Philips products.

The largest store with the largest assortment was Bauhaus. They offered both ordinary garden lamps, but also smart garden lamps from Philips hue and Ledvance. They had another smart solution like Ecolite, where the customer could install an Ecolite Leo smart bridge to their garden lights, to control the luminaire's smart functions via an app. Most often, the lamps did not use RGD colors, due to the popularity of the white traditional lamps. They did not get many questions about it and it is not an increased market for RGB. They believe in the smart future of garden lamps and believe that it has an opportunity to grow. The best way would be to introduce a smart alternative to the well-known garden brands that are well known as Markslöjd to sell large sums. In their opinion, the headlights were too bright, and not even in relation to the garden lamps when they were placed elsewhere in the store.

Claes Ohlson was the last store visited and they certainly believe in a future market with smart garden lamps, but they did not have any in the store yet.

Lessons from the visit to the store were that the smart garden lamps must be easy to use and install. Even though they believe that there would be a market in smart garden lighting, it is still early in the process. RGB can be a complement, but it is not necessary due to the high popularity of white light. Philips and Deltaco today had the majority of market sales, but other brands will approach.

3.3.2 Patent Research

A rough patent research was done to analyze to get an idea of what is available, take inspiration and what not to copy. This excel sheet for patent research is in C.1 and C.2 in appendix.

3.3.3 Benchmark analysis

The benchmark analysis was done through internet research and the excel sheet is displayed in C.3, C.4, C.5 and C.6 in appendix.

The benchmark resulted in an overview of many interesting products available on the market. Some of these were useful in the project and were ordered for the company. The purpose of buying these was to learn how these types of products are structured and how to find ways to reconstruct and make a better product. Three smart garden luminaires were ordered, Philips Hue Lily, Deltaco garden lamp and Ledvance Floodlight.

3.3.4 Product Testing and comparison

Before disassembly, the products were tested and compared. Three products specified as smart garden lamps were tested against each other and four ordinary garden lamps. All lamps differed in 230 volts and 12/24 volts.

Three smart garden luminaires were tested while connected and controlled by its app. Philips Hue had a robust and stylish design, it was controlled individually and had a nice adjustment with notches. Although Lily required a gateway and had many separate parts as many screws as could disappear. Deltaco garden lamp was cheaper, had Bluetooth and everything was included. Although the Deltaco lamp was not individually controlled, the angle adjustment was slippery and the design was not very good. The Ledvance headlight was quite different from the others, but the lamp had a brighter brightness and colors, but had poorer app and instructions and a bad design.

3.3.5 Disassembly

To get an overall understanding of how a garden lighting is built, a process was done to disassemble products as seen in the figure 3.6. It was quite difficult to disassemble some of the lamps, due to the lid being glued to the other parts. While dismantling, each part could be unplaced to learn how to build a waterproof garden fixture. Some of the lessons learned from the disassembly were that the individually controlled Philips shade had much more components on its circuit board than Deltaco and therefore needed more interior space. In general, the luminaire can be made smaller, there is a lot of dead space. The transmitter is probably located where there is no metal, for example on the front of the lens, or as on the Philips Hue, in the plastic cover on the back. This is mainly due to the metal cutting off the connection.

While the four original garden luminaires were disassembled, it was discovered that some of them have a traditional GU10 lamp that makes the lamp much less innovative. There are some solids in plastic and some in metal, no typical choice of material. This disassembly session also learned how to make the product waterproof and where to put rubber rings etc.

Figure 3.6: Disassembly

4

Product Specification

This chapter describes the customer needs list, the function analysis and the requirements specification.

4.1 Customer Needs List

Based on answers from interviews and the survey, a customer needs list could be created. The responses were analyzed by the four-step method. The grouped answers may later be customer needs. The questions in the survey were both about what function people want and which design parameters are important. The lamp must have an astronomical timer, be dimmable, have a timer, tunable white and be able to be connected to a system.

Customer Needs List		
Functions	**Armature**	**Whole concept / User friendliness**
Astronomical timer	Satisfying design	Having a low price
Dimmable	Avoid glare	Being energy efficient
Tunable white	Mountability in different places	Being easy to use
Timer	Unity with other armatures	Easy to install
Connected system	Blend well into the background	Intelligent
	Adjustable beam angle	Independency
	Have a reasonable size	

Figure 4.1: Customer Needs List

4.2 Function Analysis

Due to the simple functions of the garden luminaire, a functional tree was made [26]. A hierarchic function tree were made to understand the functions of the product, as in [25].

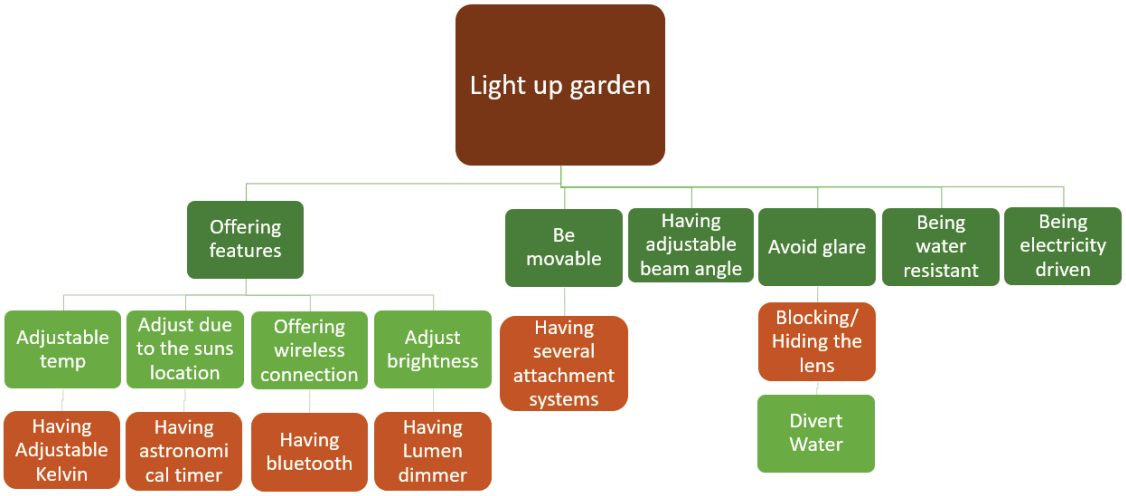

Figure 4.2: Function Analysis

4.3 Requirement Specification

The requirements specification is based on lecture notes within Product Development Project 2020 [24]. The customer needs list was transformed into technical requirements with target values, which later created the requirements specification. The specification contains both requirements and rated wishes. During this project, the specification begins, but does not end. Much ongoing work is underway on this project and development opportunities, and in this way the requirements specification will continue to be met. An example is the price of the product, because material selection and manufacturing are not so specified, the price is difficult to choose a reference so early in the development. At this stage, requirements such as nominal service life and design can be specified due to regulations / recommendations from the company. The requirements specification is shown in D.1 in appendix.

5

Concept generation

The concept generation was done with both systematic and creative methods. Systematic methods such as a morphological matrix. The creative methods included brainstorming and a workshop. This concept generation was also inspired by some moodboards.

5.1 Inspiration gathering

In figure E.1 in the appendix, it illustrates two moodboards. The one on the left is a moodboard created to visualize the importance of a discreet structure. According to the lighting designer, it was important that the luminaire was discreet and matched the outdoor colors.

The second mood board illustrates the importance of creating a lamp that matches the main characters in the other products in the company's portfolio. The design guidelines were to create a product with a simple and Scandinavian design. Consistency was also an important factor for garden owners in the survey.

5.2 Creative concept generation

5.2.1 Brainstorming

The first brainstorming session was done by the author of this report and it was divided into different functions to make a better structure. Later, these functions will be combined into one concept. In figure 5.1 the lens hood, beam angle, beam angle and mounting are shown. Several solutions are also marked with numbers that are to appear in the morphological matrix.

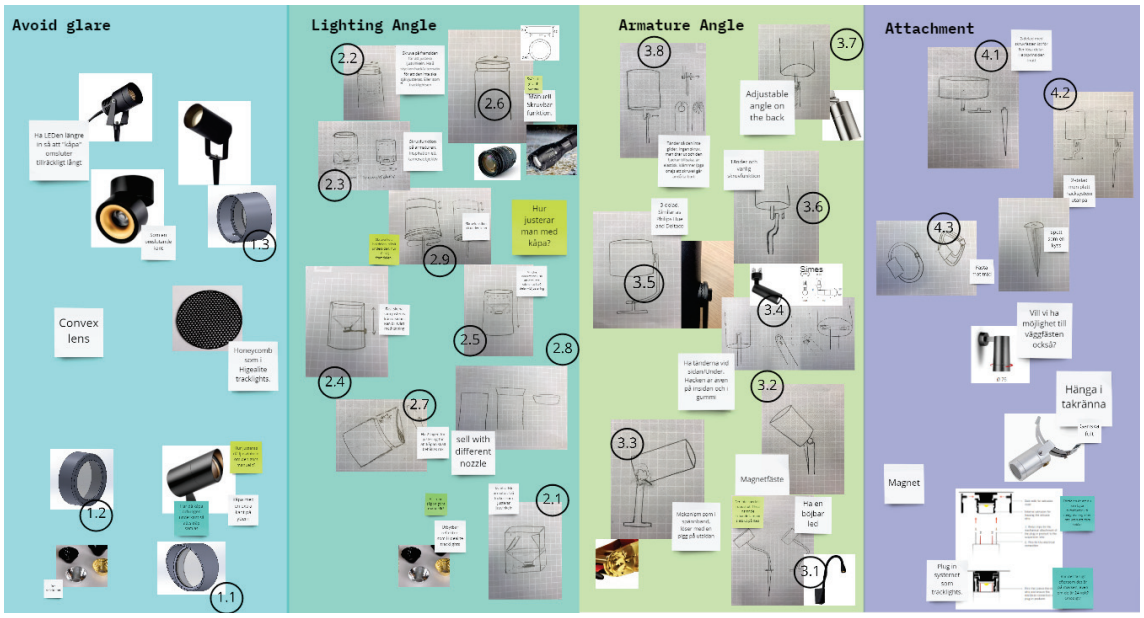

Figure 5.1: Brainstorming

5.2.2 Workshop

The workshop was done with several experts at the company, both civil and mechanical engineers, electricians and salesmen. This workshop resembled a brainstorming session together as a team with different skills. This mix of skills made the brainstorming session very useful due to different points of view. Many of the self-made brainstorming concepts were similar to the concepts that already existed. Although some inputs and concepts were new and could complement the second brainstorm. An example of useful input for further development of the project is shown in figure 5.2, where the concept was to use cast components for waterproofing layers. Another solution in the brainstorming functions was to adjust the beam angle digitally through an application. This means that you do not need a manual function to adjust the cover. This solution is shown on the right in figure 5.2.

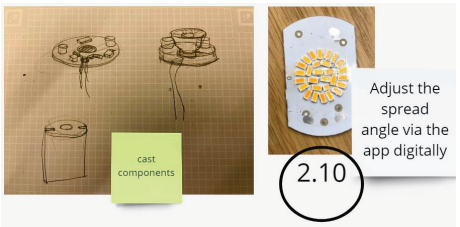

Figure 5.2: Inputs

5.3 Systematic concept generation

The systematic concept generation was made with a morphological matrix as described below.

5.3.1 Morphological matrix

To generate concepts, a morphological matrix was made. This generates a huge amount of concepts. This generation was divided into functions, due to the fact that the lamp has several functions that must interact.

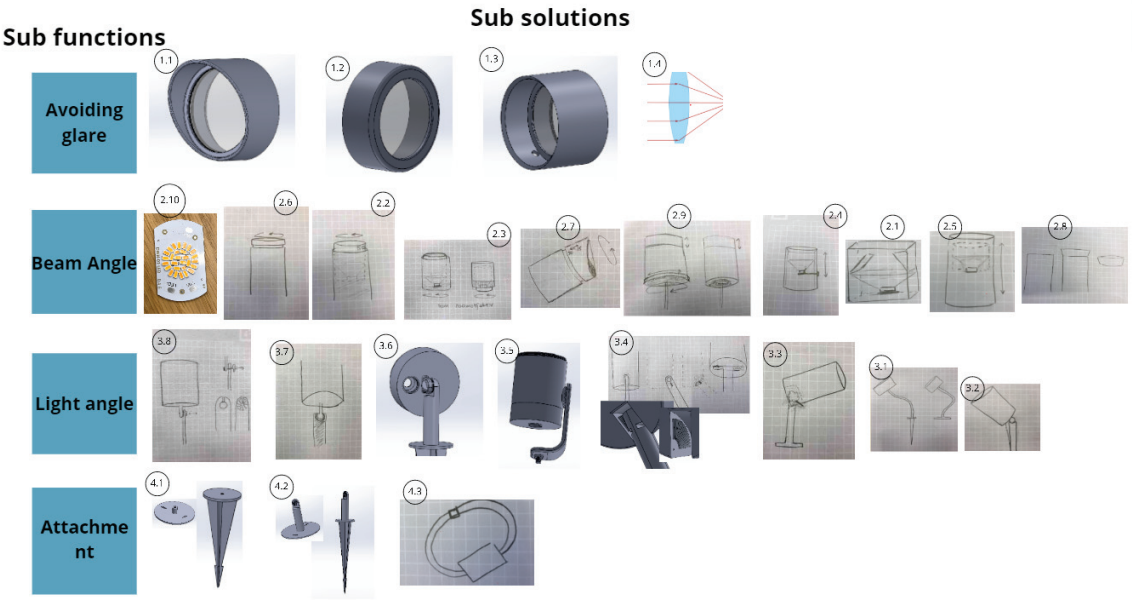

Figure 5.3: Morphological matrix

6

Screening and Evaluations

6.1 Evaluation matrices and elaborated Morphological matrix

Due to the large number of concepts, some guidance from educators at Chalmers was needed. This resulted in the various sub-solutions being organized into groups. These groups could later be evaluated in the elimination matrix. This is important because otherwise there would be a large amount of concepts in the morphological matrix that are difficult to continue with. The grouped morphological matrix is seen in the figure 6.1.

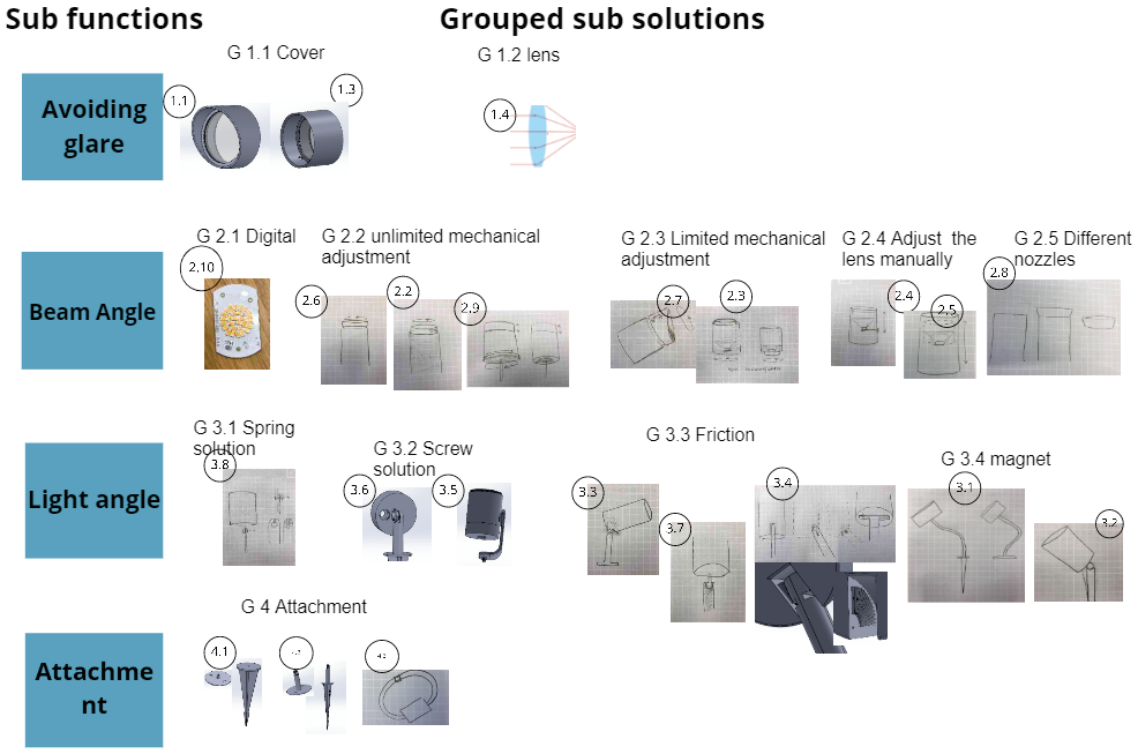

Figure 6.1: Grouped Morphological matrix

These concepts could then be evaluated in an Elimination matrix which in seen in appendix F.1, F.2, F.3 and F.4. Some of the groups were eliminated and the majority were able to continue the process. The next step was to build concepts by combining grouped sub-solutions. Each concept was given its color and the morphological

matrix generated a total of 40 concepts that could be further evaluated, as shown in the figure 6.2.

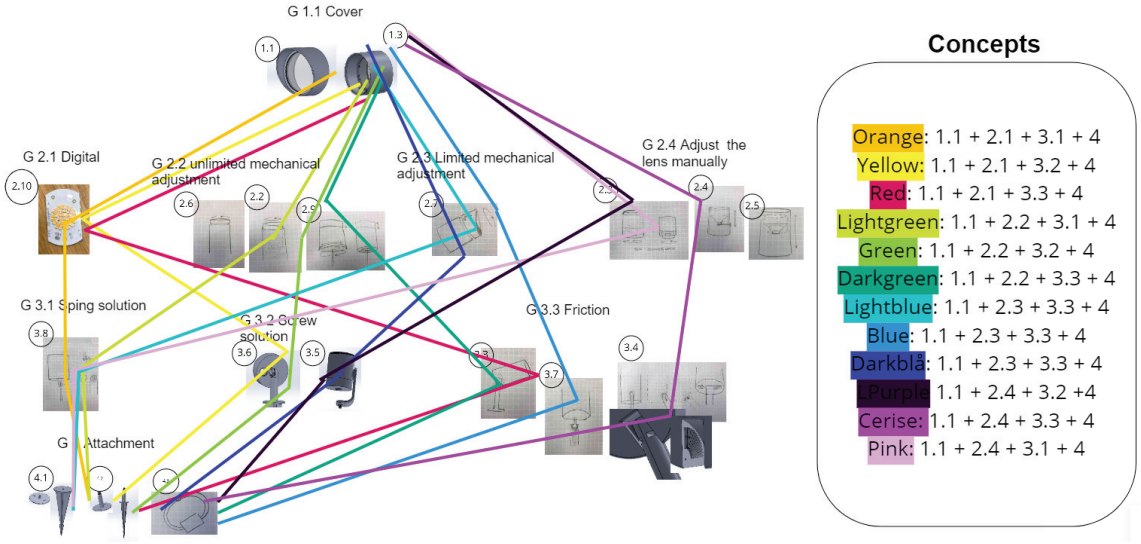

Figure 6.2: Final Morfological matrix

This process continued by comparing the remaining concepts with several Pugh matrices. The Pugh matrix was made with three iterations to achieve good results. Three concepts were chosen as references in each iteration, first orange concept, second purple concept and lastly the concept cerise. The first reference concept was chosen by the author of this report, in the belief that it would work best. After an iteration, the best-ranked concept was the new reference in the next iteration. These Pugh matrices are shown in F.5, F.6 and F.7 in appendix.

6.2 Expert review

The Pugh matrix resulted in three remaining concepts, the purple, the cerise and the yellow. These three performed best overall after three iterations. To decide which one to continue with, a meeting was arranged with some experts from the company. This resulted in the purple concept being chosen as the best one to continue with. This concept was divided into functions and the exact design was not yet modified. The next chapter will introduce the concept and how it was redesigned and prototyped several times to get the best result in the end.

6.3 Pros and cons list

In addition to these matrices, a major influence in this project was the decision to have a low-voltage system or a 230-volt system for the luminaire. This decision would affect the concept in requirements and design. To make this decision, some research, interviews and discussions were done to create a list of pros and cons. This list guided the author of this report to make a decision on a 230 volt system, mainly

due to its more robust system, the technical features have the right frequency and its higher quality. The list of advantages and disadvantages is shown in figure 6.3.

230 volt

Pros	Cons
• No problem with cable length • Its usual to have wall outlets outside • The astronomical timer will work • The technology / system is available by the company • Cheaper • Easier to communicate between sources • There are not as many smart garden lamps with 230V	• Must be buried in pipes, or plex cable (at least 2 sods) • Must be installed by electrician • Unsafe (earth fault circuit breaker etc) • Cost for burial / pipes • Electrician required

12/24 volt

Pros	Cons
• Safer • No need to bury cables • No need of an electrician	• You always need a transformer, and the transformer has limited capacity • Can be expensive if you have few lights • There is no standard transformer system • Need to develop a transformer as well

Figure 6.3: Pros and Cons List

7

Concept Development

7.1 Design

The construction and the design of the concept were made as a CAD model in Solidworks. The two CAD models with several mountings, a skewer and a plate, are shown in figure 7.1. An exploded view of the final CAD design is seen in figure 7.2.

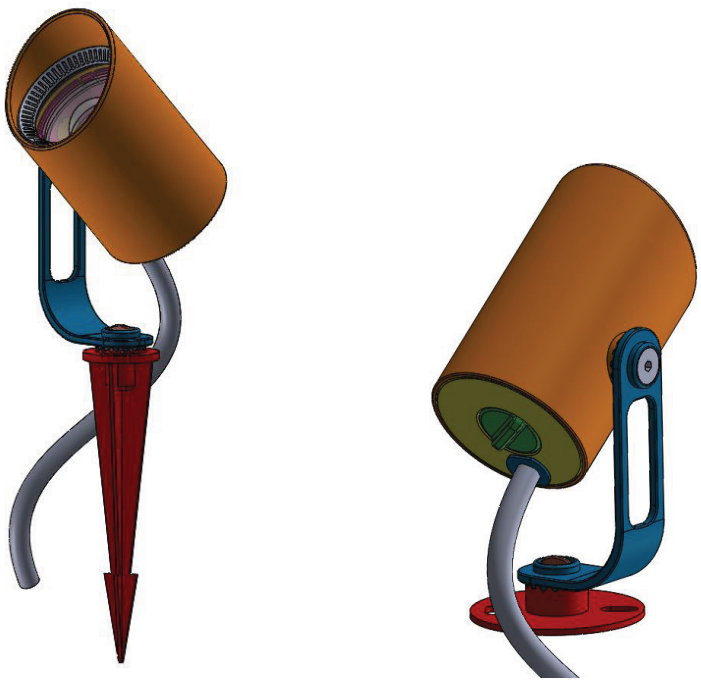

Figure 7.1: CAD model skewer and plate

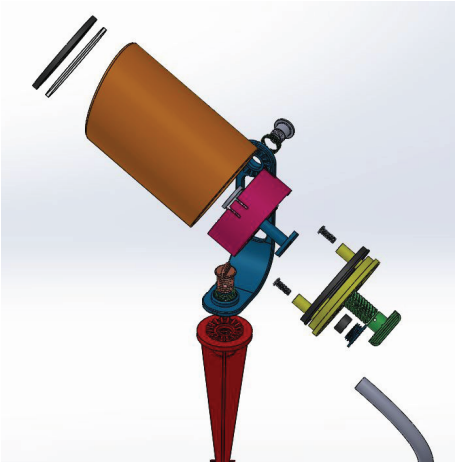

Figure 7.2: CAD model in exploded view

7.2 Improve concept

7.2.1 3D printing and test

To develop a good and functional concept, all parts needed to be 3D-printed, to detect any mistakes. And speaking of which, it took more than two prints and CAD enhancements to get a good model. Most of the mistakes were that the threads did not fit together, or that the dimension did not match in reality.

Figure 7.3: 3D printed parts

7.2.2 Expert reviews and feedback

Experts at the company were involved in the process of building a model. Together with the team, a functional model finally worked, and it was ready for prototype.

The feedback along the way was especially about the design. By mentioning one of them, the previous CAD version meant a dividing line between the lid and the middle part as seen in the figure 7.4. The dividing line did not match the design requirements and it was then rebuilt together with some experts. This resulted in the lid and the middle part becoming the same part, and the glass was mounted with a threaded ring and rubber on top, and pressed against an inner edge as in the picture 7.5.

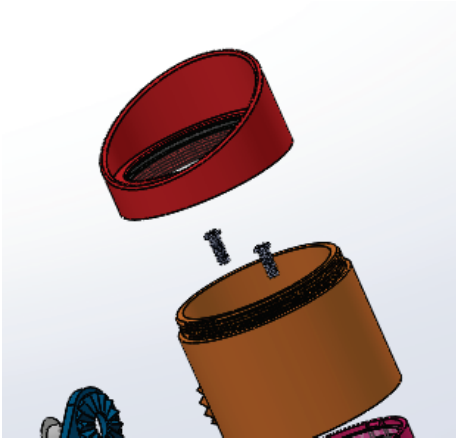

Figure 7.4: Middle part and the cover version 1

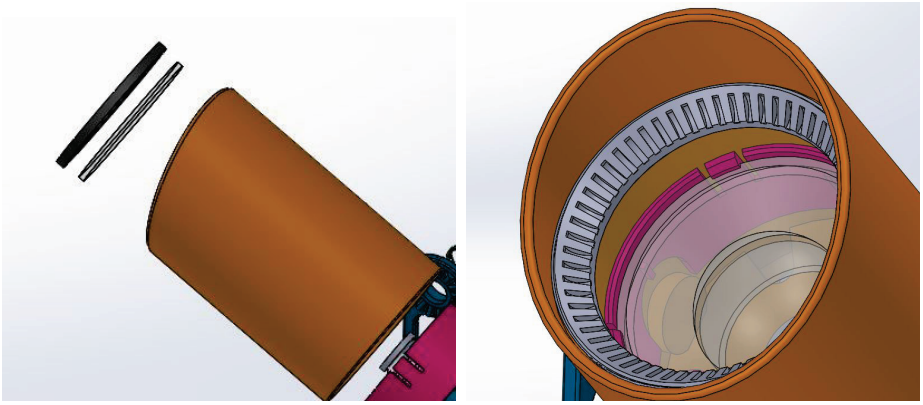

Figure 7.5: Middle part and the cover version 2

The other reconstructions were done in the same way, made in CAD and print new versions until the model fit together.

8

Validation and Final Concept

Design of the final garden lamp The final design of the garden lamp was created and rendered in Solidworks. These renderings are created by solid parts along with material choices. Each of the features will be described further below.

8.1 Functions of the garden lamp

8.1.1 Adjustable Beam Angle

Regardless of the survey's answers, users want a garden luminaire where they can adjust the beam angle. For most of its competitors, the beam angle is not adjustable, there are either one or two different types of luminaires instead. At first, they thought of adjusting this with an application, but it was a bigger challenge to create it manually. If you are installing a lamp in your garden, it can be a nice thing to adjust the beam angle at the moment manually, and you will probably not adjust it more than once. With some input from the company, this manual design was made. This solution will make this product stand out from its competitors and create greater value.

The beam angle is made with a threaded screw and a lens holder. While screwing, the lens holder will automatically move horizontally. This must be done with as little friction as possible, and there are some markings on the back of the lamp to know which angle to choose. The mechanism is shown on the right in 8.1.

Figure 8.1: The adjustable beam angle

8.1.2 Adjustable angle of the two axis, the arm and the bottom

Arm and bottom have the same function. The final design of the arm and the bottom adjustment are illustrated in figure 8.2. Between the screw and the arm / bottom there is a mechanical spring washer, which is shown at the bottom right. This spring will be compressed to be adjustable as seen in the first picture on the left and it will be mounted inside the screw hole. Later, the screw is added to the model and it can be seen in the other two pictures in the figure 8.2.

Figure 8.2: Axis adjustment

8.1.3 Tunable white

The garden lamp will offer an adjustable white function. The temperature of the light can be adjusted via the app. In figure 8.3 two different temperatures are shown. The luminaire on the left has a cold white color and the right one has the warm one. The tunable white function will be able to vary the color temperature between 2700-4000 Kelvin.

Figure 8.3: Cold and warm white

8.2 Attachment

The concept has two different attachments, which are suitable for different occasions. The skewer is made to be pushed into the ground and the flat, round base will be mounted either on the ground or on a wall with screws. These two types are shown in the figure 8.4 and 8.5.

Figure 8.4: Garden lamp fixed with a plate

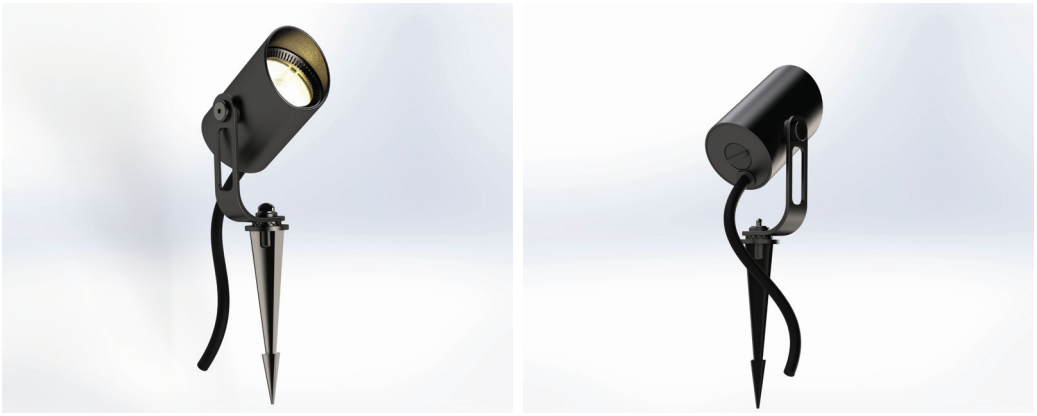

Figure 8.5: Garden lamp fastened with a skewer

To get an basic understanding of the size of the lamp, and how it will be mounted in reality, a rendered picture in a real garden is illustrated in 8.6.

Figure 8.6: Rendering with background

8.2.1 Other technical functions

The garden luminaire will also have some technical functions to be called a smart garden lamp, and these are:

- Dimmable
- Controlled individually
- Astronomical timer
- 500 lumen and 6 watt

Initially, the lamp will be dimmable. This means that the power supply will be adapted to the lamp, which results in a changed brightness. The brightness will change in the lumen, from 0 to 500.

Each luminaire will be controlled individually. This is mainly due to the 230 volt system and no need for a transformer. The 230 volt system has a frequency of 50 Hz, which means that the astronomical timer works best. If the frequency were different, the astronomical timer would not work.

Other parameters that are relevant to inform are that the LED vessel will be able to produce 500 lumens. This number is chosen for many reasons. The company already has another product with the same lumen, which makes it possible to use the same LED. 500 lumens is also compared to the most popular garden products from the competition. Interviews and research have shown that the most popular range that garden owners buy is between 400-500 lumens. Although the lighting designer recommended a smaller number, but with the function of a dimmer, it is more useful to have a wider range and an adjustable lumen.

The power of the lamp will be six watts, and is mainly based on the benchmark. Most garden fixtures have about six-eight watts if they have a lumen number of 400/500. According to the lighting designer, you do not need to strive for efficiency (lumen / watt), as there are no such strict rules for outdoor luminaires.

8.3 Prototype building

When having a final CAD design and 3D-printed parts that fit together, the surface finish could begin. The part that enclosed the internal components was spray-painted with three layers of different contents. Before spraying, the part was polished to get the spray paint solid. The first layer was made with beige spray material to fill in irregularities in the surface seen on the left in the figure 8.7. The second and third layers were made with matte black spray paint. The result is shown on the right in the figure 8.7.

Figure 8.7: First and third layer layer of spray

After the surface finish, the other 3D parts could be printed and the arm and bottom adjustment mounted. The mechanical spring washer was made with a 0.8 mm vertical wire and mounted between the M8 screw and the arm seen on the left in the figure 8.8. The second spring was mounted between the bottom and the M8 screw, with the arm in between seen to the right in the figure 8.8. The improvements with these adjustments compared to existing garden fixtures by competitors, is that there are fewer components and easier to adjust. The user does not need to touch the screw and no tools are needed.

Figure 8.8: Adjustments

In order to make the prototype shine, an LED vessel had to be mounted inside the outer shell. From another luminaire, an LED ship could be disassembled from the product and used in this garden lamp. The LED ship could be mounted and soldered to cables as seen on the left in the figure 8.9. The solded cables were then connected to a converter, that could convert the 230 volt system to a low volt system that suited the LED ship. Later the lens could be mounted on top of the LED ship. Above the lens, a glass and a threaded ring were attached to protect the lens and make it as waterproof as possible. This lens in shown to the right in figure 8.9

Figure 8.9: The LED ship and the lens

The converter was then connected to a plug in the socket. The converter can then be installed and controlled with a dimmer button, and the entire system is shown in the figure 8.10.

Figure 8.10: Final prototype

The final prototype has two different attachments, which are suitable for different occasions. The skewer is made to be pushed into the ground and the flat, round base will be mounted either on the ground or on a wall with screws. These two types are shown in the figure 8.11.

Figure 8.11: Final prototype with two types of attachments

9
Conclusion

The project began with a research phase, which defined the product's needs and user behavior. The product specification could be started, to introduce the fun concept generation through several methods. The concepts were later evaluated into three concepts that were discussed with experts in the field. A final concept could be modeled in CAD and 3D-printed to be gradually improved. After several iterations, the project ended up in a final design in CAD and a functional prototype.

Although there are many opportunities for further development of this product. Areas such as material selection, how to manufacture the product, business case for the product and more have not yet been considered. To develop a new product and succeed, there are many more areas to involve and include. This report is the beginning of a product that may be on the market in the future. After this project, there are some who believe that it can be useful research and results for the company to continue with.

10

Discussion

10.1 General discussion of phases in the report

10.1.1 Research phase

As previously mentioned, the project began with a research phase, with both literature studies and interviews, surveys, benchmarks and more. It is quite difficult to seek information at such an early stage that is believed to be useful in the project. To get a general knowledge, it is good, but the information in the report is almost rewritten at the end of the project. Many categories and parameters were not useful in the end and so to speak destroyed the common thread.

Most interviews were conducted with electricians, sales people, competitors and experts. The users of the garden lighting products participated in the questionnaire. To reach these users, the author posted the questionnaire in Facebook groups for garden enthusiasts. This was a good plan for a day, but then the author was kicked out because of rules. However, there were 115 responses in the survey, which was enough to get good and useful information. For the next time, it may be a good idea to find other places to post a survey.

The interviews went well and it resulted in worthy information. Many of the interviewees were garden owners and could get input from their own experiences. For further research, it may be a good idea to also interview garden owners to find root causes and behaviors from experts.

The store visits, product tests and disassembly went well and were extremely important for the project due to the practical learning and understanding of what sells in the market. The literature benchmark was useful for gaining a general overview. But from the author to the perspective of this report, the benchmark could have diminished the creativity of the brainstorming session. It was quite difficult to think outside the box, when you have already gained a good understanding of what is on the market, therefore the design went the same way as the competitors. This is one of the main differences between this master's project and other courses, which most companies do overall large benchmark analyzes, and schools prefer to do in a small scaled version.

10.1.2 Product specification

Due to many parameters and the complexity of the project, some of the parts of the product specification phase were difficult to achieve. The customer needs list can be analyzed with a four-step method and then rewritten to technical requirements in the requirements list. Some of these requirements were valued qualitatively, which was difficult to rewrite and find target values. The list of requirements is also a beginning and not a conclusion. The company has much more information that needs to be developed and used.

10.1.3 Concept Generation

The concept generation was divided into several methods, both creative and systematic. Brainstorming sessions were distributed both individually and together in an expert group from the company. The individual brainstorming led to many concepts and the workshop led to many useful discussions which was a good complement. Due to the large number of people involved, it was difficult to come up with many more concepts, but most concepts were developed and combined. With experience, the morphological matrix results in many more concepts than desired. To minimize this amount, some teachers helped to organize and group all concepts into sub-functions. This effort made the project much more organized.

10.1.4 Screening and Evaluation

Due to the grouped morphological matrix, the evaluation matrices may be less complicated. The elimination matrix involved 40 concepts and ended up in 12 concepts with sub-functions. These 12 concepts ended up in three combined concepts after the three pugh matrices. As usual, it is quite difficult to select the first reference to be used in the pugh matrix. But with the results in hand, the guess about orange concept was not so bad. According to the author of this report, these matrices are not a method used by the company. Instead, they have a more design-oriented thinking and methods such as fast prototyping with many users / expert reviews. There were also many pros and con lists, because it was easy to make decisions. These are methods that the report writer is used to from previous courses from the exchange period. Due to lessons learned from Chalmers, matrices, pros and cons and expert reviews were used. However, the design had an important part of the project, which was very fun but was a new experience, such as avoiding dividing lines in the surface. In further projects, it would have been fun to test the second way of thinking as a company, make prototypes early in the process and constantly pitch the concept to get input on improvements until it is ready. It would be fun to see if the resulting product would be the same or something far from what this author came up with.

10.1.5 Concept development

The CAD modeling was done in Solidworks. Due to the learning of the software, the CAD modeling took a little longer than expected. The 3D print was also something

new for the author of this report, but with a lot of help from the company, it ended up in a prototype in the end. Along the way, many experts and engineers from the company had input and different opinions about the project that were useful, especially to think about the whole and the practical function. For the company, it was important that the product will work and it was measured together with different ways of thinking and experiences. The people at the company were very involved in each project, which was very grateful.

10.1.6 Validation and final concept

After several improvements, the final CAD modeling could be 3D printed and assembled. The prototype was well made, but the lack of time meant that the prototype was made of plastic. For further development, it can be a good idea to have real materials as in the end product to give a better understanding of the product and its function. Overall, the time to build a prototype could have been longer to order materials, etc. With a lot of help from the company, the prototype can still provide light and show its functions.

10.2 Risks, consequences and ethics

Product development requires conscious environmental effects that the product may cause. The product's life cycle is central, such as environmentally sustainable manufacturing and renewable material choices, as well as the ability to recycle the entire product to reduce climate impact.

Something that all people on earth need is electricity, to light up, heat and run society. On the other hand, all types of energy production affect the environment and fossil production, which ultimately affects the climate. Private individuals are also an important factor in reducing global emissions, such as energy efficiency and reducing their energy use [8]. Thus, the creation of luxury products that consume energy can be a contributing factor to increased energy consumption.

Artificial light at night is increasing exponentially around the world, as a result of new efficient lighting techniques. The resulting light pollution can cause unintended psychological consequences. The production of melatonin (the hormone that the brain creates for response in the dark) can also be disrupted during production in the animals' circadian rhythm regulation [9]. Outdoor lighting can also affect biological systems, such as animals can become dazzled and not finding enough food.

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A

Interview

Interview questions with electrician,

A.1 Interview with an electrician

- Have you installed garden lighting?
- Do you think there will be a market for smart garden lighting systems?
- How do you install garden lighting?
- What is the best alternative, 12V or 230 V in smart garden lighting?
- What is the the main problem when installing garden lighting?
- What is the main problem with garden lighting overall?
- Do the system need a Gateaway?
- Is there any other solutions for the transformer?
- Which requirements is needed?
- What functions is needed to have?

A.2 Interview with lighting expert with experience of garden lighting

- How do you usually think when lighting gardens?
- Is there a clear trend in lighting?
- 230 or low voltage?
- What kind of problems do you encounter?
- What features do customers usually ask about?
- Do you think you should sell with different fasteners?
- What do you think about RGB in the garden?
- Choice of material, plastic or metal?

B

Questionnaire

B.0.1 Questions

- Har du trädgårdsbelysning
- Vad för typ belyser du?
- Vad för typ av belysning använder du?
- Vad är funktionen av din trädgårdsbelysning?
- Vilka funktioner har du på din trädgårdsbelysning?
- Vilka funktioner skulle du vilja ha på din trädgårdsbelysning?
- Vilka parametrar är viktiga med din trädgårdsbelysning?
- Har du smart trädgårdsbelysning?
- Hur nöjd är du med ditt smarta system idag?
- Vad är det som funkar bra i ditt system?
- Vad skulle kunna bli bättre i ditt system?
- Är du intresserad av ett smart trädgårdssystem i framtiden?
- Vilka funktioner skulle du vilja ha på din smarta trädgårdsbelysning?
- Varför är du inte är intresserad av ett smart trädgårdssystem
- Skulle du vilja ha trädgårdsbelysning?
- Vad är det som intresserar dig för att köpa trädgårdsbelysning?
- Varför har du valt att inte ha trädgårdsbelysning?
- Hade du använt trädgårdsbelysning om den varit smart?
- Vilka parametrar skulle vara viktiga med din trädgårdsbelysning?
- Om du inte har justerbart ljus, vilken typ av ljus har du (ex kallvitt 6000K eller varmvitt 2700K)?
- Skulle du va intresserad av att ha smart trädgårdsbelysning?
- Vad är din ålder?
- Vad definierar du dig som?
- Är det viktigt för dig att kunna styra var lampa för sig?
- Om du inte har justerbart ljus, vilken typ av ljus har du (ex kallvitt 6000K eller varmvitt 2700K)?

C

Market analysis and Benchmark

C.1 Patent analysis

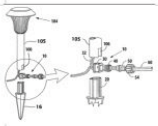
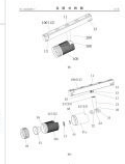
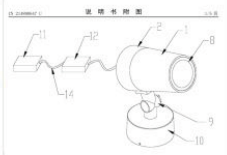
	Patentname	Paternt nr		Inventor	Discription	Date/Year
https://patents.google.com/patent/US7481670B2/en?q=garden+lighting&oq=garden+lighting	Quick secure connection system for outdoor lighting systems	US7481670B2		Chi Gon Chen	quick secure connection system for use with a set of outdoor lights includes a power source having a two-wired female connector surrounded by external threads	2008
https://worldwide.espacenet.com/patent/search/family/071874516/publication/CN111503556A?q=intelligent%20outdoor%20spotlight	Spotlight structure	CN111503556A		ZHANG HAICHENG	It aims to provide the spotlgiht structure which is waterproof and capable of adjusting brightness, adjusting color and adjusting light spots into a whiole.	2020-08-07
https://worldwide.espacenet.com/patent/search/family/073976008/publication/CN212252238U?q=intelligent%20outdoor%20spotlight	Rotating shaft spotlight of ball structure	CN212252238U		SHI MINGFENG	Rotating shaft spotlight with a ball structure, which compromise a base, a vonnecting column , a ball body, fixing block, spotlight, stepless rotation of the lamp holder can be achieved, lighting, decorating requirements of different angles can be met.	2020-12-19
https://worldwide.espacenet.com/patent/search/family/078931463/publication/CN214890647U?q=smart%20outdoor%20spotlight	An outdoor headlight	CN214890647U		Zhang Libo	Outdoor spotlight, rotates, intelligent module is connected with the COB light boardthorugh wires, and the output curretn and voltage of the power supply are controlled by intelligent module, realize dimmming/color matching. Waterproof prformance better, light emitting direction can be adjusted	2021-11-26

Figure C.1: Patents

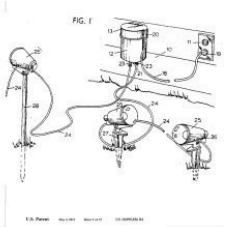
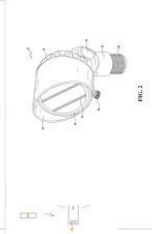
https://worldwide.espacenet.com/patent/search/family/010426974/publication/GB1199307A?q=outdoor%20transformer%20for%2024%20volt%20system	Low Voltage Outdoor Lighting Assembly	GB1199307A		Abrams Ralph	Outdoor lighting system plurality of low voltage incandescent lamps 25 are fed in paralllell	1970-07-22
https://worldwide.espacenet.com/patent/search/family/075689546/publication/US10995936B1?q=outdoor%20transformer%20for%2024%20volt%20system	Fully adjustable landscape lighting system	US10995936B1		BREEDLOVE MICHAEL GRANT	A landscape lighting system, plurality of landscape lighting fixtures somprise a light source and circuitry. Give combined power and control signal over power supply wiring, seperate the control signal from a power component of the combined signal, and cause the lgiht source to be controlled based on th econtrol signal.	2021-05-04
https://patents.google.com/patent/US8279079?oq=philips+hue	Control device for controlling the hue of light emitted from a light source	US8279079B2		Anthonie H. BergmanLucius T. VinkenvleugelBram F. JoosenHebertus M. R. Cortenraad	The invention relates to a control device for controlling the hue of light emitted by a light source.	2007

Figure C.2: Patents

C.2 Benchmark

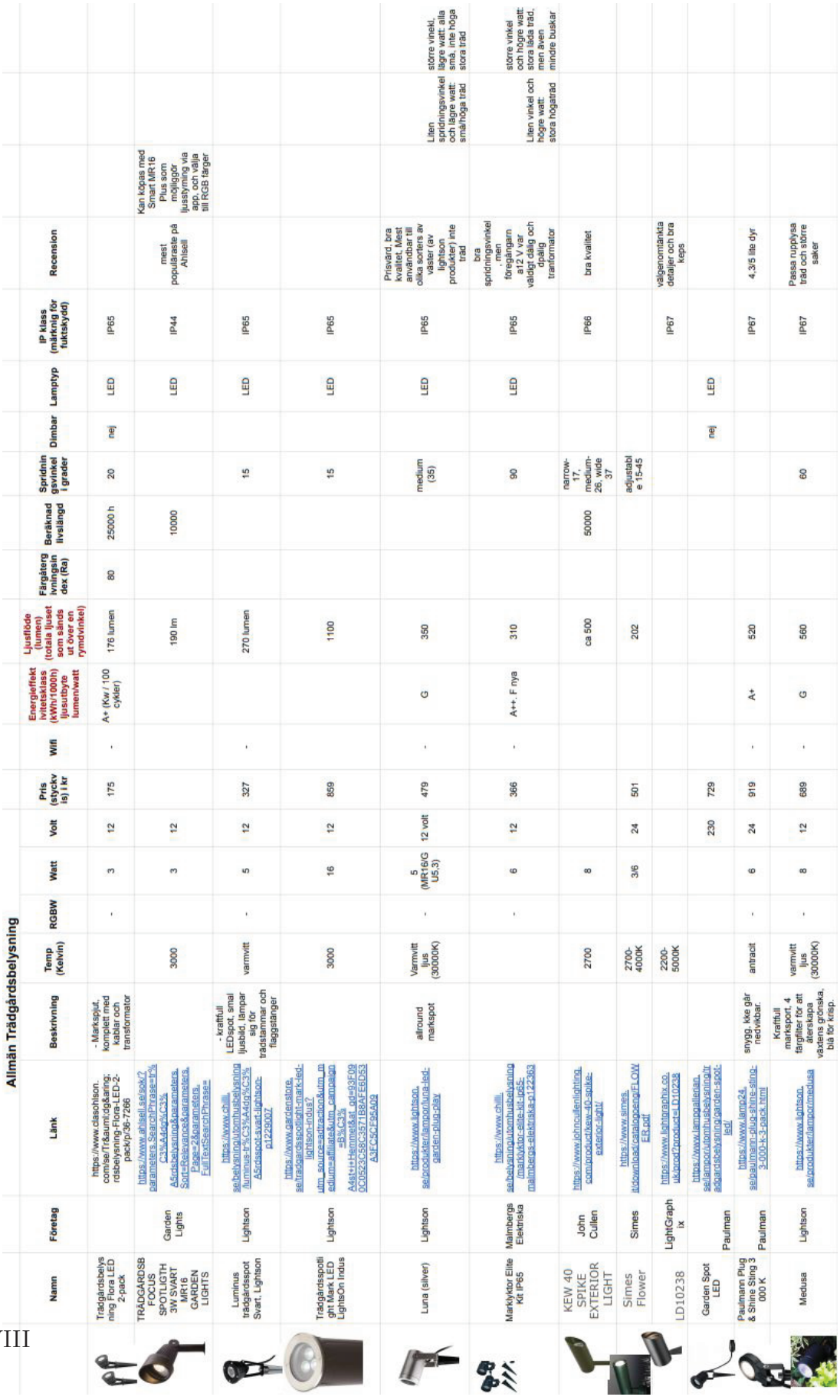


Figure C.3: Benchmark p.1

HEISSNER LED-damm- och trädgårdsbelysning	Heissner	https://www.vidaxl.se/e/heissner-damm-och-tradgardsspotlights-3-st-3-w/4006873397953.html?gclid=CjwKCAiA3L6PBhBvEiwAINlJ9NehQHcnGF7h1lkIPJ-GxEDZGWQSH0_ITO6vBKh-rwsrdbR06S0m3xoC8BwQAvD_BwE		varmvit (2700K)	-	3	12	400	-	G	270										
TRÄDGÅRDSSPOTLIGHT MARKSLÖJD GARDEN 24 15W	Markslöjd	https://www.bauhaus.se/tradgardsspotlight-markslojd-garden-24-15w?utm_source=pricerunner&utm_medium=cpc&utm_campaign=pricerunner		3000K	-	15	24	579	-	A++, F nya	950			24		LED	IP44	Väldigt bra men lite mer tydlighet på kabellängd mellan spot och transformator			
Capella	Lightson	https://www.lightson.se/produkter/lampor/capella			-	5	12	459	-	G	270 lumen			30			IP67				
Hovden Grafit Micro	SG	https://www.sg-as.com/sv/produkter/hovden/7766653	https://www.computersalg.se/i/7478929/hovden-micro-250lm-3000k-36?utm_source=adtraction&utm_medium=affiliate&utm_campaign=adtraction&at_gd=FFA856802932A6290B9A04C0551CA84A694B76D0	3000		4	230	1120			250			15/36				Upp ill 23W bakkantsdimmer	Har Decklights 1W med driver	Säljs inte mycket	
Hovden Mini	SG	https://www.vvsochbad.se/spot-hovden-mini-led-8w-3000k-540-lumen-36-grafit-1185820?gclid=Cj0KCQiA95aRBhCsARIsAC2xvfyhmfhMpio22YaqqlYRfPk_MecUnfQi6BqjJWVjS5-prG0AP-uxJ8aAjFnEALw_wcB		3000		8	230	1345/1999			540			15/36							
Hovden midi/maxi	SG					12/24	230	2499/3499													
Lot	Westal	https://www.westal.se/sv/produkter/exterior/markspett/lot-markspett-gu10	GU10 sockel, drivdon ingår ej	3000		5	AC/DC	277			380						IP54				
Lumina markspett LED	Westal	https://www.westal.se/sv/produkter/exterior/markspett/lumina-markspett-led	Integrerat drivdon	3000		8	AC/DC	1955			560			30			IP65				
SPOT IT MULTI 17 3000K	Hiedalite	https://www.elektroskandia.se/s?s=tr%C3%A4dg%C3%A5rdsbelysning&artnr=7761571		3000	-	17	230 Volt	450/3919	-	A	1027	80-89	50000 h	20-40		LED	IP65	4/5			
Spotlight Garden Kit	Hidealite	https://www.hidealite.com/sv-se/produkter/utomhus/12v-system/spotlight-garden-kit-_-266732	spotlight garden kit, finns massa olika styrkor, kan kopplas ihop med decklight	3000		0,8	12	2325					50000h	36			IP44				
Spot It Multi 1	Hidealite	https://www.hidealite.com/en/products/outdoors/floodlight/spot-it-multi-1-_-62729				1,5	driver to 230 V	710						25							
Spot it Multi 3	Hidealite	https://www.hidealite.com/sv-se/produkter/utomhus/stralkastare/spot-it-multi-3-_-56852		3000		3	inbyggt drivdon 230V	847			124			30					Gränsen verkar gå mellan 0,8 och 3 W, inbyggda dri		
Flora Black	SG	https://www.sg-as.com/products/flora/614003		3000		5/6,2W	230 V	1310			400			säljer både 15 och 36.					Fanns inga 24 volt lampor		
Hildealite Spot IT S	Hidealite	https://www.hidealite.com/sv-se/produkter/utomhus/stralkastare/spot-it-s-_-674977		3000		5,5	230V	2240			400										
Garden COB Flood Spot Light with spike		Aluminum Ip65 Outdoor 12v 24v 110v 220v Cob 10w 15w 20w Garden Cob Flood Spot Light With Spike - Buy 12v Garden Spike Lights,Garden Cob Flood Spot Light With				10	12/24/110/220 etc										IP65				

Figure C.4: Benchmark p.2

Arne LED	Lucide	https://www.lampgallerian.se/lampor/utomhusbelysning/arne-led/		2700		5	230V			G	350			38							
Lecce trädgårdsspot	Konstmide	https://www.lysman.com/sv/articles/2.94.2730/konstsmide-lecce-tradgardsspot-230v-4w-led-svart-7695-750		3000		4	230V	735			260				nej						
SLV HELIA		https://www.ltt-versand.de/en/light/lights-for-home-commercial-use/outdoor-lights/floodlights-outdoor/6156/slv-helia-outdoor-spot-led-3000k-350-anthracite-ip55?gclid=Cj0KCQiA3rKQBhCNARIsACUEW_Y_tlb65ei9HUQiyKpK4HO_GXE5s48W4cDla_a2MTU4I4TOsD17_cYaAs9REALw_wcB		3000		8	230V	1460			440						IP55				
Tatum LED	Lucide	https://www.lampgallerian.se/lampor/utomhusbelysning/tatum-led-spot/		3000		4,5									nej						
Anton	LUCANDE	https://www.lamp24.se/utomhus-led-spot-anton-med-jordspett.html?gclid=Cj0KCQiAu62QBhC7ARIsALXijXR78O4jiseLeO9XZlOy0Fez8z-gY3LXKv85aHPTB-5TmzPsvw8DfgQaAnSNEALw_wcB&gclsrc=aw.ds	snygg design			12	230V				878										

SMART BELSYNING

Namn	Företag	Länk	Beskrivning	Typ av ljus (Kelvin)	RGBW	Watt	Volt	Pris (styckvis) i kr	Wifi	Energieffektivitetsklass (kWh/1000h) Ljusutbyte lumen/Watt	Ljusflöde (lumen) (totala ljuset som sänds ut över en rymdvinkel)	Färgåtergivningsindex (Ra)	Beräknad livslängd	Spridningsvinkel i grader	Dimbar	Lamptyp	IP klass (märknig för fuktskydd)	Recension	Pros	Cons	
Deltaco smart garden lights	Deltaco	https://www.netonnet.se/art/hem-fritid/deltaco-smart-garden-lights/1017834.8883/	Wifi, RGB kompatibel för google etc, styr via mobilen	2700 K	Ja	6	24 V	350	Ja/bluetooth		500				ja	LED	IP54	5,0 på NETONNET 2 st, köpa till förlängningsslad där, annars bra app och prisvärd. inget skräp men philips är bättre	cheaper	less quality	
Lily	Philips	https://www.philips-hue.com/sv-se/p/hue-white-and-color-ambiance-lily-spotlight-for-utomhusbruk/1741530P7	krävs brygga	2000-6500	Ja	8	24 V	736 bauhaus(bäst pris)	Ja	G (2021-)	600	80	25000 h		Ja	LED	IP65	4,5 stjärnor på de flesta sidor. zigbee har limiterad längd, dyr, requires hue bridge	best quality and system, dim/bright/color	not superbrigh, expensive	räckvidd 20 m
Lily XL	Philips	https://www.philips-hue.com/sv-se/p/hue-white-and-color-ambiance-lily-xl-spotlight-for-utomhusbruk/1746230P7	Större och mer kraftfull	2 000–6 500	Ja	15	24 V	1643	Ja	G (2021-)	1050				ja	LED	IP65	4,5 stjärnor. stor lågvolt. fanns knappt högre utomhus tranformatorer än på 100 watt	quality, dim/bright/color	not superbrigh, expensive	
Scope med bryggsystem	In-lite	https://in-lite.com/se/smart-hub-150, https://in-lite.com/se/big-scope-12v	Inlite med smart hub				12V											lampan som Inlite säljer mest av			
Spot Garden Sensor Connect	Steinel	https://www.steinel.de/en/lights-sensors/products-oxid/lights/product-category/floodlights-and-spotlights/spot-garden-058685.html	Sensor-switched LED floodlight, motion dectector	3000K		7,9 W	230	557	bluetooth		512			38		GU10	IP44	IK03		Fanns inga 24 volt lampor	

Figure C.5: Benchmark p.3

Paulmann Plug & Shine Pike ZigBee RGBW	Paulman	https://en.paulmann.com/p/plug-shine-led-garden-spotlight-smart-home-zigbee-pike-individual-spot-ip65-rgbw-4-5w-anthracite/94283	Mobilstyrd, färgval och stor markbelysning	flerfärgad + varmvit (3000 K), - dagsljus (6500K) antacit	Ja	4,5	24V	549 kr på Hornbach 1120	ja	A+/G	330		30000		ja	LED	IP65, IP44	3,9 i Amazon, better get Philips Hue, kopplar inte till alla zigbee		kopplar inte till alla zigbee, inte tillräckligt vattentät (IP44), dålig connection	https://www.hornbach.se/shop/Tradgardsspot-PAULMANN-Spot-Pike-Plug-Shine-ZigBee-RGBW-4W-IP44-antracit/10290736/artikel-detaljer.html
Paulmann Plug & Shine inbyggnad ZigBee RGBW	Paulman	https://www.lamp24.se/paulmann-plug-shine-inbyggnad-zigbee-rgbw-3-pack.html	Färg, färgtemp och ljusstyrka kan ställas in med app/fjärrkontroll eller röststyrd. kan alltid slås av via ljusbrytare. kan opplas ihoo med Amazon alexa ex.	flerfärgad + varmvit (3000K) - dagsljus (6500K)	Ja	3,6	24V	964	ja	A+	350		30000		ja	LED	IP65	-			
Floodlight Smart wifi	Ledvance	https://www.lamp24.se/ledvance-smart-wifi-flood-utomhusvaeggspot-rgbw.html		3000K	Ja	10	230V	667/801 /935	Ja	A+	630				ja	LED	IP65	5,0 (2st) easy to install and control with the app			
LEDVANCE SMART+ WiFi Flood	Ledvance SMART +	https://www.lamp24.se/ledvance-smart-wifi-flood-vaeggspot-3-000-k-50-w.html		3000	Nej	50		935	ja	A	4250				Ja	LED	IP65				
SMART+ WIFI GARDEN 1 Spot extension	Ledvance	https://www.ledvance.se/konsument/produkter/smart-home/smart-home-armaturer/armaturer-for-utomhusbruk/armaturer-for-utomhusbruk/dekorativa-spotlights-for-utomhusbruk-med-wifi-teknik-c6475		3000	Ja	4,5	12	1195 Bauhaus, billigar epå hemsidor (425)	ja	G	260	80 +		76	ja	LED	IP65	The interace between ledvance and google can be confusing. Wifi, bluetooth and zigbee. 1/5 (1 pers) (svårt attconnecta till wifi)			
SMART+ WIFI GARDEN 1 Spot	Ledvance	https://www.ledvance.se/konsument/produkter/smart-home/smart-home-armaturer/armaturer-for-utomhusbruk/armaturer-for-utomhusbruk/dekorativa-spotlights-for-utomhusbruk-med-wifi-teknik-c6475		3000	Ja	5	12	1495	ja	G	260	80 +	25000	76	ja	LED	IP65				
Philips Hue Discover utomhusstrålkastare 743530P7	Philips	https://www.elgiganten.se/product/hem-och-hushall/lampor-och-belysning/utomhusbelysning/17170/philips-hue-discover-utomhusstralkastare-743530p7			Ja	15	240 V	1349	ja	A	2300		25000		ja	LED	IP44	4/5 inte inbyggd rörelsevakt. enkel att installera			
Techmar SMART RGB Focus	Techmar	https://www.gardenlightshop.com/smart-lighting/855-techmar-smart-focus-rgb-led-8719979281816.html			Ja	5	12	58£ (x12 =kr)	ja		370				Ja	LED	IP44	-			
Techmar SMART RGB Arcus	Techmar	https://www.gardenlightshop.com/smart-lighting/856-techmar-smart-arcus-rgb-led-8719979281618.html			Ja	5	12	£ 86.50	ja	A	370	80+	40000		Ja	LED	IP44	-			
Innr utomhus LED-spot Smart Outdoor	Innr lighting	https://www.lamp24.se/innr-utomhus-led-spot-smart-outdoor-3-pack.html		flerfärg + varmvitt	Ja	14,5	24	623	ja	A/G 5kW/10000h	230	80		80	Ja(ingpr ej)	LED	IP65	4.5/5. Cant be controlled seperately. Sämre konstruktion och ljus än Lily	zigbee		
Mobri LED Flood Lights Outdoor	Mobri	https://www.amazon.co.uk/Mobri-Bluetooth-Floodlight-Changing-Equivalent/dp/B082HX1KVC/ref=sr_1_fkmr1_2?crid=E599M3NB42NG&keywords=Techmar%2BSMART%2BRGB%2BFocus&qid=1643028391&smid=A2HZ56MCFRYWUU&sprefix=techmar%2Bsmart%		2700-	ja	15	90-240V	£ 38 /2	nej bluetooth					120	Ja	LED	IP66			CE approved? inte wifi, dålig bluetooth connection	

Figure C.6: Benchmark p.4

D

Product specification

D.1 Requirement Specification

Requirements Specification				
Development of smart garden lighting 2022-02-14				
		Criteria	***Target***	***Verification***
1 Safety				
1.1. Legacy/Standards	1.1.1	R: Protection	> IP67 standard	test
1.2 Energy	1.1.2	D: Energy classification		
	1.1.3	R: Effect	< 8 Watt	
2 Design				
2.1 Armature	2.1.1	R: Having a satisfying design	Qualitative	Expert reviews
	2.1.2	R: Having a robust design		
	2.1.3	D5: Size	< competitors (60x130 mm)	Calculation in CAD
	2.1.4	D5: Mass	< 1 kg?	Calculation in CAD
	2.1.6	D5: Easy to install	Qualitative	test
	2.1.7	D5: Easy to use	Qualitative	test
	2.1.8	D5: Consistent with other products by the company	Qualitative	Expert Reviews
2.2 Features	2.2.1	R: Adjustable beam angle	15-40 degrees	Engineering assessment/ CAD
	2.2.2	R: Glare avoiding	<30 cm	Engineering assessment/ CAD
	2.2.3	R: Adjustable angle	0-180 degrees	Engineering assessment/ CAD
3 Quality				
3.1 Robustness	3.1.1	R: Being robust	Consider material data	Robustness analysis/FEM
3.2 Life	3.3.1	R: Nominall service life	> 10 years	test
4 Curcuit board				
4.1 Safety	4.1.1	R: Heat transfer	Enough space and material	Material data/CAD/test
		The heat must be transfered from the curcuit board to the artmature		
4.2 Features	4.2.1	R: Being bluetooth connected		Engineering assessment
	4.2.2	D5 Offering astronomical timer		Engineering assessment
	4.2.3	D5: Tunable white	2700-4000	Engineering assessment
	4.2.4	D5: Dimmable	0-100 %	Engineering assessment
	4.2.6	D2: RGB	16 million colors	Engineering assessment
	4.2.7	D5: Lumen	500	

Figure D.1: Requirement Specification

E

Concept Generation

E.1 Moodboards

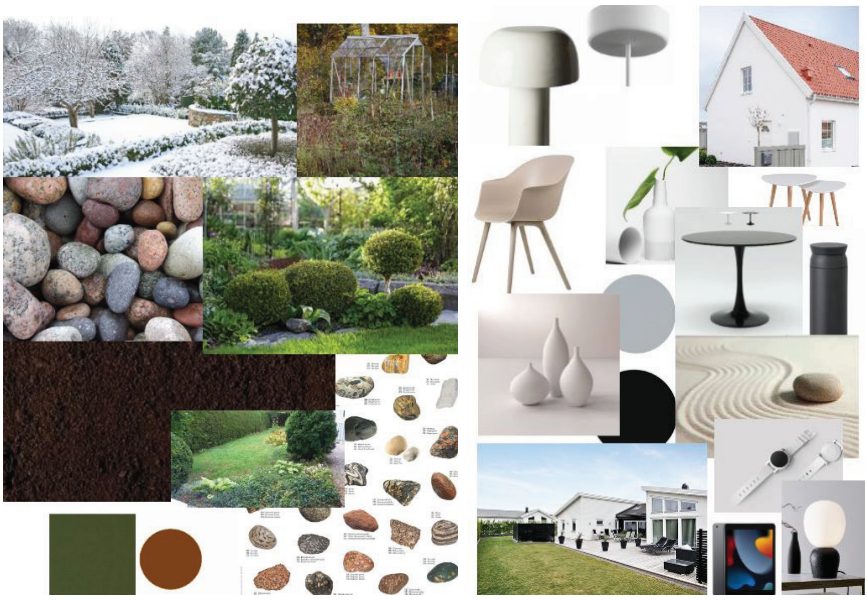


Figure E.1: Moodboards

F

Matrices

F.1 Elimination matrix

Elimination matrix

Concepts	Solves Main problem	Inovative / special	Fulfil design/construction requirement	Fulfill all demands	Compatible/Realizable	Safe	Reasonable cost	Comment	Decision
1.1 + 2.1 + 3.1 + 4	+	+	+	+	+	+	+		
1.1 + 2.1 + 3.2 + 4	+	+	+	+	+	+	+		
1.1 + 2.1 + 3.3 + 4	+	+	+	+	?	+	+		
1.1 + 2.1 + 3.4 + 4	+	+	+	-	+	+	-	lack in durability	
1.1 + 2.2 + 3.1 + 4	?	+	?	+	+	+	+		
1.1 + 2.2 + 3.2 + 4	?	+	?	+	+	+	+		
1.1 + 2.2 + 3.3 + 4	?	+	?	+	+	+	+		
1.1 + 2.2 + 3.4 + 4	?	+	-	-	+	+	+	lack of durability	
1.1 + 2.3 + 3.1 + 4	+	+	+	+	+	+	+		
1.1 + 2.3 + 3.2 + 4	+	+	+	+	+	+	+		
1.1 + 2.3 + 3.3 + 4	+	+	+	+	+	+	+		

Criteria fulfilment:
(+) Yes
(-) No
(?) More info needed
(!) Check with specification

Decision:
(green) Continue
(red) Remove
(yellow) More info needed

Figure F.1: Elimination matrix p.1

Elimination matrix

Criteria fulfilment:
(+) Yes
(-) No
(?) More info needed
(!) Check with specification

Decision:
(green) Continue
(red) Remove
(yellow) More info needed

Concepts	Solves Main problem	Inovative / special	Fulfil design/construction requirement	Fulfill all demands	Compatible/Realizable	Safe	Reasonable cost	Comment	Decision
1.1 + 2.3 + 3.4 + 4	?	+	-	-	+	+	+	lack of durability	
1.1 + 2.4 + 3.1 + 4	+	+	+	?	?	+	+		
1.1 + 2.4 + 3.2 + 4	+	+	+	?	?	+	+		
1.1 + 2.4 + 3.3 + 4	+	+	+	?	?	+	+		
1.1 + 2.4 + 3.4 + 4	?	+	-	-	+	+	+	lack of durability	
1.1 + 2.5 + 3.1 + 4	?	-	+	+	+	+	+	less inovative	
1.1 + 2.5 + 3.2 + 4	?	-	+	+	+	+	+	less inovative	
1.1 + 2.5 + 3.3 + 4	?	-	+	+	+	+	+	less inovative	
1.1 + 2.5 + 3.4 + 4	?	-	+	-	+	+	+	less inovative	
1.2 + 2.1 + 3.1 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.1 + 3.2 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	

Figure F.2: Elimination matrix p.2

Elimination matrix

Criteria fulfilment:
(+) Yes
(-) No
(?) More info needed
(!) Check with specification

Decision:
(green) Continue
(red) Remove
(yellow) More info needed

Concepts	Solves Main problem	Inovative / special	Fulfil design/construction requirement	Fulfill all demands	Compatible/Realizable	Safe	Reasonable cost	Comment	Decision
1.2 + 2.1 + 3.3 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.1 + 3.4 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.2 + 3.1 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.2 + 3.2 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.2 + 3.3 + 4	?	?	-		+	+	?	hard to make the adjustment working	
1.2 + 2.2 + 3.4 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.3 + 3.1 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.3 + 3.2 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.3 + 3.3 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.3 + 3.4 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.4 + 3.1 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	

Figure F.3: Elimination matrix p.3

Elimination matrix								Criteria fulfilment: (+) Yes (-) No (?) More info needed (!) Check with specification Decision: (green) Continue (red) Remove (yellow) More info needed	
Concepts	**Solves Main problem**	**Inovative / special**	**Fulfil design/construction requirement**	**Fulfill all demands**	**Compatible/Realizable**	**Safe**	**Reasonable cost**	**Comment**	**Decision**
1.2 + 2.4 + 3.2 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.4 + 3.3 + 4	?	?	-	?	+	+	?	hard to make the adjustment working	
1.2 + 2.4 + 3.4 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.5 + 3.1 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.5 + 3.2 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.5 + 3.3 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	
1.2 + 2.5 + 3.4 + 4	?	?	-	-	+	+	?	hard to make the adjustment working	

Figure F.4: Elimination matrix p.4

F.2 Pugh Matrices

		Concepts for Pugh Matrix												(+) is better (-) is worse (0) is same
No.	**Criterion**	**Orange**	Yellow	Red	Lightgreen	Green	Darkgreen	Lightblue	Blue	Darkblue	Purple	Cerise	Lightpink	
1	Having a satisfying design	0	0	0	-	-	-	-	-	-	+	+	+	
2	Having a robust design	0	+	-	-	-	-	-	-	-	0	0	0	
4	Robustness of adjustble angle	0	+	0	0	+	0	0	0	+	+	0	0	
5	Nominal service life of 10 years	0	+	0	-	+	0	0	0	+	+	0	0	
6	Innovative spreading angle	0	0	0	-	-	-	-	-	-	-	-	-	
7	Innovative angle	0	-	0	0	-	0	0	0	-	-	0	0	
8	Solution of Adjustable light spreading angle	0	0	0	-	-	-	-	-	-	0	0	0	
9	Easy to install	0	-	+	0	+	-	0	+	-	+	+	0	
10	Technology level as other products by the company	0	0	0	-	-	-	-	-	-	0	0	0	
11	Consistent design with other products by the company	0	0	0	0	0	0	0	0	0	+	+	0	
	Sum +1	0	3	1	0	3	0	0	1	2	5	3	1	
	Sum -1	0	2	1	6	6	6	5	5	7	2	1	1	
	Net value	0	1	0	−6	−3	−6	−5	−4	−5	3	2	0	
	Ranking	**4**	**3**	**4**	**11**	**7**	**11**	**9**	**8**	**9**	**1**	**2**	**4**	
	Further development (yes/no)	yes	yes	yes	no	no	no	no	no	no	yes	yes	yes	

Figure F.5: Pugh Matrix 1

		Concepts for Pugh Matrix												(+) is better (-) is worse (0) is same
No.	**Criterion**	**Orange**	Yellow	Red	Lightgreen	Green	Darkgreen	Lightblue	Blue	Darkblue	Purple	Cerise	Lightpink	
1	Having a satisfying design	0	0	0	0	0	0	0	0	0	0	0	0	
2	Having a robust design	0	0	-	0	0	0	0	0	0	0	-	0	
4	Robustness of adjustble angle	-	0	-	-	0	-	-	-	0	0	0	-	
5	Nominal service life of 10 years	0	0	0	0	0	0	0	0	0	0	0	0	
6	Innovative spreading angle	0	0	0	-	-	-	-	-	-	0	0	0	
7	Innovative angle	0	0	0	-	-	-	-	-	-	0	0	0	
8	Solution of Adjustable light spreading angle	0	-	0	0	0	0	0	0	0	0	0	0	
9	Easy to install	-	0	0	-	0	0	-	0	0	0	0	-	
10	Technology level as other products by the company	0	0	0	0	0	0	0	0	0	0	0	0	
11	Consistent design with other products by the company	0	0	0	0	0	0	0	0	0	0	0	0	
	Sum +1	0	0	0	0	0	0	0	0	0	0	0	0	
	Sum -1	2	1	2	4	2	3	4	3	2	0	1	2	
	Net value	−2	−1	−2	−4	−2	−3	−4	−3	−2	0	−1	−2	
	Ranking	**4**	**2**	**4**	**11**	**4**	**9**	**11**	**9**	**4**	**1**	**2**	**4**	
	Further development (yes/no)													

Figure F.6: Pugh Matrix 2

No.	Criterion	Concepts for Pugh Matrix												(+) is better (-) is worse (0) is same
		Orange	Yellow	Red	Lightgreen	Green	Darkgreen	Lightblue	Blue	Darkblue	Purple	Cerise	Lightpink	
1	Having a satisfying design	0	0	0	-	-	-	-	-	-	+	0	0	
2	Having a robust design	0	0	0	-	-	-	-	-	-	0	0	0	
4	Robustness of adjustble angle	0	+	0	-	0	0	-	0	0	+	0	-	
5	Nominal service life of 10 years	0	0	0	0	0	0	0	0	0	0	0	0	
6	Innovative spreading angle	+	0	0	-	-	-	-	-	-	0	0	0	
7	Innovative angle	0	0	0	-	0	0	-	0	0	0	0	0	
8	Solution of Adjustable light spreading angle	-	0	0	-	-	-	-	-	-	0	0	0	
9	Easy to install	0	0	0	0	0	0	0	0	0	0	0	0	
10	Technology level as other products by the company	0	+	+	0	0	0	0	0	0	0	0	0	
11	Consistent design with other products by the company	0	0	0	-	-	-	-	-	-	0	0	0	
	Sum +1	1	2	1	0	0	0	0	0	0	2	0	0	
	Sum -1	1	0	0	7	5	5	7	5	5	0	0	1	
	Net value	0	2	1	−7	−5	−5	−7	−5	−5	2	0	−1	
	Ranking	**4**	**1**	**3**	**11**	**7**	**7**	**11**	**7**	**7**	**1**	**2**	**6**	
	Further development (yes/no)	yes	yes	yes	no	no	no	no	no	no	yes	yes	yes	

Figure F.7: Pugh Matrix 3

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