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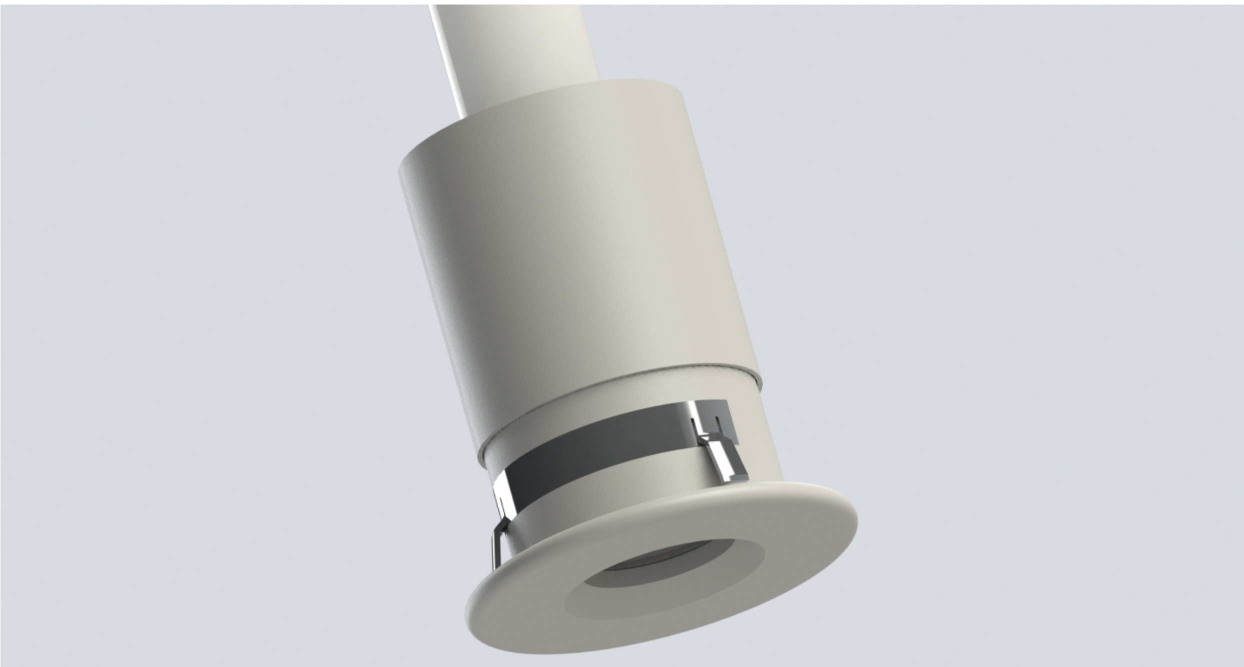

Development of a downlight casing for a modern home design

Master's thesis in Master Programme Product Development

Thim Johansson
Linus Nilsson

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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Supervisor: Lars Lindkvist, Industrial and Materials Science
Examiner: Lars Lindkvist, Industrial and Materials Science

Master's Thesis 2022
Department of Industrial and Materials Science
Division of Product Development
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

Lighting in newer homes today is not all about casting light upon the ordinary spaces in a dark room. Decoration lighting has become more of a thing that homeowners want to install to illuminate specific parts or objects.

This report presents a product development project where the aim was to develop a casing for a new 230V downlight located on the window sill. The downlight will ease the installation work for the electrician since no LED driver is needed, and the downlight can be directly installed from the power supply.

A market analysis was carried out to find the user needs of the electricians, and research regarding the different standards and regulations had to be carried out to fulfill the aims and requirements for the downlight.

A prototype is the result of this project that complies with the customer's needs and regulations from the IEC standards. It will go through the different requirements it has achieved and what is needed in the further development of this product.

Keywords: Product development, downlight, concepts, illumination, market analysis.

Acknowledgements

The authors of this report would like to thank the whole Company Bulb for all the support and guidance during the time of this project. The authors also want to thank our examiner Lars Lindkvist for his good input and support along the process.

Thim Johansson & Linus Nilsson, Gothenburg, May 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AC	Alternating current
DC	Direct current
ESD	Electrostatic Discharge
FDM	Fused Deposition Modeling
GDPR	General Data Protection Regulation
lm	Luminous flux
PBF-LB	Powder Bed Fusion - Laser Beam
PCB	Printed Circuit Board
ROI	Return of investment
SELV	Separated Extra Low Voltage

Contents

1
Introduction

Smart homes are becoming more common in today's household environments[1]. The ability to turn on and off the lights with an application and monitor and regulate the energy consumption is sought after by the homeowners.

When building new homes, lighting now is not only for illuminating the house's dark corners. It has become more of a way to enhance the home's design. Installing downlights on the window sill to illuminate the decorations in the windows has become very popular in recent years.

1.1 Background

The small downlights currently on the market and used in window frames are powered with low voltage DC and therefore require a separate electric drive that converts the AC to DC. This results in the installation taking more time for the electrician to perform and therefore costs more money for the homeowners. Because of this, a company that will be called company Bulb wants to develop a new small smart downlight that runs directly on 230V AC to save installation time and lets the customers remotely control the spotlight.

1.2 Aim

The project aims to create a concept of a hidden downlight with the main focus on its casing for electronics and functions. The electronics in the form of building electric circuits and programming functions will not be included in this project. However, the shape and placement of the circuit board can be changed to fit the design.

The goals of this project will be separated into two parts, product functions, and market understanding. This will begin with a market analysis to create a basic knowledge of existing market products. Questions that will require an answer are:

- What are the users' preferences in functions for this type of product?
- What are the customers' preferences in functions?
- What will make this product unique on the market?
- What the dimensional limits of the cover and its required installation space?

Product specifications for the concept will first focus on the installer perspective of the product, which in most cases will be towards the electrician. Nevertheless, the importance of user preference is still vital, as mentioned above. The difference between the user and customer here is that the user is the homeowner, and the customers are the electricians. Here are the initial goals that have been discussed in the project upstart:

– Research of the required laws and regulations for designing and installing a 230V downlight with implementation in the design
– Create a cover for the design that meets the market demand and expectations

1.3 Limitation

This section will describe the issues that will not be dealt with.

This project is a Master's thesis which means that certain criteria are applied from the institution written for. The time frame for this project is limited to 20 weeks in order to entail a total of 30 ECTs worth of work.
Limitations regarding the project are also that the manufacturing and component design of the circuit design will not be covered. The mobile application will also not be included in this study.

1.4 Specification of issue under investigation

What properties does the market value the most in a downlight, and what properties are missing on the current ones on the Swedish market? Is it possible to develop a downlight that is powered directly with 230V AC, fulfills all the laws and regulations, and at the same time appeal to the market?

2
Theory

This chapter is to gain knowledge regarding the topics and terminology of the projects and will be used in the upcoming chapters in the report.

2.1 IP classification

This is an IP rating in protection classes from solid materials and liquids. IP stands for Ingress Protection and is designed for international use by the International Electrotechnical Commission (IEC)[2]. The IP classification contains two digits, the first is for the solid protection and a value between 0-6, and the second is from liquid with a value between 0-9. The solid digits values meaning are cited below from the GWP group written by Richard Coombes [3]:

0. No protection
1. Objects greater than 50mm
2. Objects greater than 12.5mm
3. Objects greater than 2.5 mm
4. Dust protected
5. Dust tight

These are the meaning of the digits regarding the liquid protection:

0. No protection
1. Dripping water - vertically falling when mounted in an upright position
2. Dripping water when tilted at 15 degrees, all four positions are tested
3. Spraying water - up to 60 degrees from the vertical
4. Water splash - from any direction
5. Water jets - from a nozzle of 6.3 mm
6. Powerful water jets - from a nozzle of 12.5 mm
7. Submersion of up to 1 m depth
8. Submersion for depth of 1m or more

2.2 Correlated Color temperature

CCT (Correlated Color Temperature) is a scale of the apparent light of a white LED [4]. This refers to the temperature in Kelvin when heating metal. However, the heat itself is not measured here, which is why the word "correlated" is used. The figure 2.1 below describes how the light changes with the CCT.

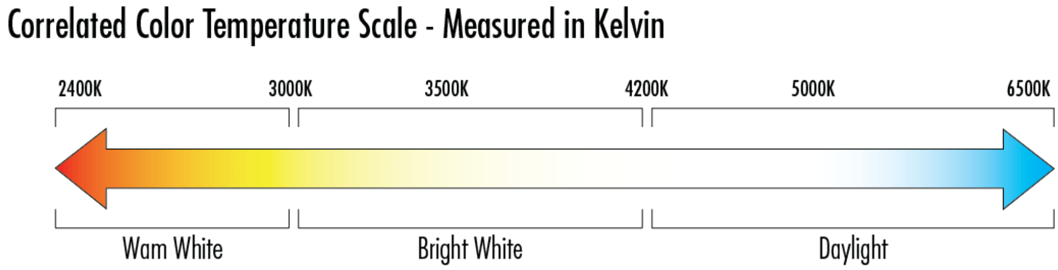

Figure 2.1: Color Temperature Scale
Source: Adapted from [4]

2.3 Luminous flux

Luminous flux is a measurement of the perceived power of light and is the total amount of visible light emitted from the lamp. The luminous flux is measured in lumen and has the SI unit of lm[5]. Lamps that are bought today usually have an lm marker that indicates how much light the lamp emits.

2.4 IEC standard

The IEC stands for International Electrotechnical Commission and is a global organization whose work is to create a neutral and independent standardization platform for electrical and electronic products. The standards that IEC is bringing forth are essential for a market that follows the same testing and certification rules[6].

2.5 Beam angle

This is the angle at which the light source is spreading the light while keeping 50 percent of its light intensity and is measured in angle degrees[7]. This is usually used for LED light focusing towards a spot or direction, e.g., spotlight and downlight. Figure 2.2 below describe the beam angle.

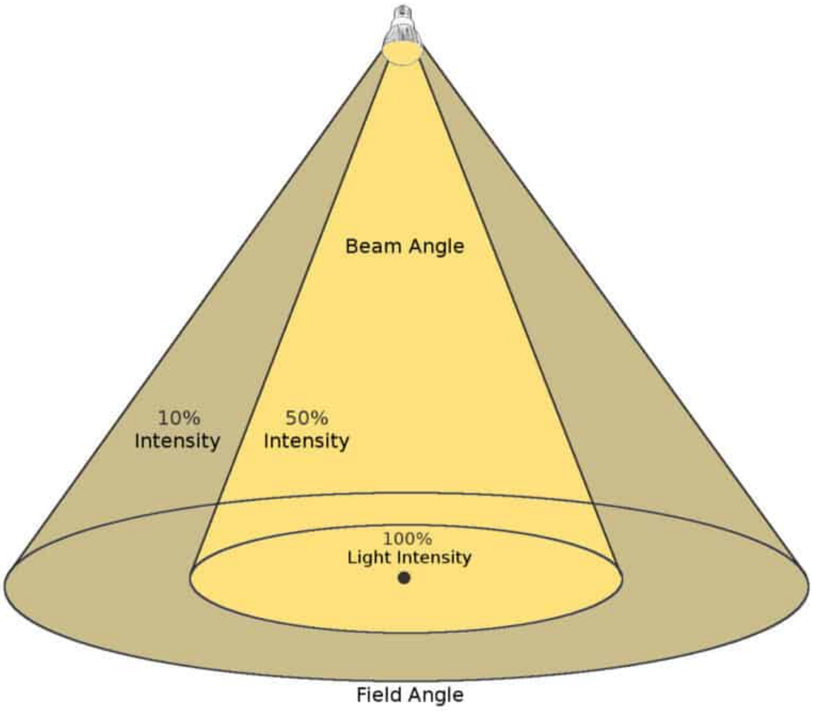

Figure 2.2: Description of beam angle
Source: Adapted from [7]

2.6 Insulation classification

The Swedish Electrical Safety Agency states that all electrical equipment that is energized with dangerous voltage shall have some kind of protection. The different type of protection is divided into three different classifications, class one, class two, and class three. These directives are cited from The Swedish Electrical Safety Agency[8].

- Class one: Electrical equipment means that the protection against electric shock is not based solely on the basic/single insulation, but in which an additional safety measure has been taken by connecting exposed tangible conductive parts to earth
- Class two: Electrical equipment means that the protection against electric shock is based solely on the basic/single insulation and an additional safety measure, such as double insulation or reinforced insulation
- Class three: Electrical equipment means that the protection against electric shock is based on supplying with SELV from a voltage of at most 50V AC or 120V DC from a protection transformer and that the utility object also does not generate higher voltage

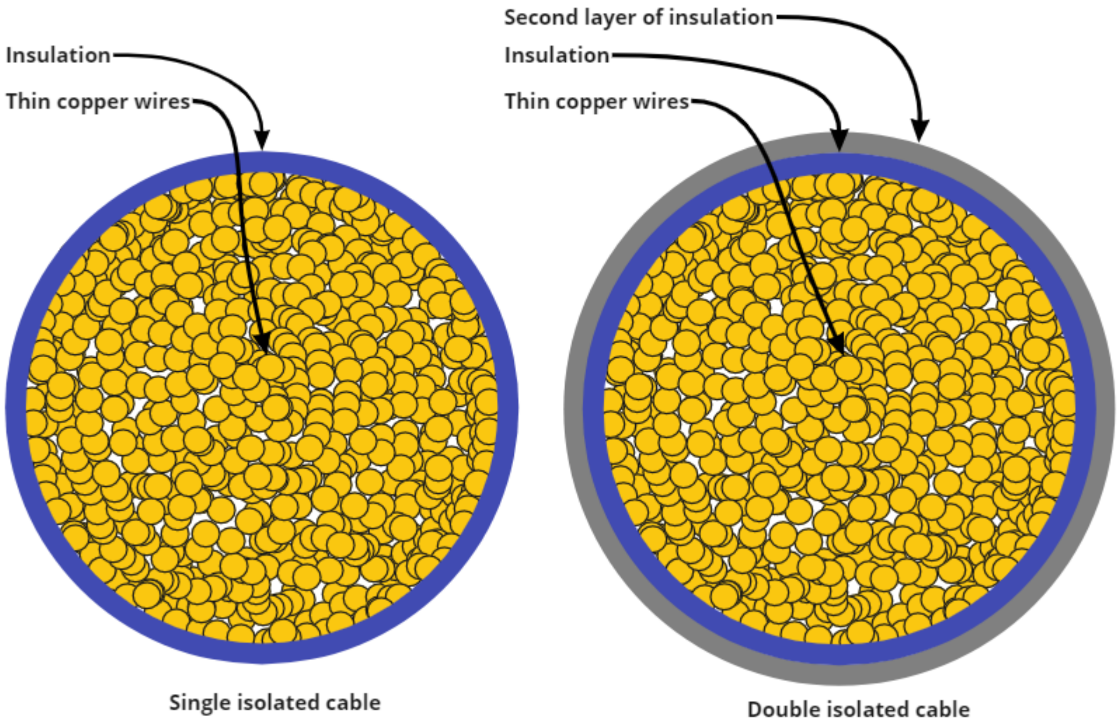

Figure 2.3: Difference between basic/single isolated cable and double isolated cable

2.7 Electrostatic Discharge

Electrostatic discharge or better known as ESD, is when an electric shock is released between two objects. An electrostatic charge needs to be built up for an ESD to occur. The build-up happens when two objects rub against each other, and one object gets positively charged, and the other gets negatively charged. The positively charged objects now have a built-up electrostatic charge that can damage components such as a circuit board[9].

3
Methods

This chapter describes the methodology used in this project which is divided in two main parts, market analysis and product development.

3.1 Market analysis

This section will describe how the data gathering methods was implemented and how they were customized for this project [10] [11]. The data gathering processes have two separate categories, quantitative and qualitative. These categories include different methods commonly used for each category, e.g., in-depth interviews and focus groups as qualitative and surveys as quantitative. However, these methods do not necessarily need to be specified in that category. It depends on how they have been conducted, but they are usually categorized like this. One example of this can be the selection of the participants the data is collected from, experts from a particular subject, a potential customer, or randomly.
The main focus of this analysis is to understand the installation process and users of this product segment. Through a deeper understanding of who the customer is and how the products are used, the customer needs can be identified [11]. The goal is to see if any latent needs can be found to exploit in the development of this product to improve on existing market. Here data needs to be interpreted from a customer statement to a customer need. However, because of the discretion of the project, the search has its limitations on where and how the information is gathered. It also concerns how the information is stored relative to GDPR and the person's preference in data gathering within the research area. It affects if it is possible to video record, take pictures, etc.

3.1.1 Survey

A survey was conducted using Google Forms and posted on forums or Facebook groups that interact primarily with electricians. This survey has been categorized as a quantitative method where the number of participants has an excellent impact on the reliability and credibility of the data. However, it focuses on participants who are educated within this area of expertise, but the experience within their occupation is random. This survey aimed to create an understanding of the miniature downlight market with a focus group of electricians. This is because the majority of the installations in Sweden regarding lighting are done by electricians or at least individuals with some background knowledge. However, because it can not be certain that only electricians have an understanding of the topic, the survey was designed in such manner that different questions were shown depending on the given answer. This was done by asking the participant if they are or have been an electrician; if yes, the assumption was made that the individual had pre-knowledge and understood topic questions and gave access to all research questions. If the participants are not electricians, they will be informed of the topic and asked if they have pre-knowledge. This will exclude questions about the installation compared to the electricians. Otherwise, the questions will be the same but sorted in a different participation category. This is mainly to categorize the participants into three different experience level groups. Therefore, none of the categories are excluded because they might have lower credibility regarding the installation process. This is because the end customer does not always have the most knowledge of the product. However, their preferences are still essential for the specifications that can influence a future purchase of the product.

These are the research questions that are presented in the survey:

1. Are you working as an electrician or, have you ever worked as an electrician? (Yes or No)
2. Have you installed a downlight in a window sill before? (Yes or No)
3. If yes, how often do you install downlights in the window sill at customers with a rating of 1-5(5 is often)?
4. Which brand of downlight do you prefer when installing it in the window sill?
    - Hide-a-lite
    - SG
    - DesignLight
    - or other (add name)
5. Which model do you often install?
6. Does the customers / yourself prefer a warmer or colder temperature color temperature? Scale from 1-10 were 1 is 2000 and 10 is 6000 Kelvin
7. How much does the price effect the choice of downlight? Scale of 1-5 were 5 is the highest.
8. How much does the mechanical design effect the choice of downlight? Scale of 1-5 were 5 is the highest.
9. How much does the aesthetic design effect the choice of downlight? Scale of 1-5 were 5 is the highest.
10. Which beam angle does the customer usually prefer? Scale from 1-5 were 1 is 15 and 5 is 120 degrees.
11. Do you feel that there are any functions that are missing or are favorable in the current design of downlights? (open-ended question)

3.1.2 Interviews

Two in-depth interviews have been conducted under this process along with several minor interviews or discussions. These interviews are categorized as a qualitative method in the data gathering process. This is because of the expertise in the subject of the interviewee and the open-end questions that can clarify and bring forwarded unknown knowledge gap of the subject. Both interviews have been documented through notes; the reasoning for this was because of privacy and the circumstances risked that recording could interrupt the natural conversation and create more discomfort.
The first in-depth interview was conducted as a group interview with two persons with an electrician background for several years. It could have an negative affected of putting words in each others mouths and therefore risking to miss valuable information and expertise from an individual. However, this created a discussion between the two individuals instead, and because it was in the early stage of the project, it gave a piece of broad basic information and individual differences or if they have the same experience. The objective of this interview was to create an understanding of the installation process, what products they prefer and dislike on the market, the pros and cons of those different products, and finally, what features or functions today's products are missing. It was to create an understanding of the customer, the user and the fundamental properties that finalize a purchase of the product. The second in-depth is an individual interview was with an electrician who is currently working as a salesman. This interview had the same content and objective as the first. However, the individual's current occupation gave a new perspective on the purchase process and communication between an electrician and end customer.

3.2 Product Specifications

Market analysis is the wishes of the consumer and describes the customer's needs. This part of the process is to translate the customer needs into metrics. The goal is to create precise and measurable specifications and understand the relationship between needs and metrics [11]. However, it is crucial to understand that one customer's need can be translated to several metrics to fulfill its purpose and understanding. This will then include implementing a target specification list, a competitive benchmarking, and a patent search.

3.2.1 Target specifications

This table of content will go through the metrics created and refer to the customer needs. Each metric is given a metrics number that is connected to a customer need reference, a marginal and ideal goal value, a unit used for that metric, and an importance level [11]. The project group added a justification, verification, and laws and standards chapter. This is to follow that reference and reasoning behind every chosen metric value, how it will be confirmed, and the regulations needed to be approved for a safe product.

3.2.2 Benchmark

The benchmark has been split into two parts, brands and products on the market and product design. The first objective is to view the current products on the Swedish market regarding more miniature downlights that fit in a window sill. The constraints in the search were a diameter of a maximum of 40 mm or a hole size of 30 mm, and output between 1 to 3 Watts. These measurements within the constraints were to fit the downlight in a window sill without taking up too much space and have an unobtrusive design.

Part two is designed focused on where some of the products will be purchased for disassembling to gain knowledge of their development process. The purpose is to get inspiration from how they are designed and their assembly and quality feeling when installing and using the product. However, all products can not be bought and tested. Therefore, small sample size will be created based on unique design and survey results as a reference.

3.3 Product development methods

Products within home electronics have high safety standards, depending on the insulation classification. These safety standards are open for interpretation, and it is not always clear how to apply them to a physical product. Therefore, an LPD (Lean product development) and Agile have been a good inspiration when planning the process strategy in this type of project. It has had the inspiration of working closely to the standards and customer's satisfactions as well working iterative similar to scrum sprints [12]. However, these iterations are not performed as Agile scrum sprints in terms of using a scrum master or a product owner. A reason for this is the small number of group members but also because each iteration is to solve equally the same product requirements as best as possible, instead of changing function and target [13]. Many of the product requirements and functions are highly interacting with each other and therefore need to be tested synchronized and frequently. However, an LPD approach of frequently testing functions was applied for learning purposes and understanding of the solutions before the overall concept assessment [14]. These iterations did not have any specified time limit when they started and were therefore more inspired by the kanban method, where following a backlog of what is needed to be done and with a WIP limit of each person to follow the process [15]. However, the iteration had a basic structure as of PDCA (plan, do, check, Adjust) methodology from Agile thinking. It has started with the preparation of planning the future iteration, execution of the plan, review of the results, and then how the next iteration can be improved [16]. Figure 3.1 shows how an overview of the process flow that has been conducted in this project. However, the building process in this tree has mainly been finalizing the prototype.

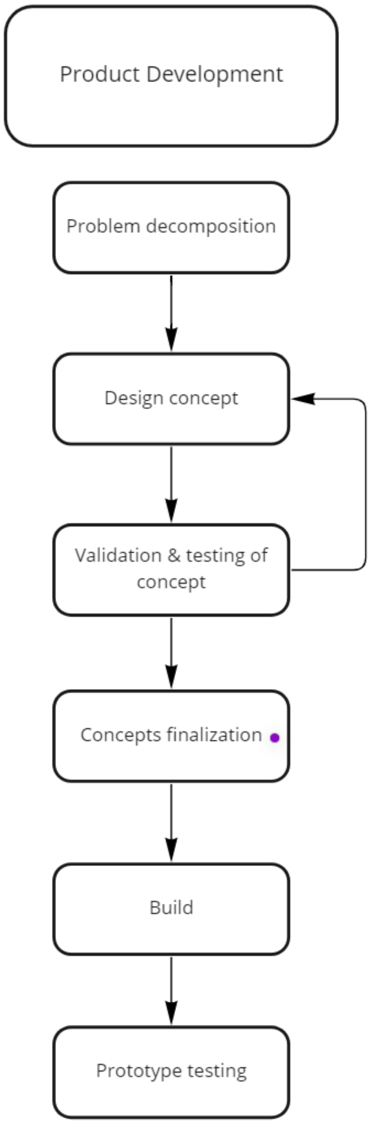

Figure 3.1: Project product development process scheme

3.3.1 Problem decomposition

This part is about better understanding the product and problems that need to be solved. It is done by breaking down the product into different functions and sub-functions. The purpose of breaking it down in this manner is to simplify a complex problem into understandable sub-problems. Then finally, to be able to combine all solutions into one product instead of focusing on everything at once. This enhances the process by focusing on solutions instead of obstacles.

A morphological matrix is used to structure the identified conceivable solutions of the functions and sub-function. The different functions and sub-functions are gathered in the first column the possible solutions are gathered in the different rows. This makes it easy to get an overview of the different solutions and combine several sub-functions and their solutions into plausible concepts[17].

3.3.2 Design concept

This part was to find solutions to the functions using external and internal search, then add them to the morphological matrix. Starting with the external search is to find already existing products or parts of the products that solve the same functions. The internal search is to generate own ideas using brainstorming techniques [18]. It was first done individually not to be interrupted or have the person's idea "infected" with anyone else. Secondly, the group will gather and go through the ideas for each other, and the others will comment on improvement that can be made and write down if it generates new ideas. These ideas were then sketched and, if not too time-consuming, drawn in the CAD program using Solidworks.

With the help of the morphological matrix, different function combinations were matched, and different concepts were created. It was done similarly to the concept combination table but in the morphological matrix [11].

Most of the concepts are sketched using Solidworks to understand how and if the function combination can work together. This is important to understand because of space issues. Creating more detailed designs will give a clear answer and generate new designs and ideas where problems and functions are clashing. These designs are created using an assembly to add and create all parts needed for that concept. This design process gives a faster response if any of the functions, including different parts, clash or include a more complex solving than initially thought. Each concept is drawn by one individual using this method. This is to have one individual who creates expertise within that concepts specific function combination. It is a continuous communication of the learning regarding the design, both obstacles and success between the individuals. This is to speed up the knowledge gap in the group and improve each iteration of testing new combinations and new ideas.

3.3.3 Validation process

Testing each concept was done in two phases, expert review and physical tests on 3D models. The expert review is a meeting including experts within each product area from the company, e.g., mechanical team, electronics, and laws&regulations. The main focus of this meeting is to review the concepts to compare if they fulfill the target specifications. This process includes reviewing the target specification list to determine if some regulations or company standards need to be added or neglected. The review of each concept included pros and cons and new ideas to improve the next iteration.

The physical test is performed continuously, testing the new ideas' functions. This is main containing 3D printing and testing an idea performs as though. However, this was mainly done on scaled products because the small size where limited on the resolution of the FDM (Fused Deposition Modeling) machines.

3.3.4 Concepts finalization

This process is to fine-tune the final concept and change minor parts in the design. This is to make sure that every part fitting size is correct and that the design can be manufactured as a prototype. There is a design for manufacturing thinking from the start, but this is about minor parameters and a more detailed design for the final prototype.

4

Market Analysis

This chapter will go through the results in the market analysis from the tools used from chapter 3.1.

4.1 Survey results

The survey resulted in 206 participants, with a high percentage of experts within the given field. Figure 4.1 percentage of the participants that are or have had the occupation as an electrician. This is a number of 187 participants that have the experience as an electrician; figure 4.2 displays the percentage of how many the electricians have installed a down-light in a window sill.

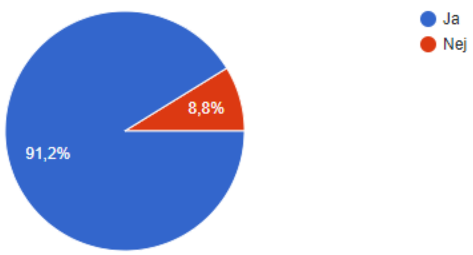

Figure 4.1: Percentage of electricians participating in Survey

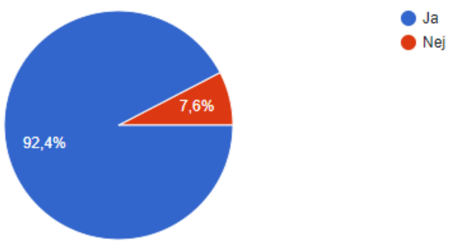

Figure 4.2: Percentage of how many of the electricians that have installed down-light in a window sill

This means that the participants have a higher level of expertise within the area, which can construe an increased quality of each answer. However, a majority of the participants state that installing downlights on a window sill is not a standard installation and are rating it as a value of 2 on a scale of 1-5, as shown in figure 4.3 below. Even if it is not common for most electricians, some frequently perform this installation. This can be interpreted in more than one way, e.g., that the experience of this installation differs a lot within the same occupation or an interpretation of how large the market is for more miniature downlights and if it is a market share worth spending more or less investment on development.

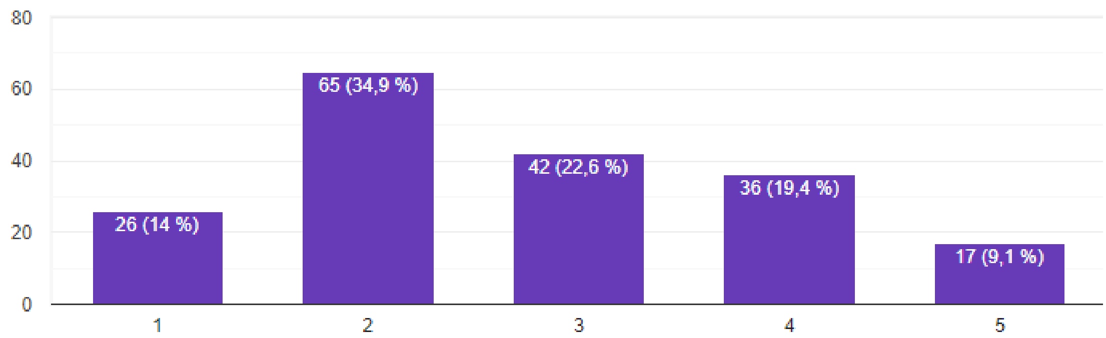

Figure 4.3: This graph display how frequently a downlight installation in the window sill occurs on a scale of 1 - 5, were five is often

When comparing which products that electricians are mostly installing, an overwhelming majority uses a brand called Hide-a-lite on the Swedish market shown in figure C.1 below. The company has a wide range of different downlights, with different specifications within the same model, e.g., different color temperatures and beam angles. However, Hide-a-lites' model "Core" is the most common product among the models.

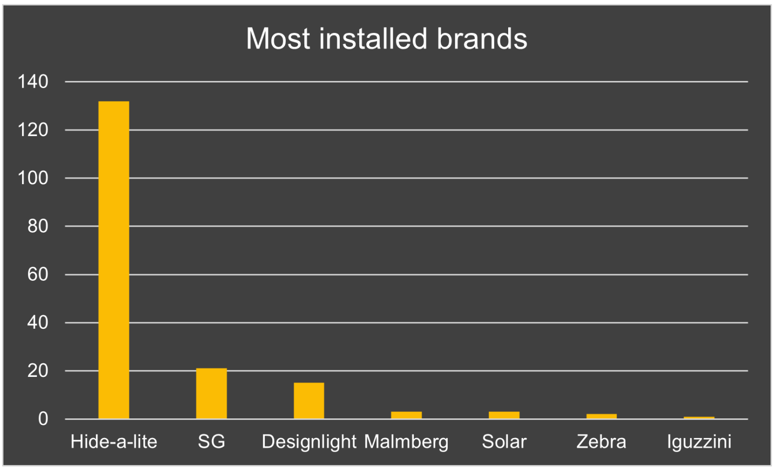

Figure 4.4: Most installed down-light brands currently on the Swedish market

The next part is about understanding the preferred specifications regarding CCT and beam angle selection. However, this does not take into consideration if the brand and model are selected at this point. The reason for this is because the exact beam angle values differ slightly between brands, and answers in a more general term are the main objective. The results in this part show that when it comes to beam angles, an absolute majority selects an angle around 45 degrees, which can be seen in figure 2.2. However, analyzing the answers of CCT (correlated color temperature), the results that the preference is not that clear, displayed in figure 4.5. Warmer light is the most popular and declining towards a cold light between the spectrum of what is currently on the market.

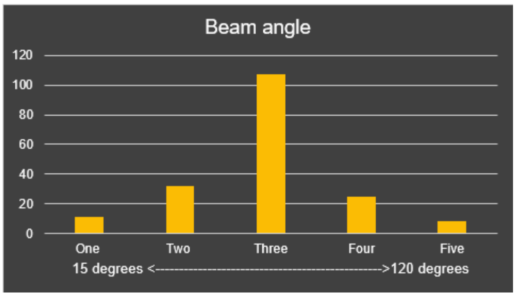

Figure 4.5: Number of answers regarding beam angle on a scale of 1 - 5, were 1 is 15 degrees and 5 is 120 degrees

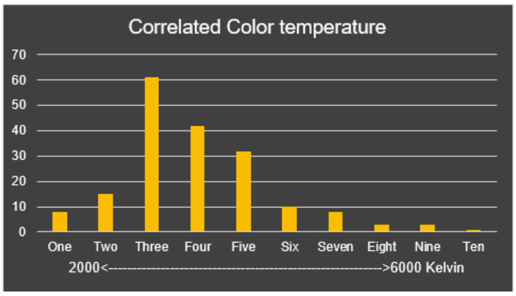

Figure 4.6: Number of answers regarding CCT on a scale of 1 - 10, were 1 is 2000K and 10 is 6000K

Understanding what design features are important in this product is key. A comparison of practical design regarding installation and usage and aesthetic design. The results are shown in figure 4.14 and 4.15 below.

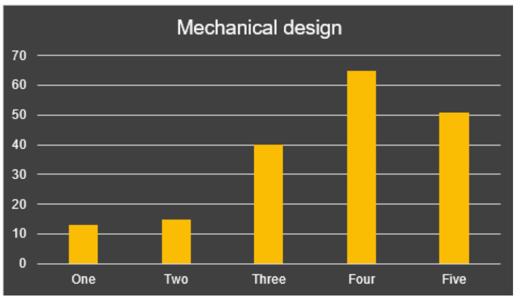

Figure 4.7: Number of answers regarding practical design on a scale of 1 - 5, were 5 is important

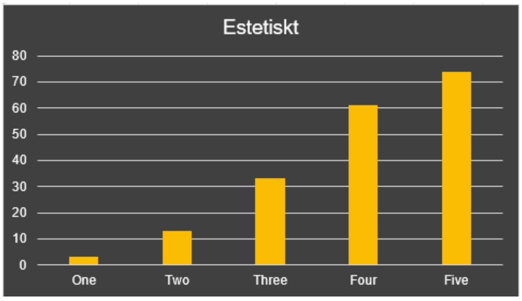

Figure 4.8: Number of answers regarding aesthetic design on a scale of 1 - 10, were 5 is important

Finally, the question was to understand how price sensitive the market of small downlights is. Accordingly to this survey, the results show that it is a middle value and that the pricing has compensation for other qualifications; figure 4.9 below displays the results.

Figure 4.9: Number of answers regarding pricing on a scale of 1 - 5, were 5 is important

4.2 Benchmark results

As mentioned in chapter 3.2.2, this benchmark has been split into two parts, understanding the product specifications and product design, and to compare their similarities and what differentiates the specifications between the products. The specification between the different brands is similar, with few parameters that change. The majority of the brands have products with a beam angle between 15 to 120 degrees, an output of 1 - 1.2 Watt, a color temperature of 2700 - 3000K, and a current of 350mA. This means that the leading product segment is driven by a continuous current with a voltage of 12 - 24V, needing an LED driver. The competitor benchmark also revealed that most of the models out on the Swedish market are made to fit holes 25mm in diameter. However, the height of each brand and model differs widely and depends on which beam angle is specified for that model. Figure 4.10 below shows a sample of the benchmark analysis, and the entire table is in appendix A.1.

Brand	Model	Effect	Color temperature	Mounting hole	Current	Diameter	Hight
Hide-a-lite	Dot VP	1,2W	2700K	16-20mm	350mA	30mm	22mm
Hide-a-lite	Spot Mini VP (2700)	1,2W	2700K	16-20mm	350mA	30mm	19mm
Hide-a-lite	Spot Mini VP (3000)	1,2W	3000K	16-20mm	350mA	30mm	19mm
Hide-a-lite	Spot Mini	1,2W	3000K	24mm	350mA	32mm	11mm
Hide-a-lite	Core Smart 120	1,2W	3000K	25mm	350mA	30mm	19mm
Hide-a-lite	Core Smart 120	1,2W	2700K	25mm	350mA	30mm	19mm
Hide-a-lite	Core Smart 45	1,2W	3000K	25mm	350mA	30mm	26mm
Hide-a-lite	Core Smart 45	1,2W	2700K	25mm	350mA	30mm	26mm
Hide-a-lite	Core Smart 15	1,2W	3000K	25mm	350mA	30mm	37mm
Hide-a-lite	Core Smart 15	1,2W	2700K	25mm	350mA	30mm	37mm
SG	7468198	1W	2700K	25mm	350mA	33mm	27mm

Figure 4.10: Small part of the benchmark analysis, most installed down-light brands, number of participants that selected the most common brand

Part 2 of the benchmark was to order and disassemble the different products. Which ones were ordered were based on the discovery of what was found in part 1 and the results from the survey. Firstly at-least one of each brand was needed to view each manufacturer. Then more were ordered from the same brand if they had more products with a significant design change, and the products with a high popularity result from the survey with more products with different beam angels were ordered. Figure 4.11 below shows a sample of the disassembled products and how some of the parts differ in design.

Figure 4.11: Disassembly of competitive products

Before the different products were disassembled, all products were installed on a testbed shown in figure C.1. This was to understand how the installation works and the simplicity perform it using their instructions and how they performed, and the aesthetic design after installation.

Figure 4.12: Testing of competitive products

4.3 Interview results

The interviews ended up with the main focus on understanding the installation process of a downlight installed in a window sill. Usually, the installation occurs in newly built real estate or if a more extensive renovation is performed, most commonly in houses but in apartments on rare occasions. When building a house, a collaboration between the carpenter, the painter, and the electrician is needed. They shift back and forth when each expertise is needed, and the communication between them differs on how they work. It means that the collaboration differs a bit depending on the communication between each other and their previous relationship. A description of a general installation of a downlight in a window sill will be described step by step, including where and how it differs among the interviewees.

4.3.1 Installation process

First on the scene is the carpenter working and finishing the outer layers in terms of the wooden joist, outer wall, and the window or glass sections installed. Figure 4.13 below shows an example of what it can look like when the electricians are there for the first time during the installation.

Figure 4.13: Example of how it can look as first sight for an electrician

Before the outer plaster wall is installed, the electricians install a junction box on a wooden joist near the windows. To fit the downlight, one or several holes are then drilled on the upper wooden joist above the window. It depends on how many downlight is being installed. A flex tube is connected down to the hole in wooden joist from the junction box. If it is several holes, it can be connected either in series using a Y-connector or parallel connecting several flex tubes to the same junction box. However, connecting several flex tubes is limited by the number of connection points on the junction box. The flex tube is then drawn through the mounting hole differently. Either it is peaking out of the drilled hole or cut off flush onto the wood joist. A LED driver is placed inside the junction box. Single isolated cables are connected to the LED-driver input from the main 230V power station and from the LED drivers output through the flex tube towards the installation point. The downlight is not connected at this point, and cables are peaking out of the flex tube prepared for installing the downlight. It is because the carpenter will install the outer plaster walls, mount the window sill around the window, and sometimes drill the final hole for the down-light to be installed upon; otherwise, this will be done by the electrician. A essential step here is that the window sill is not always flat on the wooden joist above were the flex tube is connected. This distance between wooden joist and window sill vary from installation and creating a gap between flex tube and downlight. Then it is time for the painter to put some color on where it is needed, and then finally, the electrician will connect the cables and make other final preparations to make sure everything works as intended.

Figure 4.14: Overview of installation of a downlight

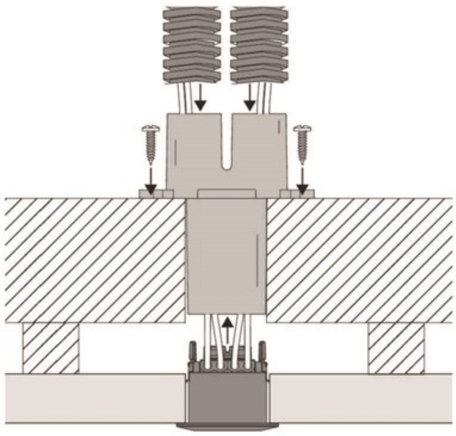

Figure 4.15: Y-connector from Hide-a-lite; source: Adapted from [19]

The selection of brands and models of downlight differs as well as when it is decided. In some cases, the electrician does not know which brand and model to select when performing the first installation of the junction box, etc. The decision is made depending on the local wholesale inventory. However, this does not directly translate that the electrician does not have a plan. Some brands are often in stock and are then planned after these measurements. Then it is those who know the exact brand and model and plan the installation according to that. Even though the dimensions of downlights in a window sill are often quite forgiving, creating a 25 mm hole will fit the most, and if it requires a larger hole, it is simple to enlarge the fitting hole. The same regarding the dimensions in height, where it is usually space to enlarge the height if necessary. However, the next part is what specifications are wished for that installation and the final customers' participation in that process. In many cases, the answer is that they are not included, and the electrician or light designer, if included in the project, makes the decision. Generally speaking, an electrician does not have much expertise in light- and aesthetic design and does not always have the interest either. Therefore, selecting what works reliable, is simple to install, and is always on stock are key factors in selecting the product.

4.4 Customer needs

This process involves going through the gathered data and interpreting what customers wish for in this product segment. The interview gave a broad understanding of what was essential and missing in the installation process. The survey gave more clear results on some specifications of the product, but the open-ended questions resulted in other wishes of the product segment. However, these results were not always precise, and understanding the customers was challenging. There are the customer needs that have been interpreted during this market analysis:

1. Simple and fast installation
2. Unobtrusive design
3. Low cable use with simple cable management
4. Installation instructions are easy performed safely
5. Safe to use and install
6. Quality design
7. Changeable light color temperature

These customer needs are broad statements that will require further interpretation through measurable requirements, which will be presented in the target specifications 5.2 linked to this customer needs list.

4.5 Regulations

From the interview results and the groups interpretation of the IEC-standard a couple of requirements were formed. These requirements are a key part of how the downlight can be designed to follow the IEC-standard. However, the standards are usually long and complex text. This required a simplification and interpretation of the paragraphs to reach this projects goals. Therefore, reserving for any misinterpretation that can have be done.

- The space inside a wall should have the same isolation protection as outside of the wall.
- The downlight should not be able to be pulled downed from the ceiling with a finger.
- Creepage distance around 6 mm from finger to electrical components.

Figure 4.16 below shows how the IEC 61032 standard describes a finger. It is a important standard to understand because of a finger should not be able to touch the electronics or any metal that can give an electrical shock.

Figure 4.16: Test probe according to IEC 61032

5

Concept Development

The next chapter in the product development is the concept development phase. This chapter is based on the market analysis chapter and shows the process of how the different concepts were designed.

5.1 Problem decomposition results

Based on the knowledge gained from the market analysis chapter 4 and the laws and regulations from the different IEC standards presented in section 4.5, several problems arose. One of the main problems was that the IEC states that the area inside the wall needs the same double isolation as if it were outside the wall. Meaning that the wall itself does not count as any electrical isolation. This creates problems because a gap can exist between the flex tube and the downlights, making it unsafe from an electrical point of view. Single isolation cables are used, usually within flex tubes inside the walls. However, using double isolation cables is an acceptable method according to electrical standards but does not necessarily make the process easier or equally difficult to install, including that the gap between the flex tube differs depending on the wooden joist and window sill but also how the flex tube is cut off as mentioned in the installation process.

5.2 Target specification results

The target specification is based on the results from the survey and the benchmark results. The target specifications were divided into two parts, design and electrical properties. Some requirements are directly based from IEC standards that must be fulfilled, and other requirements are wishes of the electricians. The target specification was updated when new information became available over the project's timeline. An example of the target specification list can be seen below in figure 5.1. The entire target specification can be found in the appendix B.1.

Metric NO	Requirement/desires	Customer Needs	Unit	Marginal goals	Ideal goals	Demand/Wish	Justification	Verification method
	Design							
1	Mounting hole dimension	1	mm	28	25	W	Benchmark analysis	Assesment using CAD
2	Dimensions (HxD)	1	mm	50x35 (Hxd)	40x30	D	Interview	Assesment using CAD

Figure 5.1: Sample of the target specification

5.3 Idea generation

The idea generation phase was divided into two parts, internal search, and external search. The team brainstormed several different ideas for possible solutions for the internal search. The solutions were both illustrated by sketches and quick CAD models. This encourages innovation by ensuring that all ideas are fully understood by all team members. For the external search, the internet was mainly used to search for ideas that could solve some of the sub-functions or give inspiration for further development.

5.3.1 Morphological matrix results

A morphological matrix was designed to show different solutions for each sub-function problem based on the market analysis in chapter4. The morphological matrix is build as a graph-system with two axis, Y- and X-axis, to make it simple refer to a solution in the matrix. The Y-axis is based a alphabetic order between A-F and the X-axis is given a number between 1-6. Pictures and sketches represent the different solutions that act as a guideline for the concept development phase, where the different ideas can be combined. The full morphological matrix can be found in the appendix C.1.

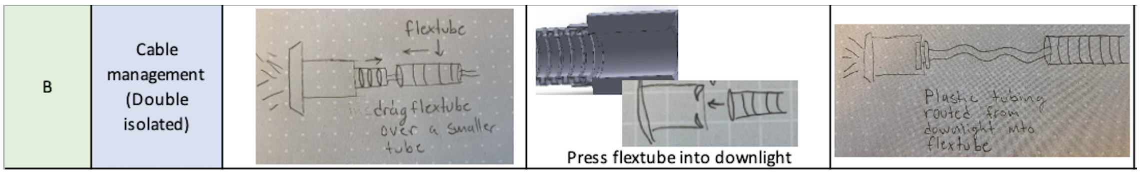

Figure 5.2: Sample of the morphological matrix

5.4 Initial concepts

From the morphological matrix, 14 different concepts were designed in Solidworks. These concepts were the first iteration and were made to show how different sub-functions could be solved. Instead of designing concepts based on all of the different solutions, the first iteration of concepts usually shows one or two sub-solutions combined to see if the concept is plausible. The concepts are shown down below, with a text describing which sub-solution was used.

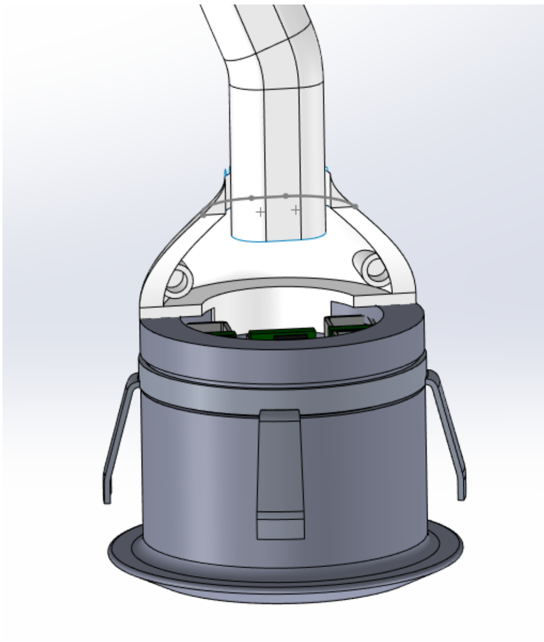

Figure 5.3: Concept 1.3, based on (B3,C3) from the morphological matrix

Concept 1.3 casing is built of three illustrated parts shown in figure 5.3. The lower part in gray is a solid piece that holds the electronics inside. Around that part is a flat spring that holds the downlight in the mounting hole. The upper part in white is a closure mechanism that protects the PCB and ensures double isolation when properly installed. This is done with a hard plastic cover and a softer plastic or rubber as a tube. However, this part is made as two similar parts and only shows one of them. It is designed to be screwed together in the two holes on each side.

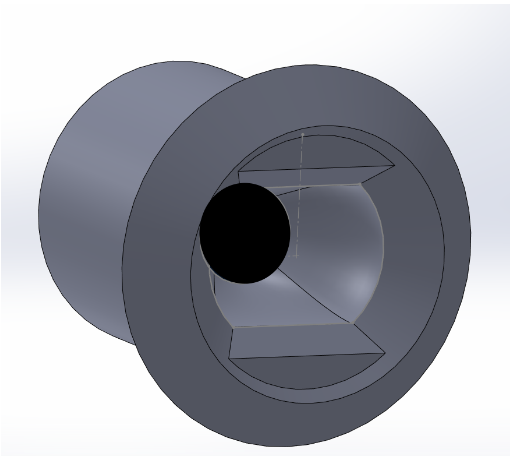

Figure 5.4: Concept 1.4

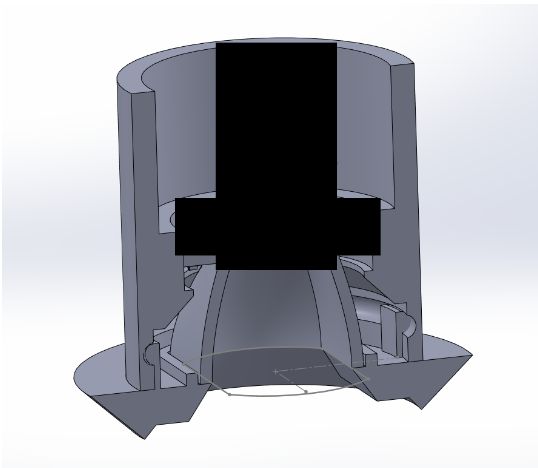

Figure 5.5: Concept with narrower beam angle

Concept 1.4 in figure 5.4 is an exploration of a different light pattern and, in this case, in a rectangular-shaped reflector and lens. This is to direct the light differently in each direction to fulfill its aesthetic purpose without blinding people around it.

This design gives a narrow beam angle at the window glass and inwards, with a wider angle at the window sill itself, not drawing people's attention toward the light source.

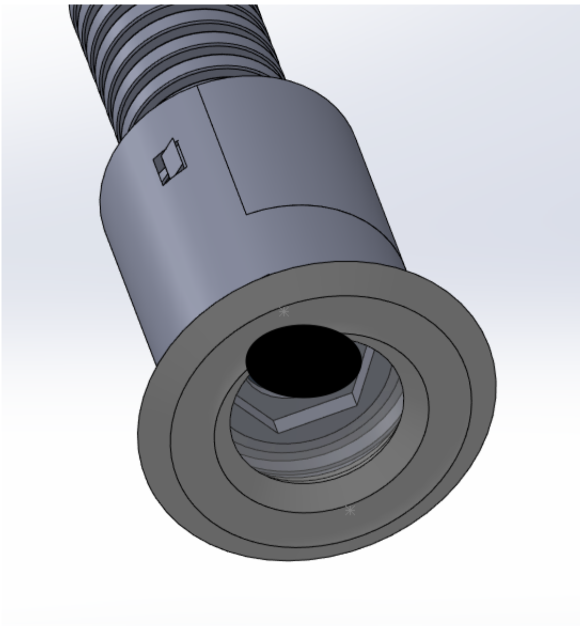

Figure 5.6: Concept 1.5, based on (B5) from the morphological matrix

To ensure that there is double isolation from the flex tube to the downlight, concept 1.5 was created, which is shown in figure 5.6. The concept is based on the fact that the flex tube runs through the window sill so that the flex tube can be directly connected to the downlight. It is then connected using a snap bracket to hold the flex tube attached to the luminaires.

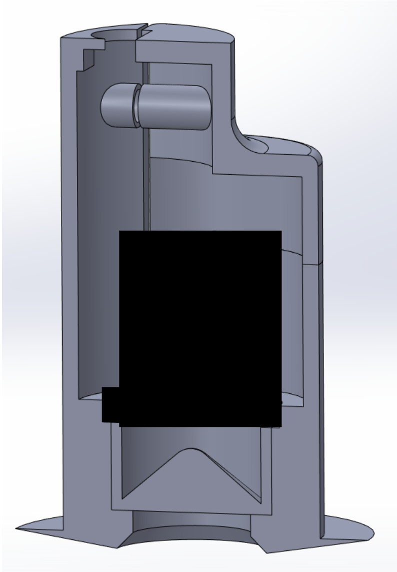

Figure 5.7: Concept 1.7

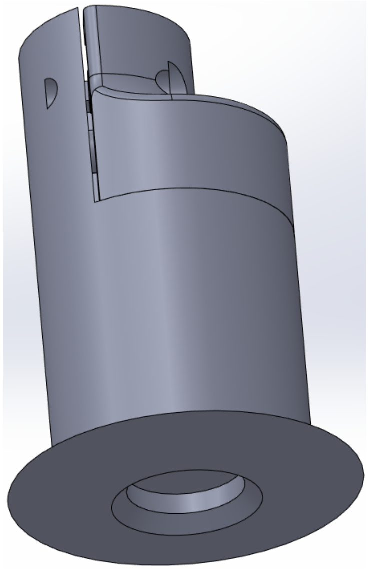

Figure 5.8: Concept based on (B4,D4,E1) from the morphological matrix

Concept 1.7 in figure 5.7 is made for the usage of double isolated cables with a strain relief to fasten the cable. Double isolated cables can also be used to ensure double isolation, but single isolated cables are used more frequently inside of flex tubes.

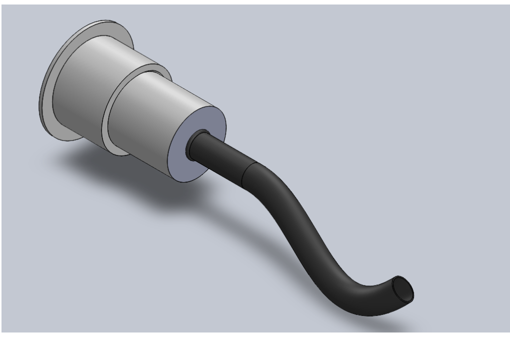

Figure 5.9: Concept 1.8

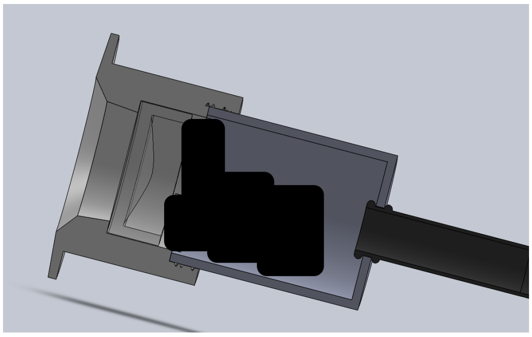

Figure 5.10: Cross section view of concept based on (B2,D4) from the morphological matrix

To ensure that the cables are double isolated, concept 1.8 has a circular plastic tubing that covers the single isolated cables shown in figure 5.9 and 5.10. This tubing are connected to the plastic piece that covers the circuit board, which is displayed as a gray piece in figure 5.10.

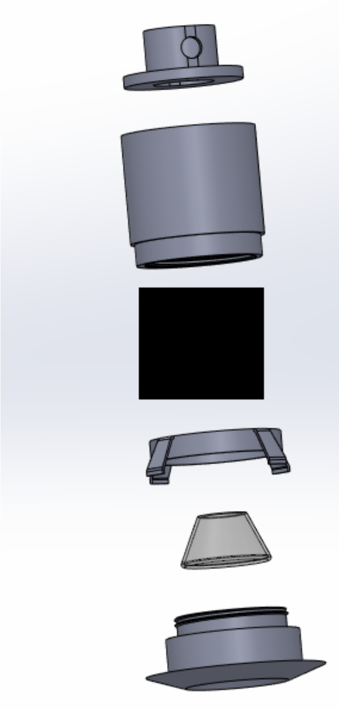

Figure 5.11: Concept 1.9

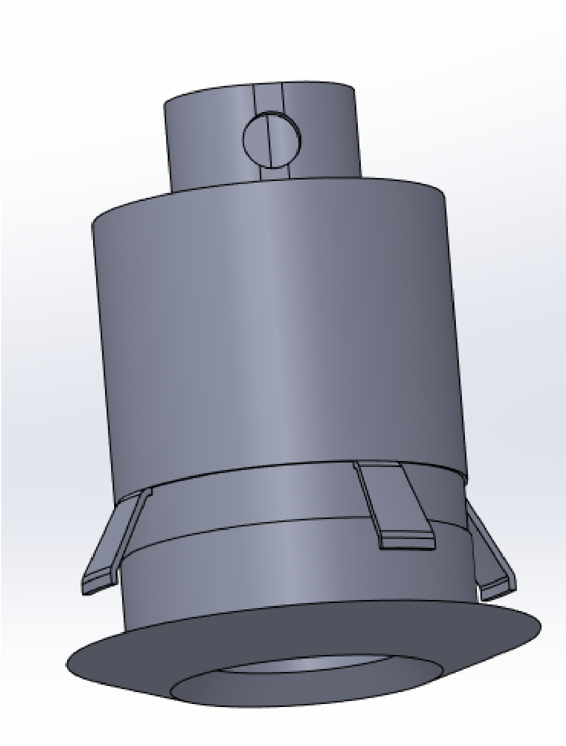

Figure 5.12: Concept based on (B4,C3,D4) from the morphological matrix

Instead of using conventional single isolated cables inside of the walls, a double isolated cable can be used to ensure double isolation all the way from the flex tube to the downlight. Concept 1.9 in figure 5.11 was an exploration on how the design of a downlight for double isolated cables can look like.

5.4.1 Concept validation

A meeting was set up with company Bulb to brainstorm and discuss the first iteration of concepts. The meeting consisted of showing all the concepts that were produced with both CAD models and 3D printed parts to get a feel of how some of them would look in real-life. The ordinary FDM printers that were used were not able to print all the fine features but still showed the concept as a whole.

One key point discussed was that the PCB needed its own housing inside of the downlight to avoid ESD short circuits and protect against human fingers when installing the downlight.

An expert at company Bulb on the IEC standards was also consulted at the meeting regarding the test finger probe that is used to validate the downlight. The expert concluded that fingernails do not count as a tool and, therefore, the downlight cannot be pulled down from the window sill with the test finger with ease. This makes the regulations for strain relief and mounting mechanism less demanding which is more beneficial to the target specifications.

Since the circuit board needed its own housing, most concepts did not fulfill the requirements. Even though the concepts were not fulfilling the requirements, some solutions to sub-functions could be used for further development. The plastic tubing attached to the top cap on concept 1.8 in figure 5.9 can be used to overcome the problem where the single isolated cables are not double isolated and exposed inside the wall between the downlight and the flex tube.

Figure 5.13: Testing different concepts and function with 3D printed parts

5.5 Second iteration

With the knowledge gained from the validation meeting with company Bulb, a new iteration phase began.

One of the new key features required from company Bulb for the new iteration was that there had to be a casing or housing for the circuit board to prevent electrical shock and electrostatic discharge. The plastic tubing accepted in the first validation moved on to the next phase and was used by all concepts in the second iteration. Another significant designed parameter was the connectors on the PCB that changed compared to the beginning. This increased the diameter size of the PCB and required a new design to fit in a 25 mm hole.

Four new concepts were developed during this phase, and different casings for the circuit board were designed for each one of them.

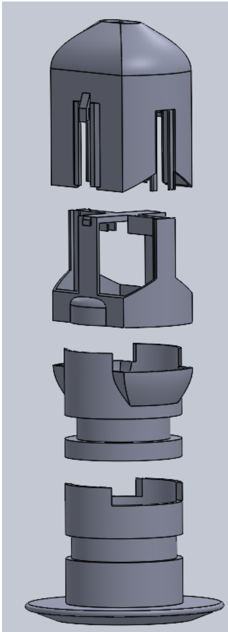

Figure 5.14: Concept 2.1

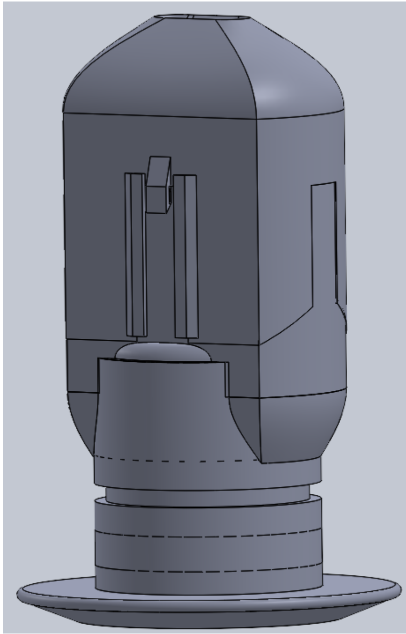

Figure 5.15: Concept 2.1

Concept 2.1 in figure 5.14 has a rectangular top cover to better fit the circuit board connectors and has a attachment to snap on to the casing that surrounds the circuit board. The casing consist of two parts to ease the insertion of the circuit board in to the casing. The casing is also designed to have a flat spring that is attached between the lens cap and the lower circuit board case.

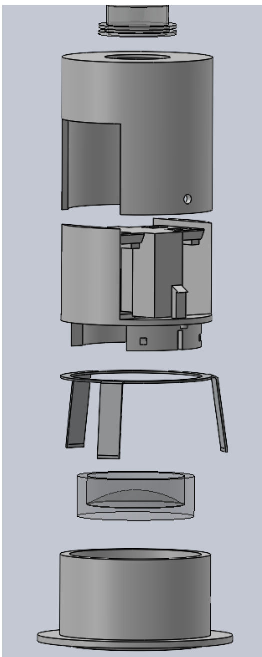

Figure 5.16: Concept 2.2

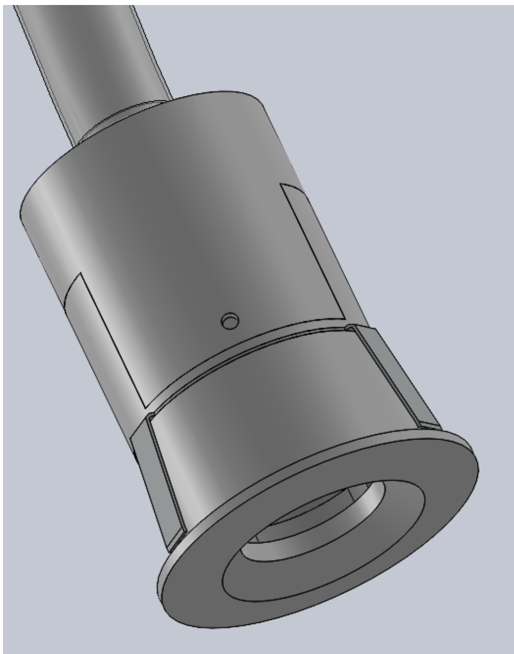

Figure 5.17: Concept 2.2

The PCB housing in concept 2.2 shown in figure 5.16 is made with one part which slides onto the circuit board from the top. It has a flat spring that is clamped horizontally between the lens cover and the PCB housing. The top cover slides over the housing and is connected with a snap bracket that can be released by inserting a thin object in to the hole in the top cover.

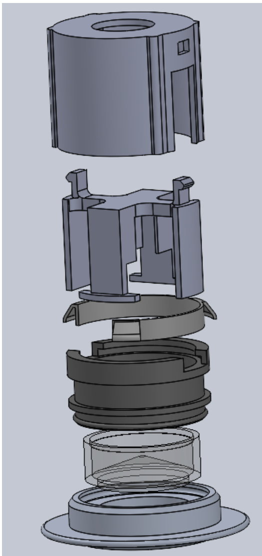

Figure 5.18: Concept 2.3 exploded view

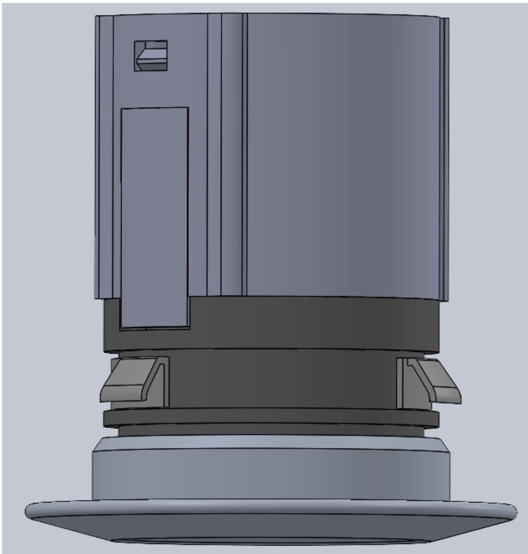

Figure 5.19: Concept 2.3

Concept 2.3 is similar to the previous concept in this iteration, with some differences in the locking mechanisms and location. However, this concept's main difference is that the lower part that is visible is thought to be metal. Therefore, needed more spacing from electric components to fulfill the standard requirement for electrical safety. This adds an extra component that can be seen as the darker part of figure 5.18 and 5.19, which is connected to a PCB cover and the lower part. The part that is not connected to the user is the upper part in figure 5.18, the cover lid, which is the only part the installer is able to disassemble from the concept.

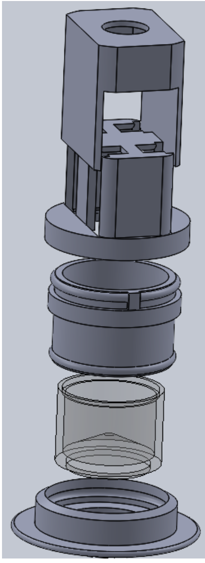

Figure 5.20: Concept 2.4 exploded view

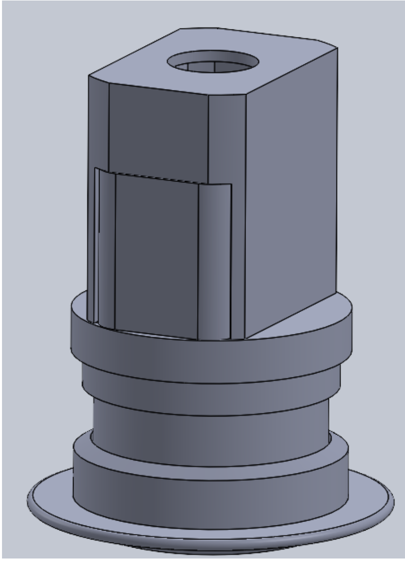

Figure 5.21: Concept 2.4

Concept 2.4 in figure 5.20 has the same structure and background thought as concept 2.3. The difference is the connection points between the distancing part from the lower metal part and the PCB cover and the upper part, the cover lid. This was to improve the stability of the connections between the PCB cover and the middle piece.

5.5.1 Concept validation of the second iteration of concepts

After the four new concepts were developed, a new validation session with the company Bulb took place. A vital design parameter of the second iteration was to design a housing for the PCB, which all the new concepts did manage to implement in its design.

Bulb's expert on IEC standards was once again consulted regarding the four new concepts to check if they passed the regulations. During the review, creepage distance was not fully taken into consideration when they were designed. The IEC standards state that the creepage distance is the shortest distance along the surface of the insulating material between two conductive parts. The shortest creepage distance that the downlight need is 6mm.

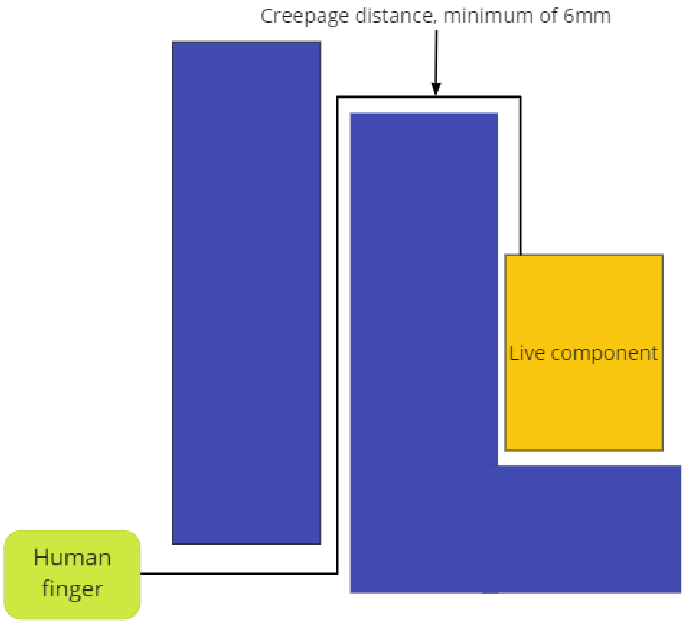

Figure 5.22: Overview of the creepage distance requirement

Figure 5.22 symbolize a product shown in a cross-section where it displays two different parts of the product. The creepage distance was added to the target specification list as a demand since it is a regulation by the IEC standards needed for the concept to be approved on the market.

5.6 Third iteration

The concepts that were designed for the second iteration did not pass the creepage distance requirement, so the new iteration phase consisted of making a new design for a concept that would pass the requirements. The outcome of the third iteration was one single concept called 3.1.

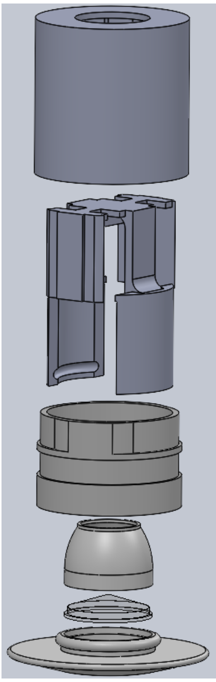

Figure 5.23: Concept 3.1 exploded view

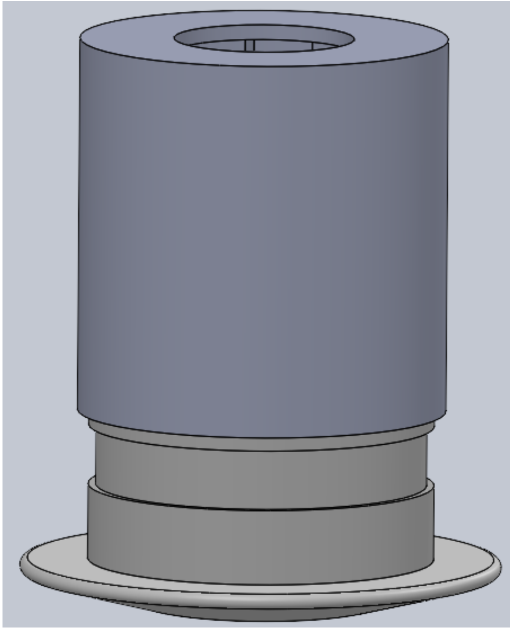

Figure 5.24: Concept 3.1

Concept 3.1 in figure 5.23 has a loose lens cover that snaps into the housing of the PCB and has a slot for the lens, which will distribute the light. Above the lens, a reflector holds up the PCB, so it stays in the right place. The reflector also acts as a shield so that other components on the PCB aren't visible through the lens. Concept 3.1 has a middle part that enclosure the lens and reflector, and there is a carving on the outside that will provide space and support for the flat spring. The top cover slides over the design to protect the PCB and makes the entire concept double isolated. The top part slides over the housing for the PCB down on the middle cover to maximize the creepage distance.

6

Final concept

In this chapter, the final concept will be presented, and the design modification made from concept 3.1. The assembly process and usage of the concept and the results of how the concept fulfilled the requirement, and customer needs, will also be presented.

6.1 Final design

Concept 3.1 was redesigned and refined to concept 4. The most significant improvement from 3.1 was the snap brackets on the PCB housing that had a circular shape instead of a "hook" shape. The hook shape snaps better onto the lens cover, securing the PCB housing. The hook-shaped snap bracket ensures that the PCB housing stays locked onto the lens cover more permanently after assembly, which it did not do on concept 3.1. The PCB housings legs were also redesigned with an angle, and this ensures that the legs have enough room to bend outwards in order to snap over the lens covers snap brackets.

Figure 6.1: Rendering of concept 4

Figure 6.1 shows how the final design of the downlight would look like when it is fully assembled. The plastic tubing connected to the top cover will act as second isolation for the single isolated cables that run from the flex tube.

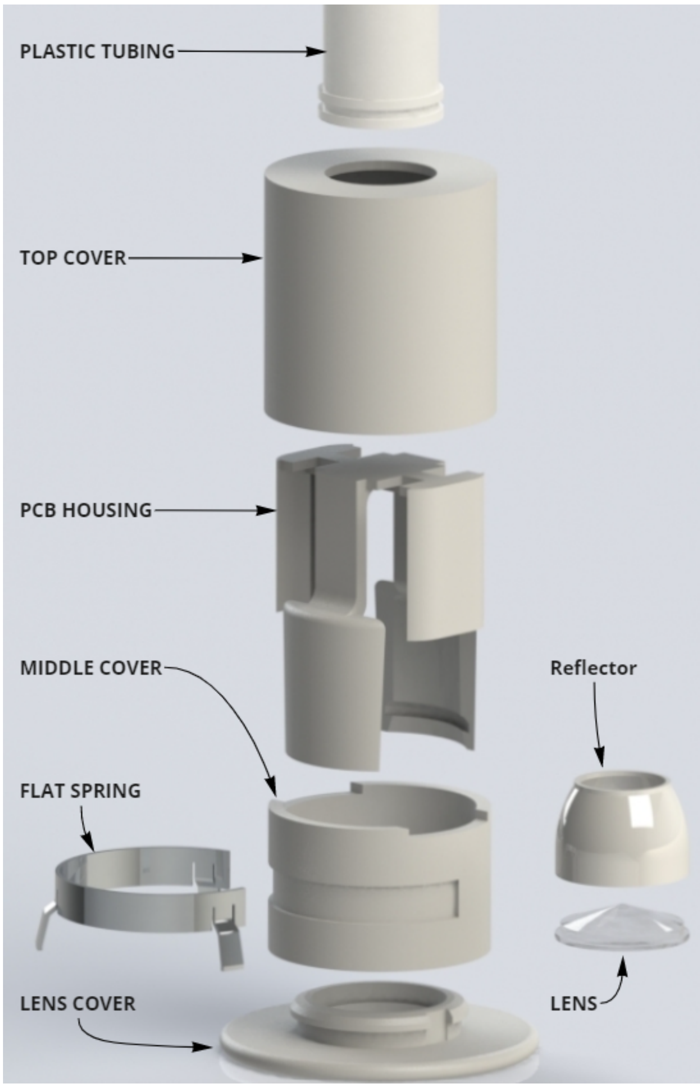

Figure 6.2: Exploded view of the final concept containing all the parts

The exploded view in figure 6.2 shows the eight components form concept 4. The reflector's task is to avoid discoloration from the PCB when looking through the lens. The lens was made convex to have a more focused beam angle.

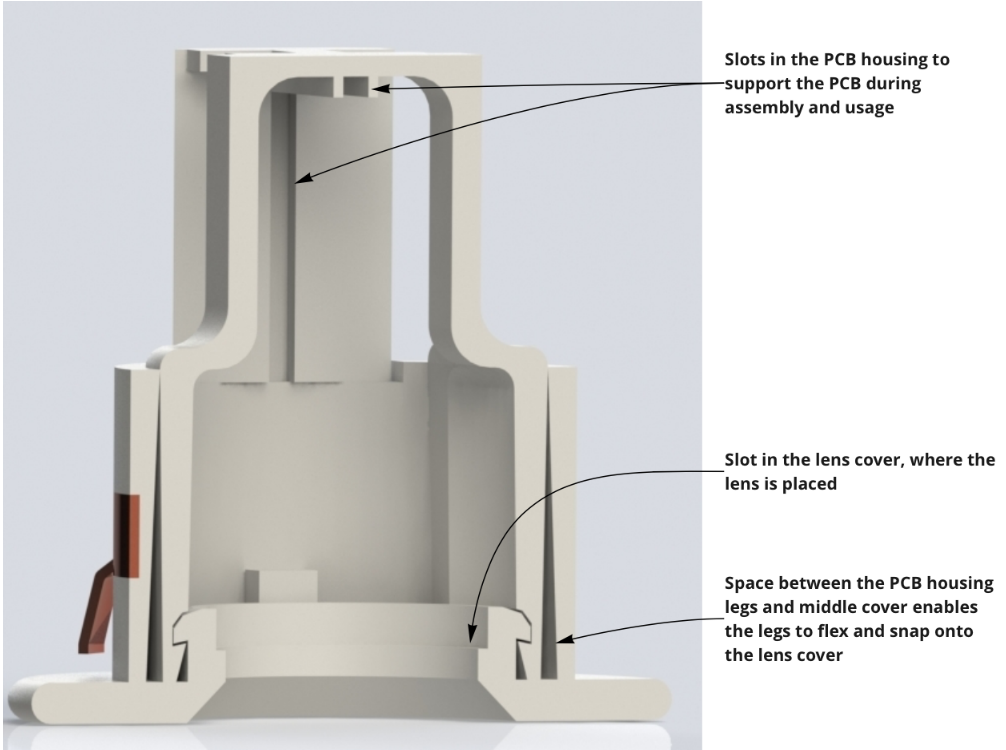

Figure 6.3: Cross section of concept 4 showing snap brackets and PCB slots

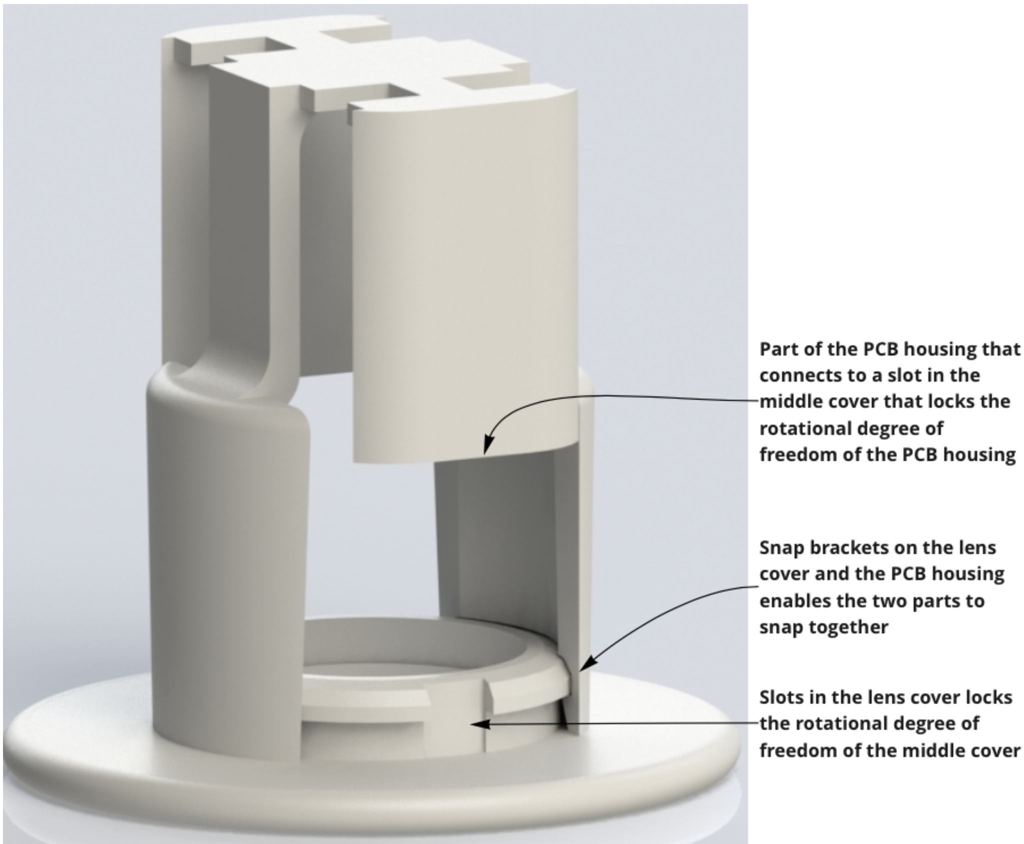

Figure 6.4: Lens cover with PCB housing attached

Figure 6.2 and 6.4shows more closely how the PCB housings legs snap onto the lens cover with its snap brackets. The lens cover was also redesigned from the previous concept 3.1, with rounded edges and with a flat surface to give it a more unobtrusive design.

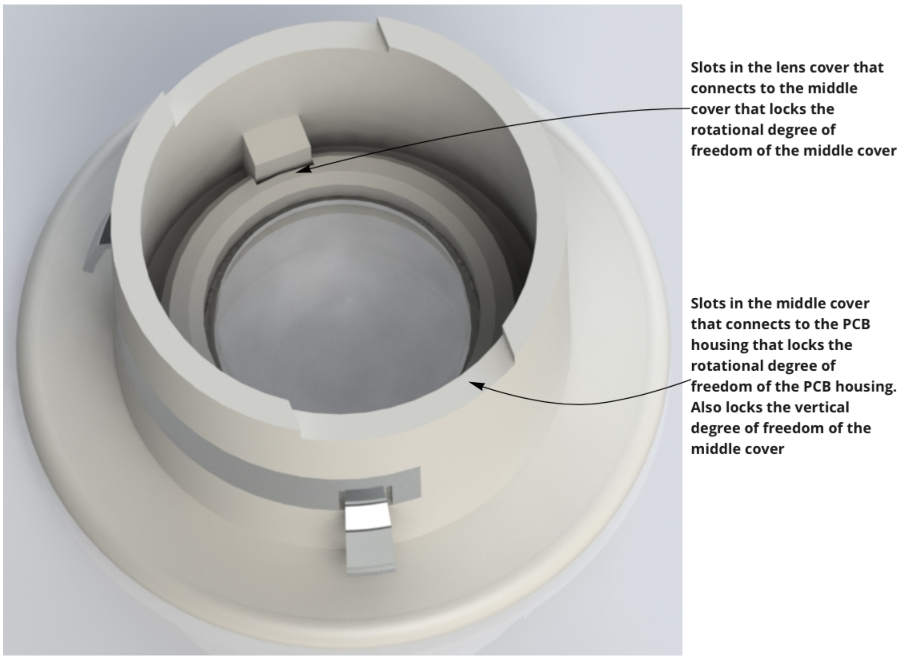

Figure 6.5: Lens cover with middle cover attached

Concept 3.1 did not have any slots in the lens cover, and the middle cover, which resulted in the rotational degree of freedom. In concept 4 as shown in figure 6.5, slots were added to ensure that the middle cover and lens cover lock onto each other.

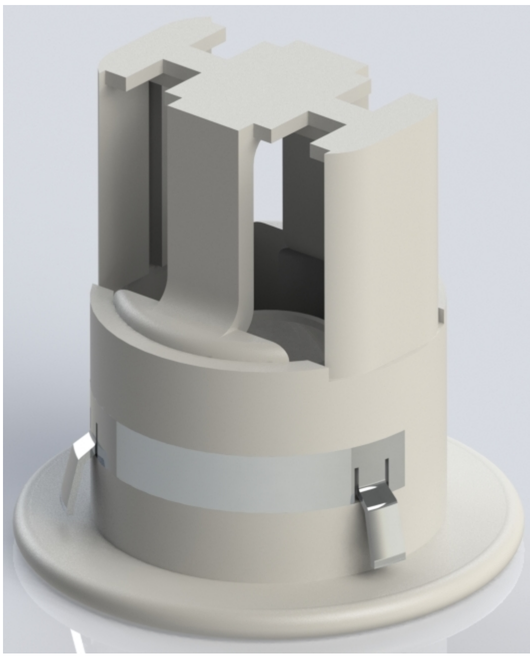

Figure 6.6: Concept 4 without the top cover and plastic tubing

Figure 6.6 shows how the downlight would look like when disassemble in a user perspective. During installation, the top cover and plastic tubing need to be removed to insert the cable through the plastic tubing and onto the PCB connectors. After the cables are connected, the cop cover is slid over the PCB housing and middle cover.

6.2 Assembly and usage

The prototype is meant to be assembled in three separate sub-assemblies to prepare for a complete assembly. The first sub-assembly will connect the reflector, the lens, and the lens cover. The second will connect the middle cover with the flat spring, and the third will connect the PCB will the PCB housing. It will be connected in the same order as mentioned in the complete assembly, where it starts to connect the first and second sub-assembly and finalizes with the third. Then it is optional if the top cover will be assembled or not in the packaging along with the plastic tubing.

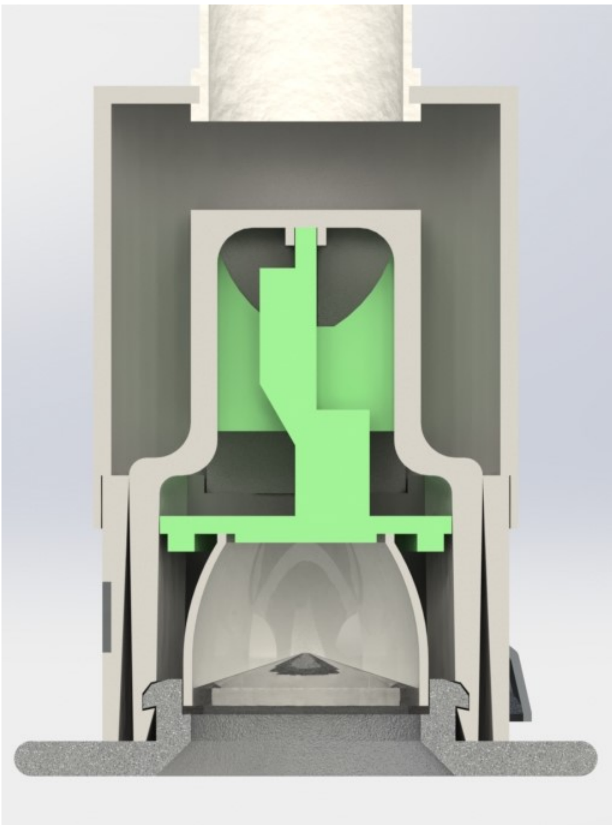

Figure 6.7: Full assembly in section view of the final concept 4, were the green parts is a representation of the PCB

Figure 6.7 shows the final prototype complete assembly and installed as it intended.

An additive manufacturing type of powder bed fusion was used to manufacture a prototype that can show all the small features of concept 4. These 3D printed parts were assembled to test the features of the different parts like the snap brackets on the lens cover and PCB housing.

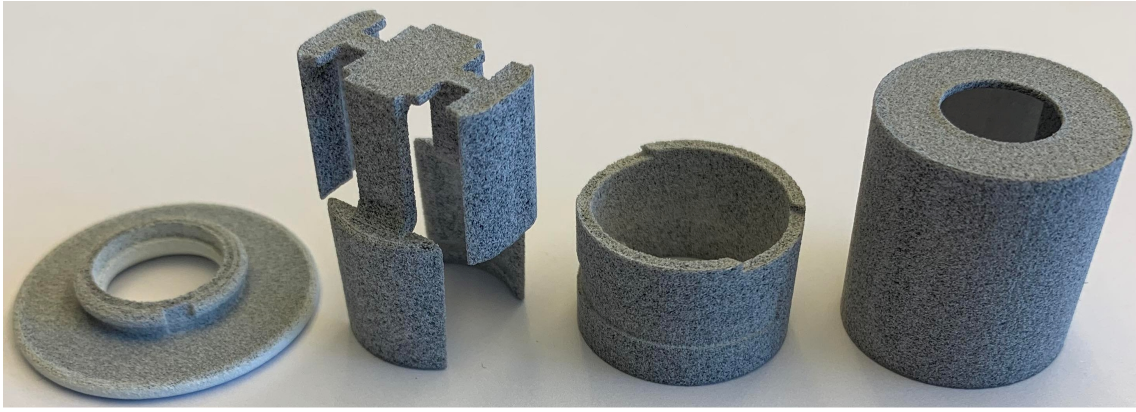

Figure 6.8: 3D printed parts of the final concept 4

Figure 6.8 shows how the four parts of the downlight look after they were 3D printed.

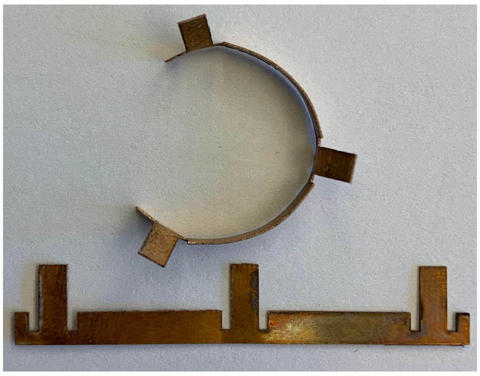

Figure 6.9: Flat spring flatten and bent to the right shape

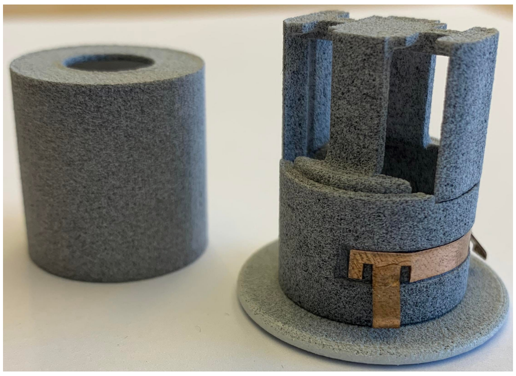

Figure 6.10: Flat spring assembled on to the middle cover

The flat spring was laser cut out of a copper sheet, bent to the right circular shape. Figure 6.10 shows how the flat spring was assembled onto the middle cover in the designated slot. The flat spring puts pressure on the drilled hole in the window sill and secures the downlight from not falling out of the hole.

Figure 6.11: Concept 3.1 exploded view

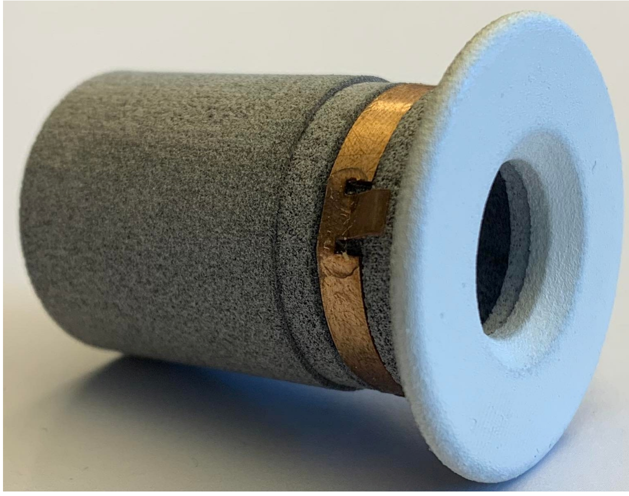

Figure 6.12

Figure 6.11 and 6.12 shows how the assembled prototype look like, and the lens cover was painted white to represent better how the real part would look after it is manufactured.

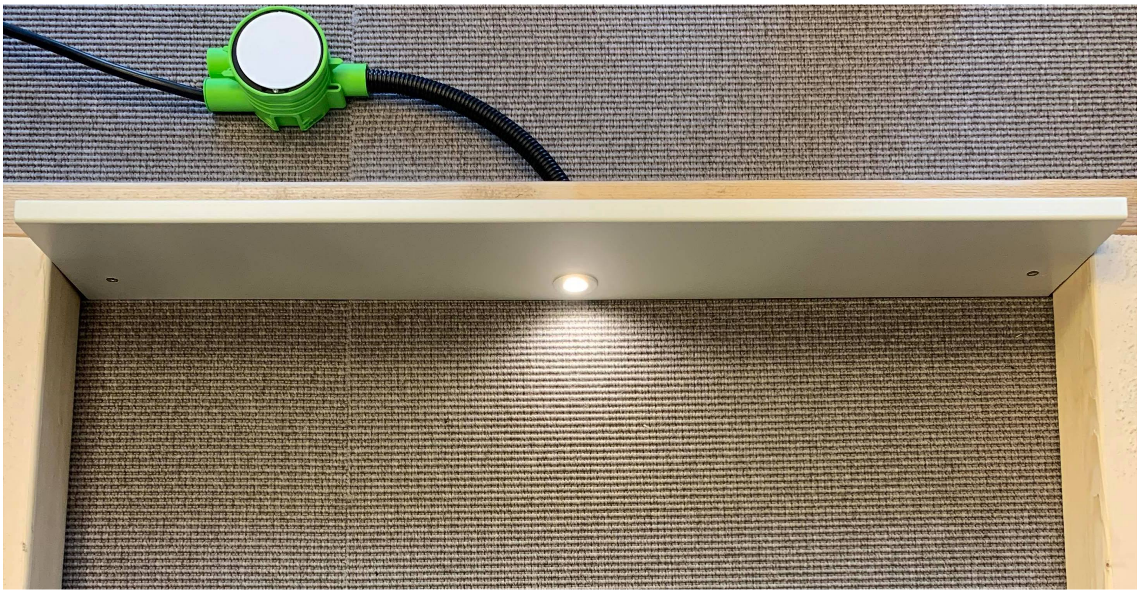

Figure 6.13: Testing of the concept 4

Finally, the concept was tested in a mock-up of a window sill. A 25mm hole was drilled in the window sill, and a flex tube was connected from a junction box to the hole, representing how it is built in a house. The prototype was then inserted into the hole and connected to the wires.

6.3 Materials and manufacturing

This part of the project has been discussed briefly over time but not decided on in detail. The majority of the product will be produced in composites/plastic and two parts in metal. Plastic parts will most likely be produced using injection molding because of the high volumes of production and the details required. However, creating tools for this method is expensive where the number of parts in the product and details directs to a significantly higher cost per unit. This affects the volume required to be sold to reach ROI (return of investment) or a higher product cost for the customer. The material selection regarding the composite depends on surface finish, mechanical properties, manufacturing complexity, and cost. Therefore, all parts will not have the same choice of material, e.g., the lens will require a transparent plastic, and the PCB holder will require better mechanical properties to no break because of higher tensions.
The lens cover and flat spring are the two parts to be made of metal. More specifically, the lens cover will be produced in aluminum. The main reason for this is its aesthetic purpose and lightweight, which can give a more premium feeling to the product. It also gives corrosion resistance and thermal properties to transport heat from the electronics. However, if this is needed or how well it will work require further testing of the products. The manufacturing method for these parts is probably casting because of cost and production volume with its necessary post-processing. The flat spring will most probably be produced by sheet metal punching using steel as a material with mechanical properties with enough strength and higher plasticity.

6.4 Results

The aim of this report was divided into two different segments. The first part was to understand the market and gain knowledge about the customer's needs regarding the preference of downlights today. The second part of the aim in section 1.2, focuses on the design of the downlight. The target was to create a downlight that fulfills the IEC standards for luminaries with an input voltage of 230V AC.

The target specification in appendix B.1, describes what requirements the downlight should fulfill. The test mounts in 6.13, show that the downlight fits inside of a 25mm hole which was the ideal goal. The downlight's ideal dimensions in the target were a maximum of 40mm in height and a diameter of 30mm, and the downlight measured in Solidworks reveals that it fulfills this requirement.

Creepage distance was another requirement that needed to be fulfilled according to the IEC standards and the target specifications. Concept 4 was designed to pass this requirement which can be seen in figure 6.14.

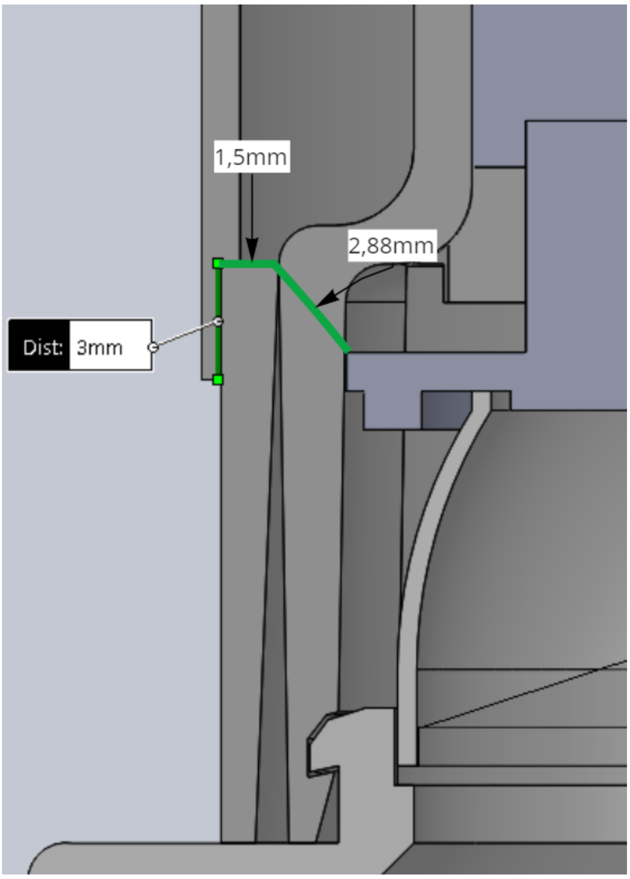

Figure 6.14: Creepage distance from the top cover to the live parts on the PCB

According to The IEC standards, there has to be at least 6mm of creepage distance to the live components on the PCB. When measuring the creepage distance in Solidworks, the distance added up to 7,38mm, passing the creepage limit.

7
Discussion

This chapter will go through the many limitations and assumptions made during the project and how they influenced the final output. There will also be a discussion on how well the final concept met the established standards and what needs to be done to validate the final product's qualities. Finally, there will be a discussion of the entire development process.

7.1 Market analysis

This market research has given a good foundation regarding this product segment. However, this might need enhancement in some parts and a review of the quality of the questions in both the interviews and survey. The interviews that have been implemented have given good quality information. However, the number of interviews can be discussed to cover a majority of how the process and thoughts of electricians. This with a more diversity regarding the interviewees for a broader range and decreases the possibility of finding more similar results. However, this was difficult to achieve because of the confidentiality.
Regarding the survey had more participants than expected and gave a good understanding of the preference of specifications of the product. However, because of how the purchase of how downlights are sold and how it differs regarding the participation in the selection of product between final user and electricians, it can create a need for rewriting some questions for clarification. Some questions have been formulated as "what do the customer/you prefer." This can dispute who the customer is and, therefore, the end customer or electrician from whom the answer and preference come. At the same time, does it matter because of how the purchase is made? However, because of the same number of interviewees, this does not necessarily need to be the whole picture and only represents a small fraction of how the process is conducted from the total mass. Some questions in the survey with a scale results system, in this case, beam angles, have more complexity and are situational. Because of the deficient expertise or difference in interest in light design, the selection process looks different depending on the dimensions of the window and the design aspects of the room, or if habits and middle value select it. The middle value, in this case, means that if it exists three choices (15,45 or 120 degrees), the middle one is selected for comfort.
A method that would be preferred but not implemented in this research is observing an installation and visiting an installation site. It is good to get a hands-on situation of the environment and observe an electrician performing an installation,

talking through the process of how this individual is thinking and acting depending on that situation. Ideally, an observation with a hidden camera would be optimal to get the "real" process without the pressure of being observed and, therefore, might not perform the installation in the same manner. However, this is impossible to implement because of moral and ethical conflicts of videotaping and recording a person without their consent.

7.2 Concept

Concept 4 shows that it is possible to design a 230V downlight, but a few items are still needed to discuss. The time for each iteration was not set to a specific time limit, which created very different time frames for each iteration. If there had been a specific time frame for each iteration, the product development phase could have been more effective, and more iterations could have been implemented and tested.
The PCB housing that was deemed a requirement after the first validation of concepts in the first iteration, there was little space to work with if it would fit inside a 25mm hole. To design a downlight that had both a PCB housing and a top cover, the material thickness had to be uneven in the PCB housing. This was because it had to be wide enough to fit around the PCB but thick enough to support it. This can create problems in the manufacturing of the PCB housing, which must be checked further.
The lens was never designed for the prototype, making it impossible to test which beam angle concept 4 would have produced.
Requirements in the target specifications have been constantly updated, but there is still a possibility that some requirements were missed. If concept 4 were to be produced, it first needs to go through an IEC standard validation where missed requirements will surface.

7.3 Further development and recommendation

There is still some further development that must be done on concept 4. When the prototype was assembled, it was noticed that the snap brackets on the PCB housing and lens cover were not joined together with enough force. It can be because the parts are 3D printed and not made with injection molding, and more tests must be conducted to develop the concept further.

The lens needs further development since it was never simulated or tested during the concept development. The targeted beam angle should strive to be 45 degrees since it was concluded in the survey that electricians most desired this beam angle. One options for this to create several lenses and give the customer the possibility to choose after their preference. This give the advantage of having the same features in the same product compared to many competitors that require multiple ones.

Based on results from the benchmark and the survey in 4.1, a couple of recommendations for the circuit board were noticed. To place the downlight in the same market segment as the rest of the DC-driven downlights on the market, it should have a luminous flux of around 100lm, and the effect that the downlight should provide is around 1,2W. The survey also showed other properties such as it being dimmable and being able to adjust the color temperature. If color temperature adjustments are achieved, electricians in the survey preferred a Kelvin between 2200K and 3000K.

8
Conclusion

This project aimed to see if it is possible to design a downlight made for 230V AC instead of the usual 12V DC. 12V DC is currently on the market, as the standards and regulations are much stricter for electrical equipment powered by 230V AC rather than 12V DC. The market analysis implemented in the project shows that 230AC is a wanted function if it can be achieved with an equal installation time. It does not necessarily need to be cheaper if it can satisfy the electrician's demands, have an unobtrusive design, and be easy to find at different suppliers.
The project resulted in a complete working prototype that fits in a 25 mm hole, the most common hole size of the existing products on the market. In theory, this concept has the potential to fulfill the laws and regulations stated in the IEC standard required for this type of product. However, further development is needed for volume production and further testing regarding light specifications.
The report shows that it is possible to design a downlight that is powered directly with 230V AC when the casing is redesigned to fulfill the laws and regulations stated in the IEC standards.

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A

Appendix A

A.1 Benchmark results

Brand	Model	Effect	Color temperature	Mounting hole	Current	Diameter	Hight	IP-classification	Beam angle (degrees)	Dimmable	Voltage	Mounting depth	Safety class	Lumen
Hide-a-lite	Dot VP	1,2W	2700K	16-20mm	350mA	30mm	22mm	IP44	45	Yes		15mm	3	90lm
Hide-a-lite	Spot Mini VP (2700)	1,2W	2700K	16-20mm	350mA	30mm	19mm	IP44	60	Yes		18mm	3	80lm
Hide-a-lite	Spot Mini VP (3000)	1,2W	3000K	16-20mm	350mA	30mm	19mm	IP44	60	Yes		18mm	3	85lm
Hide-a-lite	Spot Mini	1,2W	3000K	24mm	350mA	32mm	11mm	IP21	120	Yes		8mm	3	70lm
Hide-a-lite	Core Smart 120	1,2W	3000K	25mm	350mA	30mm	19mm	IP44	120	Yes	3V	13mm	3	70lm
Hide-a-lite	Core Smart 120	1,2W	2700K	25mm	350mA	30mm	19mm	IP44	120	Yes	3V	13mm	3	70lm
Hide-a-lite	Core Smart 45	1,2W	3000K	25mm	350mA	30mm	26mm	IP44	45	Yes	3V	20mm	3	60lm
Hide-a-lite	Core Smart 45	1,2W	2700K	25mm	350mA	30mm	26mm	IP44	45	Yes	3V	20mm	3	60lm
Hide-a-lite	Core Smart 15	1,2W	3000K	25mm	350mA	30mm	37mm	IP44	15	Yes	3V	31mm	3	30lm
Hide-a-lite	Core Smart 15	1,2W	2700K	25mm	350mA	30mm	37mm	IP44	15	Yes	3V	31mm	3	30lm
SG	7468198	1W	2700K	25mm	350mA	33mm	27mm	IP44	15			26mm	3	80lm
SG	7468204	1W	2700K	25mm	350mA	33mm	27mm	IP44	36			26mm	3	80lm
SG	7468205	1W	3000K	25mm	350mA	33mm	27mm	IP44	36			26mm	3	90lm
SG	7468199	1W	3000K	25mm	350mA	33mm	27mm	IP44	15			26mm	3	90lm
SG	7473099	1W	4000K	25mm	350mA	33mm	27mm	IP44	36			26mm	3	90lm
DesignLight	p-119MW	1,2W	3000K	27mm	350mA	33mm		IP44	20	Yes		12mm		92lm
DesignLight	P-132MW	1,2W	3000K	19mm	350mA	25mm		IP21	60	Yes		14,2mm		94lm
DesignLight	Q-20MW20	1,2W	3000K	25mm	350mA	30mm		IP21	20	Yes		15,7mm		100lm
DesignLight	Q-22MW	1,2W	2700K	25mm	350mA	30mm		IP40	20/40	Yes		37mm		100lm
DesignLight	Q-23MW	1,2W	3000K	25mm	350mA	30mm		IP40	20/40	Yes		37mm		110lm
DesignLight	Q-32MW	1,2W	3000K	27mm	350mA	32,5mm		IP21	105	Yes		13mm		71lm
DesignLight	Q-33MW	1,2W	2700K	27mm	350mA	32,5mm		IP21	105	Yes		23mm		113lm
DesignLight	Q-21MW	1,2W	3000K	11mm	350mA	30mm		IP44	60	Yes		18mm		60lm
DesignLight	Q-25MW	1,2W	2700K	11mm	350mA	30mm		IP44	60	Yes		18mm		60lm
DesignLight	P-117MW	1.2W	3000K	31mm	350mA	40mm		IP65	25	Yes		34mm		72lm
Unilamp	mini-D (7473231)	3W	3000K	26-27mm		36mm	13mm	IP44	30	Yes	230V			220lm
Unilamp	mini-D (7473228)	2W	2700K	26-27mm		36mm	13mm	IP44			230V			130lm
Unilamp	mini-D (7473229)	2W	3000K	26-27mm		36mm	13mm	IP44			230V			130lm
Unilamp	mini-D (7473230)	3W	2700K	26-27mm		36mm	13mm	IP44			230V			220lm
Unilamp	mini-D (7473232)	1W	2700K		160mA									100lm
Unilamp	mini-D (7473233)	1W	3000K		160mA									100lm
Unilamp	mini-D (7474683)	3W	2700K					IP44						220lm
-	Mini downlight (R1204	4.5W	3000-4000K	35mm		51mm	40mm	IP20	38		200-240V		-	150-180lm
	ED-T265-R-1	4W	3000-4000K	35mm		45mm	31mm	IP44		-	-	-	-	350lm
Starlite	TLED-001W/WW	1W	3000K	-		45mm	32mm	IP20	35	-	12V (DC?)	-	-	75lm
Vellnice	EDISON	3W	3000K	-	700mA	38mm	54mm	IP20	15,24,36	-	7W	-		183lm
A-Collection	Minidownlight aLED1	1,2W	3000K		350mA	33mm	12,3mm			Yes		27mm		108lm
A-Collection	Minidownlight aLED C	1,2W	3000K	27mm	350mA	33mm	34mm	IP20	20-40					98lm
Zebra	MINIDOWNLIGHT	1W	3000K	-	350mA	25mm	25mm	IP44	50	Yes		25mm		70lm
Zebra	MINIDOWNLIGHT	1W	2700K	-	350mA	25mm	25mm	IP45	51	Yes		25mm		75lm
Solar light	One VP V2 (2700K)	1W	2700K	18-22mm	350mA	30mm	24mm	IP44	20-40	Yes		24mm	3	80lm
Solar light	One VP V2 (3000K)	1W	3000K	18-22mm	350mA	30mm	24mm	IP44	20-40	Yes		24mm	3	90lm
Solar light	One Spot (2700K)	1W	2700K	25mm	350mA	30mm	24mm	IP44	40-80	Yes		24mm	3	80lm
Solar light	One Spot (3000K)	1W	3000K	25mm	350mA	30mm	24mm	IP44	40-80	Yes		24mm	3	90lm
Solar light	Highline Spot	3W	2700K	15mm	350mA	25mm	18mm	IP44	40-60			25mm		100lm
Iguzzini	Laser Blade XS QI85	2W	2700K		700mA	28x28mm	50mm	IP20	24			51mm	3	190lm
Nordtronic	**Elena**	2W	2700K		350mA	33mm	40.5mm	IP44	-	Yes	DC	-		140lm
Nordtronic	Viola	2W	2700K		250W			IP44		Yes	SC	34mm		140lm
SLV	HORN MINI	-	3000K		350mA	45mm	54mm	IP20						70lm

Figure A.1: Benchmarking of competitors

B

Appendix B

B.1 Target specification

Target specification: Downlight for window sills							Date: 2022-02-17	Last modified: 2022-04-29
Metric NO	Requirement/desires	Customer Needs	Unit	Marginal goals	Ideal goals	Demand /Wish	Justification	Verification method
	Design							
1	Mounting hole dimension	1	mm	28	25	W	Benchmark analysis	Assesment using CAD
2	Dimensions (HxD)	1	mm	50x35 (HxD)	40x30	D	Interview	Assesment using CAD
3	Adjustable Beam angle	2	Boolean	NO	YES	W	Survey/Interview	Computer simulation
4	Beam angle	2	Degrees	45	30-80	D	Survey/Interview	Computer simulation & testing
5	IP-classification	6	List	IP20	IP44	W		Certification
6	Strain relief	4,5	Boolean	YES	NO	W/D	SS-EN IEC 60598-1	Nemko / Strain relief test
7	Corrosion resistance	6	Boolean	NO	YES	W	Customer needs	Enginering assesment
8	Encapsulation of PCB	5,6	Boolean	YES		D	Company requirement	Enginering assesment
9	Creepage distance	5	mm	6mm		D	SS-EN IEC 60598-1	Assesment using CAD
	Electrical							
10	Isolation class	5	List	CLASS 3	CLASS 2	D	Swedish Electrical Safety Agency	Enginering assesment
11	Input voltage	1,3	Volt	>50V DC	230V AC	D	Customer needs	Enginering assesment
12	Cable isolations type	1,3,4	List	Double	Single	D	SS-EN IEC 60598-1	Enginering assesment
13	Series connection	3	Boolean	NO	YES	W	Customer needs	Enginering assesment

Figure B.1: Target specification

C

Appendix C

C.1 Morphological matrix

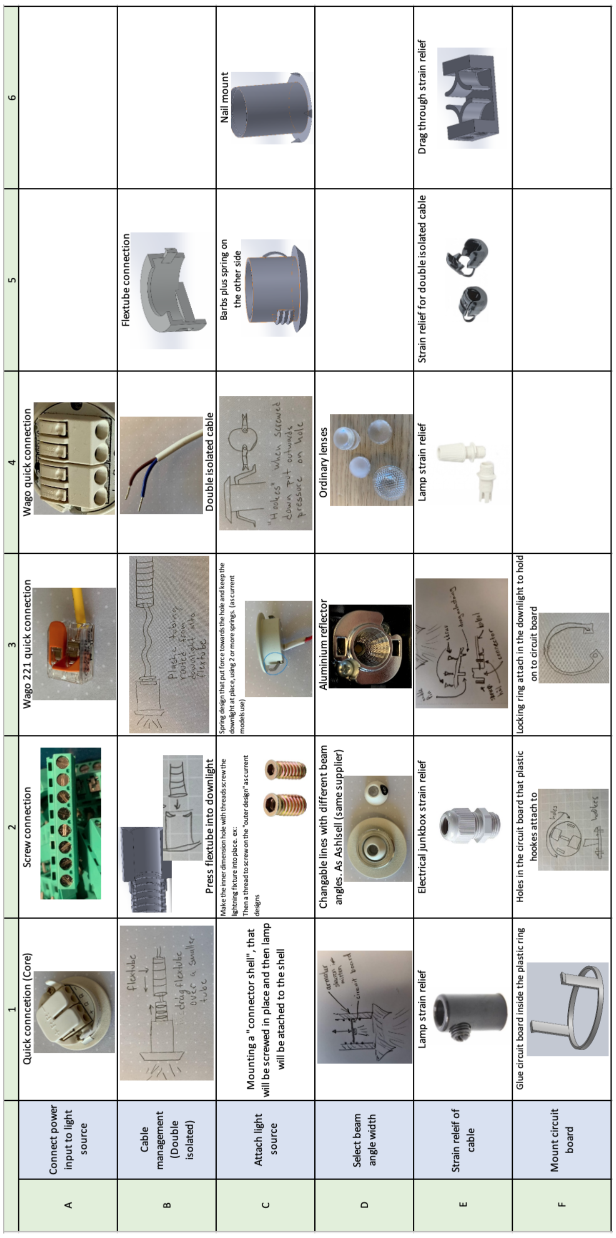

Figure C.1: Morphological matrix

The pictures in the morphological matrix are adapted from the references below:

- C2 [20]
- E1 [21]
- E2 [22]
- E4 [23]
- E5 [24]

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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