CHALMERS

LED plant lighting for household environments

Development of a cultivation lamp that enhances and simplifies the growth and keeping of edible plants.

Master of Science Thesis in the Master Degree Program, Industrial Design Engineering

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Abstract

Due to insufficient light conditions, artificial lighting has long been an important factor in the performance of indoor cultivation. But it is only in recent years that the technology of Light Emitting Diodes (LED) has been introduced to the market. The technology of LEDs provides an efficient light of specific wavelengths which allows improved plant production and quality.

This master's thesis work was carried out in collaboration with the company Heliospectra, who specialize in smart LED lighting solutions for greenhouse environments and different fields of plant research. The key aspect of their technology is the ability to control the intensity of individual diodes of different colours, making it possible to create spectrums of light adjusted to different plants and growth purposes. The company is now looking to expand their product range to include an option for the consumer market.

The purpose of this thesis work was to investigate the user requirements related to a product for indoor cultivation and the possibility of adapting Heliospectra's technology to such a product.

The transformation from an advanced industrial technology to a consumer product started with a thorough research of the market. A competitor analysis was conducted and different types of information gathering methods such as surveys, interviews and focus groups were utilized. The gathered information was used in an idea generation process where different concepts were created. The concepts were then evaluated in order to select a final concept. The final concept was developed further in terms of functionality, design, usability, material and manufacturing.

The project resulted in a cultivation lamp called Enlight, that enhances and simplifies the growth and keeping of edible plants in the home environment.

Key words: *Industrial Design Engineering, Product development, Heliospectra, Indoor cultivation, Horticulture, Cultivation lighting, LED, Grow light, Enlight*

Contents

1. Introduction

In this section the background to the project is presented. First of all the company, which the project was performed in collaboration with, is shortly described. Some background information follows, together with the purpose, goals, project questions and delimitations. At the end of this section is an outline for the rest of the report.

1.1 Project background

Heliospectra was founded in 2006 and is based on research in horticulture. The company is specialized in smart LED lighting solutions for greenhouse environments of which the key technological aspect is the ability to control the intensity of individual diodes of different colour, creating a spectrum of light adjusted to different plants and growth purposes. High brightness light emitting diodes are used in order to reduce the energy consumption, while at the same time produce crops that look better, taste better and have longer shelf-life than those grown under the High-pressure sodium lights that are traditionally used. The current product, the L4A, is adapted to industrial growth environments, such as greenhouses, indoor and vertical farms, walk-in chambers and growth cabinets, see Figure 1. The product is further used for research in fields such as plant development, physiology, biochemistry, molecular biology, plant entomology et cetera.

The company is now looking to expand their product range to include an option for the consumer market. This requires the development of a smaller luminaire that is better fitted for household use, taking into account design, ergonomics, usability, technical properties, construction and material selection.

The intent of the project is to utilize Heliospectra's technology and adapt it to a product fitted for household environments. When transforming the technology to better fit the consumer market there are some aspects that need to be taken into consideration. First of all, a suitable target group needs to be identified for whom a potential product can be motivated from both a functional and sustainable perspective. The development needs to be focused on the human-product relationship and the product requires a high aesthetic value as well as usability and ergonomics. Further, the product's technical properties have to be adapted to fit in the area of household usage concerning size, heat transmission, noise and luminous intensity.

Figure 1. *Heliospectra's current product (Image source: Heliospectra (2013)).*

1.2 Purpose and goal

A purpose and goal is stated in order to specify what the project should achieve.

1.2.1 Purpose

The purpose of the project is to investigate the opportunities for implementation of LED based cultivation solutions with adjustable spectrums for the consumer market and in household environments.

The primary focus of the project will be to investigate the possible applications of the technology and to determine a suitable design, functionality and interface that makes it accessible to the user.

1.2.2 Goal

The project goal is to develop a lighting solution and luminaire that enhances the ability of growing and keeping plants in a household environment. The development should result in a product that could be ready for production and available on the market within a two year period.

The result will be presented digitally in the form of a CAD model as well as in the form of a physical prototype, displaying the main function of the concept.

1.3 Project questions

In order to fulfil the purpose and goal of the project, three different questions were stated.

1. How can the technology of LED-lighting with adjustable spectrum be utilized in the domestic environment and implemented on the consumer market?

2. What is the most favourable target group and how can the technology be adapted to best meet the requirements of that target group?

3. How can Heliospectra's research expertise and focus on sustainability, technology and quality be expressed in a consumer product?

1.4 Delimitations

The development project needs some boundaries in order to make the project feasible in relation to the amount of time and resources available. The main boundaries for the project are presented below.

1. No investigation or evaluation of different light source technologies will be conducted. The reason is that Heliospectra's main focus is in plant lighting with the use of LED technology and it is also an area which they are associated with.

2. The project will not consider technologies that are not yet available. Therefore no futuristic concepts will be created. The reason is that the end product should be possible to realise in the near future.

1.5 Project process

A process plan was created in the beginning of the project, in the form of a flowchart, in order to create a layout of the project process, see Figure 2. The purpose of the flowchart was to provide an overview of all the steps that was to be included. The chart consists of ten major blocks with three decision gates between them. The plan has not been followed through exactly the way it was first constructed and presented in the figure. It does however provide a rough layout of the process and the procedure of the different phases.

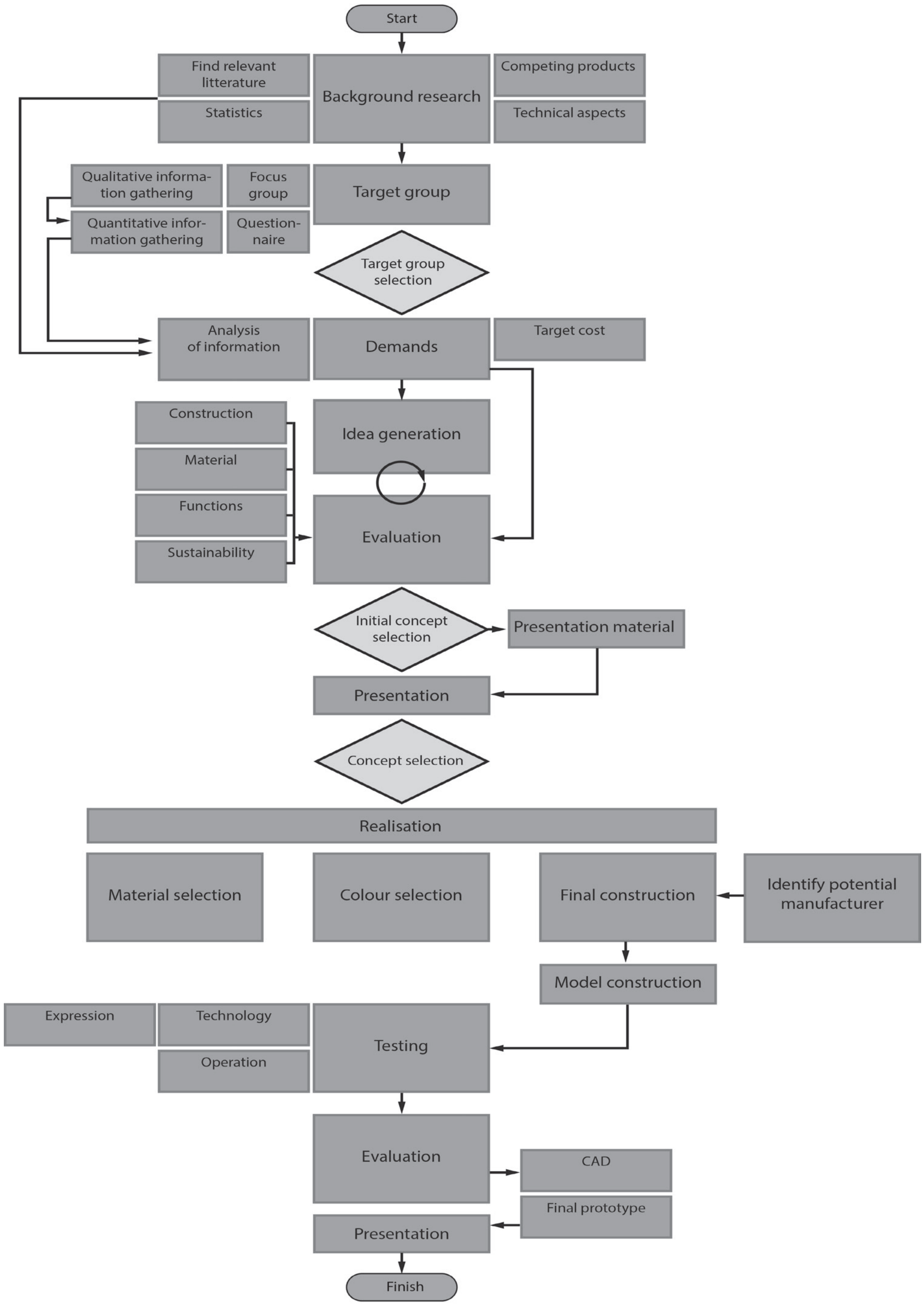


Figure 2. *Process plan in the form of a flow chart.*

1.6 Report outline

Chapter 1 - Introduction: This chapter presents the background and scope of the project, with the project goals and delimitations. It also provides a layout of the project process.

Chapter 2 - Theory: The chapter presents the underlying theory that has been used during the project. It covers the basics of cultivation, plant requirements, LED-lighting and different cultivation technologies. Many of the decisions made during the project are based on information found in this section.

Chapter 3 - Methods: In this chapter the different methods used in the project are presented. The information can be used to understand the basis of the work or as a guide on how to carry out the different methods. The methods are grouped according to the phases in which they were conducted; planning, research and analysis, concept development and concept selection.

Chapter 4 - Research and analysis: This chapter describes the research and analysis of the market for the intended product. A data collection section is first presented where different methods were used to gain knowledge about the market and the possible target group of the product. This information is then evaluated by different methods to establish a basis for the further work. A section on the final result and the conclusions drawn from it can be found at the end of the chapter.

Chapter 5 - Concept development: This chapter describes how the information gathered in the research phase was translated into different concepts using a variety of idea generation methods. After categorising and evaluating the results, a selection of seven concepts was chosen for further consideration.

Chapter 6 - Concept selection: This chapter addresses how the concepts, with the use of different methods, were evaluated in terms of feasibility, expression, functionality, aesthetics, usage and economy. The evaluation resulted in a better overview, which made it possible to make a selection of a final concept.

Chapter 7 - Further development: The chapter presents the development of the final concept. First there is a summary of the functions that the product should have and the requirements that it should fulfil. A description of how different components were tested and analysed in order to find the best fitted solution follows. Thereafter the exterior design concerning size, colour and materials is described as well as the design of the product interface.

Chapter 8 - Final results: In this chapter the product is presented in its final design. All of the product's different functions and properties are further described.

Chapter 9 - Testing and verification: This section presents an evaluation of the final product, where it is possible to see if the product fulfils the demands that have been set up throughout the project. The evaluation concerns the illuminative capabilities, cost, appearance and environmental aspects of the product.

Chapter 10 - Discussion: The chapter presents a discussion of the project at large. The discussion includes the process and the methods used. There is also a presentation of the lessons learnt and a paragraph with recommendations for the further development of the product.

Chapter 11 - Conclusion: This chapter concludes the project with regards to the fulfillment of the project goals.

2. Theory

This section presents the underlying theory that has been used during the project. It covers the basics of cultivation, plant requirements, LED-lighting and different cultivation technologies. Many of the decisions made during the project are based on information found in this section.

2.1 Cultivation

Urban cultivation is on the rise and with an increase in environmental awareness; the growing of utilitarian plants is becoming more popular. This section concerns the basics of modern cultivation with a focus on the recreational cultivation in Sweden, the way modern agriculture affects the environment and the importance of urban cultivation.

2.1.2 Recreational cultivation in Sweden

During the last century, society's view on cultivation has changed. Whereas commercial agriculture has become more mechanized and specialized, private cultivation have been given a recreational role where the focus is shifted from utility towards beauty and pleasure (Björkman, 2012).

However, with increased interest in environmental and health issues, the private cultivation of utilitarian plants has once again become more appreciated. According to a survey conducted in 2011, edible crops were cultivated in 88 percent of the Swedish households, including both outdoor and indoor cultivation. Most of the cultivation (56 percent) is tied to the garden while windows and balconies are used by 8 percent of the respondents respectively. As much as 73 percent of the respondents cultivate herbs of some kind. Other popular crops include currant, rhubarb, apples, tomatoes, lettuce and strawberries (Björkman, 2012).

In 2011, 41.6 percent of the Swedish population expressed an interest in gardening. Women have the most pronounced interest with 49.6 percent compared to the men's 33.6 percent. The interest in gardening increase with age; only 14.5 percent of people between the ages 15 and 19 expressed an interest compared to 56.8 percent among people aged 70 to 79 (Björkman, 2012).

2.1.3 Sustainability

The use of fossil fuel has become an integral part of modern agriculture. The processing of the soil with the use of tractors, the acquisition of irrigation water through pumping and the production of artificial fertilizers all contribute to this. International transportation of grocery products is another contributing factor which also causes a shift in the distribution of nutrition. When agricultural products are exported the nutrition used to grow them needs to be replaced through an increased use of fertilizers. This problem is further aggravated by an urbanization which reduces the amount of nutrition recovered from human waste in agricultural areas (Brown, 2008).

Today more than half of all the people in the world live in urban areas and by 2050 it is projected that the urban population might constitute as much as 70 percent of the total human population (Population Reference Bureau, 2008). Brown (2008) predicts that cities will have to change to accommodate the increased lack of resources. One such change could be an increased utilization of urban farming. According to FAO (2005) 700 million, or one quarter, of the world's urban population was supplied by urban or peri-urban farms in 2005.

2.1.4 Urban cultivation

According to Brown and Carter (2003) urban growers can be divided in three broad groups: commercial farmers, community gardeners and backyard gardeners. All the groups are diverse in terms of gender, ethnicity and age and while some have previous knowledge of farming, urban agriculture also attracts people with no previous experience. The opportunities for urban growers increase as city dwellers become more interested in buying fresh and locally grown produce, meat and dairy products.

The interest for urban cultivation has increased in Sweden during the 21st century (Björkman, 2012). Residential gardens represent the largest part of urban cultivation. For apartment residents who do not have access to their own gardens, allotment gardening is the most common choice but they also make use of balconies and other gardening spaces close to their apartments.

2.2 Plant requirements

In order for plants to grow, different external factors have to be fulfilled. This section addresses the basic requirements of plants and explains how it is possible to optimize plant growth.

2.2.1 Absorption spectrum

According to Moe (1997) artificial light is an important factor in greenhouse cultivation. The possibility of manipulating light allows the farmers to increase photosynthesis, controlling the timing of physiological events and modulating crop morphogenesis, which could improve plant production and quality. According to Vänninen et al. (2010) the principal aspects of artificial lighting affecting photosynthesis and growth are (1) light quality (spectral distribution compared to the plant's needs); (2) light intensity and light integral compared to the plant requirements and production purposes; (3) duration of lighting per day for maximizing plant growth and photomorphogenetic processes such as flowering and (4) placement of lights to optimize the light availability for the plants. Regarding the first principal of light quality Lambers et al. (2008) claims that the wavelengths between 400 and 700 nanometres (nm) are the ones useful for photosynthesis, photomorphogenesis (light mediated development) and phototropism (directional growth), and according to Mockler et al. (2002) far-red light (700-1000nm) is the most important for flowering. The two most important absorption peaks are located in the red (625-675nm) and blue light (425-475nm). However according to Massa et al. (2008) studies have been conducted where a small amount of green light has been added to the blue and red, which has resulted in plants with higher fresh and dry weights and greater leaf areas, compared to those grown under blue and red light alone. The combination of red, green and blue light also gives the plants their natural appearance, while using only red and blue light can give the leaves a darker, purplish hue.

2.2.2 Light requirements

Apart from wavelengths, the growth of a plant is also determined by the amount of light that it is exposed to. This quantity can be measured in photosynthetic photon flux (PPF) which is the number of photons making contact with an area within a certain timeframe, usually defined as $\mu mol*m^{-2}*s^{-1}$. The amount of light required by plants differs between different species. An experiment conducted at Iowa State University concluded that the greatest biomass production of sweet basil was achieved at an irradiance level of 500 $\mu mol*m^{-2}*s^{-1}$. The results also indicated that higher irradiance levels might be harmful to the growth of the plant (Beaman et al., 2007). A study on the production of a high-value protein in transgenic tomatoes showed a positive correlation between fruit yield and PPF up to 400 $\mu mol*m^{-2}*s^{-1}$. Higher PPF also had a positive effect on harvesting time (Kato et al., 2011). The experiments utilized fluorescent and incandescent lights to promote growth. Utilizing LEDs with optimized light spectrums should require a lower PPF to produce the same results since the light can be tailored to the absorption spectrum of the plants.

Runkle (2007) states that external lighting may be a necessity in order to grow certain plants. That is because some plants requires amounts of light that may not always be fulfilled naturally, depending on geographical location and time of year. Daily light integral (DLI) is according to Lopez and Runkle (2005) defined as the quality of light received each day as a function of PPF and duration (day). DLI is expressed as the amount of light per square metre in one day ($mol*m^{-2}*d^{-1}$). The amount of light that a plant receives per day can have a large impact on the quality of the plant in terms of root formation, shoot growth and stem elongation. According to Torres and Lopez (2010) plants can be separated into groups according to their DLI-requirements. Plants with a DLI requirement of 3 to 6 $mol*m^{-2}*d^{-1}$ are considered low light plants. Plants requiring 6 to 12 $mol*m^{-2}*d^{-1}$ are called medium-light plants and the ones requiring 12 to 18 $mol*m^{-2}*d^{-1}$ are considered high-light plants. There also exist a small amount of plants requiring more than 18 $mol*m^{-2}*d^{-1}$, and these are considered very high light plants. The DLI indicates that plants have large differences in requirements of light intensity, however most edible plants such as herbs, tomato and chili are in general specified as high light plants.

2.2.3 Temperature

According to Lopez and Runkle (2005) a desirable soil temperature for plants is between 23 and 25°C and this usually requires external heating. The surrounding temperature should be maintained between 20 and 23°C when bottom heat is utilized. However, if bottom heat is not available, the surrounding temperature should be increased to between 25 and 26.5°C. The temperature should further be lower at night; a good rule of thumb is to keep night time temperature four to eight degrees lower than daytime temperatures.

2.3 LED based cultivation

Since Heliospectra is focusing on plant research using LED technology, it was a primary requirement that the project should utilize this light source technology. In the following section the basics of LEDs will be presented, as well as information on how LEDs can be used to improve cultivation.

2.3.1 LED Technology

According to Gary et al. (2008) light-emitting diodes (LEDs) are based on a semiconductor technology that convert electricity to light. The light from LEDs is emitted from a solid object of semiconductor material, rather than from vacuum or gas tubes as in traditional incandescent or fluorescent lights. Another difference between LED light and the traditional lights is that LEDs are not inherently white. White light is a mix of wavelengths in the visible spectrum, but LEDs only emit light in a very narrow range of wavelengths, and are therefore ideal for producing coloured light. LED technology has been available since the 1960's, and today it is widely used to create colourful light in devices such as digital clocks, televisions and traffic lights.

One of the significant advantages with LEDs is the potential for energy savings. According to The Climate Group (2012) LED saves between 50-70 percent in energy consumption and carbon emissions compared to other conventional technologies. Other advantages of using LEDs are the superior control over light colour, intensity and directions as well as the lifespan of 50 000-100 000 hours (two to five times longer than advanced fluorescent light). The most efficient LEDs on the market are producing 148 lumens per watt, but according to The Climate Group (2012) the efficiency will be doubled by 2020, resulting in light 2-2.5 times as efficient as today's best fluorescent lamps. This could increase energy savings with as much as 90 percent. The LED technology does however, according to Gary et al. (2008) and The Climate Group (2012), have some drawbacks, one of which is the price. LEDs are still a more expensive choice of light compared to the traditional lighting technologies, however according to The Climate Group (2012) the price of LED is falling 15-20 percent per year and are expected to have fallen in price by more than 80 percent over the next eight years. Another drawback with the LED technology is the heat conduction. According to Gary et al. (2008) traditional fixtures are designed to radiate the heat generated by incandescent bulbs outwards; however the heat generated by an LED must be conducted through and away from the device using heat sinks.

2.3.2 Single- and multi die LEDs

As previously stated, plants prefer specific wavelengths of light in order to grow and bloom, and with the use of LEDs there are different ways of mixing the light into a customized spectrum for the plants. The light source can consist of a single core with several diodes of different colours that together are mixed into the preferred spectrum (multi die LED). The light source could also consist of separate diodes of different colours that together provide the plants with the required wavelengths (single die LEDs). According to Treurniet and Lammens (2006) the pros of using a multi die LEDs is that the light enables a full spectrum of high quality colours. Because of the close arrangement of the diodes it also provides a smaller footprint with a high flux density and superior colour mixing. This creates better conditions for the plants and provides a more pleasant light for the human eye. There are however some disadvantages of using a multi die LED compared to using single die LEDs. The biggest problem is that the multi die LEDs in general requires a more efficient cooling system since the generated heat is focused in the small footprint of the chip. With single die LEDs the area of the generated heat is distributed over a larger area.

2.3.3 Thermal management

With the ongoing development of the LED technology, thermal management has become a bigger problem. This is because the intensity and power consumption of the LEDs have increased over time which results in a larger generation of heat; this is especially the case of High brightness LEDs. According to Marongiu (2009) the power consumption, lifetime, light output and reliability of LEDs is dependent on how well their temperature can be controlled or dissipated. As mentioned in section 2.3.1 the heat generated by an LED must be dissipated through the back of the component to ensure that the junction temperature (a predictor of the useful life of the LED) is prevented from rising above prescribed levels. According to Cheung et al. (2009) a reduction of the junction temperature of the LED by just ten degrees can add fifty percent to its lifetime and significantly increase the light output. Marongiu (2009) further states that the junction temperature in many cases must be kept relatively constant since fluctuations and shifts may affect the intensity and colour of the LED light. The junction temperature is affected by the power levels of the LED, ambient temperature, materials and external cooling.

According to Cheung et al. (2009) there are currently two options that resolve thermal management issues – passive cooling utilizing heat sinks and active cooling utilizing fans to create forced convection. When comparing the two options Cheung et al. (2009) expresses three elements that should be evaluated when selecting the cooling solution best suited for the lighting design; size, weight and orientation. Regarding size the use of active cooling is almost always preferable, since passive cooling needs a larger area in order to fulfil an equal thermal dissipation. The same goes for the weight; heat sinks are in general constructed of some kind of metal and therefore become relatively heavy. Orientation plays a bigger part when designing passive heat sinks since these must be placed in the correct position of the air flow, which may have a large effect on the design. There is however some drawbacks with using active cooling as well. The price of an active cooling system is in general higher than the price of heat sinks and it is also less reliable since the component can break down. An active system also consumes power and generates a noise factor. The noise level can however be minimized, but this results in a higher cost.

2.3.4 Optics

In order to optimize the light emitted from LEDs the diode is usually equipped with some kind of optics. This optics modifies the output beam of the LED to fit the desired photometric specification. According to Lumileds (2002) there are two primary categories of optics used; diverging optics (which spreads the incoming light) and collimating optics (which gathers the incoming light into a collimated beam). The most common type of diverging optic used is lenses which spread the incoming light into a more divergent beam pattern. The lens can be made out of glass or plastic and the scattering angle is determined by its shape. Collimating optics is usually made up by reflectors, which are typically metalized cavities with a straight or parabolic profile. Designs that utilize collimating optics are, according to Lumileds (2002), more efficient and produce a more uniform illumination than designs using only diverging or other non-collimating optics. They are also more efficient at illuminating non-circular areas.

2.3.5 LED as a source of light for cultivation

According to Massa et al. (2008) LEDs are ideal as supplemental or sole-source lighting systems for crop production. Because of their small size, durability, long operating lifetime, low thermal output, low energy consumption, high photoelectric conversion efficiency and the possibility to adjust light intensity and quality, these light sources have tremendous potential in plant lighting designs. Another advantage of using LEDs as a source of light in areas of cultivation is, according to Yeh and Chung (2009), that LEDs enables the possibility to eliminate excessive wavelengths found within normal white light, which reduces the amount of energy required to power the cultivation lamps. With the technology of LEDs, it is possible to optimize the production as well as influence plant morphology and composition. According to Vänninen et al. (2010) LEDs can, in principle, be configured to produce light more specified for plants and in levels well in excess of sunlight.

In addition to light quality, Massa et al. (2008) also states the importance of light positioning as a factor of crop productivity. The radiation energy intercepted by a surface from a point source is related to the inverse square of the distance between them. Therefore a reduction of the distance will have a large impact on the incident light level. Since LEDs have a lower thermal output compared to other light sources, they can be brought much closer to plant tissues. Therefore, LEDs can be operated at much lower energy levels, while still subjecting the plants to an adequate amount of light.

2.4 Visual ergonomics

Due to the high intensity of light required for cultivation it is important to take into account aspects of visual ergonomics such as glare. According to Bohgard et al. (2008) there are four types of glare to be considered. Direct glare occurs when light from the light source hits the eye uninterrupted. Indirect glare is created by light that is reflected in a surface. Glare can also be caused by large differences in luminance in the field of view, called contrast glare, or by rapid changes between high and low levels of luminance, called adaptation glare.

Another thing to consider in regards to visual ergonomics is the colour contrast. Since different wavelengths of light also have different refractive indices, they will not converge toward the same point on the retina when they refract in the eye. If the wavelength variance is large, such as between red and blue light, it is difficult to focus on each separate colour at the same time which can cause strain in the eye (Bohgard et al., 2008).

2.5 Other indoor cultivation technologies

Similarly to how artificial light is used to replace or supplement sunlight, there are other technologies used to overcome some of the other issues with indoor cultivation.

2.5.1 Hydroponic cultivation

According to Echeverria (2008) hydroponics is an ancient cultivation technique that dates back approximately 2600 years. The technique was widely used in ancient history, but got its breakthrough in modern time as late as in the 1940's. Initially the concept of hydroponics meant working with water, but later the concept has been expanded to all methods of growing plants without using soil. This can, according to Echeverria (2008), be done at three different levels. *Pure hydroponic culture* involves using a "fastening" system for holding the plants in place in a liquid medium (nutrients dissolved in water), without any solid support for the roots. *Hydroponic culture* means growing plants using solid and porous substrates (such as rock, gravel etc.) through which the nutrient laden water circulates. *Semi-hydroponic culture* means using substrates of an organic nature (such as bark or rice chaff etc.), as these material decompose and supply part of the plant's nutrients without damaging the environment. The advantages of these hydroponic techniques are that they can produce a higher yield in less time. As an example Echeverria (2008) states that in a square metre of soil, approximately nine lettuces can be harvested eight weeks after planting. When instead using hydroponics 20-25 lettuces can be harvested after five weeks using the same space. Other benefits with hydroponic cultivation compared to cultivation in soil are that it makes the culture more resistant to pests and that it has lower water consumption. The disadvantages with using hydroponics are for example that it requires some more technical knowledge, since some systems can be rather complex due to the components required. It also creates an environment that stimulates salmonella growth, moulds and other plant pathogens which makes it extremely important to wash the plants before eating them. According to Kessler et al. (2006) hydroponics further requires a constant replenishment of nutrients. In traditional soil-based gardening, the breakdown of organic materials and release of mineral nutrients in the soil provides the plants with fertilizer. In a hydroponic based garden the water has to be mixed with mineral nutrient, in order to fulfil the plant's needs. For an example of a hydroponic system, see Figure 3.

Figure 3. *An example of a hydroponic cultivation system (Image source: Hydroponicist (2013)).*

2.5.2 Heating mats

Electrical heating mats can be utilized to speed up germination and improve the root growth in some plants, see Figure 4. This is due to temperature being one of the factors that determine when a seed goes from a dormant to germinal state (Bewley & Black, 1982). By using a heating mat, the seeds can be germinated even if they are kept in a low temperature environment.

Figure 4. *An example of a heating mat, used to improve root growth (Image source: Growland (2013)).*

2.5.3 Ventilation

Plants consume both oxygen and carbon dioxide and it is therefore important that they are placed in an adequately ventilated environment. For large scale cultivation some form of ventilation system can be required, especially if a heat emitting light source is used in which case the ventilation can also serve as a temperature control. The expulsion of heat might be required for small scale indoor cultivation in some cases but as far as access to oxygen and carbon dioxide is concerned, the ventilation of the room itself should be adequate. Even though ventilation is a necessity for successful plant growth, Davison (1998) says that sudden temperature changes caused by drafts from doors and windows can be harmful for interior plants. Placing plants in areas with too much ventilation should therefore be avoided.

2.6 Result and conclusions from theory

The studied theory implies that the interest in growing your own plants increase as more people move to urban environments which indicates that there might be an interest in a product that facilitates indoor cultivation. As much as 88 percent of the Swedish households cultivate edible plants in some way. Most of the cultivation is done in the garden but indoor cultivation is also occurring to some extent. Two of the big reasons why people cultivate their own plants are the increased interest in the environment and the personal health. The most pronounced interest in gardening is found among women and it increases with age.

There seem to be a need for external help when growing plants indoors, since most plants demands conditions that are not possible to fulfil during all the different seasons. For example, some plants require more light than they can receive during the winter. The light and temperature conditions appear to be the two largest factors of a healthy growth.

Regarding the light conditions LEDs seems to be a good alternative since it is possible to manipulate the light to better fit the plant's absorption spectrum. LEDs are further a good alternative from an environmental point of view. However the theory implies that a big problem with the LEDs is the required heat dissipation, which has to be further investigated.

Since plants require high intensity light, the risk of direct and indirect glare must be considered. The light source of the product should be protected from the user's field of view and any parts within the illuminated area should have a surface with low reflectivity. The risk of glare is especially important to consider in regards to a potential interface. Due to the difficulty of focusing on blue and red light simultaniously it is also important that the product provides a sufficient blending of the light to avoid eye strain.

3. Methods

In this section the different methods used in the project are presented. The information can be used to understand the basis of the work or as a guide on how to carry out the different methods. The methods are grouped according to the phases in which they were conducted; planning, research and analysis, concept development and concept selection. A more detailed description of the execution is presented in each specific section where the method was used.

3.1 Planning

A thorough planning is an essential factor for a successful project. In this project two different planning methods were used to structure the work. A flowchart was created to map the basic phases of the project, and a Gantt chart was used to present the workflow in greater detail.

3.1.1 Flowchart

Flowcharts can be used as a basic way of structuring the different phases of a project in order to get an overview of what has to be performed. Sugai (1997) describes flowcharts as a method of showing the sequential relationship of the major components of a procedure. The method is a powerful communication tool for managing and presenting problem-solving processes. The flowchart is, constructed by different symbols representing terminal, connector, process, decision and flow line (Sugai, 1997).

3.1.2 Gantt chart

A Gantt chart is a type of flow chart which is constructed in the project planning phase (Pinto, 2007). The chart consists of a horizontal axis representing a timeline and a vertical axis where the different phases or tasks of the project are listed. In the horizontal axis the different phases are presented in different bars, where the length of the bar represents the time available for the particular phase or task. According to Ulrich and Eppinger (2008) the Gantt chart does not display the relationships between the different phases and tasks in detail, but it does however show which tasks that have to be completed before the next one can start. It also shows which tasks are possible to do parallel or sequentially. The Gantt chart is useful since it gives a graphical overview of the planning and workload for the entire project.

3.2 Research and analysis

In order to collect the underlying data needed to conduct a product development, a research and analysis phase is necessary. In the project several methods, such as benchmarking, surveys, interviews and focus groups were used to gain knowledge about the market, possible users and more. To analyse the information gained and to create a basis for the further work, methods such as KJ-analysis, personas, target costing and function analysis were used.

3.2.1 Benchmarking and market positioning

According to Ulrich and Eppinger (2008) the product developer should use benchmarking (competitor analysis) to analyse existing products, since these could be a rich source of ideas for the product and the production process design. To analyse and further develop existing products is also a faster and less expensive way than creating completely new solutions. Benchmarking is further useful in the positioning of new products, since it makes it possible to find open slots on the market. When benchmarking, data from existing products is first gathered. The data is then compared with the projects own specifications and goals. The method will give a hint of the possible price range and the different functions that should be included in the new product.

3.2.2 Survey

Surveys are becoming more widely used as a source of information gathering, and according to Porter (2004) it is especially the web-surveys that are increasing. The web-surveys are a cheap way of reaching out to many respondents in a short period of time. Another advantage is that the online survey systems are often able to compile the result in a smart way, making it possible to weigh different answers against each other. According to Kotler et al. (2005) a number of about 100 answers are preferred in order to get sufficient statistical data in a survey.

3.2.3 Interviews

An interview is a conversation between one or two members of the development team and a single interviewee where questions are asked by the interviewer in order to elicit information. When gathering data, it is important to remain neutral and be receptive to the information provided by the interviewee in order to get an honest response. The interviewer should therefore not try to convince the interviewee to answer in any specific way. It is also important to be wary of customer biases related to different technologies or concepts. The interviewer should always probe for the underlying reasons (Ulrich & Eppinger, 2000).

When using interviews to identify user needs it is recommended that at least 10 should be conducted in order to reveal most of the needs. To increase efficiency the interviews can involve the so called lead users. This group consists of users with an active interest in product innovation within the product category in question. They are more likely to experience needs that are latent for the majority of the market and will also have an easier time expressing those needs (Ulrich & Eppinger, 2000).

3.2.4 Focus group

A focus group involves a moderator and several participants from the user group. According to Morgan (1996) a focus group should fulfil the following three criteria: the purpose should be to collect data, the source of the data should be the interactive discussion within the group and the moderator should have an active role in guiding the discussion in a way that enables the collection of data.

The appropriate size of a focus group can vary depending on the topic. If the participants have a high degree of interest in what is being discussed, a smaller group gives each participant more room to express their view. However, for topics that result in a low level of involvement from the participants, a larger group contains a wider set of possible responses (Morgan, 1996).

The strength of the focus group is the interaction between the participants where they both pose questions and provide explanations to each other. The group interaction also makes it possible to compare experiences and evaluate the extent and nature of agreement or disagreement within the group. However, the participants could also potentially influence each other in ways that limit the responses (Morgan, 1996).

3.2.5 KJ-analysis

KJ-analysis is a method of data processing with the goal of organizing field data heuristically (Kawakita, 1973). The method consists of four steps: label making, label grouping, chart-making and explanation. Thoughts and concepts unearthed during the gathering of data are written down on separate note cards. The note cards are then intuitively sorted in groups consisting of related thoughts and concepts. When all note cards are sorted the emerging groups should be labelled and possibly sorted into bigger families if overarching relations can be identified. In order to visualize the connection between different labels, groups and families they can be organized in a chart where for example cause and effect relations, interdependence and contradictions are displayed. The final step to the KJ-analysis is to explain the chart in a way that reduces the complexity of the gathered data to a manageable form while expressing the interrelationships of all the different elements (Scupin, 1997).

3.2.6 Personas

Personas can be used as a way visualizing the different target groups found in the data collection. By creating a made up person, representing the characteristics of a specific customer audience, the designer can focus on creating a product fitted for only one person rather than a large group. Pruitt and Grudin (2003) describes personas as fully fleshed out fictional persons, based on actual data, that are given specific names, ages, genders, families, occupations, hobbies and so on. The use of personas is a way of better understanding the different customer groups; however their greatest value is, according to Pruitt and Grudin (2003), in providing a shared basis for communication. As Allen Cooper (the man who coined the term persona) said - "It's easy to explain and justify design decisions when they're based on Persona goals."

3.2.7 Target costing

Target costing is described by Cooper and Slagmulder (1999) as a technique to strategically handle a company's future profit. By defining the entire lifecycle cost of the future product, with all the steps from manufacturing to the sale of the product, the target cost can be decided. The method of target costing makes the price into a cost of the product development and not a result of it. Ax et al. (2008) describes the process of target costing as follows: by creating an estimation of the retail price (with information from the customer needs, the company's sales and earnings targets, the product lifecycle, existing product's price and product quality and functions) and then subtract it with all the different profit margins, the target cost is decided upon. The goal is then to design the product with regards of the customer needs, technical properties, material and manufacturing possibilities to the intended target cost.

3.2.8 Function analysis

The function analysis is a method that provides an overview of the products different functions. The list of functions can be used to see which functions that are necessary in order to fulfil the customer requirements and to meet the intended target cost. Österlin (2007) argue that every product has a so called main function, a couple of sub-functions and a lot of support functions. The main function is dependent on the sub-functions, while the support functions are not of as high importance. Österlin (2007) suggests that a function analysis is conducted in the product development process to get an overview of which functions that are required in order to fulfil the main function of the product. The functions could even be categorized to the different states of the products lifecycle, such as during manufacturing, transport, marketing, use and recycling.

3.3 Concept development

With the pre investigation conducted, the next step of the process is to generate different concepts. This was done in the idea generation phase where different creativity methods such as image boards, brainstorming, morphological matrix, brainwriting and SCAMPER were used. The ideas were evaluated using Pugh's concept evaluation matrix, in order to select the ones to create concepts out of.

3.3.1 Image boards

Garner and McDonagh-Philip (2001) describes image boards as assemblages of images which are used to assist analysis, creativity and idea development in design activity. Image boards do usually consist of a collection found or created images fixed to a board. The collection of images aims to represent emotion, feelings or mood evoked by the original design brief, or the brief as it develops.

3.3.2 Brainstorming

Brainstorming is by Cross (2008) described as the most famous and frequently used creativity method. The method is used to generate a large amount of ideas, where only a few of the ideas are good enough to be followed up upon. The method is conducted verbally with questions like "How can we improve X?". In order for a brainstorming session to be as effective as possible the group should, according to Cross (2008), create a large amount of brief and concise ideas. These ideas should then be combined in order to find optimized concepts. An important rule when brainstorming is that criticism is totally forbidden, since there should be no limits to the participant's ideas.

3.3.3 Morphological matrix

The morphological matrix is, according to Cross (2008), used when several functions and part solutions of the product has been generated. The matrix is used as a cut and paste tool, where several different concept combinations are created from the features of the product. The method gives the product developer directives of the product design, since different concepts with similar features will be generated. According to Cross (2008) a morphological matrix is constructed in four steps:

1. Create a matrix and list the features and func tions of the product. Keep the number of features down, since the method easily gets complicated.
2. Find several possible part solutions for every feature.
3. Draw and/or write the part solutions into the matrix.
4. Draw combinations among the part solutions in order to create new concepts.

3.3.4 Brainwriting

Brainwriting is, according to Van Gundy (1984), a silent version of brainstorming based on sketching. The participants of the session each sketches or write down a decided number of ideas during time pressure and when the time has run out the sketches are sent to the person sitting to the left. This person takes inspiration from the previous sketches and repeats the procedure. The method is used to generate many ideas in a short period of time.

3.3.5 SCAMPER

SCAMPER is according to Johannesson et al. (2004) a method to enhance the brainstorming based on Osborne's idea spurs. The method is to be used when the idea generation group starts to lose their creativity. The method can provide new energy by giving the participants new ways of looking at the problems. The original method of Osborne's idea spurring consists of 73 spurring questions. However the simplified version, called SCAMPER consists of only seven questions, representing the seven letters of the name. The questions are meant to give the group other ways to approach the problem. According to Glenn (1997) SCAMPER stands for:

> *Substitute:* Can components, functions or the entire object be substituted?
>
> *Combine:* Can the object be combined with any extra function or component?
>
> *Adapt:* Can the object be adapted to another goal or purpose?
>
> *Modify, magnify or minify:* Can the object be modified, magnified or minified?
>
> *Put to other uses:* Can the object be used for another purpose?
>
> *Eliminate:* Can a function or component be eliminated from the object?
>
> *Reverse or rearrange:* Is it possible to reverse or rearrange components?

3.3.6 Pugh's concept selection matrix

When a selection of ideas has been developed, some form of concept screening is used to determine the most promising one. In Pugh's concept selection, the ideas or concepts are evaluated against a list of the most important selection criteria. One concepts is selected as the reference and the others are then rated "minus", "zero" or "plus" depending on if they fulfil the criteria to a lesser, equal or higher extent than the reference (Ulrich & Eppinger, 2000).

The criteria are selected from the identified user needs as well as needs related to manufacturing and other aspects that affect the concepts. The method favour nonspecific criteria since the concepts are not fully developed at this stage. If the criteria are given equal weight in the matrix it is also important to select criteria that are equally important and offer distinction between the different concepts (Ulrich & Eppinger, 2000).

3.4 Concept selection

When different concepts have been created, an evaluation and selection phase has to be conducted in order to decide on which concept to move forward with. The concepts were presented for the stakeholders and afterwards jointly evaluated. To further analyse the strengths and weaknesses of the concepts a pros and cons list was constructed based on the previous feedback. To further identify potential problems that could affect the final product and which concepts that would best avoid them a Failure Modes and Effects Analysis was conducted.

3.4.1 Stakeholder feedback

In the case where the project is performed in collaboration with a company it is important to receive the company's feedback and impressions before making big decisions. This can be done in many ways, as for example in open discussions. The stakeholders can also be asked to fill out an evaluation survey when decisions need to made, as for example in the concept selection stage.

3.4.2 Pros and cons list

A pros and cons list can be created in order to analyse the strengths and weaknesses of different concepts. The list can be constructed in different ways. A simple way is to create a matrix with the different concepts in a column to the left, with a pros column and a cons column beside it. The method simplifies the way of evaluating similarities and differences between concepts. It further provides a good overview of the amount of pros and cons which could simplify the concept selection.

3.4.3 Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) is by Chin et al. (2009) described as a method for analysing and eliminating possible product problems and accidents that may occur. With help from Risk Priority Numbers (RPN) a risk prioritization can be made. There are three different risk factors that have to be weighted in order to receive a RPN-value; these are occurrence, severity of a failure and ability to detect the failure before it reaches the customer. The different risk factors receive a value between one and ten. These values are then multiplied with each other in order to gain the RPN-value. The problem or failure with the highest RPN-value is considered to be the highest priority. The FMEA gives a clear estimation of which improvements that should be carried out before production (Chin et al., 2009).

4. Research and analysis

This section describes the research and analysis of the market for the intended product. A data collection section is first presented where different methods were used to gain knowledge about the market and the possible target group of the product. This information is then evaluated by different methods to establish a basis for the further work. The different procedures are presented in the order in which they were conducted and a section on the final result and the conclusions drawn from it can be found at the end of the chapter.

4.1 Methods used

The research and analysis started off with different methods for data collection. Benchmarking was used to compare existing products with regards to technical functions and price. This information was then used to create a market positioning matrix with the intent of finding an opening for the new product. A web survey was then used to gather information regarding peoples interest in cultivation and their perspective on indoor cultivation.

In order to gather information from expert individuals, such as vendors with knowledge of the market and enthusiasts with extensive knowledge and experience in cultivation, several interviews have been conducted during the project. The interviews were semi-structured with query templates to guide the dialogue. As a complement to the survey and interviews a focus group was conducted. The method focused on gaining information from users that had been hard to reach out to with the previous information gathering methods.

When sorting the data obtained from the previous methods, a KJ-analysis was utilised. The method enabled the creation of a unified picture that facilitated the creation of the specification of requirements. Different personas were then created to better define, understand and differentiate the customer groups found in the research phase.

In order to create a guideline of the budget for the project a target cost was conducted. The method was based on the information previously gathered, such as the price requested by the customers, the price of similar products and a rough estimation of the price of components. The target price was calculated backwards, with all the different profit margins, into a target cost.

A function analysis was subsequently created to get an overview of the different functions, relevant for each lifecycle phase that might affect the development. Some generally desirable functions were identified and the selection was compared to the specification of requirements which resulted in some additional product specific functions being added.

4.2 Market analysis

There is a wide range of products available on the market, designed to overcome the obstacles of growing plants indoor. These include various lighting solutions, ventilation and water systems as well as nutrients and containers.

Cultivation focused LED lights are sold in a wide variety of sizes, from smaller units intended for regular lamp sockets to large panels with hundreds of diodes, see Figure 5. The light is often created by a mix of red and blue diodes but some incorporate other colours as well. Smaller variants usually only need passive cooling while the larger units often utilize cooling fans. The price is determined by the number and quality of diodes and the total wattage and fall in the range of a couple of hundred to several thousand SEK.

Figure 5. *Two different cultivation lighting solutions utilizing LED lights (Image source from left to right: Eco solutions (2013); Trade Korea (2013)).*

There is also a category of products that combine different functions in a complete package, most commonly in the form of a hydroponic system with integrated fluorescent or LED lighting. These products are generally marketed as systems for growing herbs or vegetables for the kitchen. The price varies between about 700 to 3000 SEK depending mainly on size and functions. The more advanced systems incorporate features such as adjustable heights of the lamps, timers and automated watering and nutrient distribution. The most expensive units utilize LED lighting of different wavelengths with adjustable intensity.

A selection of the identified products were inserted into a matrix mapping the relation between price and features, see Figure 6. The result shows that each quadrant contained at least one product. The first quadrant contain a top of the line product from Parus which utilize adjustable LED light of different wavelengths and provide a large cultivation area that can be used for either soil based or hydroponic cultivation. The products found in the second quadrant either provide a large cultivation area or have a higher quality of finish than the other products. This is also where many of the high quality cultivation lamps are found. In the third quadrant are the simplest solutions that only offer light and in some cases hydroponic cultivation. The fourth quadrant mainly contain products from AeroGarden which use the same type of light as the basic products but have added control panels which communicate watering and nutrition needs and in case of the most expensive unit, timer-settings and step-by-step cultivation instructions.

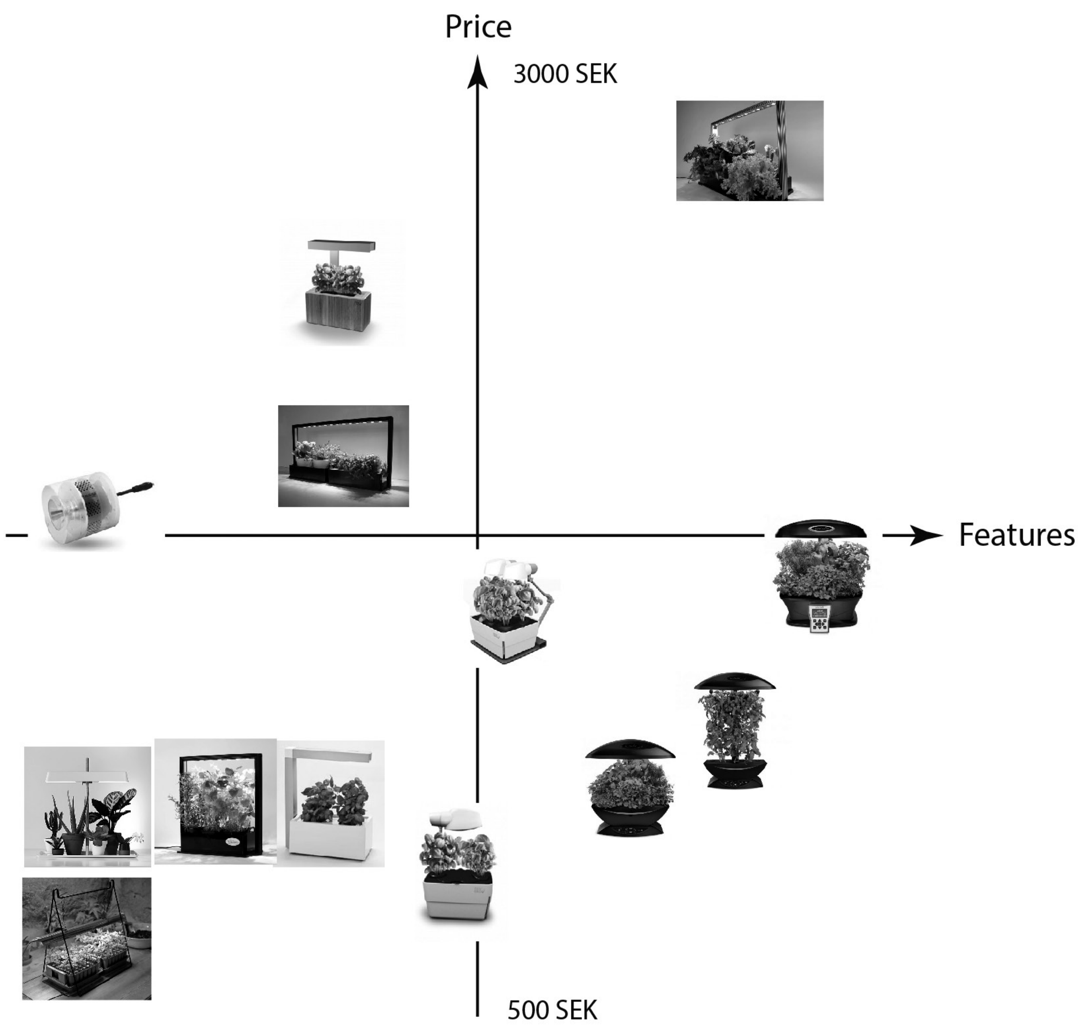


Figure 6. *Matrix mapping of existing products (Image sources from left to right quadrant one: Plant Factory (1) (2013) quadrant two: Kessil (2013); Plant Factory (2) (2013); Zengrow (2013) quadrant three: Hasselfors Garden (2013); Årets Trädgård (2013); Plant Factory (3) (2013); Wexthuset (2013); Hydrogarden (1) (2013) quadrant four: Hydrogarden (2) (2013); Aerogarden (1) (2013); Aerogarden (2) (2013); Aerogarden (3) (2013)).*

4.3 Online survey

In order to get an initial understanding of what potential users of the product consider important and problematic in regards to indoor cultivation, an online survey was constructed and spread through various channels. The focus was on Swedish gardening forums, such as odla.nu, tradgardsamatorerna.nu and alltomtradgard.se, where the interest in cultivation would be the highest. The gardening sections of forums dedicated to family life and home owning such as familjeliv.se and husohem.se was also targeted. The survey was submitted to the sections for general gardening discussion since these are the most frequented. With the submission of the questionnaire, the participants were also invited to a general discussion regarding indoor gardening in the forum threads. However, no substantial discussion was achieved.

The questionnaire used during the survey was designed to provide a general view of the participants and their attitude towards cultivation, both outdoors and indoors, see Appendix 1. Some specific questions regarding a potential product were also included.

4.4 Interviews with enthusiasts

Most of the of participants in the online survey described gardening as a major interest. In order to get a deeper understanding of this user group a series of five telephone interviews were conducted with members of the non-profit organization Förbundet organisk-biologisk odling (FOBO). The participants were between 33 to 71 years old and consisted of three males and two females. A query template with questions was used as a guide, see Appendix 2. The intent was to elicit explanations and more extensive reasoning concerning some of the answers given in the online survey. As such, the first part of the interview included general questions about the participant's relation to cultivation while the second part was focused on difficulties and practises concerning indoor cultivation. The final part included questions regarding technical aids and what aspects would be desirable in a product meant to facilitate indoor cultivation. In case the participant was not engaged in indoor cultivation, a separate selection of questions was posed concerning their reasons for abstaining.

4.5 Interviews with vendors

In order to get a deeper understanding of the possible target audience and different trends in cultivation, a couple of interviews were conducted with vendors of plants and cultivation equipment. Personal interviews were conducted with shop assistants from Plantagen and Blomsterlandet, which are two of the biggest chains of gardening stores in Sweden. The questions asked pertained mostly to what is being sold and what recommendations they give to customers, see Appendix 3. Further, a telephone interview was conducted with a shop assistant at Hydrogarden, a store specialized in hydroponic cultivation and advanced indoor cultivation equipment. Similar questions were posed but with a focus on technical equipment, see Appendix 4. Specific questions regarding plant lighting and hydroponic cultivation were also included.

4.6 Focus group

The result from the survey showed that the large majority of the respondents were over 30 years old. Only 11 out of the 64 respondents were in the age 20 to 29. This could be explained with the statistics provided by Björkman (2012) which shows that people in the ages 20 to 29 does not have as large of an interest in gardening as the ones in the older age groups, and may therefore less frequently visit gardening forums. However according to the interviews with vendors of gardening equipment the interest for plants and indoor cultivation is increasing among younger people, and therefore this age group could still be a possible target group for the product. Since young people are more likely to live in apartments, they are also more likely to not have access to any extensive gardening areas and are therefore, if they have an interest in gardening, forced to carry out their gardening indoors or at allotment gardens. Since it seemed beneficial for the project to get this user group's perspective, and to find out how to reach out to this group of customers, a focus group consisting of seven participants between 23 to 29 years old was interviewed. The arrangement of the focus group can be found in Appendix 5.

4.7 Result from interviews and survey

The interviews and survey resulted in a large amount of gathered information on a wide variety of topics. In this section the information is summarized according to those topics and complemented by the findings from literature.

4.7.1 Attitudes toward cultivation

The attitudes toward cultivation seem to follow the data presented by Björkman (2012) which describes a steady increase in interest with increased age. Among the respondents to the online survey, 78 percent expressed having a major or considerable interest in gardening. Since the median respondent fall in the age span of 50 to 59 years, the result seems to conform to the findings of Björkman (2012). However, it should be noted that the high degree of interest is affected by the fact that the survey was mostly distributed to gardening related forums. The interest in gardening as described by the participants in the focus group was almost non-existent before the interview which further supports Björkman's (2012) findings.

The main reasons for engaging in cultivation according to the survey respondents are the beauty of the plants, it being a hobby and the superior taste of home grown vegetables. The gardening enthusiasts expanded on these responses by describing the creative outlet and relaxation it provides and how it can be a means to get in contact with nature and life. The environmental benefits were also highlighted. In the survey of the Swedish people's attitudes toward cultivation where different statements were presented, the most agreed upon statements were the superior taste of home grown vegetables as well as the environmental and psychological benefits of gardening (Björkman, 2012). None of the participants in the focus group engage in cultivation which was explained by a lack of interest, time and knowledge. They mostly associate cultivation with edible crops and old people but some of them think it might become more popular among younger people as well. This sentiment is shared by the vendors who experience an increased interest in cultivation, especially among city-living young adults.

4.7.2 Attitudes toward indoor cultivation

Some form of indoor cultivation is performed by three quarters of the survey respondents. Ornamental plants are most commonly grown with herbs having half as many responses and vegetables slightly less than that. Another common practice is the pre-cultivation of plants that are later replanted in the garden. This was the most frequently given response during the interviews with the gardening enthusiasts. To a large extent they seem to view indoor cultivation as a means to get healthier plants and to get a head start on the gardening season.

When asked why they do not cultivate anything indoors, the respondents in the survey cited a lack of interest and space as well as the fact that they cultivate at other locations as the biggest reasons. Some mentioned that they were unable to achieve the right conditions for plants to grow. While the focus group participants do not conduct any indoor cultivation themselves, they considered the lack of plant options and the commitment required to be the biggest drawbacks.

According to the gardening enthusiasts the most critical aspects of indoor cultivation is light and temperature, which corresponds to the findings of the theory research. The light from a window is often not strong enough for cultivation but the plants can still dry out in the heat. It can also be too cold for the plants if there is a downdraught. Issues regarding watering and moisture were also mentioned, especially during the winter season. These difficulties were recognized by the survey respondents as well and a majority claimed to have had related issues with their indoor cultures. Another commonly mentioned problem is pests such as spider mites, aphids and fruit flies.

4.7.3 Environment

The gardening enthusiasts generally considered the environmental benefits to be an important motivator for cultivating their own crops. It should be noted however, that FOBO is an ecologically focused organization so the interest in this aspect might not be representative for all people involved in gardening. This is supported by the fact that environmental benefits were only the fourth biggest motivator for cultivation among the survey respondents. According to Björkman (2012) there are no indications that garden owners are more environmentally conscious than the population at large.

4.7.4 Attitudes toward plant lights and other technical aids

A majority of the survey respondents as well as the gardening enthusiasts have used some form of plant lighting, most commonly fluorescent lamps. Surprisingly, the amount of survey respondents who answered in the affirmative when asked if they had used any technical aids for their indoor cultivation were less than the amount who claimed to have used plant lighting. However, the vast majority of respondents who confirmed their use of technical aids mentioned plant lighting which indicated that it is by far the most commonly used supplement. Among the 24 survey respondents who have not used plant lighting only 11 said they would also not consider doing so, mostly due to not perceiving a need for it or due to the associated cost. While having no personal experience of plant lighting, the participants in the focus group were open to the idea. They considered it a basic requirement of a product for indoor cultivation and some suggested it could either be made aesthetically pleasing or hidden from view in order to not disturb the user.

Regarding the purpose of a product for indoor cultivation, the gardening enthusiasts generally thought it should be dependable and relieve the user of some of the work required. The survey respondents answered that its main purposes should be to facilitate pre-cultivation and enable cultivation in insufficient light. Optimizing the cultivation of both edible and ornamental plants as well as enabling the cultivation of especially demanding plants was also considered as somewhat important properties. The participants in the focus group also premiered the ability of a product to relieve them of responsibility and reduce the knowledge threshold to successful cultivation.

In general, the perceived main purposes of a product for indoor cultivation can be described as decreasing workload and expanding possibilities for the user.

4.7.5 Purpose and functionality of a new product

For the participants in the focus group the most important properties of the product would be that it does most of the work itself, but also that it has an appealing design and performs its functions well. The environmental aspects of the product do not seem as important, which is motivated by the fact that cultivation in itself is regarded as environmentally friendly. When the gardening enthusiasts were asked about the new product, the automation of different functions was the most common suggestion. They claimed that it is important that the product can be trusted to take care of the plants and that it can function independently to some extent. Energy efficiency and durability was also considered important, mostly for environmental benefit.

According to the survey respondents, the most important characteristics of a new product for indoor cultivation is a low operating cost, environmental friendliness and the ability to increase the yield. About two thirds of the respondents were interested in a self-watering function while one third wanted the product to give them information about the condition of the plants. Slightly fewer expressed interest in having an integrated cultivation area and only one fifth of the respondents wished for the possibility of hydroponic cultivation. Commonly suggested functions included the incorporation of plant lighting, the possibility of growing differently sized plants, temperature regulation and extensive placement options.

The gardening enthusiasts showed little interest in being able to manually adjust light spectrums and share with others. It was perceived as unnecessarily advanced without any definitive benefits. The participants in the focus group on the other hand, were more positive to the idea and considered it to be in line with general trends in society. They also mentioned the possibility of controlling the device and receiving information about the conditions of the plants directly via their smartphones.

4.7.6 Pricing

When asked about the pricing of a product that would fulfil all their indoor cultivation demands the majority of the survey respondents set the desirable price under 1000 SEK. The gardening enthusiasts generally claimed to be prepared to pay a couple of thousand SEK if the product was of high quality. The focus group participants did not put down any specific price points but argued that someone interested in cultivation or the possibility of having access to fresh herbs would probably be prepared to pay quite a lot.

4.8 Customer requirements

In order to compile, structure and identify connections, a KJ-analysis (see section 3.2.5) was conducted on the information gathered during the background research. The analysis was carried out by gathering and writing down all the comments from the survey, interviews and focus group and organizing them in groups according to themes, see Figure 7. The purpose was to get a better overview of the ideas, opinions and demands from the users and thereby make it easier to rate their significance.

Based on the result of the KJ-analysis, a specification of requirements was created. The different comments, as well as information gathered from the literature study, were translated into requirements and wishes. The requirements were then rated on a scale from one to five in order to find the most essential ones to fulfil. The requirements that were most frequently expressed and those that were subjectively assessed as important were rated with a high number, while the less commonly found and less important requirements were rated with a low number. The specification of requirements can be found in Appendix 6.

The different ideas, opinions and demands gathered in the background research resulted in 70 requirements divided into ten different categories; technical, functional, durability, aesthetic, ergonomic, semantic, manufacture and transportation, environmental and safety requirements as well as desirables.

Most of the requirements are related to the technology of the product. This is explained by the necessity of the technology in order for the product to be able to fulfil the most basic requirements. The requirements with the highest rating in the technical group are mostly related to the light source and the possibility of growing different plants regardless of season and external lighting. Among the functional requirements the highest ratings are given to those where manual labour is involved as well as to those related to the adjustment of the light settings. The durability requirements got overall high ratings. This is due to the long lifespan of the LED's, and the requirement that the product at large should not break down before the separate technical components. When it comes to the environmental requirements the main goal seems to be to reduce the amount of materials and components in the product. The aesthetical requirements are rated in relation to the products currently on the market. The final product should be rated as more appealing than 50 percent of the products evaluate during the focus group interview. The ergonomic requirements rated with the highest numbers are connected to the disturbing noise and light that the product could possibly emit. It is also important that the product should be easy to move and therefore possess a low weight. The semantic requirements are connected to the expression of the product and the interpretation of the different functions. That the product should be possible to manufacture by existing production techniques is the requirement rated highest among the ones associated with manufacture and transportation. All of the different safety requirements are rated with the highest possible number, since injuries should be counteracted at all time. The last group consisted of different desirables rather than requirements and therefore none of them receive a high number in the rating.

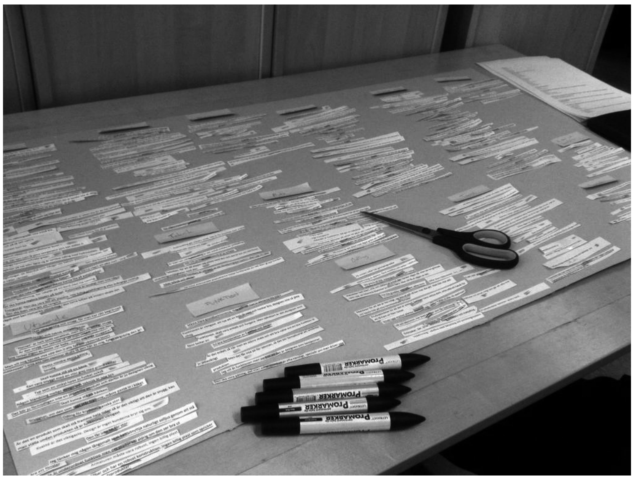


Figure 7. *The information gathered in the background research was organized using a KJ-analysis.*

4.9 Personas

From the information gathering methods there emerged some different possible customer groups. In order to better separate and understand the groups different problems and needs, three personas were created, representing the three different possible target groups.

4.9.1 Persona number 1

Anna grew up in a rural area of Sweden where she has remained for most of her life. At 67 she is recently retired, living with her husband and their cats in a house with a big garden. Anna inherited her interest in cultivation from her father and the lush garden surrounding her house is now her greatest pride. To Anna, gardening is not only a way of getting fresh vegetables on the table but also an opportunity to connect with nature and experience true peace of mind. The environmental aspects have become increasingly important for her and she strives to keep her garden healthy without resorting to pesticides and artificial nutrition.

Living in Sweden means that Anna's garden is dormant from November to March and when spring comes around she cannot wait to get the plants going. She does a lot of pre-cultivation but the feeling of growing indoors is just not the same. A couple of years ago Anna bought some fluorescent lights that would allow her to get a head start on the season but they do not seem to have done a lot of good. She is somewhat hesitant to use the most modern technologies, preferring instead to trust her instincts and substantial hands on experience.

Keywords:

- Enthusiast
- Proud of the garden
- Hesitant towards technology
- Values the environment
- Cultivation is a source of enjoyment and pride
- Home grown plants is a substantial part of the food supply

4.9.2 Persona number 2

Jessica is 38 years old real estate agent. She lives with her husband and two young children in a row house with a small garden in the suburbs. The family enjoys cooking and has just finished renovating the kitchen. Jessica likes to take on new projects and is an avid sourdough baker. Recently her interest has turned towards gardening but she feels she has neither the time nor the space to get anything going outside. Instead, a collection of chili plants on the windowsill and a small herb garden will have to make due.

Jessica and her husband enjoys having friends over for dinner and Jessica will always try to find a way to incorporate the crop of the home grown plants in the recipes. While the social aspect and the luxurious feeling of having your own fresh herbs and vegetables is important, Jessica also values being aware of what she and her family eat. As such she would like to expand her indoor garden but the chili plants take up the best spot in the window and they are already struggling to stay alive with the lack of sunlight, so for now, growing additional plants seem futile.

Keywords:

- Hobbyist
- Proud of the home
- Open to new technology
- Values everyday luxury
- Cultivation is healthy
- Home grown plants are used for seasoning and as a novelty

4.9.3 Persona number 3

Jesper is a 27 year old single man, who lives by himself in a small two room apartment in the centre of the city of Gothenburg. Since graduating from college, Jesper has been working as a software programmer for the last eight months. His main interests are exercising and hanging out with friends. He is also interested in technology and is usually the first in his circle of friends to buy new trendy products.

Jesper enjoys a healthy lifestyle and tries to eat vegetables and fruit on a daily basis. He has become interested in urban sustainability due to an article he read in a magazine and has made attempts to grow his own vegetables in the apartment. However since Jesper's mind is most of the time caught up on other things from his busy life, he often forgets to water his plants, and they always end up withered. He also thinks that his apartment does not provide the plants with enough sunlight, and that these two factors are the reason that his attempts continues to fail.

Keywords:

- Trendsetter
- Enjoys life in the city
- Interest in technology
- Values a healthy lifestyle
- Cultivation is trendy
- Home grown plants are healthy, sustainable and cheap

4.10 Target costing

From the information gathered in the research phase, a desired maximum price for the product was decided upon, of circa 2500 SEK. The decided price is a combination of the low price requested by the customers, the price of similar products on the market and a rough estimation of the price of components. Since the technology used by Heliospectra is quite advanced and the components of high quality, it was noted that it would be hard to reach a price as low as the cheapest products on the market. The focus is instead on developing a product with Heliospectra's advanced technology to a reasonable price.

In order to develop a product corresponding to the price, all of the different steps from production to sale have to be considered. This was done by using the method of target costing, see section 3.2.7. By defining the entire lifecycle cost of the future product, the method provided a final target cost, which is the maximum price of components and material for the product.

The target cost calculation is based on the different profit margins (from the manufacturer, Heliospectra, distributor and retailer). Today Heliospectra distribute the majority of their own products and it is suggested that the same procedure also applies for the new product, since this will result in a possibility of generating a larger profit. Depending on the volume of sales, the self managed distribution may become too much work for the company and they may therefore look to find external distributors. The company profit, in the

Calculation	Cost elements	%-factor	Price (SEK)
	Retail price		2500
-	VAT	25%	
-	Retailer's profit margin	X%	
=	Price to retailer		
-	Heliospectra's profit margin	X%	
=	Price to Helio-spectra		
-	Manufacturer's profit margin	X%	
=	Target cost		776

Table 1. *The target costing calculated with Swedish VAT.*

Calculation	Cost elements	%-factor	Price (SEK)
	Retail price		2500
-	VAT	15%	
-	Retailer's profit margin	X%	
=	Price to retailer		
-	Heliospectra's profit margin	X%	
=	Price to Helio-spectra		
-	Manufacturer's profit margin	X%	
=	Target cost		911

Table 2. *The target costing calculated with European VAT.*

calculation, is based on a mean value of a desired profit from Heliospectra. It is further suggested that the product should be sold via a retailer, since the product will reach out to a larger mass of people this way. The retailer profit margin is a calculated estimation of the average margins for technical products. The same goes for the manufacturer's profit margin. There will also occur some shipping costs and possibly custom costs, but these are considered quite small and therefore not included in the calculation.

The target costing is calculated both with Swedish and EU-VAT, since the goal is to make the sale international. The Swedish-VAT is 25 percent, while the lowest EU-VAT is 15 percent (Skatteverket, 2013). In the tables (Table 1 and 2) some of the costs and profits are added together, since some margins may not be presented.

As seen in the tables, the target cost with the Swedish-VAT is the lowest one, and therefore this is also the definite target cost since it provides the smallest budget to work with.

4.11 Function analysis

In order to identify which functions that will affect the cost of the product and which are required to fulfil the users' needs, a function analysis was conducted based on the information gathered in the research phase. The functions were separated into a main function, sub functions and support functions. The support functions were then divided into five different stages of the products lifecycle; manufacturing, transportation, marketing/sale, use and recycling/demolition. This way, all of the different functions during the product's lifetime were taken into consideration. The function analysis can be seen in Appendix 7.

4.12 Result and conclusions from Research and Analysis

Three user groups were identified during the research phase. While all of them could potentially be interested in a product for indoor cultivation, it was decided that the older enthusiast group would not be focused on during development. The reason for this is that their interest in indoor cultivation seems to be mostly as an transition towards early season outdoor gardening. They seem to value functionality above all else and request a product optimized for pre-cultivation. If the product is tailored to this user group it risks being niched towards a smaller market where the benefits of Heliospectra's technology is not as noticeable. On the other hand, if the product is made more general it might still appeal to the enthusiasts as long as the included functions are not perceived as superfluous.

The two remaining user groups put more similar demands on the product even if their motivation for using it might be slightly different. A dependable product that does not require specialised knowledge or extensive interaction appears to be desired. Furthermore, the gathered information indicates that it should be focused towards the cultivation of edible plants. While cultivation of ornamental plants is common, few express a need for an assisting product in this category.

As for the technology used there are few obvious choices. A fundamental requirement of the product is that it should utilize LEDs but as shown there are many different variants and applications. In general the product should use a less complex lighting solution than Heliospectra's current product line in order to not overwhelm inexperienced users or become too expensive. At the same time, it is desirable to make use of the company's knowledge in light spectrums for cultivation and put out a product that offers more in this aspect than the ones currently available on the market.

While hydroponic cultivation have many advantages and is incorporated in many indoor cultivation products, the interviews and survey study show no significant interest in the technology from users. Since a lot of people are also unfamiliar with the technology, incorporating it in a product might add unnecessary complexity and alienate potential users. The use of hydroponics in the product would also lead to Heliospectra being forced to manufacture hydroponic systems and all the accessories that comes along with it. This would also make their product seem less focused on the actual grow light which is the company's speciality.

The result from the function analysis suggests that the product does not demand many functions in order to fulfil its main purpose (enabling the cultivation of plants). There are however numerous of support functions that could be used to improve the product, but this will increase the final price. It will therefore be impossible to fulfil all of the support functions while at the same time provide a competitive product price.

The desired maximum target price of the future product is circa 2500 SEK. The price is as mentioned a combination of the low price requested by the customers, the price of similar products and a rough estimation of the price of components. It should be mentioned that the requested price from the customers in the survey may not be of high validity. This is since it is hard for the respondents to make an estimation of how much they are willing to pay for a product that is not yet developed. Without the knowledge of the product's functionality and benefits it is hard to evaluate the price compared to the effect of the product. It is even harder for the respondents with no experience of similar products and their prices, and since LED is a quite new technology in the area of cultivation few people may know of its big advantages. These aspects suggest that the requested price should not be followed to the letter. The answers do however provide a vague estimation of the requested price, and it could be argued that the respondents do not want a luxurious product, but rather a product with high functionality.

When evaluating the market analysis it seems as there exists a open slot for more advanced technological products, which corresponds to the opportunity to develop a product with Heliospectra's technology. The price of 2500 SEK would make the intended product a little more expensive than the majority of existing products, as seen in Figure 8. It is however thought that the proposed target groups are prepared to pay a little more for an technologically advanced solution, which simplifies and improves the cultivation process significantly.

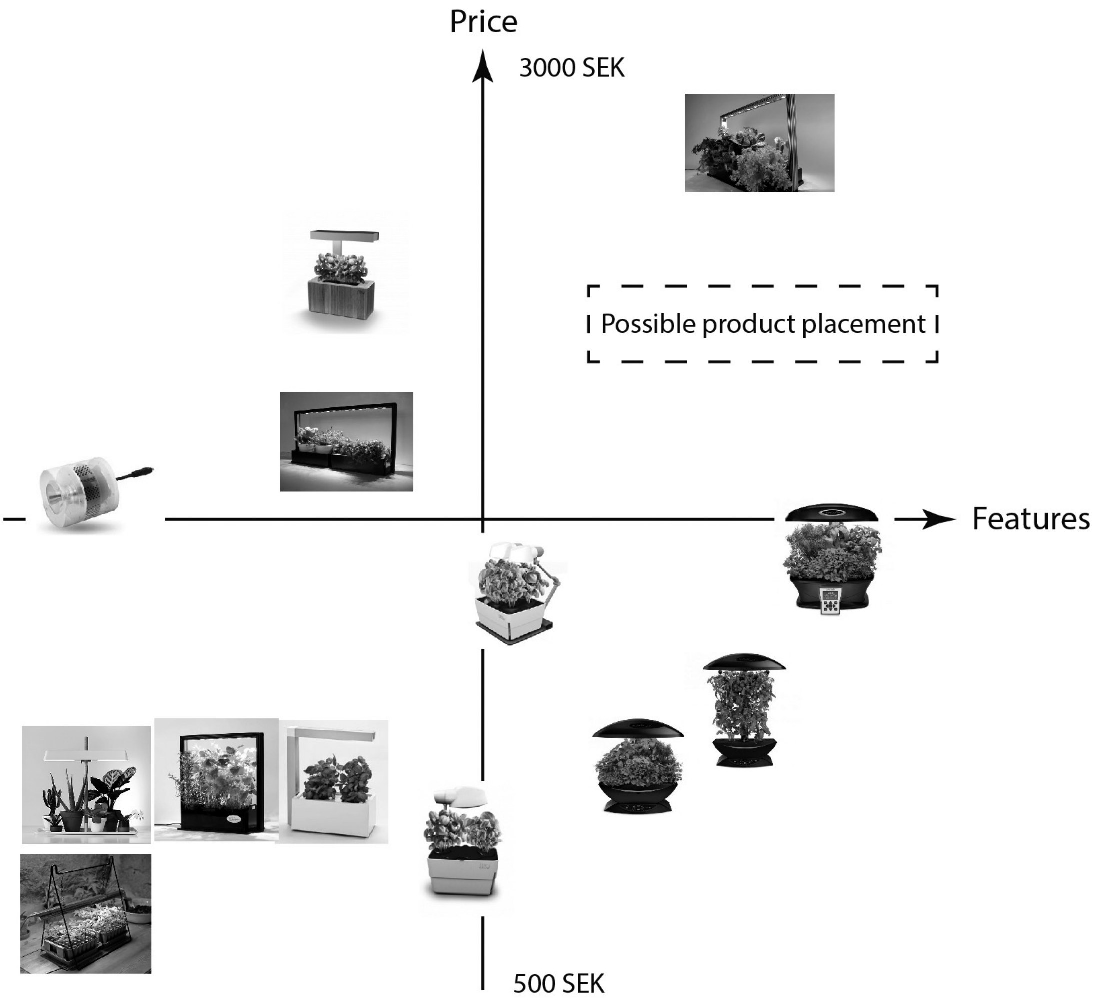


Figure 8. *Possible market positioning.*

5. Concept development

This chapter describes how the information gathered in the research phase was translated into different concepts using a variety of idea generation methods. After categorising and evaluating the results, a selection of seven concepts was chosen for further consideration.

5.1 Methods used

At the beginning of the concept development phase different image boards were created. The image boards were used to gain inspiration, both regarding expression and moods, throughout the entire idea generation phase.

In order to get the creativity going, a brainstorming session was conducted where different ideas and thoughts generated from the research and analysis phase were discussed. As a tool of developing the first actual concepts, the method morphological matrix was used, by trying out different combinations of product functions and requirements. A brainwriting session was also conducted, with the intent to create a large amount of ideas in a short period of time.

When the ideas started to run out, the method SCAMPER was used to improve the ideas that already had been developed. These ideas were then evaluated with the method Pugh's concept selection matrix. The method provided a guideline of which ideas to continue with, when creating more specific concepts.

5.2 Image boards

To inspire the idea generation, a couple of image boards (see section 3.3.1) were created. Some of the created image boards represented the expression the concepts should possess, as wished by Heliospectra; these were advanced technology, Swedish design language, and environmental friendliness. The other image boards represented the context surrounding the product. These include different plants, kitchens and kitchen products.

5.2.1 Technology

Since Heliospectra is associated with advanced technology it was important to be able to express this in the created concepts. The image board, see Figure 9, represents a sense of advanced technology that creates interest but is also intuitive to the user. While the LEDs used in the product will be quite advanced, cultivation is at the core a natural process so it is important to avoid creating a technological barrier between the plants and the user. The inspiration drawn from these images consists of the choice of materials, the limited use of colour as well as the distinct interfaces that help the user understand the complex functions.

Figure 9. *Image board: Technology (Image sources from left to right: Feber (1) (2013); Techhog (2013); Techfresh (2013); Feber (2) (2013); Enter2life (2013); Uniteclaw (2013); The Cool Gadgets (2013); Apple-blog (2013); Designbuzz (2013)).*

5.2.2 Swedish design language

Heliospectra wants to be recognized as a Swedish brand, with Swedish product quality. A Swedish design language based on simplicity and functionality was taken into consideration when creating the different concepts, see Figure 10.

Figure 10. *Image board: Swedish design language (Image sources from left to right: Mixat Hem (2013); Svpply (2013); Playsam (2013); Drink Hacker (2013); Bloesem (2013); Allt Om Däck (2013); My New Desk (2013); Pippi & Snickarboa (2013); Cest Beau Ca (2013); Hemmamode (2013); Inredningsnyheter (2013)).*

5.2.3 Environmental friendliness

Cultivation is in general regarded as something environmentally friendly, and therefore it was important that the created concepts are compatible with this expression. The images presented in this board, see Figure 11, represents different products that can be perceived as environmentally friendly, mainly because of their simplicity and the materials used.

Figure 11. *Image board: Environmental friendliness (Image sources from left to right: Ypsilon2 (2013); The Gorgeous Company (2013); Daily Tonic (2013); PAP Sweden (2013); Dtail (2013); iBamboo Speaker (2013); Trend Hunter (1) (2013)).*

5.2.4 Kitchen environments

From the information gathered in the research phase it was recognized that the intended target groups in general preferred to grow edible plants. It is therefore likely that the product will be kept in the kitchen and should thus be designed to fit into this environment. An image board representing different kitchens was created to act as inspiration, see Figure 12.

Figure 12. *Image board: Kitchen environments (Image sources from left to right: Kitchen Design (2013); Blogspot (2) (2013); Vi i Villa (2013); 232 Designs (2013); Barretstown (2013); House Beautiful (2013); Getto Know Steve (2013); Nouvelle (2013); Trend Decoration (2013); Blogspot (3) (2013)).*

5.2.5 Kitchen products

For the same reasons as the image board presented above, an image board representing different kitchen products was created, see Figure 13. The products represent everyday kitchen products, with a degree of technology and functionality, possessing the desirable expressions of the concepts.

Figure 13. *Image board: Kitchen products (Image sources from left to right: Discshop (2013); Tretti (2013); Homedit (2013); Gizmodo (2013); Juicepressar (2013); Tumblr (2013); Trend Hunter (2) (2013); Currys (2013); Monica (2013); Wikipedia (2) (2013)).*

5.3 Idea generation

The idea generation started with sessions of Brainstorming, see section 3.3.2. Different ideas and thoughts that had been generated from the data collecting phase were discussed, as well as different functions and possible solutions to the identified problems. The ideas and discussion from the Brainstorming formed the basis for the following methods. A Morphological matrix (see section 3.3.3) was used to expand the number of ideas by creating concepts out of different combinations of functions and requirements. A session of the method was first conducted based on the specification of requirements. Three different requirements were randomly combined and served as a basis for the creation of a possible solution. The method was at a later time carried out according to specific themes. These were size, placement, light, watering, cultivation area and settings. By creating combinations using one function from each theme, different concepts were created.

As a last measure of developing a large amount of ideas the method called Brainwriting (see section 3.3.4) was used. With help from three other students (working on a separate project in collaboration with Heliospectra) a brainwriting session with a subsequent discussion was conducted. The assignment was to create ideas of lighting for indoor cultivation utilizing LEDs, with no other boundaries. The reason to not include boundaries was so that the creativity should not be limited. The result of the method was 75 different ideas generated in about an hour.

5.3.1 Categorisation of ideas

When examining the result of the different idea generation methods it was found that the ideas could be sorted into eight broad categories. The identified categories were:

Counter placement

This group of ideas represents products that are supposed to be placed on a counter or table. These ideas are the ones most similar to the products existing on the market, consisting of an integrated cultivation area (often hydroponic) with a light source mounted on it, see Figure 14. The counter placed ideas were a result of looking at existing products and thinking of how to possibly improve these, for example by integrating climate control.

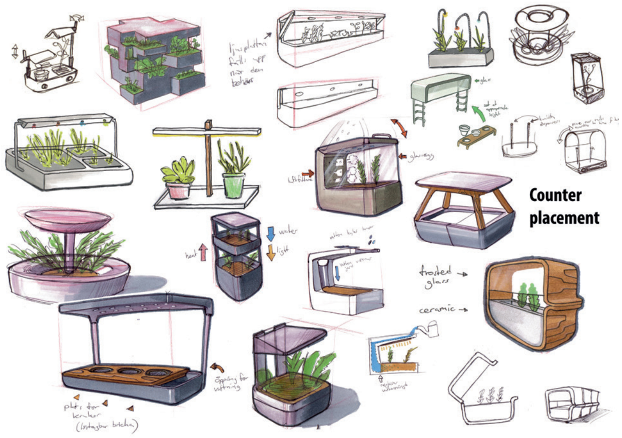


Figure 14. *Group of ideas – Counter placement*

Integrated

This group of ideas consist of products that in some way are integrated in walls or furniture, see Figure 15. The product could for example be placed under or inside a kitchen cabinet or similar. Other ideas involve how it could be hidden when not in use. The idea of integrating the product into walls or furniture came from the request to keep the product small and discrete.

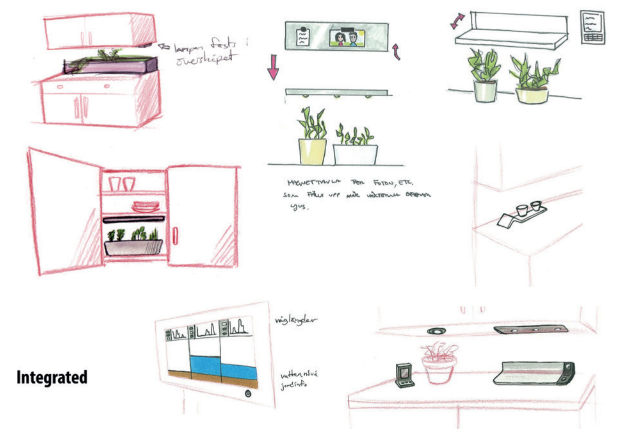


Figure 15. *Group of ideas – Integrated*

Kitchen

The ideas generated in this group are products that in some way are integrated with the kitchen or with kitchen products, see Figure 16. The products could for example, as in the previous group, be integrated in the kitchen furniture or they could be used in combination with different kitchen tools such as cutting boards or similar. These ideas were a result of the possible users requesting that they would like to use the product to grow edible plants in the kitchen.

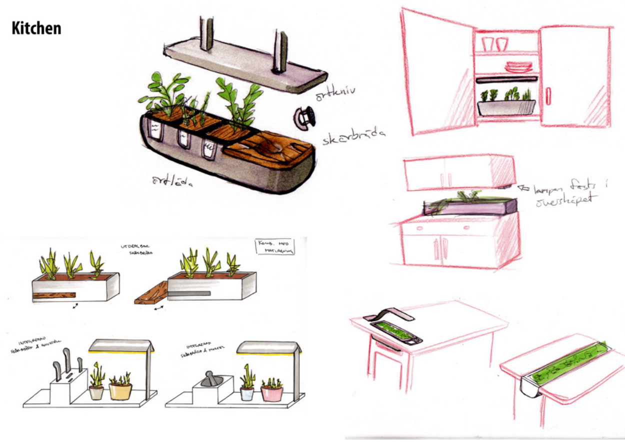


Figure 16. *Group of ideas – Kitchen*

Modular

The modular systems consists of ideas where products or functions can be combined, see Figure 17. This way the user can chose to buy products according to the a desired size of cultivation area and amount of functions. The modular ideas were based on the diversity in user requirements, with some users wanting a small product with extensive placement options while others requested the opposite.

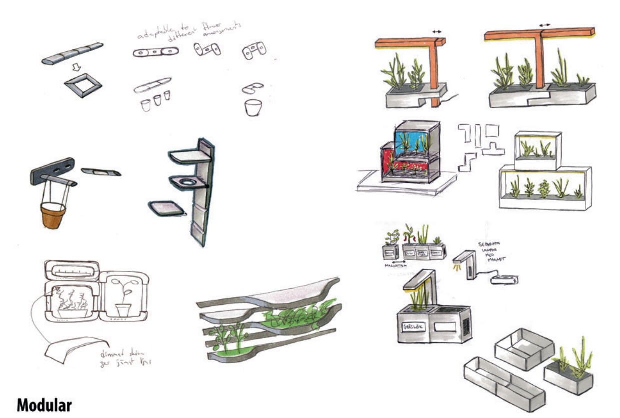


Figure 17. *Group of ideas – Modular*

Separate lamp

This group of ideas are products that does not provide an integrated cultivation area, see Figure 18. This way the customers can use their own pots and cultivation boxes. The reason for developing ideas of separate lamps comes from the fact that Heliospectra's expertise is focused on the light source, and by incorporating for example an integrated hydroponic system they will have to step into a whole new area of technology. Letting the users use their own pots further makes it easier to integrate the product in the home.

Figure 18. *Group of ideas – Separate lamp*

Shelf

These ideas represent products that are supposed to be wall mounted, see Figure 19. The products could be complete wall mounted systems, but they could also be modular systems in the form of a shelf. The idea of wall mounted systems comes from the fact that the customer may not have a counter or table with space for the product. By placing the product on the wall it will take up less space and at the same time create a display of the plants.

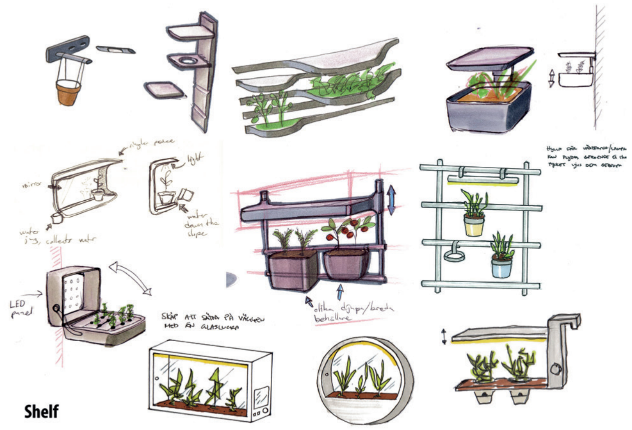


Figure 19. *Group of ideas – Shelf*

Single plant

The products in this category are focused on a single plant, see Figure 20. By making the light source small and without integrating a cultivation area the user can easily move the product between plants in need of extra light.

Figure 20. *Group of ideas – Single plant*

Interface

The interface category consists of different ideas on how the product can be operated and how it can provide information to the user, see Figure 21. It is based on the expressed interest from users in having a product that helps them take care of the plants and the potential benefits of having an adjustable light spectrum. The ideas also explore the possibility of making the product compatible with devices such as smartphones, tablets and computers.

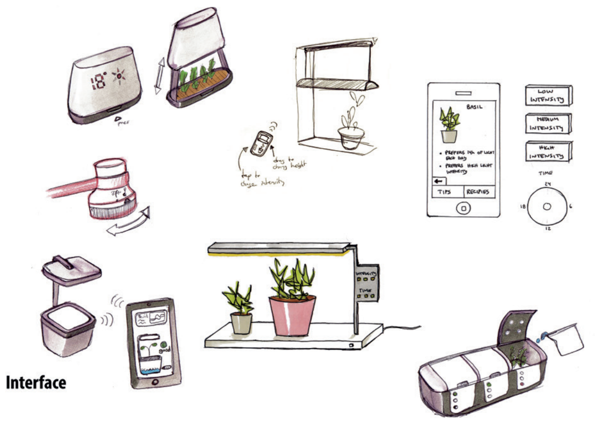


Figure 21. *Group of ideas – Interface*

5.3.2 SCAMPER

To take the eight groups of ideas further and trying to improve them the method called SCAMPER (see section 3.3.5) was used. Since it was wanted to cover all the difference approaches, some of the categories was represented by two ideas, Single plant did for example result in one idea based on the optimization of growth for one plant as well as an idea based on creating the most affordable alternative. This resulted in eleven representations, see Figure 22. The method was conducted by sketching every idea representation in a new way, i.e. by using the seven different spurring questions (substitute, combine, adapt, modify/magnify/minify, put to other uses, eliminate and rearrange).

Figure 22. *The eleven representations used in SCAMPER. The representations names from left to right – Bench placement; Integrated; Foldable; Herb station; Window; Modular; Separate lamp; Shelf; Decoration; One plant; Budget.*

5.4 Evaluation of ideas

When evaluating the eleven different ideas the evaluation matrix known as Pugh's concept selection matrix (see section 3.3.6) was used. The matrix was used in two steps, first the concepts were rated in comparison to the concept called bench placement since this was most similar to existing solutions. This was done to evaluate how well the different ideas held up in comparison to a type of product already available on the market. A second matrix was created with the highest rated idea from the previous matrix as a reference. This was done to get a more pronounced and trustworthy result with a greater variance in scores between the different ideas. The combined ratings of the different concepts can be seen in Table 3, where a low point is equal to a high rating. The two matrixes in their entirety can be found in Appendix 8.

One plant	*1,5*
Modular	*2,5*
Separate lamp	*3*
Budget	*3,5*
Decoration	*3,5*
Integrated	*5*
Herb station	*8,5*
Shelf	*8,5*
Foldable	*9*
Window	*9*
Bench placement	*10*

Table 3. *The ratings from Pugh's concept selection matrix.*

When evaluating the ratings it was decided that the four ideas with the lowest scores were to be discarded. This decision was not made only based on the idea's low ratings but also because they were considered to be the least interesting ideas to move forward with, due to their complexity and similarity with the other ideas and existing products. The ideas that were chosen for further development were; *One plant, Modular, Separate lamp, Budget, Decoration, Integrated, Herb station.*

5.5 Concepts

In order to create more concrete concepts that could be presented to Heliospectra, the seven ideas were further processed. Each idea resulted in a separate concept and they are presented in this section.

5.5.1 Showcase

Showcase is a concept consisting of a wall mounted cultivation box and lamp unit, see Figure 23. The plants grow behind a glass surface, creating an attractive display. The glass surface is slightly frosted giving it the added benefit of diffusing the light that radiate from the product. To provide easy access to the plants, the glass surface can be slid to the side. *Showcase* is meant to become a part of the interior design in the user's home and bring out the aesthetic properties of the plants. Its placement on the wall is supposed to elicit an association with framed pictures but also has the added benefit of minimizing the amount of space required for the product.

Showcase has an adjustable light spectrum and a passive watering system consisting of a water reservoir located at the bottom of the cultivation box. Watering is done through a hidden opening in the side of the cultivation box.

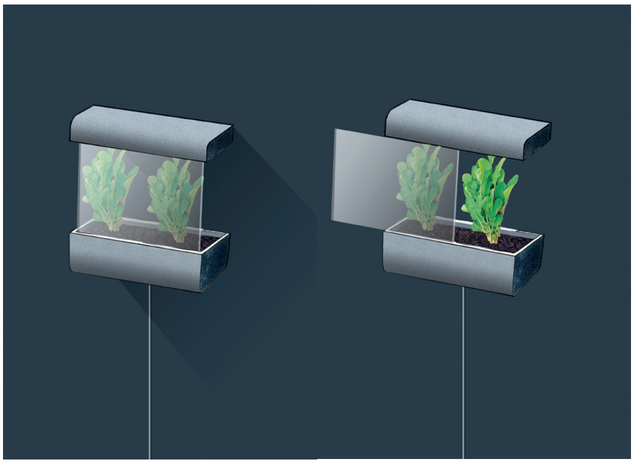


Figure 23. *Concept – Show*case.

5.5.2 Highlight

Highlight is dedicated to cultivation of a single plant, see Figure 24. The concept consists of a circular platform to which a lamp is attached via a wide arm. The height of lamp can be adjusted along the arm in order to ensure that the optimal distance to the plant is always achievable. *Highlight* contains several functions with the purpose of optimizing the growth of the plant. These include a fully adjustable light spectrum and a heating pad installed in the circular platform that helps keep the soil at an appropriate temperature to promote root growth.

Highlight can be controlled via an application downloadable to computers, smartphones and tablets. From the application the user can set the colour mix of the light spectrum or use one of the available light recipes. The application can also provide the user with information about the care of the plants and could be made to communicate with sensors that warn the user if water or nutrient levels become too low.

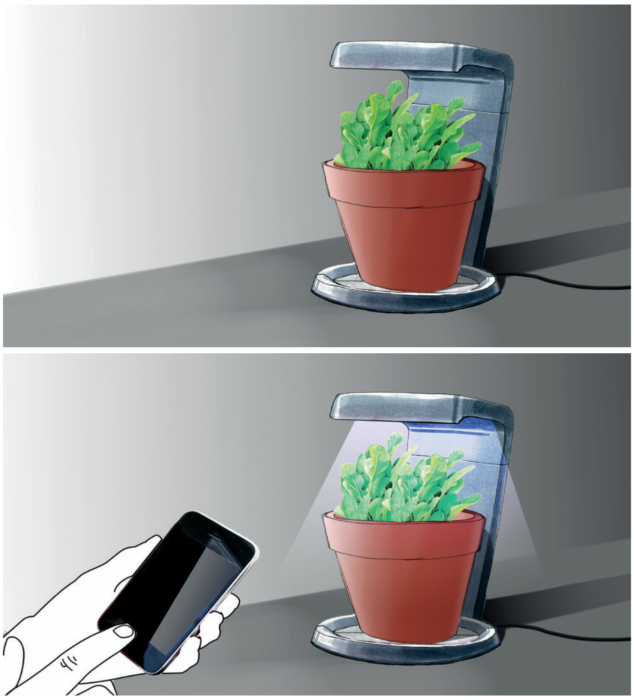
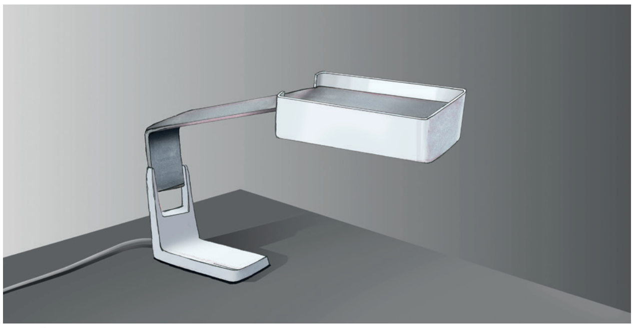


Figure 24. *Concept – Highlight.*

5.5.3 Separate Lamp

The idea behind *Separate Lamp* is to create a familiar product with a new application. In appearance it resembles a regular desk lamp and it can easily be integrated in any existing cultivation area, see Figure 25. The light source is attached to a foldable arm that can also be adjusted in height to enable configuration to differently sized pots and plants.

The lamp is constructed of simple shapes with large smooth surfaces inspired by the Technology imageboard, as seen in section 5.2.1. The LED unit is enclosed by a large panel that directs the light towards the plants and makes them the centre of attention. The panel also acts to minimize the risk of glare. An interface for controlling the light spectrum will be inset in the foot of the lamp.



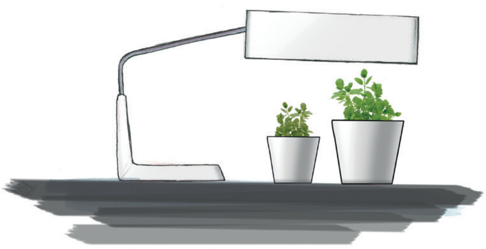


Figure 25. *Concept – Separate lamp.*

5.5.4 Herb Garden

Herb Garden is based on the idea of creating a kitchen product dedicated to growing and preparing herbs for cooking, see Figure 26. The concept includes a cultivation area separated into six sections which the user can either use to plant new seeds or fill with purchased plants. Beside the cultivation area is a separable cutting board which can be used when mincing the fresh herbs. Underneath the cutting board is a storage area for the included herb knife and other utensils and accessories that the user needs. It is also in this area that the user has access to the water tank that sustains the herbs. In front of each cultivation section there is a holder of name tags which lets the user keep track of what is planted in the product.

Figure 26. *Concept – Herb garden*

5.5.5 Modular

The *Modular* concept consists of several products that can be combined in a number of ways, see Figure 27. The base unit is a lamp and a stand that also acts as a power supply to the other components. A variety of different products could be made compatible with the base unit such as soil-based and hydroponic cultivation boxes, heating pads and different suspension modules. All the products would include identical connective elements making it easy to create a combination that fulfil each user's needs.

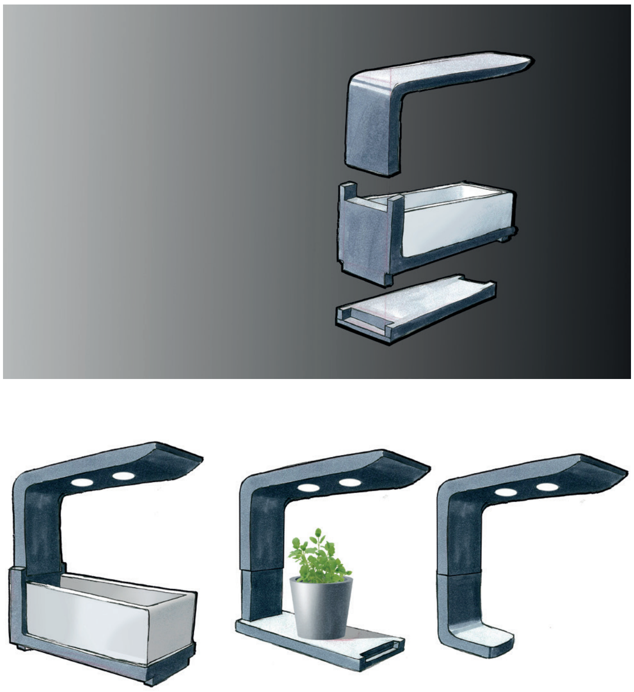


Figure 27. *Concept – Modular*

Figure 28. *Concept – Cabinet light*

5.5.6 Cabinet Light

Cabinet Light consists of an LED panel attached to the underside of a kitchen cabinet, either built in or as a separate unit, see Figure 28. The light can be controlled via display unit placed on the counter where the user can set a light spectrum and timer for when the light should be on. The display unit can also potentially be used to provide the user with information about how to care for different plants or how they can be used in cooking for example.

The concept creates a cultivation area right on the counter where the plants are easily accessed. By changing the spectrum, the lamp can also be used to provide working light while preparing food.

5.5.7 Easy Light

Easy Light is the most affordable concept and is supposed to provide an easy to use alternative to someone who just wants to give a small boost to a plants growth. It consists of a jointed arm with a LED unit at one end and a tapered section at the other, see Figure 29. The tapered section is put directly in the soil, making the placement and height of the lamp adjustable to some degree. This also makes it easy to move the product between different pots if desired.

To keep the concept simple and at a low cost it does not have a changeable spectrum but rather a fixed light that is optimised toward plants in general.

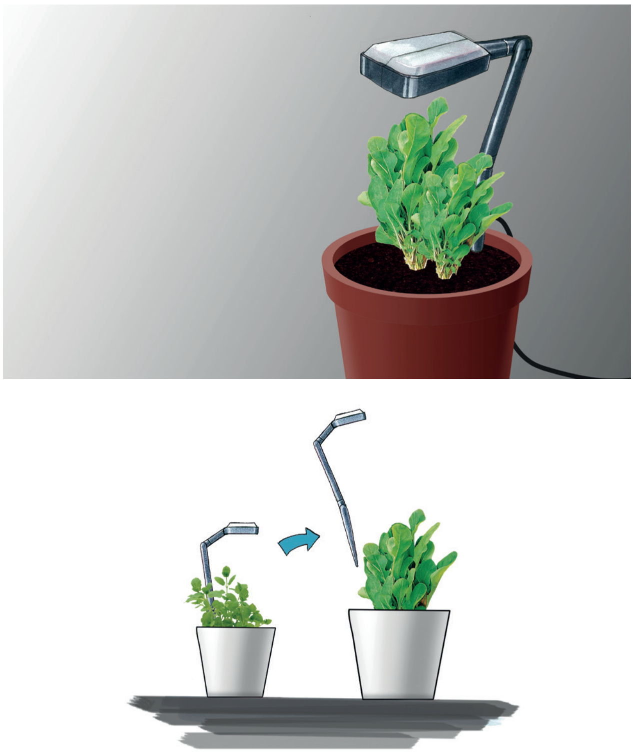


Figure 29. *Concept – Easy light*

6. Concept selection

This section addresses how the concepts, with the use of different methods, were evaluated in terms of feasibility, expression, functionality, aesthetics, usage and economy. The evaluation resulted in a better overview, which made it possible to make a selection of a final concept.

6.1 Methods used

In order to receive the stakeholder's input regarding the different concepts, the concept selection started out with a concept presentation for Heliospectra. After the presentation the concepts were evaluated and discussed. The input was later used in a pros and cons list, where the concepts were compared with regards to their benefits and flaws.

A Failure Modes and Effects Analysis was conducted on a general description of the new product in order to guide the concept selection and identify potential problems as well as the preventive measures that can be implemented to avoid them.

6.2 Stakeholder feedback

After being presented with the seven concepts the CEO, the Senior Project and Product Manager and the Vice President of Sales and Marketing at Heliospectra were asked to fill out the stakeholder feedback survey, see Appendix 9. The survey presents each concept on a separate page in the form of a visual representation. For each concept there is an eight point scale where the respondent can rate their first impression from negative to positive as well as a comment section where the respondent can describe what they like or do not like about the concept or leave other remarks. A summarised result of the survey can be seen in Table 4. The scores are based on the average rating on the eight point scale and a higher score corresponds to a more positive impression.

In general the stakeholders seem to agree that it is better to focus on creating a great lighting product rather than something that tries to solve all the problems with indoor cultivation at the same time. While the modular concept did not receive a very high score the idea of adaptability was popular and central to many of the suggested improvements. Before selecting a concept for further development it was recommended to investigate different cooling solutions and find out how much it would add to the size and weight of the product since this might limit the feasibility of some of the concepts.

Concept	Comments	Score
Showcase	A nice looking concept but it might not be too practical. Getting dirt or water on the wall is especially a problem.	6.0
Highlight	Might have a few unnecessary functions which make it too expensive.	6.0
Separate Lamp	It looks like an ordinary lamp which makes it boring. It also might take up a lot of space. Having a single arm holding up the lamp head might be problematic if the cooling requires large and heavy components.	4.7
Herb Garden	Someone who would be interested in this product probably already have high quality tools. Combined products are often bad, it is better to do one thing really well. This concept would also be expensive to produce.	5.0
Modular	Making modular components can be problematic since you cannot be sure they will all sell. This particular concept looks a lot like the products already available on the market; however the basic idea of modularity is good.	5.7
Cabinet Light	The display is superfluous and makes the product too expensive. This is the least intrusive solution. It would be compatible with many different sales channels, for example kitchen manufacturers. Could even be combined with an inset cultivation area in the counter. It could also be made detachable so that it can be used in windows or shelves as well. It would probably be quite easy to implement. The problem will be to provide efficient cooling.	7.0
Easy Light	The concept is simple and versatile. It feels like an IKEA product. A separate stand could be included when it cannot be put in the soil. Many other placement options would be worth considering, maybe combining this concept with the functionality of *Cabinet Light*. This concept will also suffer if the LED unit becomes too big or heavy due to the cooling required.	7.7

Table 4. *A summarisation of the result from the Stakeholder feedback.*

6.3 Pros and cons of concepts

To further analyse the difference between the concepts and what their strengths and weaknesses are, a pros and cons list was constructed based on the stakeholder's feedback as well as the result of the Pugh matrix, see Table 5. The intent was to get a more detailed description of what effect the positive and negative aspects would have on each specific concept to contrast and explain the numbers and ranking provided by the matrix.

Concept	Pros	Cons
Showcase	+ Takes up a small amount of space + Creates a beautiful display + Makes the plants look more special + Hard to reach for children and pets + Can use passive watering	- Risk of getting dirt or water on the wall - Risk of glare due to high placement - Requires mounting - Limited depth of cultivation area (limits selection of plants) - Difficult to move
Highlight	+ New product with new features + Should produce high quality crops + Adaptable to a wide range of species + Efficient use of light + Express technical research	- Limited cultivation area - Only one plant at a time - Expensive - Might be difficult to learn/understand functions - Demands commitment - Limited amount of light recipes available at launch - Functions require more energy
Separate lamp	+ Flexible in terms of placement and plant choice + Could be used as a regular lamp + Do not pay for unwanted functions + Easy to handle	- Difficult to differentiate from regular lamps - Difficult to communicate technical research - Might be difficult to balance - Limited height - Will not provide a cultivation area
Herb garden	+ Easy to associate with cultivation + Provides the user with everything required to cultivate and use herbs + Can be sold as a kitchen product	- Extra features might not be useful to the user - Limited to growing herbs - Takes up a lot of space - Do not express technical research - Product combination might be perceived as a gimmick - Difficult to connect to Heliospectra's brand - No expertise in kitchen products
Modular	+ Users can buy only what they need + Can change function	- Lots of modules will be expensive to manufacture - Might be perceived as insecure - Difficult to connect all modules in an aesthetically pleasing way - Modular function makes it more expensive
Cabinet light	+ Discreet + Space efficient + Can be marketed as a new function of the kitchen + Requires little material and few parts + Will not be in the way when not in use	- Non-visible design, low brand recognition - Difficult to create a user friendly interface - Fixed height - Might be difficult to install - Difficult to express technical research - Heat dissipation might be problematic
Easy light	+ Space efficient + Easy to move + Comparatively cheap + Minimize materials and components + Marketable to many	- Limited to one pot - Price sensitive - Might have limited effect on growth if spectrum is fixed - Requires a certain soil depth for balance - Difficult to express technical research

Table 5. *Pros and cons of the different concepts.*

6.4 Failure Modes and Effects Analysis

The FMEA (see section 3.4.3) was constructed based on a generic plant lighting solution, see Appendix 10. The intent was to identify potential problems that can affect the final product and analyse which concept or combination of concepts that would best avoid them. The problems with the highest RPN values include direct and reflective glare which risks becoming a frequent disturbance if not carefully handled. The light source is a critical component in other ways as well. It might be difficult for the user to position it in a way that result in an even spread of light and the structure holding the light in place might wear out, resulting in unintentional movement that further impair the functionality of the product.

Several risks were also identified regarding the expression of the product. Mainly that the product will be perceived as not being technically advanced enough which would be a problem if it means that users do not realize the advantages it has over less advanced products. At the same time an expression that is too technological might be perceived as incongruent with the purpose of the product, however, this risk seem to be lower based on the result of the analysis. Similarly, another potential risk is that the product resembles a conventional lamp to a high enough degree that users cannot distinguish its purpose.

The included functions can also result in problems. If complexity is high the risk of error increases and the benefits of the product might be lost. The functions can also demand a lot of commitment from the user which according to the interviews is not desired.

Another type of risk is associated with the perceived value of the product. In relation to the price, it is important that the users experience that the product provide the desired effect. This applies both to a sufficient increase in plant growth and a sufficiently large area of effect.

Finally, there are also potential problems related to the usage of the product. Mainly that the user will use incorrect settings or an incorrect placement which can result in impaired functionality.

6.5 Result and Conclusions of Concept selection

The stakeholder feedback and the subsequently applied evaluation methods provided a more varied picture of the concepts than what was gained from the initial Pugh matrix. For example, a better understanding of the limiting factors of the height and weight of the cooling components put the previously highly rated concept *Separate lamp* at a disadvantage. When discussing component prices with the stakeholders it also became apparent that the product would not become inexpensive enough to make the concepts focusing on a single plant worthwhile. Thus it was decided that in order to maximize the benefit of the LED lighting, the product needed to be useful for more than one plant at a time.

While some of the secondary functions included in the concepts could potentially be of value to the user, Heliospectra's expertise is in lighting and anything that strays too far from that would require more time and money to develop. It was therefore decided that the product should focus on providing a high quality lighting solution while still being compatible with other products related to cultivation. This also gives the user the possibility of personalizing the product by integrating it with cultivation products of their own choice.

Together with Heliospectra it was decided that the concepts *Easy light* and *Cabinet light* would be considered for further development. The main advantages of these concepts are that they are versatile, easy to implement and stay true to the company's focus. However, they both depend on the design of the cooling components.

7. Further development

This section presents the development of the final concept. First there is a summary of the functions that the product should have and the requirements that it should fulfil. A description of how different components were tested and analysed in order to find the best fitted solution follows. Thereafter the exterior design concerning size, colour and materials is described as well as the design of the product interface.

7.1 Functions and requirements

Based on the conclusions drawn from the concept selection, the final concept should focus on providing high quality light for an area fitting a couple of plants. The light source should provide an even distribution of light over the entire cultivation area. The focus should be on adapting the product to cultivation of edible plants, based on the result from the research phase. The provided light intensity should therefore be high enough for most herbs and vegetables commonly grown inside. According to Heliospectra, a minimum output of 120 $\mu mol*m^{-2}*s^{-1}$ is required.

When discussing thermal management with Börje Gillholm at Aluwave (a company that develops and delivers customer-specific modules and systems based on modern LED technology), it was decided that the maximum temperature of the LED chip should not exceed 80 °C since a higher temperature may have an impact on the soldering of the circuit board. The product should further not exceed a noise factor of 30 decibel, since a higher number could result in a disturbing sound.

Based on the requirement of being able to function independently without constant input from the user, the product should include timer settings for scheduling the lighting periods. The product should also make it possible to adjust the light settings to better fit the demands of different species of plants and different situations.

7.2 Component selection

A selection of components is required to fulfil the specified functions of the product, of which the most critical are the components related to lighting and heat management. As such, various alternatives were investigated through market research, analysis and tests. Two different tests were conducted to evaluate the amount of light produced and the thermal energy created while running the different component configurations at various effects.

7.2.1 Component alternatives

Regarding lighting there are two possible alternatives for the product: multi die chips or an array of single die diodes. While the single die diodes would result in a more easily managed heat distribution they do not provide the high level of colour blending achieved by placing the dies together on a single chip. Regarding the price, the single LED array would potentially be cheaper since there are companies who mass-produce single die diodes at a low price. Because of the improved colour blending and the suggestion from Heliospectra, the multi die chip was chosen as the most suitable solution for the product as long as a adequate heat dissipation can be achieved.

A 12 die chip from LEDengine was chosen for the tests. The selection of five deep red, three blue, three green and one far red die was done by Heliospectra to ensure that the chip would provide a blended light that is beneficial for plants while also being able to produce a pleasant neutral light. The chip is mounted on a circular circuit board with dimensions 28.3x1.7 millimetre, see Figure 30.

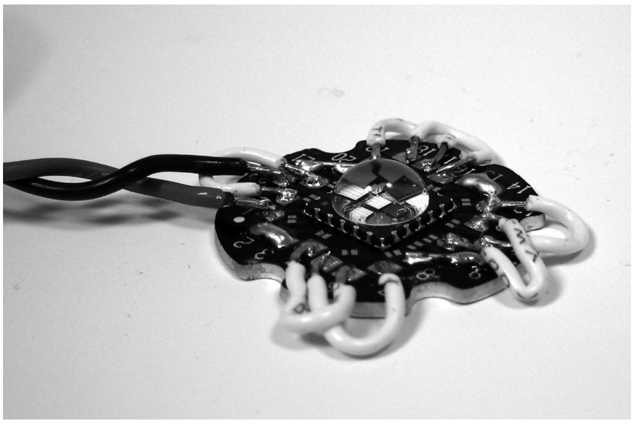


Figure 30. *The circuit board, on which the LED chip is mounted.*

The heat can be dissipated using passive or active cooling. Passive cooling is achieved by attaching the circuit board to a heat sink and letting the heat dissipate into the surrounding air by natural convection. The active cooling alternative also utilizes a heat sink but combine it with a fan or other air-mover to create forced convection. Since natural convection have a lower rate of heat dissipation it requires a larger heat sink which results in a higher weight. Utilizing forced convection enables a smaller volume heat sink but become less reliable due to the risk of failure in the electronic components. There is also an added noise factor that needs to be taken into consideration.

In determining the best alternative, three heat sinks from Fischer Elektronik were tested for passive cooling and one heat sink with a synthetic jet module from Nuventix was tested for active cooling, see Figure 31.

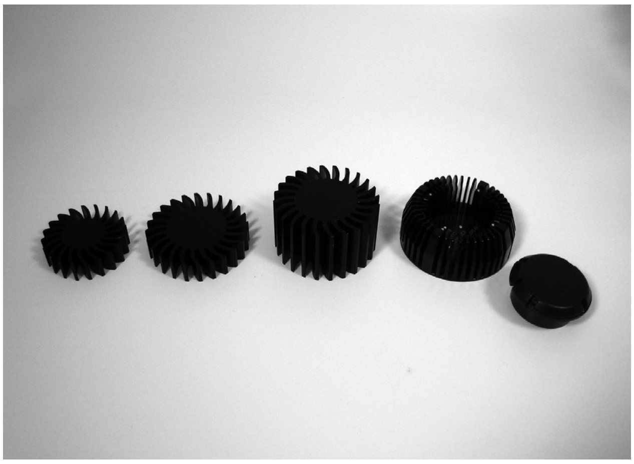


Figure 31. *The different thermal management tested.*

The three passive heat sinks all had the same form factor but varied in size. The sizes were 70x20, 85x20 and 85x50 millimetre with a thermal resistance of between 2.15 and 1.22 Celsius per Watt (Fischer Elektronik, 2013). The module from Nuventix utilizes a synthetic jet flow created by an oscillating membrane to move air. By pulling in air and expelling it at a higher speed, a high momentum pulse is created which entrains the surrounding ambient air resulting in a turbulent air flow which provide efficient cooling, see Figure 32.

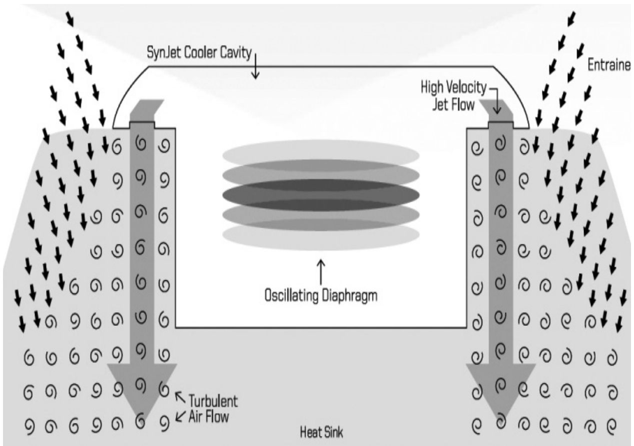


Figure 32. *The cooling system of the Nuventix synthetic jet module (Image source: Nuventix (2013)).*

The synthetic jet module requires no friction between parts which ensures a low noise level and long life (Ahearn, 2011). According to Nuventix (2013) the synthetic jet modules have a L10 lifetime of 100,000 hours at 60 °C (L10 being when cumulative failures of a product reach 10 percent and 90 percent remain functioning as intended). The thermal resistance varies between 1.55 and 1.00 depending on oscillation speed.

7.2.2 Testing of thermal management

A thermal management test was conducted on all four different cooling solutions. The circuit board containing the multi die chip was fastened to the heat sinks using screws to get a close fit that would enable efficient heat transfer while also making it possible to disassemble the components, see Figure 33.

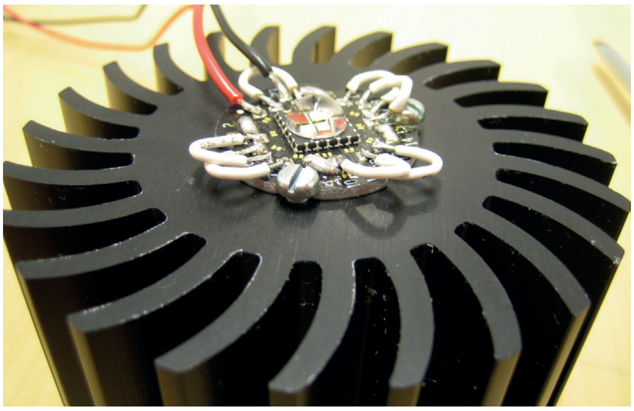


Figure 33. *The multi chip fastened on a heat sink using screws.*

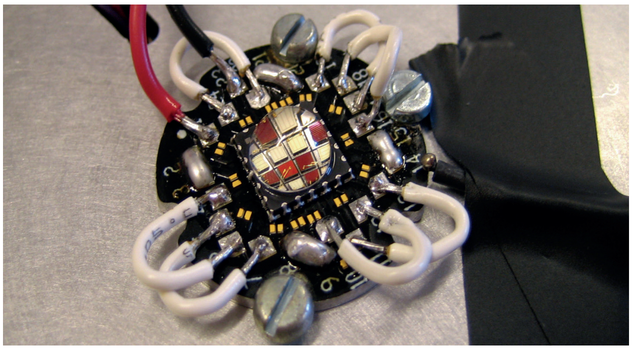


Figure 34. *The heat sensor fastened onto the circuit board using cable tie and tape.*

A heat sensor connected to a multimeter was attached to the heat sink, with its tip in contact with the circuit board, using a cable tie, see Figure 34.

The whole unit was suspended in steel wires to allow airflow around the heat sink, see Figure 35.

The first test (using the medium sized heat sink) was performed at 25, 50, 75 and 100 percent output. At each interval the maximum temperature reached in the circuit board was noted as well as the time it took to reach it and the corresponding temperature at the top surface of the heat sink. The circuit board was considered to have reached its maximum temperature if no temperature change above 0.1 °C occurred during five minutes. If the temperature was still rising after 20 minutes the test was aborted and the current temperatures were noted. The test was also aborted if the circuit board temperature reached the critical temperature of 80 °C. Between each test the circuit board and heat sink was allowed to cool down to approximately room temperature.

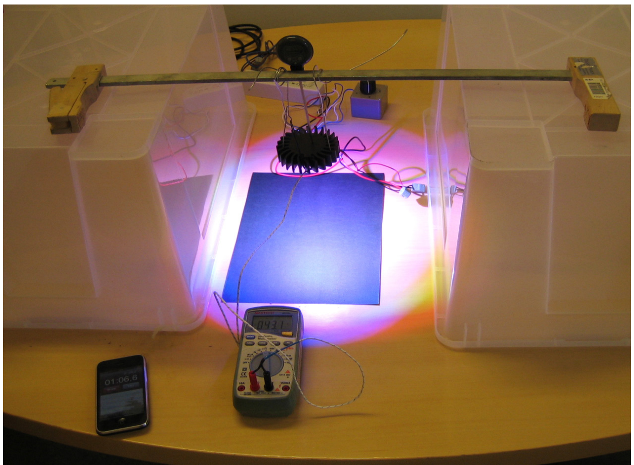


Figure 35. *The tests were conducted with the components suspended in mid air to allow airflow around the heat sink.*

Since the medium sized heat sink was close to reaching the critical temperature after 20 minutes at 75 percent output it was decided that the temperature of the circuit board and heatsink would be noted each minute on the following tests in order to get a better understanding of the heat development. After it failed to cool the chip at 100 percent output it was also decided that the following tests would only be per-

Heat sink	Effect (%)	Initial temp. circuit (C°)	Max temp. (C°)	Time to max temp. (min)	Initial temp. heat sink (C°)	Heat sink temp. at max-temp. (C°)
50x20	100	25,8	80	10:55	24,5	57,3
35x20	100	26	80	08:53	24,9	67,7
50x50	100	26,2	75	60	24,5	62,7
Synjet PAR30	100	25,5	66,4	40	24,8	34,8

Table 6. *Results from the thermal management tests.*

formed with maximum output in order to determine if any of the alternatives was effective enough. The last two tests (using the largest heat sink and the heat sink connected to the SynJet module) were extended to 60 minutes since the circuit board had not reached its critical temperature after 20 minutes but heat level was projected to stabilize before reaching 80 °C. The result of the test can be seen in Table 6.

The result from the tests showed that the thermal management of the two smallest heat sinks would not be sufficient enough to cool the multi die chip. The larger separate heat sink and the heat sink connected to the SynJet module did however show results that implies sufficient cooling with the synjet module being the most efficient one stabilizing at around 66 °C compared to the separate heat sink at 75 °C.

7.2.3 Testing of light

To test the light output of the intended diode it was suspended over a luxmeter. The diode was placed at a height of 100, 200, 300, 400 and 500 millimetre above the meter to simulate different settings of the lamp height, see Figure 36. For each height, measurements were taken directly under the light as well as at 100 millimetre vertical increments up to 500 millimetre. Tests were conducted using both one and two multi die chips in order to test the difference in intensity and spread. Tests were also performed using self-constructed reflectors of different sizes in order to intensify and find a proper size for the illuminated area.

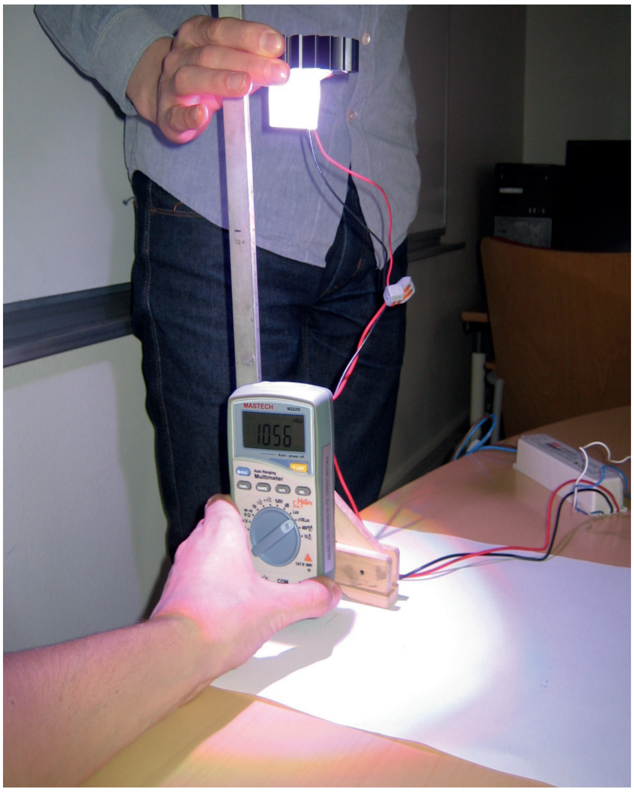


Figure 36. *The light tests were made at different heights to simulate different lamp heights.*

The result from the tests implies that a single chip can provide the target intensity of 120 µmol*m^{-2}*s^{-1} for a circular area with a diameter of between 200 and 400 millimetres at a height of between 100 and 200 millimetres, see Table 7. The tests further implied that the intensity of the light increases with the use of a lens or reflector and that the illuminated area can easily be shaped by adjusting the size and form of the lens or reflector. The results from all the light tests can be found in Appendix 11.

Height/width (mm)	0	100	200	300	400	500
600	22,6	23,8	22,1	19,6	16,8	14,5
500	33,0	32,0	30,8	26,5	20,8	15,8
400	49,6	47,8	43,5	35,1	24,3	16,5
300	87,7	76,3	65,8	44,6	26,0	18,3
200	198,3	149,7	102,1	47,0	18,8	5,7
100	>400	370,5	92,6	8,8	8,3	5,7

Table 7. *Results from the light test calculated in μmol photons*m^{-2}*s^{-1} using conversion factor for sunlight. Source: Apogeeinstruments.co.uk*

7.2.4 Testing of noise level

A test of the noise level provided by the cooling system was conducted to find out if the intended product would create any disturbing noises. The test was conducted with the use of a multimeter with the ability to measure decibels. The multimeter was placed at different distances from the cooling system in order to see at which distance the noise could be considered disturbing. The result can be seen in Table 8.

	Total	**Difference**
Ambient	42,7 dB	
100 mm	56,6 dB	13,9 dB
500 mm	44,5 dB	1,8 dB
1000 mm	44,5 dB	1,5 dB

Table 8. *Results from the noise tests.*

The result from the test implies that the system is quiet enough to not cause any disturbance at all. The test even showed better results than the levels provided by the manufacturer of the system (18-28 decibel), which is a noise factor comparable to a quiet bedroom.

7.2.5 Cost analysis

The component cost of the different configurations can be seen in Table 9. The prices do not reflect the actual cost in production but reflect the comparative difference between the alternatives.

7.2.6 Result of component selection

The result of the lighting test indicates that a single multi die chip will provide sufficient light to an area up to 400 millimetre in diameter. While using two multi die chips provide the best illumination of the tested configurations, it is not enough to motivate the increase in component cost. To reach the minimum light output requirement of 120 μmol*m^{-2}*s^{-1} for the cultivation area the test results show that a distance of between 100 and 200 millimetres from the plants to the light source is optimal. In order to optimize the light and specify the illuminated area the product needs to be equipped with a reflector. Different tests of self-constructed reflectors made out of KAPA board shows that in order to concentrate the light to the 400 millimetre in diameter cultivation area from a height of between 100 and 200 millimetres, the reflector should have a height of about 25 millimetres and a diameter of 60 millimetres.

Both the synjet module and the biggest heat sink are possible options for managing the heat dissipation since both managed to keep the circuit board beneath the critical temperature. The advantage of the passive heat sink is that it is cheaper and does not require a driver. However, it weighs more and run about nine degrees hotter than the heat sink with the SynJet module which means there is a higher risk of deterioration in the chip. Coupled with the fact that both heat sinks have similar form factors, the advantages of the SynJet module are enough to motivate the higher price. However, a passive cooling solution adapted to the design of the product could potentially provide a

Components	Component cost	Conversion rate****	Component cost in SEK	Total cost in SEK
70x20 Heat sink SK 571 20 SA Multi die chip	34:64 SEK* $24	- 6,55	34:64 157:20	191:84
85x20 Heat sink SK 572 20 SA Multi die chip	52:72 SEK* $24	- 6,55	52:72 157:20	209:92
85x50 Heat sink SK 572 50 SA Multi die chip	97:60 SEK* $24	- 6,55	97:60 157:20	254:80
PAR30 Cooler LED heat sink 40W ZFlow 65 Multi die chip	$8:15** $14:36*** $24	6,55 6,55 6,55	53:38 94:06 157:20	304:64

**Prices for purchasing 50+ components excluding VAT from www.conrad.se*

***Prices for purchasing 75+ components from www.futurelightingsolutions.com*

****Prices for purchasing 50+ components from www.futurelightingsolutions.com*

*****Conversion rate from www.valuta.se [30 April 2013]*

Table 9. *Cost analysis of the different components.*

higher efficiency than the commercially available heat sinks used in the test which makes it an option worth investigating further.

7.3 Design development

This section addresses the design development of the final concept. A basic introduction to the design and how it evolved from the concept selection is first presented. This is followed by a description of how the general measurements and the exterior design was decided. The concept's different parts are then presented in better detail, and lastly the colour selection is described.

7.3.1 Introduction to the design

During the concept selection it was decided that the concepts *Cabinet light* and *Easy light* would be considered for further development. The test of the components did however provide results that spoke against the possibility of constructing these concepts in the way that they were first designed. The thermal test showed a larger generation of heat than what was first expected and therefore it was decided to not move forward with either *Cabinet light* or *Easy light*, since both of these concepts were dependent on a thin design. *Cabinet light* was supposed to be a slender construction mounted under a kitchen cabinet. However the demands on thermal management would result in a height that would be unsuitable for such mounting and make it difficult to provide adequate ventialtion. Furthermore, the result of the lighting test shows that the output is sensitive to height differences which argues against the static *Cabinet light* concept. The concept *Easy light* is also negatively impacted by the thermal management requirements since the construction would become larger than intended and also heavier. This would create a balancing problem since the concept is supposed to be standing in the soil.

Instead of focusing on one of these concepts, it was decided that a new concept would be developed inspired by the positive aspects of the two and that would also be possible to construct with the required cooling components.

Instead of placing the product under a kitchen cabinet or in the soil of the plants, it was decided that the new construction should be placed on a solid surface. This way the product gets greater variation in its placement and is less restricted by the size of the cooling components. The placement of the product could however create the same problem that was experienced with the concept *Separate lamp*, where the concept was thought to resemble a regular desk lamp more than a lamp for cultivation. This is counteracted by providing the product with a specified cultivation area. The cultivation area is supposed to communicate to the user that something is supposed to be placed beneath the lamp. The shape of the cultivation area was decided to be rectangular, since this is suitable for different placement options, such as kitchen counters and windowsills. The rectangular shape is also the most common shape of cultivation boxes, seed greenhouses and other growth equipment such as heating pads, which could be used as complements to the product.

Another feature of the product is the adjustable light position. Since it should be possible to grow a seed into a fully grown plant, and since different plant species grow to different heights it should be possible to adjust the distance between the light source and the cultivation area.

The arm holding the lampshade is placed on the long side of the base, since a placement on the short side would require a longer arm in order to get the light source centered over the cultivation area. This would require a larger amount of materials and possibly impair the impression of the arm's strength. The arm is further placed off centre on the long side. This is because the arm will obstruct the placement of the plants to a degree and a centre placement would create equal obstruction from both sides. By placing the arm further to the right the user can chose to place the larger pots, requiring more space, on the left side where the arm is not in the way.

The design of the lampshade is mainly incident to the size of the components it contain, with the cooling components being the largest factor. The other components are the multi die chip, the circuit board and the reflector. When measuring the different components the resul implies that it would be possible to construct the lampshade with the height of 80 millimetres, see Figure 37. The measurment of the reflector is based

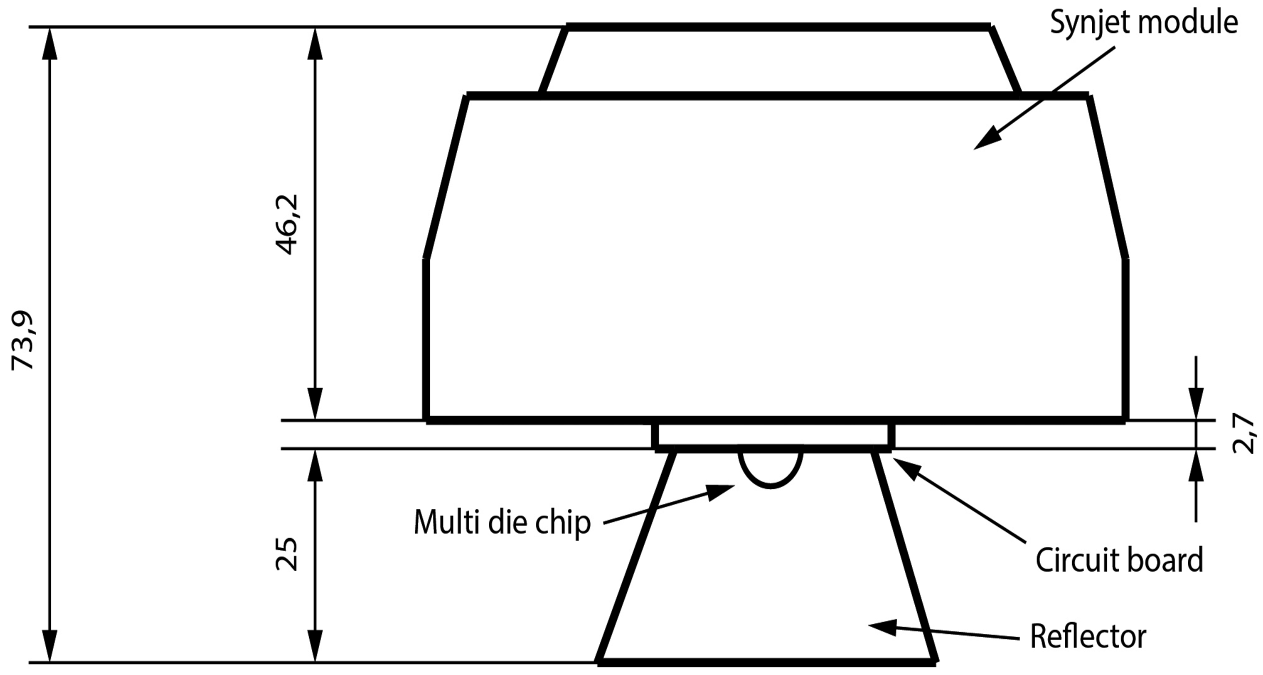


Figure 37. *Measurements of the components placed inside the lampshade.*

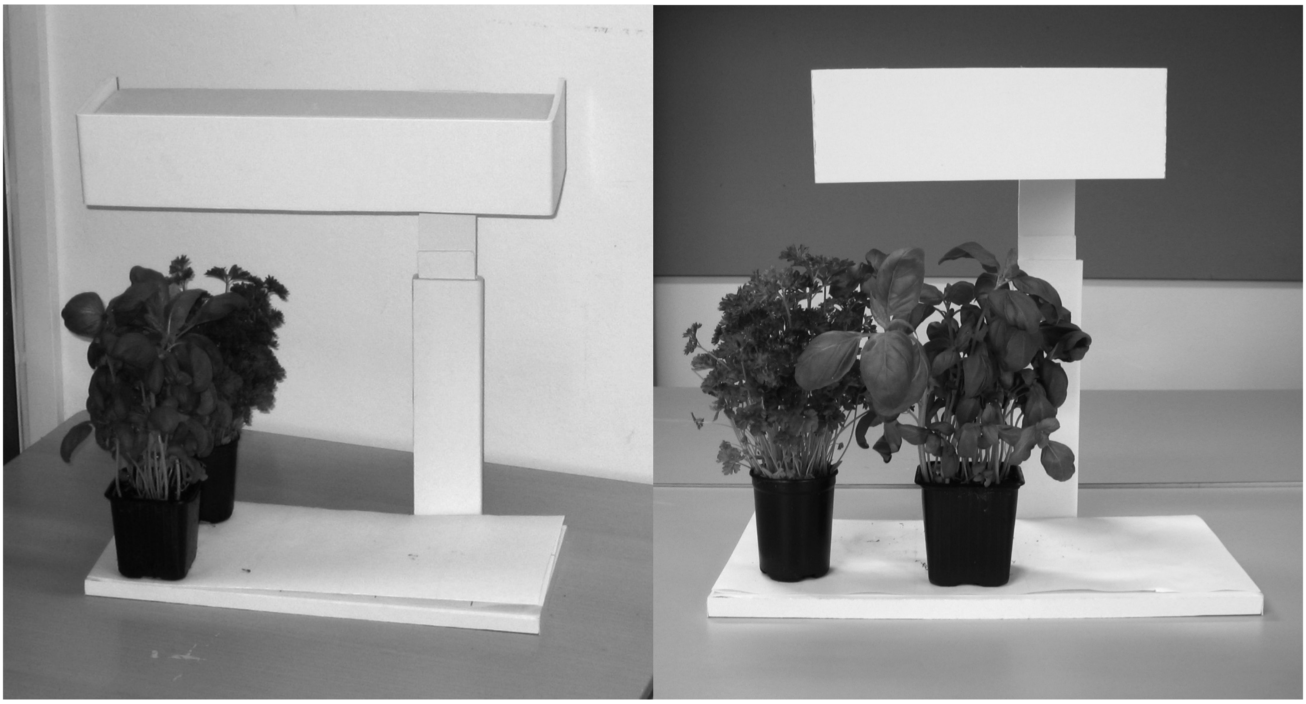


Figure 38. *Two different sketch models were created to analyse the size and expression of the product.*

on a model with, what is thought to be an appropiate reflective angle.

The diameter of the heat sink is 95 millimetres and since some airflow is required it was decided to make the depth of the lampshade 120 millimetres. The length of the lampshade had the same restrictions as the depth (95 millimetres). However since the cultivation area is rectangular it was decided to also make the lampshade rectangular, and thereby increase the length of it. The increased length is further a way of expressing that the lamp will illuminate the entire cultivation area, something that might not be as clear if the lampshade is a quadratic construction placed in the middle of the cultivation area. Two sketch models were created of the intended design, one where the length of the lampshade was as long as the cultivation area and one where it was 3/5 of its length, see Figure 38.

7.3.2 Size

When deciding upon the size of the product, numerous aspects were taken into consideration such as how big the illuminated area is, how many plants the users want to have and how high the plants grow.

Regarding the size of the illuminated area, the light test showed that it is possible to illuminate an area of circa 400 millimetre in diameter. The information gathered in the data collection phase regarding the desired number of plants consisted of phrases like "I would like to grow a couple of herbs" and "You should at least be able to grow three to five plants". To find out the required size of the cultivation area to fulfil these needs, different pots intended for herbs were measured, see Figure 39. The circles in the figure represent pot sizes of 100, 120, 150, which seem to be common sizes on the market. By placing the circles in different combinations it was possible to measure approximately how big the cultivation area had to be in order to be able to grow the requested amount of plants. It should be mentioned that the pots are measured at the top, and due to their conical shape their bottom surface has a smaller diameter, meaning that the pots will require a smaller area to stand on than seen in the figures.

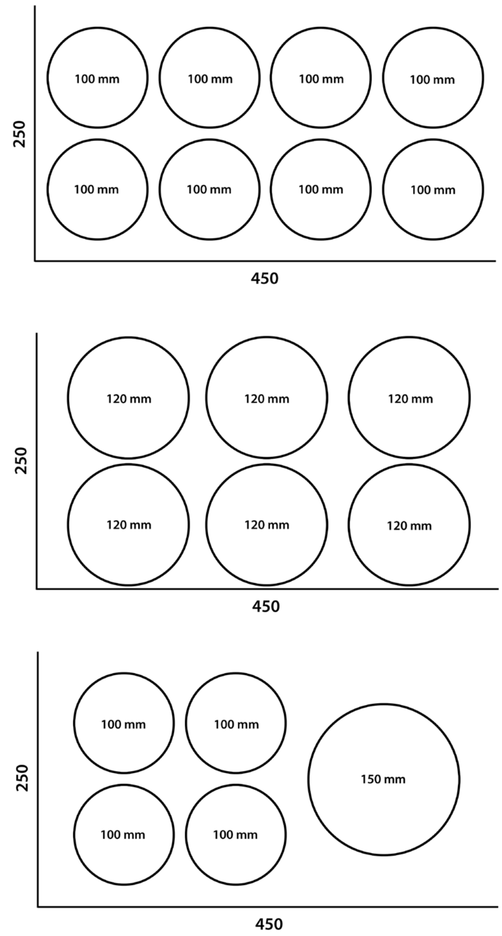


Figure 39. *Different sizes of pots were combined to find an appropriate sized cultivation area.*

In order to determine the required distance between the cultivation area and the light source, a compilation of different plants and their heights was created, see Table 9. The selection consist of common herbs and vegetables grown indoors. Further, the height of different pots was investigated, since these in combination with the plant height results in the total distance that is needed between the base and the light source. The result showed that the majority of the pots, with a size appropriate for the product, are lower than 200 millimetres.

Based on the gathered information, the outer dimensions of the product was decided, see Figure 40. The dimensions result in a cultivation area of eight square decimetre (400x200 millimetres) that is able to contain somewhere between three to eight plants. The size is suiteable for either two rows of smaller

Plant	**Height (centimetres)**
Chili	50-100
Tomato	30-50
Basil	30-50
Lemon balm	40
Oregano	30
Mint	30
Lettuce	20-30
Thyme	15-30
Parsley	15-30
Chive	25
Dill	20
Rosemary	15

Table 9. *A compilation of different plants and their maximum height.*

pots or one row of larger pots. With an asymmetric, rectangular design, the product can also more easily fit on counter tops and in window sills. The adjustable height of the light source has a minimum of 300 millimetres and a maximum of 500 millimetres, making it possible to grow most of the considered plants as long as they are trimmed when necessary. The length of the lampshade was decided to be 250 millimetres (3/5 the length of the cultivation area), since making it the entire 400 millimetres made it look heavy and unstable. The 250 millimetres was also thought to be

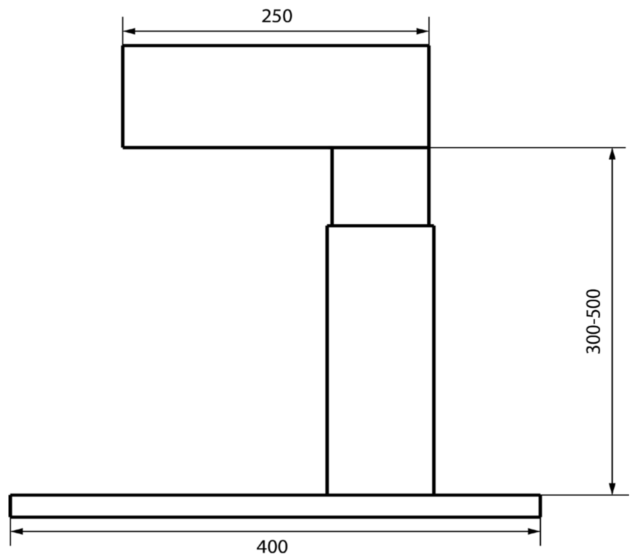


Figure 40. *The product's outer measurements.*

a sufficient length, enough to communicate that it would illuminate the entire cultivation area.

7.3.3 Exterior design

When the different components had been selected and the size of the product was specified a new phase of idea generation took place. By printing templates created in CAD, representing the size of the cultivation area and lamp shade, see Figure 41, new ideas regarding the shape of the product were created.

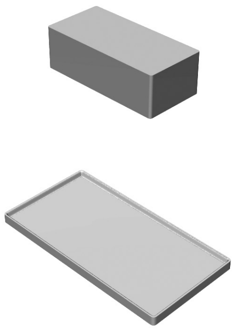


Figure 41. *A template representing the size of the cultivation area and lamp shade were created in CAD to simplify the idea generation.*

A total of circa twenty concepts were created and discussed before three of the shapes were selected for further evaluation, see Figure 42.

Nine external people were then asked to evaluate the designs. The respondents consisted of people between 20 and 50 years old, which corresponds to the age span of the intended target groups. No further limitations were put on the selection of participants so it is unclear if the test group consist of actual potential users. However, since form and not function was evaluated, their input is considered valid concerning which design that is preferred. The evaluation consisted of a rating of the concepts regarding the first impression, different stated expressions and how well they fit together with plants and the home environment. Results from the evaluation can be seen in Table 10, where the concepts are rated on a scale from one to eight.

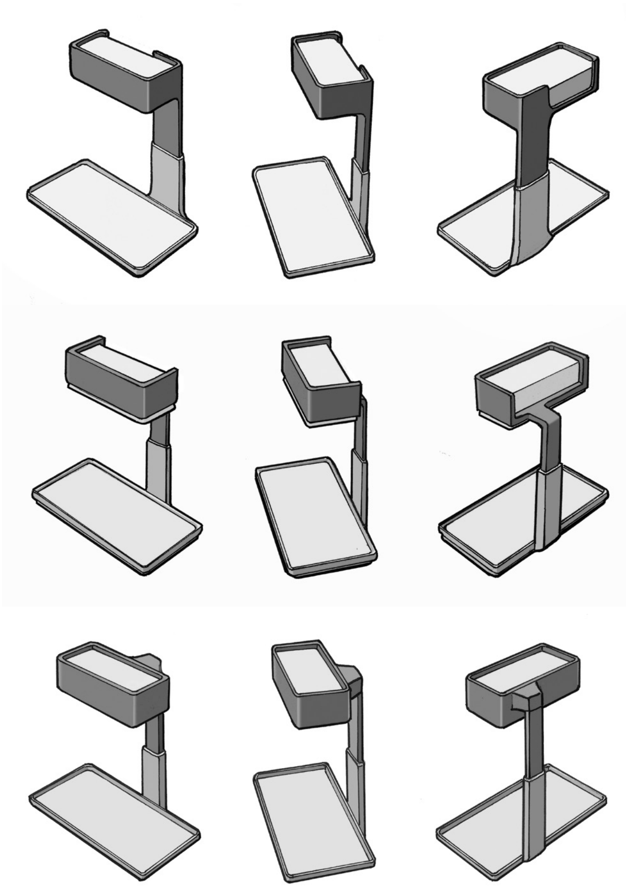


Figure 42. *The three concepts chosen for further evaluation. From top to bottom – Concept 1; Concept 2; Concept 3*

	Concept 1	Concept 2	Concept 3
Stable	7	5,67	5,67
Reliable	6,67	5,56	5,56
Effective	6,44	6,44	6
Technical	6,67	6,33	5,33
Environmentally friendly	6,22	5,22	5,33
Inviting	7	6	6,11
Functional	7,56	6,44	6,67

Table 10. *Evaluation of the design.*

The responses indicate that concept number one possesses the shape that best convey the desired expressions of the product. Concept number one did also receive higher numbers than the two other concepts in the question of how well it fits with plants and in the indoor environment. Overall, concept number one was preferred by seven of the nine participants.

The reason why the respondents rated concept number one higher than the other two was mainly because of its simple shape and rounded corners which prompted expressions such as technical, designed and organic. The respondents further said that the concept looked more stable because of its thicker arm and lampshade placement, directly on the arm. The smaller arms in concepts two and three were by some respondents perceived as weak, and the way the lampshade is connected to the arm was said to make the top look heavy and overbalanced. One respondent further preferred the placement of the lampshade in concept one because it would be easier to reach the plants for watering and trimming with the lampshade mounted further back.

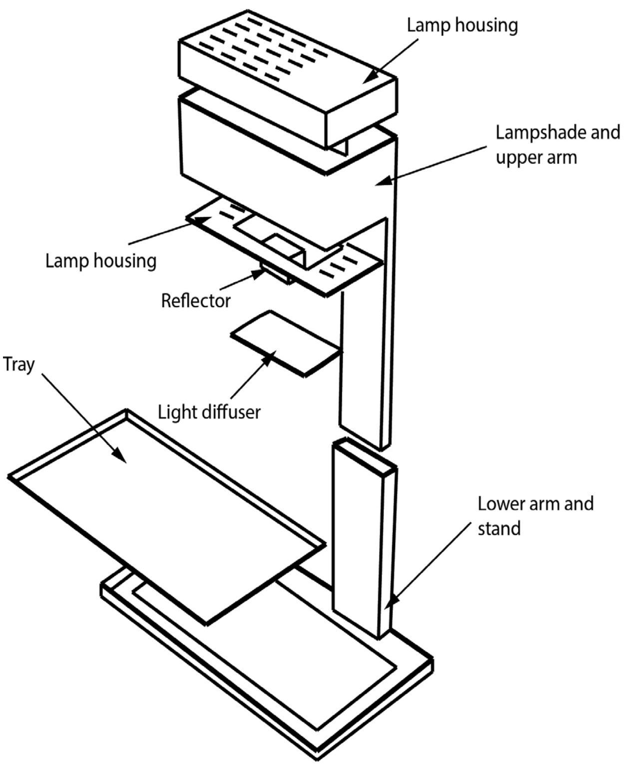


Figure 43. *The product's different parts.*

7.3.4 Parts

Excluding the internal components the product consists of six main parts which can be seen in Figure 43. The parts are presented from the top down in better detail below.

7.3.4.1 Lampshade and upper arm

The lampshade horizontally encapsulates the lamp housing and constitute the main front surface of the product. By having the it extend below and above the housing, the risk of glare is reduced and a barrier is created around the main ventilation surface. The backside of the shade has a cutout to break up the form and make room for more ventilation.

The lampshade seamlessly attach to the upper arm for improved strength and stability. The upper arm's main functions are to hold the weight of the lamp head and to provide a grip for adjusting the height of the product.

7.3.4.2 Lamp housing

The lamp housing is a box-like construction placed inside the lampshade. The bottom part of the housing is used to mount the thermal management, multi die chip and light diffuser. All of the sides of the lamp housing are equipped with vents to provide the inside with cold air and let the warm air out.

7.3.4.3 Reflector

In order to optimize the illumination of the cultivation area and prevent the light from spreading the product is equipped with a reflector. Since the lamp head is not placed above the center of the cultivation area, the reflector needs to be asymmetrical in order to spread the light correctly. Based on the result of the light test, the optimal distance between the plants and the lightsource falls between 100 and 200 millimetres. With the height set at 150 millimetres and the light source placed 40 millimetres from the centre of the cultivation area, the required size of the reflector can be calculated. However, the size is also limited by how close to the multi die chip it can be placed and how the height will affect the total height of the lamp head.

Assuming the reflector walls can be placed within a few millimetres of the multi die chip, a wall height of 20 millimetres and an opening of 27 times 54 millimetres will illuminate the cultivation area from a height of 150 millimetres, see Figure 44.

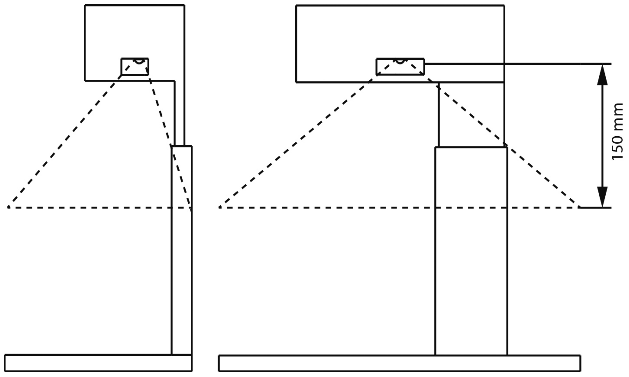


Figure 44. *The illumination area of the reflector.*

7.3.4.4 Light diffuser

The light diffuser is mounted under the light source retained in the lower lamp housing. Its main function is to protect the multi die chip and its circuit board while at the same time let through as much light as possible and transform it to a more pleasant light. The diffuser is also a way of enlarging the perceived area illuminated by the product. Since the product contain a single multi die chip the light source is quite small, and by spreading the light in the light diffuser this could give an impression that the light source is bigger. This could possibly enhance its expression of effectiveness.

7.3.4.5 Lower arm and base

The lower part of the arm is telescopically attached to the upper arm which provide the height adjustability of the light source. It is also attached to the base which give the product balance. The base consist of a rectangular framework with an open center in which tray can be placed.

7.3.4.6 Tray

As mentioned in section 7.3.1 the product is equipped with a cultivation area. The cultivation area consists of a detachable tray with 10 millimetres raised edges, which prevents excessive water from pouring out. The reason that it is detachable is to facilitate the cleaning process and to make it possible to easily move the plants when needed, as for example when cooking.

7.3.5 Colour selection

Regarding the colour selection several aspects needed to be considered. The colours should fit the desired expressions related to Swedish design language, technical research and environmental friendliness. The plants and their condition should be the focus of the user and the colours of the product should therefore not be overwhelming. However, the lamp should also be confident and convey a sense of dependability. Semantically, the colours can be used to reduce the perceived weight of the lamp head and to give the base a stable expression.

7.4 Materials and manufacturing

This section presents the part's different materials and manufacturing processes. Every part has a suggested material which is thought to best fulfil the intended requirements and the desired expressions. The suggestion of manufacturing processes is based on the estimated volume of production and how well it fits the material and shape of each part.

7.4.1 Material and manufacturing method selection

The selection of materials was based on numerous of aspects. Similar products, such as kitchen appliances, lamps and competing cultivation stations were first studied to find out which materials that are normally used. With knowledge of possible materials, the next step was to evaluate how these could be used in the product. By evaluating the price, weight, manufacturing possibilities and environmental impact of the materials, with help from the material selection software CES Edupack (2012), the materials best fitted for the construction could be chosen. The evaluation of the materials can be seen in Appendix 12. It should be mentioned that the numbers given in the evaluation are based on virgin material and might therefore not be representative. The aluminium could for example partly consist of recycled material, which would decrease the cost and environmental impact of it. The evaluation does however provide a rough estimate of the benefits and drawbacks of the materials.

Usually there are several manufacturing processes that can be used for a component. There is however a couple of factors that needs to be taken into consideration in order to find the optimal one. Swift and Booker (2013) states that these factors are mainly associated with technical capabilities and process economics, such as material, size, geometry, tolerances, surface finish, capital equipment and labour costs. The product quantity is also a large factor in the selection of manufacturing processes since some processes are only viable for low-volume production and some are only viable for high-volume production. Swift and Booker (2013) use the following ranges for the product quantity:

- Very low volume = 1–100
- Low volume = 100–1,000
- Medium volume = 1,000–10,000
- Medium to high volume = 10,000–100,000
- High volume = 100,000+

The result of the material and manufacturing selection is presented below part by part.

7.4.1.1 Lampshade and upper arm

Since the light source is the most essential part of the product, it should be enhanced by the material surrounding it. The material should further convey the technical and effective expression of the product. It is also essential that the material of the lampshade is not too heavy since the part is held up by a single arm mounted off centre. The lampshade further needs to be durable, easily cleaned and water resistant. It is also advantageous if the material has a high thermal resistance to keep the surface cold.

The important functions of the upper arm are to hold the weight of the lamp head and allow its telescopic movement. As such the material used for this part needs a sufficiently high yield strength and be possible to process with accurate dimensions. The weight is also critical since it will affect the balance of the product and the force required to raise the lamp.

The material chosen for the lampshade and upper arm is medium to high strength aluminium from the 6000 series, meaning it is alloyed with magnesium and silicon. The Al-Mg-Si alloys are good for producing thin surfaces with a high quality finish (De Graeve and Hirsch, 2013). Aluminium is used in many technical products such as computers, mobile phones and tablets and is therefore connected to high quality and technical functionality. It is further a lightweight metal with high strength, high thermal resistance and great recyclability.

The lampshade and upper arm can be manufactured in two possible ways, depending on the volume of production. The first method is investment casting, which according to Swift and Booker (2013) is a useful process for low and medium size volumes. The method allows metal production of components with high accuracy, versatility, repeatability and excellent surface. The process starts with a mould that is used to generate a wax pattern of the requested shape, see Figure 45. To coat the pattern a refractory material, a ceramic slurry and finally a binder is used. When the coating is done the pattern is slow fired in an oven to cure. The wax is then melted out, and the metal is put into the mould. When the metal is casted the mould is destroyed to remove the part. An advantage compared to other casting processes is that investment casting

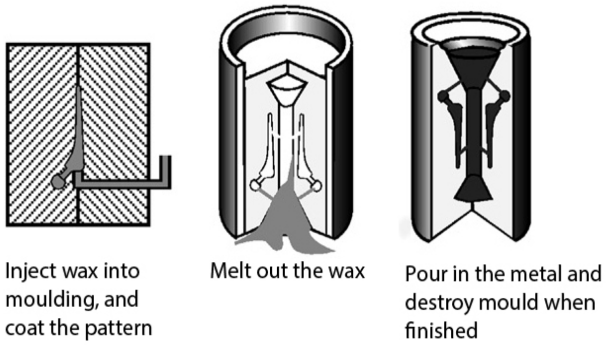


Figure 45. *Investment casting (Image source: Swift and Booker (2013)).*

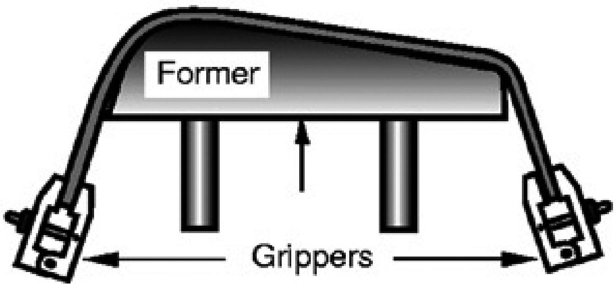


Figure 46. *Stretch forming (Image source: Swift and Booker (2013)).*

requires either small or no draft angles at all (Swift and Booker, 2013).

According to Hackås Precisionsgjuteri AB (2013) an estimated tool cost for the production would be circa 40 000 SEK.

A more economical alternative of production is to use the manufacturing method sheet metal forming, which include many different processes. The most common processes are deep drawing, bending, stretch forming and roll forming. The method is suited for medium to high volumes and provides a low cost production (Swift and Booker, 2013).

By using bending and stretch forming, see Figure 46, the part can be shaped from one single metal sheet. This will however create a splice somewhere on the lampshade. When making the part out of sheet metal the arm will also have to be thinner than it could be when using a casting method.

7.4.1.2 Lower arm and base

In order to keep the weight and cost of the product down, it was decided that the lower arm and the base of the product should not consist of aluminium as used in the part above. This decision is also based on the lower strength requirements of the parts. The main focus of the parts is instead a high surface finish and a durable construction.

Since polymers in general possess a low price and weight it was decided that these parts should be manufactured in some kind of plastic. When looking at similar products with high surface finish, Acrylonitrile butadiene styrene (ABS) seemed to be the most suitable choice. ABS plastic does according to Smith and Hashemi (2006) provide properties such as good impact and mechanical strength. It further possesses a high surface gloss, rigidity and is easy to process.

The manufacturing process suggested for the

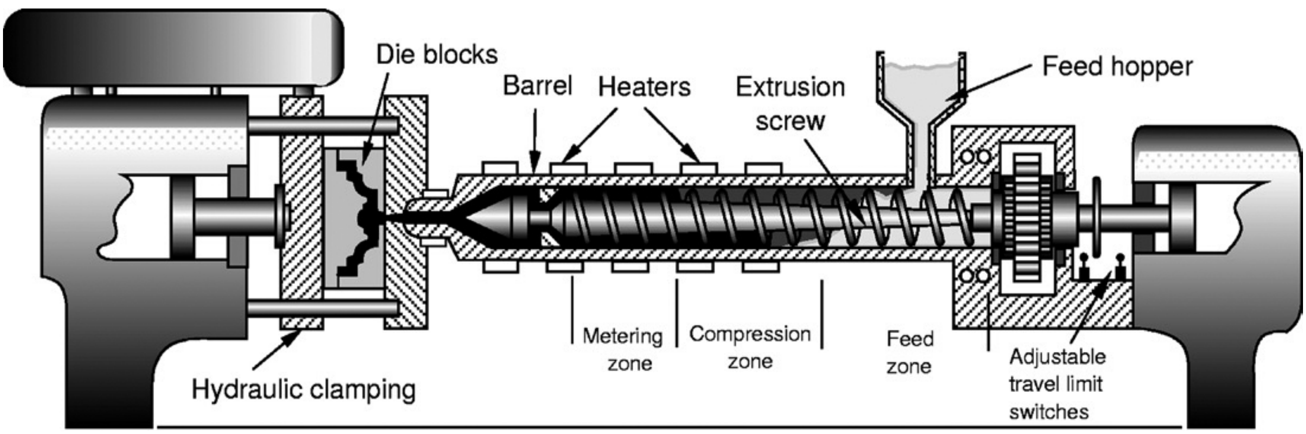


Figure 47. *Injection moulding (Image source: Swift and Booker (2013)).*

lower arm and base is injection moulding. That is because the part has a rather complex shape that can not be processed in many other ways. Swift and Booker (2013) suggests injection moulding for high precision complex parts that requires excellent surface detial. The process uses granules of polymer which are heated and then forced into the die under pressure from a screw, see Figure 47. When the material has cooled, the part can be seperated from the mould.

According to Pari Plast AB (2013) the estimated tool cost of the production via injection moulding would be circa 80 000 SEK.

7.4.1.3 Lamp housing

Since the lamp housing is constructed by simple flat surfaces and its purpose is just to contain the internal components it does not have any specific durability requirements. The focus of the material is instead mainly aesthetic since part of the covers will be visible. The material should also have a relatively high thermal resistance, since the area around it could get quite hot. It is also preferable that the material is light so as to not add too much weight to the top of the product.

In order minimize the amount of materials and give the product a coherent visual appearance, ABS should be used for the lamp housing as well. ABS is as mentioned a good alternative for high quality surfaces with low weights. It does also, as mentioned by Thompson (2007) have a high thermal resistance.

The upper housing has the shape of a rectangular, open box which is suggested to be manufactured through vacuumforming, which according to Swift and Booker (2013) is a cheap and easy way of processing open plastic containers. The part will be transformed out of a plastic sheet, that is softened to a forming temperature by heating elements and pulled under vacuum onto the surface form of a mould, see Figure 48. Swift and Booker (2013) further suggests the use of vacuum forming for low to medium volumes of production, since this makes the process economically feasible.

The bottom part of the housing consists of a simpler shape, namely a sheet with cut out holes for the light diffuser and ventilation. This part is suggested to be cut out from from plastic sheets and milled to create ventilation holes and mounting for the light diffuser.

7.4.1.4 Tray

The tray is the part of the product that probably will be exposed to most dirt since the plants will be placed on this area. Therefore the important functions of the tray are that it is water resistant, easily cleaned and scratch resistant. The tray further has to be of relatively low weight since it should be easy to lift. It also has to be stiff in order to handle the weight of the pots and the plants.

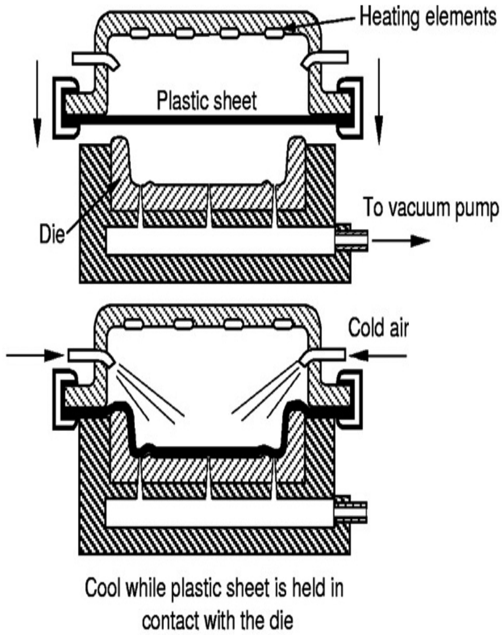


Figure 48. *Vacuum forming (Image source: (Image source: Swift and Booker (2013)).*

With these requirements the choice of material was once again ABS plastic. This is because of the previous mentioned properties that fit for this part as well. To use of the same material as the lower arm and stand is further a way of making it possible to use the same colour for the different parts, which could be hard if the parts consisted of different materials.

Because of its simple shape the tray is, as the upper housing suggested to be processed through vacuum forming.

According to PR-Plast (2013) the estimated tool cost for the lamp housings would be circa 45 000 SEK and for the tray 31 500 SEK.

7.4.1.5 Light diffuser

The important functions of the light diffuser is to let through as much light as possible while at the same time diffuse the light if the user accidentally looks directly into it. The diffuser should not spread the light further than the dimensions created by the reflector but it is however favourable if it spreads and evens out the light within this area. To enhance the perceived effect of the light it is also preferable that the light spreads within the material of the diffuser to create a large illuminated surface rather than a single bright spot. The light diffuser should further be durable and water resistant in order to protect the multi die chip and its circuit board.

The materials that seem best fitted for the diffuser are polymethyl methacrylate (PMMA) and polycarbonate (PC). These materials have similar properties and are both used for similar purposes. They are according to Thompson (2007) mainly used for their combination of mechanical properties, clarity, impact resistance, surface hardness and gloss. PC is considered the toughest clear plastic, but it is a more expensive alternative than PMMA, and since the strength of this part is considered to be enough with PMMA, this was the chosen material.

Since the diffuser is a simple sheet of plastic with a single side treatment, and since there exist suppliers that are specialized in the material, it is suggested that the manufacturer of the product buys this part from a supplier.

7.5 Software and interface design

The major decisions to be made regarding the product interface were which options that should be available and where the interface should be located. Since the intensity can be adjusted for individual dies in the multi die chip, the product is able to put out a wide variety of spectrums. To make use of this together with the scheduling functions requires an interface with a display that can visualise all the possible settings. To keep down costs it was decided that no display would be incorporated in the product and that the advanced settings would instead be adjusted through an application running on a computer, smartphone or tablet. Apart from avoiding the cost of a display, the application also makes it possible to monitor and interact with the product remotely. However, assigning functionality to a separate device introduces new problems. The user might not have access to the application at all times and being forced to use a separate device when making temporary adjustments to the light would be time consuming. To avoid this, some settings can be accessed on the product itself.

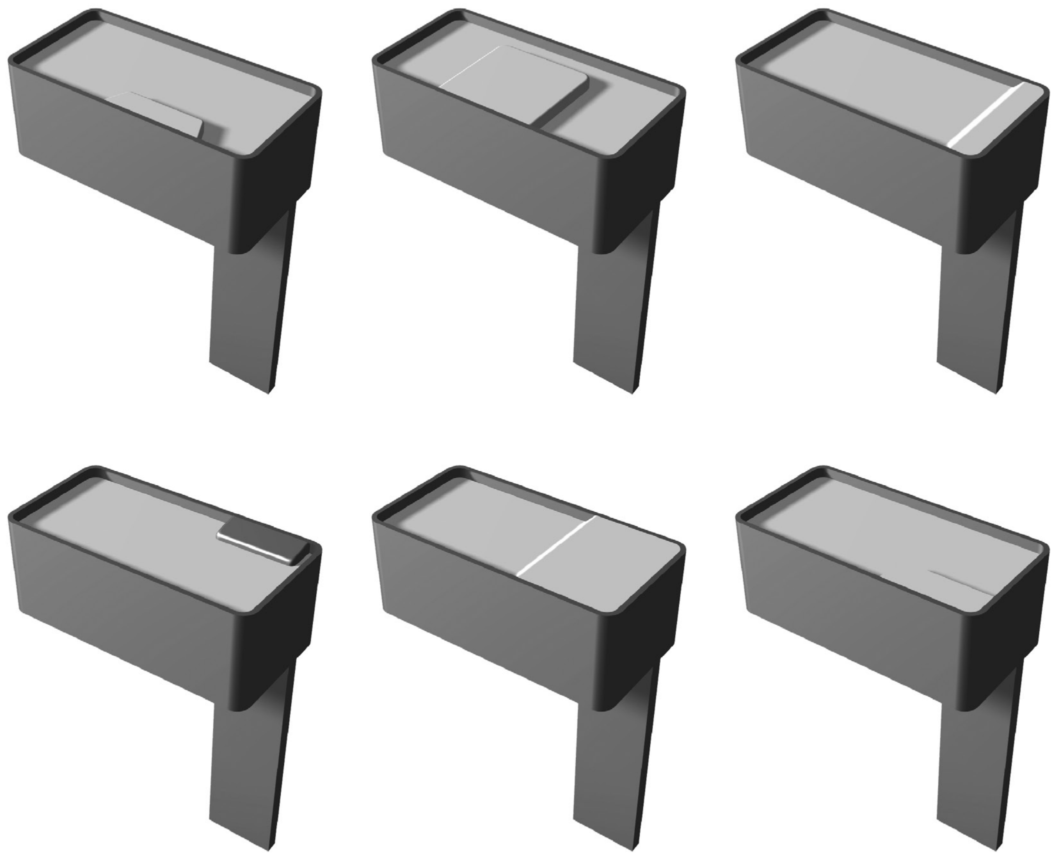


Figure 49. *Different possible placements of the interface.*

7.5.1 Product software and interface

Several options for the product interface were discussed in relation to the user's needs and the different situations that might arise. For example, if the product is placed in a kitchen, the user might want to temporarily suspend the schedule and switch to a more balanced and dimmed light while eating. Another scenario is that the user does not have access to the application but still want to provide a light beneficial to the growth of plants. To make this possible, a system based on different modes is used. The different modes are: *Schedule* which follows the light spectrum and timer settings made in the application, *Grow* which provides a general plant adapted light and *Comfort* which provides a neutral light akin to regular indoor lighting. The *Grow* and *Comfort* modes do not follow any timer settings; instead their intensity can be adjusted from zero to a hundred percent.

Since the main functionality of the product is to run according to the schedule it needs to remain in standby mode while the light is not on. The power switch is therefore placed on the back of the product away from the rest of the interface to make it more clear that it should only be used when the user wish to completely cut power to the product.

Regarding the placement of the rest of the interface, the two main options are to integrate it with the foot or the lamp head. To come to a decision a pros and cons list was compiled and several sketches produced. The main advantage of integrating the interface with the lamp head is that the proximity to the multi die chip creates a closer connection between interface and function. The wiring is also made simpler by placing all the electronic components close together. Integrating the interface with the foot would make it more accessible but increase the risk of spilling water or soil on it. Together with the more complicated construction, this was determined to be a big enough drawback to reject the idea and it was decided that the interface will be integrated in the lamp head.

In order to determine the optimal placement of the interface, several variations were visualised, see Figure 49. The different ideas were discussed and evaluated based on construction, ergonomics and aesthetics.

7.5.2 Application software and interface

The main purpose of the application is to provide a higher amount of control over the the product's functions than what is possible through the product interface. As such the application should provide the possibility of setting schedules where light spectrum and duration can be programmed. The application should also be focused on making complex settings easily accessible. It should therefore contain preloaded schedules suited for different plants and situations. However, since the product could also appeal to enthusiasts with a deeper interest in cultivation, the application should also have a more advanced level of settings where the user can tweak the intensity of individual wavelengths.

To make the software accessible it should be available on as many platforms as possible. This is achieved by making it scale well over different display sizes and making it usable on both touch based interfaces and with other types of input devices.

8. Final results

The developed product, called Enlight, is a product focused on providing the light conditions that makes it possible to grow plants indoors all year round. By utilizing LED technology Enlight can tune the spectrum of the light to suit different plants and different stages of their lifecycles. The name Enlight is thought to correspond to the brand of Heliospectra and the product's main focus.

Figure 50. *The final product - Enlight*

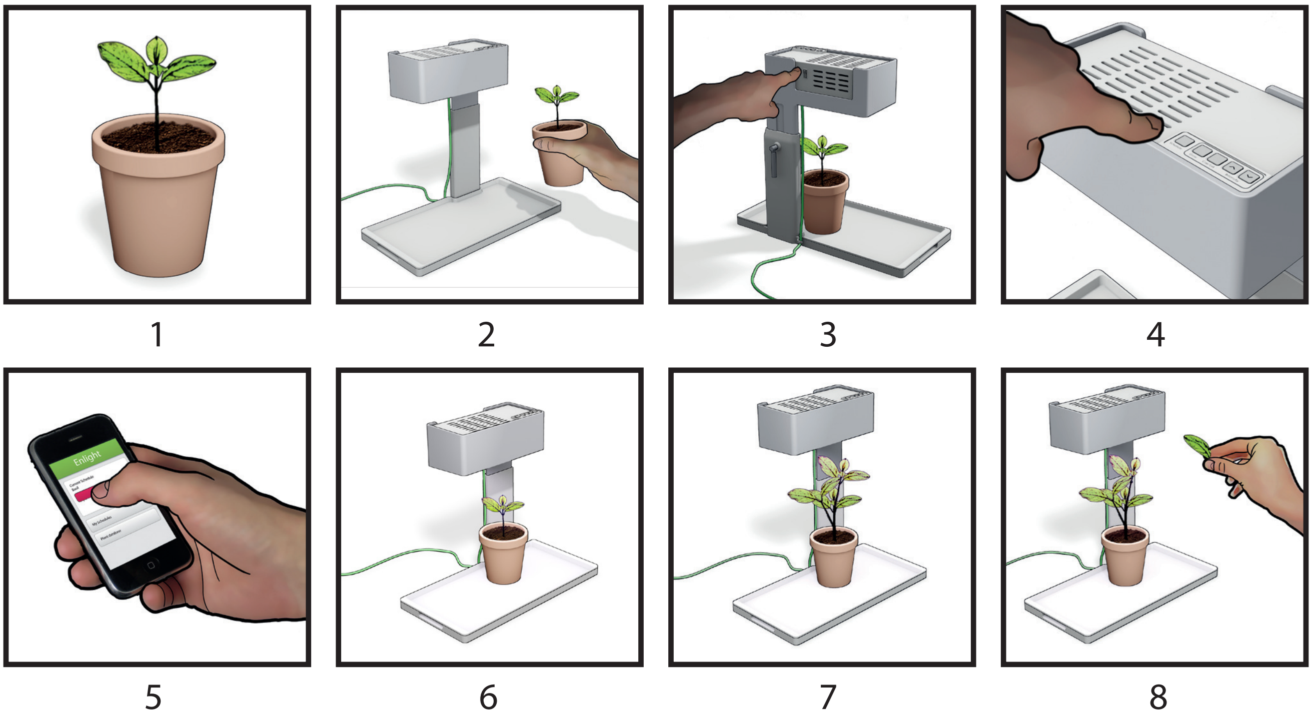


Figure 51. *A typical use scenario. 1. Grow a seed in a pot. 2. Place the pot on the defined cultivation area. 3. Turn on the product by pressing the switch at the back of the product. 4. Set the light to the desired setting. 5. If wanted, choose your schedule in the application. 6. Let the plant grow. 7. If needed, raise the height of the light source. 8. Enjoy your fresh plant.*

8.1 Functions and use

Enlight is a product that should make indoor cultivation easier without entirely taking control away from the user, see Figure 50. As such it has an accessible interface that does not overwhelm the user with options. Instead, many of the advanced options are accessed via a software application that let the user explore all the possibilities at their own pace. In this section, a typical use situation is explained together with a presentation of the interface of both the product itself and the application. The required care and maintenance is also detailed. For a typical use scenario, see Figure 51.

8.1.1 Cultivation

A typical first time use situation for *Enlight* would be that the user has a pot with seeds or a seedling that they want to cultivate. The user can then put the pot on the tray and if necessary adjust the height of the lamp head to ensure optimal illumination. When turned on the multi die chip will be set to *Grow* and the user can at this point leave the lamp to itself for the time being. If the user has installed and become familiarized with the application, they can instead select a premade light schedule or create a new one based on the recommendations provided by the software. When switched to the schedule setting, *Enlight* will provide the selected light condition for the plants without further input and the user can feel confident that the plants will thrive in their new light environment. If the plants are watered and cared for, the user will soon be able to enjoy the fully grown plants.

Enlight provides flexible placement options on tables, counters and windowsills. The only requirement is a nearby power socket since the product needs electricity to function. The product is focused on edibles such as herbs and small fruit bearing plants, but can however be used to grow most indoor plants depending on size. *Enlight* does not provide an integrated container for the plants and is instead dependent on the user's own pots and cultivation boxes. The users simply plant the seeds or whole plant in the cultivation container of their choice and place it on the product's tray.

The product will provide the light conditions necessary for growth. It is however up to the user to provide the plants with other necessities, such as water, nutrition and appropriate temperature conditions.

Since light conditions and cultivation possibilities change with the seasons, some users might not have a need for the products cultivation capabilities all year round. If that is the case, the changeable spectrum of the multi die chip makes it possible to use *Enlight* as a regular desk lamp instead.

8.1.2 Product interface

The power switch of the product is placed on the back of the lamp head, integrated in the plastic cover, see Figure 52. The reason for the placement is to keep the switch as discrete as possible, since it should only be used when the user wants to completely cut the power to the product. The placement of the switch is also a way of simplifying the wiring, since all of the technology is placed inside the lamp head.

Figure 52. *Placement of the power switch.*

The rest of the product interface is placed on top of the lamp head in the bottom right corner, see Figure 53. In this position it is easily accessed and the proximity to the components that it controls makes its purpose intuitive. The interface is made up by a panel with five buttons with the same width as the arm on the opposite side, in order to follow the basic shape of the lamphead.

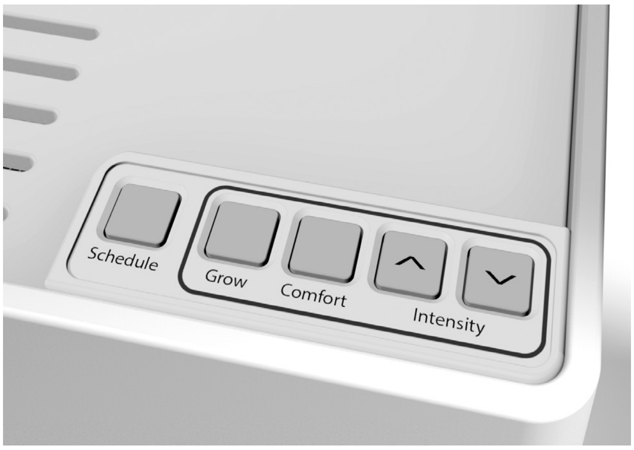


Figure 53. *Placement of the product interface.*

The interface provides three different options; schedule-, grow- and comfort light. Further, there are two buttons to decrese or increase the intensity of the light when set to *Grow* or *Comfort* mode. The light intensity can not be adjusted on the product when the lamp is in the schedule mode. This has to be done by adjusting the schedule in the application. The reason is that the user may forget that the intensity has been changed which would disrupt the schedule settings. In order to show that the light intensity buttons are only connected to the grow and comfort light there is a coloured border separating the four buttons from the schedule setting. The active mode will be indicated by a light in the splice surrounding each button, see Figure 54.

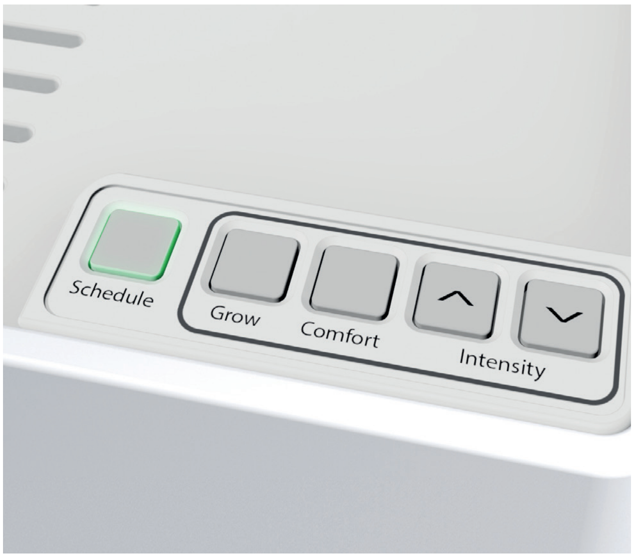


Figure 54. *The active mode is indicated with a light.*

8.1.3 Application

The suggested application interface consists of a home screen where the currently active schedule is displayed as a timeline. The timeline include a colour representation of the light spectrum as well as the time intervals in which it is active, see Figure 55. From the home screen the user will also have the option of accessing the schedule settings and a database of commonly cultivated plants. The database will contain information about the requirements and use of the plants. It will also present plants with similar characteristics that can be cultivated together and recommend suitable light schedules, see Figure 56.

When accessing the schedule settings the user will be presented with a list to which schedules can be added and removed. For each schedule in the list, the name and time interval will be visible as well as an indication of whether the schedule is currently active or not. The schedules can be activated or deactivated directly in the list and the user can also select them to get a more detailed view of their spectrum and timer settings. In the detailed view it is also possible to adjust the start time for the schedule.

When adding a new schedule to the list the user will have the option of either selecting a premade schedule or creating a new one. The creation of a new

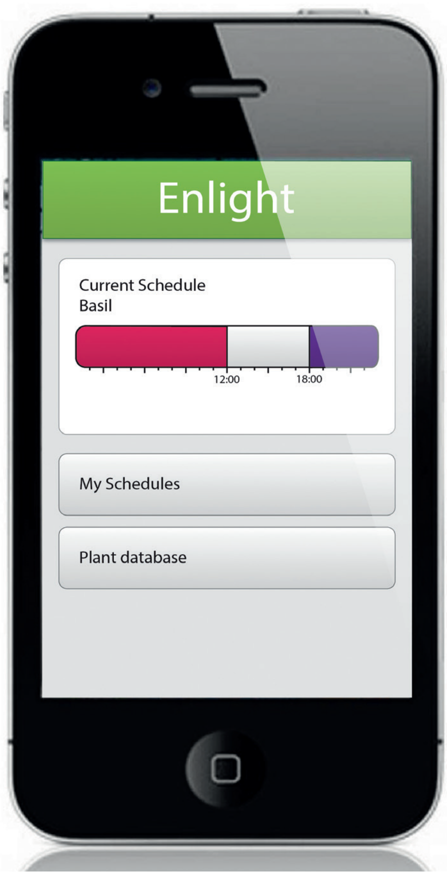


Figure 55. *Home screen of the application.*

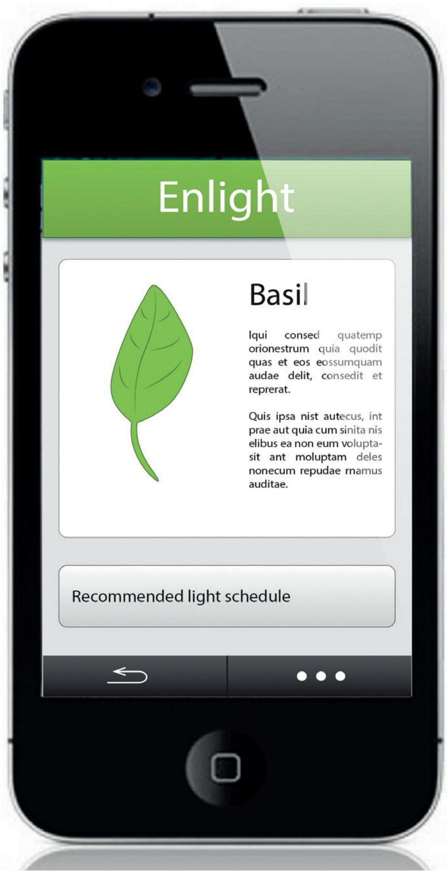


Figure 56. *The application database.*

schedule give full freedom for setting intensity levels for each wavelength and the time interval for when it should be active.

The data from the application is transferred to the product primarily via Bluetooth but there is also a USB-connection available if the user does not have access to any Bluetooth devices.

8.1.4 Cleaning and maintenance

The maintenance of the product is kept simple with the use of uncomplicated shapes and water resistant materials. The main areas that will require cleaning is the top of the lamp housing and the tray, since these parts will be most exposed to dust. The tray might also require cleaning due to soil and water spill. Because of the possibility to separate the tray from the rest of the product it can easily be washed, see Figure 57.

Figure 57. *The tray is detachable.*

Since the top of the lamp housing will contain air holes, a fine mesh is placed on the inside to limit the amount of dust that gets into the housing. While the product is active, the constant jets of air from the SynJet module should prevent any buildup of dust that might affect the performance of the heat sink. Furthermore, the dust that gets into the housing can exit through the air holes in the bottom.

An area that might require cleaning to optimize the effect of the product is the light diffuser placed on the underside of the lamp housing. If this area gets dirty it could prevent the light from reaching the plants with full effect. The area is however, as the rest of the product easily cleaned with a dishcloth. To prevent dirt from getting on the inside of the diffuser where it would be difficult to remove, the diffuser, together with the multi die chip and the reflector, is entirely encapsulated.

8.2 Technical principle

Enlight spreads the light from the multi die chip with the use of a reflector. The heat produced by the chip is dissipated through a heat sink that is cooled off by the use of a SynJet module. Both the lighting and heat management components are regulated via a central circuit board that connect to the product interface. The height of the lamp head can be adjusted via a telescopic connection between the two arm components. In this section, the technical principle of these functions will be explained.

Figure 58. *The height adjustment is made using the lever placed on the back of the product.*

8.2.1 Height adjustment

The height of the lamp head is adjusted telescopically by moving the upper arm inside the lower arm. Fastening the arm is done by turning a lever at the back of the lower arm which moves in a threaded track and puts pressure on the upper arm, see Figure 58. The fit between the two arm parts will be tight enough that the upper arm is prevented from falling freely even when not fastened to prevent damage to the plants and the product. A stop at bottom of the upper arm prevents it from detaching when raised to the maximum height. In total, the lamp head can be raised 30 centimetres, giving a total distance of 50 centimetres between the tray and the bottom of the lamp head.

8.2.2 Lighting

The asymmetric design of the reflector allows it to be placed off center in relation to the tray while still illuminating the cultivation area. Its reflective walls direct the light downwards which will both increase the concentration of light and allow the different wavelengths to blend. This will also help to reduce the risk of direct glare.

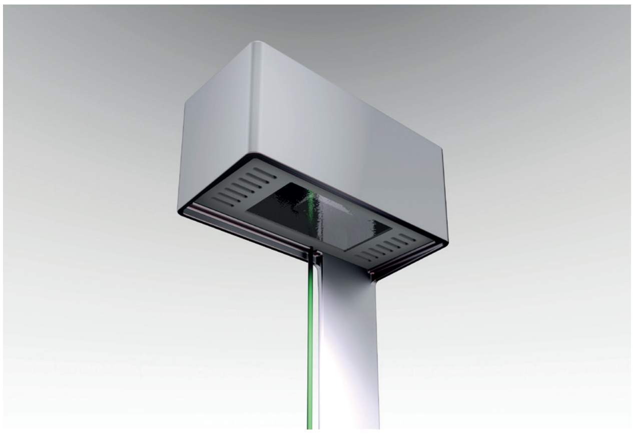


Figure 59. *The vents will let in cold air and let the warm air out in order to prevent overheating.*

8.2.3 Airflow and heat management

To ensure that air circulates within the lamp housing, it is perforated with air holes on all exposed surfaces. Air from the surrounding environment can rise through the openings in the bottom surface. Once inside the SynJet module will keep the air around the heat sink moving and heated air can exit through the openings in the top and back of the lamp housing, see Figure 59.

In order to not use unnecessary energy, the output of the SynJet module will be connected to the effect of the multi die chip. This will for example allow the SynJet module to run at a lower output level if *Enlight* is used as a regular lamp at a lower intensity.

8.2.4 Wiring

All the electronic components used in the product are gathered in the lamp housing. The wires from the SynJet module, the multi die chip and the circuit breaker connect to a circuit board placed underneath the interface.

Figure 60. *The power cord exits from the lamp head in order to simplify the wiring.*

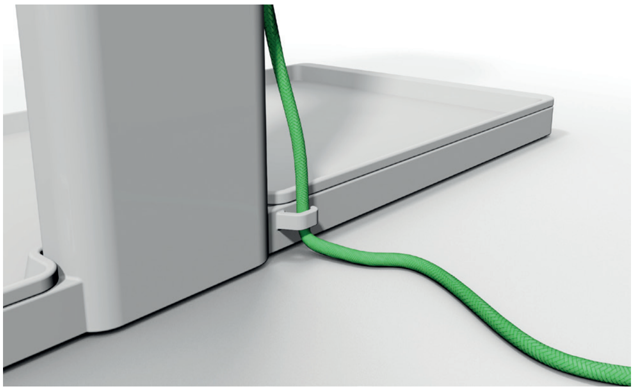


Figure 61. *The power cord is fastened to a hook placed at the base of the product.*

The buttons on the top of the lamp housing are directly attached to the circuit board to avoid unnecessary wiring. To avoid the complexity involved with wiring within the telescopic arm, the power cord exits from the bottom part of the lamp housing next to the arm, see Figure 60. The cord is clad in textile to give it a smoother shape and at the base of the product is a hook that can hold the cord so that it can be kept straight and not be in the way, see Figure 61. Further down the cord is a plastic housing containing the ballast for the multi die chip and the SynJet module.

8.3 Product identity and expression

Enlight is supposed to be a product that expresses a combination of high level technology, Swedish design and environmental friendliness. These expressions have been integrated in the shape, materials and colouring of the product.

8.3.1 Shape

Enlight is formed out of simple shapes and few parts which creates a focus on functionality, see Figure 62. In the different desired expressions functionality is a common ingredient, which can be seen in the imageboards in section 5.2. The technology board displays products with basic shapes constructed with distinct interfaces, making the use obvious for the user. The image board representing Swedish design language focuses on products with few parts and no unnecessary features, making the products express simplicity and functionality. The environmental friendliness board also presents products with simple constructions, few parts and high functionality.

8.3.2 Materials

The product is constructed mainly by aluminium and ABS plastic, which is an attempt to decrease the amount of materials, while at the same time fulfil the desired expressions. The use of few materials is consistent in the three image boards, where the representative products most often are constructed by only one or two visible materials. The products seen in the

Figure 62. *The different views of the product.*

technology imageboard are in many cases constructed by a metal in combination with a shiny plastic material. The use of a metal gives the product a sense of quality, which is common in products with advanced technology since these products are supposed to be durable and protect the expensive components inside. In the Swedish design image board, plastics are not as commonly used. The combination of two materials does however seem to be a common feature in these products as well. The environmentally friendly products are often constructed from natural materials with surface finishes that does not hide the materials' origins. Metal and plastics may not be materials that are perceived as environmentally friendly. However, aluminium is in general perceived as a sustainable material because of its possibility to easily be recycled. The low amount of materials used in the product may further enhance the sustainable feeling because of its simple material separation.

8.3.3 Colouring

The colouring of the product is kept simple and discrete. The aluminium panel maintaines its natural colour, and is uncoated in order to clearly show the material properties. This makes it stand out from the rest of the product which puts focus on the lamp head, which is desired, since this is the most important part of the product.

The ABS plastic parts of the product are all provided with the same colour, in order to simplify the production and maintain a clean appearance. The colour chosen for these parts is a light grey one, with the NCS-code S 0500-N, see Figure 63. The colour choice is based on the desire of keeping the plants in focus and providing a product that is neutral and fits into most households. The colouring is further a way of making the product correspond to the desired expressions.

The technological products found in the imageboard are all coloured in a grayscale, which puts a larger focus on their technological features rather than their appearance. This is desired in *Enlight* as well, where the light and plants should be in focus. In the Swedish design image board the use of light colours are common, which provides a clean appearance to the products, making them suitable for almost any home. The distinct colours further highlight the functionality of the products, which as mentioned is requested in the cultivation lamp as well. The environmentally friendly products are mostly kept in their natural colours, which puts focus on the material. This is desired for the lampshade as well; it should be obvious that it is constructed in aluminium, in order to highlight the material's characteristics and associations.

The placement of the power cord may seem as a simple and unattractive way of solving the wiring. However, instead of trying to hide the power cord as an inconvenient necessity, it has been given a distinct colour to enhance its appearance. The green colour is chosen to create contrast between the cord and the rest of the product, while at the same time provide a connection with the plants.

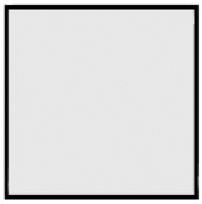


Figure 63. *The colour chosen for the ABS plastic parts.*

8.3.4 Stability

Because of all the demands from the different components, the lamphead has been made relatively large compared to the rest of the product. This could give the impression that the product is unstable and top heavy. The product has been shaped with the intent to counteract that impression by a couple of means. By making the lampshade and upper arm into a single part and by placing the lamphead at the edge of the cultivation area, directly on top of the arm, the construction will look more stable. In the evaluation seen in section 8.3.3, the shape that inspired the final design was rewarded with a much higher rating in the expression of stability. The reason was, according to the respondents, that the single piece shade and arm felt more stable because there exist no splices. The placement at the edge of the cultivation area was further said to make the lamphead look like it is standing on the arm, instead of hanging from it, as in the other evaluated shapes.

Another way of increasing the expression of stability was giving the product a base with a large surface area. The stand is made in the same dimensions as the tray, which is an area approximately three times larger than the area covered by the lamphead. The stand further has raised edges where the tray is placed in, making it look thicker and more stable.

The possibility that the product will be perceived as unstable is further counteracted when the it is put to use. With a number of pots placed on the tray, the visual impression of the product will be more balanced due to the size and weight of the pots and their content.

8.3.5 Efficiency

A possible problem with using a multi die chip is that it could be perceived as insufficient to illuminate a large area, since the diodes are placed in such a narrow footprint. This is, as proven in the light tests not the case, but the user could still perceive it as such. In order to make the multi chip feel efficient enough the product has been constructed with an oversized housing and light diffuser. When the product is turned on the entire light diffuser will be lit, and this is supposed to make the area of the light source feel bigger and hence more spread out.

Another factor that may affect how the efficiency of the product is perceived is the placement of the lamphead. Placed at the back edge of the product it may be perceived as if the light will not reach the front edge of the cultivation area. This is however not the case thanks to the reflector. As a way of communicating that the light will actually reach the whole cultivation area the lamphead panel has been modified. The sides of the panel are kept straight to indicate that the light is directed downwards and not meant to spread within the environment. However, the lamp panel has a slight chamfer on the bottom in order to communicate the angle of the light, see Figure 64.

Figure 64. *The lamp panel has a slight chamfer to communicate the angle of the light.*

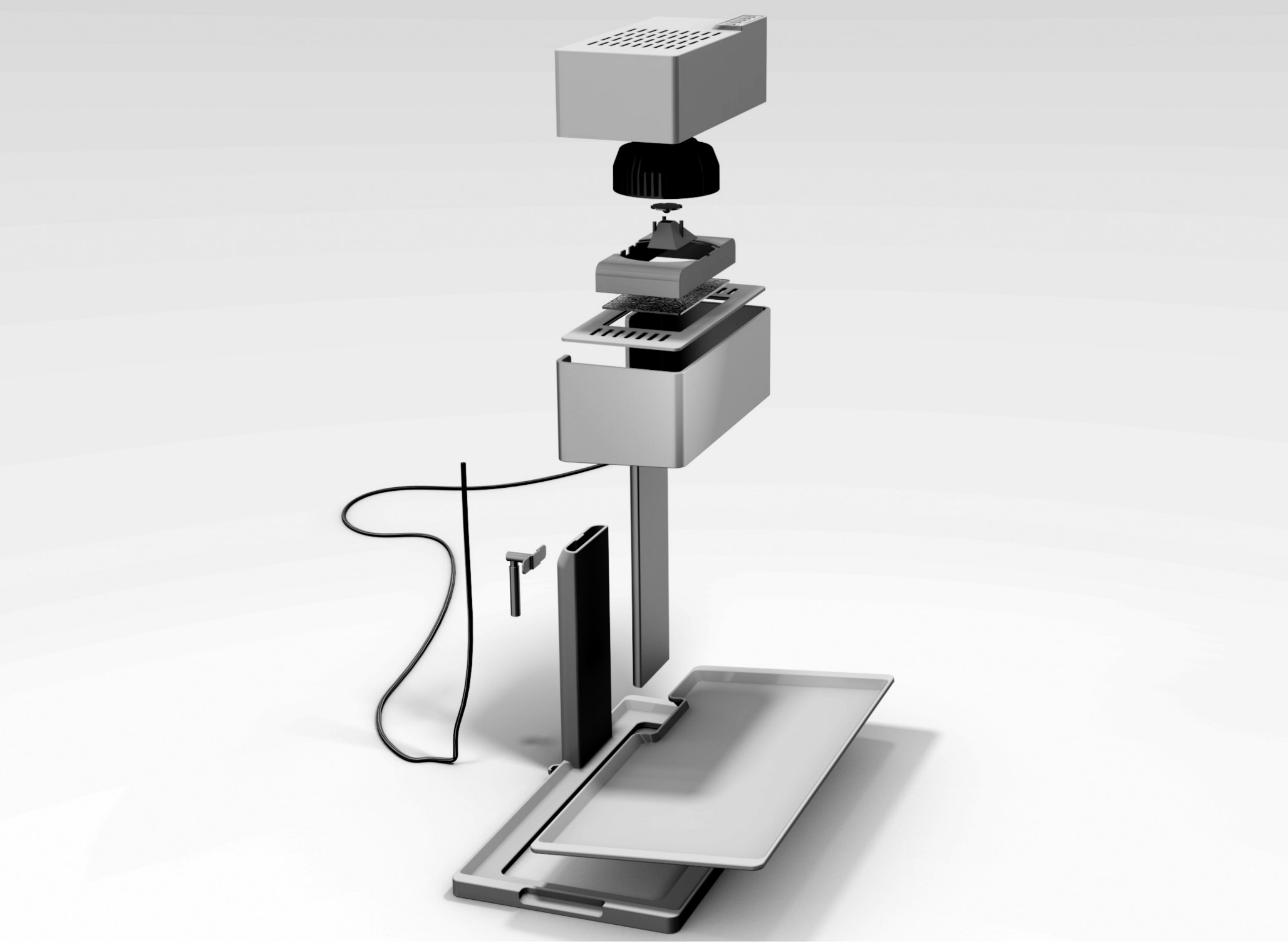


Figure 65. The fourteen main parts of the product.

8.4 Specification of construction

The product is constructed out of fourteen main parts, as seen in Figure 65. The parts are connected to each other by a simple assembly. The tray is the only part that is detachable, while the other parts are assembled together. The lampshade and upper arm are placed in the lower arm, and with the help from the trail on the back of the upper arm, it is held in place by the height adjustability lever.

The reflector and light diffuser is glued on to the lower lamphousing, before screwing the heat management and light source in place. The upper lamp housing is then glued togheter with the lower lamp housing and screwed in place onto the lampshade's extruded platform, see Figure 66. For a better understanding of the different parts, see the drawing in Appendix 13.

Figure 66. *The lamphousing is screwed in place onto the lampshade's extruded platform.*

9. Testing and verification

This section presents an evaluation of the final product, where it is possible to see if the product fulfils the demands that have been set up throughout the project. The illuminative capabilities of the product were tested by conducting a new light test is on a prototype of the reflector construction. A cost analysis was conducted to evaluate and compare the cost of the product to the desired target price. The product appearance is further evaluated by comparing it to products on the market and finally the product's environmental aspects are evaluated with the use of the eco strategy wheel.

9.1 Prototype

In order to evaluate the functionality of the multi die chip and the reflector as they would appear in the final product, a model was printed in a 3D printer, see Figure 67. Apart from the reflector, the model also included a housing component. Due to the wiring of the test unit, it was not possible to achieve a perfect physical representation but the functionality should still be comparable. This meant that the reflector and subsequently the housing had to be made five millimetres taller than in the actual product in order to produce the correct spread of light.

Figure 67. *A 3D printed part representing the reflector and housing component surrounding it.*

In order to increase the light intensity, the inside of the reflector was clad in a reflective paper material. A PMMA sheet of the same type used in Heliospectra's other products was attached to the opening in the bottom of the housing in order to diffuse the light and blend the different colours more evenly, see Figure 68.

Figure 68. *The light diffuser attached to the reflector.*

A new light test was conducted in order to evaluate the effect of the prototype's construction. The proceedings were similar to the previous light tests, where the light source was held on different heights and measured at different vertical distances. Tests were conducted both with and without the use of reflective material in order to see the difference it made to the light intensity and spread. The results of the tests can be seen in Table 11.

Height/width	0	100	150	200
200	210,0	148	105,1	66,4
150	415,0	254,2	100,8	80,3
100	N/A	444,9	153,4	64,0

Height/width	0	100	150	200
200	195,0	124,9	84,7	63,3
150	361,1	230,0	95,8	63,8
100	N/A	671,4	112,1	60,9

Table 11. *The results form the new light test, with and without the use of a reflective material, calculated in µmol photons*m^{-2}*s^{-1}.*

The light test without the reflective material attached showed that the light intensity increased close to the center of the illuminated area with values of over 400 µmol*m^{-2}*s^{-1}. In contrast, the values decreased for the off center measurements, especially at 200 millimetre. This could be due to the PMMA sheet reflecting more light when the angle to the lightsource increase. To counter this, the walls of the reflector were angled when testing with the reflective material attached. This resulted in an overall improvement of the values but the desired light intensity was still not achieved at 200 millimetres vertical distance.

To further evaluate the light diffuser and its impact on the results, a final test was conducted without it attached. The results, see Table 12, shows a significant increase in light intensity of between 15 and up towards 50 percent for the different measurement points. The difference is larger further away from the light source which indicates that the PMMA sheet reflects more light as the angle of incidence increase.

Height/width	0	100	150	200
200	247,2	204,4	154,5	103,0
150	482,9	374,1	230,7	113,0
100	N/A	444,9	262,7	9,8

Table 12. *Results from tests without the light diffuser, calculated in µmol photons*m^{-2}*s^{-1}.*

Visually, the new reflector construction produced positive results. The PMMA sheet blended the light enough to remove any hints of colour shifts, see Figure 69. It was also mostly illuminated by the multi die chip although the reflector blocked out some of the light, see Figure 70. The results are still considered adequate from a visual point of view.

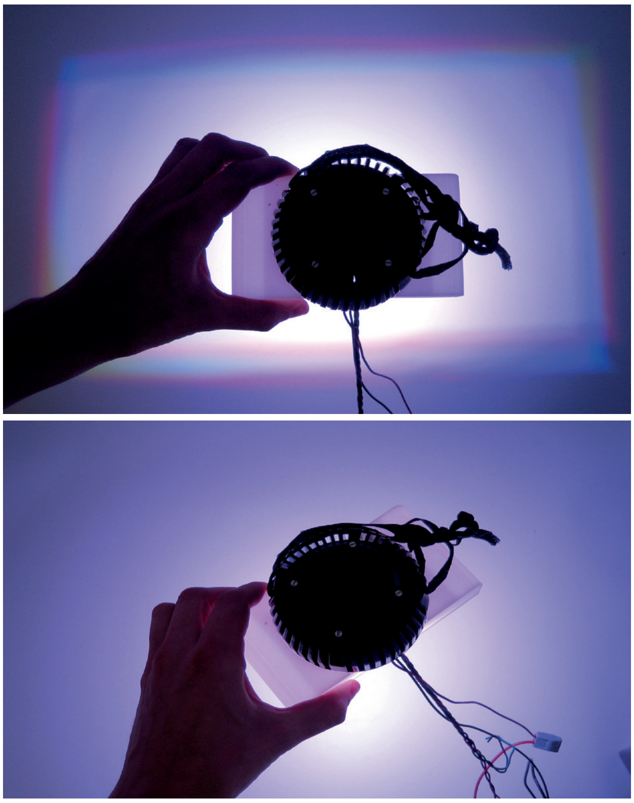


Figure 69. *The light without and with the PMMA light diffuser.*

Figure 70. *The reflector blocked out some of the light for the light diffuser.*

Figure 72. *The prototype with plants and the light turned on.*

Overall the values were improved compared to the previously conducted light test which shows that the prototype components have a positive effect. Towards the center of the product, the light is strong enough to reach the high-light plants requirement of 12 to 18 mole per square metre and day in 8 to 12 hours assuming no other light is present. However, this will not be possible at the edges of the cultivation area due to the decrease in light intensity.

In order to increase the illuminative capabilities of the product, a thinner or more transmissive sheet of PMMA can be used. However, it should not be entirely transparent since this will affect the visual appearance of the diffuser and increase the risk of glare.

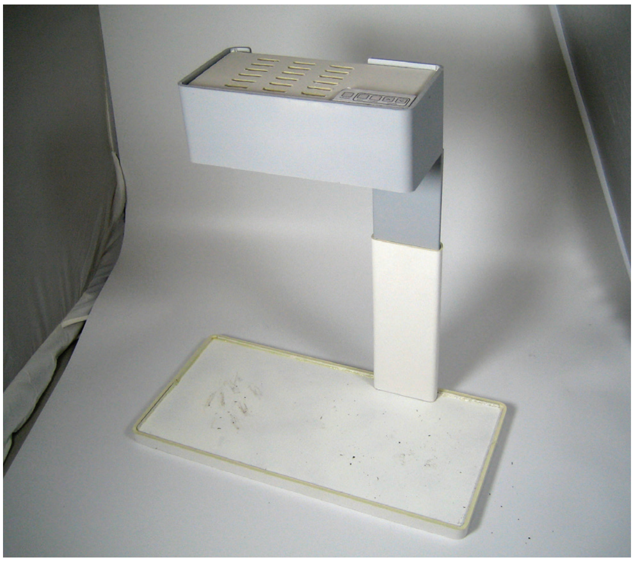


Figure 71. *A full scale model of the product.*

In order to get a better understanding of the product at large, a full scale prototype was build out of MDF-board and KAPA-board, see Figure 71. The prototype was further painted, in order to make a separation of the different materials. Different plants were placed on the product and the light was turned on to simulate a possible usage, see Figure 72.

9.2 Cost analysis

The result from the target costing suggested a component and manufacturing cost of 776 SEK, in order to fulfil the targeted retail price of 2500 SEK. To determine if the new product would be possible to produced to such a cost, a cost analysis was conducted. The cost of the components can be found in section 7.2.5, where the cost of the multi die chip and the heat sink with the SynJet module resulted in a cost of circa 305 SEK. These are the components that are estimated to be the most expensive. Additional costs of components will be the ballast, wiring, circuit board, keypad, Bluetooth and USB connection.

The material cost for the product is retrieved from the material selection program CES Edupack (2012), where a mean value of the cost was used, see Appendix 12. This resulted in a total material cost of 53.21 SEK per unit.

The tooling costs of the different manufacturing processes used for the lampshade, lamp housing, base and tray were estimated to a total of 196 500 SEK, which by dividing it to a volume of 10 000, would result in a tool cost of 19.65 SEK per unit. Additional costs will be added for the actual production of every part.

The different prices resulted in a material and component cost of circa 378 SEK. A cost calculation was created from the price, see Table 13. The different profit margins are, like in the target costing, included in the calculation.

Calculation	Cost elements	%-factor	Price (SEK)
	Material cost		378
-	Manufacturer's profit margin	X%	
=	Price to Heliospectra		
-	Heliospectra's profit margin	X%	
=	Price to retailer		
-	Retailer's profit margin	X%	
-	VAT	25%	
=	Retail cost		1218

Table 13. *The target costing calculated with Swedish VAT.*

The result shows a possible retail price of 1218 SEK. It should however be mentioned that this price is a result of costs calculated on mean values and estimations. The cost of the materials are numbers based on virgin material and as mentioned in section 7.4.1.1, this may not be representative if recycled materials are taken into consideration. The costs of the cooling components are further based on a consumer retail price. It is believed that the price of these components could be reduced with a higher purchase volume. Perhaps it is also possible to reduce the price of the components if they are customised and manufactured to the specific lamp instead of bought as separate products. The calculation does further not include costs of certain components, the manual labour connected to the manufacturing or the cost of post-processing and assembly. The price will therefore not be equal to the calculated retail price, but the analysis does however provide an indication of the possibility of reaching the target price. At this stage the difference between the calculated price and the maximum component and manufacturing cost is circa 400 SEK. So if it would be possible to buy the additional components and reach a production cost lower than 400 SEK per unit, it would probably be possible to produce the product to its intended retail price of 2500 SEK.

9.3 User acceptance test

To evaluate the expression and appearance of the product a user acceptance test was conducted. The respondents, which consisted of seven persons in the ages between 25-50, were asked to rank Enlight in comparison with six other products on the market, in terms of the expressions: Technical, Swedish design and environmental friendliness, see Figure 73. The respondents were handed a rendering of Enlight and pictures of the other products, and should with help from the different imageboards rank the products in the order that they best fulfilled the expression. The respondents were further asked to explain their rankings. A similar evaluation was also made regarding the product aesthetics.

The result showed that the desired expressions were fulfilled in the product, at least to some extent. In the evaluation of the technical expression Enlight got the very highest rating. It was said that the product's simple shapes, discrete use of colours and minimalistic design made it feel technical and that it corresponds to the products seen in the imageboard. Enlight was rated high in the evaluation of the Swedish design expression as well. It came in second place and was said to fulfil the expression because of its light colours and simple shapes, which made it feel functional and

Figure 73. *Enlight and the six other products it was evaluated against. (Image sources from left to right, up and down: Odla (2013); Suomela (2013); Decoracion2 (2013); Plant Factory (3) (2013); Wexthuset (2013) and Hasselfors Garden (2013)).*

clear. In the last expression evaluation, regarding environmental friendliness Enlight was ranked in third place. Some of the respondents said that it possesses the correct expression, but that it possibly lacked more natural materials. In the aesthetic evaluation Enlight came in second place, just one point after the winner.

When the expression and aesthetics of the product was evaluated the respondents were further asked to evaluate the usage of the product. Presented with a rendering of the product from different angles and its interface the respondents were asked to describe the way they thought the product and its different functions were to be used. The result was quite positive; most of the respondents had an estimation of how to use the product and its different features. They did not fully understand how the Schedule setting worked, but understood that it had something with time settings to do. The majority of the respondents had the correct perception about the Grow and Comfort settings, and understood that the intensity applied only to these two settings. The respondents further mentioned that the product could be height adjusted.

9.4 Sustainability

In order to evaluate the created product from an environmental perspective, the framework of the method called Eco strategy wheel has been used, see Figure 74. According to Swedish Industrial Design Foundation (2013) (SVID) the Eco strategy wheel is a tool to stimulate new ideas of how to make a product more environmentally benign. The wheel consists of eight main areas; optimize function, reduce environmental impact during usage, reduce diversity of materials, choose the right material, optimize the lifetime, optimize production, optimize waste management and optimize distribution.

Instead of using the tool as a brainstorming session to improve the product, as suggested by SVID, the method has been used as a tool for reflecting over the result of the products environmental impact and the possible improvements in this area.

Time (hours)	Duration (days)	Energy consumption (kWh)	Yearly cost (SEK)
16	365	206,4	196,12
16	150	84,8	80,60
12	365	154,8	147,09
12	150	63,6	60,45
8	365	103,2	98,06
8	150	42,4	40,30

Table 14. *An approximation of the product's energy consumption and yearly cost.*

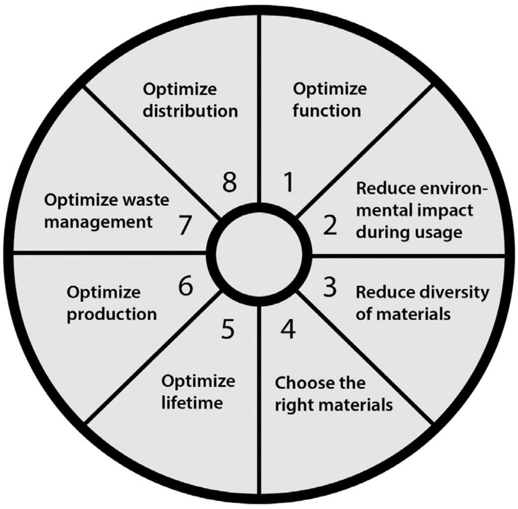


Figure 74. *The Eco strategy wheel.*

1. Optimize function

Compared to most of the similar products on the market, *Enlight* is focused more on the actual light generated for the plants. Since the lighting seemed to be the main problem with indoor cultivation, the focus of the project was to create a solution with better light technology than the majority of the market. There are however products with higher light intensity existing on the market, but these are mainly products for larger crops with higher demands. With the use of LEDs the intensity of the light can be improved and the spectrum can be adjusted to better fit the plant needs. The LED technology is further a better solution from a sustainable point of view, since it produces more light with less power consumption compared to other plant lighting solutions. The technology does also have a longer lifetime, which could result in a more economical and sustainable solution in the long run.

2. Reduce environmental impact during usage

The biggest environmental impact of the product during use is the energy consumed by the electrical components. An approximation of the total energy consumption is calculated for various use scenarios, see Table 14. It is primarily the multi die chip that affect the consumption but the SynJet module has also been included in the calculation. The calculations are based on two extreme cases, where the product is used every day of the year or five months of the year (an approximation of the time where it is impossible to cultivate outdoors in Sweden). The cost per kWh is based on an avarage electricity price in Sweden.

Comparing the consumption of the product to the average yearly amount of electricity devoted to appliances in households of different sizes show that its contribution might increase the consumption with a few percent. The extreme case of having the product running at full effect, 16 hours a day each day of the year result in a consumption of about 200 kWh. For an apartment using 3000 kWh a year for household appliances, this constitutes 6.9 percent of the total amount. However, in most cases the product would likely have less active hours per year.

When comparing *Enlight* to other types of grow lights, the advantage of using LEDs become apparent. Since the multi die chip is by far the largest contributor to the energy consumption of the product, the increase in effect required to produce the same amount of light with other types of light technologies would be almost directly proportional to the total consumption.

Determining if *Enlight* has less environmental impact per plant than large scale industrial cultivation is more difficult. According to Jordbruksverket (2012) the energy consumption for general cultivation in Swedish greenhouses 2011 was 215 kWh per square metre. For greenhouses specialized in tomatoes the corresponding figure was 345 kWh per square metre. To reach a similar yearly consumption with *Enlight* it could run at full effect for between 78 and 129 minutes each day which is too little time to satisfy the light requirements of most plants. While the energy consumption of the product might be higher per square metre than an industrial greenhouse, additional savings are done by avoiding the transportation of crop.

3. Reduce diversity of materials

By focusing on the light and avoid complex solutions such as an integrated hydroponic system, *Enlight* can be assembled from a small amount of parts. This has also made it possible to keep the number of different materials to a minimum as well. It would be possible to construct the product from only ABS plastic or aluminium. However, the reason to use a combination of the materials is to reduce the weight and cost of the product, while at the same time enhance the feeling of a high-end product and increase the durability, which hopefully lead to an extended usage of the product.

4. Choose the right materials

The materials chosen for *Enlight* has been evaluated with regards to their different properties, as seen in Appendix 12. The price, weight, aesthetic, durability and environmental aspects were taken into consideration when making the choice. It should however be mentioned that the materials were mainly chosen with regards to their technical properties rather than their environmental impact. The energy consumption and carbon dioxide emissions were compared against materials with similar properties, and more used as a way of confirming that the chosen material did not harm the environment far more than the other alternatives. It was however of high importance that the materials were non-toxic and provided easy recyclability.

5. Optimize lifetime

The LED technology has, as mentioned in section 2.3.1, a lifetime of between 50 000-100 000 hours, which is far more than other commonly used cultivation light sources. This provides *Enlight* with a longer lifetime for the light source, but it does not affect the products lifetime at large, as long as the light source can be exchanged. Focus has therefore been on using materials and support components with high durability as well. The intent was to make the rest of the product as durable as the LEDs. The materials chosen are presented as durable and resistant to the external factors found in the indoor environment. The choice of using an electric heat management without moving parts was also a way of optimizing the lifetime for the product. Without moving parts, the cooling system should be less fragile, compared to an electric fan where parts can get stuck and worn out.

6. Optimize production

The sustainability of the production techniques suggested for *Enlight* has only been evaluated to a small extent. The manufacturing processes have rather been selected for their suitability to the different parts and materials, with regards to price, suggested volume and aesthetic possibilities. A more thorough investigation of the environmental impact from the different processes is suggested as a part of the further development.

7. Optimize waste management

The waste management of *Enlight* has been simplified by reducing the amount of parts and materials in the product. The parts are further easy to disassemble; the ABS plastic lamp housing is for example simply placed inside the aluminium lampshade and can easily be removed. The same goes for the aluminium arm that is moving inside the ABS plastic lower arm.

The manufacturing processes creates different amounts of scrap, as for example a production of the aluminium part by sheet metal forming will probably produce more scrap than by producing it by investment casting. The materials are however recyclable so the scrap can be reused.

8. Optimize distribution

No investigation of different manufacturers and component retailers has been conducted during the project; it is therefore difficult to evaluate the distribution.

When comparing the transportation of the product to the transportation of plants brought in the store, one may think that the product will minimize transports in the long run. However, the user still has to buy soil and seeds to be able to use the product. But since the user is able to produce more edible plants over a long period of time, the consumption of store bought plants will hopefully decrease, which could reduce transportation overall.

10. Discussion

This chapter presents a discussion of the project at large. The discussion includes the process and the methods used. There is also a presentation of the lessons learnt and a paragraph with recommendations for the further development of the product.

10.1 Process

The pre conducted planning of the project differs from the actual execution to some extent. Some parts of the project became more time consuming than first expected. The reason is thought to be a result of a series of factors. For example, when planning the process it was thought that the concept selection phase would result in a decision of a final concept to move forward with. Instead the selection resulted in two concepts that needed further investigation in order to be created into a final concept.

Problems were also encountered during the thermal testing, which showed that larger dimensions than first expected were required for the cooling components. The difference in the project planning and the actual execution of it did however not have that big of an impact on the final result. Due to active choices, such as for example by focusing on creating a more basic prototype, most of the work has been corresponding to the initial project description and planning.

10.2 Methods used

When comparing the project planning and the final result of the project, there have been adjustments made regarding the methods used and the order in which they were executed. This is however regarded as an usual occurrence in research and development projects, since the design process is a nonlinear path. The majority of the predefined methods have however been used with good results.

In the research and analysis phase the methods were used in a different order than planned. The phase started out with a benchmarking in order to gain knowledge of the existing market. This was helpful for the further research since more knowledge of the different project opportunities had been received. Regarding the survey, which was the next step in the phase, a problem was to reach out to people that did not have a big interest in gardening. People who were interested in answering the survey were mostly reached through different gardening forums. Therefore the focus group, which was first predicted to be used on a selection of members from the whole target group, was instead used on younger people with less expressed interest in cultivation. The focus group was of great use in the project, since it provided information from a potential user group that had not been reached by the other methods. Namely the group of people who do not want to spend much time on gardening, but still wants to be able to have fresh vegetables and herbs in the kitchen.

The interviews with the gardening enthusiasts and vendors was also useful in order to get deeper understanding of the results received in the survey and knowledge of the market and its future predictions.

In order to structure all of the information gathered in the research phase a KJ analysis was constructed. This method is quite time consuming, although, it does simplify the creation of the specification of requirements. The tool could however have been skipped and the grouping of demands could have been done directly in the specification of requirements to save some time.

The three personas created was a good way of visualizing the different target groups, which made it easier to describe them for the stakeholder. It is easier to refer to a person by name, representing a target group, than referring to a group of different persons with the same demands.

The creation of the target costing was quite time consuming since it was hard to decide upon a target price from the information gained in the research phase. The respondents of the survey requested a low price, which is quite obvious since they did not have any deeper understanding of the features the product could offer. But with knowledge of the price of similar products and components an estimation of the retail price could be made. It was also difficult to find information about profit margins for different branches. The result is therefore created by a mean value of profits gained from different sources. Although not entirely accurarate, the method does provide a rough estimatate of the target cost for the product, which could give an indication if the created product is possible to manufacture to the intended retail price or not.

The function analysis was useful in the sense that it provided an overview of what had to be taken under consideration during the different stages of the product's lifetime. It did however become quite similar to the specification of requirements, but with a more general presentation. Therefore the method did not seem necessary for the project, but was rather viewed as a helpful and more orderly tool.

In the concept development phase the methods used were mainly idea generation methods. They were sometimes a bit too general, resulting in a large amount of ideas but few that were valuable or realistic. When grouping the many different ideas it was however possible to find patterns which made it possible to group the ideas into different concepts groups. It is however thought that this phase took longer time than necessary and that some methods should have been used earlier to further develop previous ideas, in the way that SCAMPER was used.

Pugh's concept evaluation matrix was used in two steps of the project. First in the concept development, as a way of choosing which concepts to present for the stakeholder, and secondly as a way of evaluating the concepts further and provide support for the concept selection. The method was helpful in the evaluation of the concepts. It should however be mentioned that the results provided by the matrix were taken with careful consideration since the ranking of the different criteria did not feel fully trustworthy. The ranking was made subjectively based on the information gathered in the research phase. But even with the collected information as a source it was hard to evaluate the severity of each criterion, and a difference in ranking from one to three may have a big impact on the result.

In the further concept evaluation and selection the stakeholders were introduced to the concepts. The presentation and subsequent discussion was of great use and simplified the choice of concept. Since the project was conducted in collaboration with the company, their opinions were very important. A problem found using this method was the way the concepts should be presented. Since the image representing a concept idea is no final concept or design, the different concept representations should be as similar as possible in style in order to not steer the stakeholders in any direction. The stake holders were also told not to focus too much on the design of the representations in their evaluation, but rather on the concept idea at large. It is however impossible to know if a specific representation was perceived as more appealing and given a higher rating because of this.

In order to not only rely on the stakeholders feedback two additional evaluation methods were conducted. The pros and cons list presented a good overview of the similarities and differences of the concepts. It further made it easy to see what different problems the concepts possessed. In order to find more possible problems with the concepts a FMEA was also conducted. The method is usually conducted when evaluating the final product, but in this project it was used as a tool in the concept selection phase to evaluate the different concepts with regards to the problems that may affect the product.

10.3 Lessons learnt

A challenge in the project was to balance the technical requirements with the visual appearance, use and cost of the product. The demands that resulted from the choice of lighting technology necessitated an iteration of concept development that led to result different from the highest rated concepts. However, it also led to a product with a substantiated possibility to be manufactured and fulfill the demands of the users.

The iterative process was beneficial to the project since it allowed us to be relatively free during the idea generation but also made us look deeper into the technological limitations and adapt the concept to what we learnt from that.

10.4 Further development and recommendations

In order to make *Enlight* ready for production there are some aspects that needs further investigation. These aspects are presented below in combination with recommendations of how to possibly improve the product further.

- Tests has to be conducted using a physical prototype of the lamphead in order to evaluate the heat management. Measuring the temperature of the circuit board in its correct surrounding will prove if the heat management is efficient enough. The amount of ventilation holes and their placement also needs to be studied and modified if necessary.
- Further investigation is also needed to evaluate the effect of the lamp. The evaluation made in this project suggest that the lamp will produce sufficient light for the plants in theory, but tests has to be conducted where the lamp is used on actual plants to evaluate the result in practice. This should include tests where spectrums different from the standard are tested since non-standard colour settings result in a lower intensity of light.
- A test where the multi die chip is compared with the use of several single die LEDs is also suggested. In theory the multi die chip will provide better colour mixing, it is however uncertain how much difference this does for the plants. The use of single die LEDs may also provide a more economic solution, which could reduce the price of the product in total.
- The suggested application needs further investigation. A user study is suggested in order to find more information of what the users want to be able to do through it. Studies are also necessary in order to develop/find a database

with the information of different plants.

- In order to decrease the cost of components, different solutions should be evaluated further. For example the heat management, which could potentially be changed to a passive cooling system. The cooling does however require different tests where a heat sink better fitted for the construction can be found. This would potentially also make it possible to reduce the height of the lamphead. This might also be achievable by finding or constructing a flatter heatsink for the SynJet module.
- While it is believed that the suggested production methods can be used to manufacture the product, further investigation is required in order to optimize the choice of methods towards the volume of production. It is also believed that the individual parts can be better adapted to manufacturing, in order to decrease costs.
- If the company looks to expand the product and its functionality it is suggested that additions such as a hydroponic system, heating mats and similar is developed with the same form factor as the tray. This will make it possible for the more experienced users to expand the use of the product and adapt it to their needs.

11. Conclusion

The goal of the project, to develop a lighting solution and luminaire that enhances the ability of growing and keeping plants in a household environment, is achieved through the development of *Enlight*. The result is a product that provide optimised spectrums of light for common edible plants while allowing the users their own choice of plants and pot configuration.

The result is verified through a test of the illuminative capabilities of a prototype and a user acceptance test, which showed that the product's techical properties are enought to fulfil its purpose and that user response to the product is positive.

The studied theory and the conducted research and analysis show that LED lighting with adjustable spectrum is a technology that can be useful in a domestic environment. It offers a high quality of light for cultivation of common edible plants and herbs while limiting energy use.

During the interviews and surveys it was discovered that the people most interested in cultivation might not be the people who would most benefit from the technology. The target group should rather be people with limited cultivation possibilities but with an interest in having access to fresh herbs and vegetables. To meet the requirements of this group demanded a product that would facilitate cultivation and make it more accessible. This was achieved by designing a product with advanced light capabilities but a low complexity interface.

The challenge of expressing Heliospectra's research expertise and focus on sustainability, technology and quality was met by the creation of several image boards as well as evaluations with potential users.

The result is a product that emphasize both the plants and the advanced components of the lighting solution. This is achieved by a subdued colour scheme and large featureless surfaces that contrast the colourful and organic expression of the plants.

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Appendix

Appendix 1 - Survey

Thank you for taking time to fill out this questionnaire! The survey is conducted as part of a master thesis at Chalmers University of Technology in Sweden. The result will be used as basis for a product development project concerning indoor cultivation. The questionnaire takes 5 to 10 minutes to fill in and you will be completely anonymous.

1. Gender

- ○ Male
- ○ Female

2. Age

- ○ under 20
- ○ 20-29
- ○ 30-39
- ○ 40-49
- ○ 50-59
- ○ 60-69
- ○ 70-79
- ○ over 79

3. Country

4. Profession

5. Living

- ○ House
- ○ Townhouse
- ○ Appartment
- ○ Other

6. Does the household have access to a cultivation area? (Multiple choices)

- ☐ Own garden
- ☐ Allotment garden
- ☐ Greenhouse
- ☐ Summerhouse
- ☐ Shared garden
- ☐ I do not have access to a cultivation area

Other ____________

7. How would you describe your interest in gardening?

	1 No interest at all	2	3	4	5	6 Great interest
	○	○	○	○	○	○

8. If you cultivate, what is it that motivates you? (If you do NOT cultivate, skip this question)

I cultivate because...

	1 Strongly disagree	2	3	4	5	6 Completely agree
It's economical	○	○	○	○	○	○
Get exercise	○	○	○	○	○	○
It's healthy to eat green	○	○	○	○	○	○
It's good for the environment	○	○	○	○	○	○
It's my hobby	○	○	○	○	○	○
Have for sale	○	○	○	○	○	○
The plants are beautiful	○	○	○	○	○	○
It tastes better with homegrown plants	○	○	○	○	○	○

9. Do you grow anything indoors?

- ○ Yes
- ○ No

10. If you answered NO on the previous question, why not? (Multiple choices)

- ☐ I cultivate at a different location
- ☐ Lack of interest
- ☐ Lack of space
- ☐ Lack of time
- ☐ Lack of knowledge

Other __________

11. What do you grow indoors? (Multiple choices) (If you do NOT cultivate, skip this question)

- ☐ Ornamental plants
- ☐ Vegetables
- ☐ Fruit
- ☐ Herbs

Other __________

12. Have you experienced any problems with indoor cultivation? If yes, please describe the problems.

- ○ No
- ○ Yes, what kind of problems?

____

13. Do you use any technical tools for your indoor gardening? If yes, which ones?

- ○ No
- ○ Yes, which ones?

____

14. Have you ever used plant lighting?

- ○ No
- ○ Yes, what type of plant lighting was it? How did you experience it?

[ ]

15. If you answered NO to the previous question, would you be interested in using plant lighting?

- ○ Yes
- ○ No, because:

[ ]

16. To what do you / would you like to use plant lighting?

To...

	1 Strongly disagree	2	3	4	5	6 Completely agree
Optimize the cultivation of edible plants	○	○	○	○	○	○
Optimize the cultivation of ornamental plants	○	○	○	○	○	○
Pre-cultivation for planting elsewhere	○	○	○	○	○	○
Increase the shelf life of purchased edible plants	○	○	○	○	○	○
Increase the shelf life of purchased ornamentals	○	○	○	○	○	○
Grow more demanding plants	○	○	○	○	○	○
Grow plants in environments with insufficient natural light	○	○	○	○	○	○

17. The following properties are important for a product for indoor cultivation:

	1 Not important at all	2	3	4	5	6 Very important
Provides greater growth	○	○	○	○	○	○
Provides increased shelf life for plants	○	○	○	○	○	○
Has appealing design	○	○	○	○	○	○
Has many settings	○	○	○	○	○	○
Requires little commitment	○	○	○	○	○	○
Give feeling of high quality	○	○	○	○	○	○
Is environmental friendly	○	○	○	○	○	○
Has a low operating cost	○	○	○	○	○	○
Has a low price	○	○	○	○	○	○

18. Which of the following features would you find interesting in a product for indoor cultivation? (Multiple choices)

☐ Self-watering system

☐ Possibility of hydroponic farming (growing in water)

☐ Integrated space for the plants (in contrast to pots)

☐ Information of the plants (eg, when they need watering or are ready for harvesting, etc.)

19. What other features would you like a product for indoor cultivation to have? (Think freely)

20. How much would you be willing to pay for a product that meets your required functions?

- ○ €0-50
- ○ €50-100
- ○ €100-150
- ○ €150-200
- ○ €200-250
- ○ €250-300
- ○ €300-

Appendix 2 – Questions for gardening enthusiasts

1. När är du född?
2. Hur skulle du beskriva ditt intresse för odling?
3. Vad för slags odling ägnar du dig åt?
4. Vad har du för associationer till odling?
5. Vad är det huvudsakliga syftet med att odla själv istället för att köpa färdiga växter?
6. Odlar ni något inomhus? Vad?

Om JA:

7. Till vilket syfte?
8. Vad är viktigt att tänka på när det gäller inomhusodling?
9. Vad upplever ni för problem vid inomhusodling?
10. Har ni några speciella knep som ni tar till när ni odlar inomhus?
11. Hur skiljer sig upplevelsen av att odla inne från upplevelsen av att odla ute?
12. Använder ni några tekniska produkter för er inomhusodling?
13. Vad ska en produkt som underlättar inomhusodling ha för uppgift?
14. Vilka aspekter skulle vara viktigast för en produkt för inomhusodling?
15. Vilka funktioner bör produkten ha?
16. Har du använt växtbelysning och vad tycker du i så fall om det? Om inte, varför inte?
17. Skulle det vara intressant att involvera användarna i framtagningen av ljusrecept?
18. Vad skulle en produkt för inomhusodling få kosta?

Om NEJ:

19. Vad är den huvudsakliga anledningen till att ni inte odlar inomhus?
20. Vad skulle kunna få dig att börja odla inomhus?
21. Vad ska en produkt som underlättar inomhusodling ha för uppgift?
22. Vilka aspekter skulle vara viktigast för en produkt för inomhusodling?
23. Vilka funktioner bör produkten ha?
24. Har du använt växtbelysning och vad tycker du i så fall om det? Om inte, varför inte?
25. Skulle det vara intressant att involvera användarna i framtagningen av ljusrecept?
26. Vad skulle en produkt för inomhusodling få kosta?

Appendix 3 – Questions for vendors

Frågor till försäljare av växter och trädgårdsprodukter:

1. Vilka växter säljer ni mest av?
2. Vad ger ni för råd avseende skötsel av inomhusväxter?
3. Vad brukar kunderna fråga om när det gäller inomhusodling?
4. Vad brukar kunderna vara mest intresserade av vad gäller matväxter och örter?
5. Hur skiljer sig försäljningen mellan sommar- och vinterhalvåret?
6. Rekommenderar ni någon form av växtbelysning? Andra hjälpmedel?
7. Vad säljer ni inom detta område? (tekniska tillbehör?)
8. Vet du varför ni inte säljer ex. växtbelysning?
9. Ser ni att det finns några specifika kundgrupper som utmärker sig vad gäller inomhusodling?
10. Vad ser ni för trender?

Frågor till försäljare av växtbelysning:

1. Vad är det viktigaste att tänka på när det gäller inomhusodling?
2. Vad säljer ni mest av?
3. Varför säljer ni inte växtbelysning med LED-lampor?
4. Är det något kunderna brukar efterfråga?
5. Vem köper växtbelysning?
6. Köper de oftast färdiga odlingsstationer eller bygger de sina egna system?
7. Vilka är de viktigaste kriterierna?
8. Vad brukar de köpa för tillbehör?
9. Vad finns det för fördelar och nackdelar med hydroponisk odling?
10. Vad ser ni för trender? Ökar intresset för inomhusodling? Mer avancerad teknik?
11. Är det något som saknas på marknaden?

Appendix 4 – Questions for Hydrogarden

1. Vad är det viktigaste att tänka på när det gäller inomhusodling?
2. Vad säljer ni mest av?
3. Varför säljer ni inte växtbelysning med LED-lampor?
4. Är det något kunderna brukar efterfråga?
5. Vad har ni för kunder?
6. Köper de oftast färdiga odlingsstationer eller bygger de sina egna system?
7. Vilka är de viktigaste kriterierna?
8. Vad brukar de köpa för tillbehör?
9. Vad finns det för fördelar och nackdelar med hydroponisk odling?
10. Vad ser ni för trender? Ökar intresset för inomhusodling? Mer avancerad teknik?
11. Är det något som saknas på marknaden?

Appendix 5 – Focus group interview template

Moment	Beskrivning	Material	Tid
Introduktion	Tack för att ni kommit hit idag. Vi håller på med ett examensarbete som handlar om inomhusodling och växtbelysning. Målet med projektet är att ta fram en växtbelysningsprodukt som underlättar odling av växter inomhus. Växtbelysning behövs när det naturliga ljuset inte räcker till vilket är fallet under stora delar av året här i norden. För att kunna ta fram en så bra produkt som möjligt så behöver vi veta vad potentiella användare av produkten har för behov och åsikter och det är därför ni är här idag. För att få ut så mycket som möjligt av det här mötet tänkte vi filma processen. Filmen kommer endast användas av mig och min exjobbspartner för informationsinsamling och kommer inte visas i några andra sammanhang, är det OK med alla? Det här mötet kommer ta ca en timme, vi börjar med några generella diskussionspunkter och ni ska sedan få reagera på lite olika bilder. Det finns inga rätt och fel i det vi diskuterar idag och allas åsikter är välkomna. Är det någon som har några frågor innan vi börjar?	Kamera Fika Namnskyltar	5min
Uppgift 1	Det första ni ska få göra är att under 5 minuter skissa en produkt som ni skulle vilja ha för att på något sätt kan underlätta inomhusodling. Det finns inga begränsningar för vad ni kan hitta på och ni får gärna förklara med text. Kvalitén på skissen är oväsentlig.	Papper Pennor Suddgummi	5min
Odling	1. Beskriv ert intresse för odling rent generellt 2. Vad har ni för associationer till odling? 3. Hur många är det som odlar något inomhus? Vad odlar ni? Varför odlar ni inte inomhus? 4. Vad är det jobbigaste med att odla växter inomhus? 5. Vad skulle ni beskriva som det huvudsakliga syftet med att själv odla växter? 6. Om ni var tvungna att välja mellan att odla enbart matväxter eller enbart prydnadsväxter, vad skulle ni välja och varför?		10min

Kök och odling	1. Vad är de viktigaste aspekterna för en köksprodukt? 2. Tror ni att det kommer bli vanligare att folk odlar sin egen mat? Vad skulle ni tycka om att göra det?		5min
Produkt	1. Om ni fick bestämma, vilka funktioner skulle en produkt som underlättar inomhusodling ha? Använd gärna era skisser som ni gjorde tidigare för att förklara. 2. Vad skulle ni tycka om att använda växtbelysning? 3. Vilket av dessa bildcollage (expression boards) skulle ni vilja förknippa en produkt för inomhusodling med? 4. Vad har ni för åsikter angående: a. Storlek b. Utseende c. Pris 5. Växter använder olika ljusvåglängder för olika faser av sin tillväxt. Vad skulle ni tycka om en växtbelysningsprodukt där ni själva kan ställa in ljuset och påverka växterna på olika sätt? Skulle det vara intressant att kunna byta ”ljusrecept” med andra?	Expression boards	15min
Uppgift 2	Nu ska ni få titta på olika produkter som finns på marknaden idag. Ni har fått en uppsättning produkter var och ni ska få rangordna dem utifrån hur gärna ni skulle vilja ha dem. Beskriv vad som fick er att rangordna [produkt] högst. Beskriv vad som fick er att rangordna [produkt] lägst.	Bilder Kamera	15min
Avslutning	Är det någon som har några fler tankar som dykt upp under diskussionen? Tack så mycket för att ni kom hit idag!		5min

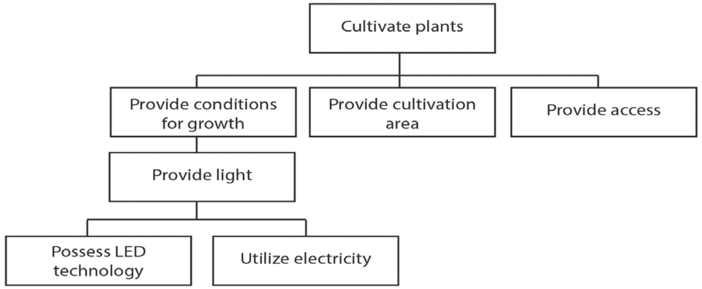
Appendix 6 – Specification of requirements

No.	Requirements	Terms	Rank
1	*Technical requirements*		
1.1	Possess LED technology		5
1.2	Possess compatibility with external lighting		5
1.3	Provide even distribution of light over the entire cultivation area	120 µmol photons/m^2/s (100mm)	5
1.4	Provide functionality regardless of season		5
1.5	Provide conditions for pre-cultivation		5
1.6	Provide cultivation area	of at least 5 dm^2	5
1.7	Consume electricity	< 50W	5
1.8	Provide conditions for growing	above ground vegetables herbs ornamental plants fruits Mediterranean plants root crops	5 5 5 4 3 3 2
1.9	Possess a maximum selling price	3000 SEK 2500 SEK 2000 SEK	5 4 3
1.10	Possess a maximum price per cultivation area	200 SEK/dm^2 150 SEK/dm^2	5 4
1.11	Provide installation without the need of tools		4
1.12	Provide possibility of soil cultivation		4
1.13	Provide functionality without human interaction	during 1 week during 2 weeks	4 3
1.14	Provide automatic	irrigation temperature regulation humidity regulation nutrition	4 3 2 2
1.15	Provide possibility of hydroponic cultivation		3
1.16	Enable display of information		3
1.17	Provide information about the condition of the plants regarding	moisture light temperature harvest nutrition	3 2 2 1 1
1.18	Possess maximum dimensions	½ m^3	2
2	Functional requirements		
2.1	Enable cleaning		5
2.2	Provide access for manual watering		5

2.3	Provide possibility of adjustment of	light intensity light spectrum soil temperature humidity ambient temperature	5 4 4 2 2
2.4	Provide adjustment of light source position	vertically horizontally tilt	5 2 2
2.5	Provide possibility of schedule lighting		4
2.6	Enable space efficient storage of product		3
2.7	Provide protection against excess watering		3
2.8	Enable reading of	light intensity soil temperature light spectrum humidity ambient temperature	3 3 2 2 1
2.9	Provide warning when the plants are in critical condition		2
3	Durability requirements		
3.1	Provide maximum LED die temperature	<150C°	5
3.2	Possess outer material resistant against moisture		5
3.3	Withstand physical stress of	500 N	5
3.4	Provide structural integrity	5 years 10 years 15 years	5 4 3
3.5	Possess functional lifetime	5 years 10 years 15 years	5 4 3
3.6	Maintain constant temperature of LEDs		4
3.7	Enable exchange of light sources		2
4	Environmental requirements		
4.1	Minimize amount of materials		5
4.2	Minimize number of parts		4
4.3	Minimize material usage		4
4.4	Consist of recyclable materials		4
4.5	Enable separation of	components materials	4 4
4.6	Manufactured from locally produced material		3
5	Aesthetical requirements		
5.1	Possess appealing aesthetics	rated higher than 50% of comparable products	5
5.2	Possess Swedish design language		3

6	Ergonomic requirements		
6.1	Enable transportation	by 5th percentile woman	5
6.2	Prevent noise caused by product	<30 dB (1 meter)	5
6.3	Prevent disruptive light caused by product		5
6.4	Enable operation by user with impaired body function	sight grip arm strength	4 3 3
6.5	Minimize workload	50% less time consuming than manual cultivation	3
7	Semantic requirements		
7.1	Express reliability	75% in a seven point scale survey	4
7.2	Express technical research	75% in a seven point scale survey	4
7.3	Express sustainability	75% in a seven point scale survey	4
7.4	Enable comprehension of functions	8 out of 10 first time users	4
8	Manufacture and transportation requirements		
8.1	Enable manufacturing by existing production techniques		5
8.2	Minimize manufacturing cost		4
8.3	Possess stackable packaging		4
9	Safety requirements		
9.1	Resist leakage		5
9.2	Prevent electronic components being exposed to water		5
9.3	Maintain a surface temperature that does not cause discomfort when touched	≤ 50°C	5
9.4	Minimize risk of injury		5
9.5	Consist of food approved materials	Parts in contact with culture	5
10	Desirables		
10.1	Provide compatibility with window		3
10.2	Resist pest infestation within the product's perimeter		2
10.3	Provide cultivation guide		2
10.4	Enable control via electric devises		2
10.5	Enable installation without suspension		2
10.6	Enable modular installation		2
10.7	Enable transfer of information to electronic devises		2
10.8	Provide sharing of product settings		2
10.9	Provide possibility of documentation		2
10.10	Provide condition for plant hibernation		2
10.11	Provide cultivation schedule		1

Appendix 7 – Funtion analysis



Manufacturing

- Minimize manufacturing cost
- Minimize amount of components
- Minimize amount of materials
- Minimize material usage
- Provide easy assembly
- Minimize operations
- Minimize manufacturing time
- Minimize scrap material
- Manufactured by locally produced material
- Minimize environmental impact
- Utilize recyclable materials
- Enable manufacturing by existing manufacturing techniques

Transportation

- Enable stacking of packaging
- Resist physical stress
- Resist moisture
- Minimize weight
- Enable grip
- Withstand climate
- Minimize environmental impact

Marketing/sale

- Convey Heliospectra's expression
- Express Swedish design language
- Express technical research
- Express reliability
- Express sustainability
- Possess appealing aesthetics
- Invoke interest
- Convey function
- Possess appealing packaging
- Possess competitive price
- Possess competetive functions

Use

- Comunicate usage
- Minimize incorrect usage
- Minimize personal damage
- Minimize damage on surroundings
- Provide product service
- Enable cleaning
- Provide intuitive functions
- Enable reparation
- Enable transportation
- Enable easy installation
- Enable efficient storage
- Convey Heliospectra's expression
- Express Swedish design language
- Express technical research
- Express reliability
- Express sustainability
- Possess appealing aesthetics
- Resist wear
- Resist corrosion
- Provide functionality regardless of season
- Allow flexible placement
- Enable interaction
- Withstand physical stress
- Prevent disturbance
- Fit surroundings

Recycling/demolition

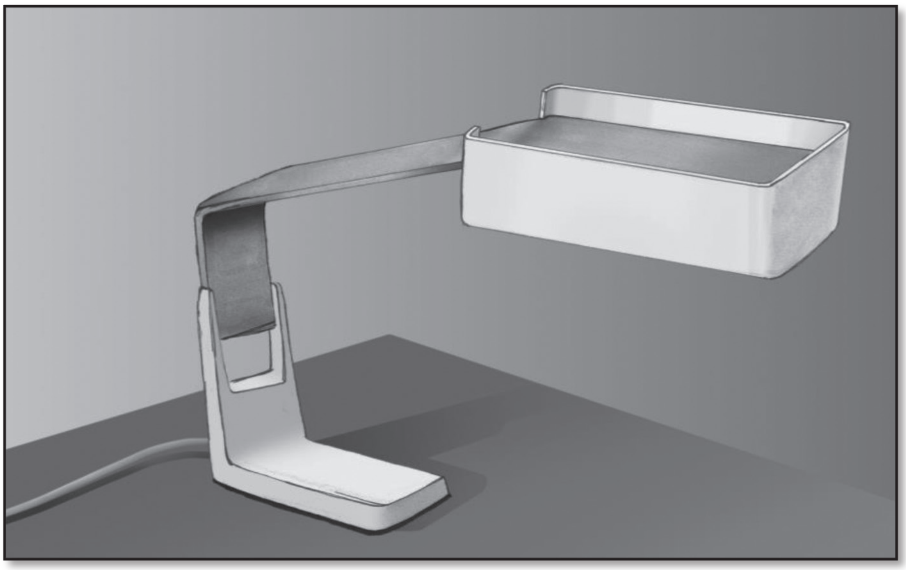
- Facilitate dismantling
- Minimize amount of components
- Minimize amount of materials
- Minimize material usage
- Minimize environmental impact
- Utilize recyclable materials

Appendix 8 – Pugh matrix

Rank	Criterion	Ref (Bench placement)	"Separate lamp"	"One plant"	"Modular"	"Integrate	"Budget"	"Decoration"	"Herb station"	"Shelf"	"Foldable"	"Window"
3	Compatibility with external lighting	0	0	0	0	0	0	0	0	0	0	+
3	Cost	0	+	0	0	+	+	+	0	-	0	-
3	User influence on plant condition	0	0	+	+	0	-	0	0	0	0	-
3	Space efficiency	0	+	+	0	+	+	+	0	+	+	+
3	Electricity consumption	0	+	0	+	+	+	+	+	+	0	0
3	Durability	0	+	+	+	+	+	+	+	+	0	0
3	Efficient usage of light	0	-	+	0	-	-	-	0	-	-	-
3	Easy to operate	0	+	+	+	+	+	+	+	+	+	+
3	Feasibility for Heliospectra	0	+	0	0	0	+	0	0	0	0	-
3	Quality of crop	0	0	0	0	0	-	-	0	0	0	0
3	Fit to environment	0	+	0	+	+	0	+	0	0	+	-
2	Minimize materials	0	+	0	+	+	+	0	-	0	+	+
2	Minimize number of parts	0	+	+	0	+	+	+	0	0	0	0
2	Easy installation	0	+	0	0	-	+	-	0	-	-	-
2	Crop possibilities	0	0	0	0	-	0	-	-	0	-	-
2	Cultivation area	0	0	-	0	-	-	0	-	+	-	-
2	Express technical research	0	-	+	0	0	-	0	-	-	-	-
2	Minimize workload	0	-	-	-	-	-	0	0	-	-	0
2	Showcase plants	0	0	+	+	0	-	+	+	+	0	0
2	Easy cleaning	0	+	+	+	+	+	+	+	+	+	+
2	Transportability	0	+	+	+	-	+	-	0	-	-	-
1	Provide information	0	-	0	-	-	-	-	-	-	-	-
1	Access to plants	0	+	0	0	+	+	0	+	0	+	+
1	Extra features	0	0	+	+	0	0	0	+	0	+	0
	Number of +	0	13	11	10	10	12	9	7	7	7	6
	Number of 0	25	7	11	12	7	4	9	12	10	9	7
	Number of -	0	4	2	2	7	8	6	5	7	8	11
	Net	0	24	22	21	12	11	11	7	3	-1	-12
	Rank	9	1	2	3	4	5	5	7	8	10	11

Rank	Criterion	Ref (Separate lamp)	"Bench placement"	"One plant"	"Budget"	"Modular"	"Integrated"	"Herb station"	"Decoration"	"Shelf"	"Foldable"	"Window"
3	Compatibility with external lighting	0	0	0	0	0	0	0	0	0	0	+
3	Cost	0	-	0	+	-	-	-	-	-	-	-
3	User influence on plant condition	0	0	+	-	+	0	0	0	0	0	-
3	Space efficiency	0	-	0	+	0	+	-	+	0	+	0
3	Electricity consumption	0	-	-	+	0	0	0	0	0	-	+
3	Durability	0	-	0	0	0	0	0	0	0	0	0
3	Efficient usage of light	0	+	+	-	0	0	0	+	0	0	+
3	Easy to operate	0	-	-	+	0	0	0	0	0	0	0
3	Feasibility for Heliospectra	0	-	-	0	-	-	0	0	0	-	-
3	Quality of crop	0	0	+	-	+	0	0	0	0	0	0
3	Fit to environment	0	-	0	+	0	+	-	+	-	+	-
2	Minimize materials	0	-	0	+	0	0	-	0	0	0	0
2	Minimize number of parts	0	-	-	+	-	-	-	0	-	-	-
2	Easy installation	0	-	0	0	0	-	0	-	-	-	-
2	Crop possibilities	0	0	+	0	0	-	-	-	0	-	0
2	Cultivation area	0	+	-	-	0	0	0	0	0	0	0
2	Express technical research	0	+	+	-	+	+	0	+	-	0	+
2	Minimize workload	0	+	+	0	+	0	+	+	0	0	0
2	Showcase plants	0	0	+	-	+	0	0	+	+	0	0
2	Easy cleaning	0	-	0	0	0	0	-	-	-	0	0
2	Transportability	0	-	0	+	-	-	-	-	-	-	-
1	Provide information	0	+	+	0	0	+	0	0	0	0	0
1	Access to plants	0	-	0	0	0	0	-	-	0	0	0
1	Extra features	0	0	+	0	+	0	+	0	0	+	+
	Number of +	0	5	9	8	6	4	1	5	1	3	5
	Number of 0	25	7	11	11	15	14	13	14	17	15	12
	Number of -	0	13	5	6	4	6	9	6	7	7	7
	Net	0	-24	6	3	3	-5	-17	3	-14	-10	-6
	Rank	5	**11**	**1**	**2**	**2**	**6**	**10**	**2**	**9**	**8**	**7**

Concept:
Separate lamp



First impression

Negative ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ Positive

Comments:

Appendix 10 – Failure Mode and Effect Analysis

RPN levels
1-49
50-99
100-149
150-1000

Item/Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause of Failure	Fre-quency	Dete-ction	RPN	Possible solutions
Chassi	Reach too high temperature	Personal injury	10	Insufficient cooling	2	1	20	
	Direct glare	Disturbance	7	Insufficient screening	9	2	126	Protective covering Prohibit exposure to lightsource
	Reflective glare	Disturbance	6	Placed on reflective surface	10	3	180	Protective covering Prohibit light hitting surface outside of product
	Sharp edges	Personal injury	10	Design of chassi	1	1	10	
	Unstable	Product damage	9	Design	1	1	9	
				Handling	2	4	72	Impact resistance Provide instruction
	Fragile	Product damage	9	Design - material	1	2	18	
Lightsource	Unintentional movement	Impaired function	7	Wear	3	5	105	Strong joints Settings not affected by gravity
	Uneven spread	Impaired function	7	Handling	3	8	168	Instruction Product design guides user More LEDs
Interface	Difficult to use/understand	Time consuming	3	Interface design	4	6	72	Limit settings Instructions Adapt interface to mental model Feedforward Feedback
		Impaired function	5	Interface design	2	3	30	
Cultivation area	Too small to fit pots	Reduced application	7	Design	5	2	70	Adaptable size Make height of light independent Different product sizes
	Difficult to clean	Health risk	10	Design	1	1	10	
Electronics	Comes in contact with water	Product damage	10	Breakage of chassi	1	2	20	
Transportation	Difficult to disassemble	Increased transportation	6	Design	5	1	30	
Materials	Heavy	Increased transportation cost	3	Size and material	3	1	9	
		Difficult to move	4	Size and material	4	2	32	
	Damaged by water	Impaired function	8	Material choice	1	1	8	
		Aestetics	7	Material choice	2	2	28	
	Hazardous	Negative environmental impact	9	LED	10	1	90	Choose the least damaging option Facilitate disposal of LEDs
		Health risk	10	Material choice	1	1	10	
	Number of	Negative environmental impact	4	Material choice	3	1	12	
		Increased cost	5	Material choice	8	1	40	
	Discolouring	Aestetics	7	Material choice	2	5	70	Not using the same colour on different materials Use resistant materials/coatings
Expression	Too technically advanced	Limit customer group	5	Design	3	5	75	Hide light Hide electronics Organic shapes
	Not technically advanced enough	Damage Heliospectra's image	7	Design	2	5	70	Expose light Expose electronics Inorganic shapes
		Limit customer group	7	Design	6	5	210	Expose light Expose electronics Inorganic shapes
	Energy consuming	Limit customer group	7	Design	3	5	105	Hide light Hide electronics Hide display Hide indicators Hide cord
	Resembles conventional lamp	Limit customer group	5	Design	8	5	200	Use form elements not found in conventional lamps Expose light strength Use unconvetional light colour

Item/Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause of Failure	Fre-quency	Dete-ction	RPN	Possible solutions
Components	Number of	Negative environmental impact	4	Desired functions	3	2	24	
		Increased cost	5	Desired functions	7	1	35	
		Prolonged assembly	5	Desired functions	4	3	60	Only one correct way to assembly Minimize number of components
	Difficult to replace	Reduced product life	4	Assembly	9	1	36	
	Mounted incorrectly	Impaired function	9	Assembly line failure	1	9	81	Only one correct way to assembly Minimize number of components
	Noice	Disturbance	8	Insufficient isolation	2	1	16	
LEDs	Breaks down	Impaired function	9	Wear	1	1	9	
				Accident	2	2	36	
	Temperature fluctuates	Reduced product life	7	Changing spectrum	2	5	70	Limit spectrum changes
Functions	Complexity	Increased cost	6	Desired functions	7	1	42	
		Increased risk of error	4	Desired functions	6	5	120	Separate functions Hide functions not often used Instructions Automate functions Interface follow mental model Feedforward Feedback
	Demands commitment	Limit customer group	4	Desired functions	5	8	160	Automate functions
		Time consuming	7	Desired functions	7	2	98	Automate functions Make settings optional Guide user
Value	Does not provide desired efficiency	Limit customer group	8	Insufficient plant growth	2	8	128	Honest marketing Optimize light spectrum
				Size	5	3	120	Offer different sizes Adjustable size Make modular
Technical	Reach too high temperature	Impaired function	7	Insufficient cooling	2	1	14	
	Requires special manufacturing tools	Increase cost	3	Design	2	2	12	
	Energy consumption	Negative environmental impact	4	Desired functions	2	1	8	
		increased operating cost	8	Desired functions	3	1	24	
Usage	Incorrect settings	Impaired function	5	User error	4	6	120	Recomend settings based on crop Limit possible settings Give warning
		increased operating cost	6	User error	2	6	72	Visualize energy consumption Limit possible settings Give warning
	Incorrect placement	Impaired function	4	User error	5	7	140	Limit placement options Provide many placement options Automate placement settings

Appendix 11 – Light tests

Conditions:	OL = over 40000lux Ambient light is excluded in the calculations

Effect 100% Without lens/reflector

Height/width (mm)	0	100	200	300	400	500
600	1360	1280	1130	960	800	660
500	1980	1850	1600	1290	1030	700
400	2980	2710	2180	1600	1060	590
300	5270	4480	3130	1930	860	340
200	11910	8380	4060	1410	160	60
100	OL	13620	120	60	40	30

Effect 75% Without lens/reflector

Height/width (mm)	0	100	200	300	400	500
600	1230	1200	1070	900	750	610
500	1790	1660	1460	1130	900	680
400	2590	2370	1940	1430	990	550
300	4650	3980	2780	1700	780	290
200	10280	7480	3680	1230	170	50
100	OL	11480	120	50	30	30

Effect 100% 2 diodes with distance 125mm, without lens/reflector

Height/width (mm)	-62,5	0	100	200	300	400	500
600							
500	4000	3840	3350	2730	2050	1510	1010
400	5940	5720	4710	3470	2360	1610	950
300	9970	9550	7330	4640	2250	1230	620
200	21010	20630	11710	4480	160	80	
100	OL	OL	13563	153			

Effect 100% 2 diodes with distance 200mm, without lens/reflector

Height/width (mm)	-100	0	100	200	300	400	500
600							
500	3890	3660	3240	2730	2070	1490	1060
400	5720	5360	4580	3200	2190	1530	670
300	9180	8370	6080	3780	2220	1110	530
200	16020	15510	9560	4040	1480	140	50
100	25450	OL	15820	140	70	50	40

Effect 100% Without lens/reflector with multimeter angled against diode

Height/width (mm)	0	100	200	300	400	500
600	1360	1430	1330	1180	1010	870
500	1980	1920	1850	1590	1250	950
400	2980	2870	2610	2110	1460	990
300	5270	4580	3950	2680	1560	1100
200	11910	8990	6130	2820	1130	340
100	OL	22250	5560	530	500	340

Effect 100% With 30mm straight reflector, 30mm in diametre

Height/width (mm)	0	100	200	300	400	500
600						
500						
400						
300	6010	4850	720			
200	14340	5060	890			
100						

Effect 100% With 20mm straight reflector, 30mm in diametre

Height/width (mm)	0	100	200	300	400	500
600						
500						
400						
300	5860	5150	3230	350		
200	13550	9930	760			
100						

Effect 100% With 15mm straight reflector, 30mm in diametre

Height/width (mm)	0	100	200	300	400	500
600						
500						
400						
300	5640	4910	3430	1490	180	
200	13600	9830	3400	290		
100						

Effect 100% With 45 degree lens

Height/width (mm)	0	100	200	300	400	500
600						
500						
400						
300	6420	7370	2180	520		
200	13380	12960	1400	240		
100						

Effect 100% Without lens/reflector recalculated to micro mol with 10% loss

Height/width (mm)	0	100	200	300	400	500
600	22,6	21,3	18,8	16,0	13,3	11,0
500	33,0	30,8	26,6	21,5	17,1	11,7
400	49,6	45,1	36,3	26,6	17,6	9,8
300	87,7	74,6	52,1	32,1	14,3	5,7
200	198,3	139,5	67,6	23,5	2,7	1,0
100	OL	226,8	2,0	1,0	0,7	0,5

Effect 100% Without lens/reflector with angled against multimetre recalculated to micro mol with 10% loss

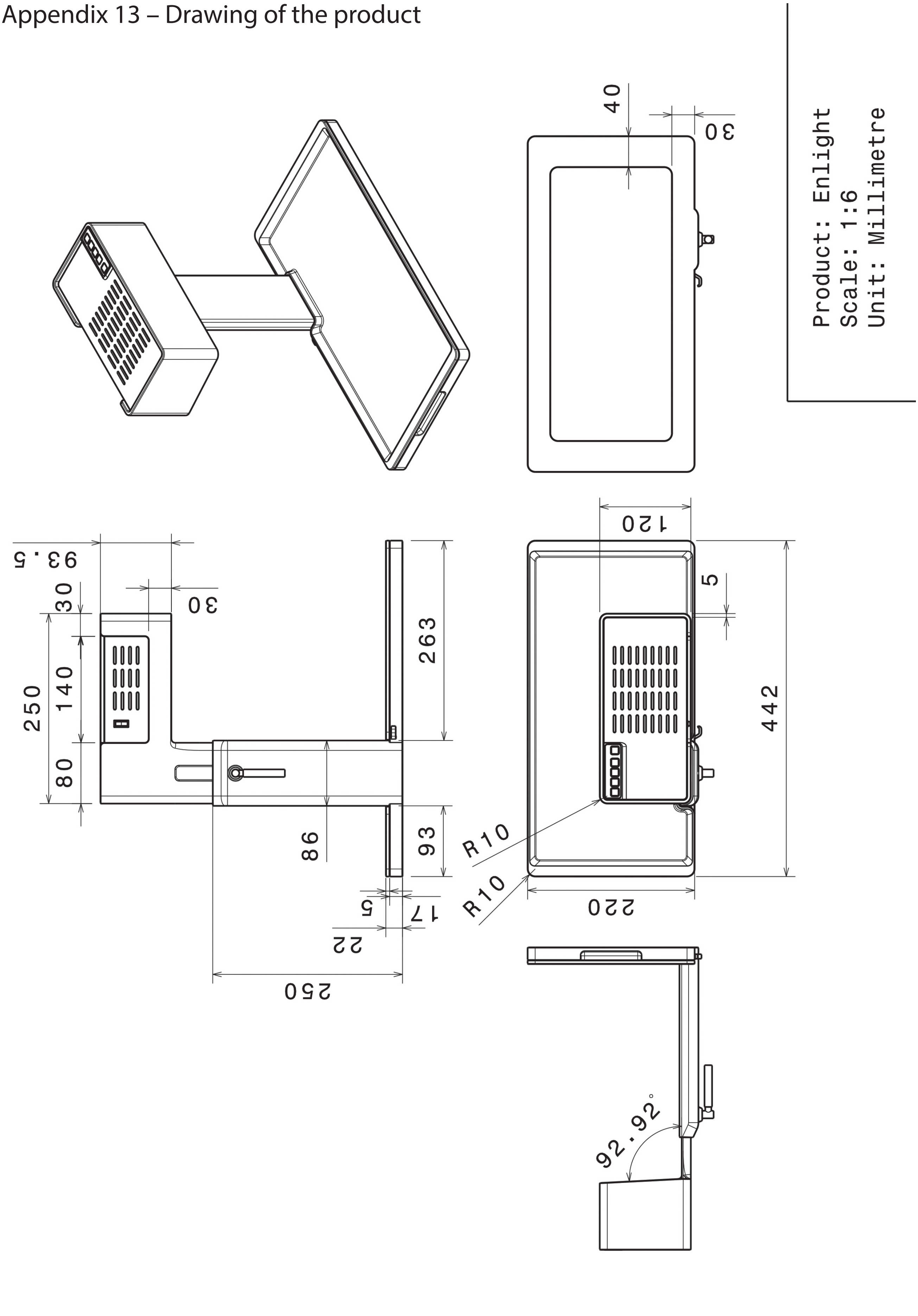
Height/width (mm)	0	100	200	300	400	500
600	22,6	23,8	22,1	19,6	16,8	14,5
500	33,0	32,0	30,8	26,5	20,8	15,8
400	49,6	47,8	43,5	35,1	24,3	16,5
300	87,7	76,3	65,8	44,6	26,0	18,3
200	198,3	149,7	102,1	47,0	18,8	5,7
100	OL	370,5	92,6	8,8	8,3	5,7

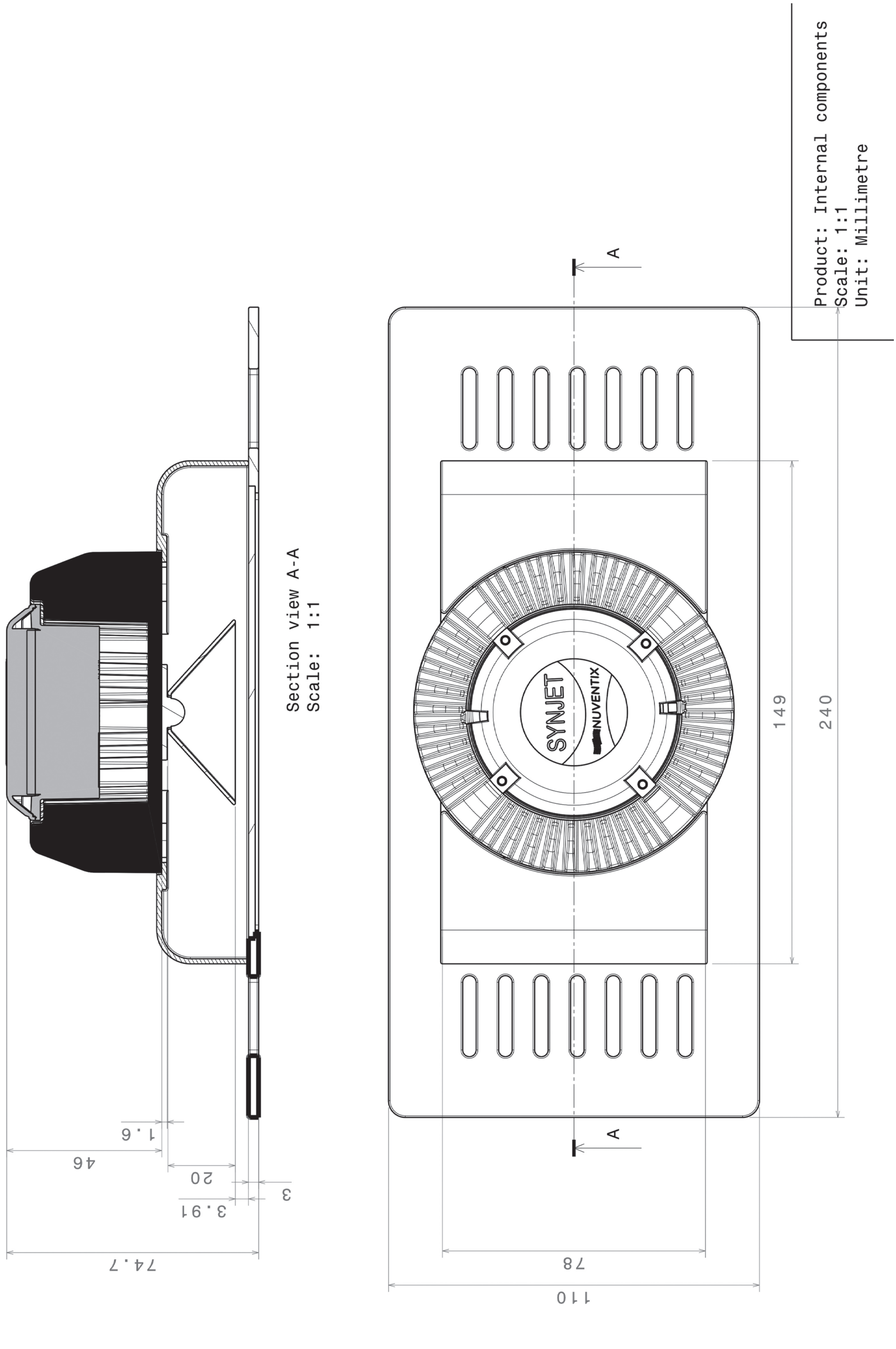
Appendix 12 – Material evaluatior

Material	Info	δ (kg/m³)	Price (kr/kg)	Production	MJ/Kg	CO_2/Kg	Processing	MJ/Kg	CO_2/Kg	Recycling	MJ/Kg	CO_2/Kg	Total	MJ/Kg	CO_2/Kg
Aluminum		2700	20,0		208,00	12,10	*Casting*	10,60	0,80	*Possible*	35,00	2,76		**253,60**	**15,66**
Steel		7850	4,7		30,20	2,03	*Casting*	6,39	0,47	*Possible*	8,11	0,63		**44,70**	**3,14**
PMMA		1850	19,1		112,00	6,80	*Extrusion*	6,08	0,46	*Possible*	39,40	3,16		**157,48**	**10,42**
PC		1175	26,4		108,50	6,08	*Extrusion*	6,08	0,46	*Possible*	42,10	3,34		**156,68**	**9,88**
ABS		1055	21,3		95,10	3,83	*Moulding*	20,70	1,55	*Possible*	46,30	3,64		**162,10**	**9,02**
PP		900	11.8		87.9	2.97	*Moulding*	21.8	1.75	*Possible*	52.6	1.58		**162.3**	**6.3**

Part	Material	Mass (Kg)	Energy (MJ/Kg)	Total MJ	CO_2/Kg	Total CO_2	Price
Lampshade and upper arm	Aluminum	1,017	253,60	**257,91**	15,66	**15,93**	20,34
Light diffuser	PMMA	0,037	157	**5,83**	10,42	**0,39**	0,71
Lower arm and stand, lamp housings, tray	ABS	1,510	162	**244,77**	9,02	**13,62**	32,16
				508,51		**29,94**	**53,21**

Appendix 13 – Drawing of the product

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Unit: Millimetre
Section view A-A
Scale: 1:1
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A
SYNJET
NUVENTIX
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240
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110
74.7
3.91
3
20
46
1.6

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