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Applying Wayfaring to a Project with Prefixed Design Requirements

Development of a Hydroponic Home Growing System

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Abstract

This master's thesis describes the development of a hydroponic home growing system. The system is meant be utilized by both users with and without any pre-existing experience in hydroponic growth. To achieve this, a user-centered design that is easy to operate and assemble, have been one of the main goals during the development process. Relevant technologies and existing research have been identified in order to understand the inherent features and components necessary in order to develop a hydroponic system. The project has utilized wayfaring as its governing product development methodology, and concept generation, prototyping and testing, have guided the development process forward. This all lead to a proposed system and a prototype that proves the validity of its concepts. The author was engaged in this project from January 2018 until the thesis was delivered in July 2018.

Sammendrag

Denne masteroppgaven beskriver utviklingen av et hydroponisk vekstsystem, ment for et vanlig hjem. Systemets målgruppe er brukere både med og uten eksisterende erfaring innen hydroponisk vekst. For å oppnå dette, har et bruker-sentrert design, som er enkel å betjene og montere, vært et av hovedmålene under utviklingsprosessen. Relevante teknologier og eksisterende forskning er identifisert for å forstå de iboende egenskapene og komponentene som er nødvendige for å utvikle et hydroponisk system. Prosjektet har benyttet seg av wayfaring som sin styrende produktutviklingsmetodikk, og konseptgenerering, prototyping og testing, har styrt utviklingsprosessen fremover. Alt dette fører til en foreslått løsning og en prototype som beviser konseptene bak det foreslåtte systemet. Forfatteren var engasjert i dette prosjektet fra januar 2018 til avhandlingen ble levert i juli 2018.

Preface and Acknowledgements

I would like to take this opportunity to show my grattitude to the people who have helped and supported me, and made the realization of this thesis possible. I would first like to give special thanks to my supervisor, Professor Martin Steinert. Thank you for spiking my interest in prototyping and front end development, and for being my supervisor and advisor during the course of this thesis. Secondly, I would like to acknowledge the motivating and inspiring environment at Troll LABS - the rapid prototyping lab where most of the development work described in this thesis were performed. Lastly, I want to give thanks to Heikki Sjöman for the personal guidance you have offered me throughout the year.

Pål Weldingh Wisløff Nilssen
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Contents

List of Figures

1 Introduction

The challenge for this project has been created and designed in a collaboration between Jørn Hammer, Professor Martin Steinert and me. Jørn Hammer is the founder of a company called Den Lille Gartner. This company retails home growing systems and the necessary related articles. The company was founded in order to give normal consumers the opportunity to easily grow some of the food that they consume, in the comfort of their own home. To make this both desirable and accessible for the common user, it is important that the method of growing is easy, low maintenance and that the user succeeds with their growing projects, already on their first attempt. This is to not discourage the user but rather give them a feeling of accomplishment in order to create further interest in the activity. The underlying vision is to raise awareness surrounding the importance of sustainable food production in our modern society. To achieve this, a learning platform is to be developed together with a new hydroponic home growing system, and this is where this project comes into play.

This master's thesis will describe the development of a hydroponic home growing system. The product development process has taken place in the fuzzy front end and wayfaring has been applied as the governing product development methodology. What this entails, will be explained further in chapter 2.

1.1 Problem Description

The challenge is to develop a hydroponic home growing system. This is to be done by identifying relevant technologies, generate concepts, building prototypes and testing. At the end of the project, a proposed system must be presented. The system should be developed considering user-friendliness, modularity and one module of the system should be able to fit on a kitchen counter.

Deliverables

- A functioning home growing system
- The system should be modular
- Easy to assemble and operate
- The water reservoir should hold a minimum of 2.5 liters of water
- Show the core principles

Actions

- Identify relevant technologies
- Conceptualize
- Prototype
- Technical testing
- Providing prototypes for testing

1.2 Outline

Since this, first and foremost, is a master's thesis in product development, the form of the thesis will be structured accordingly. The focus will be divided between *what* has been done, *how* it has been done and *why* it has been done. Chapter 2 will describe the product development methodology used to govern and guide the development process. It will also present and explain the relevant research and technologies related to the field of hydroponic growth. Chapter 3 will be the main part of the thesis, as it documents the development process. This chapter describes the journey from the results obtained in the pre-master's thesis, to a proof of concept prototype of the proposed solution. This work will be rooted in the foundation described in chapter 2. Chapter 4 will describe a short user test performed to assert if the proposed solution is easy to assemble. Chapter 5 will present the proposed solution. Chapter 6 contains the evaluation of the work conducted and the proposed solution. In this chapter there will also be presented suggestions for further work. Finally, in chapter 7, I will evaluate the project as a whole.

2 Literature and Technology review

2.1 Literature review

This section will explain the underlying product development methodologies that helped govern the development process. It is also important to understand the basic needs of a plant and how a seed develops, in order to develop a hydroponic growing system. Relevant literature on these subjects will also be presented here.

2.1.1 Product development methodologies

Fuzzy Front End

The first phase of an innovation process is the Front End, often called the "Fuzzy Front End". Smith and Reinertsen (Smith & Reinertsen, 1992) coined this phrase, due to its ambiguous nature. They explained that the early stages of a development process offer the best opportunities for large changes to both product idea and concept, compared to the later stages where changes can be costly. They called it the fuzzy time between idea generations and large investment of resources, thereby the name. The Fuzzy Front End is the starting point where the developer or team in question identifies opportunities and develop concepts, before they enter the more formal product development process where bigger investments are needed. Concept development, idea generation and opportunity identification, are all dynamic variables, and this can make this stage of the development hard to control and manage effectively. Pinpointing mistakes, generating concepts, identifying potential value in a concept while managing resources can be especially tricky when dealing with a process that so heavily rely on unpredictable concepts such as creativity and reflection.

J.P. Guilford proposed that there are two different types of thinking: divergent and convergent thinking (Guilford, 1950). Convergent thinking, as described by Guilford, begins with a general knowledge and then closes its scope as the level of detail is increased. Naturally, divergent thinking is the opposite. It starts with an idea and then moves to increase its scope. Although divergent thinking is used to generate ideas, both ways of thinking must be included to succeed in a creative process such as the fuzzy front end.

According to Dornberger and Suvelza (Dornberger & Suvelza, 2012) the creative process, from the perspective of the two types of thinking, can be split up into three parts. The first is the problem analysis (convergent thinking), the second is idea research (divergent thinking) and finally the third, evaluation (convergent thinking). This cycle repeats itself throughout the fuzzy front end as ideas are generated, obstacles arise, and choices are made. This continues until the idea and concept is developed enough and ready to move on to the more formal product development process (unless the viability is deemed too low and the project is terminated). In order to produce desirable results in this phase, it is important to apply ways of thinking that can facilitate idea generation and creativity, seen as creativity is the basis for innovation (Dornberger & Suvelza, 2012)

The Wayfaring Model

This development project, from the start of the pre-master's thesis and throughout the master's thesis, have utilized the wayfaring model as its governing product development methodology. The wayfaring model is a way to approach the concept creation in the early stages of a product development, where the project allows the developer a high degree of freedom, but in turn presents a high degree of uncertainty. Since the optimal solution is impossible to attain at the start of the project, asking the right questions and addressing the right problems are key to managing and succeeding in the fuzzy front end (Gassmann & Schweitzer, 2014). The wayfaring model can be introduced, in order to help maneuver and manage these uncertainties (Steinert & Leifer, 2012; Gerstenberg et al., 2015). This model, thus the name, is utilizing the same methods that the first explorers used. When the destination and the path is unknown, taking clues from and observing your surroundings can help you find your way. The model is based on the assumption that radical innovations cannot be planned and found through a linear approach, but that its rather the result of an iterative journey based on continuous learning. A typical wayfaring model can be seen in Figure 1.

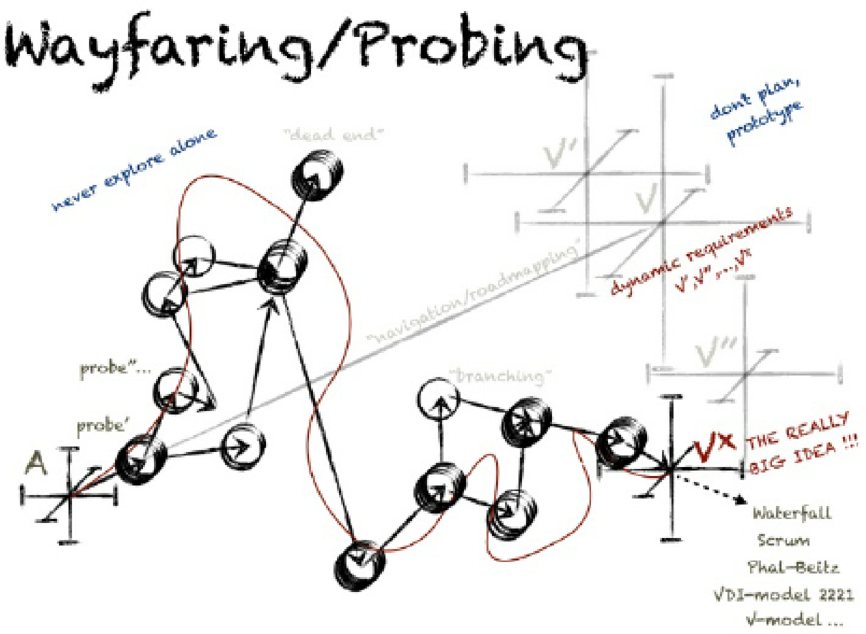


Figure 1: A typical wayfaring journey in product development. (Gerstenberg et al., 2015)

As a result of using this model, the developers might find themselves in situations where drastic changes to functionality and design are necessary for the project to progress, and thus, rendering a lot of the previous work seemingly insignificant. This might at first seem counterproductive, but according to Gerstenberg and the other authors (Gerstenberg et al., 2015), one the main benefits of applying the wayfaring model to a development project with high degrees of freedom, is that it allows for the possibility of exploring the unknown unknowns. This can in turn lead to new and innovative discoveries as a direct cause of serendipity. These unknown unknowns are described by the authors as variables that are part of your problem or solution, that your neither aware of, nor their inherent value. This newfound understanding, knowledge or idea can be actively sought by testing, prototyping and evaluating. This process is referred to as probing and the concept is depicted in Figure 2. The idea is that the knowledge gained through probing, can be knowledge that is impossible to accurately anticipate. This will in turn help the developer get a deeper understanding of the problem and the possible solution space. Evolving a concept in one domain can also elicit new ideas and concepts in other domains. The wayfaring model is made up of many instances of the probing process, and this is what guides the project forward. Ideation, prototyping, testing and evaluating, gives the developer the insight needed to assert where to take the project next.

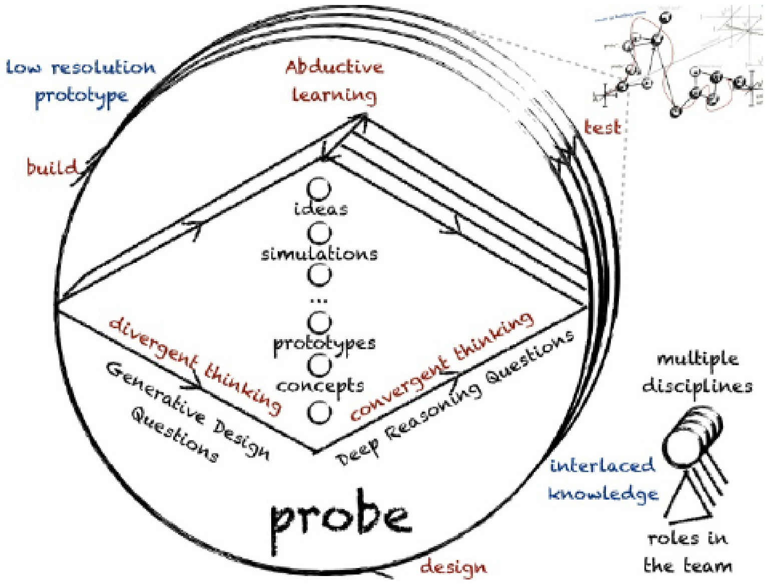


Figure 2: Probing-cycle (Gerstenberg et al., 2015)

We can see from the illustration of the probing concept Figure 2, that this process is easily comparable with the process of creativity proposed by Dornberger and Suvelza (Dornberger & Suvelza, 2012). By extension, it can then be said that the wayfaring model is in essence, made up of many intenseness of facilitated creativity.

2.1.2 Seed growth and influencing factors

To fully understand the challenges involved in building a home growing system, it is important to get a deeper understanding of the needs of a seed. In order for the seed to sprout, it is important that the surrounding environmental conditions are right. These conditions are usually availability of water, how deep in the surrounding medium the seed is planted and the temperature surrounding the seed. The process of the early seed growth is called germination. Germination incorporates the events that start when the dormant seed takes up water until the elongation and penetration of the embryotic axis (Bewley & Black, 2012). The visible sign of the germination being complete is usually when the radicle (embryonic root) penetrates the seed coat; the result is often called visible germination (Bewley, 1997).

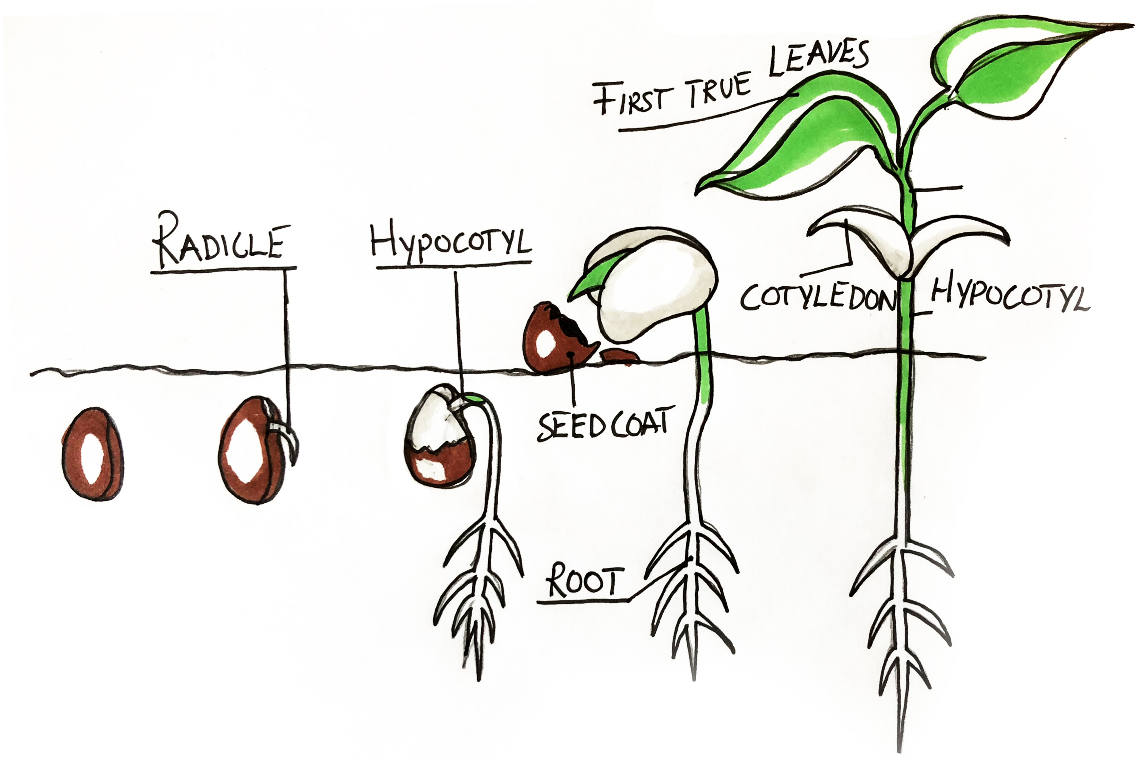


Figure 3: Illustration of the germination process

Imbibition is the process of the seed filling with water, and when the water is absorbed, it activates enzymes that initiate the seed growth. The radicle will then penetrate the seed in order to improve the seeds access to water and nutrients. The seed itself contains the embryo, that will become the new plant, and is well equipped both structurally and physiologically to act as a dispersal unit. There is also a surplus of carbohydrates and proteins inside the seed. This makes the seed able to sustain the growing seedling until it can establish itself as a self-sufficient organism with leaves and roots that can draw energy from available light and nutrients (Bewley, 1997; *What is Seed Germination? - Definition, Process, Steps Factors*, 2017).

It is however important that the seed is not surrounded by too much water. Before the seedling have breached the surface of the surrounding growing medium and the root formation is still undergoing, oxygen and light are very limited resources. During this time the seed is fully reliant on the oxygen stored in the ground and the nutrients in the seed. This means that an excess of water can ultimately drown the seed by limiting the oxygen supply. It is also important to account for the fact that different seeds require different temperatures in order for the germination process to start. This is usually dependent on geographical origin as seeds indigenous to northern environments, tend to start the germination process at a lower temperature than seeds indigenous to environments closer to the equator (*What is Seed Germination? - Definition, Process, Steps Factors*, 2017)

It should be noted that some seeds can stay dormant although the surrounding environmental conditions are optimal. The seed may achieve virtually all the metabolic steps that is required for germination, but still experience that the elongation of the radicle fails. Despite the fact that many researchers have studied dormancy, there is still no unambiguous definition for the phenomenon (Bewley & Black, 2012).

2.1.3 Symptoms of nutrient deficiencies

There are several factors that can influence the plants development under the course of its lifespan. In home growing systems, the source of nutrients can be a variety of different commercially available nutrient solutions. Since different plants have different nutritional needs, it is important to choose the right nutrient solution for each type of plant. If the wrong type of nutrient solution is chosen, the plant growth might be inhibited and start to show unwanted growth behavior. The plants exhibit different symptoms for different nutrient deficiencies. The most common symptoms can be found in Table 1, according to Thiyagarajan *et al.* (Thiyagarajan, Umadevi, & Ramesh, 2007).

Defficient Nutrient	Symptoms
Nitrogen	Leaves are small and light green. The lower leaves have a lighter color than the upper leaves. The plant stems are weak.
Phosphorus	Dark-green foliage. Lower leaves become yellow between the veins. Purplish color on leaves or petioles
Potassium	Lower leaves may be spotted (light to dark blotches). Dead areas near tips and margins of the leaves. Yellowing starting at the margins and continuing towards the center of the leaf.
Calcium	Tips of shoot dies. Tips of young leaves die. Leaf tips become hook-shaped
Magnesium	Lower leaves are yellow between the veins (veins remain green). Leaf margins may curl up or down, or leaves may pucker. Leaves die in later stages.
Sulfur	Tip of the shoot stays alive. Light-green upper leaves. Leaf veins are lighter than surrounding areas.
Iron	Tips of shoot stays alive. New upper leaves turn yellow between veins (large veins remain green). Edges and tips of leaves may die
Manganese	Tip of shoot stays alive. New upper leaves have dead spots on the surface. Leaf may appear netted as small veins remain green.
Boron	Tip of shoot dies. Stems and petioles become brittle.

Table 1: Symptoms of nutrient deficiencies in plants (Thiyagarajan et al., 2007)

2.2 Technology review

In order to better understand what separates the different hydroponic methods of growth, I have benchmarked the six most common types of hydroponic systems. This describes how they deliver water and nutrients to the plants and their limitations. In addition, different growing media and options for the artificial light source will be discussed.

2.2.1 Hydroponics

Hydroponics is a form of hydroculture and a way of growing plants by using a mineral nutrient solution in a water solvent, rather than the traditional use of soil. The term hydroponics is a fairly recent term, but the method of growing plants by utilizing water instead of soil dates back much longer. It is largely believed that the floating gardens of the Aztecs of Mexico and the hanging gardens of Babylon functioned according to hydroponic principles (Resh, 2012; Thiyagarajan et al., 2007). One of the first recorded hydroponic water culture experiments was performed and published by John Woodward in 1699. By the mid-19th century Julius von Sachs and Wilhelm Knop developed a method of growing plants without soil, and in the late 1930s, Dr. W. F. Gericks used the term "hydroponics" to the describe a method of growing plants by immersing its roots in an aerated solution of nutrients.

Today the term hydroponic is actually defined as growing plants without soil (Thiyagarajan et al., 2007) With this broad definition, countless methods of growing plants hydroponically have been developed throughout the years. The six most common methods will be explained further, and the underlying concepts can be seen Figure 4.

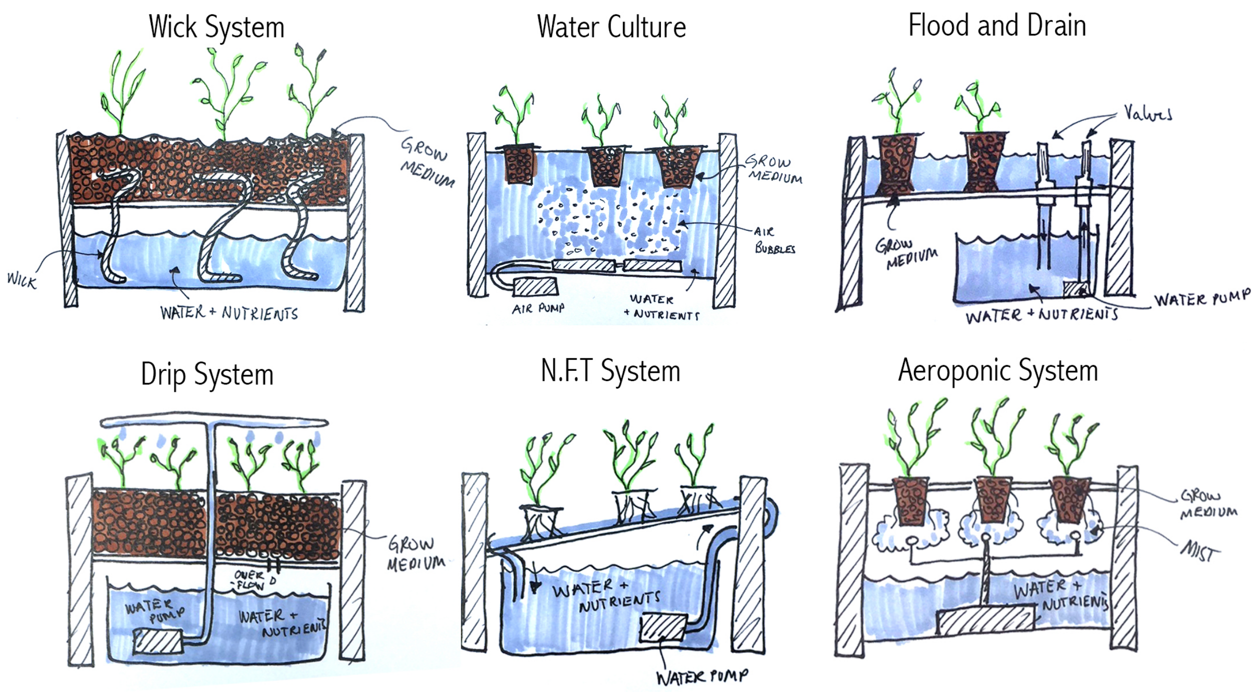


Figure 4: Illustrations of some of the most common types of hydroponic systems.

Wick System

The wick system is a low-tech, passive system and one of the most basic forms of hydroponic growth. The system relies on capillary action, in order to deliver water and nutrients to the plants. The most common setups of this type of system is a grow tray filled with a growing medium, that the plants are set in/seeds are planted in. The wicks go from the growing medium, through the grow tray and down in to a reservoir that holds a solution of water and nutrients. There are however some drawbacks with this type of system. The delivery method for the nutrient solution, limits what kind of plants the system can hold. Plants that needs a lot of water, such as tomato plants, will usually use up the water stored in the growing medium faster than the wicks can resupply it. This means that the plant will eventually wither and die. The best plants for this kind of system is usually some type of lettuce or herb. (D'Anna, 2018)

Drip System The drip system or drip irrigation uses a water pump to deliver a solution of water and nutrients. The solution is pumped from a reservoir and then dispensed in a droplet form elevated above the growing medium where the plants are situated. The goal of this system is to supply the water and nutrients directly to the root zone, where the plants can easily absorb it.

Water Culture The water culture system is one of the most basic forms of, active, hydroponic growth. The system consists of a reservoir holding a nutrient solution, an air pump and pots with some sort of growing medium that hold the plants. The plant is suspended in the pot right above the nutrient solution, with the roots fully immersed in the solution. The roots remain submerged at all times and it is because of this that it is crucial that the solution is properly aerated. Lack of proper aeration will lead to the roots suffocating and ultimately; the plant dying.

N.F.T System (Nutrient Film Technique The Nutrient Film Technique is one of the most commonly known types hydroponic systems. The system utilizes a constant flow of nutritious liquid that moves through the roots of the plants. A water pump transports the nutritious liquid from a reservoir and onto a grow tray. The plants are then suspended above the grow tray so that the roots of the plant can come in contact with the stream of water and nutrients. The major downside of this method is that the plants become very sensitive to interruptions of the continuous nutrient flow. If the flow is discontinued by, for example, a power outage, the plants will very quickly start to wither away as the roots dry out. This can however be partially worked around if the plant is situated in a grow medium that can absorb and store some of the water and nutrients from the continuous flow. The system will in this case still be affected by interruptions in the flow, but it will take a longer time for the plants to wither and die.

Flood and Drain – Ebb and Flow

The flood and drain system is also a very common, active, hydroponic system. The system contains a reservoir, water pump, grow tray and a valve or an overflow pipe. The pump carries a nutritious liquid up into the grow tray, here the plants or seeds are planted in a growing medium. The growing tray then gradually fills with the nutritious liquid, until it is drained out back into the reservoir. The draining is usually done by either opening a valve or water reaches the overflow pipe inside a bell siphon and then being siphoned out of the growing tray. This cycle goes continuously, and the cycle frequency can be set to accommodate the type of plant that is growing.

Aeroponics

Although aeroponic systems are usually quite simple, they are usually one of the more technically demanding systems. In this system, the roots hang in the air, surrounded by a nutritious mist. The mist is usually made by a mister or small sprinkling heads. One of the advantages of an aeroponic system is that there is little need for a growing media. The roots are also fully exposed to oxygen, which usually results in the plants growing faster. This does however make the roots very vulnerable to drying out, so the mist must be supplied frequently.

Aeration of the nutrient solution is considered quite important in many of these systems. This can usually be achieved in two main ways. The first way is by utilizing an air pump that pumps air into the reservoir through a membrane. This creates small bubbles, depending on the membrane, that dissolves in the nutrient solution. The second way is by integrating a small waterfall in the system. The falling nutrient solution agitate the surface of the reservoir and introduces air to the liquid. The higher the drop and the bigger the volume of the liquid, the deeper the agitation goes, and the more oxygen gets dissolved.

Growing food hydroponically in commercial food production, have become fairly common I recent years. This is most likely because of the increased control the farmers have over each element that goes into the process. Hydroponic growth also allows continuous cultivation, even in the usual off-season. The method is also very water efficient and gives farmers the ability to maximize the yield per area, due to possibility of stacking systems. Resh (Resh, 2012, pp. 1–8) writes that tomatoes grown hydroponically in green houses, have an increased production yield of 20-25%, compared to tomatoes grown in soil in green houses. This increase in yield can be credited to several reason, but Resh (Resh, 2012, pp. 1–8) suggest that the main reason is that the soil might lack nutrients and have poor structure or that the presence of pests and diseases in the soil will greatly reduce the possible yield.

2.2.2 Growing media

In hydroponic growth, growing mediums are often used to replace the soil. The growing mediums does not provide the seeds and plant with nutrition directly but is rather as a support structure so that the roots have something to grab onto. In some systems the growing medium does also function as a device to transport nutritious liquid to the plants, through capillary action. It is therefore necessary that it is able to hold moisture and provide the roots with an oxygen-rich environment. Because of these reasons, growing mediums usually consist of porous materials. It is possible to use non-porous materials as well, but this requires an increased water cycle frequency and active aeration of the nutritious liquid. There are of course countless types of materials that can be used as a growing medium. It is how ever important that the growing medium chosen, does fit the requirements of the hydroponic system being used, seeing as different materials have different qualities and attributes. The wick system is for example dependent on the growing mediums ability to absorb, transport and hold moisture. So, the choice of media, really comes down to the design of the system in question. Five of the most common types of growing media will be explained further below (*Growing Mediums and Hydroponics*, 2017):

Vermiculite is a silicate mineral. The vermiculite particles are relatively small, quite absorbent and have the ability to hold moisture for quite a long time. This makes it very suitable for applications where the seeds are planted directly into the vermiculite. The small particles will provide quick anchorage to newly developed roots and the moist environments will provide a suitable condition for the seed to start the germination process. The vermiculite does however have quite the low density, which means that it will float. This means that its applicability is very dependent on the design of the system.

Rockwool is primarily created as isolation for houses, but it is still commonly used as a growing medium. The material consists of granite and limestone that have been heated to its melting point, and then spun into thin threads. This results in a porous, non-degradable, material that can absorb and hold moisture very well. The rockwool can however become saturated very easily, if exposed to too much liquid at one time. This can in turn lead to the roots suffocating or limiting air circulation so much that the roots start to rot. The applicability of this material as a growing medium, is in other words, quite depending on the system being design so that its supplying a moderate amount of liquid/moisture to the rockwool. The fact that the material is non-degradable also makes it reusable. It should be noted that the rockwool is not a pH-neutral material. This means that it needs to be balanced and treated before it can be used, or else it might disturb the development of the plants.

Clay Pebbles, also referred to as *hydrocorn*, is a type of clay that has been super-fired in order to create a hard and porous texture. This type of clay is also called a *Light Weight Clay Aggregate*, or L.E.C.A for short. The material provides a stable support for the plants and gives longer roots the possibility of gaining great anchorage. The pebbles are able to hold moisture quite well, and when stacked upon each other, capillary action helps transport liquids upwards. The clay pebbles are pH-neutral and are non-degradable, which makes them reusable if sterilized between uses.

Growstones are in many regards similar to the clay pebbles. What separates them is that the growstones are made of a mixture of recycled glass and clay. They are light weight, have porous texture and are also non-degradable The growstones are usually bigger than the clay pebbles and unevenly shaped, this does provide great aeration for the roots but can lead to young plants having trouble getting good anchorage. The growstones do also have the ability to transport moisture upwards through capillary action, when stacked on top of each other.

Coconut Fiber and **Coconut Chips** are also a commonly used growing medium. They are considered the waste products of coconuts and is therefore an organic material. Despite this, the material does not provide the plants with any nutrients. This is because of its very long decomposing time. The coconut fibers and chips does hold moisture very well, are pH-neutral and provide great aeration for the plant roots. It is however important to note that when organic materials are used as growing media, it is very important to make sure that it does not contain any chemical fungicide, pests or diseases. If so, these contaminants can affect and inhibit the growth and development of the plants.

2.2.3 Artificial light source

When making a home growing system a reliable source of light is adamant in order to provide the plants with the energy and information they require for its development. The best way to provide this is through artificial lighting. The three most common types of artificial lighting used in indoor growing system are; Fluorescent, HID (*High-Intensity*

Discharge) and LEDs (*Light-Emitting Diode*).

Fluorescent lighting used in indoor growing and growth chambers, does usually have enhanced blue and red spectrums in order to emulate sun light. These lights function by applying a current to a phosphor coated tube, containing mercury and an inert gas. The current excites the mercury until it transitions into a gas form. In the gas form, the mercury, gives of ultraviolet light that is converted to visible light by the phosphor coating. Fluorescent lighting has the benefit of not producing a lot of waste heat, which means that they can be placed closer to the plants without disrupting the plants development. The fluorescent lights do however have a downside. When left on over a long period of time, both the spectrum and intensity of the lights, become unstable and unreliable (Darko, Heydarizadeh, Schoefs, & Sabzalian, 2014).

The two most common forms of HID lighting used for indoor growing, is metal halide (MH) and high-pressure sodium (HPS). The metal halide form uses different types of metal halides placed in an arched tube and function similar to the mercury in the fluorescent lighting. The resulting light is a combination of both visible and ultraviolet light. Another tube is placed outside the inner tube, and this tube acts like a filter for the light. Trapping the ultraviolet light inside and allows the visible light to pass through. High-pressure sodium lights consist of an inner and an outer bulb, similar to the metal halides, but instead of halides, the inner bulb contains metal sodium and mercury.

Light-emitting diodes emits light by applying a current over several small semiconductors. They produce little heat and last longer than most other forms of lighting. LEDs also comes in a variety of wavelengths and intensities, which makes it possible to optimize them in order to increase plant productivity and quality. This makes them quite suitable as an artificial light source for indoor growth. An experiment on plant growth carried out by Bula *et al.* (Bula et al., 1991), reported that lettuce grown beneath red LEDs (650nm) showed an increase in dry matter per mole of artificial lighting, compared to normal sun light. Chang *et al.* (Chang et al., 2011) also calculated that the growth of the green algae *Chlamydomonas reinhardti*, had its maximum photon utilization efficiency when subjected to lights with a wavelength of 674 nm. Schoef (Schoefs, 2002), credits this to the fact that wavelengths within the red section of the light spectrum fits perfectly with the absorption peak of chlorophylls. It has however been found that lettuce grown beneath red LEDs, presents signs of elongation in the hypocotyls (the stem of a germinating seed). This could however be prevented if the plant was subjected to a blue light in combination with the red (Hoenecke, Bula, & Tibbitts, 1992). Supplementing the plants with the blue light was also proven to give better excitation of the different photoreceptors in the plant and the combination of the red and blue lights showed a higher level of photosynthetic activity, than under either monochromatic light condition (Sabzalian et al., 2014). It is possible to compliment this light combination with green LEDs, but according to Kim *et al.*, illumination containing more than 50% green light has proven to reduce the plant growth. They reported, however, that illumination containing 24% green light has shown to enhance the growth rate in some plant species (Kim, Wheeler, Sager, Gains, & Naikane, 2005).

3 Development

3.1 Users and Need finding

Prior to this master's thesis and the pre-master's thesis, Jørn Hammer from Den Lille Gartner and a team, carried out a design-thinking process. This was done with the intention of finding out how they could engage people into growing some of their own food and at the same time take an interest in sustainable food production. When they had identified important stakeholders and gained some insights they came up with this POV (Point-of-view): "A young(ish) urban mother needs to maintain her identity as trendy and genuinely concerned about the state of the world today, as long as it's not too time-consuming and fits in with her busy lifestyle". This led to further exploration where they prototyped and tested different concepts. They then interacted, interviewed and observed over 50 people. The solution they landed on was a home growing system. The tests and interviews also led the team to land on a triangular design, to ensure that the system would fit nicely into corners and be easy to implement on a kitchen counter. The other main take-aways from the process was that the system needed to be:

- Easy to use
- Fairly self-going once the seeds have been planted
- Able to hold enough water and nutrient for a reasonable amount of time
- Have a non-intrusive design that can fit into a Norwegian home
- Be modular

These takeaways, in combination with the deliverables and actions listed in the problem description, guided the direction of the development process.

3.2 Take-aways from the pre-master's thesis

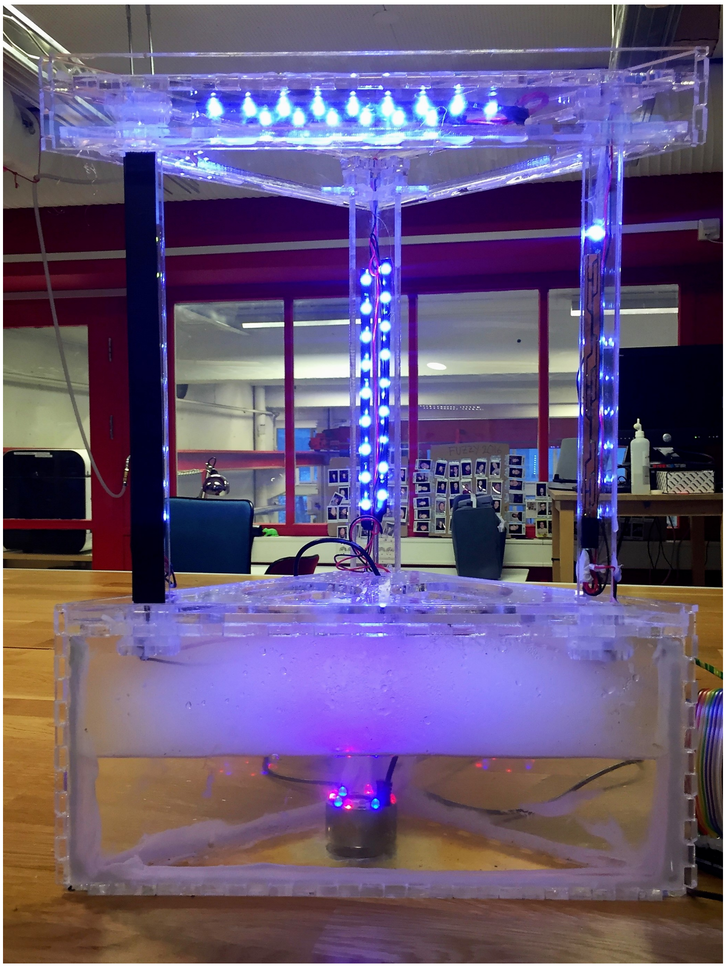


Figure 5: Proposed prototyped system from the pre-master's project

In the conclusion of the pre-master's thesis, a preliminary system was proposed. The prototyped version of this system can be seen in Figure 5. The delivery system for the nutrients utilized ultrasonic atomization. The ultrasonic vibrations create a nutritious mist that surrounds and impinge on the growing medium that are holding the seeds. The light module was suspended by three rods, mounted in each of the three corners. The light module used LED's as an artificial light source and the rods where also fitted with LED's so that the lower leaves of the plant would also be exposed to light. The suspension rods were fitted with internal cables that supplied both the LED's in the light module and the suspension rods with power. The rods were connected to the lower system and the light module by magnets, so that the rods could be "clicked" into place. Further explanation of the proposed system can be read about in the pre-master's thesis enclosed in the appendix.

After the pre-master's thesis was delivered, the findings and the direction of the continued development was discussed. It was decided, due to the unknowns surrounding the ultrasonic atomization's reliability (expected lifetime, risk of failure, lack of stress testing), that this would no longer be explored as a means of delivering the nutrient solution. The development process should rather focus on finding a way to deliver the nutrients by utilizing a water pump.

3.3 Hydroponic test in parallel with the development

In order to better empathize with the end user, get a better understanding of how a hydroponic home growing system works and in what way the user interacts with the system, a test was conducted in parallel with the project. The test started in June 2017 and consisted of using a commercial home growing system to grow different types of plants. The first commercial system that was tested was the *Fresh Garden - Easy Grow*. The system can be seen in Figure 6. In January 2018, when the work on this master's thesis started, a new system was added to the test. This system was a *Herbie - Indoor garden*. The system was tested together with the *Fresh Garden - Easy Grow* until Mai 2018. Since different types of plants have different needs and different growth rates, a selection of different plants was grown during the course of this test. Some of the plants grown was; Thyme, Tomatoes, Lemon Peppers, Dill, Lettuce and Rosemary.

Figure 6: The "Fresh Garden - Easy Grow"-system

Figure 7 illustrates the principles used in both the Fresh Garden and the Herbie system. At the bottom of the Fresh Garden system, a water pump is situated. From here the nutrient solution in the tank is pumped upwards and sprayed horizontally out in a 360-degree angle. The solution then hits the clay pebbles in the pots, and from there capillary action transports it further upwards where it gets absorbed by the vermiculite. The seed is planted in the vermiculite and this ensure that the seed gets the water and nutrients needed for the germination to start. This process will be the same when the seed has taken root. The Herbie system is a kind of "Nutrient Film Technique"-system. The nutrient solution is transported from the tank, up to the grow tray by a water pump and then spread out on the grow tray. The pots with the plants/seeds are placed on the grow tray, and capillary action draws the solution upwards to the seed/roots of the plants. This works in the same way as the Fresh Garden system.

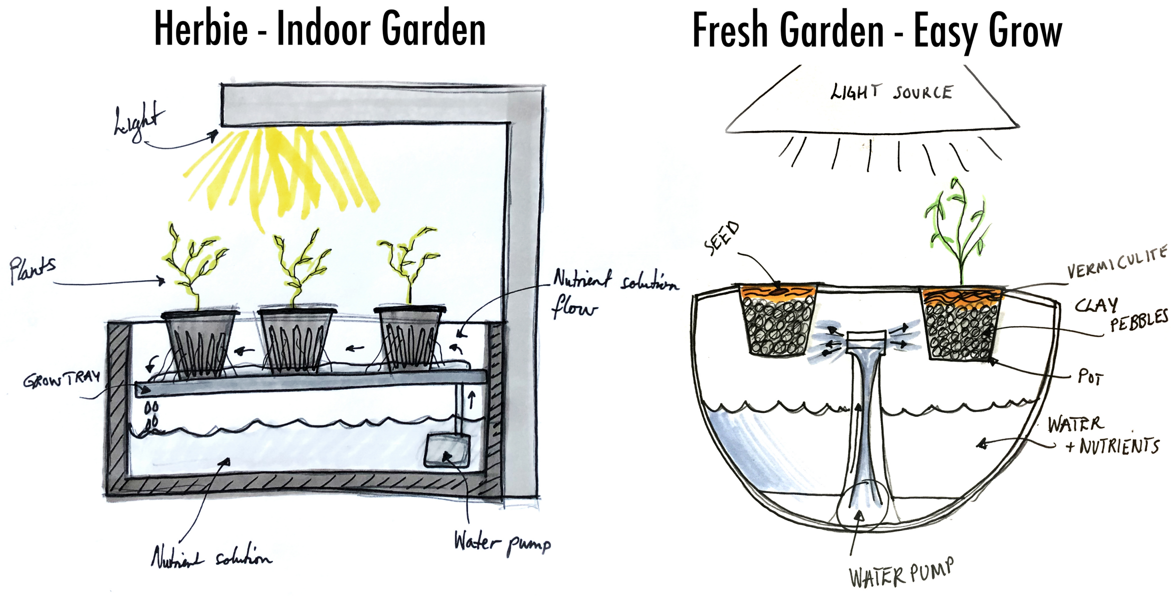


Figure 7: The principles behind the Herbie - Indoor Garden and the Fresh Garden - Easy Grow

This test ended up providing many new insights. One of the main problems experienced when using the Fresh Garden system was issues with the water pump. The water pump in the system is situated right beneath the pots, with only a filter separating the water tank and the pumps inlet. When the roots grew too long, they ended up finding their way through the filter and into the pump. This caused the pump to clog and in effect; stop the system from working. In order to fix this, the system needed to be partially disassembled. This was quite the inconvenience as the light module is directly attached to the lid that also holds the pots. So, in order to remove this part, it was necessary to remove every single pot from the system first. The circular design of the system and the amount of space above the reservoir needed for the light module to be raised high enough, did also offer some problems when finding a suitable place for the system. The system could for example not be place below the cabinets on the kitchen counter, due to the height needed for the light module.

Another nuisance that became evident with both systems over time, was that it became a little bit difficult to refill the water and nutrient when the plants became more developed. On the Fresh Garden system there is a small rubber plug that, when removed, reveals a 3 cm wide hole leading straight down to the systems reservoir. This plug was at one point covered by lettuce leaves, making it less accessible then it was when the system was set up. The Herbie-system did not have a designated hole to refill the water and nutrients, so in this system you just poured in the water and nutrients down on top of the grow tray. This was a bit easier than the with the Fresh Garden-system, but here the size of the plants and the cover on top of the system, made it somewhat difficult to see what you were doing. The LED's functioned well as an artificial light source and the plants seemed to thrive under it. The light pollution from the Fresh Garden-system to its surrounding area was in fact so big that it actually ended up as a nice supplementary light source for my work station, when the system was running. This was not the case for the Herbie-system, as the LED's are situated inside an aluminum profile. This might be the more desirable case, as most people might see the bright light as an annoyance if too much of it spills out into the room.

Both systems where placed in my bedroom, as this was the only convenient place for them. This did how ever leave me wanting for a function that none of the systems had; a button that could ensure that the lights would not turn on in the middle of the night. The Fresh Garden-system appeared to have such a button, but as long as the system was on, the lights would turn on as the chosen program reached its next cycle. So, to ensure that this did not happen, the light modules of both systems would be manually disconnected each night and plugged in again the following morning. It can be argued that most users would have the system in their bedrooms, but this feature would be good to have nonetheless.

3.4 Prototyping and testing

Due to the decision of no longer using ultrasonic atomization as a delivery system, a new system was constructed straight away. This system was built in the same manner as the preliminary system proposed in the pre-master project, only simplified and modified to use a water pump instead. The prototype was built simplistic so that it could be used for testing further iterations of the different components as problems and challenges revealed themselves. The system utilized one of the more common methods of hydroponic growth, namely the Nutrient Film Technique (N.F.T). The prototype can be seen in Figure 8.

Figure 8: First prototype utilizing a water pump

The system consisted of a water reservoir, a grow tray and a light module. The pots are placed on the grow tray and the tray is connected to a water pump that is situated in the water reservoir. The water pump is connected by a tube, that in turn is connected to a nozzle. This tube distributes the water and nutrients on to the tray and the solution exits through a hole on the other side of the tray. After a few tests, it was evident that the nutrient solution did not distribute evenly on the grow tray. The pot situated in the 90-degree corner, was not subjected to the same amount of water as the two other pots, which in turn caused the seed to not start the germination process. This was because the nutrient solution entered in one of the 45-degree corners, traveled straight across the grow tray and existed the other 45-degree corner, without touching the 90-degree corner. The grow tray was initially made to be completely horizontal within the system, so this problem was probably caused by the ground beneath the system not being perfectly horizontal. In order to fix this problem, a new grow tray was prototyped. This grow tray was made with a 1-degree tilt towards the exit hole when mounted in the system. Guide rails where also added to ensure an equal distribution of the nutrient solution throughout the growing tray. The tray can be seen in Figure 9 (Arrows indicate the flow of the nutrient solution).

Figure 9: Prototype of the growing tray

This prototype worked much better as the water was evenly distributed this time. A test was performed where pots filled with three pots of clay pebbles and vermiculite were placed on the growing tray, mounted in the system. Thyme seeds where planted in one of the pots and rosemary in the two others. The systems reservoir was filled with a mixture of water and a nutrient solution created especially for herbs, powered on, and set aside for 4 days. After four days, it was evident that something had gone wrong because all of the pots were still dry. The clay pebbles were evidently not able to transport the liquid from the grow tray and up to the plant. The same test was set up again, but this time the pots containing the clay pebbles were soaked in water ahead of adding the vermiculite and planting the seeds. This was proven to be exactly what the pebbles needed in order to continuously soak up the liquid through capillary action. After one week the seeds began to sprout in all of the pots, and thus confirmed that the prototype was working.

After letting this experiment run for a couple of weeks, it became evident that the design of the system was very flawed in terms of user-friendliness. Refilling the reservoir and interaction with the plants, were greatly inhibited by both the design of the grow tray and the three support rods used to suspend the light module. The only way to refill the reservoir without taking the pots and grow tray out of the system, was to pour the new nutrient solution straight down onto the tray. Although this iteration of the system had transparent walls that made up the reservoir, the finished system was not supposed to be transparent. This would have made it hard to assert when the system was full before the water went over the grow tray, in addition to being inconvenient. A small height differential between the grow tray and the liquid in the reservoir, would also benefit the system as it would help aerating the nutrient solution. The light module and suspension of it, also needed to be addressed. A smaller light module would be less intrusive for the user while interacting with the system and the possibility of adjusting the height of the light module would help accommodate both small and big plants. A new concept was sketched up, and this can be seen in Figure 10.

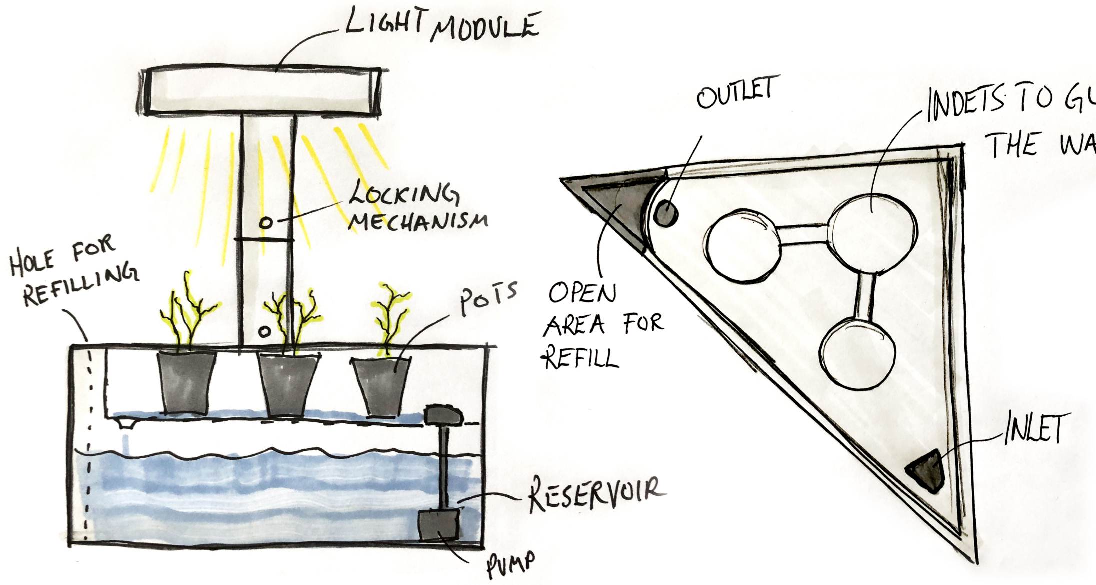


Figure 10: Illustration of the new concepts

Before setting out to build a new prototype, the existing prototype of the system was evaluated even more. When observing the system in use, it became clear that it wasn't able to utilize all the water in the reservoir before it needed to be refilled. Once the surface level of the nutrient solution in the reservoir dropped below the pump, the pumps ability to transport the liquid became greatly reduced before it came to a complete stop. This would be quite frustrating for the user, as it was necessary to refill the reservoir before it was visibly empty. This also meant that a large volume of the reservoir was in fact rendered ineffective, when it came to its ability to hold useable liquid. Another feature of the prototyped system was that there was no easy way to disassemble or partially disassemble it. It was clear that it would be beneficial if there was a way to remove the grow tray from the system, without having to disassemble anything. This would make it easy for the user to access the reservoir if anything needed to be adjusted or checked. Not being able to do this had shown itself to be quite frustrating, when testing the *Fresh Garden - Easy Grow* system. Cleaning the *Fresh Garden - Easy Grow* was also impossible without disassembling the hole system, and even then, the fixed pump at det bottom of the reservoir made it difficult. If the developed system could be designed in such a way that the grow tray and reservoir could be removed with relative ease and then be able to handle being put in the dishwasher, it would add a lot of value to the end-user. This meant that it had to be possible to remove them directly from the assembled system and that the pump could easily be disconnected from the grow tray. The last feature discovered to need further iteration where the sharp corners of the prototyped system. Seeing as they took up more horizontal space than what was needed and utilized by the different functions within the system, it was decided that a design change was in order. New concepts where developed and some of them are illustrated in Figure 11

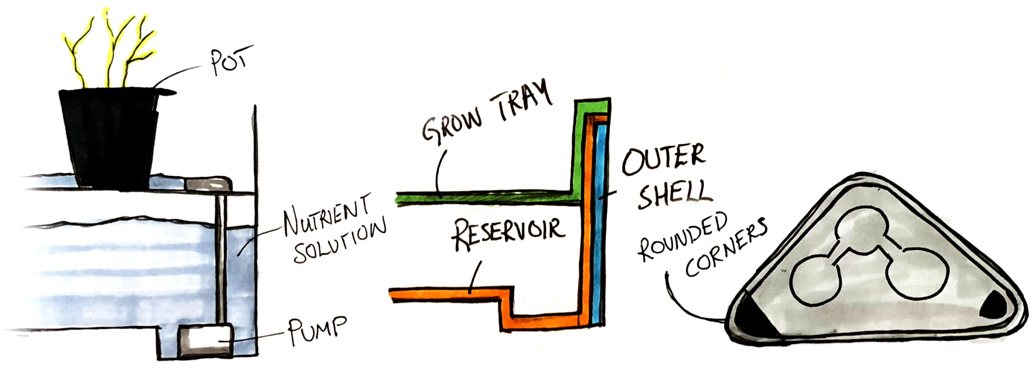


Figure 11: Illustrations of concepts to be included in the next prototype

3.4.1 Grow tray, reservoir and outer shell

The biggest concept change was that the lower part of the system now could be separated into three components: the growing tray, the reservoir and the outer shell. The main function of the outer shell is to be a support structure for the reservoir and subsequently, the grow tray. A vertical elongation of the reservoirs corners was also conceptualized. This was added in order to accommodate the pump so that most of the liquid in the reservoir remained above the pump. This feature would make sure that most of the liquid in the system could be utilized before the system had to be refilled. The reservoir is placed inside the outer shell so that the elongated part of the reservoir touches the ground and a flange around the top of the reservoir, rests on the outer shell. The grow tray is then placed inside the reservoir, resting on a ledge created as a part of the reservoirs shape. The grow tray does also have a flange around the top. This helps distributing the weight of the plants onto the support structure and make it easier for the user to grab a hold of it, when removing it from the system. The sharp corners are also replaced by rounded corners and the design of the grow tray is altered so that it does not cover the left side corner of the reservoir. This gap is created so that the user can easily refill the reservoir with water and nutrients, as well as look down and assert the remaining water level. An illustration of the grow tray, reservoir and outer shell, can be seen in Figure 12.

Figure 12: Illustration of the grow tray, reservoir and outer shell

After building new prototypes of the reservoir, outer shell and grow tray, it became clear that there had to be some sort of fastening mechanism for the pump where it connected to the grow tray. The mechanism had to be reliable so that the pump stayed securely in place, made so that the pump could be attached and detached very easily and lastly, robust so that it could handle being put in a dishwasher without something breaking off.

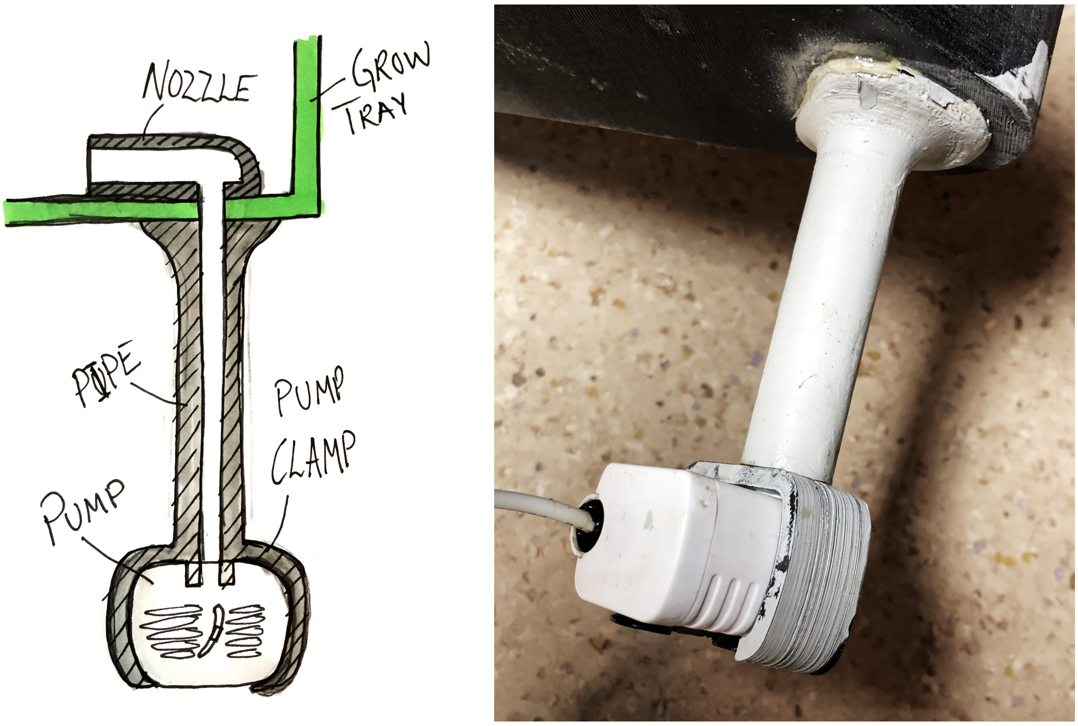


Figure 13: Illustration of the grow tray - pump connection

A fastening mechanism was conceptualized and prototyped, as seen in Figure 13. The prototype was mounted to the grow tray, and then evaluated. The prototype worked as expected and the clamp-concept ensured that the pump was locked into the right position during both assembly and operations. The pump could also be inserted and removed from the prototype with relative ease, an important feature in order to end up with a system that is easy to assemble and disassemble.

The water pump being used in the prototype had a maximum flow rate of 100 L/h, but this could easily be lowered by moving a slider that regulated the pumps inlet-size. The pump was specified to 24 volts and was chosen to match the voltage requirements of the final LEDs, so that both could run of the same power adapter without the need of a secondary transformer.

3.4.2 Artificial light source

The system proposed at the end of the pre-master, utilized LEDs suspended over the grow tray by three suspension rods, that also held LED's in order to illuminate the plants from the side. The next prototype of the systems light module was built in a similar fashion, but without the vertical LEDs. The two main takeaways from this was that the three supports and the light module was taking up as much horizontal space as the system itself and was therefore limiting the user's ability to interact with the plants and the system in general.

A new concept for both the light module and the suspension of it, were developed (concept illustration can be seen in Figure 10) and prototyped. The main concept behind the new light module was that it was suspended over the system by standardized suspension profiles that only connected to the 90-degree corner of the system. These suspension profiles could be added or removed in order to accommodate the height of plants in the system. So, if the user had two suspension profiles, it was possible to switch between a light module-height of either 15 cm or 30 cm. These profiles could also be made in smaller or larger increments, if found necessary. The profiles were made so that they could be stacked on top of each other and a simple locking mechanism helped them click in to place and remain securely. The prototyped suspension profiles can be seen in Figure 14.

The LEDs used in the prototyped light module, was the same LEDs used in the *Herbie - Indoor Garden* system. It was quickly discovered that these LEDs needed to be modified in order for them to function in the prototyped system. The LEDs was specified to and came with a 24-volt power adapter, but when connected and turned on, they quickly started to radiate heat. After 10 minutes of on-time, the LED-circuit board had become so hot that it deformed the PLA-plastic it had been mounted to. It became clear that the aluminum-profile that made up the *Herbie - Indoor Garden*s light module, had been acting like a large heat-sink. The LEDs was clearly not originally meant to handle the 24 volts, so a quick test was performed in order to determine a proper voltage level that didn't result in the LEDs overheating. The LEDs was connected to an adjustable power supply and the proper voltage level was attained. A resistor was then soldered in series with the board, with a resistor value calculated from the current and voltage data attained from the test. This was done so that the LEDs could still run on the same voltage as the pump, thus using the same power supply. This fixed the heating problem, but in turn lowered the light intensity of the LEDs. A lux-meter was then used to determine the required light intensity of the LEDs. The illuminance at pot level, with the light module mounted 30 cm above, in the *Fresh Garden - Easy Grow* system, was measured and averaged around 5000 lux. In order to match this number, the new prototype had to be fitted with two copies of the modified LEDs. The light module prototype can be seen in Figure 14.

Figure 14: The prototyped light module and suspension profiles

Lastly, a switch-button was added to the prototype. This was done to accommodate for the findings from the test of the two commercial systems. Being able to easily switch the lights off without the lights suddenly turning back on, had shown itself to be a desirable feature. The button was placed inside the light module, where it wouldn't be especially noticeable, but still easy to reach.

3.4.3 Modularity

One of the key features of the system is that it should be possible to connect four systems together.

One of the first concepts created was that the systems could be connected through magnets on the side of the system. This principle was partially tested in the prototype proposed in the pre-master, where the light module was connected through the suspension rods that had magnet connections on both ends. It gave good tactile feedback and the feature could be an interesting way of connecting the systems. The concept was however discarded due to practical concerns. If used, this concept would entail that the magnets would sit flush on the outside of the system somewhere, and this could cause a potential safety hazard for the user if they were to accidentally come in contact with them when they were not covered.

Initially, it was thought that the electronics needed for the connectivity between the systems should be added in every system, but after some discussion with Jørn Hammer (Den Lille Gartner), some new insights were gained. It was concluded that since the concept had to be able to connect four systems together, there was no reason for each system to contain the necessary electronics needed to act as a hub for the other three. As this would only increase the individual cost of the systems. A new concept was then developed, and a prototype was made.

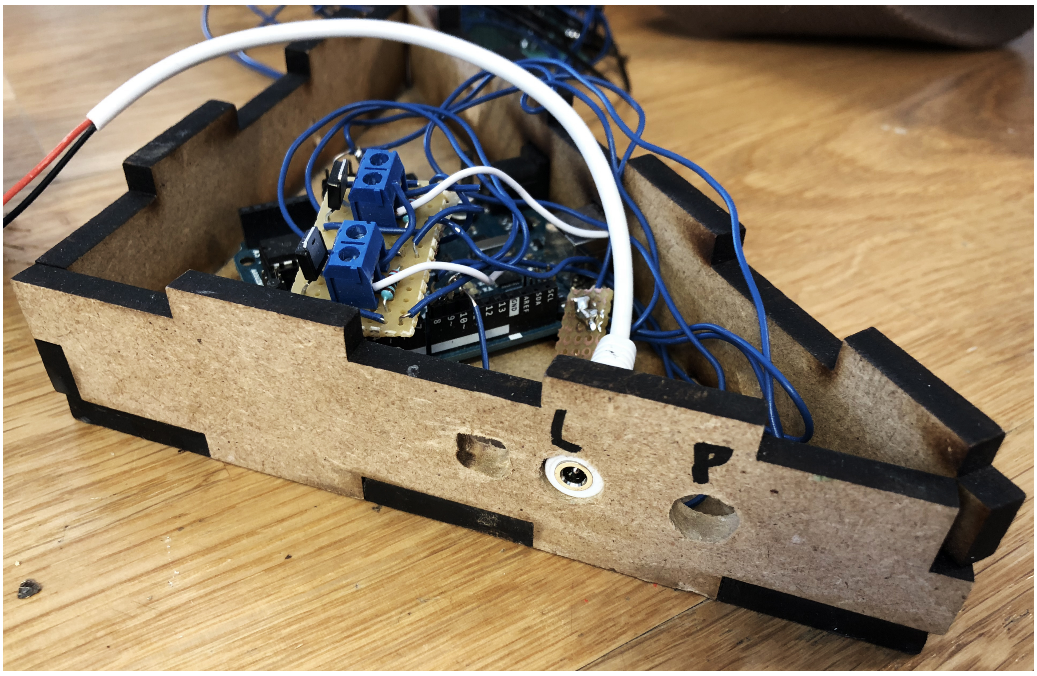


Figure 15: First prototype of the connection module between systems

The first prototype of the hub can be seen in Figure 15. This prototype functioned as a power supply and control unit for the system. The cables from the water pump and LEDs, was connected through female connectors in the hub. Inside the hub was an Arduino and a small circuit board. The Arduino was programed to take inputs from a push button that switched through a couple of programs. Since the prototyped system relies on a continuous flow of nutrient liquid, these programs only affected the frequency and duration of the light cycles. This worked well, but it became evident that there had to be some way that this module could be integrated into the system. Since the system was designed so that several of it would fit perfectly together when placed side by side, the module had to be integrated on the bottom or the top of the system. Any other place would lead to the module interfering with this feature. Since the light module is fairly small and the cables are wired to go through the "stem" of the system, fitting the module underneath the system would be the optimal placement. The redesign of the water reservoir in order to accommodate the pump, also left a good amount of free space underneath the system. A perfect example of how developing concepts in one domain, can elicit new ideas in other domains. A concept was developed, and a prototype was built (Figure 16

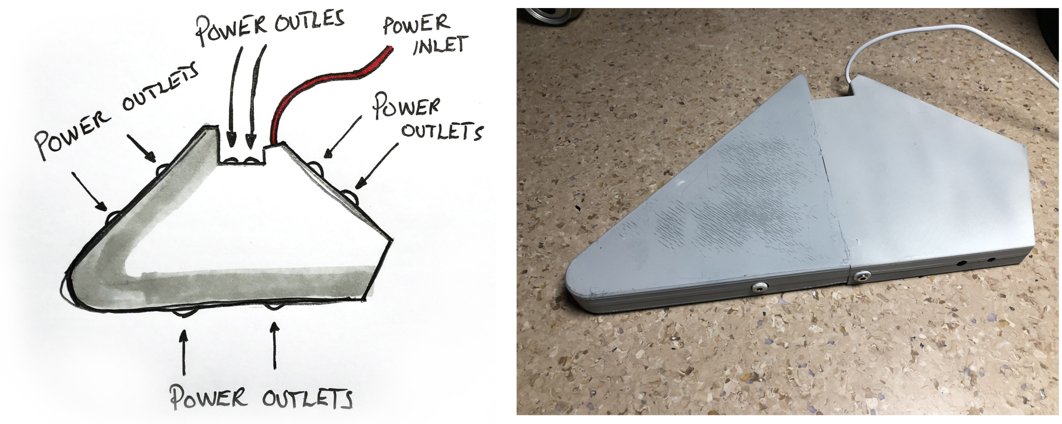


Figure 16: Hub - Concept and Prototype

The prototyped "hub" was created with the same shape and volume as the free space underneath the systems reservoir. This meant that the system could be placed on top of it and be held into place by the outer shells feet and the elongated part of the reservoir. Power outlets for both light module and water pump were added on each of the hub's three main sides. These power outlets allow for three systems to be placed adjacent to the system holding the hub and connected to it (example of this can be seen in Figure 17. A recess was created at the 90-degree corner of the hub and two power outlets were added. The power outlets here were meant for the system holding the hub. The functionalities of the hub were then discussed with Jørn from Den Lille Gartner. Seeing as the concept of controlling the light cycles had already been tested in a former prototype and since the prototyped system relies on the pump going continuously, it was decided that it was not necessary to add more functionalities to the hub at this point.

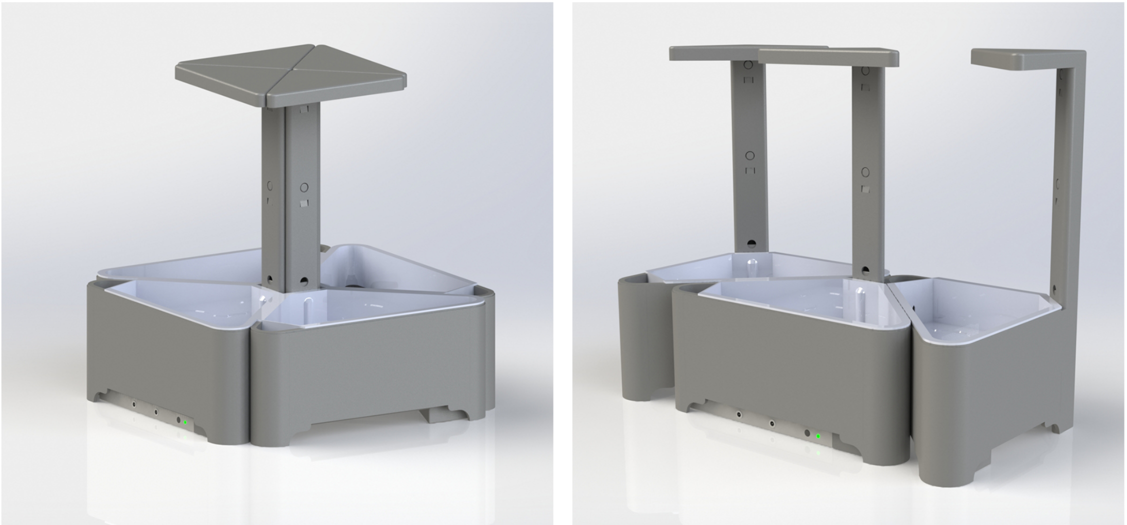


Figure 17: Examples of how multiple systems can be set up

3.4.4 Testing the system

Since all the new concepts and prototypes functioned as expected, it was time to assemble the whole system. A test was then performed to see how the system performed as a whole. The reservoir was filled with 3 liters of nutritious liquid. The liquid was a mixture made up of water and a commercial nutrient solution made especially for herbs, called *"Urtenæring"*. This was the same nutrient solution used in all the other tests. The pots were then filled with clay pebbles and soaked under running tap water. Vermiculite were sprinkled on top of the clay pebbles and basil seeds was planted in it, in all three pots. The pots were placed in the grow tray and the system was turned on. The system was placed in a windowless room, in order to assert that the illuminances from the LEDs was great enough to ensure plant growth. The system was inspected once every day and after a week, all three pots had visible shoots. The system was left to itself for another week and it was clear that the system accommodated for the basils needs, as the plants just kept on growing.

To make sure that the results were repeatable, two of the pots were cleaned out after three weeks and oregano seeds were planted in the same manner as the basil seeds. The remaining pot with the basil plants can be seen in Figure 18. After one week, both pots showed shoots and the oregano plants kept on growing in the weeks to come. The system was left on for 3 weeks after the oregano seeds were planted, and none of the plants showed any signs of nutrient deficiencies and only seemed to keep on growing. This test proved the validity of the concept and that the system functioned as desired and expected.

Figure 18: Proof of concept - results from the test of the prototyped system.

3.4.5 External water reservoir

One of the wishes from Den Lille Gartner was to develop some sort of external water supply, so that the system could be left unattended for a longer period of time. Some of the main influencing factors is that this external water supply should be:

- Easy to connect to the system
- Supplying the system with a stream of nutrient water equal to the systems consumption
- Disinclined to failures
- Have a supplementary design to the system

A brainstorm was performed for different ways this could be solved.

It became evident quite quickly that if valves, sensors and electronics could be avoided as a method of dispensing the nutrient solution, a lot of problems could be avoided.

The external water reservoir would also have to be connected to the system from the top, down into the systems reservoir. By introducing a connection that would have to go horizontally through the systems reservoir, new possibilities for failure could be introduced, like leakage in the connection.

The idea of a water dispenser that used the same principle as an inverted bottle that holds water as long as the inlet is submerged, showed itself to be an interesting concept that needed further exploration and probing.

The prototyping started by simply filling up a bottle of water and turning it upside down, while the inlet was still submerged. The water, as expected, stayed in place until you lifted the inlet above the water surface. The water then started to pour out of the bottle, until the inlet was submerged again. Then it stopped and stayed in place again. To understand the principles behind it better, a simple prototype was created, as seen in Figure 19.

Figure 19: First prototype of the dispenser concept

This prototype consisted of a bottle modified with two outlets on the bottom. The two outlets were submerged in their respective cups of water, and as expected, the water stayed in place. The water level in one of the cups were then lowered bellow its respective outlet and the prototype was observed. The outlet that was no longer submerged started to act as an air-inlet for the bottle, which resulted in water flowing out of the outlet that was already submerged. This continued until the bottle was empty and resulted in flooding the cup that already had a sufficient water level. This concept, as it is, could in other words only supply one system at a time.

A new prototype was built to explore how this concept could interact with the current prototype of the system. The prototype was built as triangular container, with the same dimensions as the prototyped system. The container was built with two separate chambers so that it would be able to supply two systems with nutrient liquid. The chambers would how ever be disconnected in order for this to work. So, the user would have to fill them up separately. The reservoir was connected to the system by rubber going into a rigid end piece that was locked onto the side of the system and down into the system reservoir. This turned out to work quite well and the setup can be seen in Figure 20.

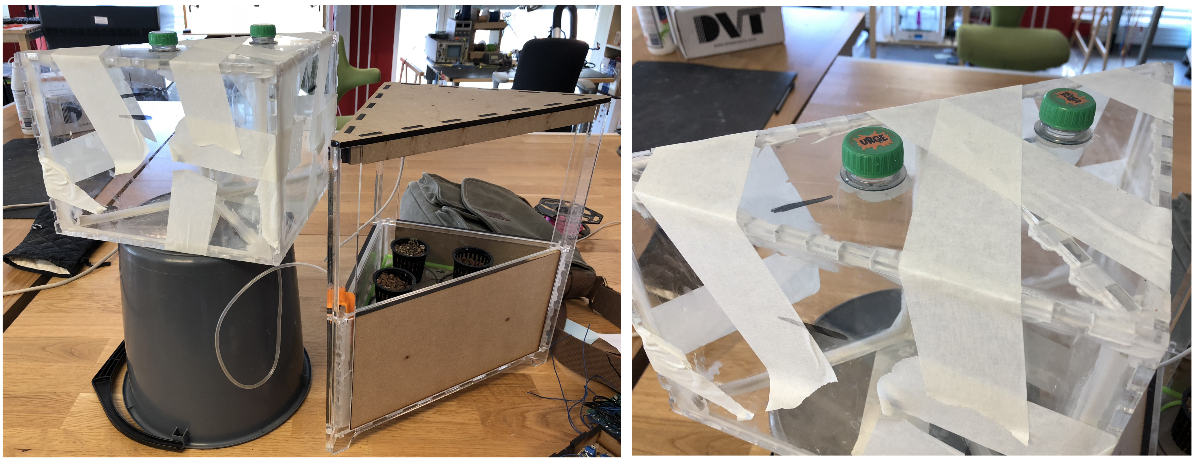


Figure 20: External Reservoir - Freestanding Module

This solution did however raise some practical and esthetic questions. If the user would need to allocate the same amount of space as needed for a system, that might be discouraging for someone that only use one or two systems. So, if the external water reservoir could take up less horizontal space and rather be integrated into the system in some way, that might be a more desirable solution. Especially since it is easier to make a bigger, freestanding module later in the development. The concept was then further explored, and it was found that the opening between the grow tray and the reservoir in the system, could act as a suitable place for the external reservoir to be mounted and connected. Since this opening was made for the user to easily refill the system, it wouldn't be needed when the external reservoir is connected. A new concept was developed, and a prototype was made. The new concept and the testing of the prototype can be seen in Figure 21.

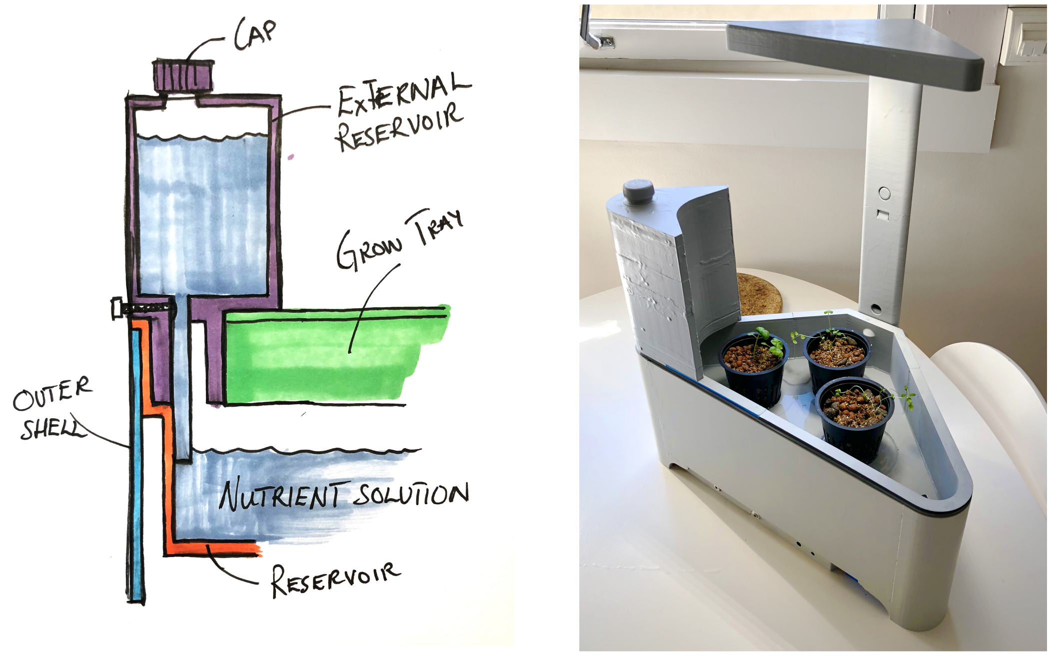


Figure 21: The concept behind the prototype of the external water reservoir

The new concept used the same principles for dispensing the nutrient solution as the last. The prototype reservoir was a closed container with a rubber tube protruding out of the lower end. On top was a screw cap that could be opened in order to refill the prototype, and the cap provided an airtight seal when properly closed. The prototype connected to the system by lowering the lower end into the gap meant for refilling the system, between the grow tray and the systems reservoir. The external reservoir then rested on top of the ledge inside the systems reservoir and the upper flanges of both the reservoir and the grow tray. When connected, the rubber tube supplied the systems reservoir with more nutritious liquid whenever the surface level inside the reservoir sunk beneath the outlet of the rubber tube. After a few iterations, the prototype was tested. The prototype was inserted into the system and used during the last three weeks of the testing explained earlier. The water level in the reservoir was monitored once every day and the prototype functioned as expected.

Understanding the principle

The principle behind this concept can be explained by using simple hydrostatics. We can assume that in order for the column of water inside the external reservoir to stay inside of its container, the pressure inside needs to be at a lower pressure then pressure at surface level in the bigger reservoir. This pressure can be found by using the following equation:

$$P_1 = P_0 - \rho g h \tag{1}$$

P_0 is the pressure at the lower red line in Figure 22, P_1 is the air pressure inside the external reservoir, ρ is the liquids density and h is the height of the water column inside the external reservoir. Some of the water will naturally escape the external water reservoir when it is connected, as the pressure inside the container lower due to gravity. This is however a very small amount, in smaller containers. The volume change of the water inside the external reservoir can be numerically calculated by using the law of perfect gases and substituting in Equation 1:

$$P_0 V_0 = P_1 V_1 \rightarrow \frac{V_1 - V_0}{V_0} = \frac{1}{\frac{P_1}{\rho g h} - 1} \approx 1\% \tag{2}$$

In this example the water column was calculated to be 10 cm high and we can see that this only resulted in 1% change in volume. There is however a limit to how high this column can be and still function. The theoretical maximum height of the water column is reach when the internal pressure dips below 0 Pa. By inserting this into Equation 1, we can see that the theoretical maximum height of the water column is 10 meters. Since this is way higher then what is applicable in this application, the principle can be used.

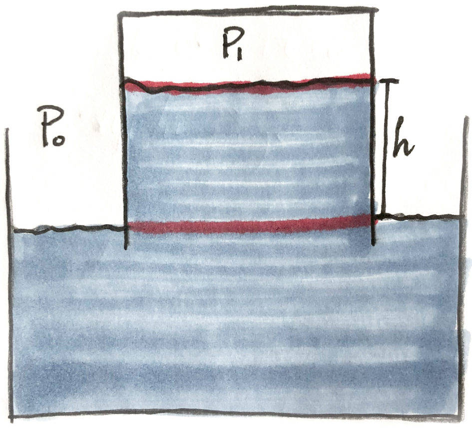


Figure 22: Illustration of the hydrostatic principle

3.4.6 Exploring the possibility of detachable covers

One of the early wishes from Den Lille Gartner was that the system could, in some way, have a natural look that could corroborated the message of sustainable growth. Having the option of customizing the look of the system would be a desirable feature. This was however not a required feature, but some options where explored. A few concepts were developed and explored, but only one concept was investigated further through prototyping. This selective approach was due to the feature not being required and time management. The prototyped concept consisted of attaching customizable plates to the outside of the system, magnetically. The prototyping started by acquiring several different neodymium magnets with different sizes, surface area and magnetic strength. Test plates made of MDF and Acrylic were cut up in an appropriate size and fitted with the different magnets. This was done in order to determine how many and how strong the magnets needed to be in order to provide a secure connection to the system, but still be easy to remove without trouble. The result of these prototypes was that using two Ø 12 mm disc magnets with an approximated strength of 23.5 N, gave the most desirable outcome. The first prototyped system was then customized so that each of the three sides held two neodymium magnets flush the walls. New MDF plates were fitted with corresponding magnets and attached to the system. This can be seen in Figure 23.

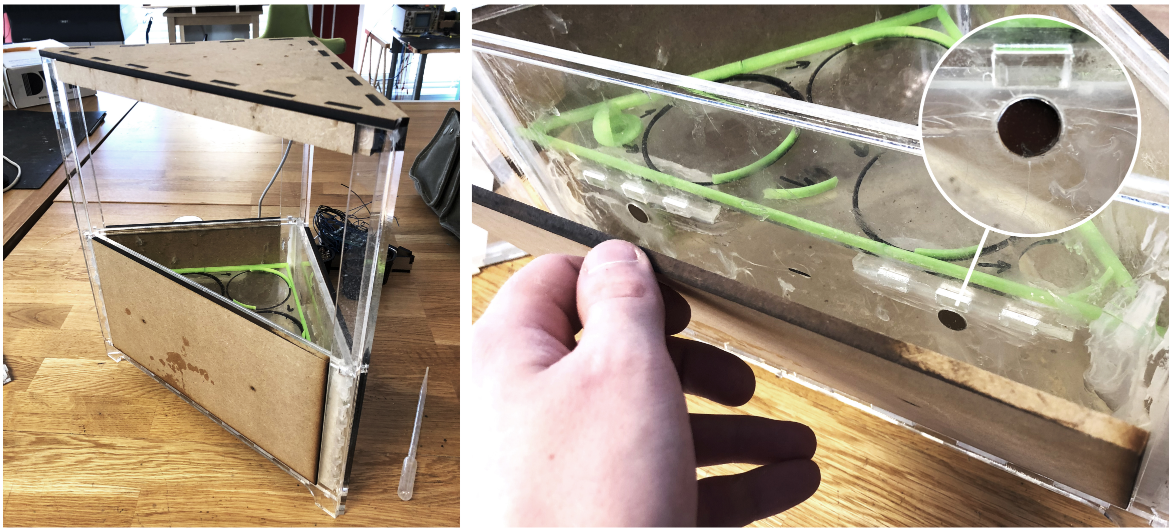


Figure 23: Prototype with detachable covers

The detachable plates functioned desirably, and the system could be lifted and handled without the fear of the plates falling off. It was also fairly easy to remove the plates, due to the magnets being centered on the plate. This concept was not explored any further, due to time constraints. The concept could be fitted to the proposed solution but would need further exploration in order ensure that the concept wouldn't affect the user experience in any negative way.

3.4.7 Exploring the possibility of implementing several growing methods

Although not a required feature, the possibility of easily being able to change the systems growing method could add great value to both end-user and Den Lille Gartner. When examining the most common ways of growing hydroponically, it is easy to see that the main difference between the methods, is how the nutrient solution is being delivered to the plants. All the methods presented in Chapter 2, consists of a reservoir beneath the plants and some kind of light source above the plants. Since all the components and concepts that make the prototyped system an N.F.T-system are a part of the grow tray, it should be possible to implement a different growing method just by replacing the grow tray with another module, designed for a different growing method. Some methods could even be used just doing some minor modifications to the existing grow tray. Some concepts were developed, and it was explored if the grow tray could be modified to accommodate for the Flood-Drain-method. It was conceptualized that just by adding a bell siphon at the grow trays outlet, this could be achieved.

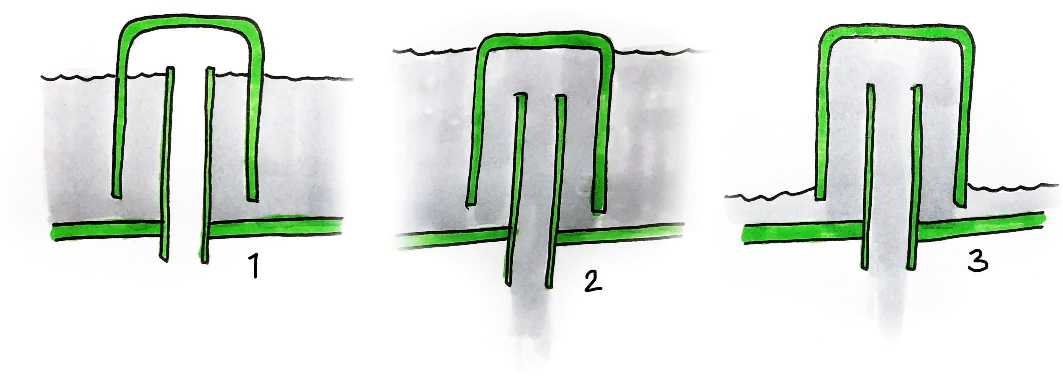


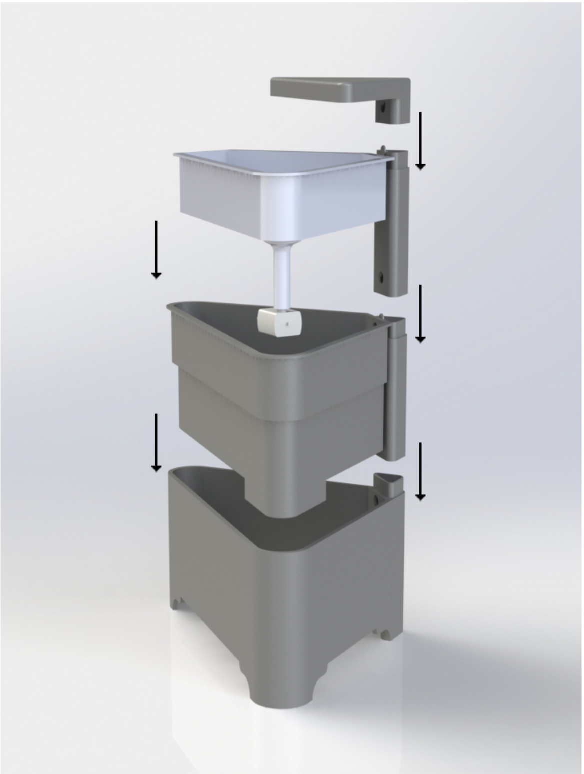
Figure 24: Principle behind the bell siphon

The bell siphon works by using the same principles as the famous Pythagorean cup and is illustrated in Figure 24. At 1 the tray is filling and as long as the level stays below the inner tube of the bell siphon, nothing happens. When the liquid level exceeds the top part of the bell siphon (2), it starts to spill down in to the reservoir below, through the inner tube. Gravity will then create a siphon, causing the whole tray to be drained through the inner tube (3). A prototype was made, placed in the grow tray and a couple of tests were performed (Figure 25). The first prototype didn't perform especially well. The siphon could not be created without assistance and the bell siphon only worked as an overflow tube. The flow rate of the pump was adjusted several times to see if this would help, but to no success. After a few iterations of the bell siphon, a working solution had been reached. The geometry of the bell siphon had to be changed so that the siphon could be created without a rapid change in water level. This was achieved by trial and error. The siphon was now able to empty the grow tray in approximately 3 minutes, while the pump was still pumping water into the grow tray. This proved that the concept worked and that the possibility of turning the grow tray in to a flood-drain tray is present.

Figure 25: Modified grow tray

4 User test

In order to determine if the proposed system was easy to assemble, a user test was conducted. Measuring and determining if something is easy or not, is rather difficult seeing as the expression is relative. So, the main take aways from the test would be the test subjects feedback and thoughts regarding the assembly.



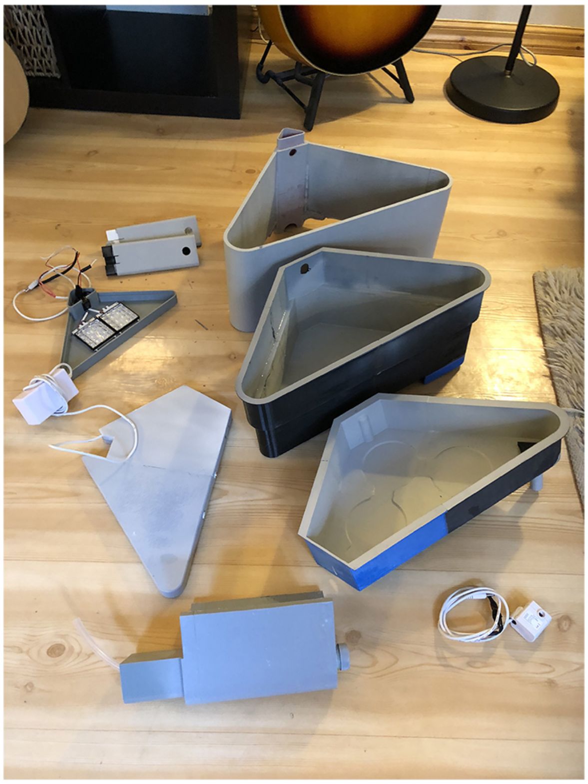


Figure 26: Assembly of the prototyped system. (Left: Illustration to show how the system is assembled. Right: Disassembled system how it was presented to the test subjects)

4.1 User testing methodology

The test subjects were given the prototyped system and the Fresh Garden - Easy Grow system, disassembled into the separate components they would have been presented with if they were to buy the system. The prototyped system can be seen in this state in Figure 26. They were then told to assemble the two systems, one at a time, without being given any instructions to follow. All subjects started to assemble the prototyped system. After this system was assembled the subjects were stopped and questioned about their thoughts surrounding the assembly. Then they were instructed to start the assembly of the Fresh

Garden system. When they were done with this system, they were questioned about this assembly compared to the assembly of the prototyped system. Although an assembly of another system might not have been necessary, this was done to give the test subjects something to compare it with so that their experience would be rooted in something a bit more tangible. Both assemblies were timed from start to finish in order to attain if there were any correlation between the subject's experience of the assembly and the time it took to complete. The fact that they were timed during the test was not disclosed until the test was concluded. They were told that they should take the time they felt that they needed. This was done in order to ensure that test subjects did not feel that was a test to measure their ability to assemble, but rather a test to assess the system. Introducing an element of competitiveness might also have lead the test subjects to rush and thus; have had a distorting effect on the outcome of the test. The test was performed on four test subjects. All four test subjects came from different backgrounds and levels of education.

4.2 Results

Test Subjects	**Prototyped System**	**Fresh Garden - Easy Grow**
Test Subject 1	5 min 10 sec	6 min 20 sec
Test Subject 2	3 min 15 sec	3 min 55 sec
Test Subject 3	4 min 30 sec	5 min 15 sec
Test Subject 4	5 min 30 sec	5 min 20 sec
Average Time	4 min 36 sec	5 min 13 sec

Table 2: Recorded times of the user tests

As we can see from the results in Table 2: the assembly times for both of the systems were quite similar. All of the test subjects said that they felt that both assemblies went well, but that the prototyped system was the easiest system to understand where all the components belonged. When asked why, the user credited two main features. The first feature was the fact that the prototyped system only consisted of "big parts" and no screws, washers, etc. The second feature was the geometry of the different components. One test subject compared the assembly to a kindergarten game where you were supposed to put the smaller triangles into the larger triangles. Three out of four test subjects also emphasized how much they liked that they did not need any tools in order to assemble the system.

Three out of four test subjects did however point out that they found the threading of the cables a bit inconvenient. The test subject that did not mention it as an inconvenience did however comment on it being a good trade off, compared to the visible cables in the Fresh Garden system, when asked about it. It should be noted that this test subject had the fastest of all the assembly times and that threading the cables was something the other test subjects used a considerable longer time completing.

4.3 Evaluation

Since the sample size of this test is fairly small, it cannot be said that the proposed system is inarguably easy to assemble. The user's ability to understand how the components fit together and perceive the proper order of assembly, without instructions, will always depend on the individual doing the assembly. The results do however give a clear indication of the system not being harder to assemble than the "Fresh Garden - Easy Grow", although consisting of more individual components. The fact that all of the test subjects assembled the proposed system quite quickly and reported that they felt it had gone well, means that the system performed desirable.

How the cables are threaded through the system can be evaluated and iterated on further in the future, if the system needs to have an even shorter assembly time.

Possible sources of error

- The order the test subjects had to assemble the system can have affected the results.
- The small sample size can give misleading results.
- The proposed system might have performed different if it were to be compared to another system than the Fresh Garden system. Seeing as "easy to assemble" is a relative term.

5 Proposed solution

When developing a hydroponic home growing system targeted towards both users with and without any pre-existing experience in hydroponic growth, it is important to always keep empathizing with the user's needs. This has been done throughout the whole development process, through testing and iteration until a desirable result have been reached. In order to make the task of building the system more comprehensible, the system have been broken down into its key components and concepts. These make up the proposed system, presented in this chapter.

Figure 27: The prototype of the proposed system - without the external water reservoir

5.1 Artificial light source

The proposed solution for the artificial light source used in the developed system are LEDs. The LEDs have been proven to be a suitable light source for the growing system, both through the discussed literature in chapter 2 and through the test performed during this project. The LEDs provide the plants with the desired lighting conditions, they are energy efficient and the heat emissions are so that they won't affect the plants. The light module is also equipped with an on/off-switch, so that the user can turn the lights off if it becomes bothersome, seeing as this is meant to be a household article.

The light module is suspended above the rest of the system, by standardized suspension profiles. These profiles attach to the 90-degree corner of the light module and connects it to the 90-degree corner of the systems outer shell. The profiles are made in standardized lengths, can be connected in series and locks together with a simple mechanism contained in each profile. The user can then add or remove the appropriate amount of profiles to adjust the light modules height, so that it is suitable for the plants in the system.

5.2 Delivery of nutrients

The proposed system uses an adapted version of the Nutrient Film Technique, discussed in chapter 2, as its underlying hydroponic growing method. The method uses a water pump to pump the nutritious liquid from the reservoir up to a grow tray, where the pots containing the are situated. The liquid then spreads out on the tray, before dropping down back into the water reservoir. This drop helps aerate the liquid, as discussed in 2. Capillary action transports the nutritious liquid from the bottom of the grow tray and up through the growing medium in the pot, supplying the seeds/plants with the necessary water and nutrients to ensure growth. The viability of adapted method has been tested and proven in chapter 3.

5.3 Growing medium

Choosing the right growing media is heavily reliant on how the nutrient solution is delivered to the system. Since the proposed system is using the *Nutrient Film Technique* to deliver the nutrient solution, the chosen growing media must have good capillary action capabilities and be able to hold moisture for some period of time. A number of growing media fits this description and can theoretically be used, but the proposed choice is clay pebbles and vermiculite. This combination has been tested in the system and proven itself to be a reliable solution.

5.4 Reservoir, Grow Tray and Outer Shell

The bottom part of system can be split into three main components: the outer shell, the reservoir and the grow tray. The outer shell is the main structural part of the system, holding all the other components. The outer shell is made in a triangular shape to accommodate for the findings discovered in the design thinking process carried out before the start of the pre-master's thesis (explained at the start of chapter 3). The reservoir is the biggest deciding factor when it comes to the size of the system. The reservoir in the proposed solution can hold 3 liters of water, in accordance with the minimum 2.5 liters, stated in the problem description. It is placed into the outer shell and is held tightly in place by its matching geometry. On the upper rim of the reservoir, there is a flange protruding that sits on the top over the outer shell. This helps distribute the weight from the reservoir onto the outer shell. The reservoir has one elongated corner touches the underlying surface of the system, when mounted in place. This elongation is made to maximize the amount of water in the reservoir that can be utilized by the pump before the reservoir needs refilling. The reservoir also has an internal ledge midway made as a part of the reservoir. This ledge holds the grow tray, that is placed into the reservoir. The grow tray holds the plants and is the module responsible for the distribution of the nutritious liquid. In the same corner as the elongated part of the reservoir, a water pump connected to the grow tray. The water pump is mounted by using a clamp mechanism. This ensures a secure and reliable connections, and at the same time making it relatively easy for the user to connect and disconnect the pump. The clamp mechanism is connected to the end of a hollow cylinder, going up the underside of the grow tray. On the other side of the grow tray, a distribution nozzle is mounted at surface level. The nozzles make sure that liquid is distributed evenly in the grow tray. In addition, the surface of the grow tray exhibits circular recesses with channels connecting them together. This ensures that the nutritious liquid find its way to the pots when the pump is set a low a flow rate.

When the reservoir is placed inside the reservoir, an opening is created between the grow tray and the reservoir. This opening is created in order for the user to easily be able to refill the reservoir with water and nutrients. The design of the reservoir and grow tray allows the user to easily remove the grow tray, without having to remove any other components. This allows the user easy access to the reservoir. Both the reservoir and grow tray are designed in such a way that they can easily be removed from the system and be placed in a dishwasher for cleaning, without any risk of damaging them. A feature that was found to be desirable in the test of the commercial home growing systems discussed in chapter 3.

5.5 Modularity

The triangular shape of the system allows for several systems to be nicely placed beside each other. The system can also be supplemented with an additional component that makes it possible to connect up to four systems together. This hub gives each system two 24-volt connectors that can supply both the light module and the water pump in each system with the necessary power. This means that when four systems are connected through the hub, only one power adapter needs to be connected to a wall socket, limiting the visible cables. The hubs shape is created to fit nicely beneath the systems reservoir and held in place by the outer shell's feet and elongated part of the systems reservoir.

Seeing as there is plenty of free space inside the hub, the functionalities can be expanded in the future. At this stage the hub is only created to enable the systems to be connected together and limit the amount of power cables needed, down to one per four systems. If it is chosen to implement different growing methods, as briefly discussed in Chapter 3, the hub can be further developed to control the necessary pump and light cycles. By adding a Wi-Fi module, the hub can even be controlled by an app.

5.6 Cable management

Being able to hide the cables within the system and ensure that the cables stick out on the same place, at bottom of the system, would help making the system more esthetically pleasing, and easier for the user when connecting it to the power supply. This feature had been taken into consideration when creating the final components of the last prototyped system. An illustration of how the cables move through the system can be found in Figure 28. The power cable from the water pump goes in between the grow tray and reservoir, through a hole in the reservoir wall, into the outer shell and out underneath the reservoir. The power cable from the light module goes through the suspension profiles, into the outer shell and out underneath the reservoir. Here the cables can be connected directly into the hub or to the standard power supply that should come with the system.

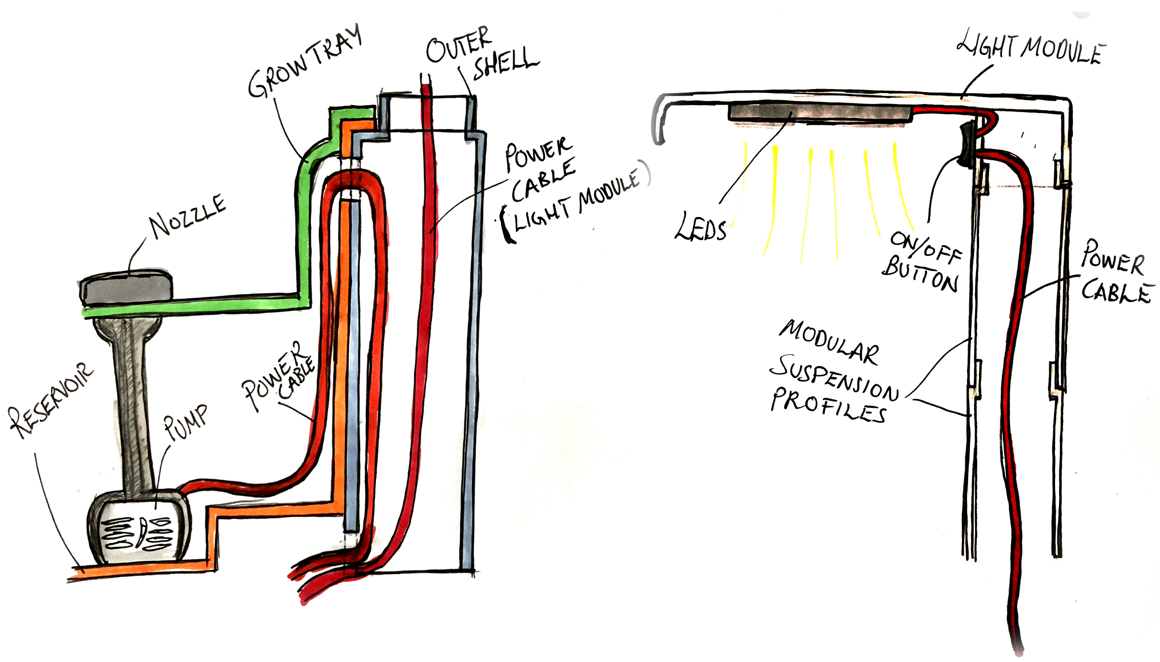


Figure 28: Illustration of the cable management

5.7 External water reservoir

An external reservoir has been developed as a supplement to the systems internal reservoir. By connecting it to the system, the user is able to leave the system for a longer period of time without having to refill the system as frequently. This can for example allow the user to go on vacation, without having to turn the system off.

The proposed external reservoir uses hydrostatic principles and pressure differential to dispense liquid into the systems reservoir at a controlled rate. This rate is decided by the surface level of the liquid in the internal reservoir. When the surface level in the internal reservoir drains below the outlet of the tube coming down from the external reservoir, the external water reservoir immediately starts to dispense until the surface level is above the outlet of the tube again. The reason for the external water reservoir not dispensing the liquid continuously, is because of the low pressure inside the module. Further explanation on how the principles behind work, can be found in chapter 3. The prototyped external reservoir has a screw cap on the top to enable easy refilling of the reservoir and ensure an air tight seal when closed. The reservoir is connected to the system by lowering to connector part into the gap between the grow tray and the systems internal reservoir. This external reservoir then rests on top of the flanges of both the grow tray and the internal reservoir, distributing its weight onto the outer shell. The reservoir is designed to fit the systems corner, so that it does not interfere with the plants in the system or other systems placed next to it.

6 Evaluation and further work

6.1 Work method

Since the challenge of this project came with prefixed design requirements, such as the system having to be hydroponic, that it had to be triangular and that it had to hold 2.5 liters of water, the possible solution space could seem limited right from the start. In order to reap the full benefits of applying the wayfaring model, the developer needs to have the freedom to explore and take the project where the continuous probing leads. Applying the wayfaring model, as described by Gerstenberg and the other authors (Gerstenberg et al., 2015), to projects with high degrees of freedom, can allow the developer to discover and exploit findings as a direct cause of serendipity. It can therefore, at first sight, seem contradictory to utilize the wayfaring model to manage this challenge. This was however not the case. Although the development had to happen with the framework set by the prefixed design requirements, there was still more than enough room for exploration and redesign. Choosing the wayfaring model as the governing product development methodology has been crucial for the success of the project. Through concept creation, prototyping and testing, the project has moved forward, and new discoveries have been made that have guided the direction of the project. Since I have been working on this project alone, concepts and prototypes have been developed in several domains at the same time and decisions have been taken rapidly. This have been really beneficial as concepts evolved in one domain have elicited new ideas and concepts in other domains. A great example of this the proposed solution for making the systems modular. As the reservoir was developed to accommodate for the needs of the water pump, the results lead to a new concept being created for the placement and design of the hub.

6.2 The proposed system

Throughout the course of this project, relevant technologies have been identified, concepts have been created, prototypes have been made and tests have been performed, and this work have accumulated into the proposed system presented in this thesis. The proposed system offers a solution to the challenges presented in the problem description and the prototyped system has performed well when submitted to testing. The system's modular design makes it possible to alter and redesign specific components without affecting the other components.

The system is very easy to operate, as all the user needs to do is to plug it in a power outlet and refill the system with water and nutrients from time to time. The system should however come with instructions on how to plant the seeds in the growing medium, as it is important for the clay pebbles to be soaked in water before placed in the system. This is to ensure that they are able to utilize capillary action to transport the nutrients and water to the seeds.

During the user test, performed to assess how easy the prototyped system is to assemble, all the test subjects managed to assemble the system in under 6 minutes. This was without guidance or instructions. Although easy to assemble is a relative term, I would say that these results speak to the system having achieved desirable results.

It should be noted that the proposed system contains the last iterations made in this project. That does not make it a perfect system without room for improvement. Further tests can be performed to assess the system's ability to replicate the same results with a large variety of plants. More iterations can be done, and components can be further developed. Suggestions for further work is made in the next section

6.3 Further Work

Based on the insights gained from the development process, one of the more interesting features to investigate further, is the possibility of making the growing method modular. Since all of the components and concepts that distinguish the growing method used in the proposed system from the other common hydroponic growing methods are a part of the grow tray, it should be possible to change method just by changing the grow tray. It is theoretically possible to make different types of modules that can accommodate for the different types of growing methods, that can be placed in the system instead of the grow tray. I would suggest starting with implementing the flood-drain or drip system methods, since these methods are most similar to the nutrient film technique method, used in the proposed system.

The hub can be further developed in order to offer more features. If modular growing methods are implemented, the hub can be used to control these features. The hub can also be fitted with a control panel where the user can choose between different growing programs that are customized for the different stages of the plants development.

Seeing as threading the cables through the system ended up being the bottleneck for most of the test subjects in the user test, options to avoid this can be explored. Although it will not affect the user's daily interactions with the system, it can contribute to making the system faster to assemble. A suggestion for this can be internal cables in the suspension profiles that supplies the light module with power from the stem of the outer shell, when connected. This way the height of the light module can be changed without having to re-thread the cable.

A more reliable closing mechanism for the external water supply, should also be explored. The current prototype uses a screw that, when tightened, forces a small cylinder against the rubber tube going in reservoir, and thereby closing it. It would also benefit the user if the external water reservoir could be developed with a transparent area, so that it is possible to see how much liquid the reservoir contains.

7 Conclusion

Working on this project has been very interesting, both in terms of the development work that has been carried out throughout the year, and in terms of helping spread awareness surrounding sustainable food production. I believe that growing food hydroponically in your own home, is something that more people should be made aware off is possible and fairly easy. The learning outcome of this project have been tremendous. The project has given me the opportunity to gain greater insight into the technologies and knowledge needed for modern food production, both commercially and private. This is knowledge I probably wouldn't have gained if it were not for this project. I especially cherish my new-found interest of plants, and will continue to grow plants hydroponically at home, even though the project is concluded. While developing a whole hydroponic system completely from scratch can seem like an overwhelming challenge at first, seeing as this requires knowledge far outside my field of study, I am happy with the proposed system and the results it have achieved. I feel that the work carried out throughout the project, and the proposed solution, satisfies all the demands given in the problem description. Having acted as a designer, mechanical engineer, electrical engineer, botanist and manufacturer in one single project, I have gained a better understanding and a unique perspective of the interactions between the fields during a development process. This experience will be invaluable in future development projects, as the lines between the different engineering fields are getting blurrier every day.

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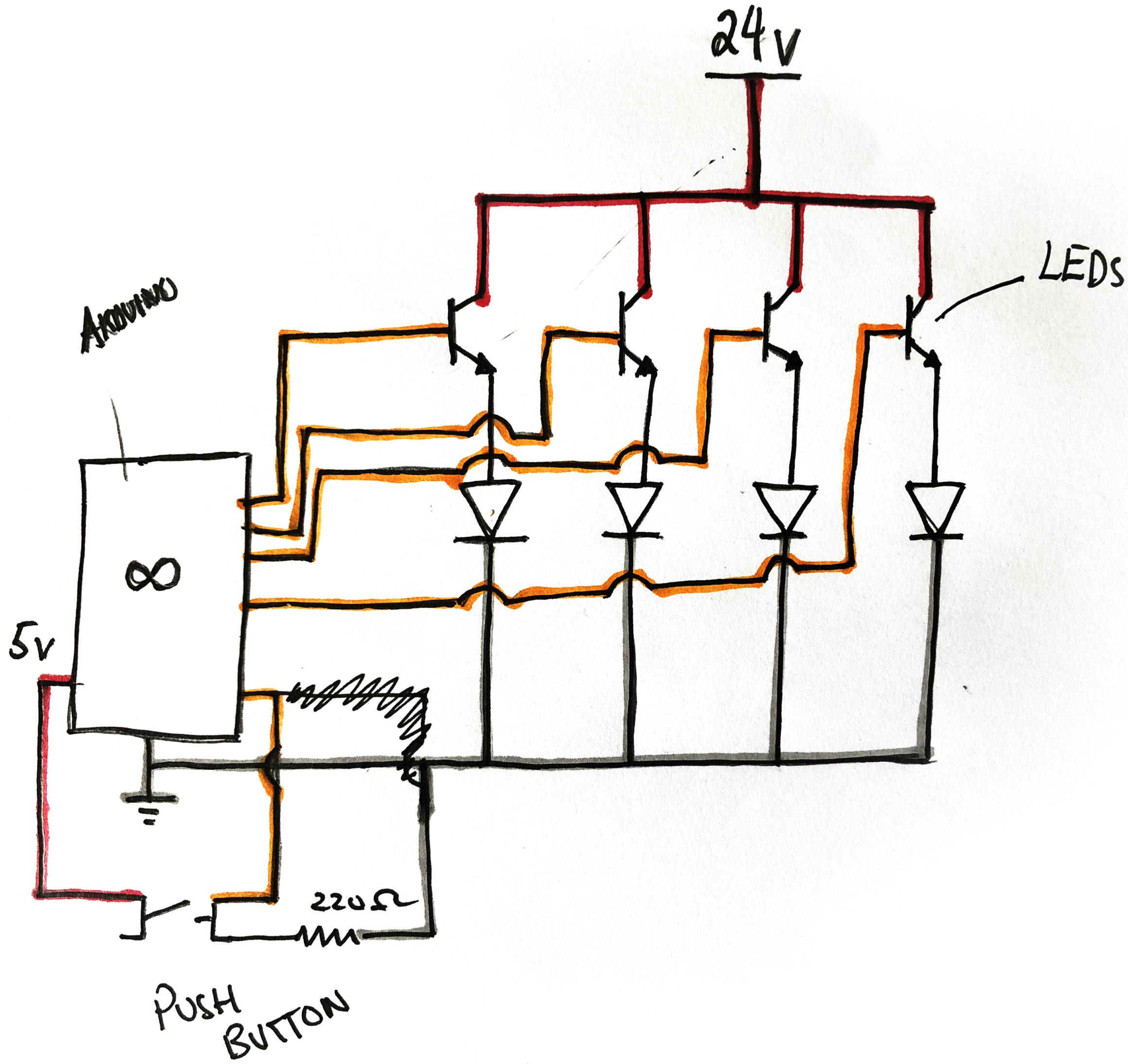
Appendix

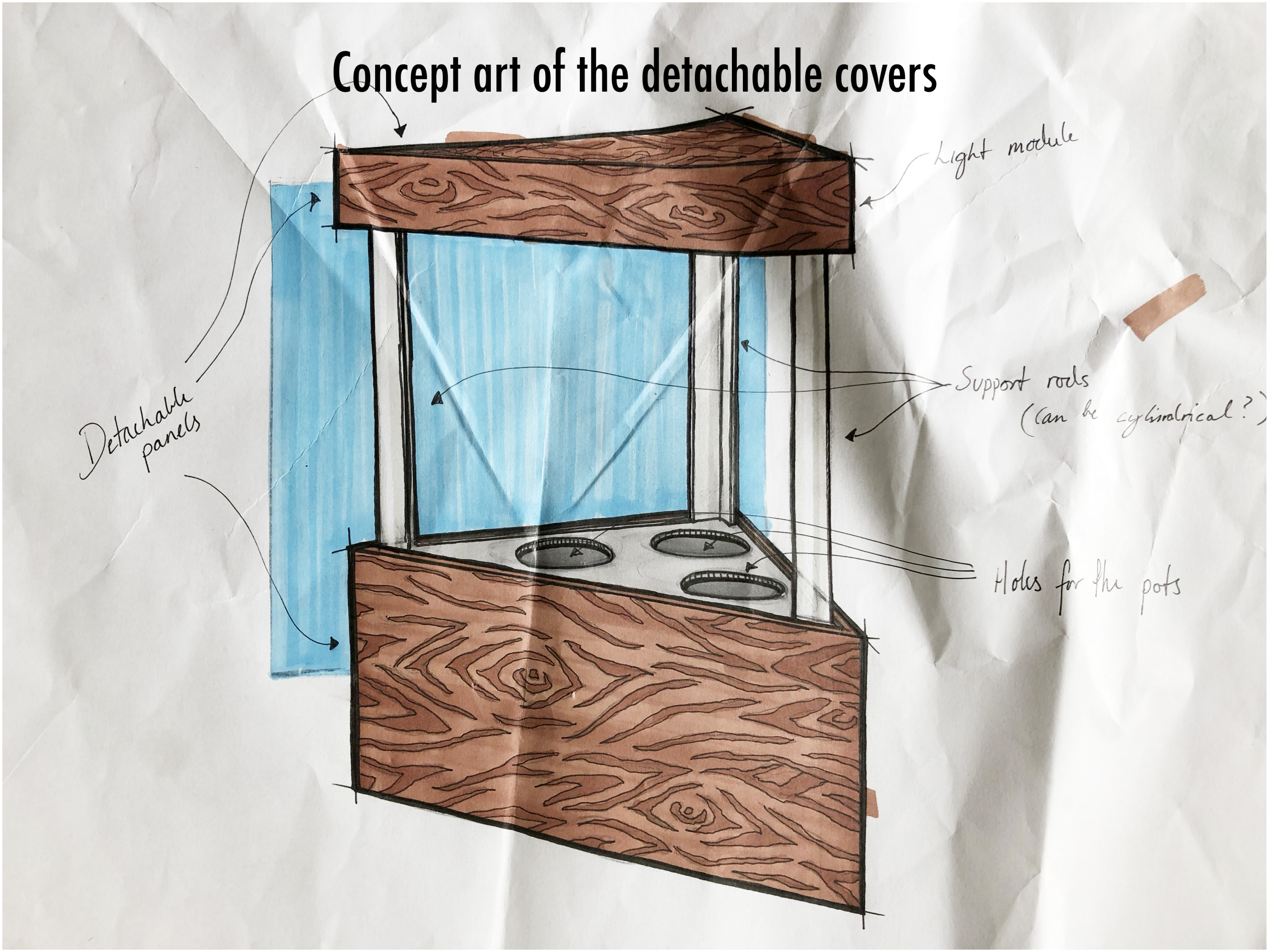
Arduino Code used in the first hub

```
const int led1 = 7;
const int led2 = 8;
const int led3 = 9;
const int led4 = 10;

const int button = 6;

int buttonState = 0;
int buttonpushcounter = 0;
int lastbuttonstate = 0;

void setup() {

  pinMode(led1, OUTPUT);
  pinMode(led2, OUTPUT);
  pinMode(led3, OUTPUT);
  pinMode(led4, OUTPUT);
  pinMode(button, INPUT);
  Serial.begin(9600);
}

void loop() {
  buttonState = digitalRead(button);
  if (buttonState != lastbuttonstate)
    if (buttonState == HIGH) {
      buttonpushcounter++; }
     else {
      delay(30);
     }
     delay(50);
    }
    delay(50);
 }
 lastbuttonstate = buttonState;
 Serial.println(buttonpushcounter);
  if (buttonpushcounter == 1) {
   digitalWrite(led, HIGH);
   digitalWrite(led, HIGH);
   digitalWrite(led, HIGH);
   digitalWrite(led, HIGH);
   delay (30000);

 } else {
   digitalWrite(led, LOW);
   digitalWrite(led, LOW);
   digitalWrite(led, LOW);
   digitalWrite(led, LOW);
 }
   if (buttonpushcounter == 2) {
   buttonpushcounter = 0;
 } else {
   digitalWrite(led, LOW);
   digitalWrite(led, LOW);
   digitalWrite(led, LOW);
   digitalWrite(led, LOW);
 }
```

Wiring diagram for controlling the LEDs in the first hub



Concept art of the detachable covers



Enhet: **Dato: 15.09.2017**

Deltakere ved kartleggingen (m/ funksjon): Martin Steiner, Veileder/ Pål Wisløff Nilssen, Student.

Kort beskrivelse av hovedaktivitet/hovedprosess: Prosjektoppgave student Pål Wisløff Nilssen

Signaturer: Ansvarlig veileder: Martin Steinert Student: Pål Wisløff Nilssen

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs		Romkort	Romkort		
1a	Bruk av laserkutter		Brukermanual	Ukjent	Ukjent	
1b	Bruk av 3D-printer		Brukermanual	Ukjent		
1c	Bruk av roterende verktøy		Brukermanual			
1d	Bruk av skjæreverktøy		Ukjent			
1e	Bruk av sammenføyningsmidler (f.eks. lim)		Brukermanual og datablad	Datablad	Ukjent	
2	Tilstedeværelse ved arbeid utført av andre	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	
3	Eksperimentelt arbeid		Egen risikovurdering må gjøres for det aktuelle eksperimentet		Prosessavhengig	

ID nr.	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sansynlighet (1-5)	Vurdering av konsekvens: Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)	Risikoverdi (menneske)	Kommentarer/status Forslag til tiltak
1	Bruk av Trolllabs								
1a-i	Bruk av laserkutter	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring og bruk hansker når varme materialer skal håndteres.
1a-ii		Øyeskade fra laser	2	D	A	A	C	2D	Ikke skru på laser før prosessen skal kjøre. Bruk øyevern.
1a-iii		Brann	2	B	A	D	C	2B	Vær nøye med opplæring. Ha brannslukningsutstyr lett tilgjengelig.
1b-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring.
1b-ii		Ødelagt maskin som følge av feil bruk	3	A	A	C	A	3A	Vær nøye med opplæring.
1b-iii		Innhalering av printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern
1c-i	Bruk av roterende verktøy	Stor kuttskade	2	D	A	A	D	2D	Vær nøye med opplæring. Tilstrekkelig sikring/tildeking av roterende deler
1c-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring. Løse klær, gjenstander på kropp og hår må sikres før bruk.
1c-iii		Flygende gjenstander/spon	3	C	A	A	B	3C	Tildekk deler som roterer hutig (fres etc.). Bruk øyevern.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk korrekt underlag og skarpe verktøy

1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk korrekt underlag og skarpe verktøy
1e-i	Bruk av sammenføyningsmidler (f.eks. lim)	Eksponering - Hud	4	A	A	A	A	4A	Benytt datablad og bruk hansker
1e-ii		Eksponering - Innhalering	4	A	A	A	A	4A	Benytt datablad og bruk åndedrettsvern
1e-iii		Eksponering - Øyne	2	D	A	A	B	2D	Benytt datablad og bruk øyevern
1e-iv		Søl	4	A	B	A	A	4A	Benytt datablad, korrekt underlag og ha rengjøringsmateriell tilgjengelig
2	Tilstedeværelse ved arbeid utført av andre	Se andres risikovurdering om du ikke har tiltro til arbeidets sikkerhet	3	C	C	C	C	3C	Kontinuerlig analyser situasjonen du befinner deg og vurder risikoen
3		Elektrisitet	3	B	A	A	A	3B	Bruk isolerte verktøy.

The identification of relevant technologies and development of a home growing system

A project report describing and identifying the relevant technologies and early stage development of a home growing system

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NTNU

December 13, 2017

Summary

This project report identifies, conceptualizes and judges technologies needed in order to develop a home growing system. Through concept generation, the building of prototypes and testing, a system is proposed and presented. Concepts and prototypes have been created to make a user friendly, intuitive and reliable system. The system has been separated into five subsystems and the proposed solution for each subsystem is systematically presented.

The proposed and presented system in this report, is the current iteration in the product development process. It should be noted that it is far from a finished product. The proposed system holds potential, but needs further development and exploration of the possible solution space, to ensure a viable and reliably functioning system.

Preface

This project thesis describes the development of a home growing system, as requested by Jørn Hammer. The report has been written to fulfill the requirements of the Product Development and Materials Engineering specialization at NTNUs Department of Mechanical and Industrial Engineering. I was engaged in this project between August 2017 and December 2017.

The task has been created and designed as a collaboration between Jørn Hammer, from Den Lille Gartner, my supervisor, Martin Steinert and me. This project has given me the opportunity to gain a greater insight into technologies needed for modern food production, both commercially and private, and a greater appreciation for growing plants and the ability to do so in my own home.

I would like to give a special thanks to my supervisor, Martin Steinert, for the support and guidance he has given me throughout this project.

Pål Weldingh Wisløff Nilssen
Trondheim, December 13, 2017

Contents

List of Figures

1 Introduction

Jørn Hammer is a science teacher from Bergen and the founder of Den Lille Gartner, a company that offers home growing systems and related articles. Jørn started this company to give people the opportunity to easily grow some of the food they consume, in the comfort of their own home. To make this more accessible for the common user, it is import that the method of growing is easy to get started, easy to implement in their day-to-day life and that the users succeed with their growing projects, already on their first attempt. This is especially import since most people need a feeling of accomplishment early on, in order to commit and create further interest in the activity. Jørn also wants to raise awareness surrounding food production and its sustainability in today's society. In order to accomplish this, Jørn wants to create a learning platform that goes together with a home growing system, and this is where the project task come into play.

This project task describes the development of a home growing system meant to be utilized by both consumers with and without previous experience in the field of horticulture. The project task will consist of:

- Identifying technologies
- Generating concepts
- Building prototypes
- Testing and comparing
- Judging the concepts

It is important that the home growing system is reliable and can re-produce the same results each time, within the limits of what is reasonable. The system must be easy to use and once the seeds have been planted, the system should provide it with what it needs to reach the point where the plant can be harvested.

This product development process has taken place in the fuzzy front end and Wayfaring is applied as the governing product development methodology. The wayfaring model is a non-linear approach to the development process and there are no fixed goals. The model encourages rapid iteration and changes, as this is far less costly in the early stages of the product development process, in comparison to doing this in a later stage. This will in turn encourage innovation, as more dimensions of interest are being explored. The wayfaring model will be explained further in the upcoming chapter.

2 Literature and Technology review

2.1 Literature review

2.1.1 Product development methodologies

The wayfaring model is an approach to the early concept creation stage of a product development process, where the developer has a high degree of intended innovation and as follows; a high degree of uncertainty. A typical wayfaring model can be seen in Figure 1. Asking the right questions and addressing the right problems, are key to managing the fuzzy front end (Gassmann & Schweitzer, 2014). Since it is impossible to know what the right solution is before you start, this is not always easy. In order to manage this, a wayfaring model can be introduced (Steinert & Leifer, 2012; Gerstenberg et al., 2015). The wayfaring approach shares a lot of attributes with how humans used to explore the world. They didn't necessarily know where they were headed or what they would find, but they used their surroundings to navigate there and obtain new knowledge on the way. The wayfaring model is based on the idea that radical innovations are not something that can be planned and found by working linearly. This also means that when applying a wayfaring model, you might find yourself in a situation where radical changes in the design are necessary in order to progress, and that a lot of your previous work is rendered insignificant.

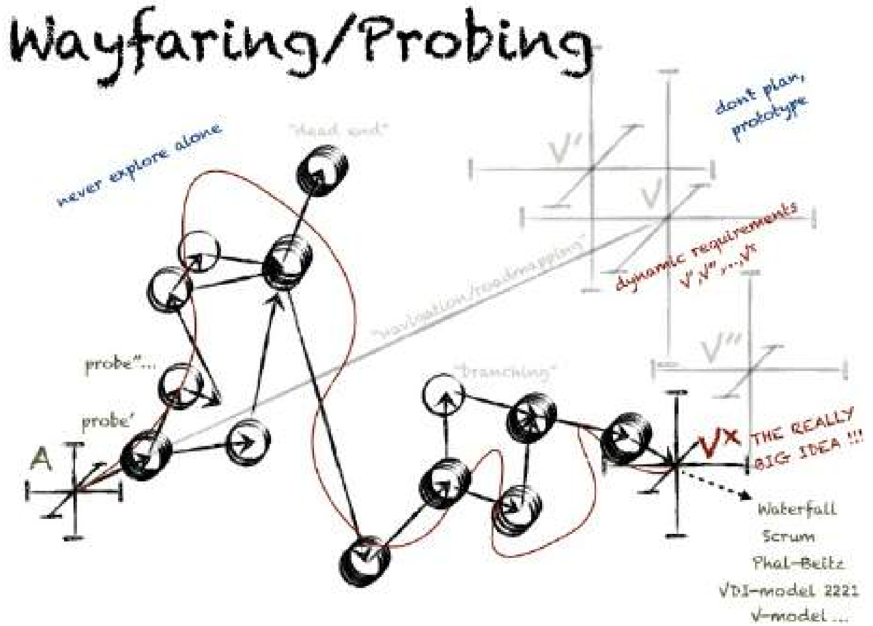

Figure 1: Wayfaring journey in product development. (Gerstenberg et al., 2015)

According to Gerstenberg and the other authors (Gerstenberg et al., 2015), one of the main benefits of applying the wayfaring model to a project with high degrees of freedom, is that it allows for the possibility of exploring and exploiting the unknown unknowns and to make findings as direct or indirect cause of serendipity. The unknown unknowns are described by the authors as; variables that are a part of your problem/solution that you are neither aware off nor their inherent value. These variables can only be discovered and understood through testing, prototyping and evaluating. This process is also referred to as probing. One of the ideas of probing is to build and test prototypes, in order for the developer to obtain completely new knowledge. This knowledge can be knowledge that is impossible to accurately anticipants, and can then in turn help you get a deeper understanding of the problem and inherent, the possible solution space. The concept of probing is depicted in Figure 2.

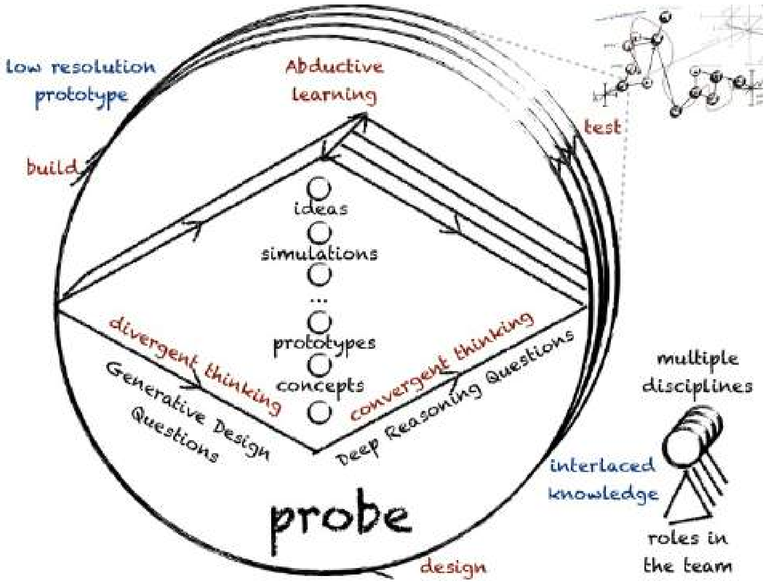

Figure 2: Probing-cycle (Gerstenberg et al., 2015)

As you can see from the figure above, the wayfaring model is made up of many instances of the probing processes. This is what guides the process forward. You ideate, prototype, test and evaluate, and in turn gain new insights into where you should take the project next.

2.1.2 Seed germination and influencing factors

Understanding the needs in order for a seed to grow into a full-grown plant, is necessary when tasked with building such a system.

Germination is the process where a seed develops into a plant. For this process to take place, the environmental conditions must be right in order to trigger the seed growth. These conditions are usually availability of water, the depth of the seed in the surrounding medium and temperature. When the amount of water surrounding the seed is sufficient, the seed absorbs some of the water and this activates enzymes in the seed that in turn initiate the seed growth. The process of the seed filling with water is called imbibition. The seed will first grow a root to improve its access to water and nutrients, and then the shoots (the growth above ground) will begin to sprout. There is also a surplus of carbohydrates and proteins inside the seed, that serves as the energy source until the plant have developed leaves and can draw energy from the available light source. There is however important that there is not too much water surrounding the seed. Before the plant have breached the surface and is undergoing root formation, the supply of light and oxygen is very limited. During this period the plant must rely on the nutrients stored inside the seed and the oxygen stored in the ground. So if the seed's surroundings are filled with water, it will limit the availability of oxygen and ultimately "drown" the seed. It is also worth mentioning that different seeds need different temperatures in order to start germination. This is usually dependent on the plants geographical origin. Seeds indigenous to northern environments, usually germinate at lower temperatures than seeds indigenous to environments closer to the equator (*What is Seed Germination? - Definition, Process, Steps Factors*, 2017).

2.2 Technology review

2.2.1 Hydroponics

Hydroponics is a form of hydroculture, and a way of growing plants without the use of soil and instead use mineral nutrient solution in a water solvent. This can be done by exposing only the plant roots to the solvent, or an inert medium such as gravel can be used to support the roots. Although the term hydroponics is a fairly recent term, the method of growing plants without soil dates back much longer. The floating gardens of the Aztecs of Mexico and the hanging gardens of Babylon, can be said to have been a form of hydroponics, although never referred to as that (Resh, 2012, pp. 1–8).

As one can deduct from the broad definition of hydroponics, there are countless methods and ways to do this. These are some concepts behind some of the more common types of hydroponic systems (*What is Hydroponic growing?*, 2017) (illustrations can be found below in Figure 3):

Wick System

The Wick system is a passive system that rely on capillary action in order to draw a nutrient solution into the growing medium from a reservoir, through one or more wicks. This system is however very limiting when it comes to both the size and type of plants it can hold. Large plants or plants that need a large amount of water, can end up using up all the nutrient solution in the medium faster than it can be supplied by the wicks.

Water Culture

The water culture system is perhaps one of the simplest, active, hydroponic systems. The roots are fully immersed into a liquid mixture of water and nutrients. Since the roots also need oxygen to survive, air pumps at the bottom of the basin helps oxygenate the water. It should however be noticed that there are seemingly few plants, other than lettuce, that will thrive in such a system.

Flood and Drain

The flood and drain system is also an active system that delivers water and nutrients through flooding and draining the growing tray, with a water/nutrient mixture. The growing tray is connected to a reservoir beneath the tank, a water pump is used to carry the liquid upwards into the growing tray and a valve is used to drain the liquid back into the reservoir. This cycle can be controlled by a timer set to accommodate the type of plants you are growing.

Drip System

This system also uses a water pump to carry nutritious liquid. The liquid is carried from a reservoir beneath the grow tray, but instead of dispensing it directly in to the growing medium, it is elevated above the growing medium and dispensed in droplet form above the plants.

Nutrient Film Technique (N.F.T)

The Nutrient Film Technique is perhaps one of the more common systems, or at least the best known when it comes to hydroponic systems. In this system you have a constant flow of nutritious liquid through the roots of your plants. The liquid is pumped upwards from your reservoir, dispensed onto the growing tray, for then to flow through the system and back into the reservoir. The growing tray does not need any growing medium, but the plants needs to be suspended above tray, so that the roots can be in contact with the flowing liquid. This system does however need to be on continuously, because the roots might dry out rapidly if they are left without water.

Aeroponic System

Aeroponic systems are similar to the N.F.T type of systems in that the growing medium is usually primarily air. The roots hang in the air and are surrounded by a nutritious mist. This mist must be supplied frequently in order to ensure that the roots do not dry out.

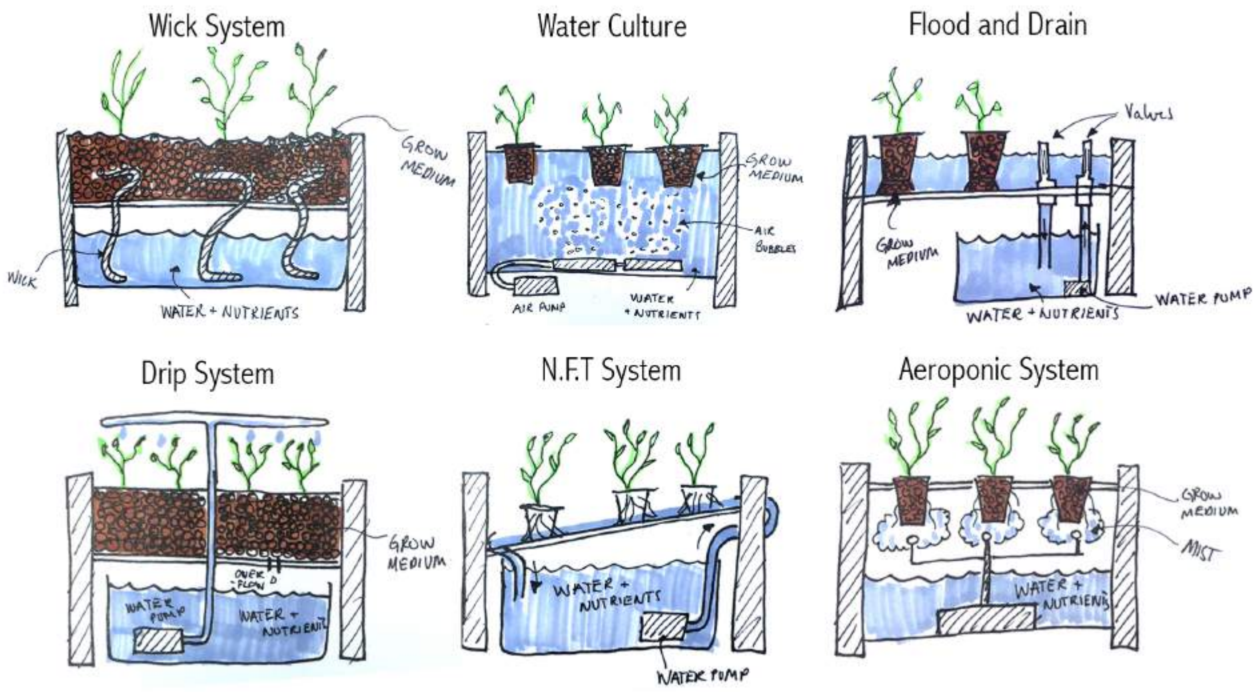

Figure 3: Illustrations of some of the most common types of hydroponic systems.

The method of growing food hydroponically, have become fairly common in commercial food production. This is probably because of the increase in control over each element that goes into the process and the increase in yield, in comparison to more traditional farming. Resh (Resh, 2012, pp. 1–8) writes that tomatoes grown in greenhouse condition, usually have an increased production of 20-25% if grown hydroponically instead of soil. The increase in yield in hydroponic culture compared to that of cultures grown in soil might be credited to several reasons. Resh (Resh, 2012, pp. 1–8) suggest that the main reasons might be that the soil might lack nutrients and have poor structure, or that the presence of pests or diseases in the soil will greatly reduce the yield.

2.2.2 Ultrasonic atomization

By utilizing a piezoelectric transducer immersed into a liquid, it is possible to create a fine mist made up of tiny droplets with only a few micrometers in diameter. The transducer converts a high frequency signal into mechanical oscillation. When the oscillation frequency reaches a high enough level, the liquid particles will no longer be able to follow the movements of the transducer. This causes a momentary vacuum and a strong compression to occur. This in turn leads to an explosive formation of air bubbles and a generation of broken capillary waves. The droplets then break the liquid's surface tension and quickly dissipate into the air, taking vapor/mist form (Derrick, 2015). The illustration of the process is depicted underneath in Figure 4.

Figure 4: Ultrasonic atomization.(Derrick, 2015)

A prediction of the diameter of the droplets that make up the mist, created by the piezoelectric transducer, can be calculated by using Equation 1 (Dalmoro, d'Amore, & Barba, 2013).

$$d_p = 0.34 \cdot \left(\frac{8 \cdot \pi \cdot \sigma}{\rho \cdot f^2} \right)^{\frac{1}{3}} \tag{1}$$

σ = Surface tension, ρ = Liquid density, f = Frequency

In an article written about aeroponic plant growth in microgravity, Clawson and the other authors (Clawson, Hoehn, Stodieck, Todd, & Stoner, 2000) report that droplets with a diameter of 1 micrometer was too small for wetting the roots and that it had troubles impinging on the roots. They found that the optimal droplet diameter for effective impingement in their conditions were 30 micrometers.

2.2.3 Growing medium

When growing plants soilless, a growing medium is used to take the place of regular soil. The growing medium so not there to provide the plants with nutrients, but to provide a supportive foundation so that the roots are able to hold the plant upright. It is also necessary for the growing medium to be able to hold moisture and oxygen, so that the roots and subsequently the plants can prosper. Therefore, the growing medium is usually of the porous type. It is however possible to use non-porous materials as a growing medium, but this will usually demand and increase in the frequency of the water cycles. Naturally there are countless types of materials that can be used as a growing medium, although it should be noted that different types of systems require different types of attributes from the growing medium. The Wick System for example, will require a growing medium that can absorb and hold onto moisture. It comes down to the design of the system and how moisture and nutrients are being delivered, when choosing a suitable growing medium. Here are some of the more common types of growing media used in hydroponic systems (*Growing Mediums and Hydroponics*, 2017).

Clay Pebbles, also referred to as *hydrocorn*, is a type of clay that is super-fired in order to create a porous texture. This type of clay is called *Lightweight Expanded Clay Aggregate* (L.E.C.A). Although this medium is relatively lightweight, it is heavy enough to provide stable support for the plants. It also holds moisture and wicks up nutrient solution, quite well. Clay pebbles has a neutral pH-value and are non-degradable, which also makes it reusable if cleaned and sterilized.

Vermiculite is a silicate mineral. This growing medium is quite absorbent and have the ability to hold nutrients over a longer period of time. Since vermiculite particles are relatively small it will give quick anchorage to young roots, in comparison to, for example, clay pebbles. Vermiculite does however have quite the low density, which means that it will float, so its applicability is very dependent on how the system is designed.

Rockwool is originally created to be used as isolation, but is still commonly used as a growing medium in hydroponic systems. The rockwool is primarily made of granite and limestone, that have been melted and spun into thin threads. As a result, it is a porous and non-degradable medium. It absorbs water well, so well in fact that it can easily become saturated. This can in turn lead to the roots being suffocated or start to rot. So, the applicability of this growing medium is very dependent on the system supplying it with a moderate amount of moisture. It should also be noticed that Rockwool is not a pH-neutral material, which means that it needs to be balanced and treated before use, so to not disturb the plant growth.

Growstone are very similar to clay pebbles, but are instead made of recycled glass and clay. They are light weight, porous and non-degradable. The Growstone are bigger than the clay pebbles and unevenly shaped, this provides good aeration for the roots. The medium also have a good wicking ability.

Coconut Fiber and **Coconut chips** are considered the waste products of coconuts. It comes from the outer layer of a coconut. Although this material is organic, it won't deliver any nutrients, due to a very long decomposing time. The coconut fibers and chips hold moisture really well, are pH-neutral and allows good aeration for the roots. When using organic materials as a growing medium it should be made sure that the material does not contain chemical fungicides, pests or diseases, as this can affect and inhibit plant growth.

2.2.4 Artificial light source

In the context of plant growth, artificial lights should provide the plant with both energy and the information that is required for its development. To meet these requirements fluorescent lamps, especially those with enhanced blue and red spectrums (cool fluorescent white light), are commonly used in growth chambers. The downside is however that over longer periods of time, both the spectrum and intensity of the fluorescent will not be stable (Darko, Heydarizadeh, Schoefs, & Sabzalian, 2014).

An experiment on plant growth carried out by Bula *et al.* (Bula et al., 1991), reported that lettuce grown under red LEDs (650nm) showed an increase in dry matter per mole of artificial lighting and Chang *et al.* (Chang et al., 2011) calculated that growth for the green algae *Chlamydomonas reinhardti* had its maximum photon utilization efficiency centered at 674 nm. According to Schoefs (Schoefs, 2002), this can be credited to the fact that the wavelengths contained inside the red section of the light spectrum, fits perfectly with the absorption peak of chlorophylls. The lettuce grown beneath red LEDs did, however, present signs of elongated hypocotyls (the stem of a germinating seedling), but this could be prevented by adding blue light (Hoenecke, Bula, & Tibbitts, 1992). The supplementation of blue light gives a better excitation of the different photoreceptors in the plant and the red-blue combination showed a higher level of photosynthetic activity than under either monochromatic light condition (Sabzalian et al., 2014). The red-blue combination can also be complimented by green LEDs. It should however only be complimentary as illumination containing more than 50% green LED light have shown to reduce plant growth. Illumination containing up 24% green LED light have however shown to enhance growth for some species (Kim, Wheeler, Sager, Gains, & Naikane, 2005). LEDs have shown themselves to be a suitable and innovative alternative to a natural light source, in regard to the plant growth. This is due to not only their intensity, low heat radiation and energy advances, but also because of the possibilities they provide for optimizing plant productivity and quality, through targeted manipulation of metabolic responses in the plant (Darko et al., 2014).

3 Development

3.1 Users and Need finding

Prior to this project a Design-thinking process was carried out by Jørn Hammer and a team. The aim for this process was to figure out how they could engage people in growing their own food and raise awareness surrounding food production and its sustainability. After identifying some of the most important stakeholders and gaining insights, they came up with a POV (Point-of-view) that sounds like this: "A young(ish) urban mother needs to maintain her identity as trendy and genuinely concerned about the state of the world today, as long as it's not too time-consuming and fits in with her busy lifestyle." They then began to prototype, test and interview. During their process they interviewed, observed and interacted with over 50 people. The solution they landed on was a home growing system. Some of the main take-aways was that the system needed to be:

- Easy to use
- Fairly self-going once the seeds have been planted
- Able to hold enough water and nutrient for a reasonable amount of time
- Have a non-intrusive design that can fit into a Norwegian home
- Be modular

In regard to the design, tests and interviews were conducted and the team landed on a triangular design, so that the system would fit nicely into corners. The modularity of the system has been kept in mind during this development process, but the main focus have been on the individual system in the first round of development.

Hydroponic test in parallel with the project

To get a deeper understanding of the project and for me to be able to empathize with the end user and what it would entail to grow plants at home, a test of a commercial hydroponic system was conducted in parallel with the project, from June to December. The hydroponics system was a *Fresh Garden - Easy Grow*-system, provided by Den Lille Gartner. The system can be seen in Figure 5. During the course of this test, it has been attempted to grow many different types of plants to gain a deeper insight into the plants individual needs. The plants that have been grown during this time are: Thyme, Tomatoes, Lemon Peppers, Dill, Lettuce and Rosemary.

Figure 5: The "Fresh Garden - Easy Grow"-system

Figure 6 illustrates the principles used in the Fresh Garden system. The system utilizes a water pump to deliver both water and nutrients to the plant. The tank is filled with a mixture of water and nutrients, and at the bottom of the reservoir, a water pump is situated. The pump propels the water mixture upwards and sprays it horizontally out in a 360-degree angle. When the liquid hits the clay pebbles in the pot, capillary action transports it further upwards and then it gets absorbed by the vermiculite. The seed is planted amongst the vermiculite, so this ensures that the seed is situated in a moist environment.

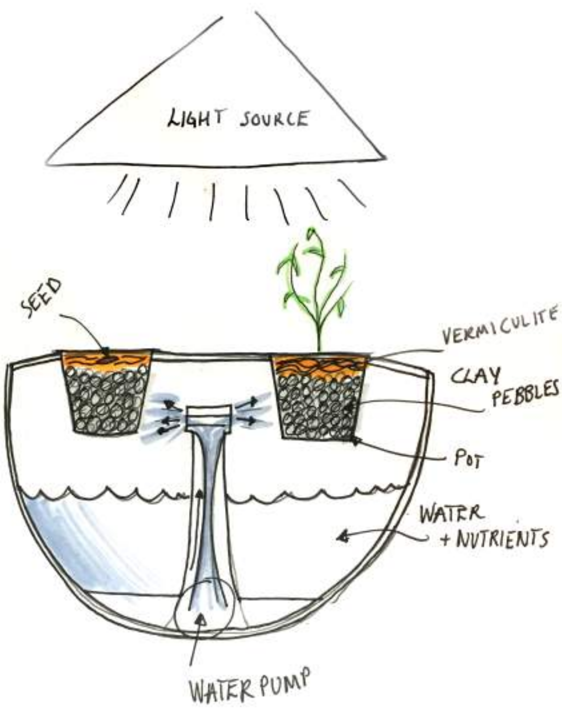

Figure 6: The principles behind the Fresh Garden - Easy Grow

One of the things that really stuck out about this system, in regards to problems that occurred, was issues with the water pump. When the roots grew too long, they eventually found their way through the filter at the bottom of the reservoir and into the water pump. This caused the pump to clog and the system needed to be partially disassembled in order to fix it. The circular design of the reservoir and the amount of space above the system needed in order for the light to be raised high enough, did also contribute to some disadvantages when finding a suitable placement for the system. The water pump also makes a considerable amount of noise when it is on, especially if the water level is starting to get low. This can make it unsuitable for some environments as this can, to some people, be perceived as somewhat annoying. The LEDs functioned well and actually ended up serving as a secondary light source for my work station, when the system was running. Since the system was situated quite a long way from a window, the LEDs was also the only light source for the plants. This was evident when the plants started to grow tall, and the lower leaves started to wither as the upper part of the plant blocked the light from the LEDs.

3.2 Prototyping and testing

Alternate growing medium

Since one of the main goals of this system is to educate and inspire people to become interested in growing plants, a transparent growing medium could be interesting test. That way the user will be able to observe the whole plant through the growth process. A common product used when making flower arrangements, are water-storing gel beads. The beads are transparent and expand when they come in contact with water. They are mainly used as a water supply for cut flowers in a vase. In order to see if would function as a growing medium a test was conducted. To rule out as many possible sources of error, the Fresh Garden system was utilized to do the test. The beads where put in the same nutrient solution as the one used in the system. Then, when they had expanded, they were put in a pot and ten lettuce seeds where planted in the medium. As a control, another ten lettuce seeds where planted in a pot with clay pebbles and vermiculite. The seeds in both pots ended up germinating and started to sprout. Past this point, however, the plants in the pot with the beads, started to wither. They showed clear signs of not being able to absorb enough nutrition. The lettuce in the other pot grew until they were ready to be harvested.

Figure 7: Water-storing gel beads

Delivery of water and nutrients

As an alternative to the widely used water pump, a couple of ultrasonic foggers were acquired. The fogger is essentially a piezoelectric transducer that uses a ceramic piezoelectric disc to create mist in the same way as explained in section 2.2.2. The oscillation frequency of these foggers is estimated to be around 1.6 Mhz. By using Equation 1 (Dalmoro et al., 2013), we can estimate that the resulting droplet size will only be a few micrometers. This is a lot smaller than the droplet size found to be optimal by Clawson and the other authors (Clawson et al., 2000), for their conditions. So, a prototype was built in order to investigate the foggers applicability in this project (Prototype can be seen on the left in Figure 8, and a close up of the fogger on the right).

Figure 8: First prototype testing ultrasonic atomization

The growing media chosen for this prototype was growstone and vermiculite. The growstone was used in order to give a good aerated environment for the roots and so that the mist would be able to reach the seeds. The Vermiculite was used on top of the grow stone to ensure a moist environment for the seed. A timer was created using an Arduino Uno, so the fogger would be on for 30 seconds every 5 minutes. Ten lettuce seeds were planted in the vermiculite and the prototype was placed underneath the LED lights used in the Fresh Garden system. The nutrient solution used in this prototype, and every other prototype during this project, was a solution supplied by Den Lille Gartner.

The lettuce seeds showed signs of germination early on, and started soon to sprout. Everything looked to be developing great until the plants had reached a height of 1-2 cm. They started to look like they did not get enough nutrition and showed signs of withering. Changes were made to the timer so that the fogger where on for one minute every third minute. The change where tested over 2 days, but the plants did not show any signs of improving. The most logical explanation at this point was that too much of the mist escaped the system before the lettuce where able to absorb it. In a last attempt to save the lettuce, a plastic dome was placed on top of the pot (the dome can be seen in the top right corner of Figure 8). Although this was done to keep more mist inside the system, it was also made sure that the gaps between dome and pot where big enough for air to circulate freely through. The state of the lettuce quickly improved, and the plants continued to grow until they touched the inside top of the dome. At this point the dome was taken off, but the plants immediately started to wither away, again.

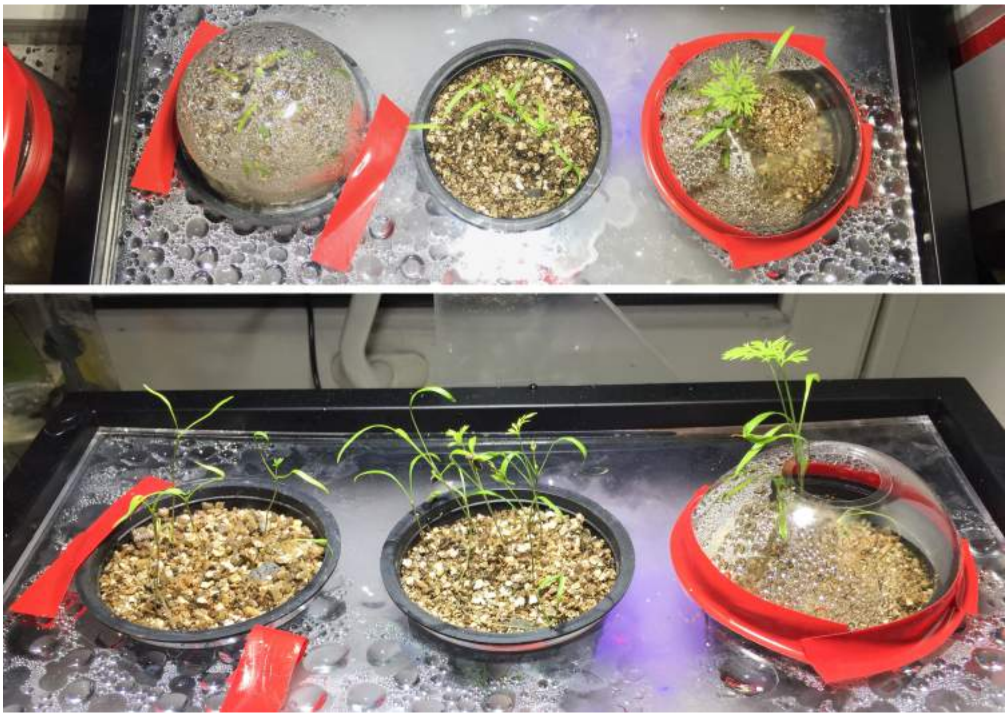

Figure 9: Plant growth in test setup after 2 weeks

Another prototype was then built to get a clearer understanding of the problem. This time the prototype contained three pots. The growing medium was the same as in the previous prototype, but with a little more vermiculite and the pots where situated underneath LEDs. Seven seeds of dill were planted in each pot and the Arduino timer from the previous prototype where used to control the fogger. The controlled variable in the test was to which extent measures were taken to keep moisture around the plants. The first pot had the same dome-setup as the previous prototype, the second pot where completely open and the third pot had a partially open dome. This can be seen in Figure 9. The test went on for several weeks and the progress after 5 weeks can be seen Figure 10. From these results we can see that the seeds in the pot without a dome and the one with the partially open ones, are the pots with the best plant growth. This might mean that the increase in vermiculite is the reason for the change in result. Although we can see from the third pot, that taking some steps to keep the mist around the plant, might have an impact on the growth. All in all, the test proves that the fogger can be a viable option for the delivery of water and nutrition in the developed system.

Figure 10: Plant growth in test setup after 5 weeks

Several more prototypes where developed during the course of this project and the current iteration of the system will be presented in the next chapter.

4 Proposed solution

This project task describes the development of a home growing system, in the early stages of the product development process. This also implies that the solution proposed here, will only be a temporary solution. The continuation of this problem will lead to continued learning and testing, which again will lead to further iterations. So, it should be noticed that the proposed solution is only the current prototype iteration in the product development process.

4.1 The system

When creating a home growing system meant to be utilized by both people with and without pre-existing experience, it is crucial that the system functions according to expectations, as well as being easy to use and intuitive in its design. A picture of the current iteration of the assembled system can be seen in Figure 11.

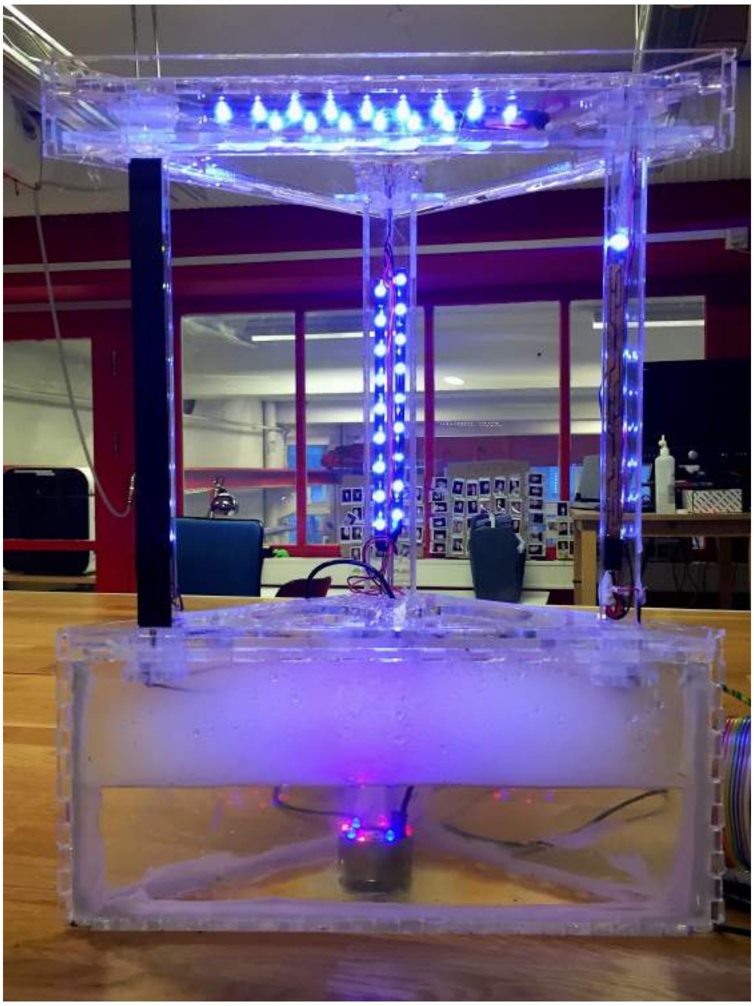

Figure 11: The assembled prototype of the proposed system

In order to make the task of building a home growing system and its key components more comprehensible, the system has been broken down and key subsystems have been identified. The subsystems and components of the proposed system are:

- Light source
- Delivery of nutrients
- Growing medium
- Water storage and pot placement
- Program selection and interface

The current iteration and proposed solution for each subsystem will now be presented and explained.

4.1.1 Light source

The proposed solution for the light source used in the developed system are LEDs. LEDs have proven be a very suitable light source as they are able to provide sufficient lighting, the wavelengths can be customized to fit the needs of the system, they are energy efficient and the heat emissions are so low that they won't affect the plants. The ability to customize wavelengths is however not integral, as it is important for the system to be as easy to operate as possible. A cool white light, as the one illuminating the plants in Figure 9 and Figure 10 is proposed. The main light source is mounted horizontally in the upper part of the system, in its own module. This can be seen in Figure 11, it should however be noted that the LEDs depicted in Figure 11 and Figure 12 are only meant to serve as placeholders for white LEDs mentioned above.

For the suspension elevating the main light module from the lower system, rods with a fixed length are proposed. This will make the system easy to assemble and disassemble for the user. This solution is also proposed to accommodate vertical modularity, as rods with a fixed length in each corner will provide the system with more structural integrity. Since the distance between the light module and the plants needs to be able to change, according to the plants height and growth stage, the system should be delivered with three sets of suspension rods. The three sets should have different lengths ranging from the height required for seed germination, to the height required for a tall, blooming plant.

In order to accommodate for the withering leaves experienced in the test of the *Fresh Garden*-system (talked about in section 3.1), an option of vertical light sources is proposed. These LEDs can be fitted into the suspension of the main light module, and in this way, supply the lower leaves with sufficient lighting. Seeing as the vertical lights can be perceived as a somewhat of nuisance when the user is looking directly at the system, covers can be placed on the outside of the rods to reduce the amount of light emitted outside of system. (This concept is illustrated on the rod to the left in Figure 11). Seeing as this light is not crucial for the user experience, it should be regarded as an optional functionality.

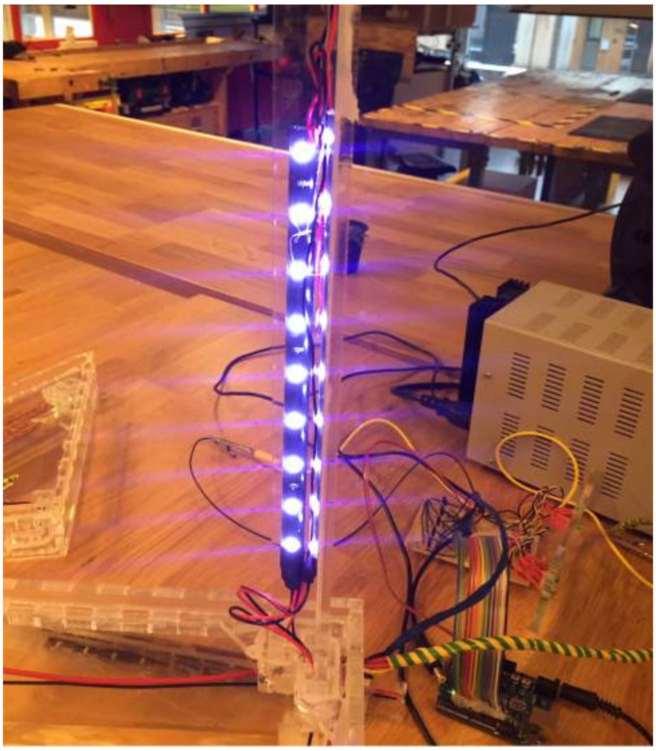

Figure 12: Vertical LEDs situated in the light module-suspension

Magnet Connectors

To avoid the potential inconvenience of free-hanging cables between the base of the system and the main light module, the proposed solution avoids external cabling all together. By utilizing the rods that holds the light source as a way of supplying power, this can be achieved. Cables fitted internally in the rods will lead the current and by having neodymium magnets fitted into both connectors at top and bottom, we can assure a reliable connection. By not having symmetrical polarities (in regard to the power in the internal cables) in the connectors on top and bottom of the rod, the rods can be assembled in both orientations and still function as expected. The prototyped rods are fitted with two magnets at top and bottom of the rod, as well as two magnets mounted in the opposing position in both the main light module and the lower part of the system. This can be seen in Figure 13.

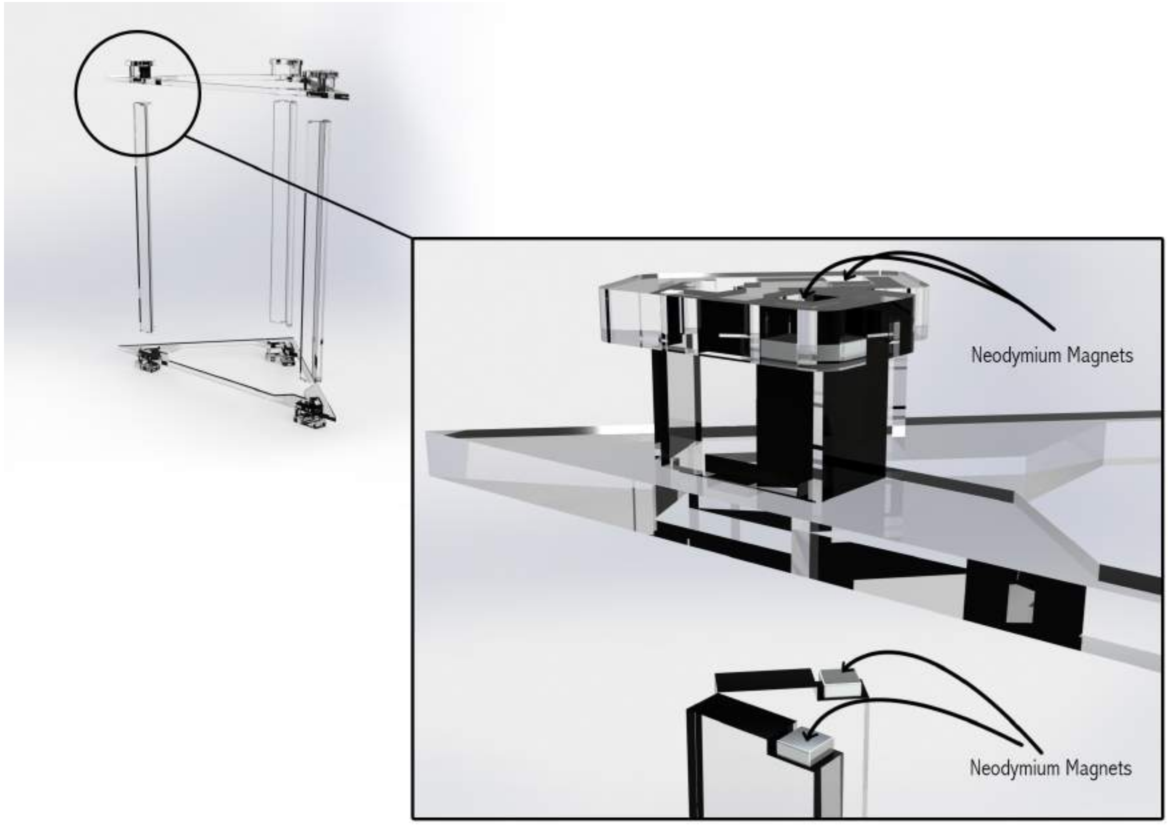

Figure 13: Illustration of magnet placement in the system

Each magnet has a pulling force equal to 300 grams of pulling force, and this has shown itself to be a suitable amount when assembling and disassembling the system. The connections are easy enough to take apart, but hard enough to make the whole system feel sturdy when it is assembled.

4.1.2 Delivery of nutrient solution

The current prototype iteration of the system functions by delivering the nutrient solution through a mist created by ultrasonic atomization. The fogger has proven to function well for this purpose and since the ceramic element oscillates within the ultrasonic range, the mist creation will be inaudible. This makes it this solution quite desirable, as this would result in the whole system functioning without making a sound. There where however some possible problems that presented themselves in the late stages of this project.

Figure 14: Accumulation of residue from the nutrient forming on the fogger

As depicted in Figure 14, salts from the nutrient solution started forming on top of the fogger. There are no signs of salts accumulating on the ceramic element, so this has not affected the performance of the fogger, but it should be explored further to determine its effect over time on the components performance and lifetime. The water level also needs to stay within, approximately 1-7cm above the element for it to function properly. It is also very important that the water level never sinks below the ceramic element, as the elements rapid oscillation generates heat and is reliant on the surrounding water for cooling. The result of the element overheating can be that it cracks, which in turn will change its resonance frequency and greatly reduce its performance.

4.1.3 Growing medium

Since the performance of the growing medium is heavily reliant on how and in what amount the nutrient solution is being delivered, the proposed solution needs to reflect the choice of delivery system. The current iteration of the system uses growstone and vermiculite, as this has proven itself to be a functional solution. This should however be investigated further.

4.1.4 Water storage and pot placement

The proposed solution of the system, and subsequently, the reservoir, were made in a triangular shape in order for it to fit nicely into corners, as requested by Jørn Hammer. The triangular shape will also make it easier when making the system horizontally modular. The proposed reservoir holds approximately 3 liters of water. When seen in comparison to the reservoir used in the Fresh Garden system, this is 0.5 liters more per pot. The pots are mounted into a plate that can easily be removed, this is to give the user easy access to the reservoir without needing to disassemble the system. When the plate is put into place, it rests on a protruding edge that goes all the way around the inside of the reservoir. An illustration of the reservoir and plate can be seen in Figure 15. The plate does also contain a third hole so the user can refill the reservoir with water and nutrient, without needing to remove the whole plate.

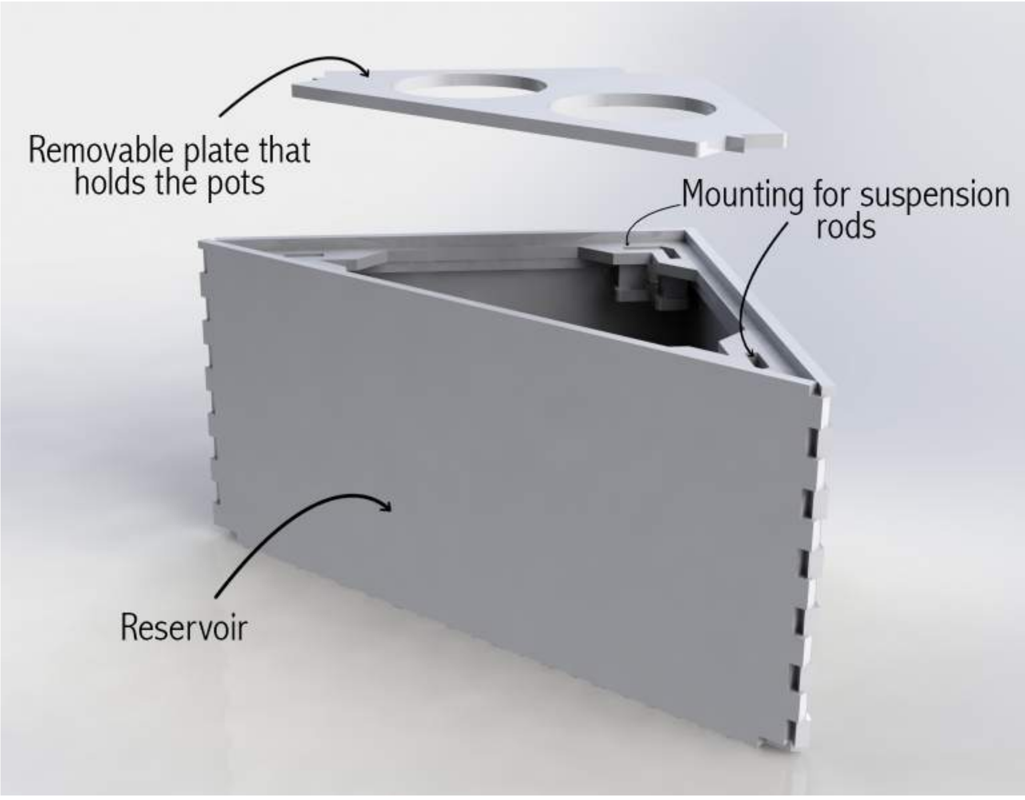

Figure 15: Illustration of the reservoir and removable plate hold the pots

Another feature of the removeable plate is that it opens up the possibility for easily changing the amount of pot holes and types of pots that be used in the system.

4.1.5 Program selection and interface

The proposed solution for the program selection and interface of the system, is that the system only utilizes two buttons. To make it as simple as possible, I propose that one button is used to toggle the whole system on and off, and one button is used to toggle between pre-existing programs. The LEDs positioned next to the buttons are meant to indicate which program and state each button is currently in. The programs control nutrition and light cycles, and should be adapted to suit the needs of the plant and the stage of growth it is in. A prototype of this interface is depicted in Figure 16. The Arduino code and wiring diagram used to create this prototype can be found in the appendix.

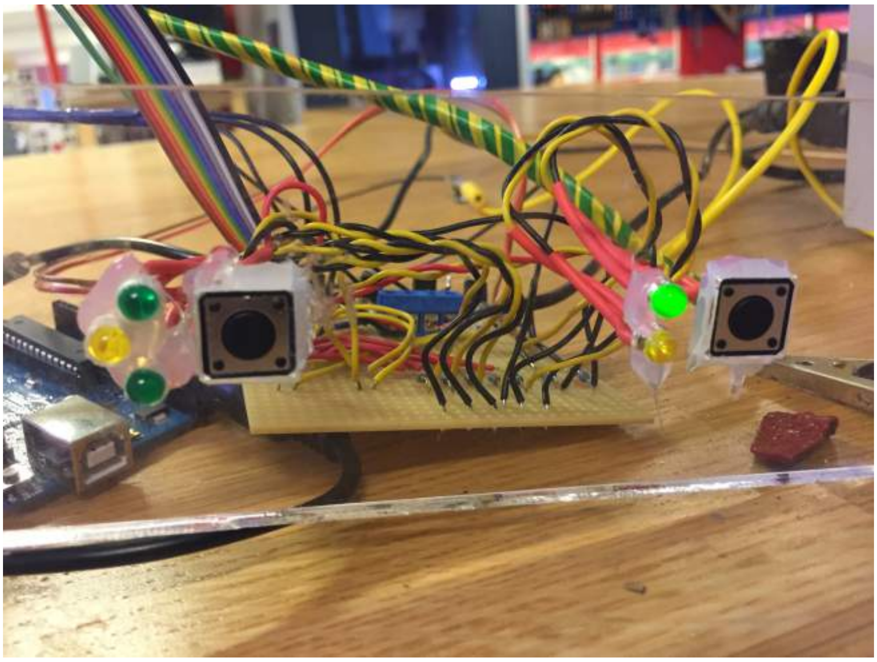

Figure 16: Control interface for the system

Another possible feature for the system, that could be added later, is an app. That way the user can have more control over the system, control it remotely and perhaps be able to customize the different growth programs. This would however not be an integral part of the system, as the user should be able to utilize the system without this feature.

5 Further work

The continuation of development will take place in several dimensions of interest:

Delivery system for nutrient solution

Further work needs to be conducted in regard to how the nutrient solution will be delivered. Ultrasonic atomization would serve as an excellent way to deliver nutrients to plants, but considering the latest discoveries, further testing and research needs to be conducted. Since it is unclear at this point in the project if the fogger is a viable option, measures should be taken in case it is not. In that regard, work on implementing a water pump into the system should commence. Three test rigs should also be built. One utilizing ordinary soil, one utilizing a water pump and one utilizing a fogger. This test will give even more insight into the advantages and disadvantages of the different concepts. It could be argued that this test should have taken place earlier in the process.

Growing medium

Since the choice of a suitable growing medium is closely connected to the choice of delivery system. This will need to be revised and further developed as the development of the system progresses.

Light source

The process of procuring a correct set of LEDs have already been set in motion, so the implementation of these should commence. The supplementary vertical light sources needs to be evaluated and their impact on plant growth should also be tested.

Modularity

As mentioned earlier, the system needs to be modular. Vertical modularity will also pose a challenge in regard to the structural integrity of the system, if it needs to carry a potentially big load. The connectivity between the systems is also an important matter. Although this has been thought of when choices have been made throughout the project, exploring and prototyping needs to be conducted, to gain more insight into the possible problems and the possible solution space. It is also desirable that the delivery system can be interchangeable in the final solution. That a user can choose to buy a system utilizing a water pump and later be able to change this to, for example a delivery system that utilizes ultrasonic atomization. A concept for this needs to be developed and explored.

Testing

The proposed system has not yet been tested on potential users. The current iteration of the system is based on the data gathered from the Design-Thinking process carried out by Jørn, and observations done by testing the *Fresh Garden*-system throughout this project. By implementing simple user tests, feedback can be gained on the system as a whole, and general thoughts surrounding the overall design and its functionalities can be obtained

6 Conclusion

Throughout this project technologies have been identified, gathered, judged and conceptualized in order to develop a user friendly, intuitive and reliable home growing system. A wayfaring model has been the governing product development methodology throughout the project, and different prototypes and some of the iterations are presented in this report. The proposed system provides some solutions to the needs that have been identified through the Design-Thinking process carried out by Jørn, and the *Fresh Garden*-test conducted in parallel to the project. The system is at an early prototyping stage, further exploration and iteration is necessary to ensure a viable and well-functioning system.

Further work and development have been proposed. The viability of the fogger and the ultrasonic atomization as a delivery system needs to be further explored and tested, in order to make a decision. A concept for the systems modularity needs to be generated and tested. When the protypes are mature enough, a user test should be conducted. As this will give further insights and a better understanding of the direction the project should be heading.

All in all, the proposed system shows great potential and this project have laid a good foundation for the continuing work that will be conducted in the upcoming master's thesis.

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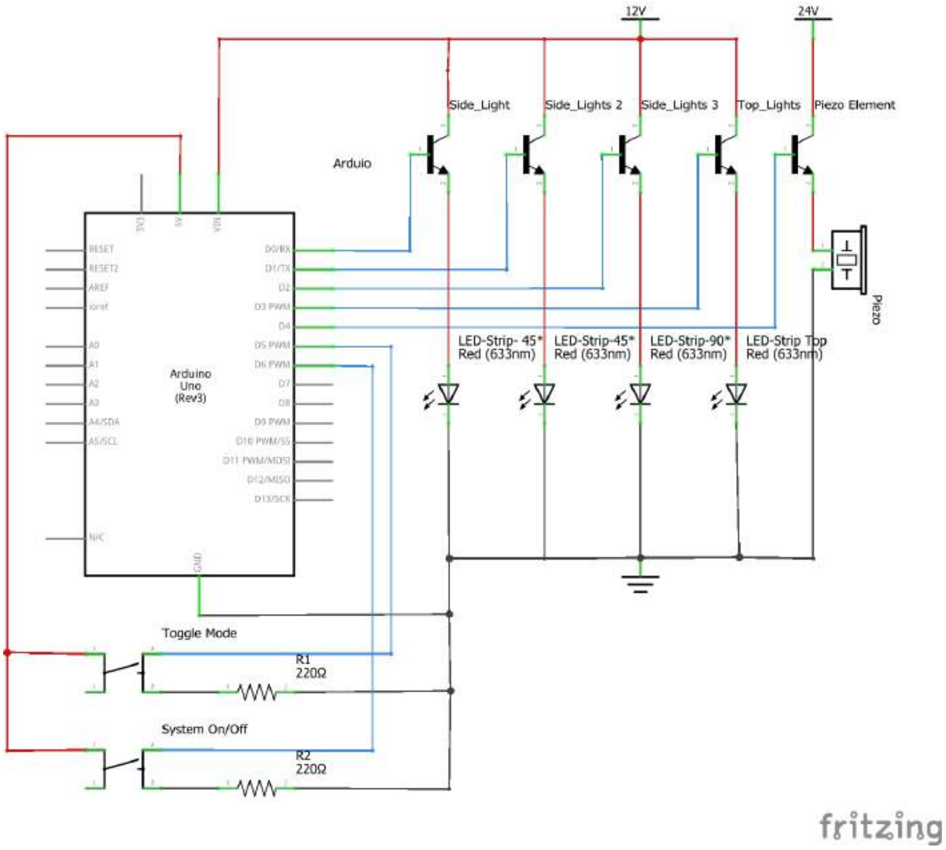
A Appendix: Arduino code used in the proposed system

```
const int  buttonPin = 10;
const int ledPin4 = 13;
const int ledPin3 = 12;
const int ledPin2 = 11;
const int Strip1 = 4;
const int Strip2 = 5;
const int TopLight = 6;
const int Strip4 = 7;
const int Piezo = 8;

int buttonPushCounter = 0;
int buttonState = 0;
int lastButtonState = 0;

void setup() {
  pinMode(buttonPin, INPUT);
  pinMode(ledPin4, OUTPUT);
  pinMode(ledPin3, OUTPUT);
  pinMode(ledPin2, OUTPUT);
  pinMode(Strip1, OUTPUT);
  pinMode(Strip2, OUTPUT);
  pinMode(TopLight, OUTPUT);
  pinMode(Strip4, OUTPUT);
  pinMode(Piezo, OUTPUT);
  Serial.begin(9600);
}


void loop() {
  buttonState = digitalRead(buttonPin);

  if (buttonState != lastButtonState) {
    if (buttonState == HIGH) {
      buttonPushCounter++;
      Serial.println("on");
      Serial.print("number of button pushes: ");
      Serial.println(buttonPushCounter);
    } else {
      Serial.println("off");
    }
    delay(50);
  }
  lastButtonState = buttonState;
```

```
}
lastButtonState = buttonState;

if (buttonPushCounter == 1) {
  digitalWrite(ledPin2, HIGH);
  digitalWrite(ledPin3, LOW);
  digitalWrite(ledPin4, LOW);
  digitalWrite(Strip1, LOW);
  digitalWrite(Strip2, LOW);
  digitalWrite(TopLight, HIGH);
  digitalWrite(Strip4, LOW);
  digitalWrite(Piezo, LOW);
}
if (buttonPushCounter == 2) {
  digitalWrite(ledPin2, HIGH);
  digitalWrite(ledPin3, LOW);
  digitalWrite(ledPin4, LOW);
  digitalWrite(Strip1, LOW);
  digitalWrite(Strip2, LOW);
  digitalWrite(TopLight, HIGH);
  digitalWrite(Strip4, HIGH);
  digitalWrite(Piezo, LOW);
}
if (buttonPushCounter == 3) {
  digitalWrite(ledPin2, HIGH);
  digitalWrite(ledPin3, LOW);
  digitalWrite(ledPin4, LOW);
  digitalWrite(Strip1, HIGH);
  digitalWrite(Strip2, HIGH);
  digitalWrite(TopLight, HIGH);
  digitalWrite(Strip4, HIGH);
  digitalWrite(Piezo, HIGH);
}
if (buttonPushCounter == 4) {
  digitalWrite(ledPin2, LOW);
  digitalWrite(ledPin3, HIGH);
  digitalWrite(ledPin4, LOW);
  digitalWrite(Strip1, LOW);
  digitalWrite(Strip2, LOW);
  digitalWrite(TopLight, LOW);
  digitalWrite(Strip4, LOW);
  digitalWrite(Piezo, LOW);
  buttonPushCounter = 0;
  }
```

B Appendix: Wiring diagram for the proposed system



NTNU	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
HMS		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av	Side	Erstatter
		Rektor		01.12.2006

Enhet: **Dato: 15.09.2017**

Deltakere ved kartleggingen (m/ funksjon): Martin Steiner, Veileder/ Pål Wisløff Nilssen, Student.

Kort beskrivelse av hovedaktivitet/hovedprosess: Prosjektoppgave student Pål Wisløff Nilssen

Signaturer: Ansvarlig veileder: Martin Steinert Student: Pål Wisløff Nilssen

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs		Romkort	Romkort		
1a	Bruk av laserkutter		Brukermanual	Ukjent	Ukjent	
1b	Bruk av 3D-printer		Brukermanual	Ukjent		
1c	Bruk av roterende verktøy		Brukermanual			
1d	Bruk av skjæreverktøy		Ukjent			
1e	Bruk av sammenføyningsmidler (f.eks. lim)		Brukermanual og datablad	Datablad	Ukjent	
2	Tilstedeværelse ved arbeid utført av andre	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	
3	Eksperimentelt arbeid		Egen risikovurdering må gjøres for det aktuelle eksperimentet		Prosessavhengig	

ID nr.	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sansynlighet (1-5)	Vurdering av konsekvens: Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)	Risikoverdi (menneske)	Kommentarer/status Forslag til tiltak
1	Bruk av Trolllabs								
1a-i	Bruk av laserkutter	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring og bruk hansker når varme materialer skal håndteres.
1a-ii		Øyeskade fra laser	2	D	A	A	C	2D	Ikke skru på laser før prosessen skal kjøre. Bruk øyevern.
1a-iii		Brann	2	B	A	D	C	2B	Vær nøye med opplæring. Ha brannslukningsutstyr lett tilgjengelig.
1b-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring.
1b-ii		Ødelagt maskin som følge av feil bruk	3	A	A	C	A	3A	Vær nøye med opplæring.
1b-iii		Innhalering av printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern
1c-i	Bruk av roterende verktøy	Stor kuttskade	2	D	A	A	D	2D	Vær nøye med opplæring. Tilstrekkelig sikring/tildeking av roterende deler
1c-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring. Løse klær, gjenstander på kropp og hår må sikres før bruk.
1c-iii		Flygende gjenstander/spon	3	C	A	A	B	3C	Tildekk deler som roterer hutig (fres etc.). Bruk øyevern.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk korrekt underlag og skarpe verktøy

1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk korrekt underlag og skarpe verktøy
1e-i	Bruk av sammenføyningsmidler (f.eks. lim)	Eksponering - Hud	4	A	A	A	A	4A	Benytt datablad og bruk hansker
1e-ii		Eksponering - Innhalering	4	A	A	A	A	4A	Benytt datablad og bruk åndedrettsvern
1e-iii		Eksponering - Øyne	2	D	A	A	B	2D	Benytt datablad og bruk øyevern
1e-iv		Søl	4	A	B	A	A	4A	Benytt datablad, korrekt underlag og ha rengjøringsmateriell tilgjengelig
2	Tilstedeværelse ved arbeid utført av andre	Se andres risikovurdering om du ikke har tiltro til arbeidets sikkerhet	3	C	C	C	C	3C	Kontinuerlig analyser situasjonen du befinner deg og vurder risikoen
3		Elektrisitet	3	B	A	A	A	3B	Bruk isolerte verktøy.