PIVOT

Home growing – your way

PROCESS REPORT

Ma04-ID11, Nik Jensen, May 2017

AALBORG UNIVERSITY
STUDENT REPORT

Architecture & Design
2017

Title page.

Title:
Pivot
Hand-in date:
May 18th 2017
Exam date:
June 9th 2017
Project Supervisor:
Nis Ovesen
Technical Supervisor:
Jørgen Kepler
Project group:
Ma04-ID11
Process report:
64 pages
Product report:
24 pages

Nik Jensen
author

Abstract.

As the vertical farming concept has been getting more and more popularity lately, controlled environment farming (CEF) technologies have gotten strong momentum in development. Large and small scale products utilize the many benefits of CEF to grow healthy and organic plants not only quicker, but also more effectively. This thesis project explored the opportunity to use some of the latest technologies in a single home-use consumer product that allows the users to grow their own organic food, without any soil or pesticides, inside their homes: Pivot. With space for 12 individual plants, Pivot uses modern technologies to grow the food faster, thanks to the rotational mechanism that ensures perfect light capture by the plants as well as better distribution of plant hormone Auxin, which results in richer harvest. Pivot also allows the users to tweak and customize different parameters of the growth cycle, in attempts to get the best possible results in shortest possible time. Pivot encourages users to cooperate or compete in the art of home growing, all the while providing healthy, organic greens to the table.

Reading guide.

The project submission is divided into three parts: the process and product reports as well as technical drawings. The product report shows off the final product concept, while the process report provides insight on research and work done in order to reach the final result. The process report is divided into several phases, each containing several different sub-topics.

The vast majority of the text is divided into two columns, and should be read the regular "top-left, down, next column, down"-way. If the text is interrupted by graphics, headline, sub-title or an equation, please read the next column before continuing reading past the obstacle.

Harvard method was used for referencing, but only in the reference list at the end of the report. In the body text itself, references are in numerical superscript format.

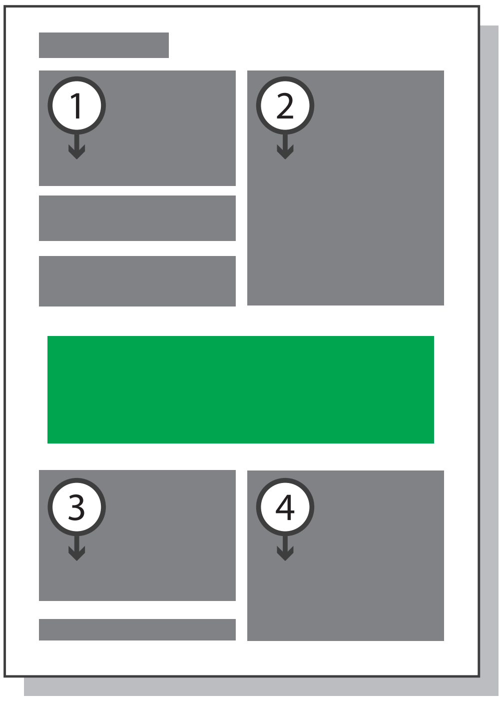


Table of contents.

INTRODUCTION PHASE

Purpose of the thesis.

Vertical farming concept has gotten a lot of attention lately, due to increased media coverage on the subject and opportunistic claims made by the media itself as well as concept advocates. Seen by some as a way to rid the world of hunger, it is undeniable that vertical farming bears innovation with its new technologies and propels a lot of research on controlled-environment-grown crops. Many startup companies are being formed around the world as well as many large multi-industry giants like Philips[1] begin to focus on the concept, supported by many educational institutions.

However, the technologies that are being developed are developed with the intended purpose of being applied in large-scale, multistory vertical farms. The purpose of this thesis is to downscale and find an application for those technologies within home-farming context, and develop a product which uses some of those technologies to deliver fresh produce straight to the consumer's table.

In long term, it would also be desired if the product could positively affect the public stance on crops that are not conventionally grown on farmland under the sun and possibly make the people be more aware of what they eat and how it is grown.

Vertical farming – history.

Vertical farming is an agricultural concept where the food is farmed in vertically stacked layers in order to drastically increase the harvest per area.

While it is difficult to say who originally thought of such a concept, the currently earliest recorded vertical farm-like building dates to 1951 Armenia[2]. Several other buildings have been either built or published, such as Ken Yeang's Bioclimatic Skyscraper in 1992.

The term "Vertical Farming" itself, however, as well as its sudden popularization is to be credited to Dickson Despommier - university professor of Environmental Health Sciences and Microbiology from Columbia University in New York, with the release of his book "The Vertical Farm: Feeding the World in the 21st Century." in October 2010.

It all started in 1999, when Despommier challenged his students to feed 2.000.000 people, using only 5 hectares of farmable land (the rooftops of Manhatten). Unfortunately, after some calculations, it was shown that such area could only feed 2 percent of the given amount of people. While trying to come up with a solution, an idea for indoor vertical layering of crops has been brought up and caught interest. The idea has gained a lot of momentum, and with an article from October 2007 in New York Magazine[3], has set a wave of media attention, with publications in The New York Times, U.S. News & World Report, Popular Science, Scientific America, and many others.

Ever since then, many small-scale vertical farms of different sorts have popped up around the world, with many startup companies doing R&D on the subject and supplying fresh crops to local shops, restaurants and cafés. In 2013, a non-profit international organization "Association for Vertical Farming" was founded in Münich, Germany, with the intent of fostering sustainable growth and development of the vertical farming movement in connection with individuals, companies, research institutions and universities[4].

Vertical farming – vision.

Despommier's original vision with his book was to save the world from hunger. Stating that the world population will reach 9 billion by 2050 and the food supply will struggle even more to keep up (as of right now, it is reported that 1 in 8 people is not getting enough food already[5]). Increased urbanization and city expansion is reducing the available arable land (which already is 38% of the landmass[6]). The water consumption of the traditional farms is very high and is especially problematic in dry areas, and overall farming methods are wasteful. Pesticides, fungicides and herbicides are necessary to use in order to produce healthy crops, but in return, they pose a huge threat to groundwater by poisoning it and thusly a big threat to human health. According to many health organizations including The World Health Organization, President's Cancer Panel and American Cancer Society, pesticides are linked to several health problems including Asthma and ADHD in children, dangers to the reproductive systems, and even cancer[7]. Finally, many ecosystems and animal habitats are being destroyed to make space for more farmlands. And the farmlands themselves can rapidly degrade from primitive farming practices[8].

The vertical farm concept offers a seemingly perfect solution to all of these problems. By stacking the crops vertically in layers, the only limit to how much you can harvest per area is the height you are willing to build it up to. The water and nutrient efficiency is almost at

Figure 1: Vertical farm benefits.

100 percent, as the nutrient water cycles through the system, while plants feed off it. The controlled indoor environment means perfect growth conditions for the plants all year round, resulting in faster and more frequent harvests and removing the risk of losing the harvest due to climatic disasters like flooding, hailstorms, hurricanes, or exceptional heatwaves. Insect and disease-free environments also mean that no pesticides, fungicides or herbicides are necessary, thusly producing organic, healthy crops. If placed within cities, the distance that the produce needs to travel to the shops or restaurants is absolutely minimum (which is one of the main "selling points" of the concept), saving a lot of carbon emissions from regular and refrigerated trucks (also known as "food miles"). And last, but not least, the new employment opportunities, fewer abandoned buildings in the cities and safer use of municipal liquid waste[9] (Fig1).

Vertical farming – criticism / challenges.

While it can sound like a magical solution that will save the world, thanks to a wide media over-glorification of the concept, it has received a lot of criticism and faces many feasibility challenges.

The biggest challenge that the concept is facing is energy consumption. In 17th century, a Belgian man Jan Baptist van Helmont has conducted experiment with a willow tree, planting it in 200 pounds of soil. Five years after, the tree itself grew to weigh 169 pounds, while the mass of the soil diminished less than a pound. This prompted Van Helmont to come up with the theory that the majority of mass of the plants comes from the water they consume. The whole hypothesis could be dated as far back as 1450, to Nicolaus of Cusa's book "*De Staticus Experimentis*". Van Helmont believed in water-forms-all-matter theory and has therefore fully ignored even the remote possibility that a lot of plant matter could come from a different source: the carbon dioxide gas, despite being the man who first coined the word "gas" and conducted many experiments with it.

In 1779, a Dutch-born British physician and scientist Jan Ingenhousz has published results of his study ***"Experiments Upon Vegetables, Discovering Their Great Power of Purifying the Common Air in Sunshine, and of Injuring It in the Shade and at Night***", which described the processes of photosynthesis and photorespiration and that the light is necessary for the photosynthesis to occur[10].

Photosynthesis itself is a process, where the chlorophyll molecules absorb the energy from the sun and use it to produce molecules of glucose sugar and oxygen out of water and carbon dioxide.

$$6CO_2 + 6H_2O \xrightarrow{Sunlight} C_6H_{12}O_6 + 6O_2$$

For over 3 billion years now, plants on Earth grew with the help of this process, taking the energy from the sunlight, which makes it just as vital part for the plants growth as water and carbon dioxide. However, as soon as farms start to get stacked on top of each other, the light will have a very hard time reaching the center of the layer. Fortunately, artificial light is as good a source of energy as natural light, and the vertical farms use LED, HPS or HID lighting to provide plants with the energy to grow.

However, the challenge that this creates for vertical farming is immense. Critics and skeptics criticize the extreme power consumption of vertical faming, which almost nullifies any sort of positive sustainable effect it otherwise has, such as food miles. Bruce Bugbee, Director of the department of Plants, Soils and Climate from Utah State University has presented a seminar criticizing the concept. He reported, among other things, that kilograms of carbon dioxide produced per kilogram of lettuce using conventional farming, put together with food miles from a farm in California to the shop shelves in Michigan (nearly 4000 km) equals just 1 kilogram, while the amount of CO2 produced per kilogram of lettuce grown at a vertical farm in Michigan is between 4.6 and 5.6 kilograms[11] (Fig2).

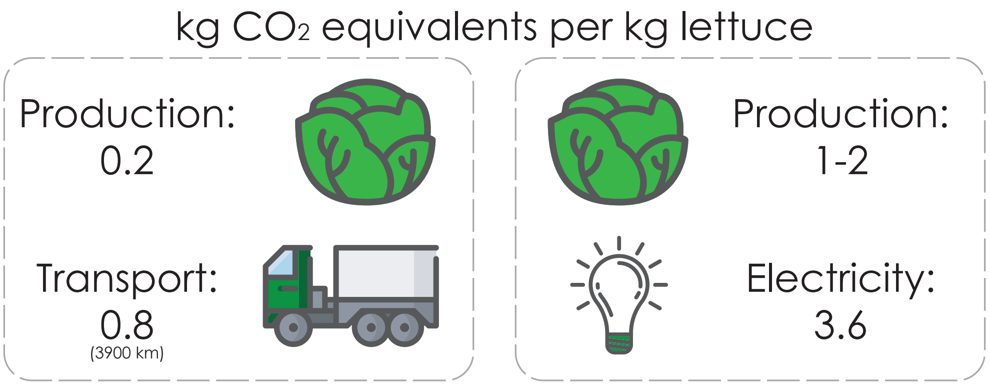


Figure 2: Carbon dioxide equivalents for lettuce.

The reason behind such high energy consumption for lighting is amount of photons needed for the plant to grow. According to a highly acclaimed paper by Bugbee[12], it takes 1 mole of photons (6.02x1023 photons) to produce 1 gram of dry biomass, or 0.5 gram of actual yield. This simple conversion allows us to calculate how much electricity would be required to produce enough photons to grow the produce and in vast majority of the cases, the numbers are very high.

This brings up the second challenge about vertical farming: crop variety. Due to high energy consumption per dry mass of the plant, the plants that are best suited for such way of farming are the ones that consist mostly of water, such as leafy greens (lettuce, spinach, etc), tomatoes, herbs (basil, parsley, etc) and others. To calculate approximate price of electricity per kilogram of produce, we can use the following equations:

$$\frac{2\ DKK}{1\ kWh} * \frac{1\ kWh}{6.12\ mol} = \frac{0.33\ DKK}{1\ mol}$$

$$\frac{0.33\ DKK}{1\ mol} * \frac{1\ mol}{0.5\ g_{dry}} = \frac{0.66\ DKK}{1\ g_{dry}}$$

Here, the price per kWh is assumed to be 2 DKK (average price, incl. taxes) and the light used is the most efficient one for indoor farming, able to produce 6.12 mol of photons per kWh[13]. These two variables give us a price of 0.66 DKK per single gram of dry weight. In case of lettuce, which consists of 95% water, price per kilogram would be:

$$1000\ g * 0.05 * 0.66\ DKK = \frac{33\ DKK}{1\ kg}$$

To compare, wheat consists of only 13% water and thusly the kilogram price under same conditions would be:

$$1000\ g * 0.87 * 0.66\ DKK = \frac{574\ DKK}{1\ kg}$$

With these things in mind, it becomes rather clear that vertical farming is not a miracle that will save the world from hunger, but rather a novelty concept that can offer a limited range of sometimes-cheaper-than-conventional crops, due to currently high consumption of energy. Even if using solar panels, the area needed in order to harvest enough sun's energy is 5.4 times greater than the area of the tillable soil[14].

Conclusion:

Due to a very high energy consumption and hereby high carbon emissions from fossil fuel-based energy production, which leads to crop price that is barely lower than store-bought food, the main selling points of the home-use vertical farming technology-based product are different than those which would appeal to environmentally-oriented consumers. Values which could be focused on instead are: freshly harvested produce straight to the table, season-independent year-round harvesting and increased growth speed, pesticide-free organic food, and high technological, soil-free home farming.

RESEARCH
PHASE

Growing plants – the requirements.

Before developing a product for home farming, one needs to be aware of the basic needs for plant growth. There are nine cardinal parameters that affect it (Fig3)[15]:

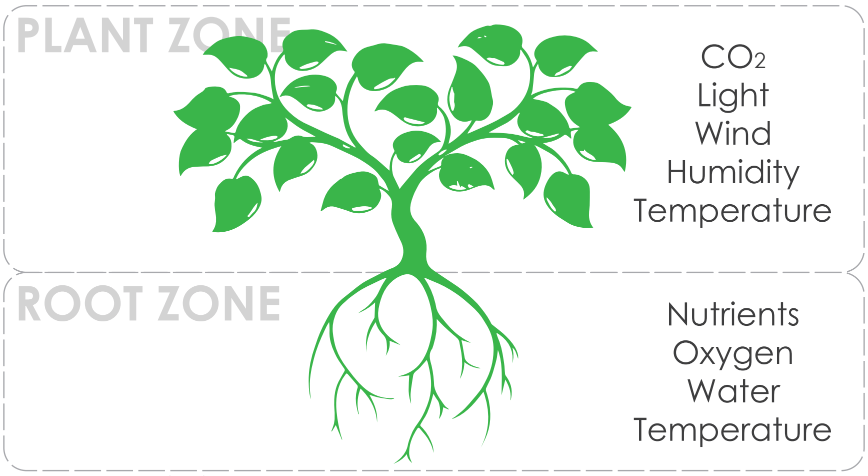


Figure 3: Nine cardinal parameters.

WATER
Roots absorb water which, combined with carbon dioxide from the air, becomes plant matter under the photosynthetic process.

HUMIDITY
As the plant opens up its pores to absorb carbon dioxide, some of the moisture kept in the leaves can escape. If the air is dry, the moisture will transpire more rapidly and if the moisture loss exceeds the water intake from the roots, the plant will attempt to fully close its pores to conserve the water, which will, unfortunately also stop CO_2 supply to the plant. This will cause the plant to die[17].

LIGHT
Light provides energy for the photosynthetic process to happen, where chlorophyll molecules use water and carbon dioxide to produce oxygen and glucose, which become a building block for plant matter.

TEMPERATURE
Plants have their own temperature preferences and are typically separated into warm and cool-season crops. Up to a certain point, some plants favor higher temperatures, however if the temperature becomes too high, plant will start losing moisture, just like in the case of low humidity. During cold seasons, plants become dormant in order to preserve energy while halting growth[18].

OXYGEN
While the leaves need carbon dioxide to photosynthesize, the roots require oxygen to do their job of absorbing water and nutrients[21].

WIND
Wind is an often-neglected environmental factor when it comes to farming, but studies have shown, that wind has effect of reducing water balance in the leaves[16].

ROOT ZONE TEMPERATURE
Root zone temperature is important for plant growth since heat serves as catalyst for many biological processes, including absorption of nutrients and overall germination process of a plant. Just like with the plant zone-, the optimal root zone temperature is individual for different plants[19 20].

CARBON DIOXIDE
Carbon Dioxide is an important resource for the plant photosynthesis process and is required for the plant to grow.

NUTRIENTS
Sixteen elements are known to be essential for plant growth. They are divided into macro- and micronutrients (often known as trace elements).

Macronutrients are:

Nitrogen (N), Oxygen (O), Carbon (C), Hydrogen (H), Potassium (K), Phosphorus (P), Calcium (Ca), Sulphur (S), Magnesium (Mg).

Micronutrients are:

Copper (Cu), Boron (B), Molybdenum (Mo), Manganese (Mn), Iron (Fe), Zinc (Zn), Chlorine (Ch).

If any of the sixteen essential elements are in deficit, plant growth and yield will be reduced, despite others possibly being in abundance[22].

Controlling and optimizing some or all of those parameters would allow the farmer to grow crops in the fastest possible way with as rich as possible harvests.

TECHNOLOGY

NUTRITION

As opposed to traditional farming in soil, called geoponics, vertical farms usually use aeroponics or hydrocultures to distribute nutrients and water to the plants.

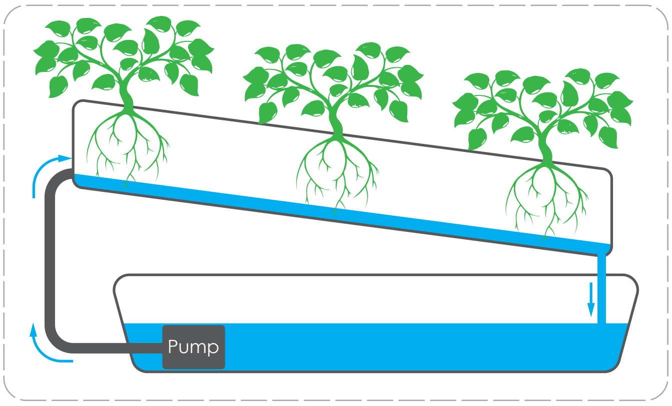
The earliest published work on growing plants without soil dates back to 1627 in a book *Sylva Sylvarum* by Francis Bacon. In 1699, naturalist John Woodward published his own experiments on soilless growing, where he stated that plants grew worse in distilled water than they did in less-pure water sources. In 1842, German botanists Julius von Sachs and Wilhelm Knop have created a list of nine elements believed to be essential for plant growth and a lot of research has been conducted on hydroculture since then. In the year 1938, two plant nutritionists from University of California Dennis R. Hoagland and Daniel I. Arnon have published a bulletin[23], where they reported that in its principle, hydroculture does not provide better crop yield over geoponics, as that is dependent on many other factors, including light. However, it provides different sort of advantages, such as plants having more oxygen by the roots and in advanced systems - having access to exactly as much water as they need, avoiding the dangers of over- or under watering. The Californian duo have developed a formula for a mineral nutrient solution which is in use until this day (although in modified versions) – the **Hoagland Solution**. Due to nutrient contents of the water, it must be kept hidden from the light to prevent formation of algae.

The earliest successful use of soilless farming happened at Wake Island in the Pacific Ocean, where vegetables were grown for passengers of passing airlines. The island itself did not have tillable soil for traditional farming and importing fresh vegetables would have been too expensive[24].

Hydroponics.

Hydroponics is subset of hydroculture for growing plants, where the nutrients are delivered to plant roots via water. The plants are planted without soil, but suspended in either specially designed holders, or simply in a medium such as gravel or rice husks.

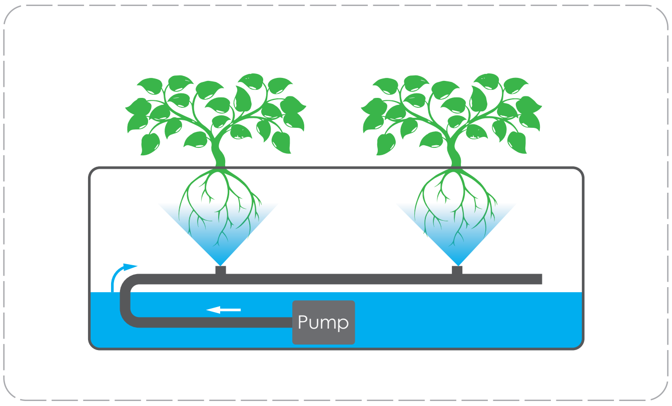
Nutrient film technique.



Nutrient Film Technique (NFT) is just one of the techniques for hydroponic farming, developed in 1960s by Dr. Allen Cooper, where a very shallow stream of nutrient water runs along the exposed roots of the plants, and is being constantly recirculated[25]. The main advantage with NFT is that thanks for the carefully calculated design of the water channel and water distribution rate, the plant is being exposed to a well balanced supply of nutrients, water and oxygen, resulting in high-yielding, high-quality healthy produce. According to research done by Produce Grower magazine, NFT was the most-used (31%) type of hydroponic system by commercial growers in 2016[26].

One of the drawbacks of hydroponic systems is that they rely on electricity in order to keep the pumps running and in case of prolonged loss of power, loss of harvest may occur. If a hydroponic system uses still-standing water, the technique is called Deep Water Culture, but it often requires use of an air stone do enrich the water with oxygen.

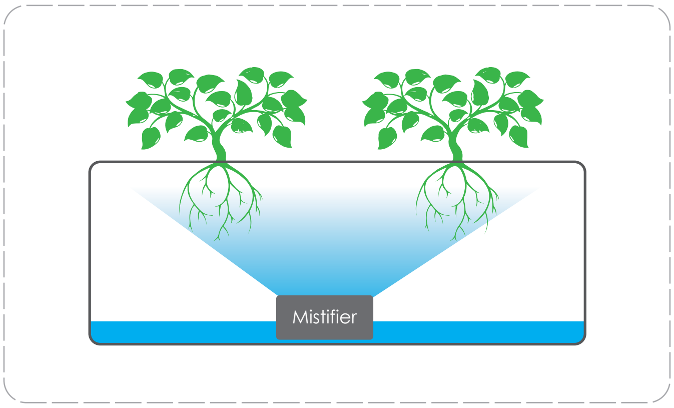
Aeroponics



Aeroponics is another subset of hydroculture, invented by Richard Stoner in 1983. In an aeroponic system, the roots of the plants are kept in a closed environment, where nutrient water is sprayed in mist or aerosol form, increasing the amount of air the plant receives and saving more water than with the hydroponic methods[27] and using only a quarter of nutrient input. Compared to traditional farming, using aeroponics can save up to 98% of the water usage, 60% of fertilizer usage and maximize the crop yield by 45-75%[28].

Just like basic hydroponics, this system is also dependent on power, but also requires more maintenance and cleaning to keep the nozzles from clogging.

Fogponics



Fogponics is very similar to aeroponics with the one exception being that the fine water mist particles for the roots are not being created by pressing the water through nozzles, like aeroponics does, but instead, the water is aerosolized by a diaphragm which vibrates at supersonic frequencies, much like a typical humidifier. The smaller droplets are easier and faster for the plant to absorb[29].

Fogponics have same maintenance requirements as aeroponics.

Aquaponics.

Aquaponics is an especially peculiar way of providing nutrients to the plants. While it is a hydroponic system, it is combined together with aquaculture, i.e. fish in a tank, in order to break down the excrements of the fish, transforming them into nitrites and nitrates that nurture the plants, thusly creating a symbiotic environment[30].

Compared to hydrocultures and aeroponics, aquaponic setups are far more complex and require more components and maintenance. Other than hydroponic subsystem for nutrient distribution and a rearing tank for the fish, the system requires a setting basin for particle filtering, bio filter for converting excrements into nitrates and a sump, where excess water is returned to the rearing tank[31].

Aquaponic systems are usually unique, as they are built by the user to accommodate their individual needs.

There are many other technologies out there for nutrient distribution; however, they either are, for the most part variants of aforementioned ones or cater for very niche segments of farming.

LIGHTING

As mentioned before, high energy consumption of lighting setups is the biggest drawback of vertical farming. Therefore, usage of most energy-efficient light emitters is a key focus of all vertical farming setups. Several companies, including Phillips are currently researching and developing new, more efficient lamps and diodes.

People are used to comparing light sources in lumen – the intensity of the light, which is independent of area. Every light source has a fixed amount of lumen, which does not change regardless of your distance to the source. It has often been assumed that the more powerful the grow light is, the better it is for the plant. However, new research shows that it is not the case and plants do in fact favor certain wavelengths, red and blue, to be precise. Those are photosynthetic effective wavebands at leaf level in both short and long terms and that the absence of either of them would create photosynthetic inefficiencies[32 33 34].

Reason for this is the absorption spectrum of plants' pigments inside the photosynthesizing molecules. The three key pigments are the chlorophyll a, chlorophyll b and β-carotene and they have different wavelengths preferences when it comes to light absorption (Fig4)[35].

What this means is that not only does lumen scale not matter for the plants at all, but also the green color itself is wasted photons that does not benefit them. It is the reason why most of modern vertical farms use pink light to grow the plants – a combination of blue and red diodes.

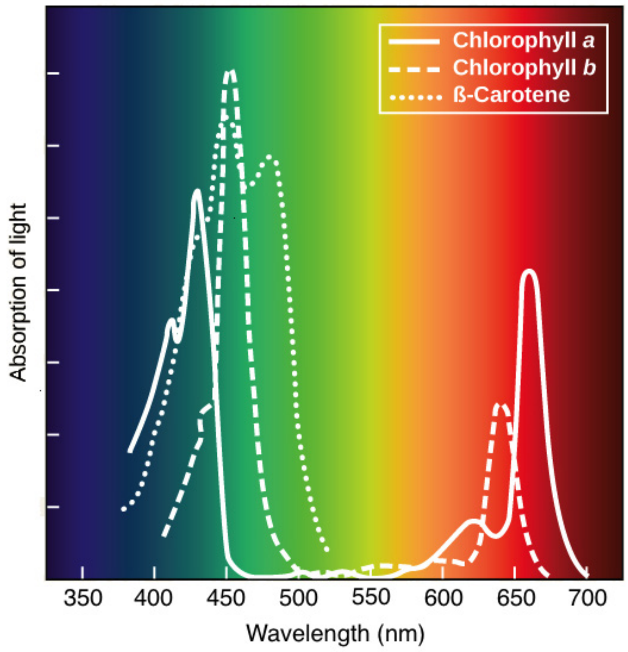


Figure 4: Absorption Spectra of Pigments. Source: Khan Academy.

However, in a research article from 2012 by Kuan-Hung Lin, et al. have conducted experiments growing lettuce under red-blue, and red-blue-white lights. The results have shown that lettuce grown under red-blue-white LED lights had higher root fresh, dry weight, nitrate content, as well as better crispness and sweetness than those grown under red-blue only lights. They suggest that white light can be used as a supplement and by precisely managing and balancing plant irradiance and light wavelengths; it is possible to maximize plant productivity, quality and nutrient potential[36].

Furthermore, in a 2013 paper, Bruce Bugbee and Kevin R. Cope demonstrated difference in plant growth under three different types of white LED lights: warm, neutral and cold. They discovered that low blue light in warm-white diodes increased stem elongation and leaf expansion, most likely due to the plant trying to capture as much of it as possible without affecting total dry weight. It was concluded that light quantity and quality interact to determine plant morphology and that the plant develops accordingly, to maximize light radiation capture[37].

Finally, while chlorophyll is the most common pigment in leaves, it is not the only one. Sven Svenson, research horticulturist with Oregon State University explains that two other leaf pigments that are common in plants are carotinoids and anthsyanins, which absorb different spectrum of colors, including green. Those pigments are more common and predominant in plants with non-green leaf colors, such as purple basil or beefsteak plant[38].

The three types of electric lights most commonly used for controlled-environment farming are:

LED.

Light emitting diodes (LED) is one of the most common emitters these days. They are more energy efficient than other types of lights on the market, thanks among other things to being directional. They are very cheap and come in different sizes and shapes. They come in IR, UV and white light spectrums, as well as more specific colors like red and blue. Even bi- and tri-color LEDs are available, where the emitted color can be changed on the fly. The LEDs use two-lead semiconductors to emit light, in a process called electroluminescence.

Directionality of LED lights is both a blessing and a curse. While they are better at sending the photons in the right direction, the high concentration of the diodes means that they cover a smaller area.

HID.

High Intensity Discharge (HID) lights create light by igniting gas inside a sealed glass tube. Containing two electrodes inside, they arc electric current, lighting the gas and emitting light and heat in all directions, which is the reason why most of the HID light setups utilize a reflector hood, to direct down the light which is emitted upwards. The HID lights come in either High Pressure Sodium (HPS), Metal Halide (MH) variants, or a combination of both (dual arc). The difference is the gas inside, as different gasses produce different spectrums of light. HPS lights tend to produce more light in the red-orange part of the spectrum, while MH has more output in the blue range.

The disadvantages of HID lights are high energy usage due to energy inefficiency – they produce a lot of heat and can be damaging to the plants, either directly burning the leaves if placed too close, or generally overheating the room, exceeding plant's optimal growth temperature. The HID lights also require a so-called ballast – a device that carefully regulates the voltage supplied to the bulbs.

FL.

Florescent light used to be very popular for indoor farming, due to low heat output and longer lifetime compared to incandescent lights that they are often compared against. However, the majority of FL lights do not output the most optimal wavelengths for plants, using a lot of energy on green light and barely emitting any red light at all, which makes them far inferior in modern days, compared to LED and HID lights.

GROWING PLATFORMS

When it comes to vertical farms, there are almost as many different concept executions as there are vertical farming companies and enthusiasts. People construct their farms in different ways, whichever are best suited for their needs. Environment and light control systems are not always present in private setups and the arrangement of plants can vary in many ways, from being wall-mounted, to being grown out of pipes or columns. The main principle remains though: they utilize the vertical axis to maximize amount of plants per area.

Some of the more peculiar versions of "farms" are the rotational ones. At least three companies exist, which develop, manufacture and sell different sorts of rotational farming/gardening aggregate: Omega Garden, Gigrow and Quantum Leap Hydroponics. The main feature of their products is that the plants are mounted on either inside or outside of a cylinder and rotate along the horizontal axis, with the light source being either inside the cylinder (in cases of omega garden and gigrow), or on the outside (quantum leap). Omega gardens even claims that their system can increase the harvest by 60% thanks to the rotational effect that they call orbitropism (Fig5)[39].

Figure 5: Pictures provided by Omega Gardens demonstrating difference in plant growth. Both plants were grown under exact same conditions with only difference being that the plant to the left was grown in a rotating machine.

Rotational farming.

Little scientific evidence exists to support the claim that constantly rotation a plant would increase the yield or speed up the growth. However, many experiments and research have been carried out on plant growth in microgravity in order to create best possible ways of cultivation in space.

In plants, tropism is growth in response to stimuli and there are two types of it: positive and negative tropisms. Positive tropism means that the plant growths towards the stimulus, while negative tropism means the opposite – it grows away from it. Plant growth reacts to phototropism and gravitropism: the light and gravity stimuli respectably, in either positive or negative way[40].

	Light Stimulus	Gravity Stimulus
Shoots	Positive phototropism	Negative gravitropism
Roots	Negative phototropism	Positive gravitropism

If you place a potted plant on its side, the roots will continue to grow down towards the ground, while the shoots will begin to bend towards the light within minutes. The reason behind this is a plant hormone known as ***Auxin***, which is responsible for elongation of plant cells. For the cells in the shoots, Auxin helps increase the growth, while in the cells of the roots - it reduces it instead[41]. The tip of the plant acts as a light sensor, detecting the direction where the light comes from. Then, auxin attaches itself to a transporter – a PIN protein, which transports the hormone to the shaded side of the stem, where it helps elongate the cells, creating unequal cell length and thusly bending the stem towards the light (Fig6).

Gravity also affects auxin. If the plant is laid on its side, gravity helps auxin to accumulate on the bottom side of the stem, elongating it and forcing it to bend up towards the light and against gravity[42]. Omega Gardens claim that it is because of constant fight against gravity that the orbitropism happens, compressing the plant and increasing amount of internodes as well as forcing a better and more thorough nutrient distribution throughout the plant.

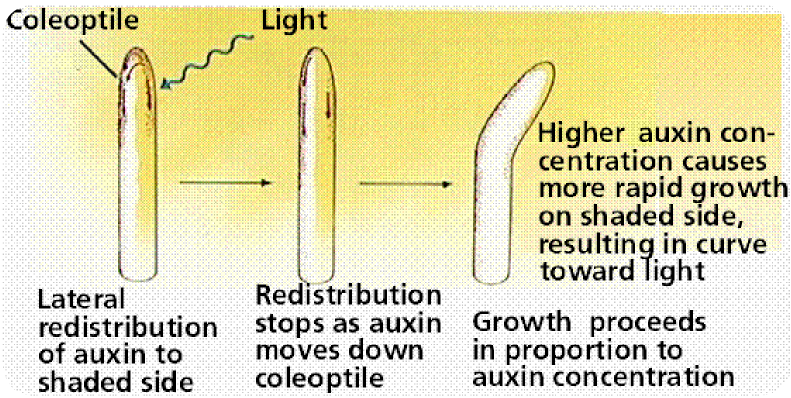


Figure 6: Auxin destribution and stem bending.

Growing medium.

In order to grow crops soil-free, some sort of medium is still required in order to hold the seed in place and surround it with nutrients without drowning it as well as to allow them to root. A balance of water and air retention is an important factor and choosing a correct medium can have a huge impact on plant growth. Porous and pH-neutral materials are favored for this task. Some of the most common mediums that are used for hydroponic farming are: sand, gravel, expanded clay, perlite, pumice, coir, peat, sheep- and Rockwool. Produce Growers magazine reports that Rockwool is currently the most used growing medium (39%), at least among commercial hydroponic farmers, followed by Perlite, Coir and other peat-based mediums[43].

There are many papers published on water and air retention levels in different mediums and some plants prefer some over others. Ultimately, it is an individual choice depending on preferences and what is being grown.

MARKET
Trends.

Many publications, magazines and research agencies believe that home gardening is a big trend on the rise.

PSFK is the world's leading provider of innovation insight and market research. In their published report "Future of Home Living Report", they mention Home Farming as a rising trend since 2013, with more and more people wanting to grow their own food in the comfort of their home[44 45]. Garden Media Group (GMG) – a marketing firm for garden industry also reports that in the US, consumers become more health aware and ingredient sensitive, paying more attention to the food they buy and consume[46], as well as generally demanding healthier, cleaner food and in fact, are willing to pay more for products that claim to be better for their health[47]. GMG predicts that "Grow 365" is a key rising trend as well, with people wanting to enjoy growing food all year round and technology is there to help them achieve that. "Growing under lights" concept is forecast to grow by 6.3% annually through 2021 in the US alone and according to 2016 IKEA Life at Home Report, 60% of people worldwide already grow vegetables or flowers indoors[48], or every third household in the US. Finally, according to IBISworld, hydroponic crop farming industry in USA has been growing by 4.5% annually between 2011-2016[49].

It is not only 2017 that sees the rise of the home gardening trend. In fact, home gardening has been on a steady rise since 2008 (with an annual average increase of 3% between 2008 and 2013), where economic crisis forced a big amount of people to grow their own food at home in fear of economic uncertainty and instability. In fact, millennials have begun taking interest in gardening, with 13 million 18-34 year olds making up second largest home gardener segment in USA in 2013[50].

National Restaurant Association creates food trend research by surveying hundreds of professional chefs, and "locally grown produce" has been #2 trend in 2015 and #1 in 2017[51].

Looking at Google Trend Analysis, it is easy to see a rising popularity in search terms like "home farming", "indoor farming" and "grow at home" from 2008 until 2017 (Fig7). This shows that people generally are getting more interested and curious in the subject.

More people want to grow their own food at home.
More people pay attention to the food they consume
People are willing to pay more for healthier products.

6.3%	4.5%	60%	33%
Forecast annual growth of "Growing under lights" concept.	Annual growth of hydroponic farming industry in USA.	Of people worldwide already grow indoors.	Of American households already grow indoors.

When it comes to a reason why some people do not grow their own food, searching online forums, message boards and articles as well as conducting own survey has revealed that most common reasons include lack of time to tend the garden, lacking perceived skills it requires, laziness or simply lack of money to invest in farming equipment, soil, accessories and the like.

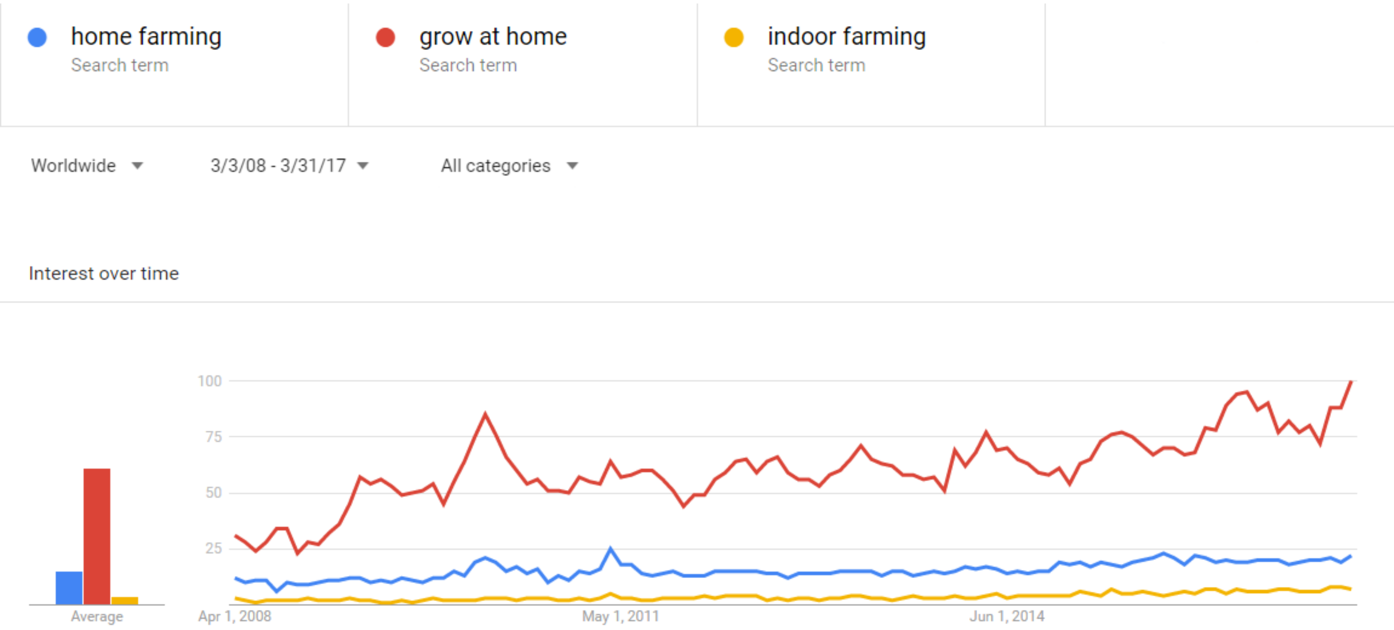


Figure 7: Google Trend Analysis of three search keywords.

Target group.

Based on an earlier conclusion and technology research as well as recent trends, the best main target group for such a product would be:

Person aged 20-45, who values organic produce and is interested in growing some of the food themselves. They are either interested in technology, do not have time to bother with conventional farming, do not have proper facilities or a combination of all or some of those.

It could be students, who would like a healthy addition to their food.

It could be mothers and fathers, who want their family to eat more vegetables that are organic.

It could be corporate workers, who want to grow their own food, but are too busy to do so with conventional methods.

Geographically, the focus lies on western first world countries such as USA and Western Europe.

Mission.

The mission is to create a product for home use, which utilizes technologies and research made for vertical- and controlled environment farming, to allow the user to grow their own organic crops, independent of seasons, all year round, without soil or pesticides.

In order to be competitive on the market, the product should not only help grow the crops, but influence them to grow faster and richer than the competitor products and conventional farming methods.

Due to time limitations of the project, the research and development will be focused on cultivation of leafy greens. However, the product itself should be able to grow several different kinds of crops, but within reason and limitations.

Competition.

Many products are either in development or already on the market that allow people to grow crops indoors easier. Some of those products have been hand-picked for comparison:

(Please note that most prices have been converted from US Dollars, thusly might not include the VAT tax otherwise applied in Denmark. Therefore, the prices should be considered an approximation, with leeway of up to 25%).

CityCrop (www.citycrop.io) (Pre-order, expected Sep. 2017)

Price: 7.850 DKK

A large tower-like product with two levels that allows the user to control several parameters, such as temperature, humidity, lighting and ventilation. Uses hydroponics for nutrients with automatic nutrient control and LED for lighting. Connects to a smart device for enabled control and monitoring of plants as well as notifies the user when the crops are done.

Since it is currently not a released product, some of the claims should be taken with a grain of salt.

IKEA VÄXER/KRYDDER (www.IKEA.com)

Price: 1.150 DKK (Full setup, as seen on the picture)

Dimensions: 440x250x800 mm

A series of products for hydroponic farming and seed germination. A full kit includes: germination unit, hydroponic cultivation trays, growing medium, seedling plugs, liquid fertilizer, LED red/blue cultivation lamp. In the suggested setup, the light only reaches the top tray.

Miracle-Gro AeroGarden Ultra LED (www.miracle-gro.com)

Price: 1.950 DKK

Dimensions: 440x285x863 mm

One of several products from the company, this particular one features height-adjustable full spectrum LED lighting, hydroponic system, and just seven slots for saplings. Has a convenient interface with a screen that guides you through planting process and notifies you when you need to add nutrients or water.

The Smart Herb Garden (www.clickandgrow.com)

Price: 420 DKK

Dimensions: 127x307x353 mm

This product also features hydroponics and LED lights and only allows for 3 plants to be grown at the same time. The low product price is weighted by the high price for new sampling capsules, costing approx. 140 DKK for a tri-pack. However, the capsules themselves come with all the necessary nutrients added to the growing medium, so the user only needs to add water.

The Wall Farm Indoor Vertical Garden (www.clickandgrow.com)

Price: 9.050 DKK

Dimensions: 1360x400x2100 mm

A triple-layered home vertical farm, capable of hosting 51 plants. Uses the same technology and plant capsules as the Smart Herb Garden.

Volksgarden (www.omegagardens.com)

Price: 14.850 DKK

Dimensions: 635x1090xx1295 mm

A rotational farming machine that uses hydroponics and fluorescent lamps. Despite its relatively huge size, it is designed to be used at home and can grow up to 80 plants at once. Omega Gardens claim that it can grow crops 60% richer than traditional farming.

Tower Garden Growing System (www.tower-garden.com)

Price: 3.800 DKK

Dimensions: 762x762x1574 mm

Tower Garden is an aeroponic system supporting 20 plants at a time and comes with all the components needed, including a germination tray, growth mediums, seedling plugs, pump, pH adjusters and plant nutrients. A light cage can be bought as an extra, providing unevenly distributed light from 4 directions.

Plantui 6 (www.plantui.com)

Price: 1.970 DKK

Dimensions: 290x290x370 mm

Created by a Finnish company, Plantui 6 uses hydroponics and LED lights to grow up to 6 plants at a time. The plants come pre-placed in seedling plugs in packages of 3, costing 50 DKK, but also include a little packet of nutrients that needs to be added to the water.

Aquasprouts Garden (www.aquasprouts.com)

Price: 1.800 DKK

Dimensions: 711x203x890 mm

A full aquaponic kit, including everything that is needed to start farming, save for the fish and seeds. Uses fluorescent light tubes for the plants and LED lights for the aquarium.

The different products have been entered into a spreadsheet for quick overview (Fig8):

	Nutrition Delivery	Lighting	Size	Capacity		Price	Notes
CityCrop	Hydroponics	LED	+++	++	24	$$$	Extensive Environment controls
VÄXER/KRYDDER	Hydroponics	LED	++	++	16	$	
Miracle-Gro	Hydroponics	LED	+	+	7	$$	On-screen notifications
Smart Herb Garden	Hydroponics	LED	+	+	3	$	Expensive saplings
Wall Farm	Hydroponics	LED	+++	+++	51	$$$$	Expensive saplings
Tower Garden	Aeroponics	-	+++	++	20	$$$	No artificial lighting
Plantui 6	Hydroponics	LED	+	+	6	$$	
Aquasprouts Garden	Aquaponics	FL	++	++	20	$$	Requires fish
Volksgarden	Hydroponics	FL	+++	++++	80	$$$$$	Enourmous size, raw aesthetics

Figure 8 Some of the market competitor products.

Even though only nine products have been looked at in this particular situation, a clear tendency can be seen in use of hydroponics and LED lights. Reason behind this may be relative ease of implementation of hydroponics for smaller, house-context products which do not even necessarily require a pump to run. LED lights are most likely so frequently chosen due to their efficiency and availability in many different colors and spectrums, not to mention ones that can be adjusted on the fly. Majority of the products are dimensioned to fit on the desk, however while they make it possible and easier to grow crops indoors, most do so in a single level.

While some companies are selling you products that allow you to grow things at home, others (such as plantui and ClickAndGrow) are selling a platform, which forces you to continuously purchase non-reusable seeds, holders, nutrients and plugs from them (Fig9), often at a high price. This might be a good business model that ensures a steady flow of revenue, however ethical standing of it can be argued.

Figure 9 Plantui seed and nutrient package, costs 50 DKK.

CONCEPT DEVELOPMENT PHASE

Pains.

The following are some of the most common pains that indoor growers face and the ones that the product should relieve:

Pain.	Why is it a pain?
Plants require watering.	Some people tend to forget to water the plants or are unable to do so if out traveling.
Using sunlight as a light source.	Not all homes have windows that are facing sunlight for the majority of the day. Some people are forced to move their plants from one room to another daily, to ensure that plant gets adequate amount of light.
Using soil as growing medium.	In order to have a growing medium and nutrients, people need to purchase fertilized plant soil, which is usually sold in large packages, often too much for a few potted plants. Soil is also messy to handle.
Some plants require replanting.	Certain plants need to germinate and sprout in certain medium, after which they need to be replanted in larger pots for growing.
Reusing soil for plants.	Once a plant has been fully harvested or is no longer needed, people either need to throw out the entire contents of the pot, incl. soil, or remove the plant matter and keep the soil for the next one. In such a case, the nutritional value of the soil has been lowered by previous plant.

Knowing these pains will help establish requirements for the product.

Product requirements.

The requirements for the product, as mentioned in the mission and derived from pains, are the following:

1 The product allows to grow crops soil-free.

2 The product is for home-use.

3 The product does not require any special facilities or conditions at home.

4 The product must utilize more area for crops than the product's own footprint.

5 The crops grown with the product do not need to be subjected to pesticides.

6 The product must not be complicated to set up and use.

7 The product must provide crops with conditions that increase growth speed or volume in order to be competitive.

In order to satisfy requirement 3, the product needs to provide artificial light for the plant to grow. Out of previously presented most common grow lights (LED, HID, FL), LED has been chosen for following reasons:

- High efficiency and low heat output compared to HID and FL lights.
- Low price per diode.
- Possibility to create rows of diodes of any lengths, not being limited by premanufactured bulb lengths of HID and FL.
- Tri-colored LEDs can change the color spectrum on the fly, which is useful for different stages of growth and different plants.
- Red and Blue LED light is not only most used by plants, but conveniently is also most energy efficient in LEDs[52].
- LED lights do not require a ballast to regulate the voltage input, unlike HID lights.

8 The product must use tri-colored LED lights to provide artificial growth light to the crops.

For the growing medium, Rockwool is chosen for several reasons:

- Rockwool has great properties for a growing medium which is the reason why it is most commonly used.
- It is possible to manufacture pH-neutral Rockwool and pre-pack it with nutrients that fresh sprouts need to begin growing.
- Rockwool is not loose, which makes it less messy to fill up the pots.
- Selling specially manufactured medium cubes can become an additional source of revenue.

9 The product will use Rockwool as a growing medium.

The three concepts.

By using the knowledge from the research phase and combining it with the observations and data from competitors, trend analysis, mission and requirements, an ideation process has been performed. Different possible solutions have been explored (Fig10), ranging from smaller, individual plant pots to kitchen appliance-looking ones.

After evaluation, the selection was narrowed-down to the following 3 concepts to be looked at in finer detail and evaluated based on pros and cons as well as certain parameters. They have been given temporary names that reflect the basic geometry of the product: boxes, wheel and tower. Please note that neither the sketches nor the 3d prints are in-scale or reflect correct proportions.

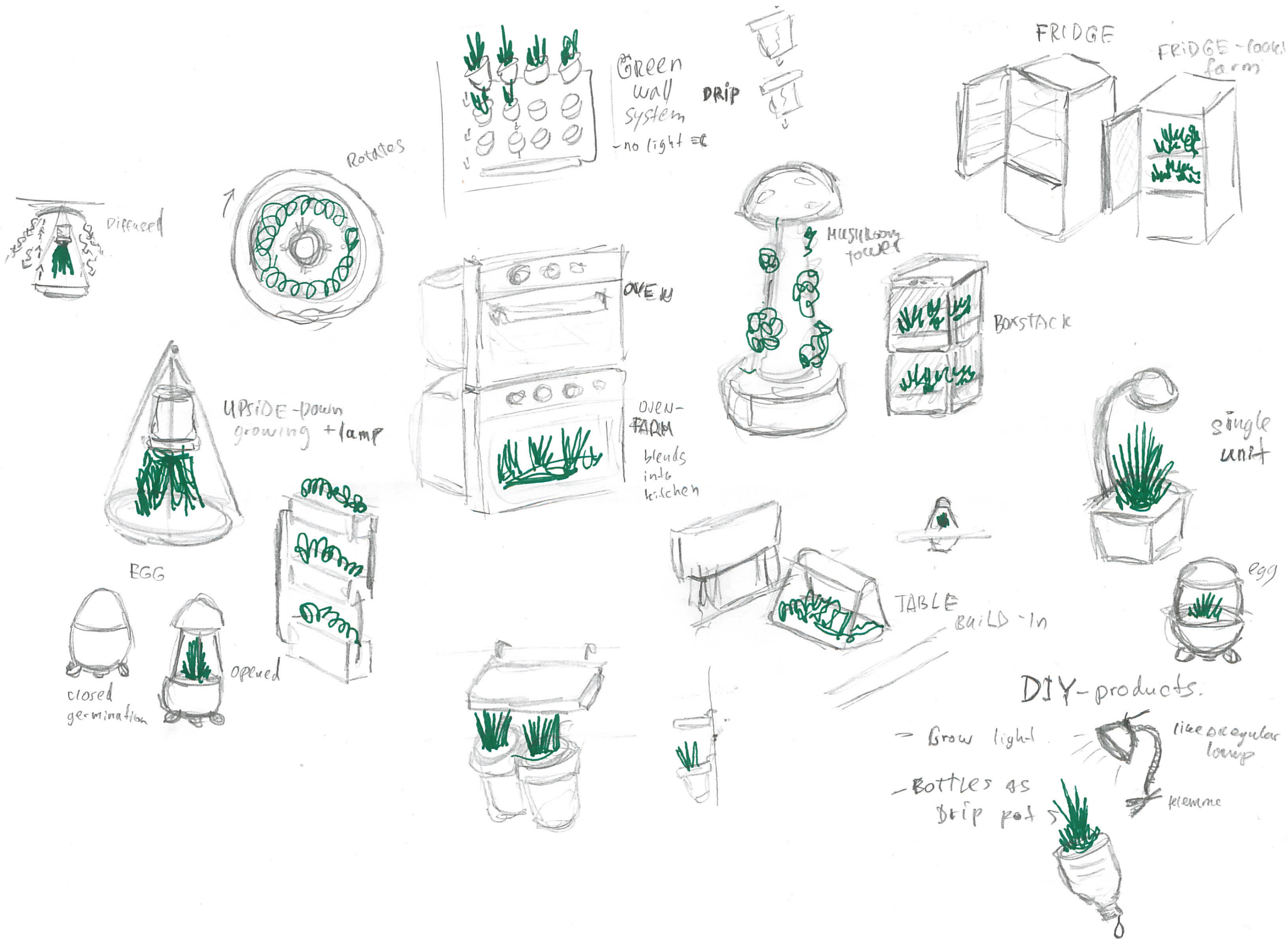


Figure 10: Various concepts from ideation.

Concept I - Boxes.

"Boxes" (Fig11) is a vertical-surface-mounted modular concept that utilizes hydroponic nutrient film technique (NFT) to deliver water and nutrients to the plants. The bottom box houses a pump, which pumps the water to the topmost box via a hose. Inside the top box, the water is spread along the angled bottom, running down to the next hose, which will transport it to the box bellow, where the same will happen. The water will continue until it reaches the bottom box, where the whole process will repeat. This concept allows users to stack an even number of boxes on top of each other, having them all interconnected. The light is provided to the plants from LED lights that are affixed to the bottom of the boxes and on a special mount for the top one.

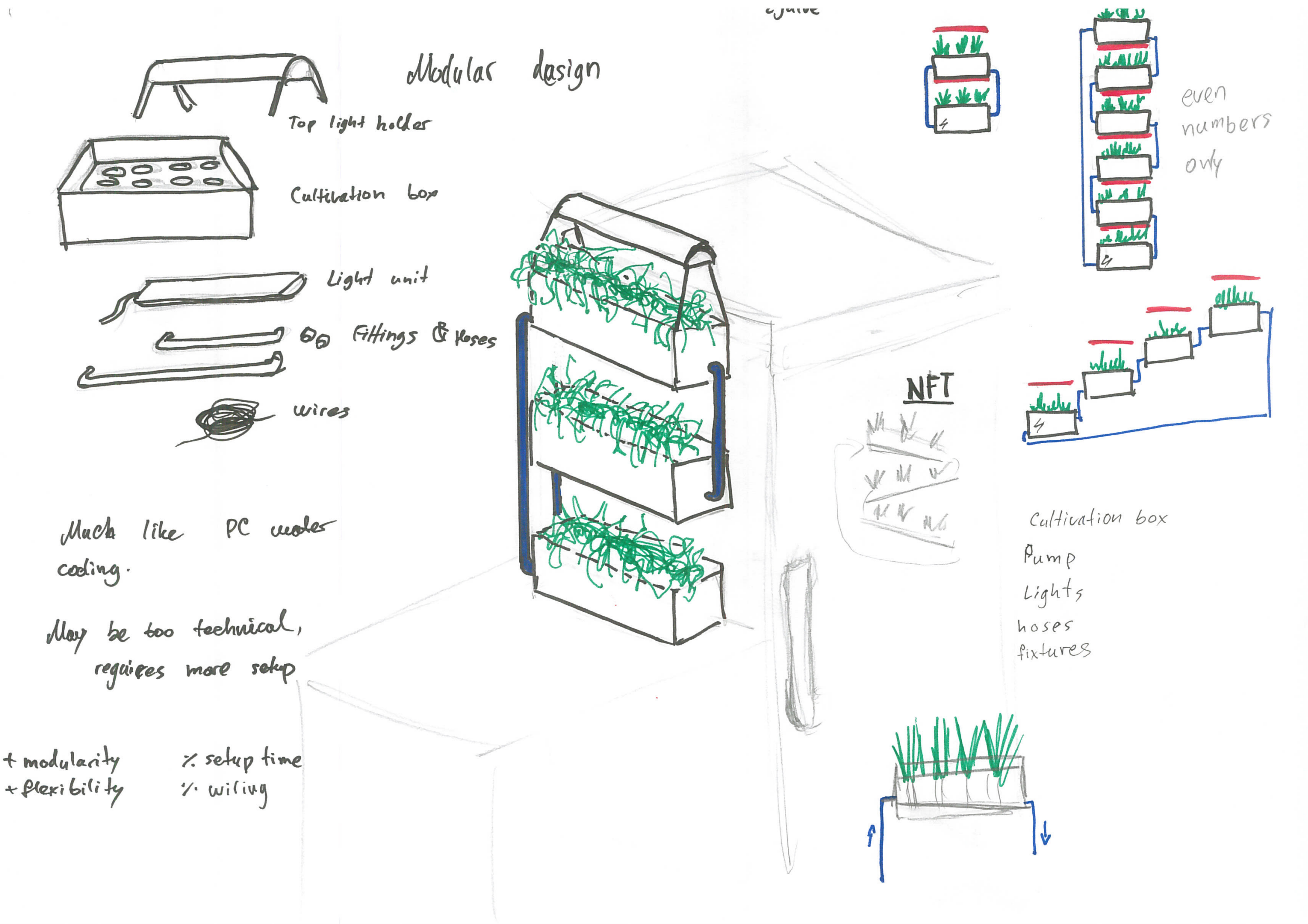


Figure 11: Boxes concept.

The modularity of this concept is both its strength and weakness. While it allows users to build their indoor vertical farm in variety of ways and heights, it still needs to be assembled using the different modules, fittings, hoses and wires. The process itself may resemble installation of a water cooler in one's desktop computer – a process that is tedious and difficult, requiring tests to make sure no leaks are present. Given the target group, it is unlikely that most of them will possess the knowledge, skills and patience to complete such a setup.

Concept II - Wheel.

The "Wheel" (Fig12) concept is inspired by Omega gardens' Volksgarden product. In the center of the wheel, a 360° LED light array is placed. On the rim, interconnected pots slowly move around with the help of a motor, being equally exposed to the light's radiance. In the bottom, nutrient water is lying dormant, while the bypassing roots and growth medium absorb and retain it on their way around.

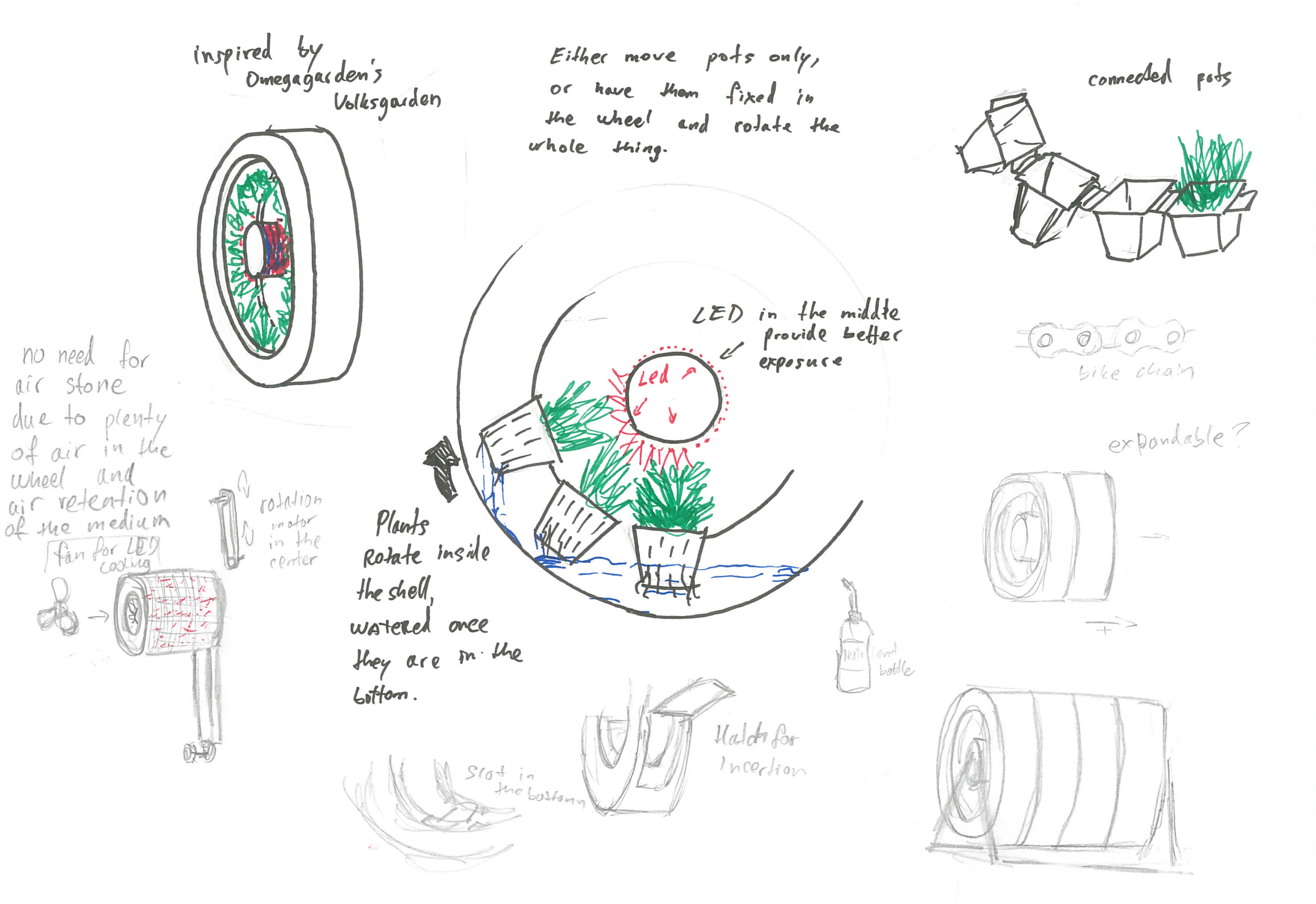


Figure 12: Wheel concept.

The main benefit on this concept is that it would actually increase crop growth thanks to the rotational system. In comparison to the Boxes concept, however, this one provides less harvestable area per footprint area. This concept uses technologies that are patented by Omega Gardens. The wheel is either vertical-surface-mounted, or could use a stand.

Concept III - Tower.

"Tower" (Fig13) is inspired by Tower Garden Growth System and is essentially an improved version of it. The Tower Garden Growth System has a water tank in the bottom and a pump that pumps it to the top. In the top, the water is allowed to fall down, touching the roots on the way. The patent filed by the company actually displays the chamber filled with loose growing medium, where the excess water would come down. The Tower concept of this project is similar, features a bottom tank with a pump, and is modular, allowing the users to decide the height of the unit. It does, however use aeroponics with nozzles placed directly opposite of the plant pots, spraying fine nutrients directly to the roots and medium. The excess water flows down for reuse. The LED grow lights are affixed in the top dish module, providing light from above, and also directly on the wall above every plant slot. This way, plants get plenty of light, but will tend to grow towards the center, thusly not overgrowing outward.

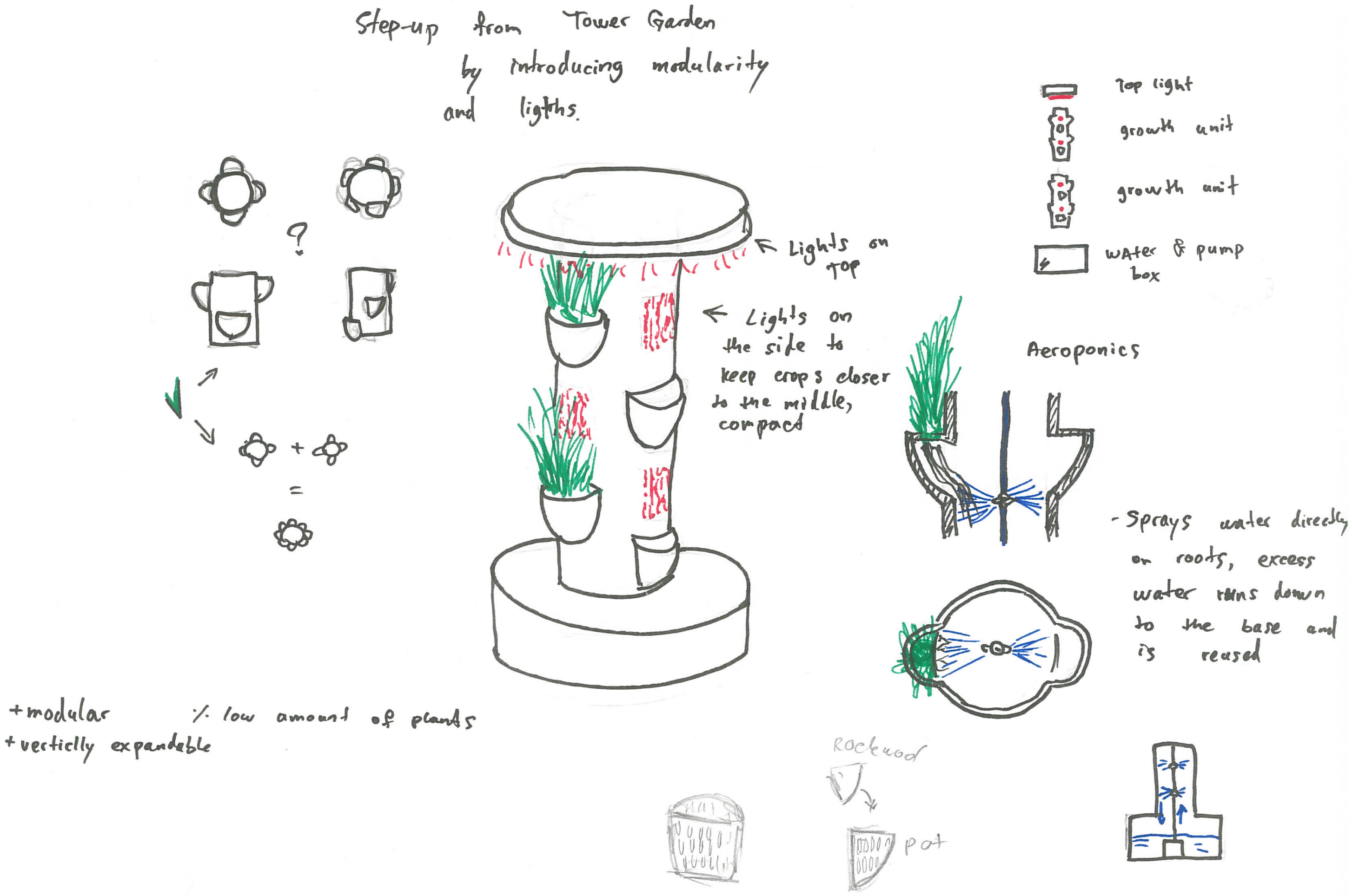


Figure 13: Tower concept.

Once again, modularity allows for some basic product customization. The wall light setup allows the plants to grow lush, yet compact. The roots get a lot of air in this concept thanks to aeroponic technology. However, the efficiency of top lighting is questionable once the plants begin to grow out as well as if many vertical modules are used. Eventually, the top plants will completely obscure the light for the bottom ones. A way to reduce that risk would be introduction of tapered modules, but that lowers the benefit of having uniform modules in manufacturing aspect.

Selection process.

Six key rating parameters were setup in accordance with the requirements as well as pros and cons of each concept. Only parameters, quality of which varied between the concepts were considered. For instance, things such as nutrition delivery might vary by technique between the concepts, but is equally efficient (Fig14). This method has been used by multimember project groups in earlier ID semesters and got to be called pointmocracy – a combination of point and democracy. Group members would rate different parameters on a scale from 0 to 5, and the final sum would show the concept that had most potential according to the group members' evaluation.

	Box	Wheel	Tower
I - Degree of modularity	3	1	2
II - Plants per foot area	3	2	2
III - Ease of setup	1	3	2
IV - Equal light exposure	2	3	1
V - Growth increase	1	3	1
VI - Mechanical non-complexity	2	1	2
Sum	12	13	10

Ratings: 1 - BAD/LOW, 2 - OK/MEDIUM, 3 - GOOD/HIGH

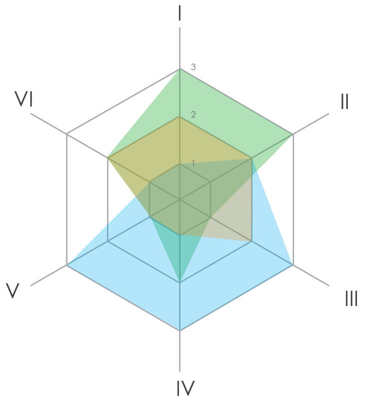


Figure 14: Parameter rating on the three concepts.

According to this simple method, the wheel concept is superior by those six parameters. Degree of modularity is not a part of the requirements, but rather a "nice to have" feature, while the other four are required.

POST-STATUS II

The progress was presented to co-students and other supervisors at the second Status Seminar. The feedback received was mostly targeted towards the target group and a seeming lack of a concrete, defined direction. That was indeed correct and therefore, target group has been re-evaluated and redefined in accordance with the feedback received. A more narrow and specific target group would help the project to narrow in on a specific solution.

Target group adjustment.

The new target group are the tech-savvy, nerdy people. Those, who embrace and enjoy technology and are not afraid of change. Those people, who enjoy tweaking things to their liking, in attempts to achieve improved results from whatever they put their hands to (Fig15).

Figure 15 Linus Sebastian - a tech reviewer and a perfect example of the new target group.

A new intend for the product is to have sort of a double purpose. While the original purpose remains (the product being used to hydroponically grow organic produce at home), a second one has been established: to allow tech-savvy users to customize and tweak different factors and parameters of the product's environmental controls and other functions. Thusly, users can experiment with different settings themselves and discover perfect optimizations that they can either share with each other or use to compete in who can get better harvest in shorter time. These opportunities can satisfy user's natural competitive or cooperative desires all the while remaining productive and practical.

To better understand what the users prefer and look for in the products, a moodboard has been set together with things common for the target group: 3d printers, custom built PCs, drones, custom electronics, etc. (Fig16)

Figure 16: Moodboard.

Feature delimination & New requirements.

In order to get the most out of the tweaking feature, it is necessary to have several things that can be adjusted and controlled. Earlier in the report, nine main parameters for plant growth have been listed. Water itself does not need to be controlled; it needs to merely be present. Lights, however can be controlled in the spectrum and uptime to find most optimal conditions. While nutrients can technically be controlled and optimized for better balance, doing so is relatively difficult, as some of the elements required need to be dissolved in extremely miniscule quantities, down to 0.01 parts-per-million. Some parameters, such as CO^2, humidity and plant-zone temperatures are co-dependent and require a closed environment to control and sustain efficiently.

There is a great difference in how easy or difficult it is to control those parameters and what equipment is required. CO^2 and humidity provide the biggest technological challenges. While there are products in existence to control these things, a question of benefit versus cost comes up. CO^2 control is possible with CO^2 injection into the environment, either by artificial means (gas tanks/capsules) or by incorporating mycelium (non-fruiting mushrooms) that produce CO^2 as a part of their metabolism. However in order to process higher amounts of CO^2, the plants will require more photons from the lights, which in return affects the temperature. Keeping CO^2 contained in the plant space would require a sealed encasement, which is also true for humidity and temperature sustaining.

The more features that are incorporated in the product, especially electronic ones, the bigger the risk of something breaking or malfunctioning. Because of that, delimitation is necessary, in order to deselect the features that are deemed either unnecessary or too complex to implement given the timeframe. Based on arguments provided previously, a decision has been made to not implement controls for temperature, humidity and CO^2 levels in the product. These controls can either be developed later as an addon/expansion of the product or as a separate, more complex one, making the currently developing product into an entry-level one for home growers.

Based on all the things mentioned above, the following requirements have been added:

10 The product should allow users to tweak light settings for different spectrum and uptime.

11 The product should allow users to use whichever liquid nutrient solution they want.

12 If the product has other controllable parameters, the users should be allowed to tweak them.

Target group representatives.

Two people who fall under the parameters of the target group were selected for interviews and feedback. These two people were introduced to the idea and intended features of the concepts and offered different perspectives on the concept. They were also asked to rate how important different parameters or features of the product are for them, to help better understand what target group would value in a product like this (Fig17, Fig18).

Rep. 1 - Tech-savvy.

Matthias Walet is a 26 years old accounting student from Netherlands. Matthias has a lot of interest in modern technologies, 3d printers and NASA space tech research. He has recently assembled a custom desktop PC and have been pushing it to the limits with overclocking to get best possible performance. He had the following to say about the idea of the concepts:

"I personally think advancement of technologies used for growing food is both important and required in today's world. Emphasis on responsible usage of natural resources, the omission of potentially harmful pesticides and other toxic substances, and the desire to augment the natural cycle of growth will be the future of agriculture. Bringing these advancements to a consumer market will help make the concept of homegrown produce more attainable for urban residents, and help provide the capital necessary for more rapid future advancements in this sector. I would be eager to try such a product for myself as I have been researching with interest the potential for growing my own food ever since I moved into my new apartment. This product would provide me with the most effective way to do so considering my limited space for more customary agricultural pursuits."

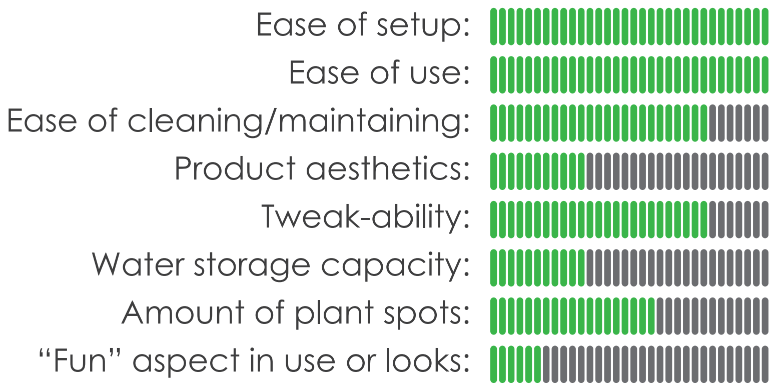


Figure 17: Matthias' ranking of features/parameters.

Rep. 2 - Cook.

Kenny Andersson is 27 years old cook from Sweden. Kenny loves cooking exotic dishes and always tries to explore and experiment with new recipes. He already grows hot peppers and herbs at home, in conventional potted method. He has not considered soilless growing before, but is interested in the idea.

"As a cook, I think such a product would be good, as it eliminates the need for sunlight which can be a rare commodity in these Northern parts of Europe, plus if it grows the herbs faster than doing it the regular way, it would means you could, for instance have fresh sage all year around without having to worry about it only being a seasonal product. I'd personally be striving to get one at home which would mean I won't need to worry about what herbs the local stores have in stock. Despite it being a piece of technology, I wouldn't be scared from using it as a kitchen is full of technology, albeit not as modern and high tech as in laboratories and the like, but still quite a fair few things."

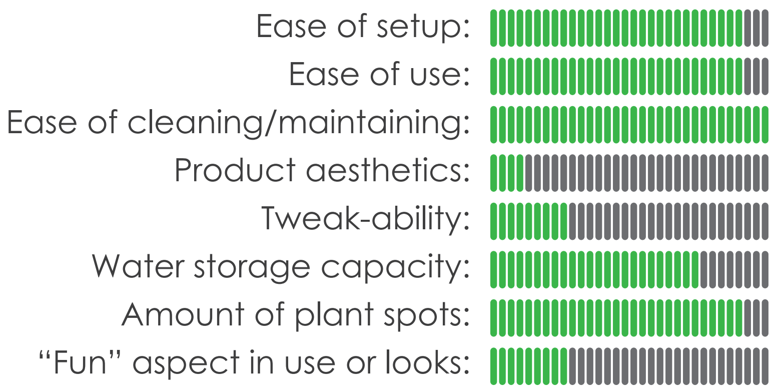


Figure 18: Kenny's ranking of features/parameters.

Selection process II.

Two new parameters were added to the selection table (Fig19) as a result of the Status II: "tweakability" – the relative amount of different parameters that can be tweaked in the product, and "fun" – how fun the product appears to be for the target group. While "fun" is a very subjective parameter, the reasoning behind rating those concepts was as following: in case of boxes, the fun comes from the fact that they need to be assembled by the user, in the way user desires. For the wheel, the fun comes from its circular design, reminiscent of popular sci-fi space station designs (Fig20). Finally, the tower concept seems to be lacking the whole "fun" aspect that the target group would appreciate

	Box	Wheel	Tower
I - Degree of modularity	3	1	2
II - Plants per foot area	3	2	2
III - Ease of setup	1	3	2
IV - Equal light exposure	2	3	1
V - Growth increase	1	3	1
VI - Mechanical non-complexity	2	1	2
VII - Tweakability	1	2	1
VIII - Fun	2	2	1
Sum	15	17	12

Ratings: 1 - BAD/LOW, 2 - OK/MEDIUM, 3 - GOOD/HIGH

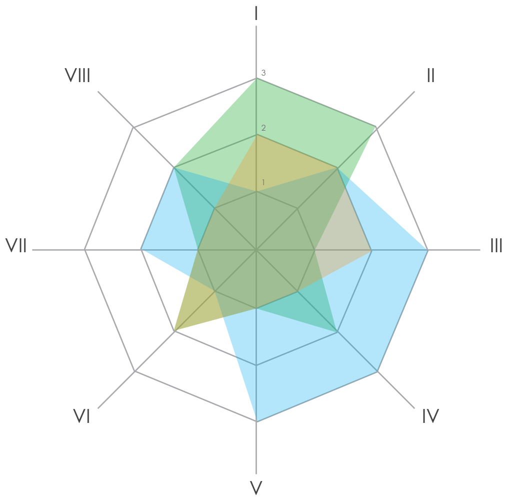


Figure 19: Updated selection table.

Figure 20: Circular sci-fi station design by PJ Dexter.

Even with the new added parameters, the wheel concept still is in the lead as the concept with the most potential and most fitting the requirements. For a final confirmation, Pugh Concept Selection matrix was used to compare the concepts to a well-established market product – the Plantui 6. The concepts were rated on the same parameters as before, however, "plants per foot area" and "tweakability" has been weighted by 2 to highlight the importance of those parameters in the upcoming product (Fig21).

	Weight	Datum	Boxes	Wheel	Tower
I - Degree of modularity	1	Plantui 6	+	S	+
II - Plants per foot area	2		+	+	+
III - Ease of setup	1		-	S	-
IV - Equal light exposure	1		S	+	-
V - Growth increase	1		S	+	S
VI - Mechanical non-complexity	1		-	S	-
VII - Tweakability	2		+	+	+
VIII - Fun	1		+	+	S
∑+			4	5	3
∑-			2	0	3
Total Score			2	5	0
Total Score - Weighted			4	7	2

Figure 21: Pugh selection matrix.

This selection process has given the same results: the Wheel concept seems to have more potential than the two others and based on those 2 selection models, the Wheel has been chosen as the main concept for the project. Futher detailing will help shape it as a full product proposal.

DETAILING
PHASE

Product name.

Now that the final concept has been chosen, it was only appropriate to give it a proper name, rather than referring to it simply as "the concept" or "the Wheel". After some brainstorming of different ideas, a name "Pivot" has been chosen for a couple of reasons. First and foremost, the name itself is related to the product, where the plants pivot around the central axis. Secondly, the name reflects some of the pivoting that has been done in the process itself, ever since the initial change of thesis topic.

It was desired to have name present in the logo, or have logo graphically incorporated into the name. Fortunately, the letter O provided such an opportunity. In the logo, the letter O symbolizes the product itself, with a sampling growing inside. The logo went through different iterations in regards to fonts, colors and slogan subtext, some of which can be seen on Fig23.

Green seemed like an obvious choice for a plant-oriented product. However, a different color – blue – was also explored, due its symbolization of creativeness, intelligence, trust, security and relaxation. However after some considerations, green has been chosen instead, not only as an obvious "natural" choice, but also for representing health, growth, safety, and emotional positivity[54].

For the slogan, something short and to the point was needed. Slogans of different similar products/companies were explored for inspiration. The original slogan was set to be "Fresh crops – your way". However, this was deemed to be too similar to Plantui's slogan "Fresh herbs. Zero Effort". Therefore, the first part was changed to "Home growing" instead, while the ending remained unchanged. In case of Pivot, the "your way" bespeaks the fact that the user can customize the growing process to their liking, if desired.

Dimensioning.

To properly dimension the Pivot, it was necessary to find out the approximate average height of a grown plant of the likes that the users will be growing. As stated in the mission, this project focuses mostly on leafy greens and other high-water crops. Scouring the internet for pages and home farming forums has shown that the following plants are most common among entry-level growers (this is just a short and not a definitive list):

Herbs: Basil, parsley, chives, thyme, sage, rosemary, oregano, coriander, dill, mint, tarragon.

Fruits: Hot peppers, cherry tomatoes

Leafy greens: Kale, lettuce, arugula, spinach, mustard greens, mesclun greens.

It is hard to get an average size of the plant, since at their maximum, some of those can grow to impressive heights, and it depends on the grower, when they wish to stop it. Therefore, choosing how much space the plant needs in the product was a call of approximation. Looking at greens, herbs and salads sold in the Danish supermarkets, it was decided to give the plants 20 cm width and 30 cm height of free growing space in order to reach adequate size while retaining some free space for the light (Fig22).

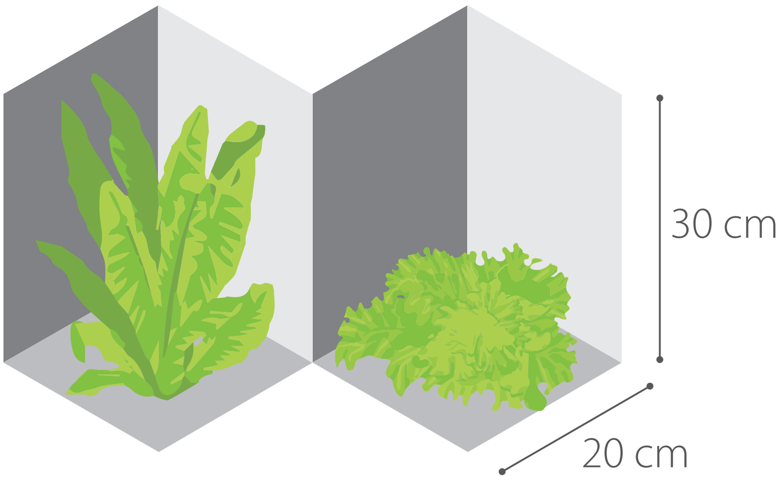


Figure 22: 20x20x30cm growing space.

Figure 23: Some of the logo iterations, bottom one being the final.

When the growing space height was being explored and lights array was being dimensioned, an idea occurred to always keep the light same distance away from the plant, no matter the stage of growth. A system that would expand the diameter of the array to bring the LEDs closer in the early stages, before closing in towards the end of the growth. In order to keep full expose at all times, a second layer would have to be implemented so that it could shine through the gaps of the first one, when it is expanded (Fig24).

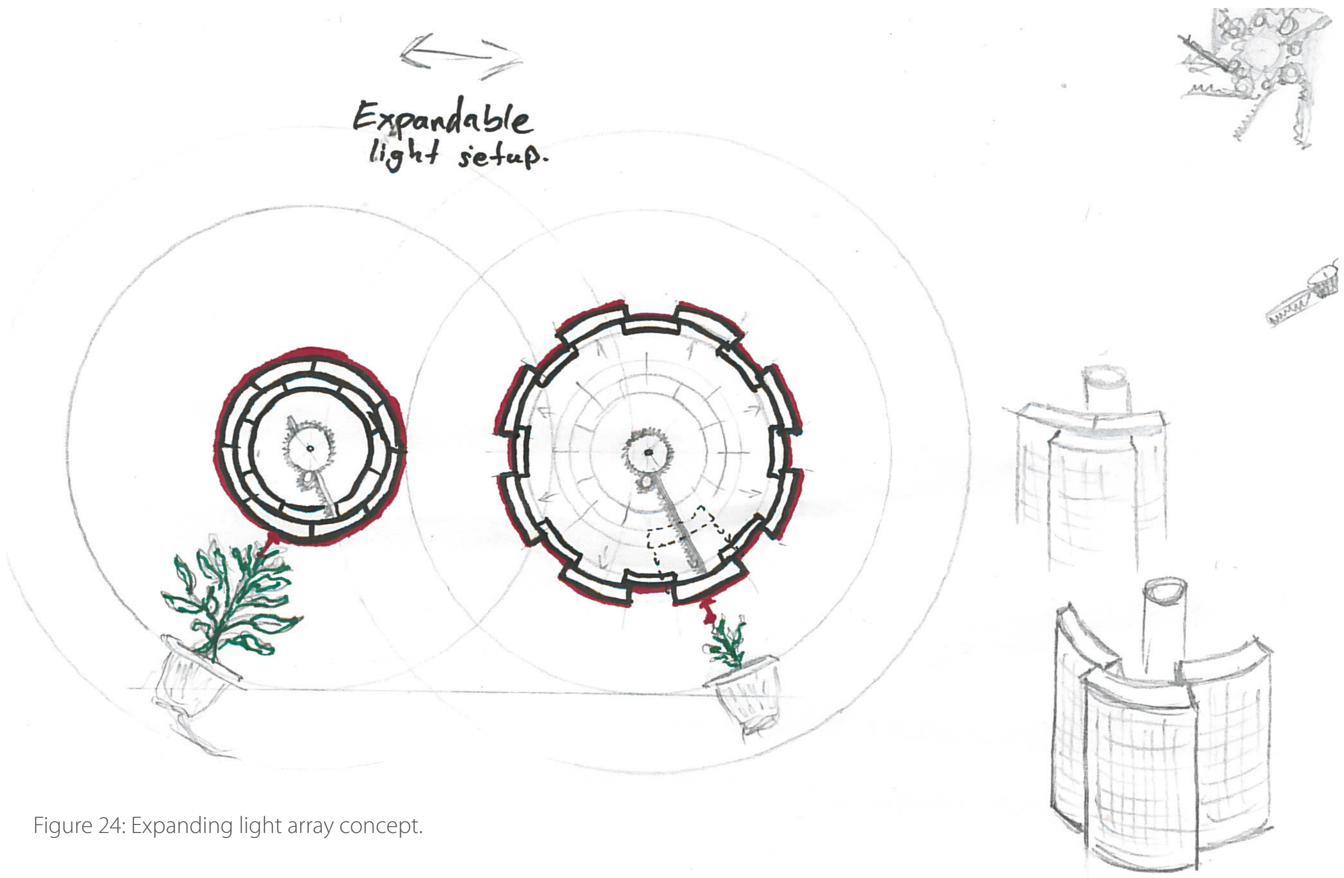


Figure 24: Expanding light array concept.

This idea has been scrapped in favor of regular, static light array, because it would add mechanical complexity and thusly more failure risk elements. It would also require a mechanism that could expand elements individually rather than all at the same time, in case the user grows a mix of plants with different growth speeds or plants at different periods.

For the size of the Pivot round frame, it has been dimensioned to 8 cm. The Rockwool medium itself is set to be 5 cm tall. The purpose of the medium is to hold the seed in the early stages and provide a moist environment for the roots. The roots themselves grow out of the medium once they reach certain length (Fig25). Therefore, bigger rockwool cubes are not necessary. Since roots behave with positive gravitropism, it is believed that constant rotation and change of point of gravity would keep the roots inside the medium more compact.

Finally, the 3 cm free space between the bottom of the frame and the growth medium will contain the nutrient water in the bottom of the product.

Figure 25: Roots growing out of the medium in a hydroponic setup (own experiment).

The light array is set to be 10 cm in diameter, which provides some space in the center, should LED cooling or overall ventilation be necessary to implement (Fig26).

A simple 1:1 scale mock-up was created in cardboard to get a better feeling for the size (Fig27). It was definitely a large and massive product, but certainly is not the only product with such large dimensions that some households have. Thanks to the autonomous work principle of Pivot, it does not have to be displayed openly and could have its place in the pantry or scullery. Or, if a fun and interesting design can be achieved, it could take a more visible place in a house, much like an aquarium does.

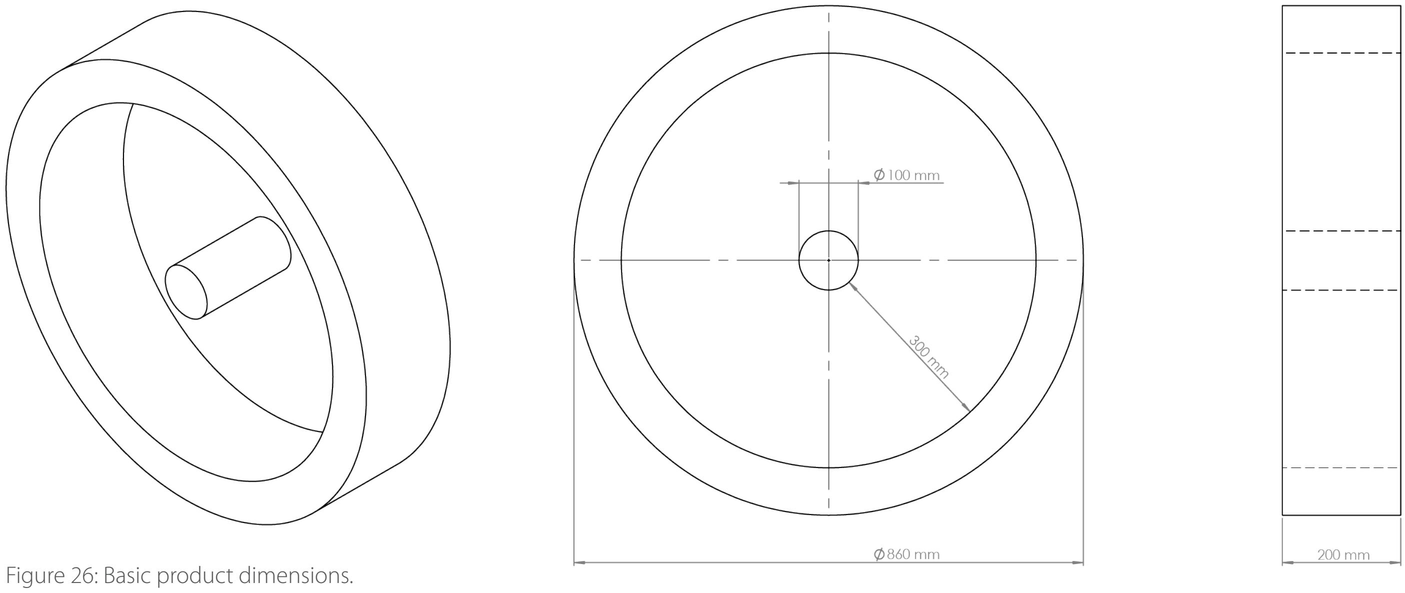


Figure 26: Basic product dimensions.

Figure 27: 1:1 Scale simple size mockup.

Inner belt.

Back in the concept developing phase, the idea behind Pivot's inner belt was that you could take it out, unlink a segment and lay it flat on the table, for easier picking or to use it for germination before installing it into the frame (Fig28). Once again, due to the fact that user may plant the plants at different times, the germination support feature was no longer appealing. And in case of unrolling the belt, in its new, defined dimensions, it would be 220 cm long when unrolled, which is a large size that isn't just unhandy, but also requires table or counter space that not all users may have for either short (harvesting) or prolonged (germination) time.

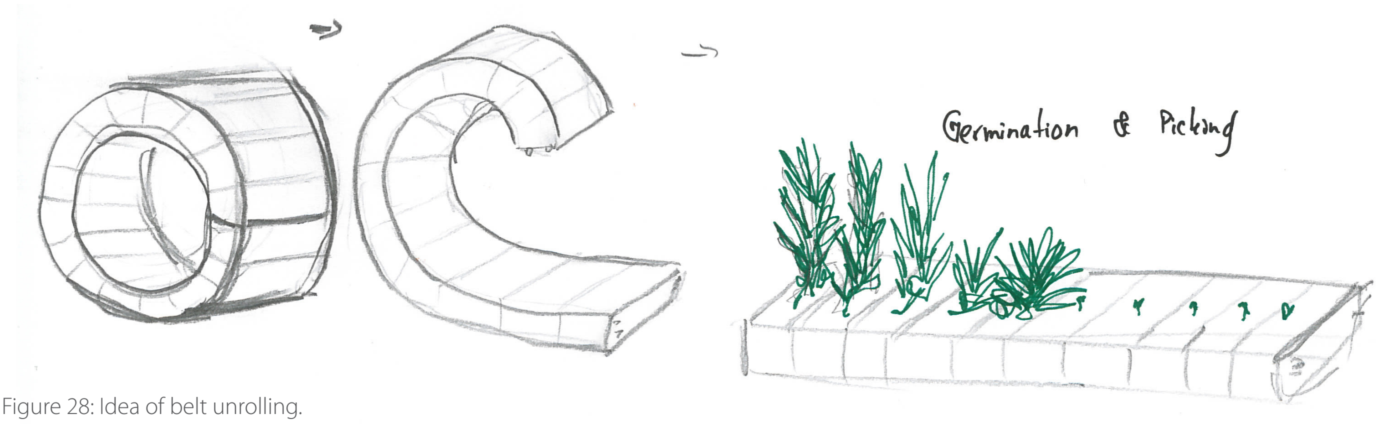


Figure 28: Idea of belt unrolling.

A rigid inner wheel has been chosen instead of unfoldable belt. The function of the wheel is to hold rockwool mediums in place, preventing them from falling out when the plant is upside down. The slots of the belt much contain plenty of holes and openings, so that the roots can come out of the medium, grow past the belt and be able to absorb the water directly, just like on Fig25. This way, the water won't need to have an air stone added either, since roots will be exposed to oxygen when they exit the watering tray. Since it was decided to give each plant 20x20 cm of growing area, the amount of individual plants the product needs to support was calculated and rounded up to be 12:

$$\frac{700mm * p}{200mm} = 10.99 \approx 12$$

Inner elements.

Different variations of internal components setup were explored using Tjalve method (Fig30) . The ideas vary depending on location and size of the elements, but also which elements are included: elements like a pump and water tank are non-essential and are only needed in few of the concepts.

To objectively compare these 9 layouts, a point system was used once again with 3 parameters that differed between those layouts (Fig29).

Based on this simple method, layout 2B seems to be most efficient with its smaller size and mechanical non-complexity, since it does not require a water pump or a belt for rotation, unlike 2A or 3C, despite its much lower water capacity compared to most of the other ones.

	1A	1B	1C	2A	2B	2C	3A	3B	3C
Water capacity	2	2	2	1	1	1	3	2.5	3
Mechanical Non-complexity	1	1	1	2.5	3	3	2	1	1
Size*	2	2.5	2.5	3	3	2.5	1	1	1
Sum	5	5.5	5.5	6.5	**7**	6.5	6	4.5	5

Rated 1-3 incl. halves.
* = Smaller size gets better score than larger one.

Figure 29: Point rating of Tjalve layouts.

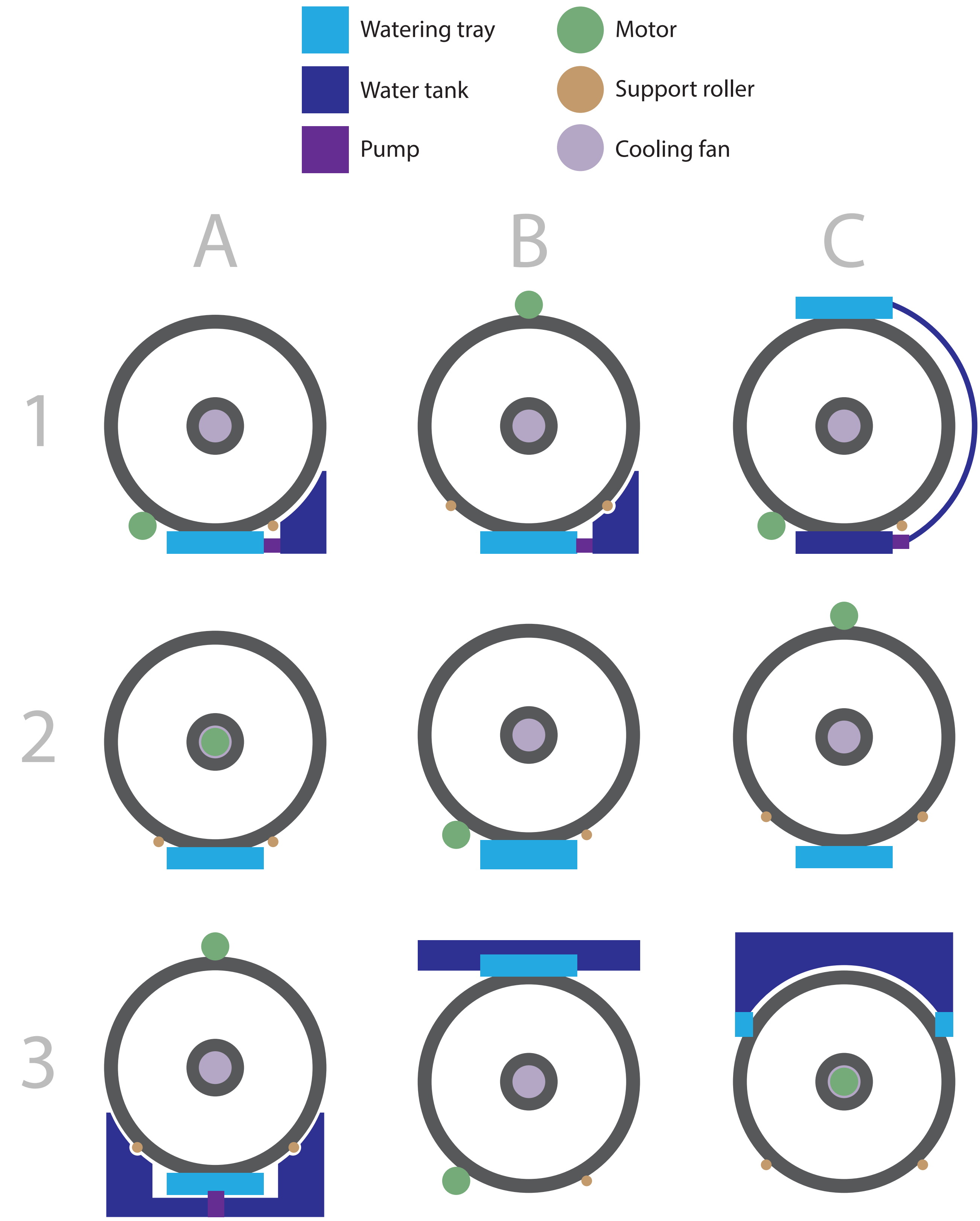


Figure 30: Tjalve method matrix.

Some of the concepts have also been given form in order to explore different possibilities in shaping (Fig31).

Some form concepts, like A and F are designed to hang, while others can either hang or stand.

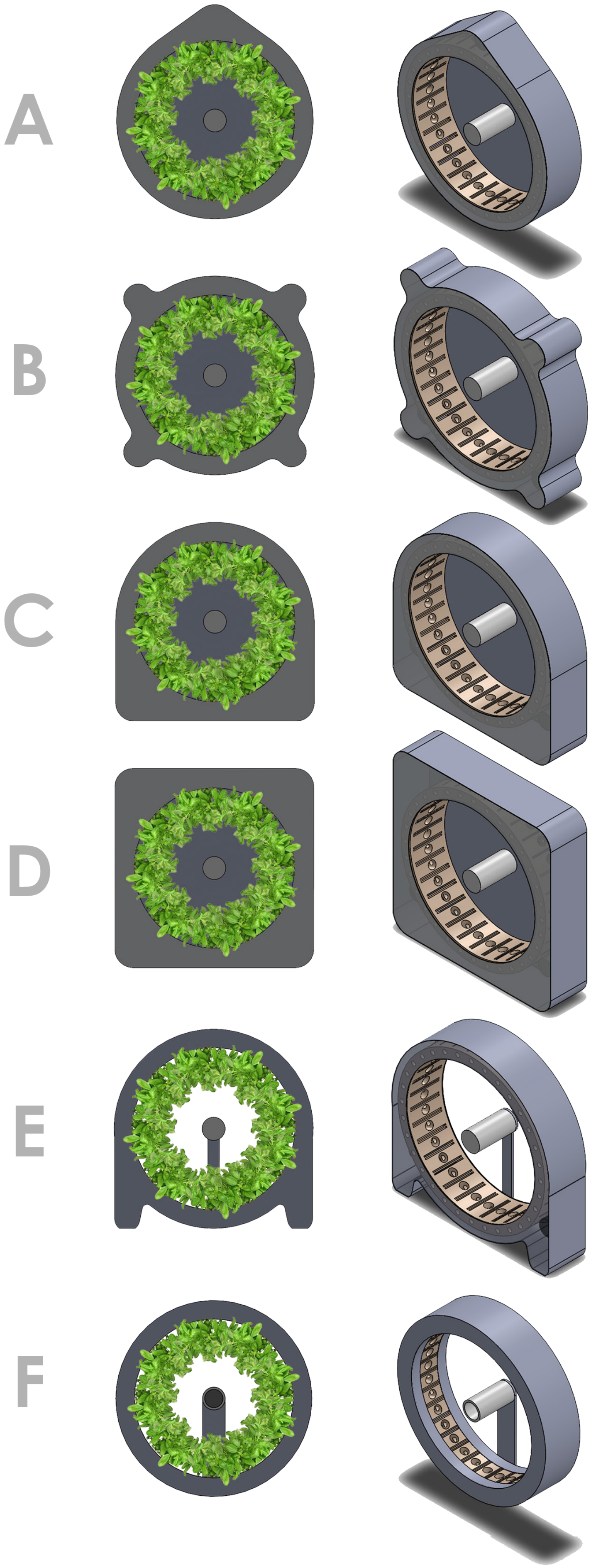


Figure 31: Exploring different form concepts.

All of the potential forms have been carefully considered and evaluated. While it is foolish to base the choice of form on the feedback of just 2 representatives of the target group, since both of them have rated "aesthetics" rather low on the scale, it was decided to take the "form follows function" approach, much like 3d printers or drones.

After placing all the crucial component placeholders in SolidWorks and taking first steps in modeling the essentials, such as the inner wheel, the product has shaped itself up and taken the form similar to form C on figure 31.

Detailing.

The inner functioning of the product are as follows (Fig32):

In the bottom left part, in an isolated compartment, main electronics box is located (1). This box contains the majority of Printed Circuit Boards (PCB) and is where the product connects to power via an IEC port. Wires leave the box, some traveling up to the PMX14-2 stepper motor (2), others along the round rim and up the wire box (3) to the central light and fan assembly (4). The inner wheel rests solely on 4 nylon bearings (Fig33), mounted on stainless steel rods (5). The aforementioned stepper motor (2) rotates the wheel, which has gearing on one of the sides (Fig34).

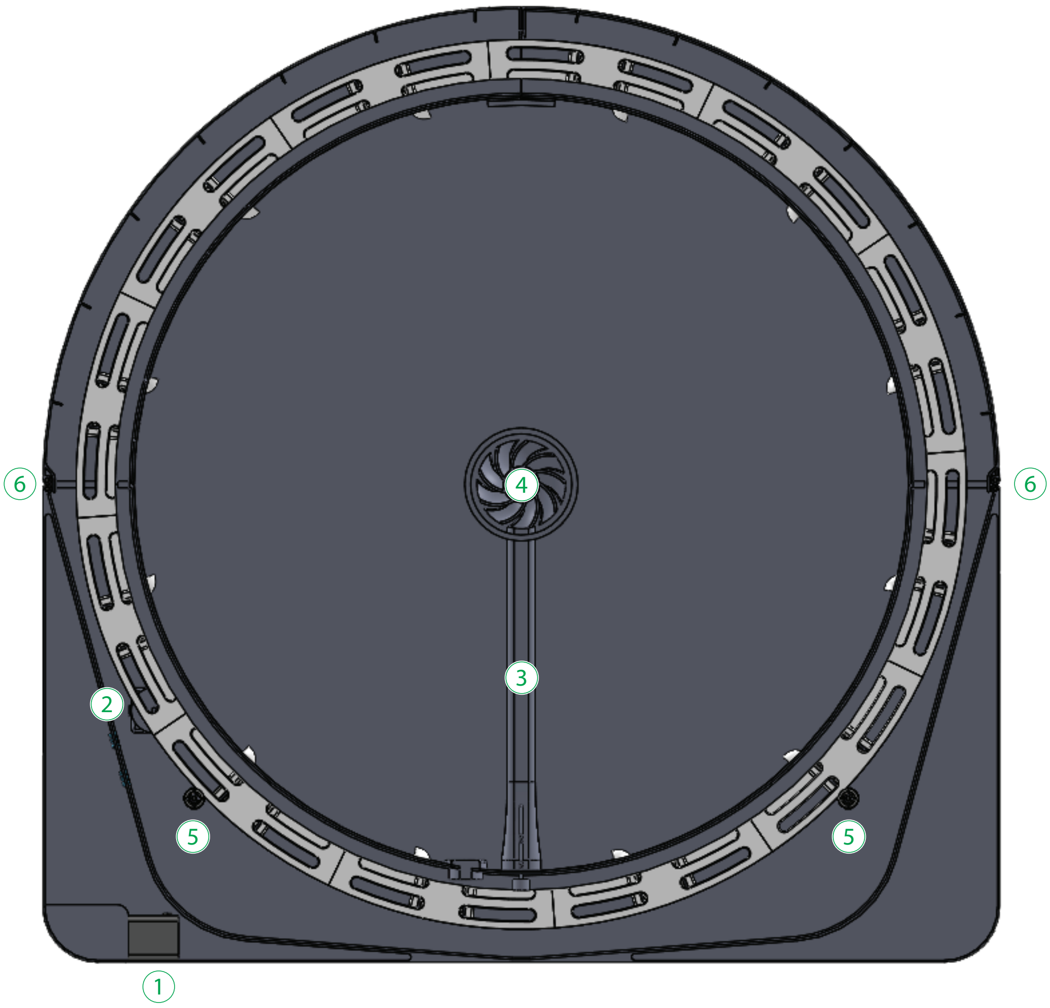


Figure 32: Product cutaway.

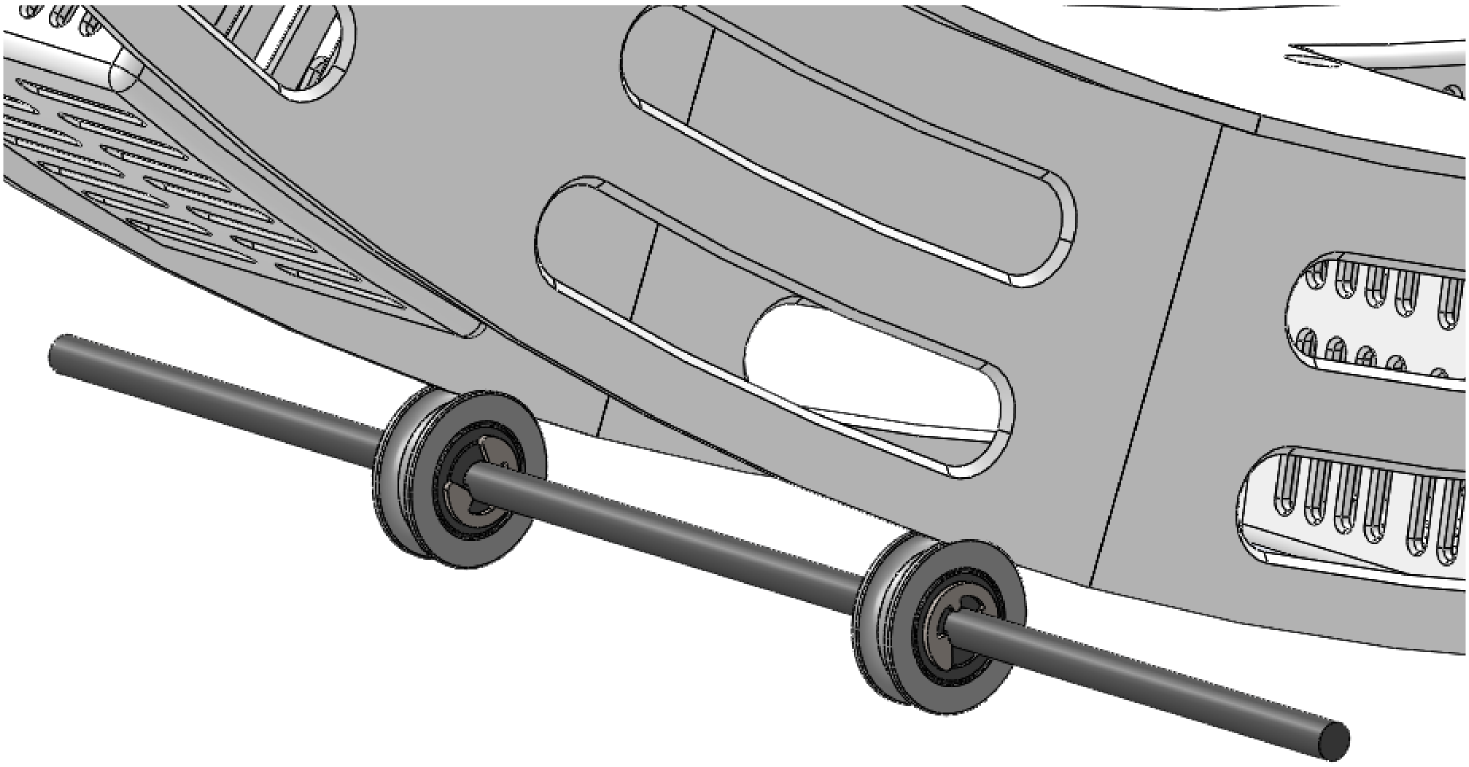


Figure 33: Wheel resting on the roller.

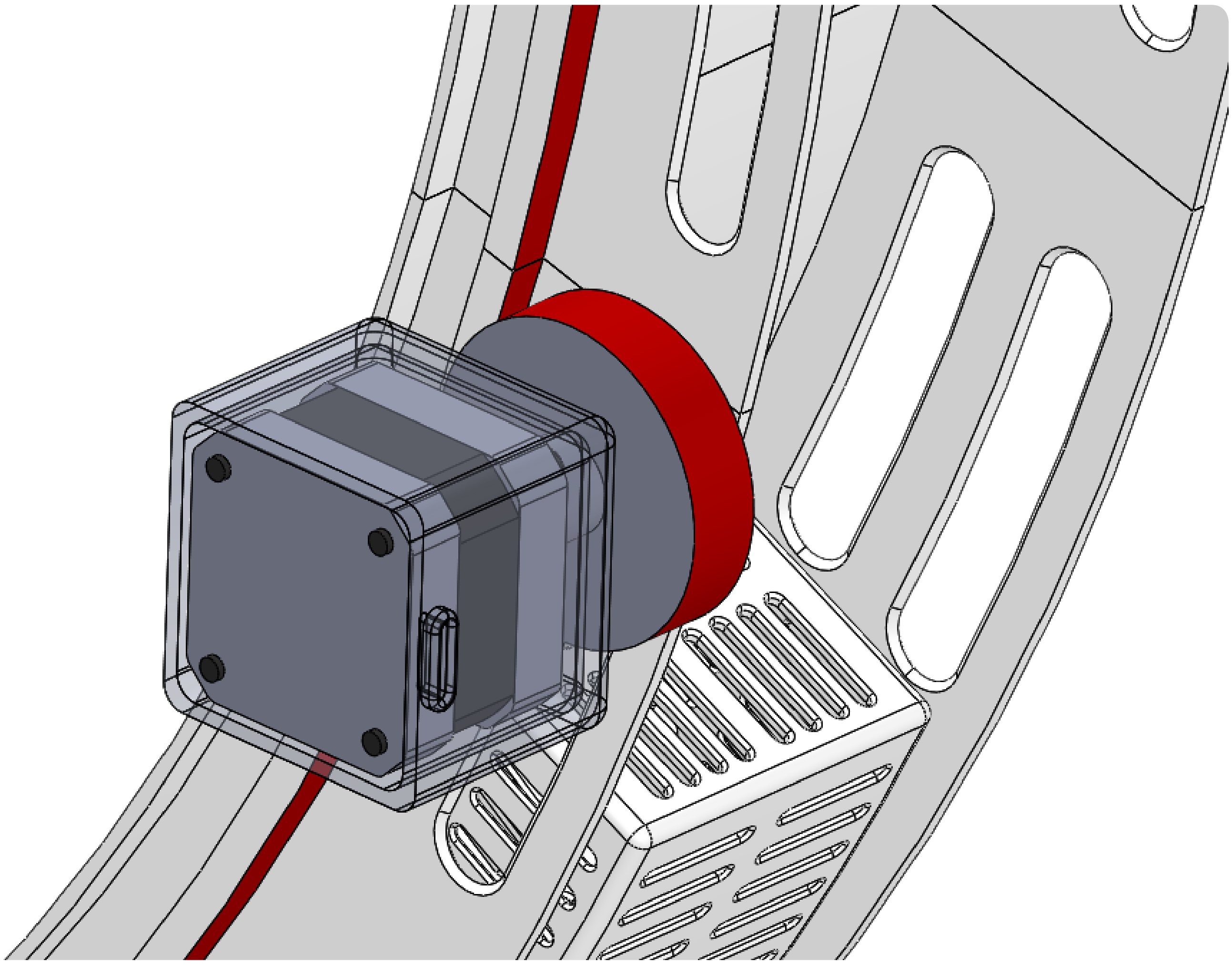


Figure 34: Motor gear and its relation to gearing on the wheel. PLEASE NOTE that red areas represent the pitch circles. No gearing is visibily present on the picture, however they are intended to be present on the product.

Having the wheel resting on the bearings rather than being affixed means that it is much easier to remove it for cleaning purposes. In order for the wheel to be removable, the top part of the product was designed to open up (Fig35), so that the wheel can be lifted up and taken out. Designing the correct hinges for this operation has proved challenging, but solvable. A double-joined hinge system is used to allow the top cover to be flipped 180 degrees while keeping the outside surface of the product relatively unchanged (Fig36) Stainless steel rods are used as axis for all the hinges. The inner side of the top cover features a lip ((6), Fig32) that would allow any excess dripping water from the roots or medium to pass over the joint between the main body and the top, and not leak out.

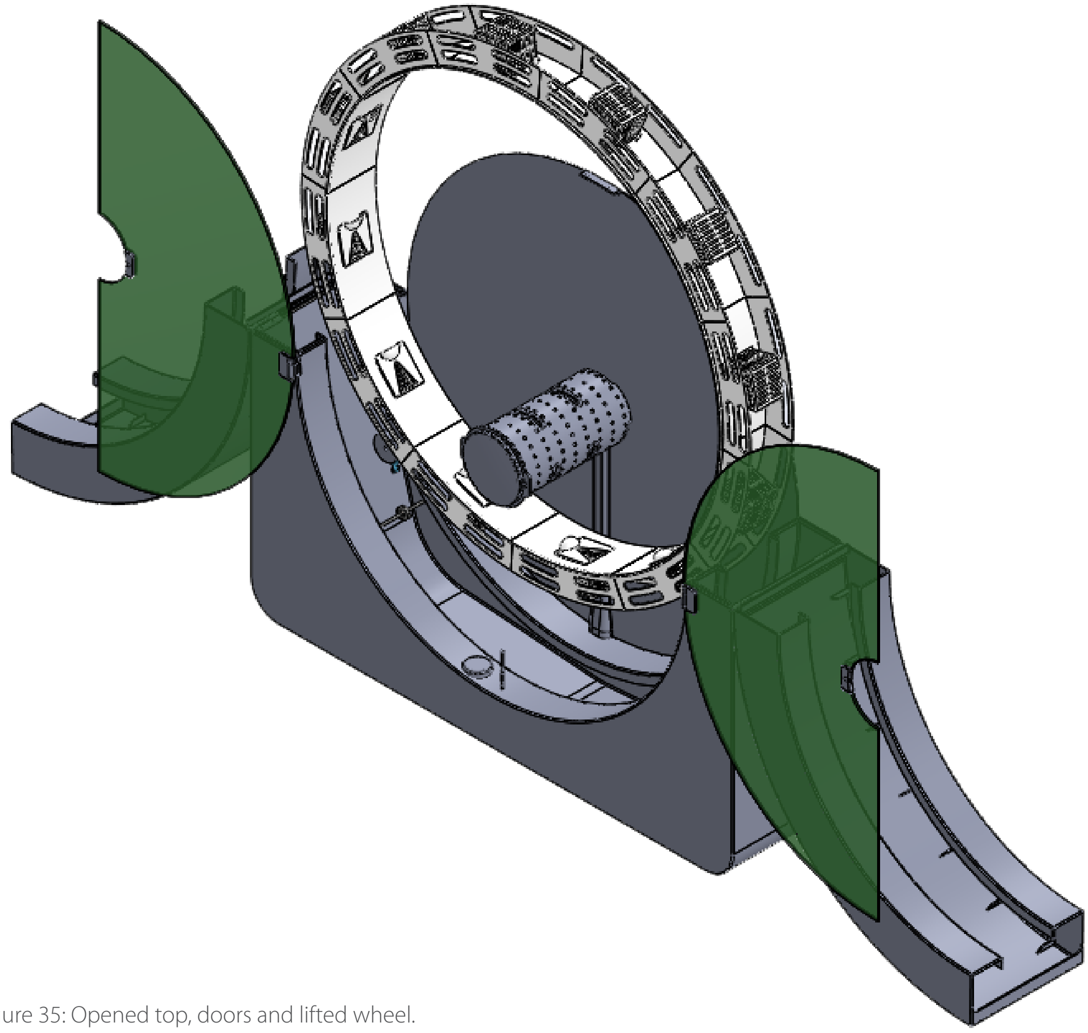


Figure 35: Opened top, doors and lifted wheel.

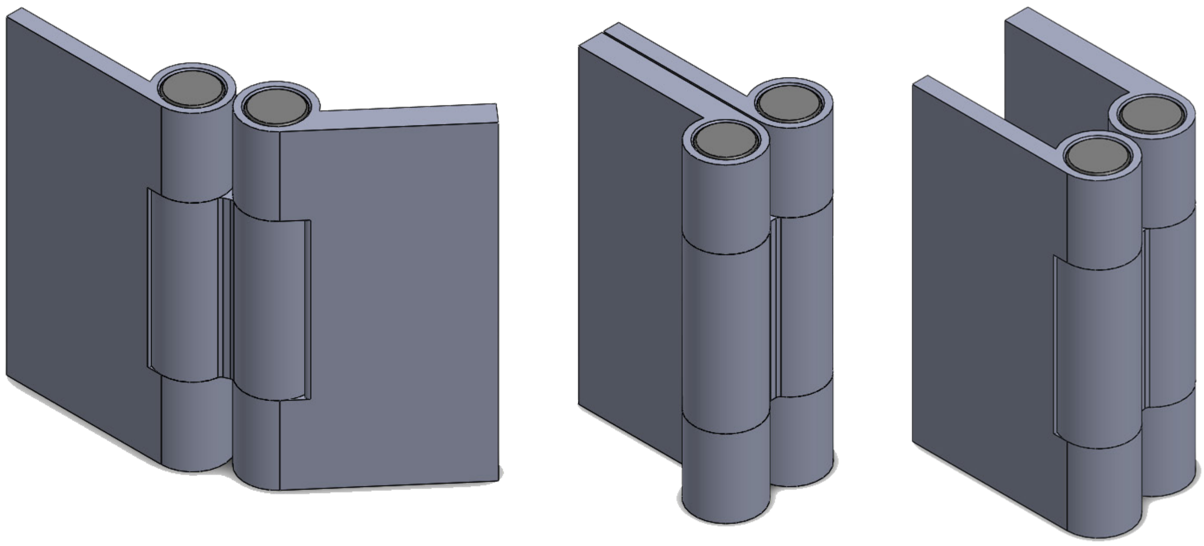


Figure 36: Hinge design.

The wires are supposed to pass between dry and wet compartments and in order to not allow any humidity to enter the dry ones and risk damaging the electronic components, all the compartment wire passes has been sealed with custom silicon wire seals (Fig37). Such a component can easily be outsourced to silicon-specializing company, such as, for instance: *Dongguan Dongrong Silicone Products Co., Ltd.* [55]

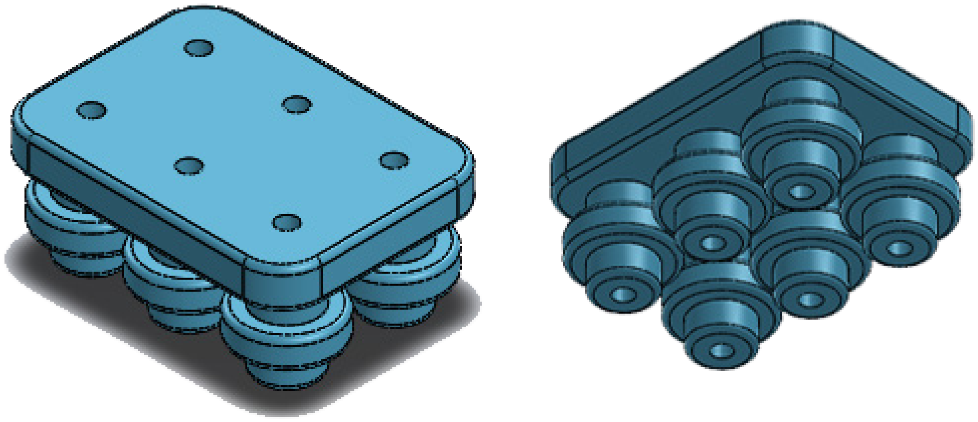


Figure 37: Silicone wire seal.

For the lights, small tricolored SMD LED chips were found that suit the intended purpose. Each product will feature 216 of those, arranged in a circular array (Fig38). The connections of the LEDs are sealed inside the light assembly, to protect against possible humidity. Those LED chips are not custom made, but rather already made and bought in bulk, for instance from *Shenzhen Yuliang Optoelectronic Technology Co., Ltd.* [56]

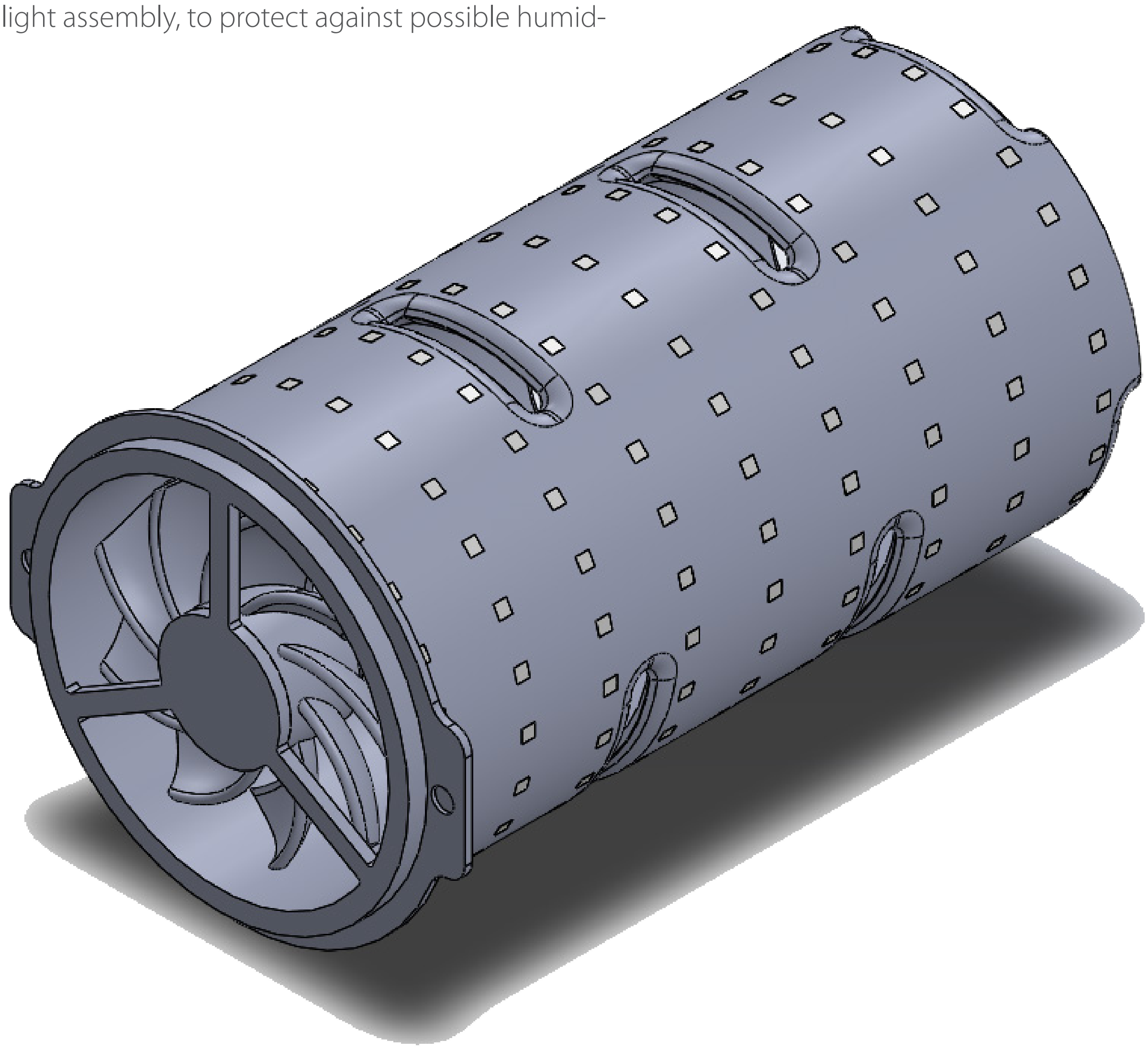


Figure 38: Lights and fan array.

In the light array, 82 mm fan is placed. The purpose of the fan is to cool down the LED lights but also to provide more CO2-rich air into the growing compartment, since lack of it might reduce or even damage the plant growth. The air is pushed out through various other openings and crannies throughout the product.

Having 216 light diodes constantly blasting purple light could sooner or later be a nuisance no matter where in the house the product is placed. Therefore, Pivot comes with green Plexiglas doors (Fig39) which eliminate the pink light and make it bearable to look inside and observe the plants. The doors are mounted with the same type of hinges as the top lid and are kept closed with help of magnets.

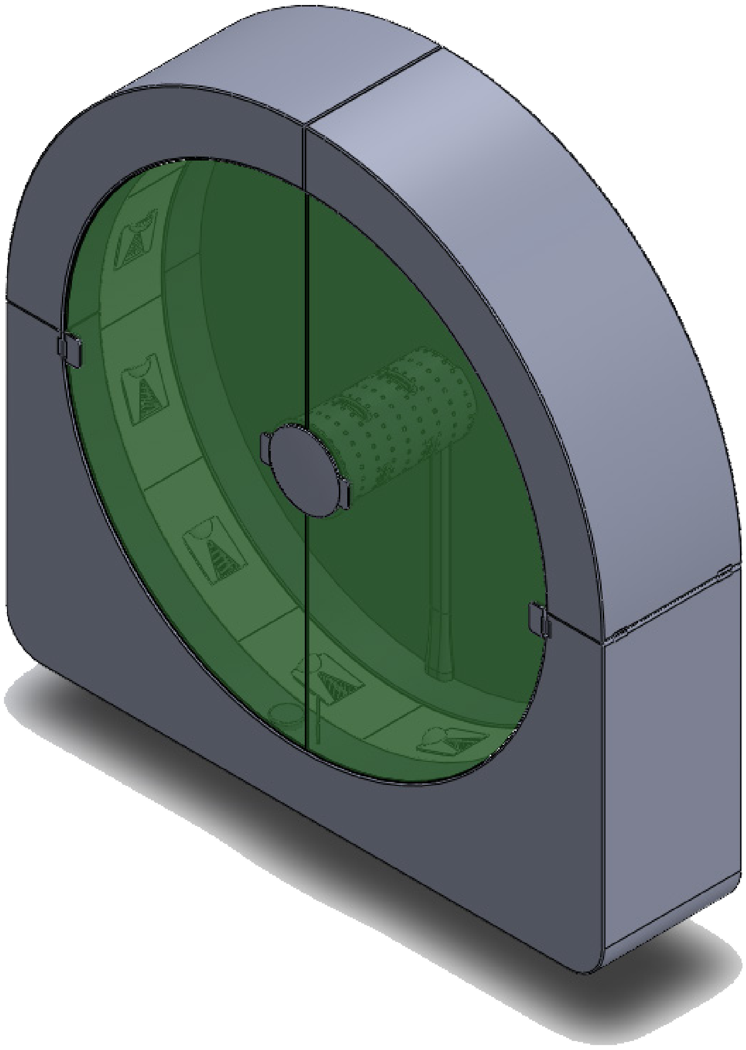


Figure 39: Green plexiglass doors.

For the water meter and water refill, a very simple solution was chosen. The meter is just a pin fixed on a floater. Poking through a hole, the pin has the MIN and MAX indicators that are visible depending on the current water level. The water refill is right next to it, with a cap covering a hole for water pouring (Fig40). Keeping them close together makes it easier to refill Pivot while keeping an eye on the meter to avoid overfill.

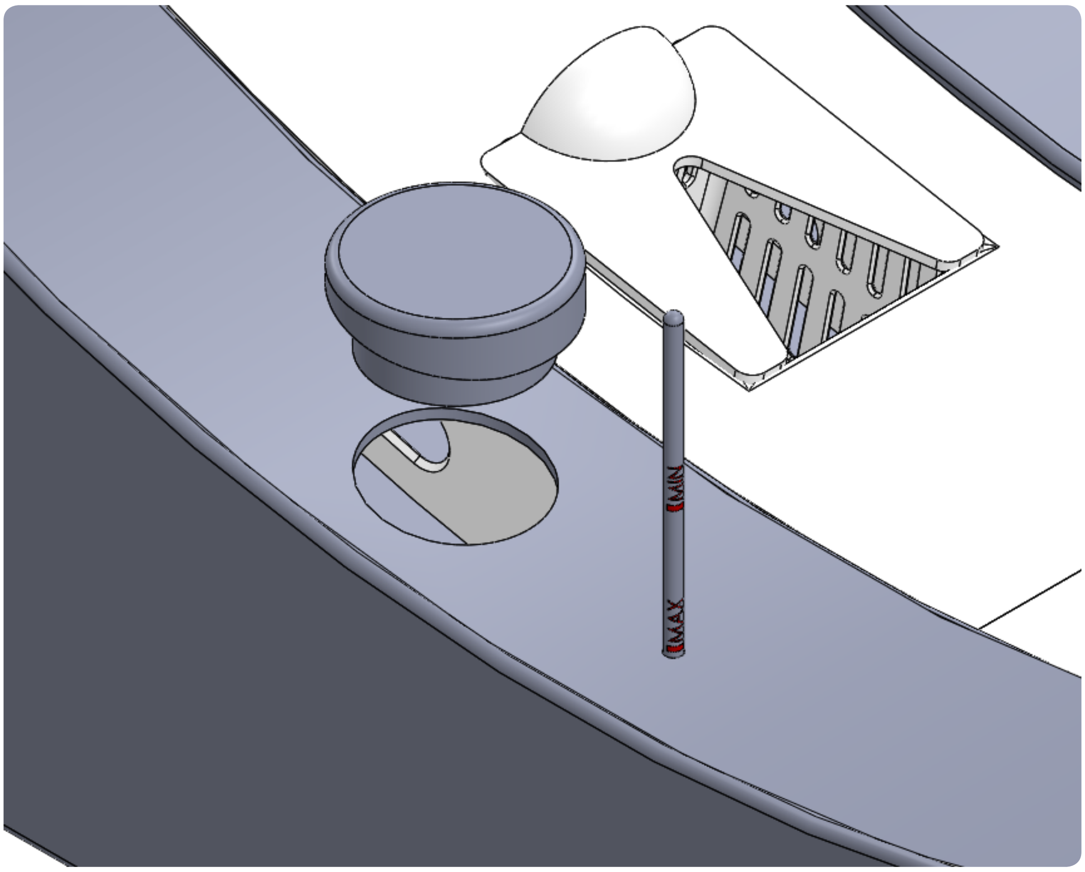


Figure 40: Water meter and refill hole.

Finally, to keep the plant and the medium in place even when they hang upside down, a cap needs to be installed after the medium has been placed. The cap comes with 2 pins that need to be pushed into conical holes on the wheel and has a practical overhang for the finger, for when it needs to be taken off again (Fig41). The cap has a slit that allows the plant to grow without any added difficulty.

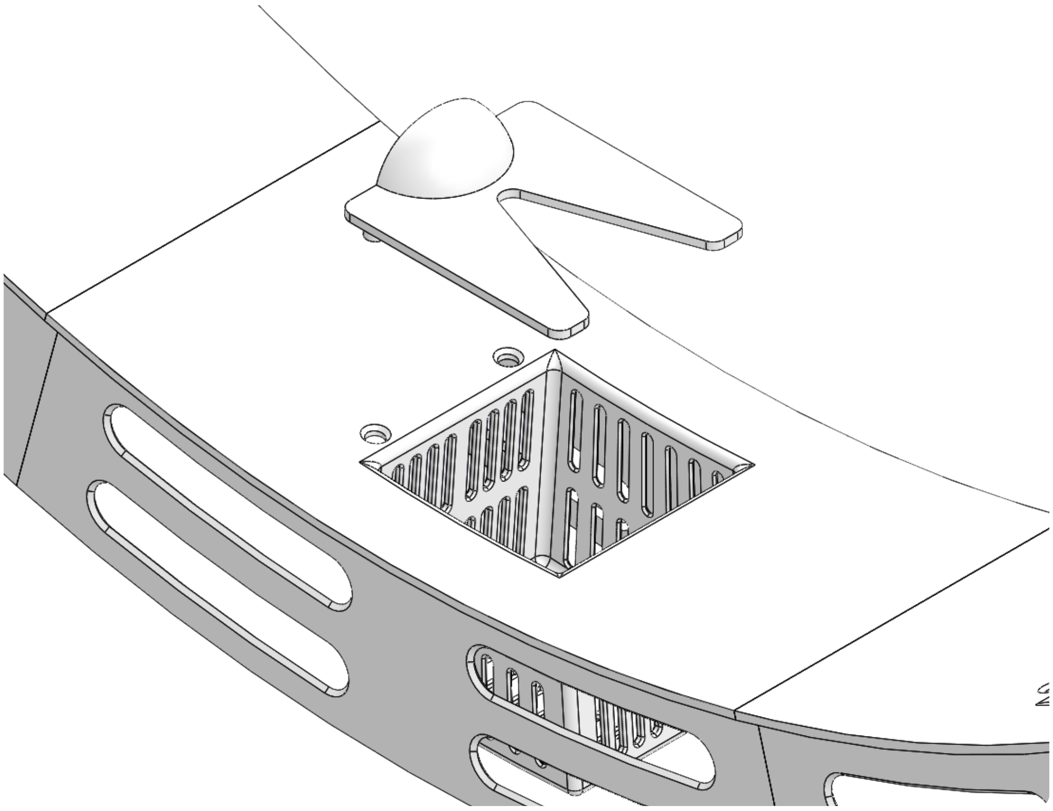


Figure 41: Medium holder cap.

Tweakability and user interface.

For this product, the following parameters can be tweaked by the user:

- Rotation speed of the wheel.

- Spectrum of the light (Individual control of Red, Green and Blue).

- Uptime of the light (Constant lighting or occasional rest periods).

- Fan speed (for temperature and air exchange control).

The original idea was to have different knobs on the product for tweaking the parameters and a display for feedback. The idea was quickly scrapped due to being more demanding on components and space as well as more limited amount of feedback, data or user interface aesthetic, unless a fancy, high resolution color screen was selected. Instead, it was decided to control and tweak Pivot via an app, using Bluetooth connection.

The app will allow the users to tweak the aforementioned parameters, either in one-time way, or create a schedule where the value can vary based on time and day. It can also log the settings to make it easier to recall the conditions with which previous harvests were grown, or share the setting files with other Pivot users. The user can also take and attach harvest pictures and other data to the saved growth logs to compare the results of growing under different settings.

Using Bluetooth with mobile connection also allows for easier firmware updates, without the need to connect Pivot to a computer.

Growing medium and nutrients.

To ensure the users have the correct growing medium, the hypothetical company behind the Pivot is to manufacture and sell packages of prepared Rockwool cubes that have undergone treatment to neutralize otherwise too alkaline pH level. During this process, the Rockwool would also be infused with the minerals that young saplings need to grow, as soon as they break free from the seed. The cubes will be supplied in the 50x50x50mm size, perfect for Pivot, but also come with a precut 25mm diameter cylinder in them. This is so that they can be placed separately into a compact germination box (included with Pivot), not wasting too much space (Fig42). Once the germination has been completed, they are to be placed back into the cube and inserted into Pivot for further growing.

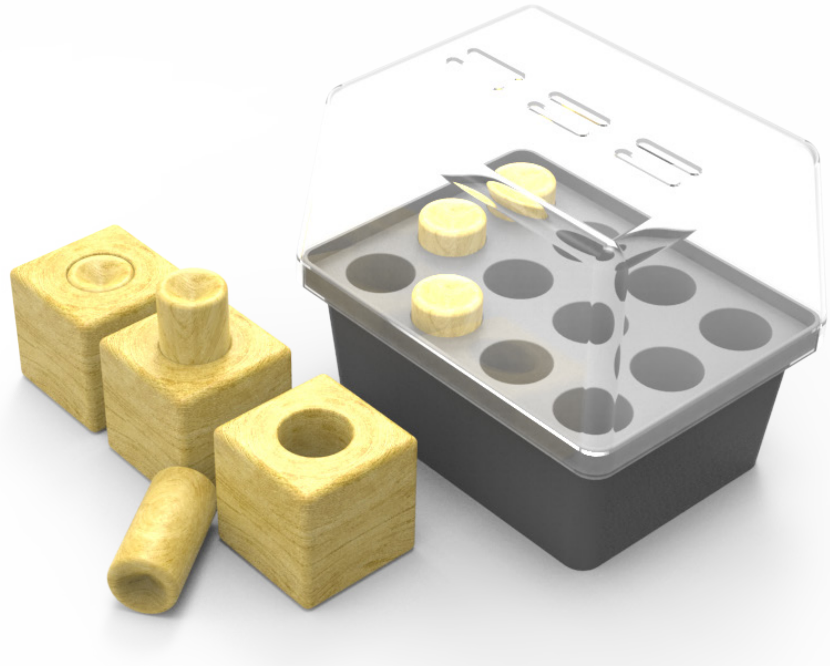


Figure 42: 50x50x50mm Rockwool mediums and the compact germination box.

Since Rockwool growing medium is not a reusable substance, the users will have to either create their own, going through tedious process of pH neutralization, or purchase affordable, Pivot-brand-name ones, providing an extra revenue stream for the company.

Same applies for the water nutrients. Smaller bags with water-solvable nutrient powder is to be out-source produced for the Pivot company. The powdered mix should be a modern version of Hoagland solution, containing all the macro- and micronutrients. Some companies sell concentrated liquid solutions, but the reason for Pivot to utilize powdered one instead is that you could ship more powdred nutrients weight-wise, compared to liquid ones.

Materials.

The majority of the parts, such as the body and the inner wheel are made out of injection molded Polypropylene (PP) plastic, as it is relatively inexpensive, has good properties such as resistance to moisture, acids and alkaline. It has low coefficient of friction, which will remove the need of bearings in the hinge assemblies. PP is also considered a "safe" plastic for food and drinks and thusly will not leach chemicals into plants' water. It is also a recyclable plastic type, which makes getting rid of the product a more environmentally friendly task.

The rods for the hinges and wheel support rollers are to be made out of 314 stainless steel, to make sure it does not rust in humid environment.

The doors are made of green Plexiglass (Polymethyl methacrylate) are chosen over regular glass due to lower weight, higher durability and not being prone to shattering.

Color.

Different color options were explored for the product (Fig43). After considerations of different user contexts as well as talking with target group representatives and people outside the target group, white color was selected for the product, The cleanliness and sterile feeling of pure white shall reflect the purity of the healthy, organic plants grown within.

Distribution and pricing.

For an entry-level product that does not contain too many complicated or expensive components, it was desired to have a price that was fair, yet profitable. Compared to some of the other similar products on the market, a price of **2999.95 DKK** was deemed appropriate, with the hope of aftersale of growth mediums and water nutrients. This also means that production and supply chain must be designed in a way that the desired price would still give profit to the company.

When it comes to distribution, the Pivot's own webstore as well as Amazon would be used for online sales, while the type of physical stores that are desired to be targeted are DIY (f.x. Silvan), gardening (f.x. Plantorama) and electronic stores (f.x. Elgiganten).

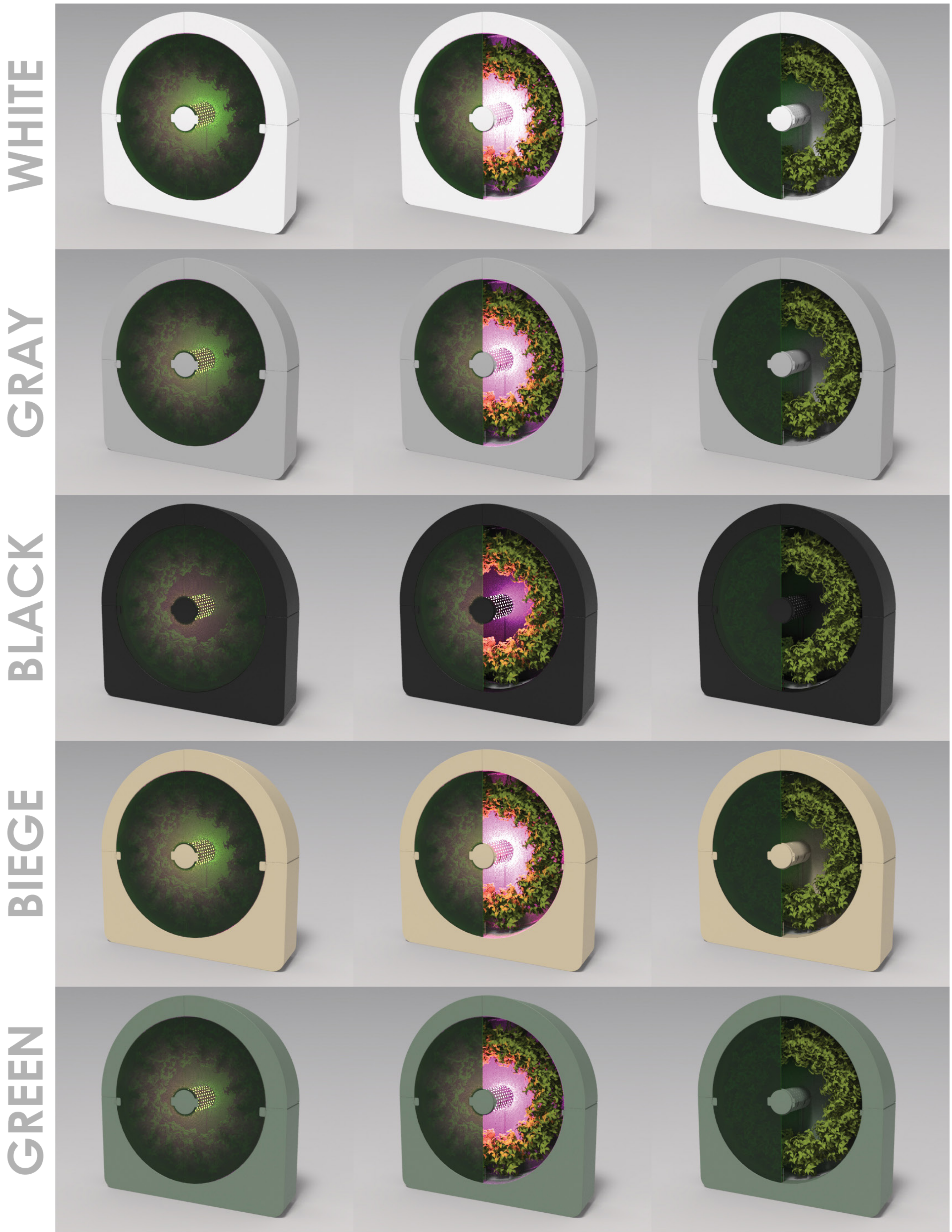
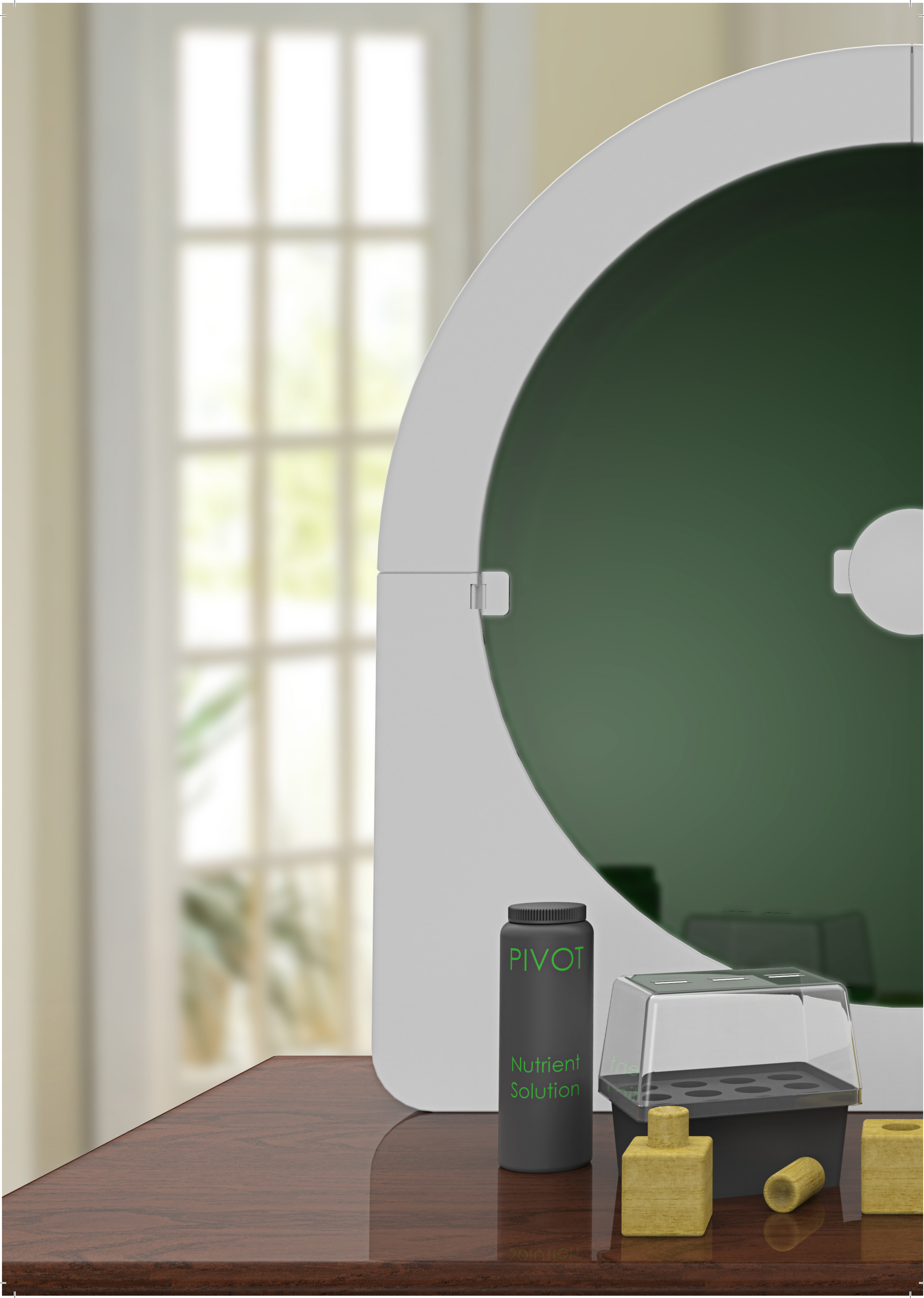


Figure 43: The 5 main considered colors with the product in different stages.


PIVOT
Nutrient
Solution

REFLECTION & DISCUSSION

Before the current topic.

Originally, I have begun my work on master thesis on a completely different topic. A topic that I chose based on my own passion and interest: riot police protective equipment. I have spent a month working on it, gathering data and the right contacts. Unfortunately as the time went on, the work stalled more and more. Time was mostly spent waiting on replies from my contact persons. Literature was extremely scarce as well and once the work stopped completely, I had no choice but to fully chance the topic of the thesis. It has proven to be a very good choice. I chose a topic which I had no previous interest or knowledge in, which truly helped me see things in an unbiased way and approach the project with a critical perspective. I did not base any of my choices and decisions on my own gut feeling or guesswork, which resulted in a more scientifically based, unbiased result. I can only recommend everyone to do the same when working on university projects. It also truly helped expand the horizons and I learned very much on the subject.

Solo work.

Working solo was a blessing and a curse. It was definitely very challenging, mostly due to motivation and lack of manpower that I was used to from previous semester projects. All the general project practices become difficult when you work alone. I am very grateful to all my co-students, friends and family who have provided me with sparing, idea brainstorming, motivation and general help with the project.

Working alone did also come with some benefits. I was the master of my own schedule, which allowed me to dictate my own working hours and days. I have resorted to working on weekends instead of 2 workdays, due to having peace and quiet in otherwise very noisy group room environment. Being alone also saved me a lot of time on certain processes, such as worksheets. I did not need to spend time communicating research information to other group members, all the research went straight into writing, being referenced right away. There were no misalignment and no relying on others to do their part right. All discussions were avoided by being alone, save for the productive ones done with the sparring partners.

With time being a rarely commodity during this semester, it was crucial to dedicate it correctly. "Having too little time" is not an excuse, but one rather needs to look at correctly prioritizing tasks instead.

Experiments.

Due to aforementioned shortage of time and manpower, I had to down-prioritize performing experiments, despite really wanting to carry out some. I would have carried out controlled experiments to determine the efficiency of rotational farming and its effect on growth vs. static growing, in order to compare with the results supplied by Omega garden. I would have also carried out tests with different LED light spectrums, such as 1:1 RB, 2:1 RB, 3:1 RB, 1:2 RB, RBW and others, to determine which lights are best suited for indoor growing based on my own experiments, rather than relying solely on results from other research papers. I would also have loved to carry out an experiment on importance of photorespiration, in the instance of plant sleep cycle vs. 24-hr daytime.

Work pace.

As the time of the hand-in drew near, the pace of the work sped up a lot. A lot of design and functionality decisions were made during the detailing phase. The vast majority were made on small paper notes, ideating different approaches and concepts, and making decisions on what to include. The high pace of this phase has unfortunately negatively affected the documentation process and a lot of considered alternative options were not documented, which could look like many taken decisions were not carefully considered. It is, however not the case and the iterative process was a complex one with several revisions of many parts and details.

End product.

Rotational farming is obviously the main feature behind the product, however it was a very dangerous and bold call to make, since there is currently no scientific or research papers or journals that officially prove that rotation positively affects the growth. Taking the word of a company that creates a similar product could have been a risky move and relying solely on desk research, rather than conducting own experiments could even be considered reckless, however due to condition previously stated, it was the only possibility that was available.

The product level of detail is not fully developed. At the current stage, the product parts in the reports are not yet optimized for intended production. The parts cannot be moulded in their current state and need to be divided into more mould-appropriate parts. At the same time, this brings up a question of how these parts will be assembled to resemble the product as it is intended now.

Structural strength of the components is another important factor. Structurally strengthening elements like ribs have not yet been added to the parts; however it is known where they are supposed to be placed. CAD FEM analyses would be performed to find structural weaknesses and reinforce them.

Not being an electrical engineer or software developer, it was not known to me, in detail, which components would be needed to create an electrical assembly that would support the electrical elements and allow them to perform the intended functions. It was also not known how complicated the programming of operating functions for the product as well as supporting app would be.

Once the end product has been rendered a couple of times, I noticed that purple light escapes from more places that I originally expected. More gaps around the doors allowed the light to shine through and extra time will be needed to designing shielding from that, although it is not a challenging task.

When it comes to maintenance, the product was designed to allow for easy cleaning. Although a detail is currently missing: a plugged hole in the bottom of water tray, which can be unscrewed in order to drain out the tray. It can then be cleaned and washed properly, from the inside. Large fillet on the corners in that compartment and planned absence of ribs on that side makes cleaning easy and accessible.

It should not be a secret that growing plants under artificial lights is definitely not an environmentally friendly way of doing it, unless the energy comes from renewable sources like wind, solar or nuclear. Unfortunately, the vast majority of electricity in the world still comes from coal and fossil fuels. It definitely is a huge and actual problem on the big scale of things. If at some point in the future, we can cease using coal and fossil fuels for energy product and open our doors to far more renewable energy, then perhaps controlled environment farming can become an actual, energy-friendly option. If we could invest into nuclear power, or more modern nuclear-based technologies and research, such as thorium reactors, we could not only grow food for barely any money, but actually increase the output and perhaps feed the world. Until then, however, it remains a utopian dream.

User involvement.

It would have been far more desirable, if the project had more user involvement in it. Working out of more finely defined User Value Canvas with confirmed pains and gains, as well as more intended user feedback throughout the whole process could have improved the overall quality of the product. Unfortunately, in reality, user involvement was rather small, with most of the feedback given by the 2 mentioned target group reps. Although, it was good that I had the chance to talk with them on a more personal level, which made the feedback they gave far more detailed and qualitative, rather than quantitative.

Working with a company would also have been very beneficial and could have helped with many things, such as framing of the project. Omega gardens, plantui or any other controlled environment or indoor farming company would be applicable and could offer richer insight into the topic and the market.

References.

A lot of references have been found for this thesis, consisting of books, scientific articles and papers, and web pages. Working with these sources, it was important to be critical of how reliable they are (in terms of web pages and books), but also when they were published (in terms of articles and journals). Hopefully none of the critical data used is yet outdated.

For the web pages, sources were controlled. Only those that were deemed reliable were considered, such as respected news outlets, community-oriented article pages (practical expert knowledge), or pages created by people or companies with confirmed knowledge and/or experience in the respective field(s).

Having so many different sources and references goes to show that the project is objective and not biased by personal opinions.

REFERENCES

[1] - Usa.lighting.philips.com. (2017). City Farming - Philips Horticulture. [online] Available at: http://www.usa.lighting.philips.com/products/horticulture/city-farming [Accessed 7 May 2017].

[2] – Sholto Douglas, J. (1975). Hydroponics: the Bengal system. 5th ed. London: Oxford University Press.

[3] – NYMag.com. (2017). Skyfarming. [online] Available at: http://nymag.com/news/features/30020/ [Accessed 7 May 2017].

[4] – Vertical-farming.net. (2017). About the Association for Vertical Farming - Association for Vertical Farming. [online] Available at: https://vertical-farming.net/about-us/ [Accessed 7 May 2017].

[5] – Actionagainsthunger.org. (2017). Action Against Hunger | ACF-USA - Ending World Hunger & Malnutrition. [online] Available at: http://www.actionagainsthunger.org [Accessed 7 May 2017].

[6] – Verticalfarm.com. (2017). The Vertical Essay. [online] Available at: http://www.verticalfarm.com/?page_id=36 [Accessed 7 May 2017].

[7] – Midwestpesticideaction.org. (2017). The Problem | Midwest Pesticide Action Center. [online] Available at: http://midwestpesticideaction.org/the-problem/ [Accessed 7 May 2017].

[8] – Earth-policy.org. (2003). Plan B Updates - 23: Deserts Advancing, Civilization Retreating | EPI. [online] Available at: http://www.earth-policy.org/plan_b_updates/2003/update23 [Accessed 7 May 2017].

[9] – Verticalfarm.com. (2017). The Vertical Essay. [online] Available at: http://www.verticalfarm.com/?page_id=36 [Accessed 7 May 2017].

[10] – Encyclopedia Britannica. (n.d.). Jan Ingenhousz | Dutch scientist. [online] Available at: https://global.britannica.com/biography/Jan-Ingenhousz [Accessed 7 May 2017].

[11] – Bruce Bugbee. (2015) Why Vertical Farming Won't Save the Planet. [Departmental Seminar], Utah State University. 18/09.

[12] – Bugbee, B. and Salisbury, F. (1988). Exploring the Limits of Crop Productivity : I. Photosynthetic Efficiency of Wheat in High Irradiance Environments. PLANT PHYSIOLOGY, 88(3), pp.869-878.

[13] – Nelson, J. and Bugbee, B. (2014). Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures. PLoS ONE, 9(6), p.e99010.

[14] – Bruce Bugbee. (2015) Why Vertical Farming Won't Save the Planet. [Departmental Seminar], Utah State University. 18/09.

[15] – Bugbee, B. (2017). Turning photons into food The future of LEDs in agriculture. [online] Available at: https://energy.gov/sites/prod/files/2017/02/f34/bugbee_agriculture_longbeach2017_0.pdf [Accessed 7 May 2017].

[16] – Humphries, A. and Roberts, F. (1965). The effect of wind on plant growth and soil moisture relations: a re-assessment. New Phytologist, 64(2), pp.315-318.

[17] – Members.optusnet.com.au. (2017). Why Humidity is Important to Plants. [online] Available at: http://members.optusnet.com.au/bdobson/Why%20Humidity%20is%20Important%20to%20Plants.html [Accessed 7 May 2017].

[18] – Anon, (2014). How Weather Affects Plants. [online] Available at: https://web.extension.illinois.edu/hkmw/downloads/55040.pdf [Accessed 7 May 2017].

[19] – Brown, E. (2017). The Importance Of Soil Temperature To Growing Plants. [online] ThriftyFun. Available at: http://www.thriftyfun.com/tf11780248.tip.html [Accessed 7 May 2017].

[20] – Kemble, J. and Musgrove, M. (2006). Soil Temperature Conditions for Vegetable Seed Germination. [online] Available at: http://www.aces.edu/pubs/docs/A/ANR-1061/ANR-1061.pdf [Accessed 7 May 2017].

[21] – Anon, (2008). Help Sheets: Things Plants Need. [online] Available at: http://www.hort.vt.edu/HORT6004/network/YouthGardener/Helpsheets/thingsPlantsNeed.pdf [Accessed 7 May 2017].

[22] – Agriculture.vic.gov.au. (2017). What nutrients do plants require. [online] Available at: http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/fertilising-dairy-pastures/what-nutrients-do-plants-require [Accessed 7 May 2017].

[23] – Hoagland, D. and Arnon, D. (1938). The Water Culture Method for Growing Plants Without Soil. 1st ed. Berkeley, CA: University of California.

[24] – Taylor, F. (1939). Nice Clean Gardening. The Rotarian, p.14.

[25] – Homehydrosystems.com. (2017). Hydroponic N.F.T. Systems. [online] Available at: http://www.homehydrosystems.com/hydroponic-systems/nft_systems.html [Accessed 7 May 2017].

[26] – Produce Grower. (2016). 2016 STATE OF HYDROPONIC PRODUCE GROWING: RESEARCH. [online] Available at: http://magazine.producegrower.com/article/june-2016/research-analysis.aspx [Accessed 7 May 2017].

[27] – Stoner, R. (1983). Aeroponics Versus Bed and Hydroponic Propagation. Florist Review, (173).

[28] – Spinoff.nasa.gov. (2017). Progressive Plant Growing Has Business Blooming. [online] Available at: https://spinoff.nasa.gov/Spinoff2006/er_2.html [Accessed 7 May 2017].

[29] – Elliott, S. (2017). Figuring Out Fogponics. [online] Maximumyield.com. Available at: https://www.maximumyield.com/figuring-out-fogponics/2/1361 [Accessed 7 May 2017].

[30] – Integrated agriculture-aquaculture. (2001). 1st ed. Rome: FAO.

[31] – Rakocy, J., Masser, M. and Losordo, T. (2006). Recirculating aquaculture tank production systems: Aquaponics — integrating fish and plant culture. Southern Regional Aquaculture Center, (454).

[32] – Fan, X., Xu, Z., Liu, X., Tang, C., Wang, L. and Han, X. (2013). Effects of light intensity on the growth and leaf development of young tomato plants grown under a combination of red and blue light. Scientia Horticulturae, 153, pp.50-55.

[33] – McCree, K. (1971). The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. Agricultural Meteorology, 9, pp.191-216.

[34] – Hogewoning, S., Trouwborst, G., Maljaars, H., Poorter, H., Van Leperen, W. and Harbinson, J. (2010). Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of Cucumis sativus grown under different combinations of red and blue light. Journal of Experimental Botany, 61(11), pp.3107-3117.

[35] – Khan Academy. (2017). Light and photosynthetic pigments. [online] Available at: https://www.khanacademy.org/science/biology/photosynthesis-in-plants/the-light-dependent-reactions-of-photosynthesis/a/light-and-photosynthetic-pigments [Accessed 7 May 2017].

[36] – Lin, K., Huang, M., Huang, W., Hsu, M., Yang, Z. and Yang, C. (2013). The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. var. capitata). Scientia Horticulturae, 150, pp.86-91.

[37] – Bugbee, B, Cope, K. (2013). Spectral Effects of Three Types of White Light-emitting Diodes on Plant Growth and Development: Absolute versus Relative Amounts of Blue Light. HortScience, 48, pp.504-509.

[38] – Oregon State University (2017). Colored leaves have chlorophyll too. [online] Available at: http://extension.oregonstate.edu/gardening/colored-leaves-have-chlorophyll-too [Accessed 7 May 2017].

[39] – Omegagarden.com. (2017). FAQs | Omega Garden. [online] Available at: http://omegagarden.com/faqs [Accessed 7 May 2017].

[40] – Bbc.co.uk. (2017). BBC - GCSE Bitesize: Sensitivity in plants. [online] Available at: http://www.bbc.co.uk/schools/gcsebitesize/science/aqa/nervesandhormones/controlinplantsrev1.shtml [Accessed 7 May 2017].

[41] – Biology-pages.info. (2017). Auxin. [online] Available at: http://www.biology-pages.info/A/Auxin.html [Accessed 7 May 2017].

[42] – Mauseth, J. (1998). Botany : An Introduction to Plant Biology. 1st ed. Jones & Bartlett Publishers.

[43] – Produce Grower. (2016). 2016 STATE OF HYDROPONIC PRODUCE GROWING: RESEARCH. [online] Available at: http://magazine.producegrower.com/article/june-2016/research-analysis.aspx [Accessed 7 May 2017].

[44] – Slideshare.net. (2013). PSFK Future Of Home Living Report 2016 presentation. [online] Available at: https://www.slideshare.net/PSFK/future-of-home-living/45-Bathroom_Mirror_Concept_Instantly_Reads [Accessed 7 May 2017].

[45] – PSFK. (2013). The Future Of Home Living - A PSFK Report. [online] Available at: https://www.psfk.com/report/future-of-home-living [Accessed 7 May 2017].

[46] – Group, G. (2017). 2017 Garden Trends Report. [online] Grow.gardenmediagroup.com. Available at: http://grow.gardenmediagroup.com/2017-garden-trends-report [Accessed 7 May 2017].

[47] – Forbes.com. (2015). Forbes Welcome. [online] Available at: https://www.forbes.com/sites/nancygagliardi/2015/02/18/consumers-want-healthy-foods-and-will-pay-more-for-them/#540c692a75c5 [Accessed 7 May 2017].

[48] – IKEA. (2017). What Makes a Home?. [online] Available at: http://lifeathome.ikea.com/home/ [Accessed 7 May 2017].

[49] – IBIS World. (2017). Hydroponic Crop Farming Market Research | IBISWorld. [online] Available at: https://www.ibisworld.com/industry/hydroponic-crop-farming.html [Accessed 7 May 2017].

[50] – Garden.org. (2014). Garden to Table - Special Report. [online] Available at: https://garden.org/special/pdf/2014-NGA-Garden-to-Table.pdf [Accessed 7 May 2017].

[51] – NRA (2015). What's Hot in 2015? Discover new menu trends. [online] National Restaurant Association. Available at: http://www.restaurant.org/News-Research/News/What-s-Hot-in-2015-culinary-forecast-predicts-top [Accessed 7 May 2017].

[52] – Nelson, J. and Bugbee, B. (2014). Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures. PLoS ONE, 9(6), p.e99010.

[53] – Ulrich, K. and Eppinger, S. (2015). Product design and development. 6th ed. McGraw-Hill Education.

[54] – Color-wheel-pro.com. (2017). Color Wheel Pro: Color Meaning. [online] Available at: http://www.color-wheel-pro.com/color-meaning.html [Accessed 7 May 2017].

[55] – Dongguan Dongrong Silicone Products Co., Ltd. (Alibaba.com) (2017). Industrial Molded Custom Heat Resisting Silicone Rubber Wire Seal. [online] Available at: https://www.alibaba.com/product-detail/Industrial-molded-China-custom-heat-resisting_1222999490.html [Accessed 7 May 2017].

[56] – Shenzhen Yuliang Optoelectronic Technology Co., Ltd. (Alibaba.com). (2017). 3535 Size Tricolor Chip SMD LED. [online] Available at: https://www.alibaba.com/product-detail/3535-size-tricolor-chip-smd-led_60482089726.html [Accessed 7 May 2017].

NOTES


PIVOT
Home growing – your way
PRODUCT REPORT
Ma04-ID11, Nik Jensen, May 2017

AALBORG UNIVERSITY
STUDENT REPORT

Architecture & Design
2017

Resume:

As the vertical farming concept has been getting more and more popularity lately, controlled environment farming (CEF) technologies have gotten strong momentum in development. Large and small scale products utilize the many benefits of CEF to grow healthy and organic plants not only quicker, but also more effectively. This thesis project explored the opportunity to use some of the latest technologies in a single home-use consumer product that allows the users to grow their own organic food, without any soil or pesticides, inside their homes: Pivot. With space for 12 individual plants, Pivot uses modern technologies to grow the food faster, thanks to the rotational mechanism that ensures perfect light capture by the plants as well as better distribution of plant hormone Auxin, which results in richer harvest. Pivot also allows the users to tweak and customize different parameters of the growth cycle, in attempts to get the best possible results in shortest possible time. Pivot encourages users to cooperate or compete in the art of home growing, all the while providing healthy, organic greens to the table.

Nik Jensen
author

Table of contents.

Acknowledgements.

This thesis project was made possible thanks to support and help from co-students, friends and family.

I would like to express special gratitude to:

Jesper Helleskov Sørensen

For his support, advice and sparring during the entire span of the project, as well as:

Emil Bjerkén Kristensen

For his artistic help with the Use Case, and:

Matthias Walet
Kenny Andersson

For representing the target group and using their time on interviews and feedback that has helpedin the development of the product.

Project title:
Pivot
Hand-in date:
May 18th 2017
Exam date:
June 9th 2017

Project Supervisor:
Nis Ovesen
Technical Supervisor:
Jørgen Kepler
Project group:
Ma04-ID11

PIVOT

Home growing – your way

What is Pivot? Pivot is a new way of home farming. Without soil, without pesticides and without hassle! Pivot utilizes some of the newest technologies in controlled environment farming to bring you the freshest organic produce, vegetables, fruits and herbs straight to your table in record time, all year round!

Create your own growing cycle settings or use some of pre-built programs to grow anything from hot peppers and tomatoes to basil and lettuce. Experiment with various cycle parameters to achieve new results and surpass what previously thought possible!

Pivot's rotating inner wheel improves the distribution of nutrients and plant hormones, increasing the richness of the crops. Artificial light provides just the right light spectrum that the plants need to grow tall and healthy.

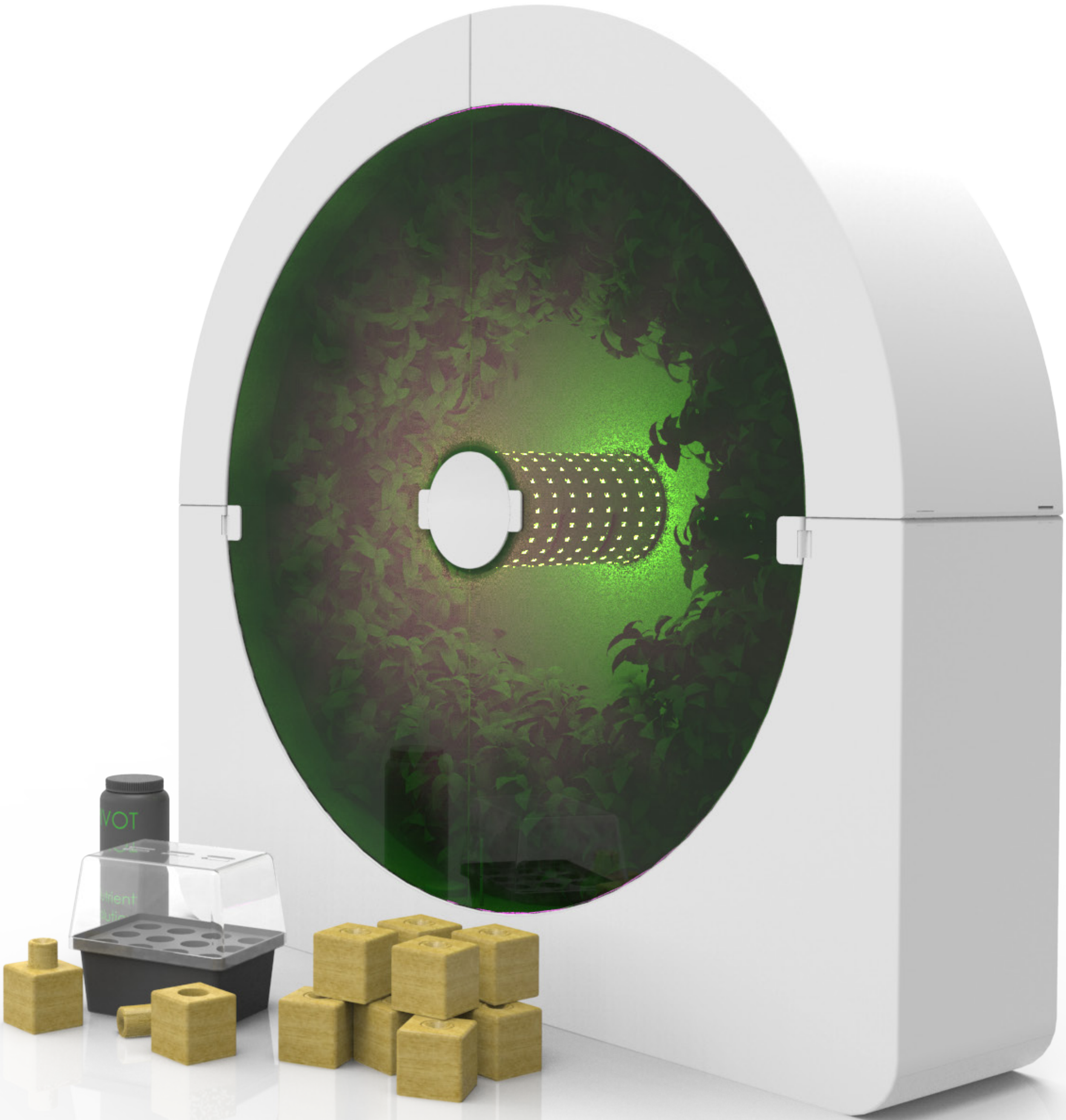
Engage with Pivot community to share your experiences or to compete for the title of master home farmer!

Pivot is easy to set up, easy to use and easy to clean, and with its 5.5 liters water tray, it can keep the plants sated for couple of weeks at a time.

Pivot comes with everything you need to begin growing at home straight from the box. The kit includes the Pivot, a germination box, nutrient solution mix, twelve Rockwool growing cubes and assorted seeds.

2999[95] DKK

Additional cubes and nutrient solutions can be purchased seperately.
Bluetooth-enabled mobile device is required for operation.



HOW IT WORKS

Behind Pivot lies many years of research by world's leading universities, companies and agencies. Every component has been carefully designed, engineered and selected do deliver exact intended performance.

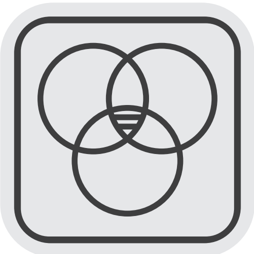
It is a common misconception that plants require soil in order to grow. In reality, soil serves no purpose other than keeping the plant in place, retain water and provide some of the nutrients. All of those functions, however, can be performed by other, better mediums. Pivot uses a medium made out of spun molten rock, commonly known as Rockwool to hold the plant and retain water, which is mixed with our nutrient mix that provides plants with Nitrogen, Calcium and many other elements that plants needs to grow big and strong. Water-based farming without soil is a common technique called Hydroponics. It sees wider and wider use each year and even NASA is using it in preparation to growing food in space.

For millions of years, plants used the energy from the sun to preform photosynthesis, converting carbon dioxide into plant matter and oxygen. Pivot provides artificial light to the plants, making it possible for them to absorb it all day long. The new research shows that the pigments that majority of plants utilize for growth use only certain wavelengths of light spectrum, namely red and blue. It is therefore that Pivot radiates pink color as a default setting, making sure that only the needed wavelengths are made and no power is wasted.

What makes Pivot stand out from many other hydroponic home farming products is the inner rotating wheel. By constantly changing the direction of gravity, the plant nutrients and hormones get better distribution, ensuring richer growth in shorter time.

For the curious and tech-savvy users, Pivot offers tweakable parameters for the growth programs, making it possible to adjust several factors in the pursuit of better harvest:

LIGHT SPECTRUM



Customize the values of red, blue and green lights.

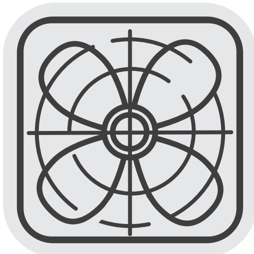
DAY CYCLE

Program wake and sleep hours for the lights, or let them run non-stop.

ROTATION SPEED

Experiment with how different rotation speeds affects different plant growth.

FAN SPEED



Control the temperature of the growing space and allow more CO2 to enter.

NUTRIENTS

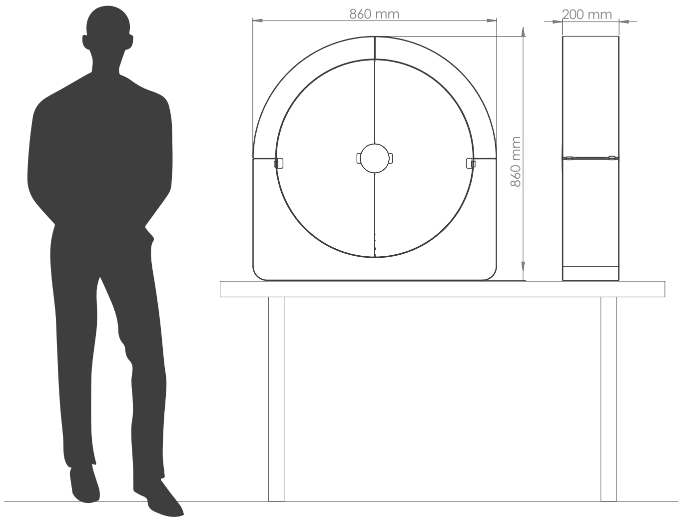
Use Pivot brand nutrient mix or experiment with 3rd party ones.

Pivot is controlled via an app that is available on all the modern Bluetooth-enabled devices such as iPhones, iPads, Android phones and tablets. The app doesn't just allow the user to start and stop the cycle, but also to tweak several growth parameters, log results and access public community knowledge base where users share their experiences in growing various crops with Pivot's help.

Download on the App Store

Get it on Google play

Pivot is not a small product, measuring 860x860x200mm, it does take up some space. However, it is designed to fit well in almost any context, be it the kitchen, the pantry, scullery or somewhere completely different, and with big product, comes big growing space, where plants can reach up to 30 cm in height and have plenty of room to grow to the sides. Pivot is also very autonomous and can operate up to a couple of weeks with its 5.5 liter water tray capacity. All it needs it constant supply of power from a regular wall socket.

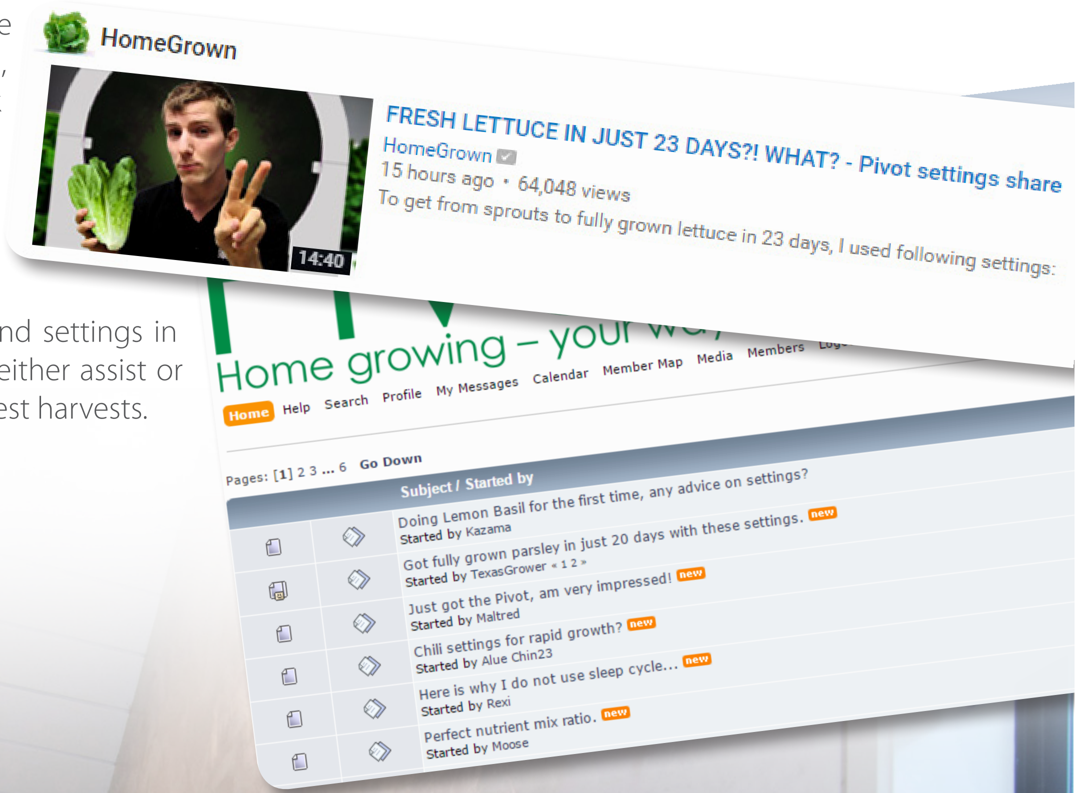


Vast majority of the parts used in Pivot are made out of Polypropylene - a food-safe plastic sort that doesn't only NOT excrete any harmful chemicals, but is also highly recyclable. The high quality parts are resistible towards corrosion and are made to last for years to come.

5
PP

STRONG COMMUNITY

Pivot supports and encourages strong communities of home farmers through various channels, be it YouTube, forums, Facebook groups and others. By enabling humans' cooperative and competitive natures, Pivot makes sure that users constantly engage in discussions and conversations about plants, growing methods and settings in order to achieve best results and either assist or beat their peers to fastest and richest harvests.




PIVOT
Home growing – your way

RECOMMENDED STARTERS

These are some of the plants we recommend to beginners, to learn the ropes of Pivot home farming.

CHERRY TOMATOES

They are delicious, bite-sized and incredibly easy to grow! Cherry tomatoes will bear fruit all year round in Pivot and will add a lot of taste to your dishes and salads. With lots of variants to choose from, cherry tomatoes are often number one choice of plant among upstarting farmers.

HOT PEPPERS

Hot peppers are also very easy to grow and require very little attention. With the artificial light of Pivot, you will only need to keep an eye on water level once in a while, as the delicious hot fruits grow to spice up your meals.

THYME

A very frequently used, greatly fragrant herb that is not only good in nearly any dish, but can also be used in home remedies against cough or a sore throat. Fresh or dry, you will always love it in your dinner.

MINT

Great in tea, cocktails, ice cream, homemade candy and many other things, mint is a refreshing, chill herb that can be grown with no hassle. Freshly harvested mint is a premium product highly sought after by gourmet restaurants.

PARSLEY

Roast pork and potatoes has been crowned as Danish national dish and it would have never gotten that award if it was not for delicious parsley sauce that comes with it. Freshly cut parsley ties up the flavors in a tasty, mouth-watering meal.

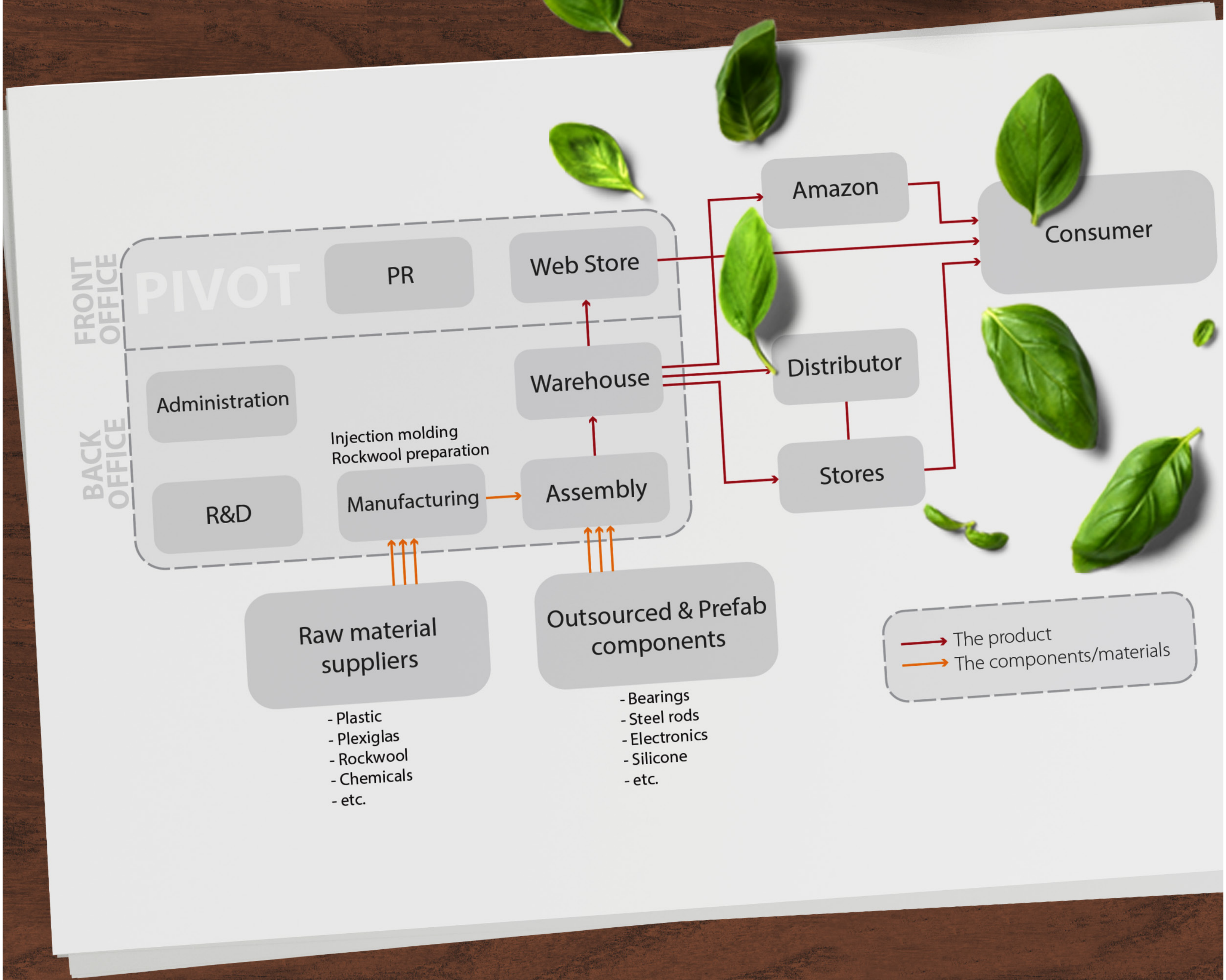
BASIL

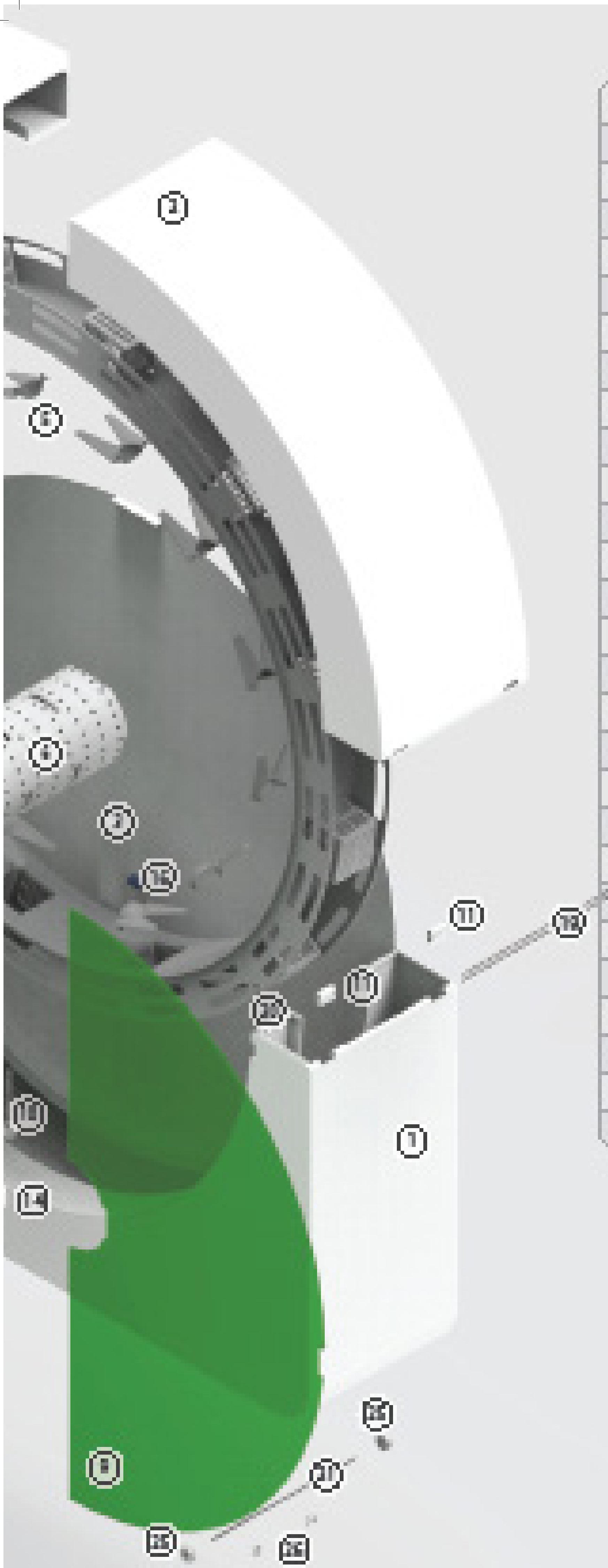
One of the most common herbs in the kitchen and one of the favorite herbs of Mediterranean cuisine, basil comes in many varieties and fits nearly any dish. Fantastic in salads, fresh basil is valued for its rich flavor and fresh colors.

Pivot is not just a product. Behind Pivot is a whole company that manufactures, sells and improves the product, the app and the community platforms behind them. Supported by a network of sub-suppliers and contrators, the company is also responsible for aftersales of nutrients and growth mediums.

R&D of the company develops new, improved products for future markets, while PR dept. makes sure that all the customers are satisfied.

With a strong front and back offices, and a reliable network of suppliers, the company can quickly deploy new products to the market and have a competitive edge.

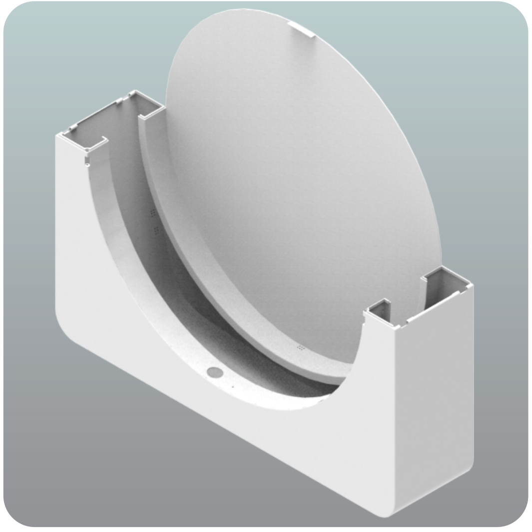




NO.	PART NAME	QTY.
1	Main Body	1
2	Top Lid	2
3	Wire Box	1
4	Wheel	1
5	Wheel Cap	12
6	Light Housing	1
7	Fan	1
8	Fan Cover	1
9	Screen Door	2
10	Electronics Box	1
11	Top Lid Hinge	4
12	Door Hinge Mount Left	1
13	Door Hinge Mount Right	1
14	Door Hinge	2
15	Motor Housing	1
16	Silicone Wire Seal	3
17	Refill Cap	1
18	Water Meter	1
19	Lid Hinge Rod	4
20	Door Hinge Rod	4
21	Roller Rod	2
22	PMX14-2 Step Motor	1
23	M4 Motor Screw	4
24	Motor Gear	1
25	Nylon Bearing	4
26	Lock Washer DIN 6799-4	8
27	Door Holders	2

ESSENTIAL PARTS

These are some of the essential components of Pivot, with indicated materials, function and manufacturing method (please note, the part previews are in different scales).



NO.	NAME
1	Main Body
QTY.	**MATERIAL**
1	Polypropylene (PP)

FUNCTION

Main body houses the majority of the components and serves as a water tray.

MANUFACTURING

NOTE: This part is assembled out of several other injection moulded parts!

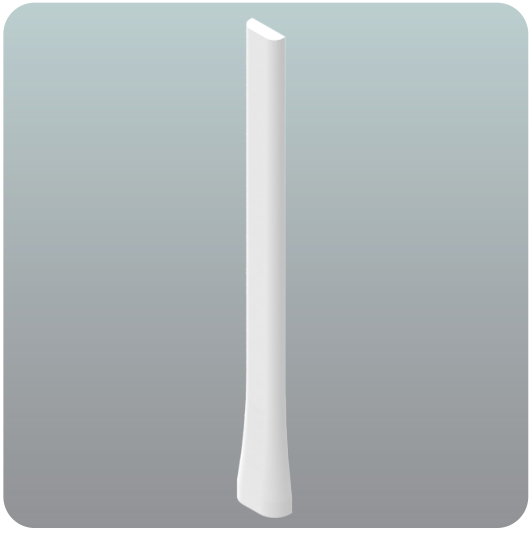
NO.	NAME
2	Top Lid
QTY.	**MATERIAL**
2	Polypropylene (PP)

FUNCTION

The top lid provides cover to the belt as well creating a more closed environment.

MANUFACTURING

NOTE: This part is assembled out of several other injection moulded parts!



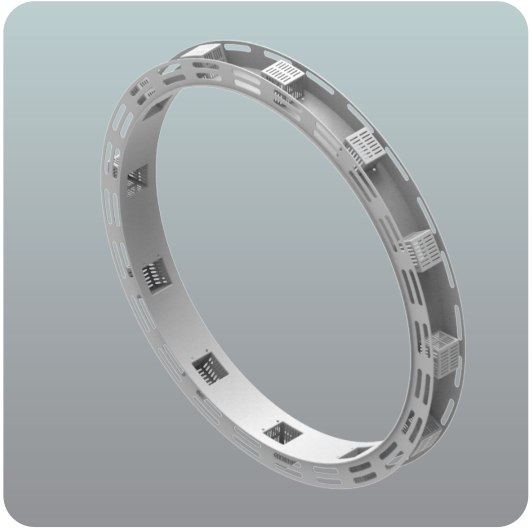
NO.	NAME
3	Wire Box
QTY.	**MATERIAL**
1	Polypropylene (PP)

FUNCTION

The wire box hides and protects the wires that come from the electronics box (10) and connect to the light housing (6).

MANUFACTURING

Injection moulded.



NO.	NAME
4	Wheel
QTY.	**MATERIAL**
1	Polypropylene (PP)

FUNCTION

The wheel houses plant growth mediums and is constantly rotated around by a step motor.

MANUFACTURING

NOTE: This part is assembled out of several other injection moulded parts!

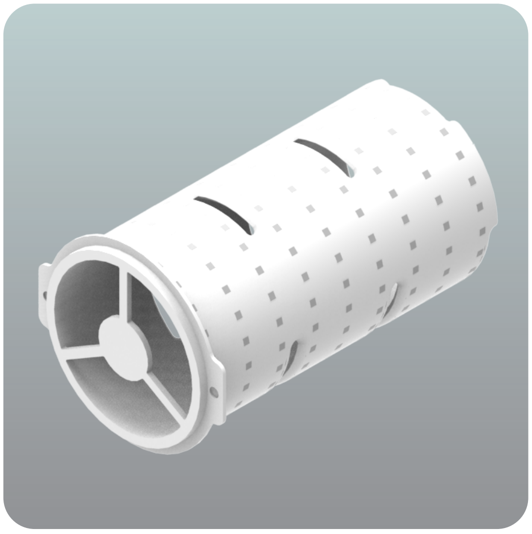
NO.	NAME
5	Wheel Cap
QTY.	**MATERIAL**
12	Polypropylene (PP)

FUNCTION

Holds the plant and medium in place on the Wheel (4).

MANUFACTURING

Injection moulded.
Is manufactured out of slightly more flexible sort of PP than other parts.



NO.	NAME
6	Light Housing
QTY.	**MATERIAL**
1	Polypropylene (PP)*

FUNCTION

Light housing provides protection and mounting to 216 LED chips as well as the fan (7) in the middle of the product.

MANUFACTURING

NOTE: This part is assembled out of several other injection moulded parts!
*Main material is PP, the part also includes wiring and LED chips.

NO.	NAME
7	Fan
QTY.	**MATERIAL**
1	-Depending on supplier-

FUNCTION

The fan cools down the light housing (6) and provides CO_2-richer air to the growing compartement.

MANUFACTURING

NOTE: This part is assembled out of several smaller parts, such as electronic components by the supplier.

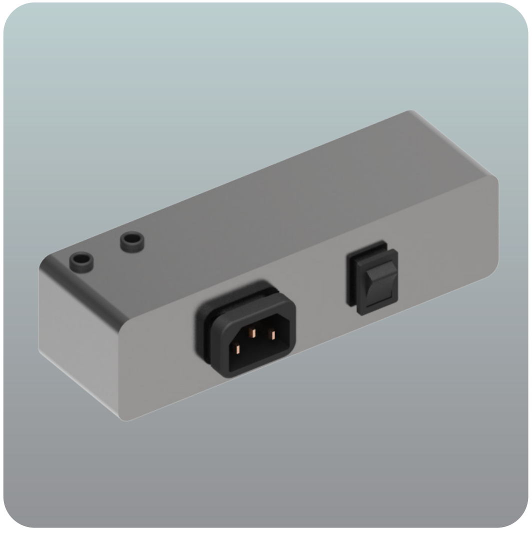
NO.	NAME
9	Screen Door
QTY.	**MATERIAL**
2	Polymethyl Methacrylate

FUNCTION

The green screen doors protect the users from powerful pink light of the product by filtering out its colors.

MANUFACTURING

Laser cut-to-shape out of 3mm sheets.



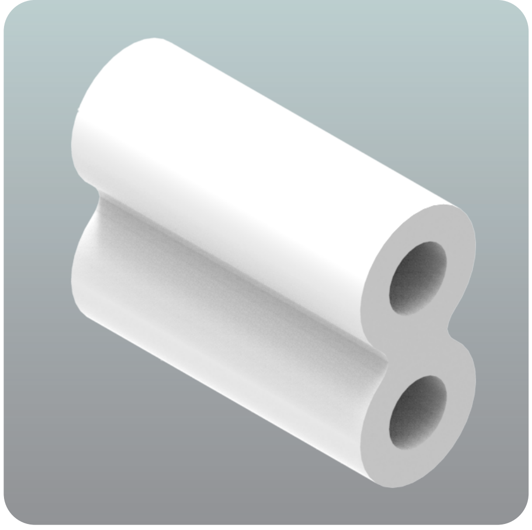
NO.	NAME
10	Electronics Box
QTY.	**MATERIAL**
1	-Various-

FUNCTION

This box houses all the neccessary electronic PCBs, has the power port as well as On/Off switch. It sends out power and data to various components.

MANUFACTURING

Hand-assembled out of pre-fabricated electronic, metal and rubber components.



NO.	NAME
11	Top Lid Hinge
QTY.	MATERIAL
4	Polypropylene (PP)

FUNCTION

Top lid hinge allows the top lids (2) to be fully opened 180 degrees.

MANUFACTURING

Injection moulded.

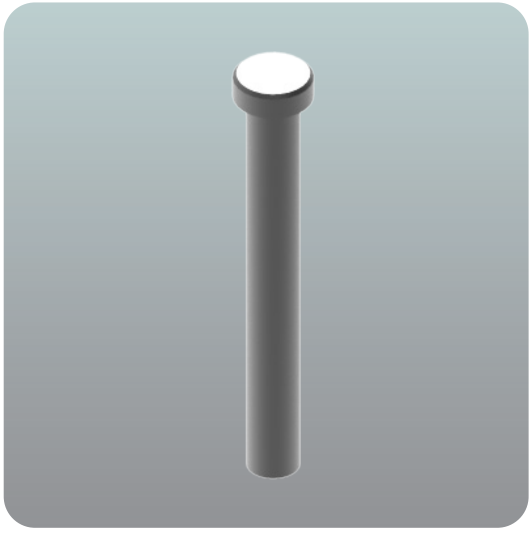
NO.	NAME
12-13	Door Hinge Mount
QTY.	MATERIAL
2	Polypropylene (PP)

FUNCTION

Door hinge mount attaches the door hinge (14) to the screen doors (9)

MANUFACTURING

Injection moulded.



NO.	NAME
20	Door Hinge Rod
QTY.	MATERIAL
4	314 Stainless Steel

FUNCTION

The rods connect and hold the hinges together and act as axis of rotation.

MANUFACTURING

Machine turned from ø6mm stainless steel rod.

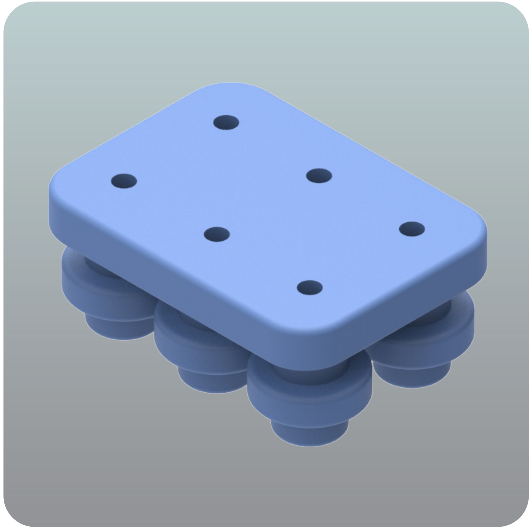
NO.	NAME
15	Motor Housing
QTY.	**MATERIAL**
1	Polypropylene (PP)*

FUNCTION

This housing protects the step motor from the humid envioument and fluids inside the main body (1).

MANUFACTURING

NOTE: This part is assembled out of several smaller parts! Injection moulded with incerted pre-fabricated rubber wire seals.



NO.	NAME
16	Silicone Wire Seal
QTY.	**MATERIAL**
3	Silicone

FUNCTION

This seal allows wires to pass between the dry and wet compartements without letting the moisture in.

MANUFACTURING

Depends on supplier.

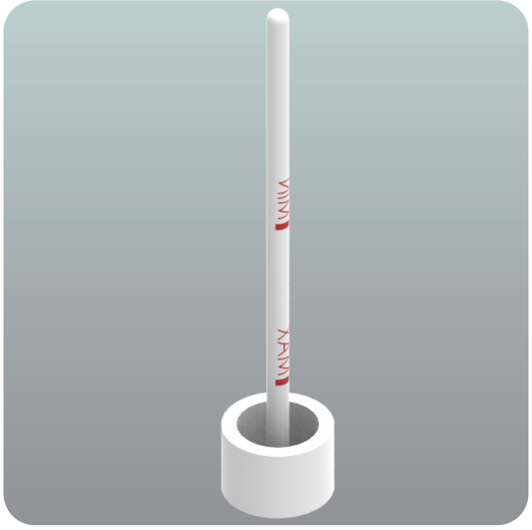
NO.	NAME
17	Refill Cap
QTY.	**MATERIAL**
1	Polypropylene (PP)

FUNCTION

Refill cap covers the refill hole in the main body (1) from light, to avoid growth of algae in the nutrient water.

MANUFACTURING

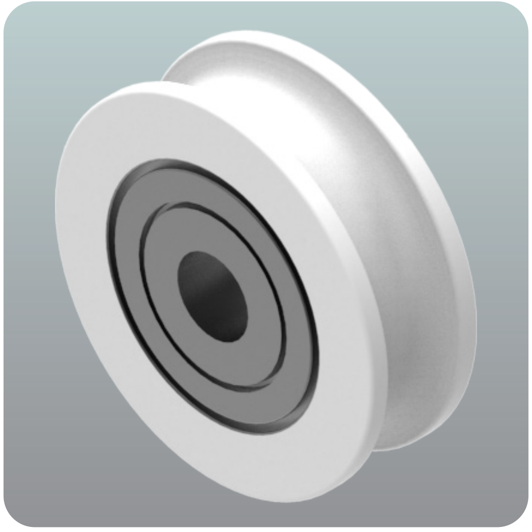
Injection moulded.



NO.	NAME
18	Water Meter
QTY.	**MATERIAL**
1	Polypropylene (PP)

FUNCTION
The water meter indicates MAX and MIN water levels for user to maintain.

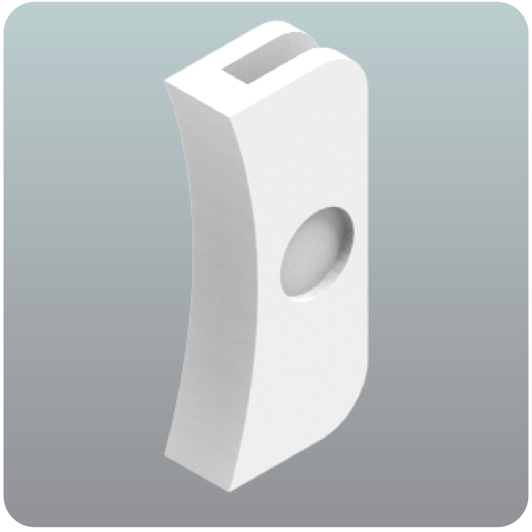
MANUFACTURING
Injection moulded, machine-printed text and marks.



NO.	NAME
25	Nylon Bearing
QTY.	**MATERIAL**
4	Nylon, 314 Stainless Steel

FUNCTION
The bearings support the wheel (4) and allow it to be rotated with ease by the step motor.

MANUFACTURING
Depends on the supplier.



NO.	NAME
27	Door Holder
QTY.	**MATERIAL**
2	Polypropylene (PP)*

FUNCTION
The door holder attaches to the screen doors (9) to be held closed against the light housing (6) by rare earth magnets.

MANUFACTURING
Injection moulded.

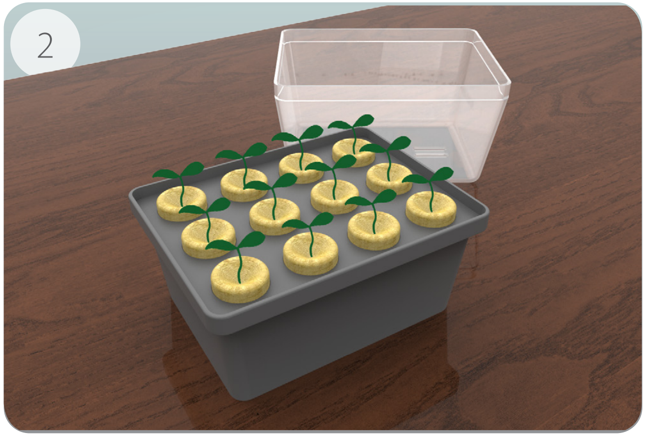
* Includes a rare earth magnet.

USE CASE

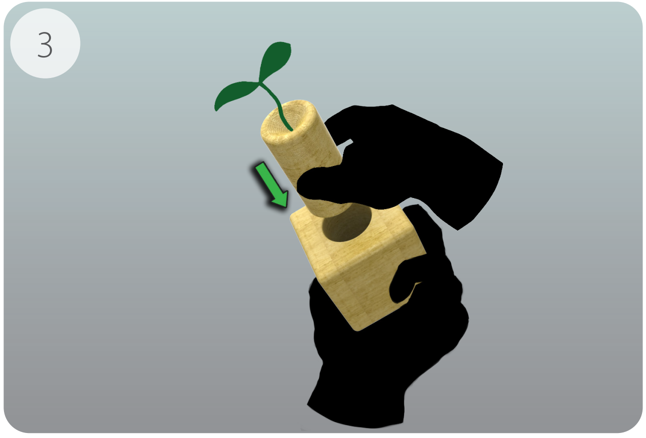
Starting out with Pivot is really easy:

~ 5-7 days

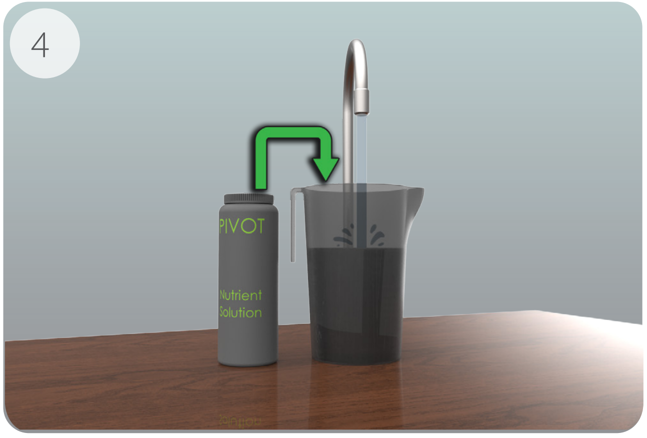
Water pre-soaked plugs are inserted into the water-filled germination box and seeds are placed in the middle of each one.



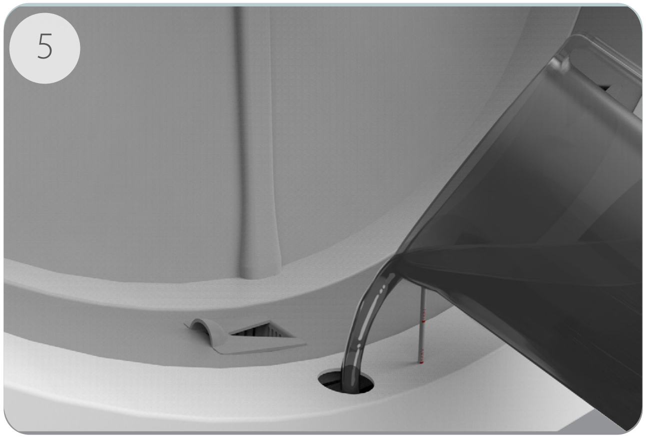
After about a week, the germination process is complete, and each plug should have a sprout with at least two leaves. They are now ready to be planted.



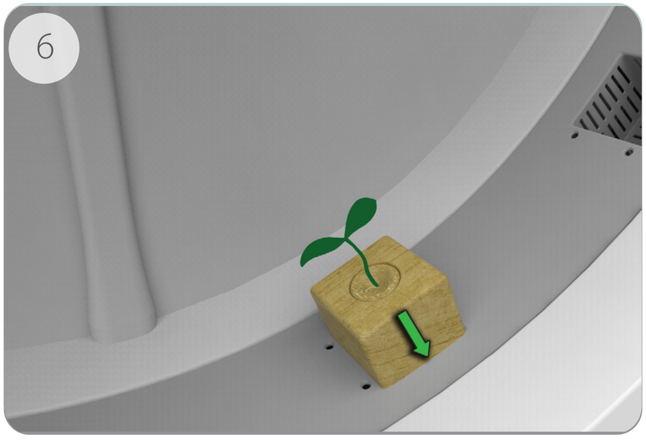
All the plugs are inserted into water pre-soaked Rockwool cubes.



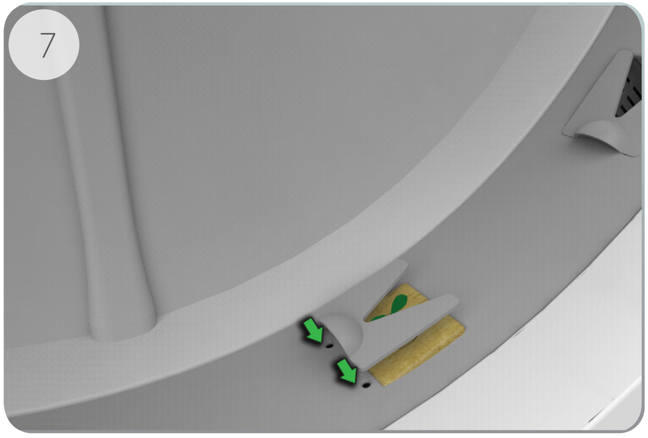
Water is mixed with appropriate amount of Pivot Nutrient Solution (follow the instructions or experiment with your own concentrations).



Now-nutrient water is poured down the refill hole on Pivot, until the water meter is at "MAX" indication.

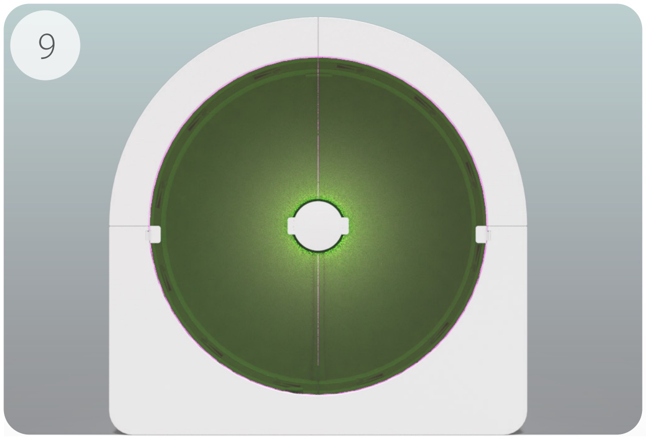


The Rockwool cube with the sapling is inserted into each of the twelve slots.

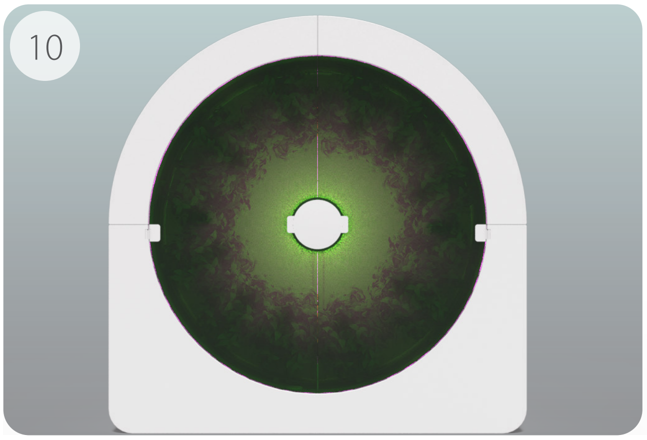


A plastic holder cap is placed in the holes to keep the plant in place. Take care not to squish the sapling.

Connect to Pivot with your smartphone, select the growth program (or make your own) and hit START.



The growing process with begin right away. Keep an eye on the water level at least once every two weeks.



Once the plants are fully grown, they can be harvested or cut, depending on the plant. You can incert new cubes with saplings at any time, if there is a free slot.

PIVOT

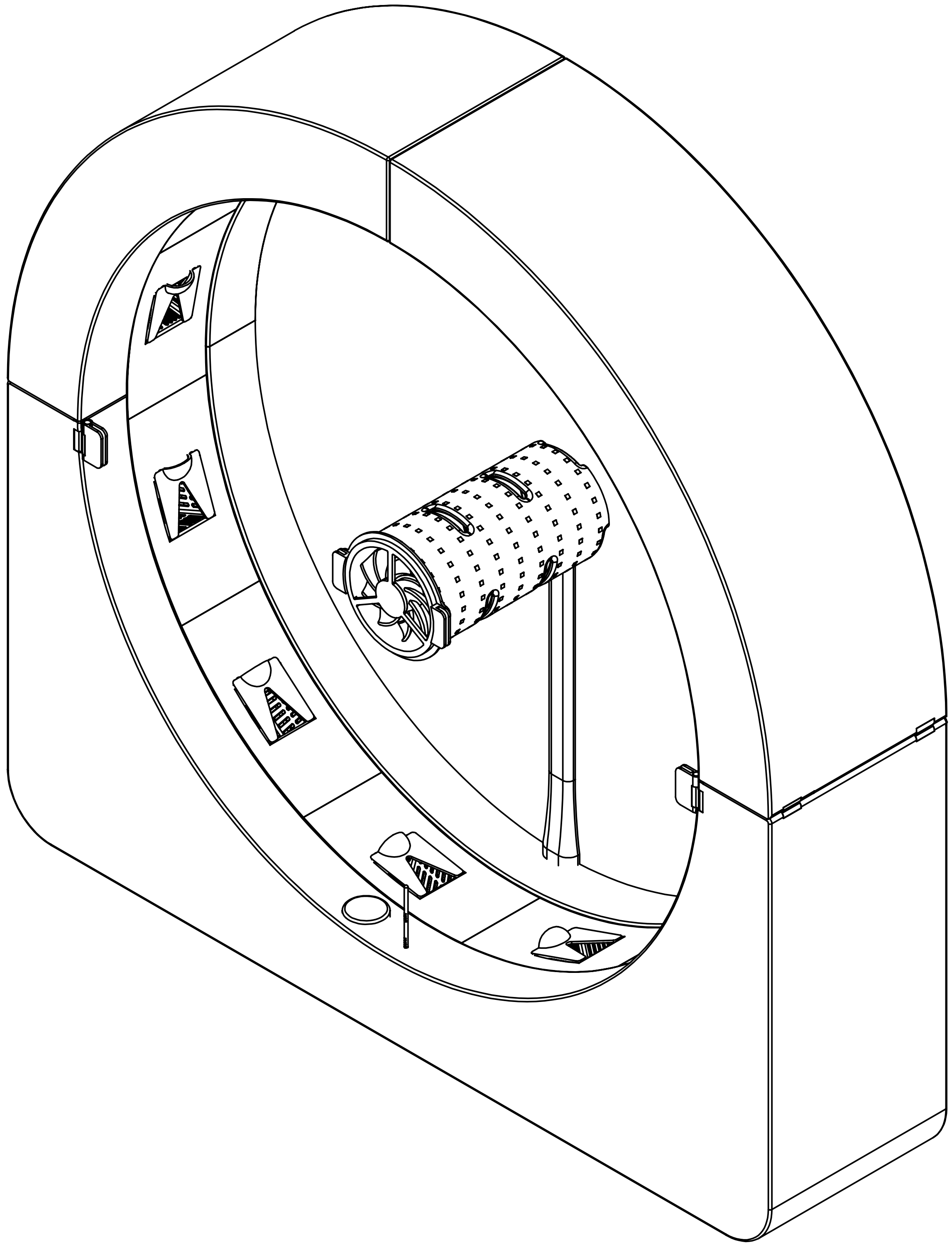
Home growing – your way

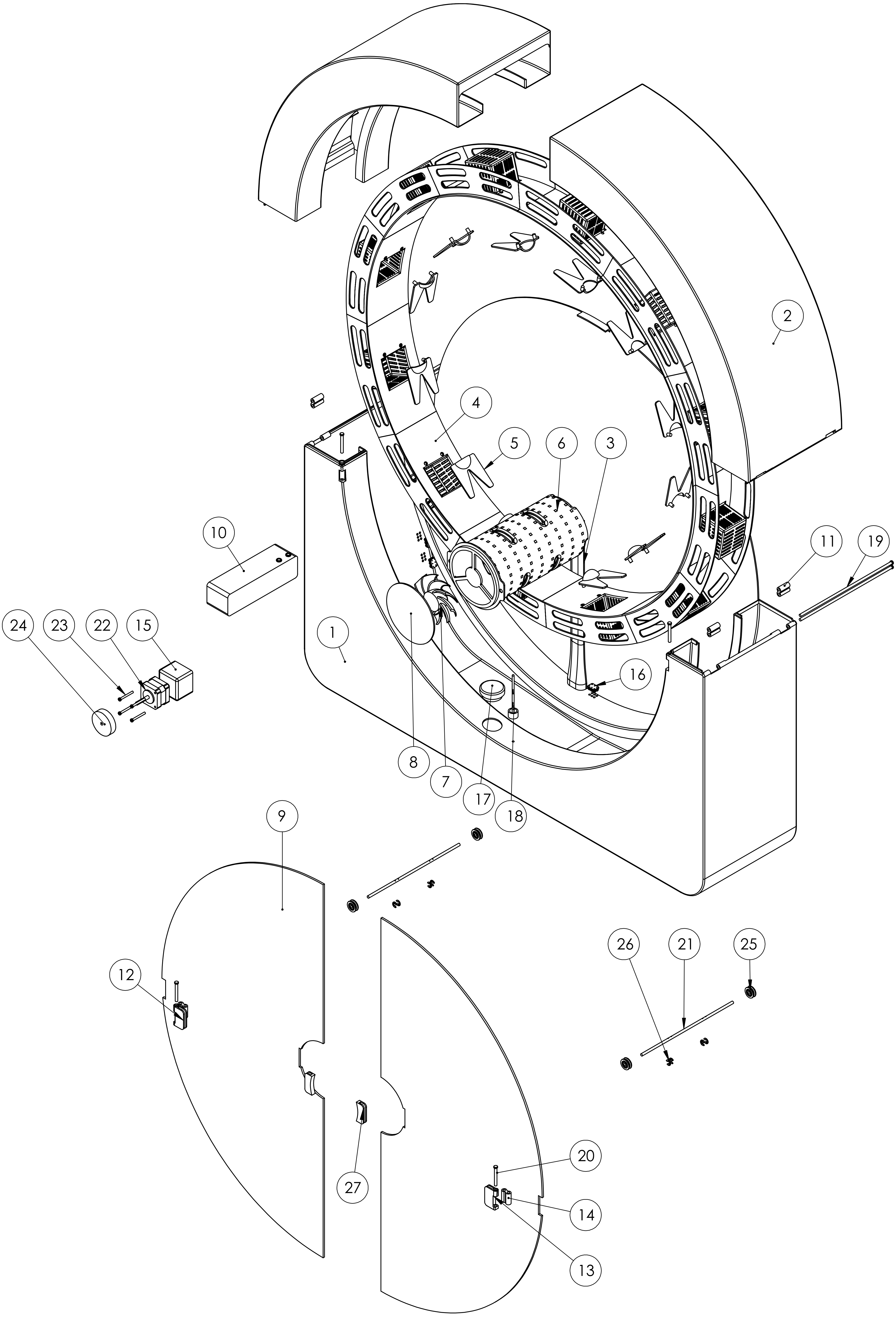
The majority of parts in Pivot are made out of injection-moulded PP plastic. These parts do not require technical drawings, since the moulds are producted out of digital files. This folder still includes an example of one of the plastic parts in technical drawing format to show the ability and knowledge of creating those.

The dimensions on the drawings do not indicate tolerance, as ALL of the tolerances are done in accordance with DS/ISO 2768 standard, MEDIUM, as noted in the header.

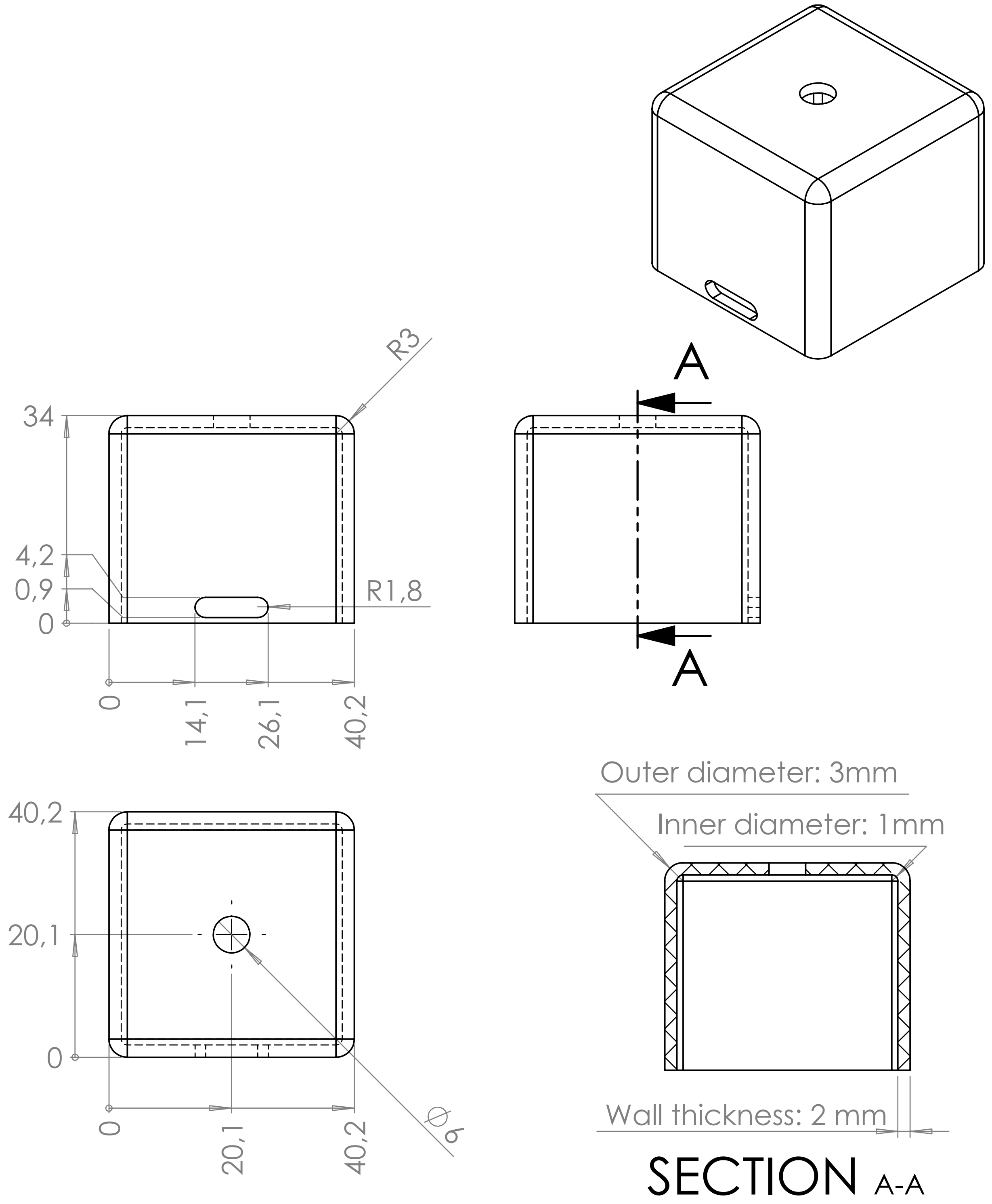
TECHNICAL FOLDER

Ma04-ID11 Nik Jensen, May 2017

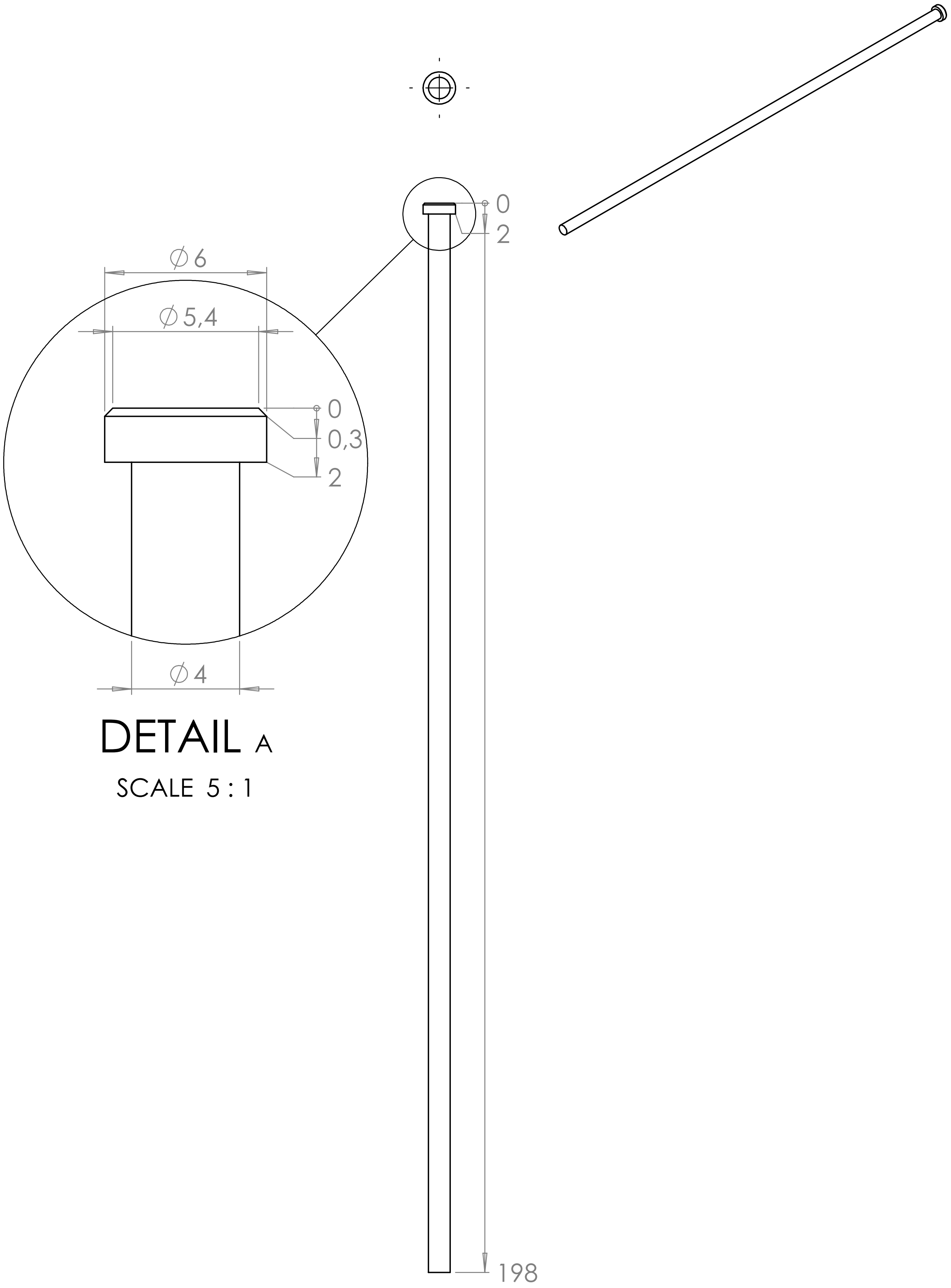



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27

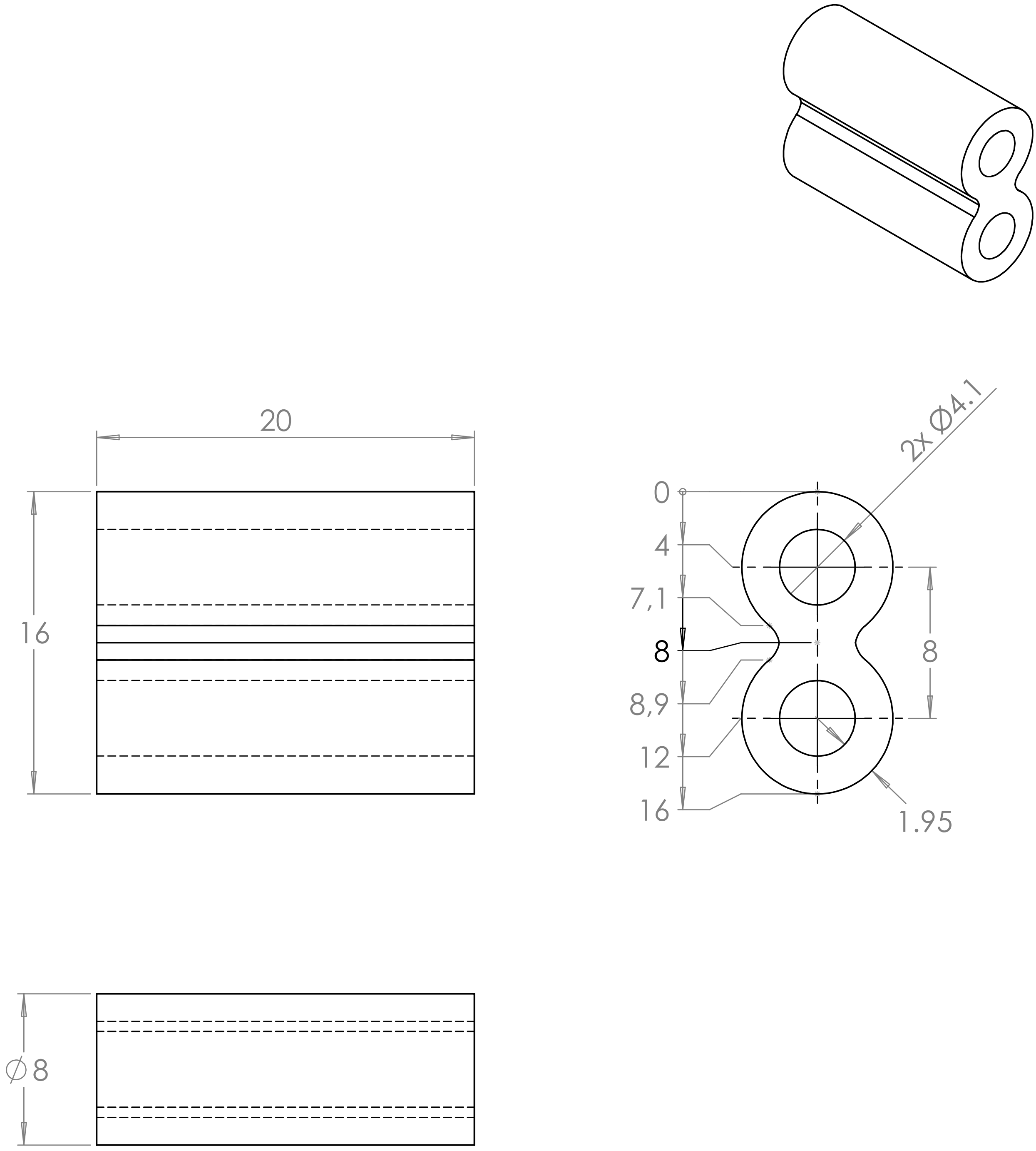
NO.	PART NAME	QTY.
1	Main Body	1
2	Top Lid	2
3	Wire Box	1
4	Wheel	1
5	Wheel Cap	12
6	Light Housing	1
7	Fan	1
8	Fan Cover	1
9	Screen Door	2
10	Electronics Box	1
11	Top Lid Hinge	4
12	Door Hinge Mount Left	1
13	Door Hinge Mount Right	1
14	Door Hinge	2
15	Motor Housing	1
16	Silicone Wire Seal	3
17	Refill Cap	1
18	Water Meter	1
19	Lid Hinge Rod	4
20	Door Hinge Rod	4
21	Roller Rod	2
22	PMX14-2 Step Motor	1
23	M4 Motor Screw	4
24	Motor Gear	1
25	Nylon Bearing	4
26	Lock Washer DIN 6799-4	8
27	Door Holders	2



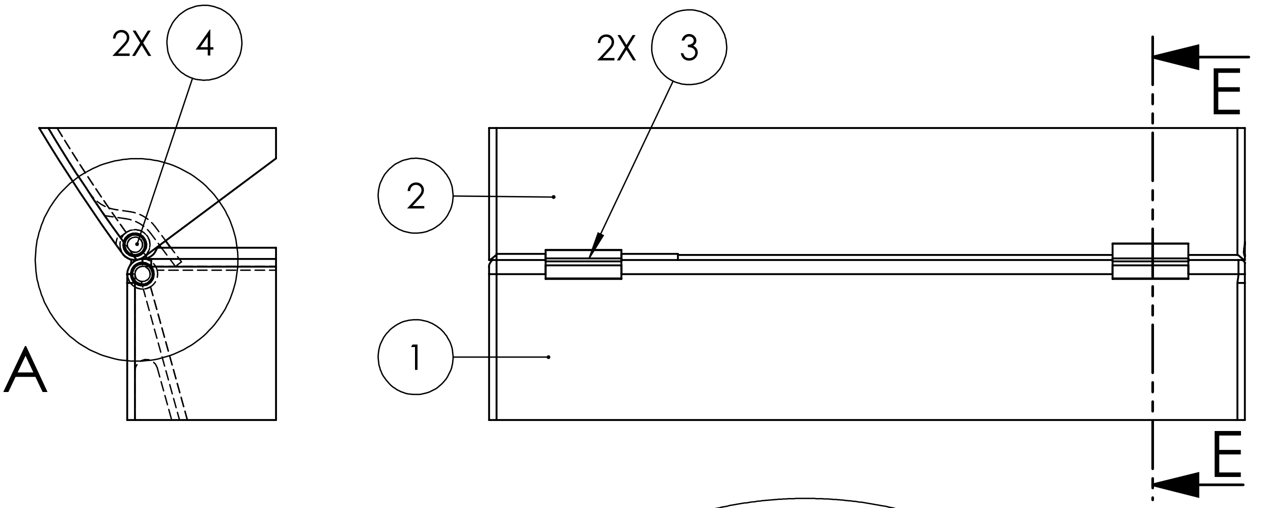
If not specified all dimensions are in milimeters Tolerance: DS/ISO 2768-m	FINISH: Glossy		Do not Scale	Revision
	Name	Dato	TITLE: Motor Housing	
DRAWN	NJ	16-05-17		
Material	Polypropylene copolymer		DWG NO. 1	A4
			Weight: 11.42g	Scale:1:1

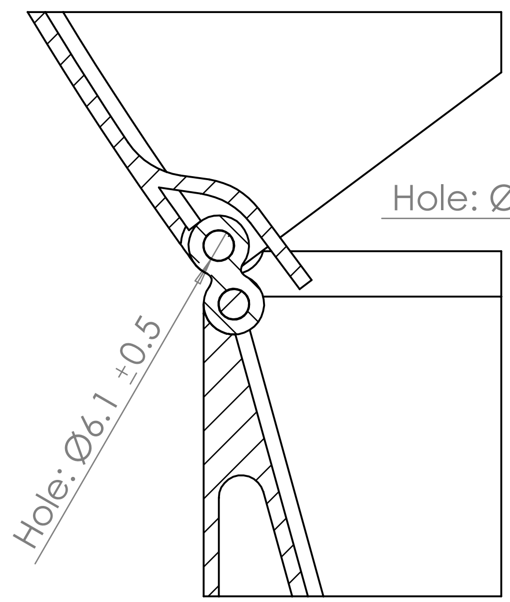


If not specified all dimensions are in milimeters Tolerance: DS/ISO 2768-m	FINISH: Polished		Do not Scale	Revision
	Name	Dato	TITLE: Steel Rod - Top Lid	
DRAWN	NJ	16-05-17		
Material 304 Stainless Steel			DWG NO. 2	A4
			Weight: 20.15g	Scale: 1:1



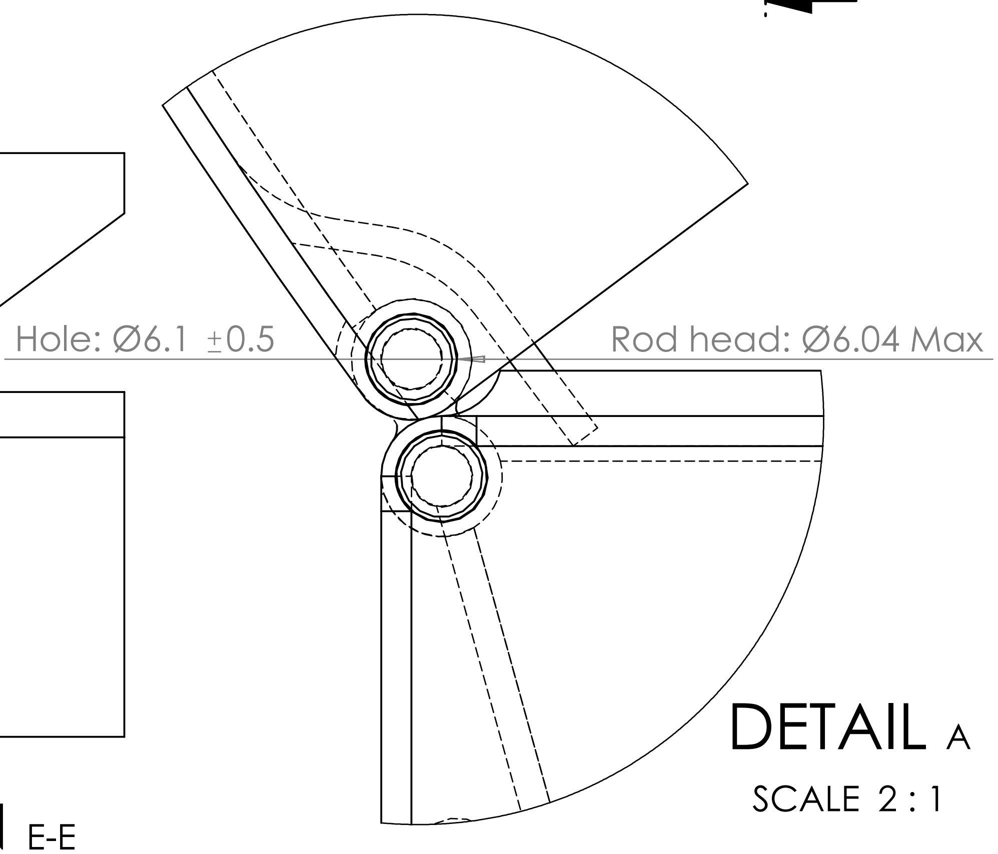
If not specified all dimensions are in milimeters Tolerance: DS/ISO 2768-m	FINISH: Glossy	Do not Scale		Revision
	Name	Dato	TITLE: Top Lid Hinge	
DRAWN	NJ	16-05-17		
Material: Polypropylene copolymer			DWG NO. 3	A4
			Weight: 1.37 g	Scale:3:1





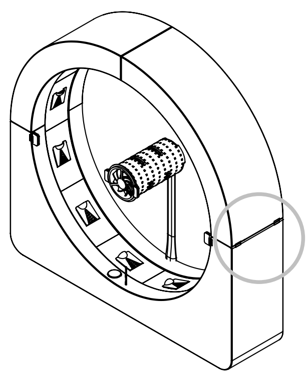
SECTION E-E

SCALE 1 : 1



DETAIL A

SCALE 2 : 1



ITEM NO.	PART NUMBER
1	Main Body
2	Top Lid
3	Top Lid Hinge
4	Lid Hinge Rod

If not specified all dimensions are in milimeters Tolerance: DS/ISO 2768-m	FINISH: -Varied-	Do not Scale	Revision
	Name / Dato	TITLE: Top Lid Hinge Assembly	
DRAWN	NJ / 16-05-17		
Material -Varied-		DWG NO. 4	A4 Scale: varies