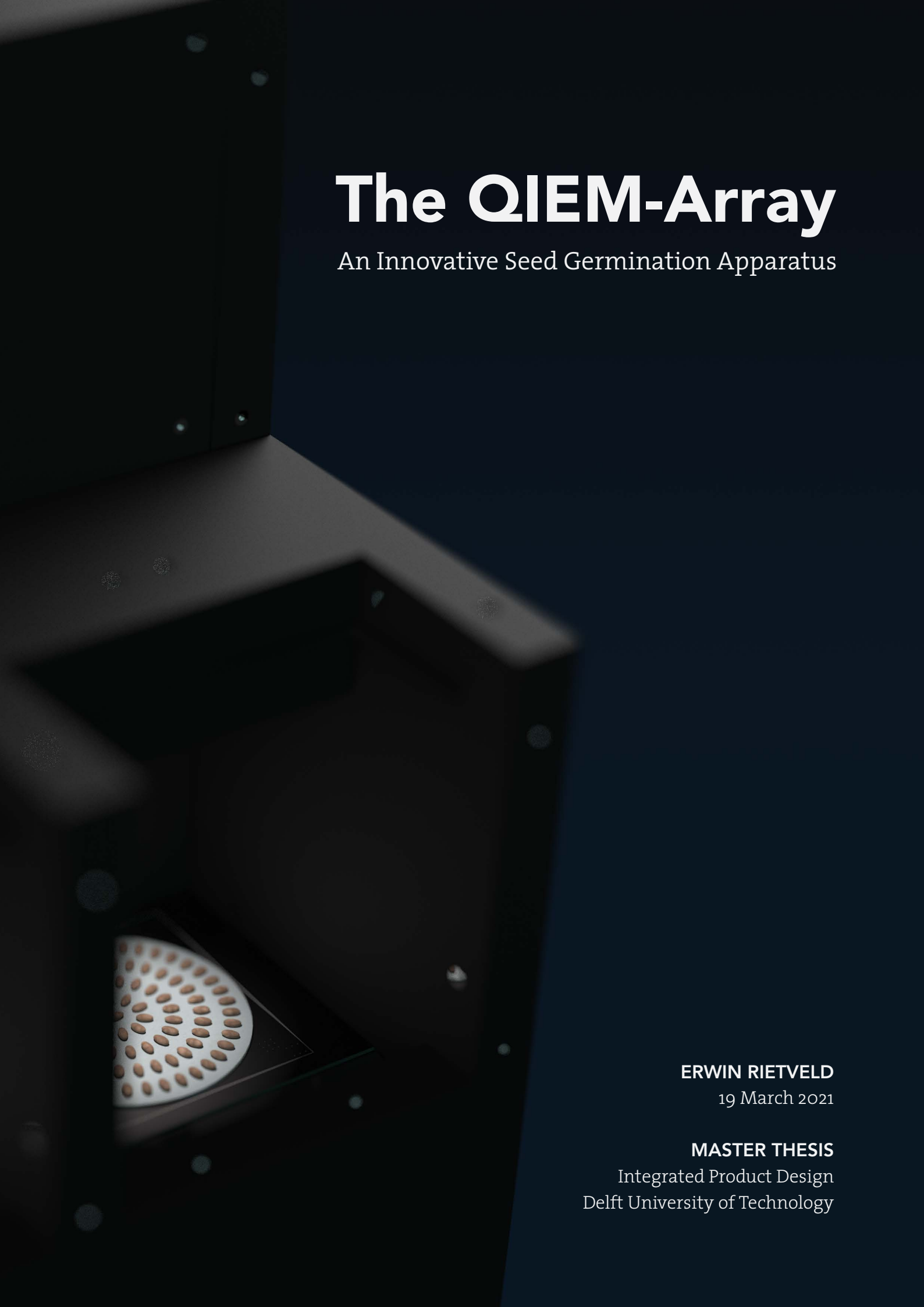

The QIEM-Array

An Innovative Seed Germination Apparatus

ERWIN RIETVELD

19 March 2021

MASTER THESIS

Integrated Product Design
Delft University of Technology

GRADUATION PROJECT REPORT

The QIEM-Array, an Innovative Seed Germination Apparatus

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Preface

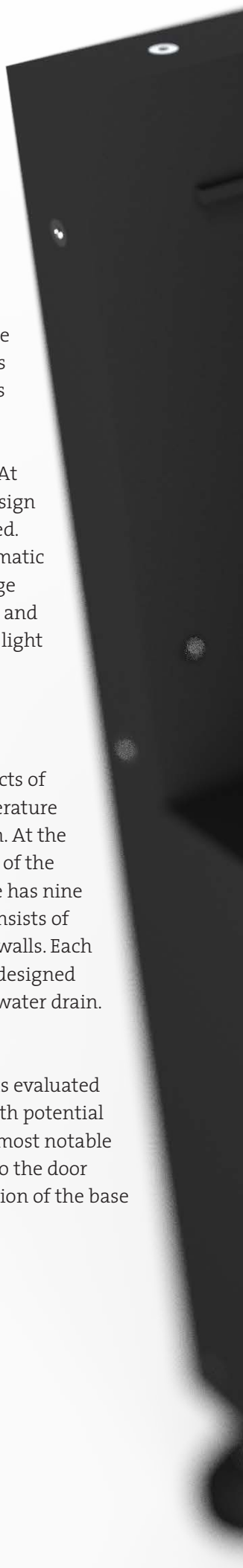
This report is the result of my graduation project for the master program Integrated Product Design at the faculty of Industrial Design Engineering on the Delft University of Technology.

I would like to thank Quantified for the opportunity to work on the QIEM-Array. The final product differs greatly from the brief. I would like to thank them for the freedom and responsibility I was given in the design process to go far beyond the intended project scope. This freedom ensured that I always enjoyed the project and was able to develop myself immensely. In particular, I would like to thank Warner Venstra for his helpful feedback, vast scientific knowledge, support and positive attitude.

Secondly, I would like to thank M91200, with in particular Marcel Flipse, for the helping me with the design of the electronics, allowing me to use their facilities to build the QIEM-Array. I have learned an awful lot about electronics and have greatly improved my soldering skills. And a big thanks for the tasty 'vlamtosti's'.

Finally, I would like to thank my Industrial Design supervisory team, consisting of Jos Oberdorf (chair) and Sander Minnoye (Mentor), for the valuable meetings, support and critical feedback. With your help, the project turned out better than I ever could have done on my own.

Executive Summary



PROJECT PHILOSOPHY

Quantified is a company that makes innovative products mainly for the agricultural industry. Quantified as a brand was analyzed. This resulted in a current brand personality (intelligent, competent, imaginative & sincere) and a desired brand personality for the future (reliable, successful, exciting & environmentally friendly).

Quantified had the idea to develop the germination table of the future. Envisioned functions were automatic classification of the seed germination process, temperature measurement and control, moisture measurement, light control, picking & placing of seeds, automatic nutrient addition, and advanced data analysis with machine learning.

For this graduation project, the initial plan was to design a 2D motion system as part of the QIEM-Array project. The project vision was analyzed further. The desired product traits were explored with a Product Envisioning Tool. The traits that Quantified found most important were: ease of use, precision, clean look, functionality and low development time.

ANALYSIS

In the analysis phase, the most important aspects of the germination process were research. Examples of factors that affect the germination process are water, temperature and light. A number of potential users from the seed industry were interviewed. They were asked about how they perform germination testing. Things they would like to measure and control are temperature, light and moisture. It was found that the ISTA regulations are important for the whole seed industry. These specify how germination tests must be done. With these tests the quality of the seeds can be determined. For example, the regulations specify per species what temperatures should be used for the tests and what the growth medium should be.

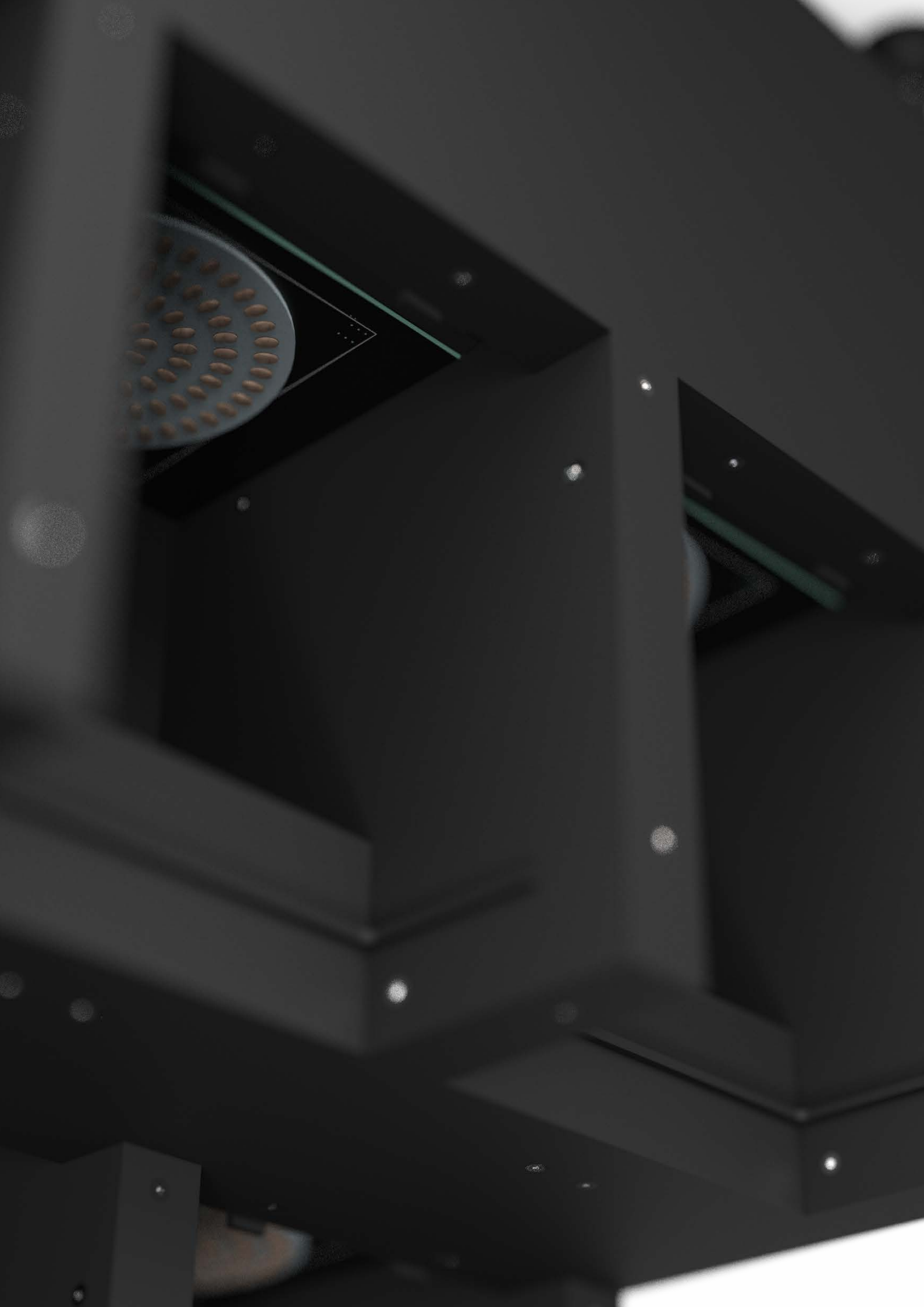
Furthermore, the requirements for automatic classification with image recognition and machine learning were examined. This showed that the use of convolutional neural networks is the most suitable. Moreover, it was decided to use a Peltier element for temperature control and capacitive sensors for moisture measurement. At the end of the analysis phase, the design vision for the QIEM-Array was formed. Functions include ISTA testing, automatic germination classification with image analysis, temperature measurement and control, moisture measurement and light control.

DESIGN SPRINTS

The design phase of this project was divided up into design sprints. Subjects of the sprints included imaging, temperature control, electronics and product form. At the end of the design phase, a prototype of the QIEM-Array was built. The prototype has nine cells in a stepped arrangement. It consists of an aluminum frame with insulated walls. Each cell has a camera and three custom-designed PCBs, temperature regulation and a water drain.

EVALUATION & RECOMMENDATION

The prototype of the QIEM-Array was evaluated in a couple of evaluation sessions with potential users and number of user tests. The most notable possible improvements are change to the door design with hinges and a simplification of the base frame construction.



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Introduction

The constantly growing world population has en ever-increasing food supply demand. With the decreasing quality of available agricultural land, innovations in the agricultural sector will play an increasingly crucial role. Increasing productivity, improving quality and increasing the nutritional values of the end products are key in combating the problems. In the seed industry, several germination tables and cabinets have been used for decades (figures on next page). These are used to determine the quality and germination power of seeds, and to find optimum germination conditions. These devices are low-tech, labor-intensive and prone to inconsistencies in results caused by subjective human classification.

The company Quantified from Leiden, along with the companies M91200 and Idematica, saw an opportunity to develop the germination table of the future; The QIEM-Array. It aims to automate some of the steps of germination research and provide advanced data to the user. This graduation project was conducted in the first phase of the QIEM-Array project. After a problem analysis, literature review and interviews with users, a first prototype was developed. This prototype has nine individually-controllable cells in which germination tests can be done. In these cells the temperature and light can be controlled, the moisture can be measured and pictures of the seeds can be taken. The data and pictures can be used for advanced analysis with machine learning algorithms.

The report is structured as follows. In Part A of the report, the QIEM-Array is presented, with the general product architecture in Chapter 1 and the working principle in Chapter 2. Chapter 3 is about the production. The cost price is calculated in Chapter 4. Part B of the report is about the project philosophy. Here the company and the company's project vision are analyzed in Chapter 5 and Chapter 6, respectively. Next, the trends and developments are explored in Chapter 7. The analysis phase is described in Part C of the report. First the Seed germination process is explored in Chapter 8. The next chapter is about the international regulations for seed testing. Chapter 11 and Chapter 12 are about the imaging and machine learning analysis of the seed germination process, respectively. In Chapter 13 and Chapter 14, methods for temperature measurement and control, and moisture measurement are discussed. In the final chapter of Part C, a distilled project vision is given. Part D is about the design phase of the project. This phase is divided up into small design sprints. The sprints cover the product form factor, seed bed, climate control, electronics, camera and prototype buiding. Finally, in Part E, the design is evaluated in Chapter 36. Recommended next steps are given in Chapter 37.


KTA 09

These seeds, after immersion for exactly one week, have all germinated, which I did not in the least expect.

Charles Darwin (1855)

PART A

Presenting the Design

This first part of the report presents the design of the QIEM-Array; an innovative seed germination apparatus. The QIEM-Array designed for the agricultural industry and can be used to perform germination research. It has individually-controllable cells in which seeds can be grown and monitored. The product is the result of the company and project analysis, literature study, user interviews and design sprints, which are described in the following parts of the report.

The product is designed according to the vision given at the end of Part C of the report. The functions and components include a camera that takes pictures of the seeds, lighting, temperature control and measurement, and moisture measurement. This gives the user much more control over the germination process. The large amount data generated can be used for advanced analysis. Although the device really looks like something different than what the industry is using now, the exterior design has remained fairly clean. The prototype in this project is capable of performing germination tests.

In this part of the reports, the product architecture and the working principle are presented. At the end of this part, the production steps are described and the cost price is calculated.

CHAPTER 1

General Product Architecture

The result of this project is a the design the QIEM-Array (Figure 1.1). This chapter shows the architecture of the design, from the basic frame to the cells and electronics. The outer dimensions of the QIEM-Array can be found in Appendix A on page 172.

The base of the frame consists of aluminum extrusion profiles (Figure 1.2). These are attached to each other with profile connectors. The walls are made of a combination of HDPE and EPS sheets.

In this version of the QIEM-Array has nine cells, in which germination tests can be performed (Figure 1.3). Each cell has a temperature-controlled seedbed PCB. It has a number of temperature and humidity sensors, allowing the process to be accurately monitored. The cells are mounted in the base frame (Figure 1.4).

The seedbed PCB is heated and cooled from below with a Peltier element (Figure 1.5). It is cooled with a water cooling block (Figure 1.6).

Two brackets are used to attach the microcontroller PCB to the seedbed PCB. The microcontroller PCB collects the sensor data, controls the camera and Peltier element, and communicates with the computer (Figure 1.6). The PCB is connected to several cables (Figure 1.7): the power supply (black cable), the camera (gray and red ribbon cable), and the computer (orange RJ45 cable).

The cooling block is connected to the cooling system with the blue tubes (Figure 1.8). Excess water from the cells is drained with the colorless tubes.

Both the cooling and data connections are chain-linked with other cells (Figure 1.9). The cooling tubes go from the cells to a pump, heat exchanger and water tank (Figure 1.10). The drain hoses converge and exit the QIEM-array.

Each cell has a camera at the top that can take pictures of the germination process (Figure 1.11). Around the camera lens is an LED ring, which can be used as a camera flash (Figure 1.12). It can also be used to constantly illuminate the seeds of species for which this is specified by ISTA regulations.

Data is communicated from and to the computer with a RJ45 cable. Figure 1.13, Figure 1.14 and Figure 1.15 show overviews of the connections of the QIEM-Array.

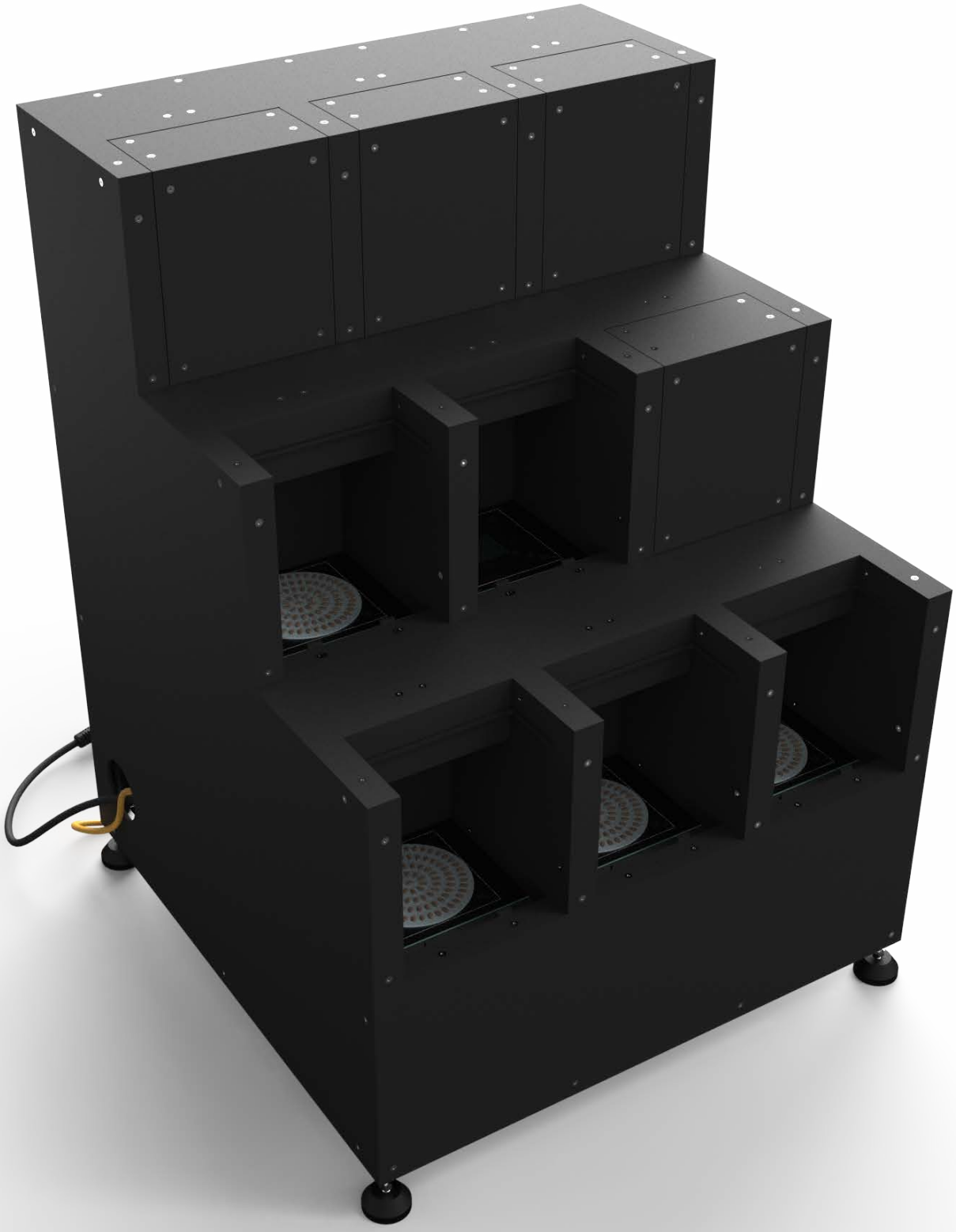


Figure 1.1: *The QIEM-Array, with a few open cells, from the outside.*

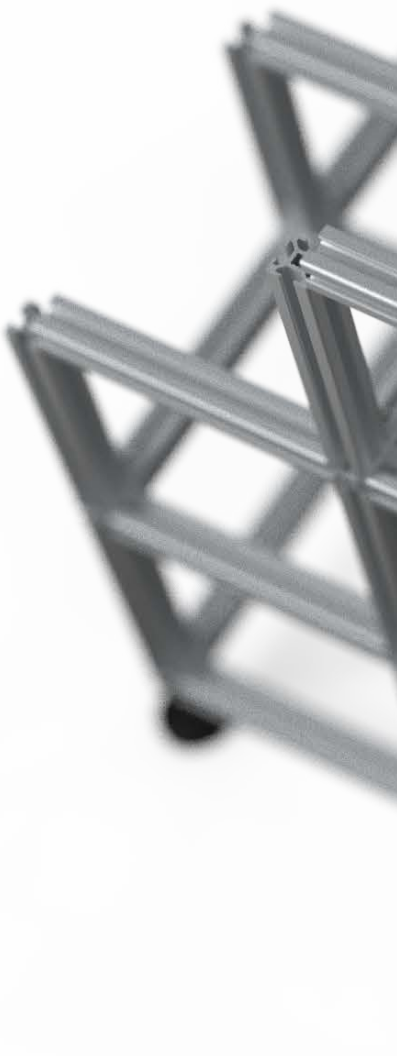


Figure 1.2: *The base of the QIEM-Array is built up from aluminum extrusion profiles, which are connected with internal frame connectors.*

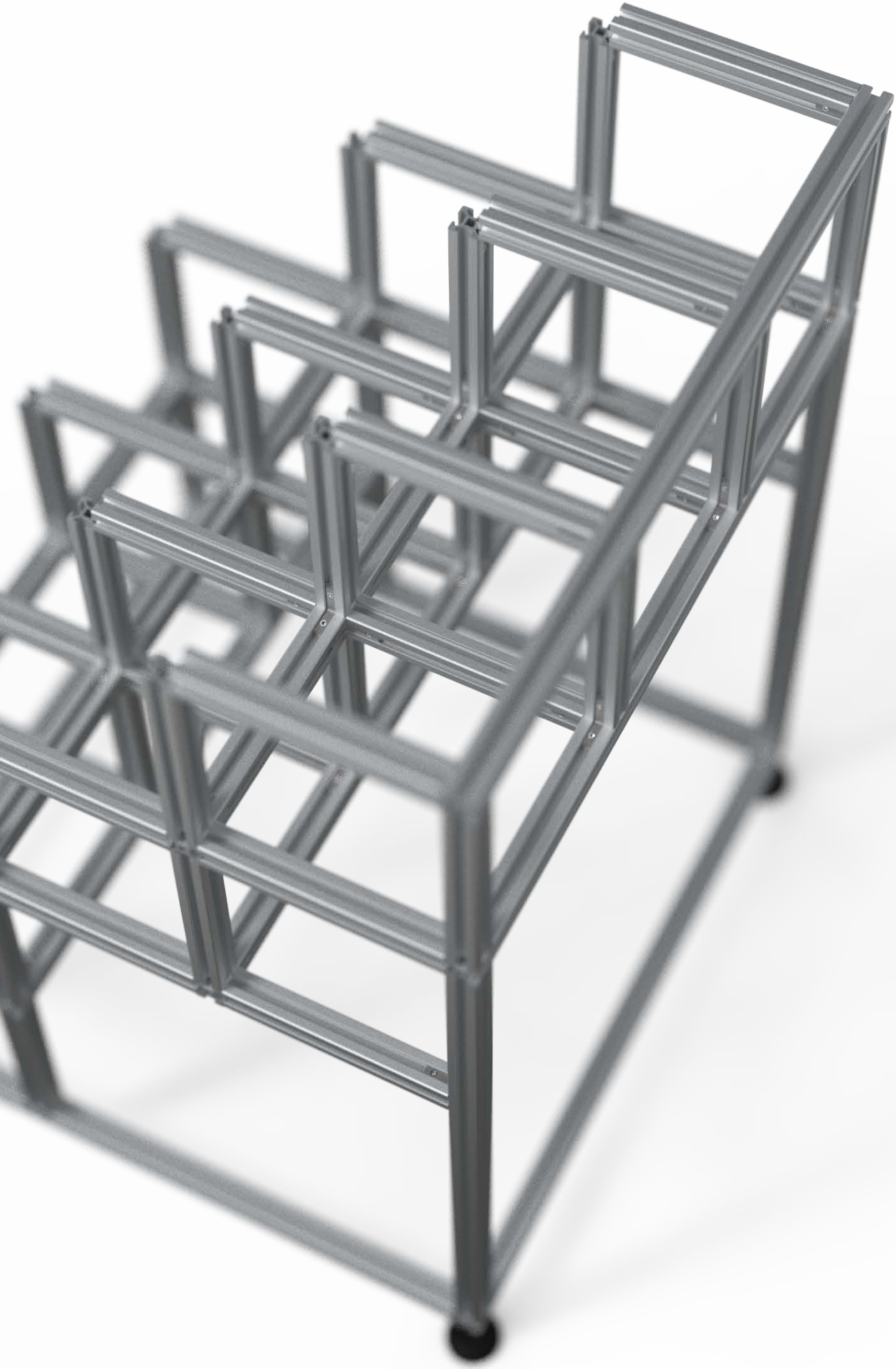


Figure 1.3: *The cells have temperature-controlled floor surface, on which filter papers with seeds can be placed to perform germination tests. The control electronics are placed in the bottom of the cell.*

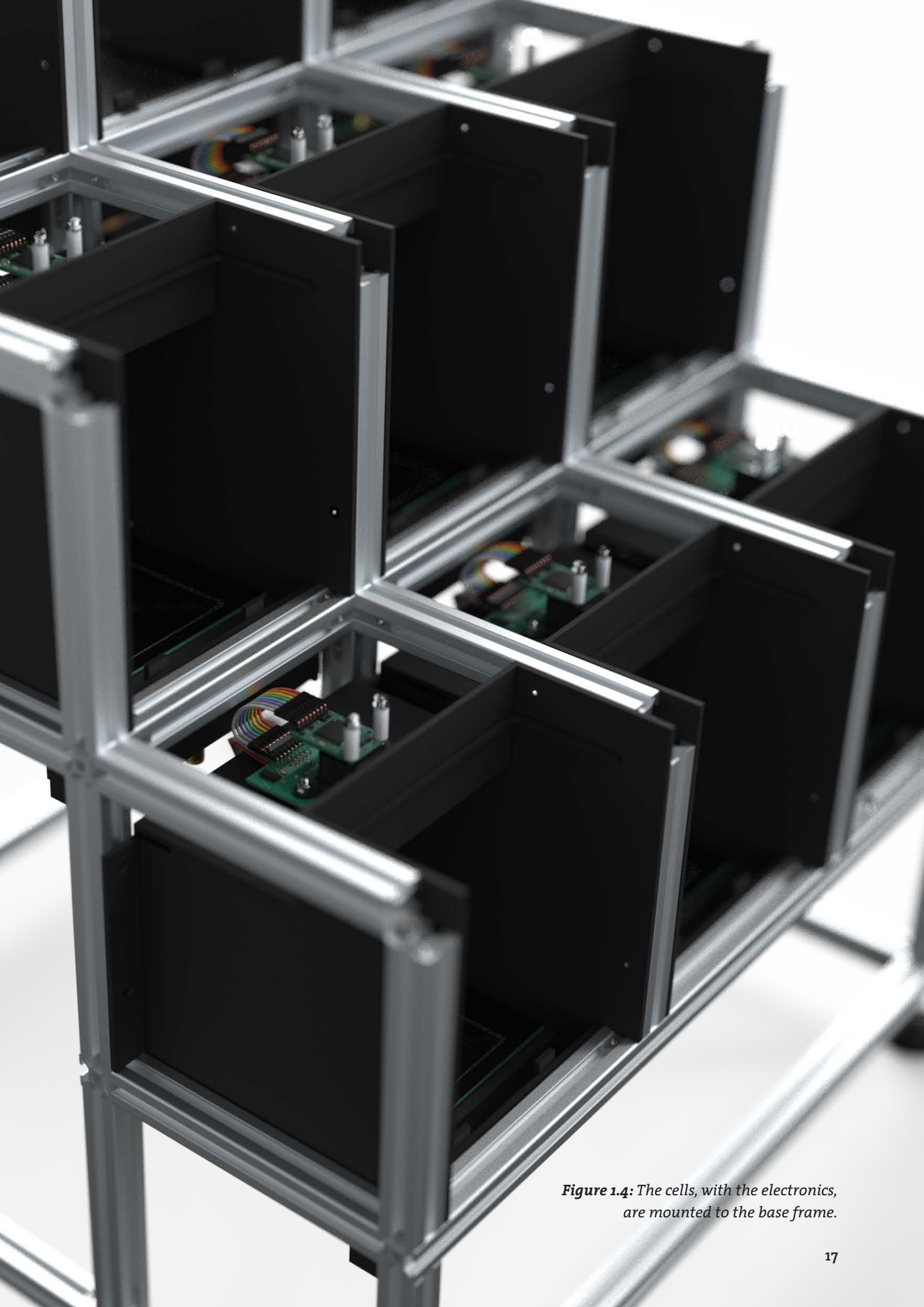


Figure 1.4: *The cells, with the electronics, are mounted to the base frame.*

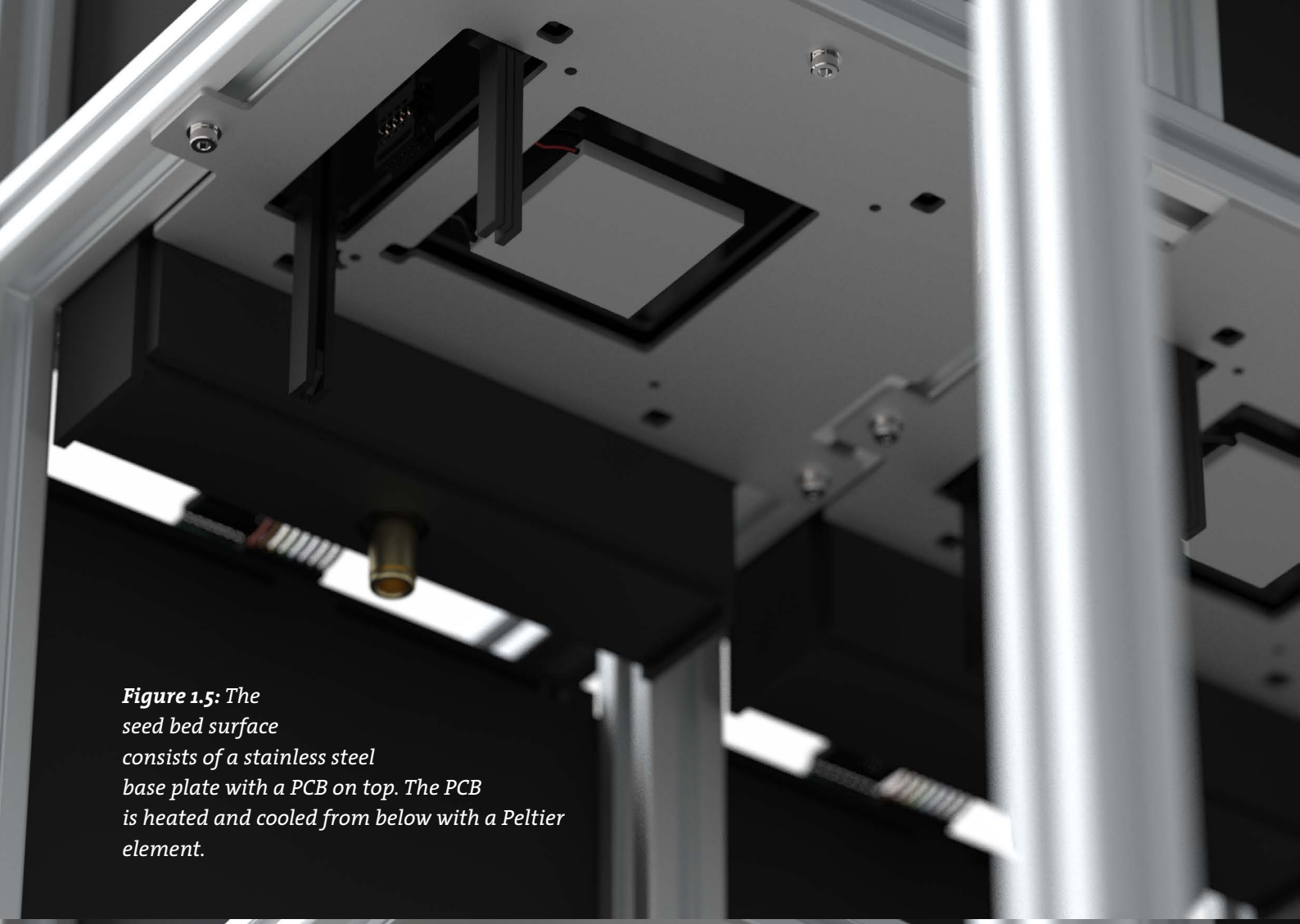


Figure 1.5: *The seed bed surface consists of a stainless steel base plate with a PCB on top. The PCB is heated and cooled from below with a Peltier element.*

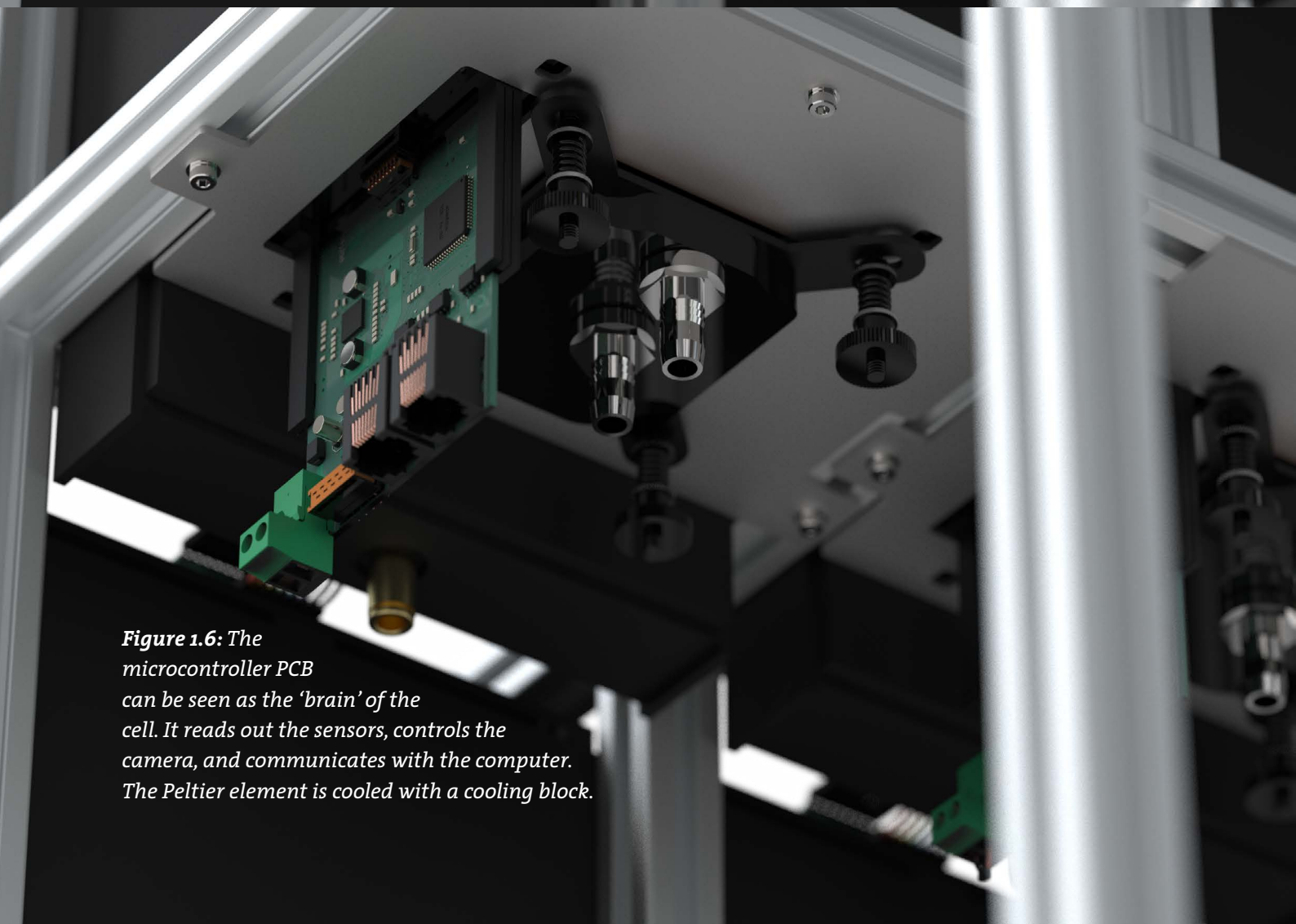


Figure 1.6: *The microcontroller PCB can be seen as the 'brain' of the cell. It reads out the sensors, controls the camera, and communicates with the computer. The Peltier element is cooled with a cooling block.*

Figure 1.7: *The microcontroller PCB is connected in a chain with other cells and the computer. A band wire connects it with the camera module in the top of the cell. There are also connections to the Peltier and power.*

Figure 1.8: *The water-cooled cooling block is chain-connected with other cells, a heat exchanger, a pump and a reservoir.*

Figure 1.9: *The data cables with RJ45 connections and cooling tubes are chain connected.*

Figure 1.10: *The pump, heat exchanger are situated in the bottom of the QIEM-Array.*

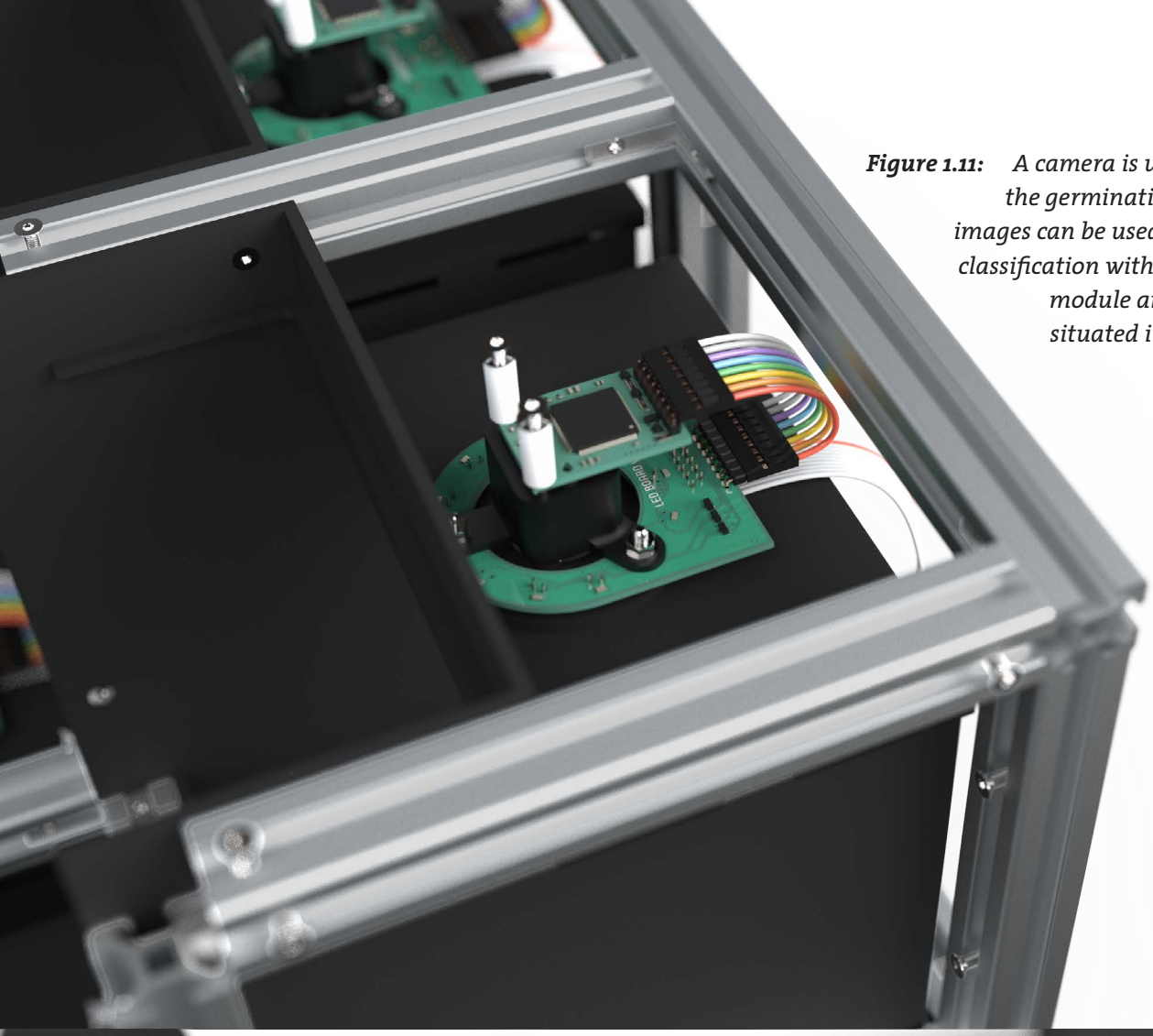


Figure 1.11: *A camera is used to monitor the germination process. The images can be used for automatic classification with AI The camera module and LED ring are situated in the top of the cell.*

Figure 1.12: *A transparent window protects the camera and the surrounding electronics from moisture from within the cell. The LED rings are used to provide light for the seeds and as a camera flash.*

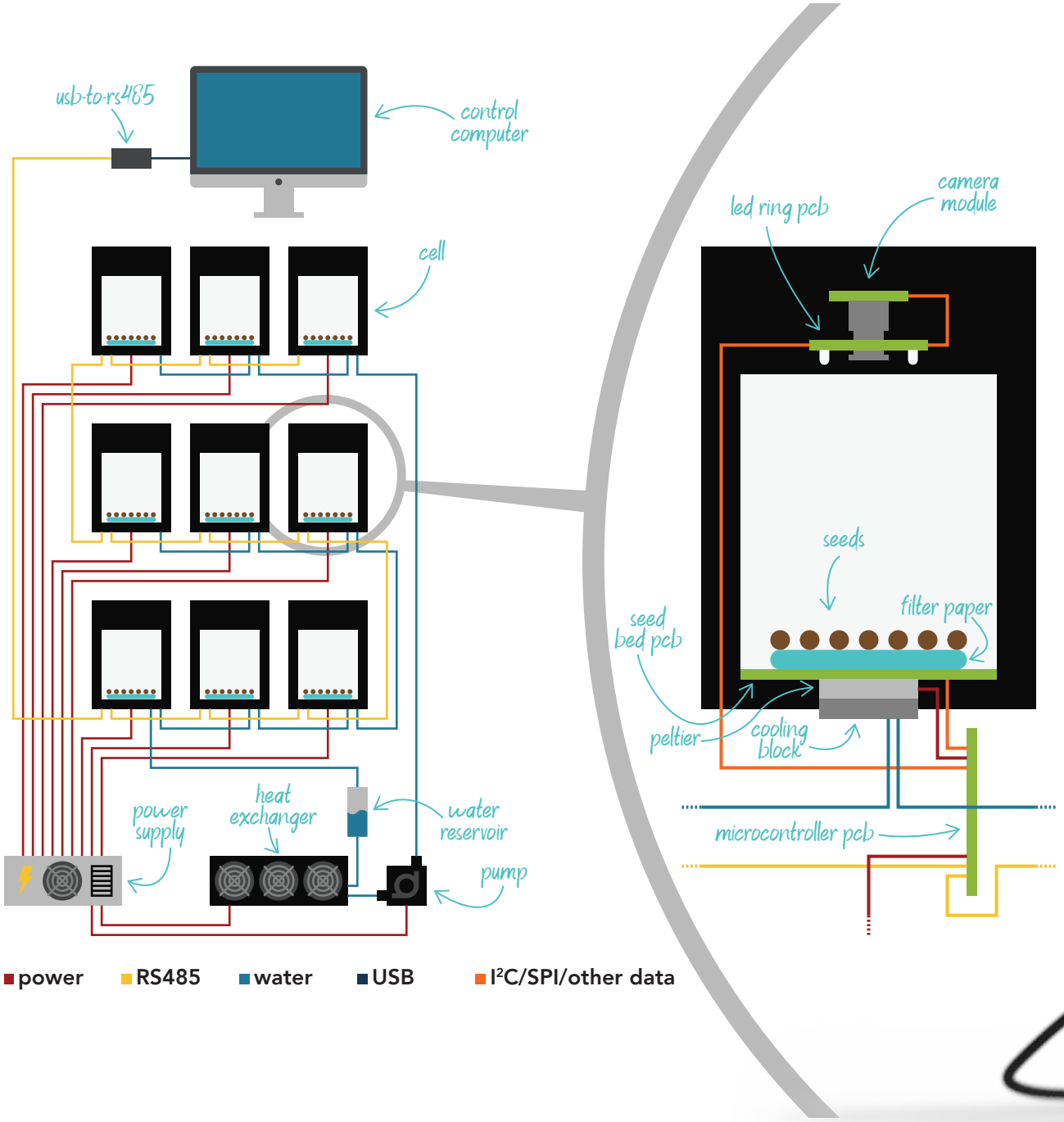


Figure 1.13: *Schematic overview of the connections between electrical and cooling components in the array. On the left the whole array and on the right one cell in more detail.*

Figure 1.14: *The QIEM-Array with some of the walls removed to make the inside connections visible.*

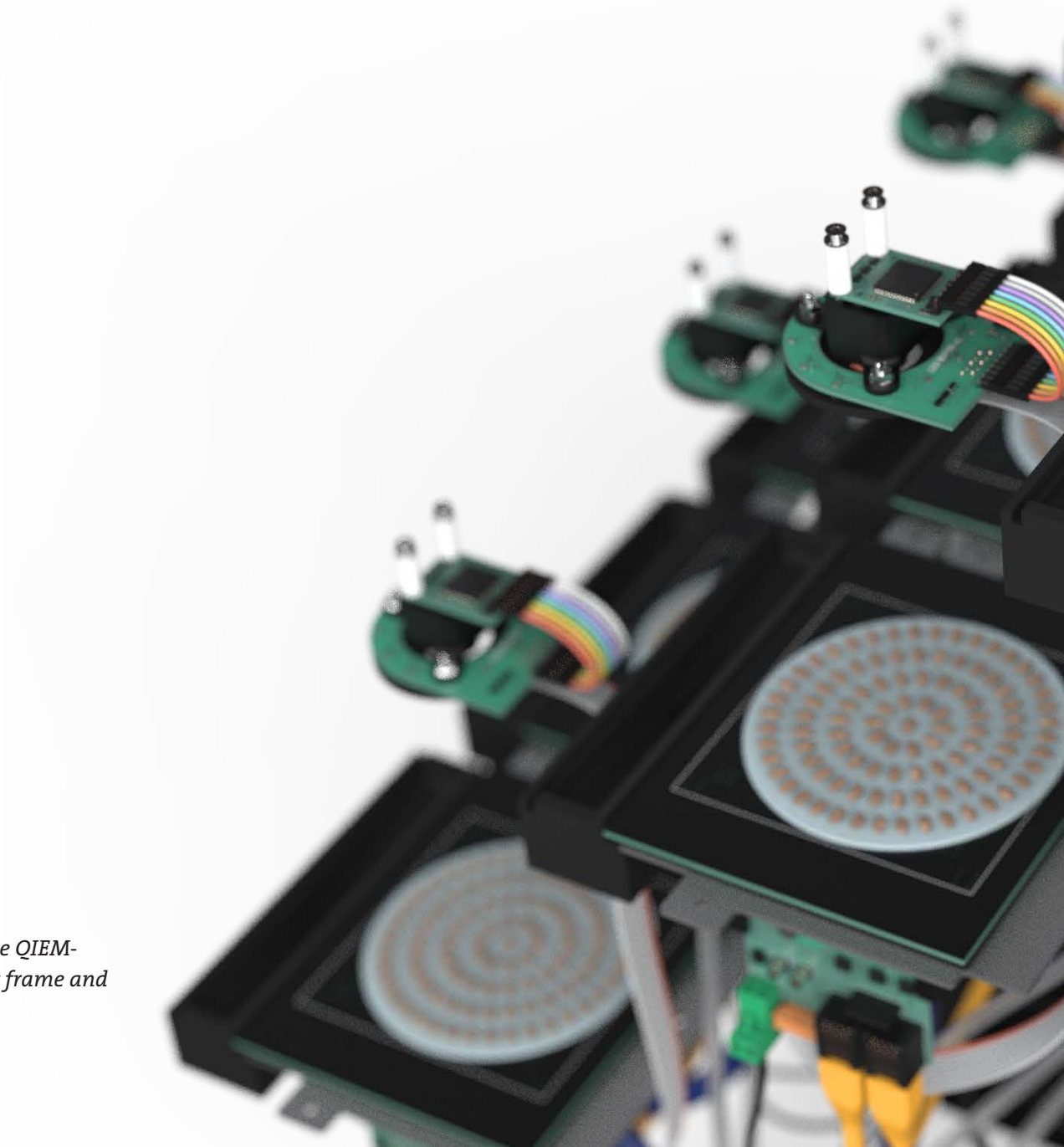


Figure 1.15: *The QIEM-Array without frame and walls.*

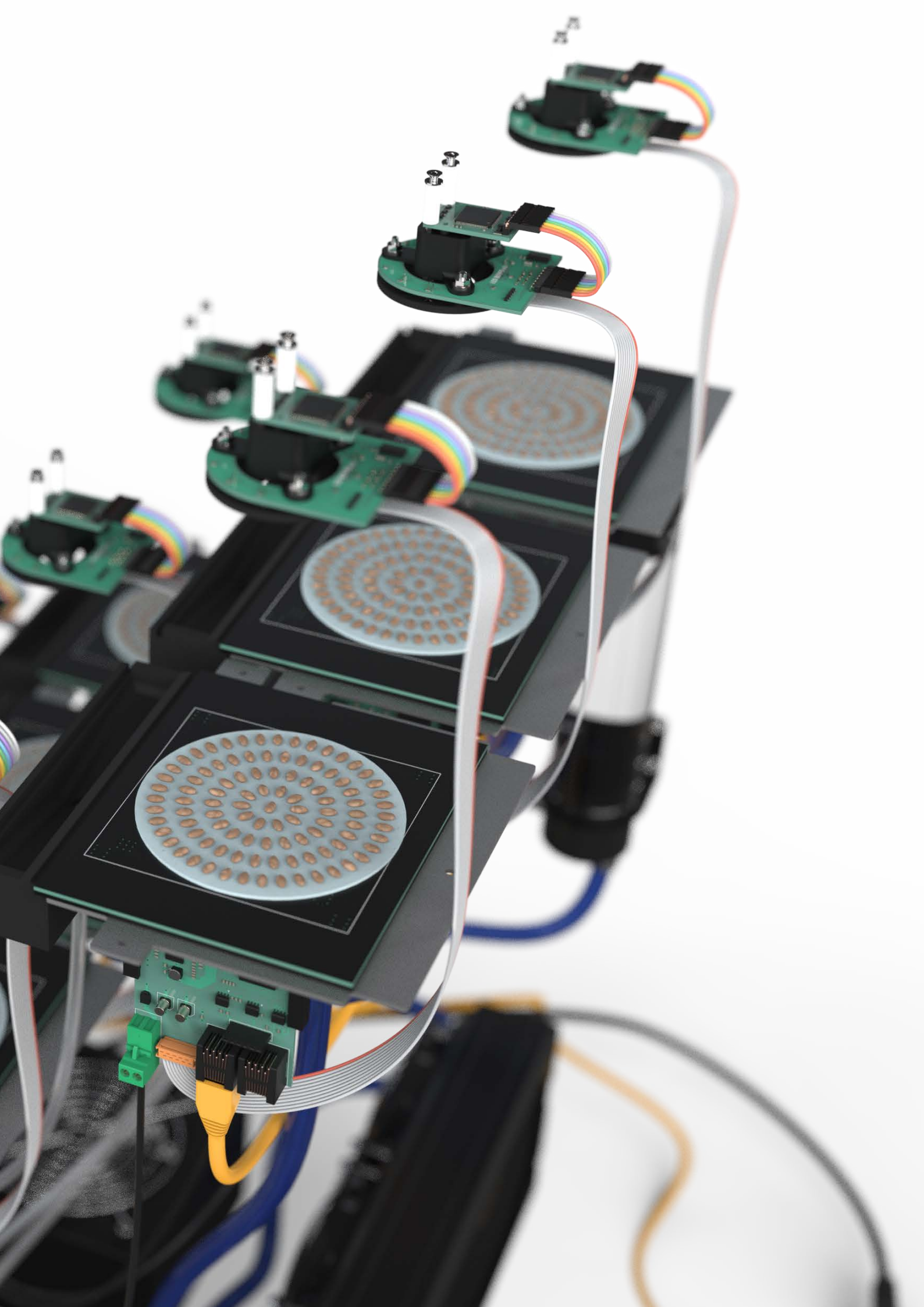


Figure 1.16: *The QIEM-Array.*

CHAPTER 2

Working Principle & Usage

This chapter goes through the working principle of the QIEM-Array from a user perspective. The interactions can be generally categorized as: starting the test, intermediate actions, ending the test.

2.1 TYPES OF TESTS

There are several tests a user can perform with the QIEM-Array: ISTA tests, custom tests and optimization tests.

2.1.1 ISTA TESTS

If the user wants to test according to the ISTA regulations (Chapter 9 on page 66), they can select the species from a list. The software has a database that includes all temperature profiles, light profiles and timing specified by ISTA for each species. The program corresponding to the seeds in the cell can be selected and the test can be started. In case a of an ISTA test, 400 seeds have to be tested in batches no larger than 100 seeds. That means a minimum of four cells have to be used per test.

2.1.2 CUSTOM TESTS

There may be times when a user would like to do a germination test, but would not necessarily want to adhere to the ISTA profiles. This could be, for example, to test new species or for other experiments. The user can then enter a test program of their own. These can also be saved and retrieved.

2.1.3 OPTIMIZATION

Some breeders produce special and exotic species. For these species it is often very valuable to find the optimal germination conditions. With the QIEM-Array the seeds can be divided over a number of cells with different conditions. The effect of temperature profiles, moisture light is can be found. In this way optimal conditions can be found.

2.2 PLACING THE SEEDS

The user can open the cell by opening the door. (Figure 2.1) Then a filter paper can be placed in the cell, after which it can be damped with water. Then the seeds can be placed on the paper, either with a vacuum placer (Figure 2.2) or by hand. After these steps are completed, the door can be closed and the test can be started.

2.3 STARTING THE TEST

If everything is setup correctly, the test can be started. In the control software on the computer, the program of choice can be started, individually for each cell or grouped (Figure 2.4). The program gives detailed feedback about the germination processes in each cell.

2.4 INTERMEDIATE ACTIONS

According to the ISTA regulations, germinated or badly decayed seeds have to be removed from the seed bed at specified moments during the test. Furthermore, the paper has to be moistened in case it gets to dry. To perform these actions, the user can open the cell door. The software indicates graphically which seeds have to be removed and weather the seed bed has to be moistened.

2.5 END OF TEST

The software will indicate when the test is complete. The cell(s) can be opened and the filter paper and remaining seeds discarded. Then the cell can be cleaned (Figure 2.5). This can be done with water and/or detergents. The water can then go into the drain in the front of the cell and exit the QIEM-Array through a tube (Figure 2.6). To disinfect the seed surface, it can be temporarily heated to a temperature above 100 degrees Celsius. Then the cell is ready for the next test.

Figure 2.1: *The door of the cell can be opened by the user to perform action inside the cell.*

Figure 2.2: *Seeds can be picked up with a vacuum head. The vacuum head makes ensures adequate spacing between the seeds and is time-saving compared to manual placement.*

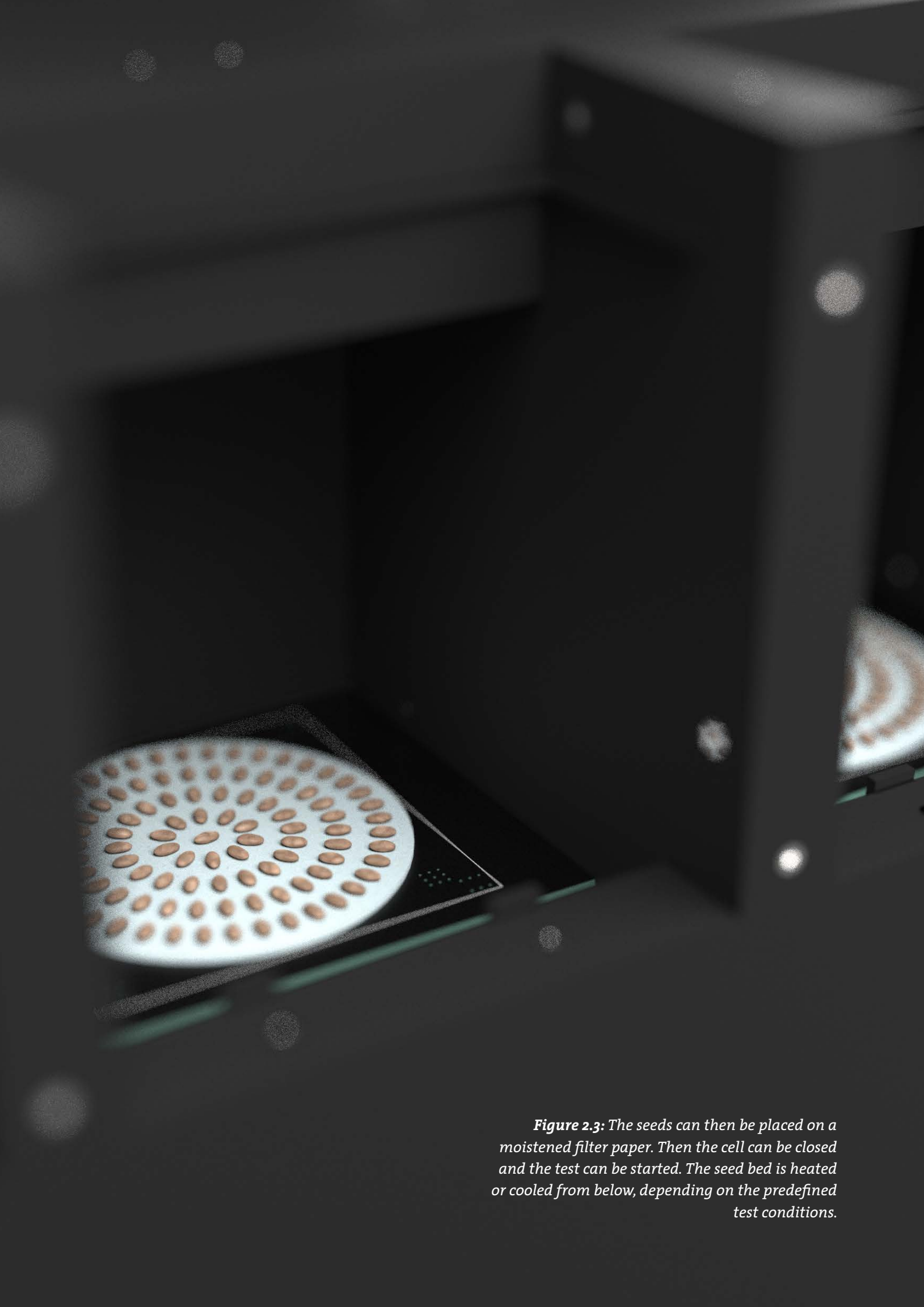
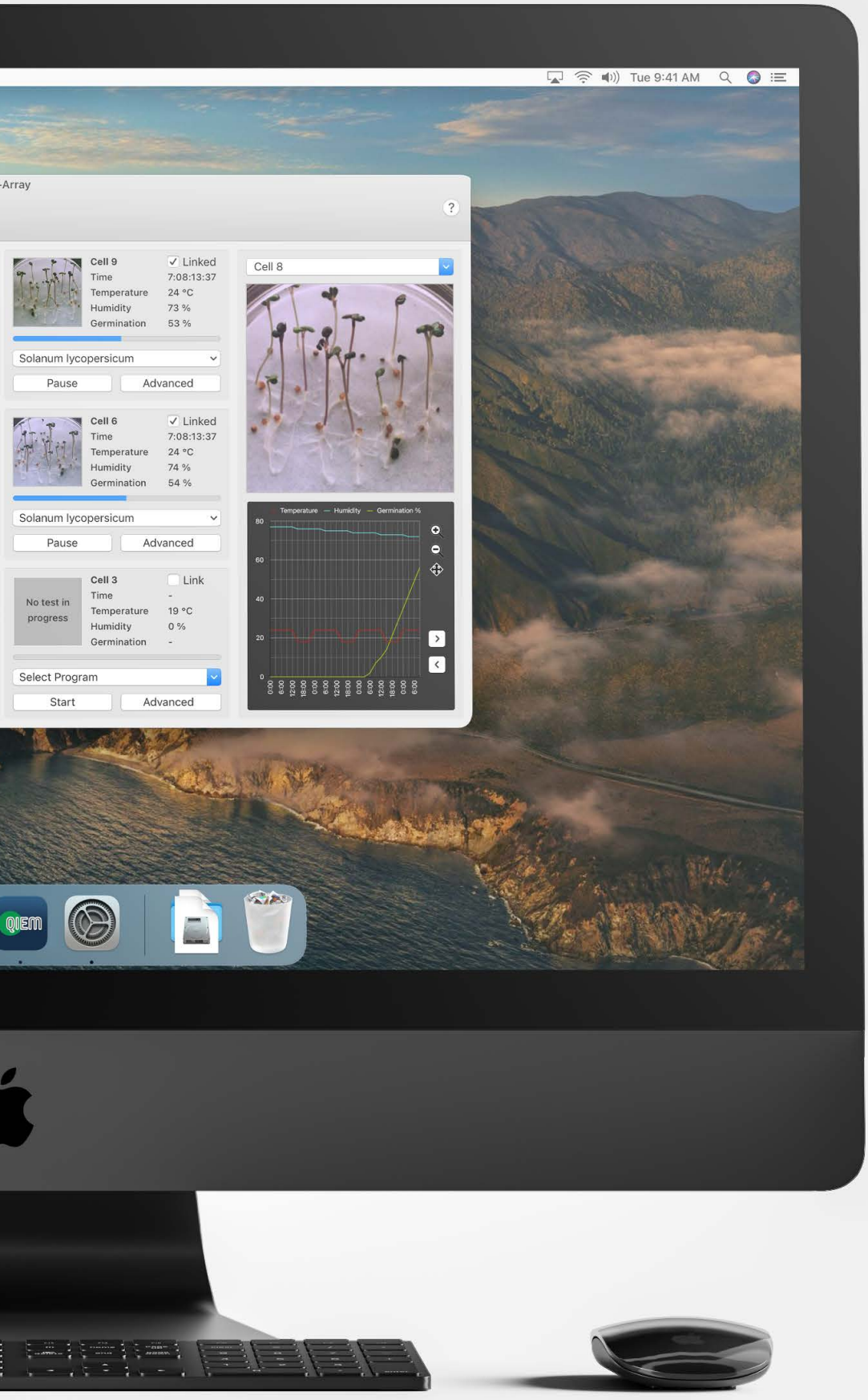


Figure 2.3: *The seeds can then be placed on a moistened filter paper. Then the cell can be closed and the test can be started. The seed bed is heated or cooled from below, depending on the predefined test conditions.*

Figure 2.4: *The QIEM-Array control software. The user is able to perform ISTA or custom tests, or optimization*



algorithms, and get detailed data. Each cell can be controlled individually or grouped together with other cells.

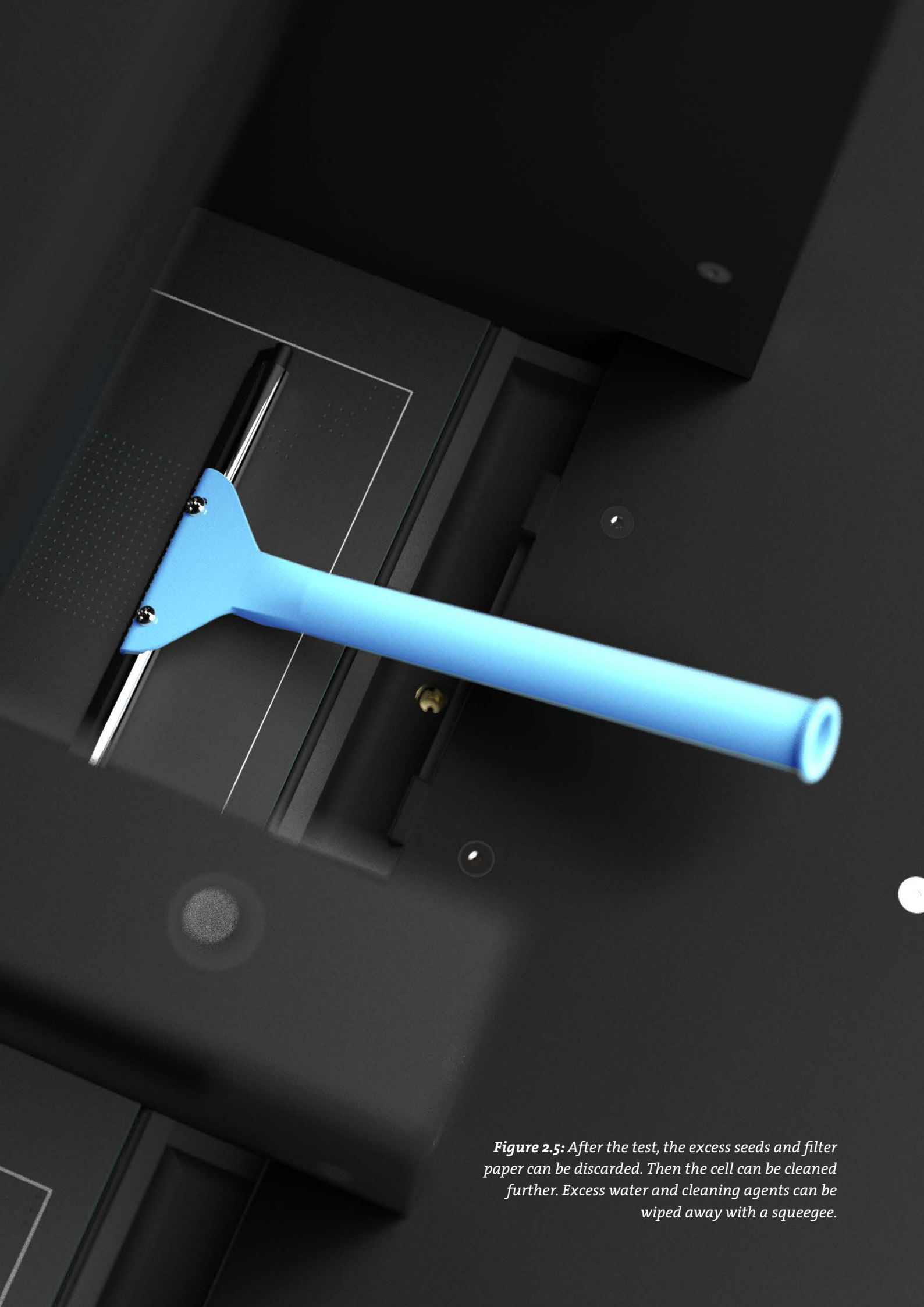


Figure 2.5: *After the test, the excess seeds and filter paper can be discarded. Then the cell can be cleaned further. Excess water and cleaning agents can be wiped away with a squeegee.*

Figure 2.6: *The water will exit the QIEM-Array through the blue tube.*

CHAPTER 3

Production

The main components of the QIEM-Array are the aluminum frame, the walls and the electronics. This chapter describes the production steps of this product.

3.1 BILL OF MATERIALS

A bill of materials (BOM), with the components needed to manufacture the QIEM-Array, can be found in Appendix B on page 174.

3.2 FRAME

The frame and cell doors are built up from aluminum extrusion profiles (Figure 3.1). The profiles are cut to length externally, by the company Aluxprofiel in Tegelen.

The frame and doors are assembled by hand. The profiles are connected with internal profile connectors in the corners (Figure 3.2). The frame connectors are bolted in place with a pair of set screws. More about the frame design can be seen in the sprint "Form 5" on page 133.

3.3 WALLS

After the frame is assembled, the walls can be attached. The walls are made of two materials: 3 mm thick HDPE and 20 mm thick EPS. The HDPE plates are laser cut externally. Most plates are attached directly to the aluminum profiles with countersunk screws and T-slot nuts that fit in the profiles (Figure 3.3). The EPS plates are cut to size with a simple utility knife. Thereafter, they can be placed in between the profile and walls (Figure 3.4).

Figure 3.1: *Construction of the frame with aluminum extrusion profiles.*

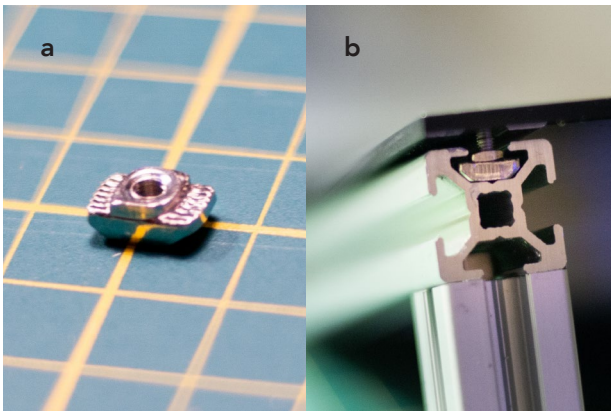


Figure 3.3: *a: M3 profile nut. b: HDPE plate being connected to a profile.*

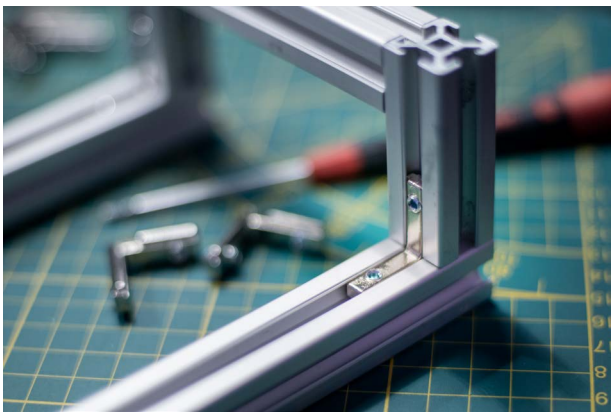


Figure 3.2: *Aluminum extrusion profiles connected with internal profile connectors.*

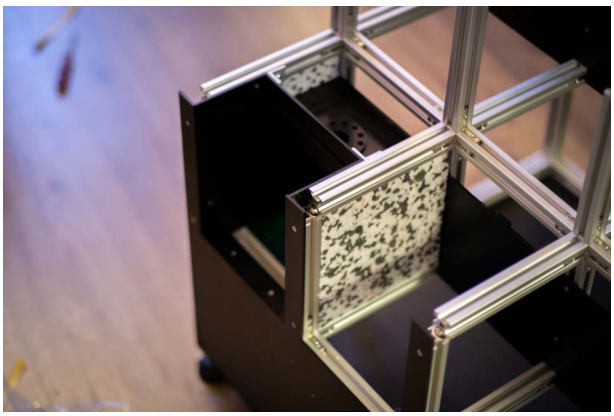


Figure 3.4: *HDPE walls connected to the frame, with EPS plates in between.*

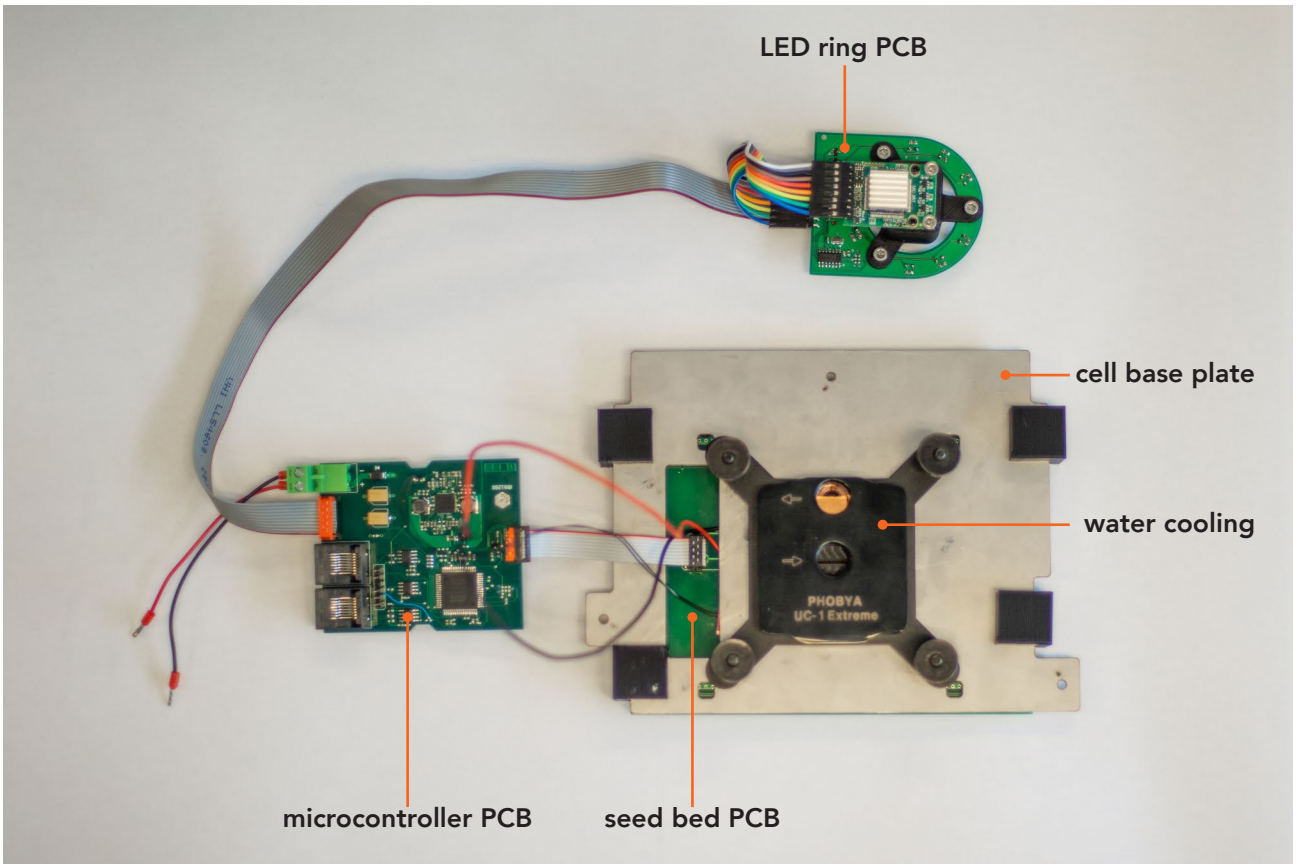


Figure 3.5: *The three PCBs connected.*

See the sprint "Climate 1" on page 129 for more about the insulation.

3.4 ELECTRONICS

The various electronic components are described in this section.

3.4.1 PCBS

Each cell of the QIEM-Array has three different PCBs (Figure 3.5):
The seed bed PCB (two layers).

- The microcontroller PCB (four layers).
- The LED ring PCB (two layers).

These PCBs are produced externally. The boards are manufactured in a factory in China. Then the other components, such as sensors, microcontrollers and cable connectors, can be soldered onto the boards. This is done by the company M91200 in Delft. All components can be soldered on by hand, but when more than a few have to be made, they can be soldered automatically by a pick and place machine and an oven. When the components are soldered onto the PCB, they can be placed in the QIEM-Array. More about the PCB designs can be seen in the sprint "Electronics 5" on page 143.

SEED BED PCB

The seed bed PCB (Figure 3.6) measures the temperature and moisture of the seed bed. It is clamped between the HDPE cell walls and the cell bottom plate. It is connected to the microcontroller PCB with a band cable.

MICROCONTROLLER PCB

The microcontroller PCB gathers data from the sensors, controls the camera and LEDs and communicates to the computer. It is connected to the seed bed PCB with a band cable and brackets (Figure 3.7). RJ45 connectors are used for the data transfer to and from the computer.

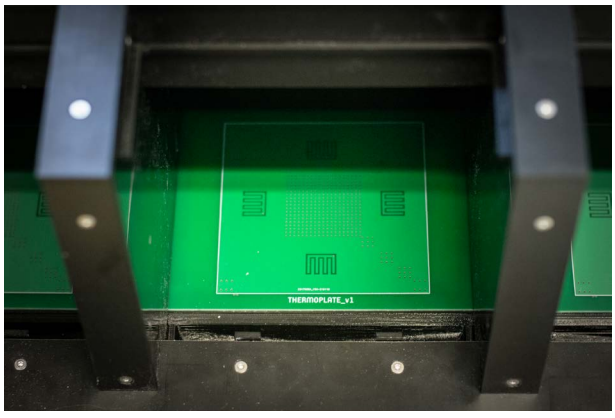


Figure 3.6: *Seed bed PCB.*

LED RING PCB

The LED ring PCB is attached to the camera mount and connected to the camera with jump wires. For the connection to the microcontroller PCB, a band cable is used.

CAMERA ASSEMBLY

The camera assembly consists of the camera, LED ring PCB, the camera mount the connecting wires and the fasteners. The assembly is attached to the top cell plate and then placed on top of the cell, aligning the camera with the round window in the top of the cell, above the seed bed (Figure 3.8).

3.4.2 POWER SUPPLY

To power the electronic components, a computer power supply is used (Figure 3.9).

3.4.3 CONNECTIONS

The array has a wide variety of electrical components, which are connected in various ways. When the electronic components are paced in the Array, they can be wired. An overview of these connections can be seen in Figure 1.13 on page 22.

3.5 CLIMATE SYSTEM

To heat and cool the seed bed, a Peltier element is used. It is placed between the seed bed PCB and a cooling block (as can be seen in Figure 3.5). To ensure sufficient heat transfer, cooling paste is used between these components (Figure 3.10).

The heat produced in the cells is dissipated with a water cooling system. From the cells, the water is pumped through a heat exchanger, dissipating the heat. Tubes are connected to the cooling blocks of each cell, the pump, water reservoir and the heat exchanger (Figure 3.11).

3.6 WATER DRAIN

To be able to get rid of excess water and water used in cleaning, each cell has a 3D printed PET-G water drain. These are produced externally. It is secured between the cell bottom plate, cell walls and drain bottom plate (Figure 3.12). The drain has two components attached to it: a tube fitting

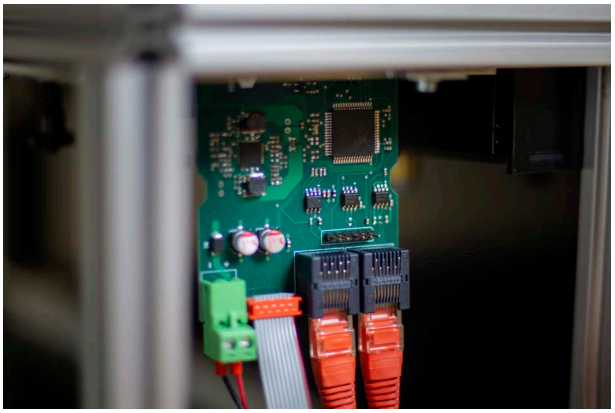


Figure 3.7: *Microcontroller PCB under the cell.*

Figure 3.9: *Power supply inside the Array.*

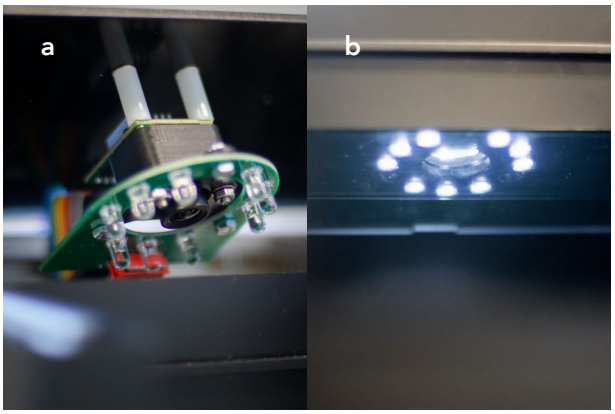


Figure 3.8: *a: Camera assembly attached to the top cell plate. b: Camera window.*

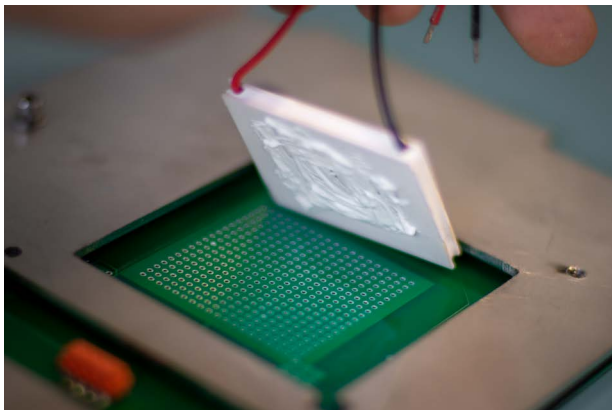


Figure 3.10: *Placing the Peltier element with the use of cooling paste.*

and an M5 insert to screw the fitting in. The brass insert is placed in the hole in the 3D printed drain by heating it, and therewith melting the drain material, securing it into its place. Then a tube fitting can be screwed in (Figure 3.13) and a tube can be attached.

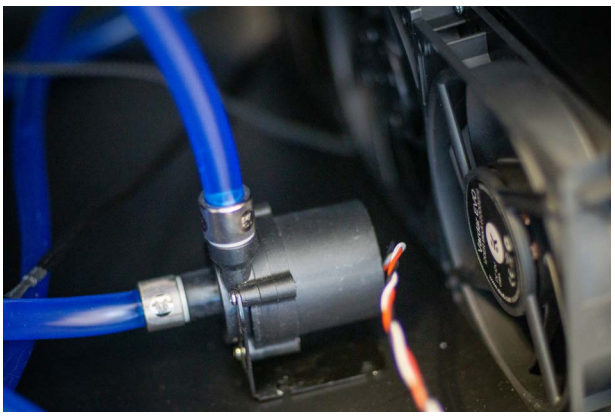


Figure 3.11: *Central heat exchanger and pump.*

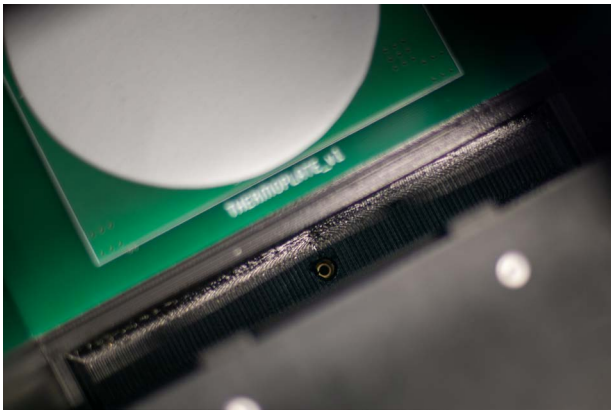


Figure 3.12: *Cell water drain.*

3.7 FINISHING

When all internal components are mounted and connected, the outside walls of the array can be attached, closing the product (Figure 3.14). Then it can be connected to the power and the computer, making it ready for seed testing.

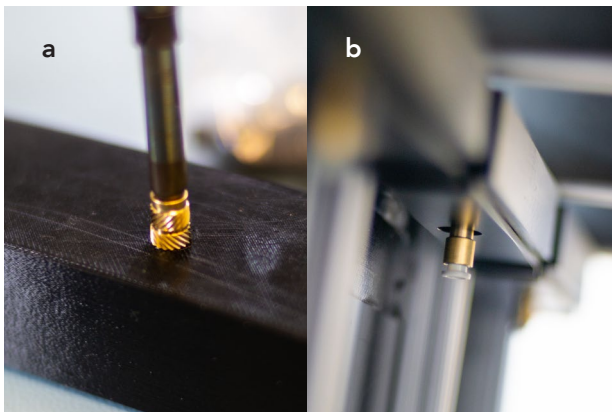


Figure 3.13: *a: Melting the insert into the drain. b: Tube fitting screwed into the insert.*

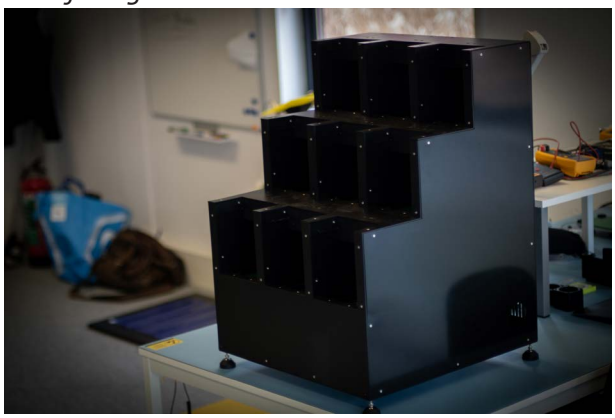


Figure 3.14: *Array from the outside.*

CHAPTER 4

Cost Price

This chapter contains a cost price calculation of the QIEM-Array. It includes costs of the individual parts, as well as the labor costs. A detailed overview of the costs per part can be found in the BOM (Appendix B on page 174).

4.1 FRAME

The aluminum extrusion profiles are produced externally, but the frame and doors are assembled internally. The profiles are connected with internal T-slot corners. It takes roughly 45 seconds to connect a corner, with a total of 202 corners. An assembler rate of € 20 per hour has been assumed. The frame cost price is calculated in Table 4.1.

***Table 4.1:** Cost price calculation of the frame.*

frame	€	76.71
connectors	€	265.23
feet	€	6.60
assembly	€	50.00
	€	**398.54**

4.2 WALLS

The walls are made of 3 mm thick HDPE and produced externally. The EPS insulation layer are cut to size internally. The walls are connected to the frame with T-slot M3 nuts. Each connection takes about 15 seconds, with a total of 451 connections. The foam cutting of the EPS plates takes about 10 minutes. The cost price of the walls have been calculated in Table 4.2.

***Table 4.2:** Cost price calculation of the walls.*

lasercut HDPE plates	€	250.38
EPS foam	€	1.50
fasteners	€	7.05
EPS foam cutting	€	10.00
assembly	€	40.00
	€	**308.93**

4.3 ELECTRONICS

The QIEM-Array has three custom-designed PCBs in each cell. These are produced by the company M91200. Other electronics used in the product include the camera module, power supply, cooling electronics and wiring. These are assembled internally.

The assembly and connection of the electronics in the bottom of the cells takes about 8 minutes per cell. The assembly of the camera parts takes about 3 minutes per cell. Including the remaining connection, the total assembly time of the electronics totals 120 minutes. The cost price of the electronics have been calculated in Table 4.3.

***Table 4.3:** Cost price calculation of the electronics.*

seed bed PCB	€	603.00
microcontroller PCB	€	1350.00
LED PCB	€	297.00
camera modules	€	305.01
camera mounts	€	21.38
hydrophobic films	€	2.16
power supply	€	25.00
wiring	€	50.00
fasteners	€	2.73
assembly	€	40.00
	€	**2696.27**

4.4 CLIMATE SYSTEM AND WATER DRAIN

The cooling system parts, such as Peltier elements, cooling blocks, heat exchanger and water pump, are purchased externally. Then these can be placed in the QIEM-Array.

The assembly of the cell bottom plate, Peltier element, cooling and water drain takes roughly 15

minutes per cell. Including the rest of the cooling system, totals an assembly time of 165 minutes. The cost price of the climate system have been calculated in Table 4.4.

***Table 4.4:** Cost price calculation of the climate system.*

Peltier element	€	40.32
drains, fittings and tubes	€	111.83
cooling system	€	320.21
cell bottom plate and tape	€	39.27
fasteners	€	1.19
assembly	€	55.00
	€	**567.83**

4.5 TOTAL COST PRICE

With the subtotals of the purchase, manufacture and assembly costs of the different parts of the QIEM-Array, the total cost price could be calculated (Table 4.5):

***Table 4.5:** Cost price calculation of the QIEM-Array.*

frame	€	398.54
walls	€	308.93
electronics	€	2696.27
climate system and water drain	€	567.83
	€	**3971.57**

4.6 CONCLUSION

As can be seen in Table 4.5, the biggest costs are the electronics. Since the PCBs were produced in small quantities, much is done manually. As a result, the cost per item is high. However, once larger quantities are made, with Arrays with more cells, much of the production process can be automated, reducing the costs per unit.

If you have faith as small as a mustard seed, nothing will be impossible for you.

Jesus Christ (32)

PART B

Project Philosophy

In the first chapter of this part, Quantified and it's brand are analyzed. This was done through interviews and by using the Brand Personality Tool (Aaker, 1997). The next chapter is about Quantified's project vision for the QIEM-Array. The original assignment for this project was to design a 2D robot movement system that could be used to monitor and control the germination process. Their vision was explored through interviews and the use of the Project Envisioning Tool. However, as can be seen in Part C of this report, the final project vision for this project, became different from what Quantified initially envisioned. In the final chapter of this part, the trends and developments in the seed industry were explored.

CHAPTER 5

Company Profile

Quantified is a company that makes low-cost internet of things (IoT) sensors for the green industry. They aim to fill in the gap between the technology seed industry uses and what is available. They want to do that by quantifying data of the seed growing process and use that for optimization. A different tools were used to explore Quantified's vision on their brand personality.

5.1 ABOUT QUANTIFIED

Quantified was founded in 2017 by Warner Venstra. Their activities started with trying to bring sensor to the market that could detect different gases in air. After a while, it was concluded that the project wasn't viable, due to the high investments required and the limitations by existing patents. Warner discovered another business opportunity in the greenhouse market.

In the start of 2019, Quantified started the development of low-cost IoT sensors for greenhouses. Meanwhile, the another opportunity rose to the surface. From the business partners in the greenhouse industry, it was learned that the seed germination research was highly inefficient. The process requires a lot of manual labor and is and is prone to inconsistencies in results, caused by subjective human classification. With the available technologies, a large proportion of the steps in the seed germination process can be automated.

The office of Quantified is located in the PLNT building in Leiden (Figure 5.1). PLNT offers workspace to individuals and organizations engaged in innovation and entrepreneurship.

Figure 5.1: *The office in PLNT in Leiden.*

5.2 COMPANY MISSION

There is a gap between the technologies that seed growers use and what is possible. There is a lot of knowledge about the optimal conditions for seed germination among the seed growers, but is kept between people and companies. It is often based on gut feeling and traditions. Quantified wants to quantify the data. Therefore, Quantified's mission is:

> *Quantify wants to supply products to the agricultural market with which they can contribute to make the food chain more sustainable, by growing products in a more efficient way, by reducing energy, water and nutrient use, and trowing away fewer products.*

5.3 BRAND PERSONALITY

The Brand Personality Tool, developed by Jennifer Aaker (1997), was used to guide the discussion about Quantified as a brand. It is a theoretical

Figure 5.2: *The brand personality characteristics.*

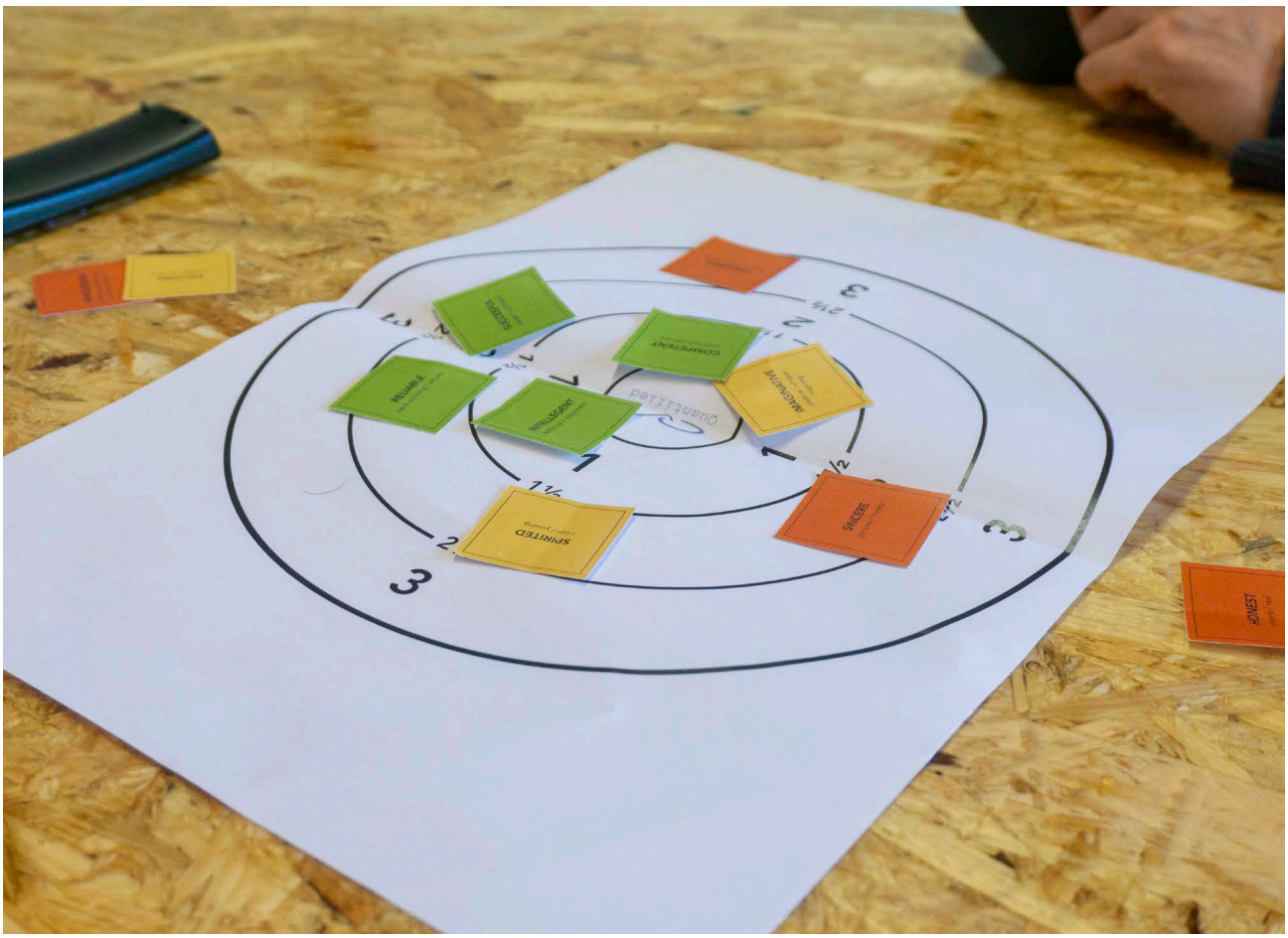


Figure 5.3: *Results of the Brand Personality Tool with Warner Venstra.*

framework to determine the profile of a brand in five dimensions: sincerity, excitement, competence, sophistication and ruggedness. Each dimension is divided up into different facets (Figure 5.2).

The participants were asked to place small cards with the different facets onto a sheet of paper. The paper had Quantified's logo in the center with rings on it. The rings represented different levels of association with the product, with 1 closest and 3 the furthest. The results of one of the sessions can be seen in Figure 5.3.

5.3.1 INSPIRATION FROM OTHER COMPANIES

Paul Kengen en Warner Venstra were asked if they could express their visions of Quantified's brand by naming other existing companies.

The company first mentioned by Paul was Google. They are very innovative and successful with a wide variety of products. Moreover, they give a lot of freedom to their employees and the people they work with. Another company mentioned is Patagonia, because of their mission to minimize the impact on the environment. Quantified's innovations in the agricultural sector could lead to increases of efficiencies of different aspect of the seed growing process, which could lead to a decrease in energy consumption.

Warner mentioned the startup company Delft Circuits. They started the company with very little financing and with a small group of students, and build it up to a successful company. The other mentioned company was Apple, for their attention to detail and their obsession with good design.

> *A customer has be exited when they open the product box end even more exited when they start using it. The use of the product has to be clear and simple, and must not be ambiguous.*

The results of these questions are shown in Figure 5.4.

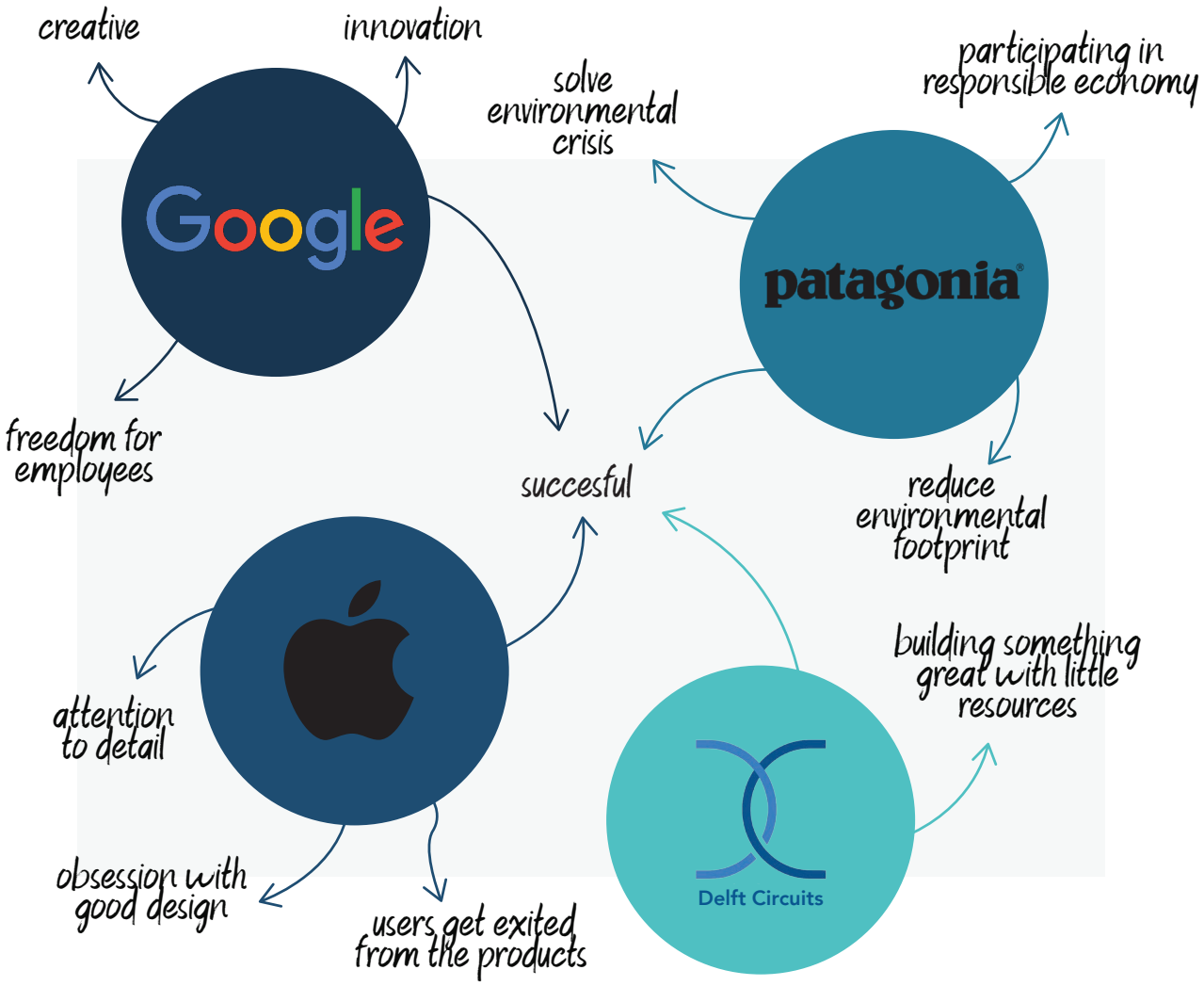


Figure 5.4: *Brand personality inspiration from other companies.*

5.3.2 MAKING CHOICES

When asked about their vision, companies often want to be everything. For example, a company might want to be the biggest player in the market, but also the most environmentally friendly. In an ideal world, the company can have it all. But in practice, there are often conflicts. And in these conflicts, it starts to get rather interesting.

CONFLICTS

The most conflicting personality traits were placed against each other. Paul and Warner were asked to indicate which they found the most important on a line (Figure 5.6).

RESULTS

The test resulted in a two sheets of paper with brand personality traits rated against each other. The two participants rated differently in terms of extremes. Therefore the results were normalized before averaging them, to give the scores of the participants equal weights. This was done with the following equations:

$$\text{trait right} = \frac{d - \min}{\max - \min}$$

$$\text{trait left} = 1 - \text{trait left}$$

Here *d* is the distance measured in mm, *min* the minimum score (in mm) given by the participant and *max* the maximum score (in mm) given by the participant. Finally, the scores for all the traits were averaged. The results are shown in Table 5.1 and Figure 5.5.

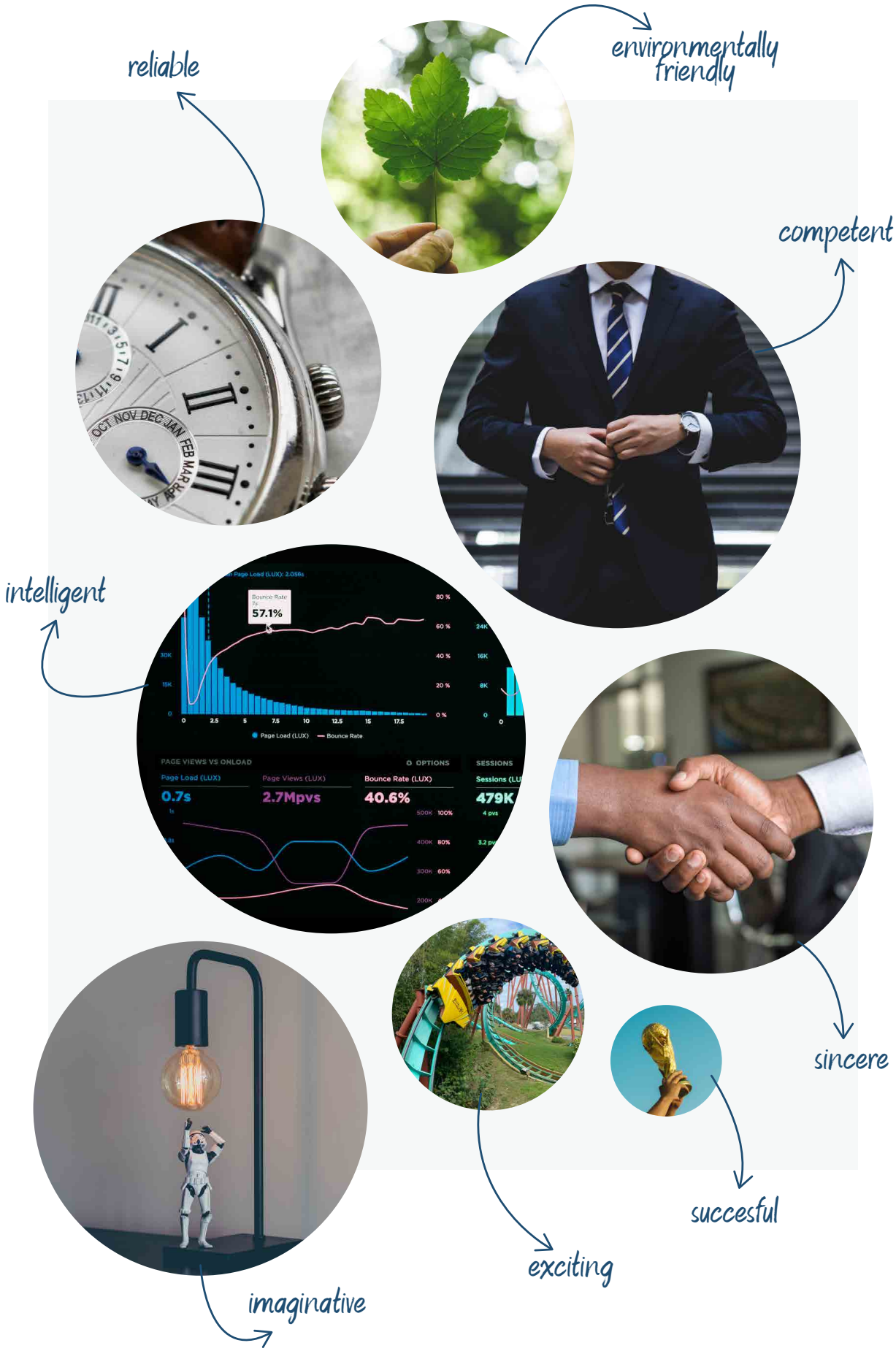


Figure 5.5: *Visualization of Quantified's vision on their brand personality. The areas of the circles represent the rated relative importance.*

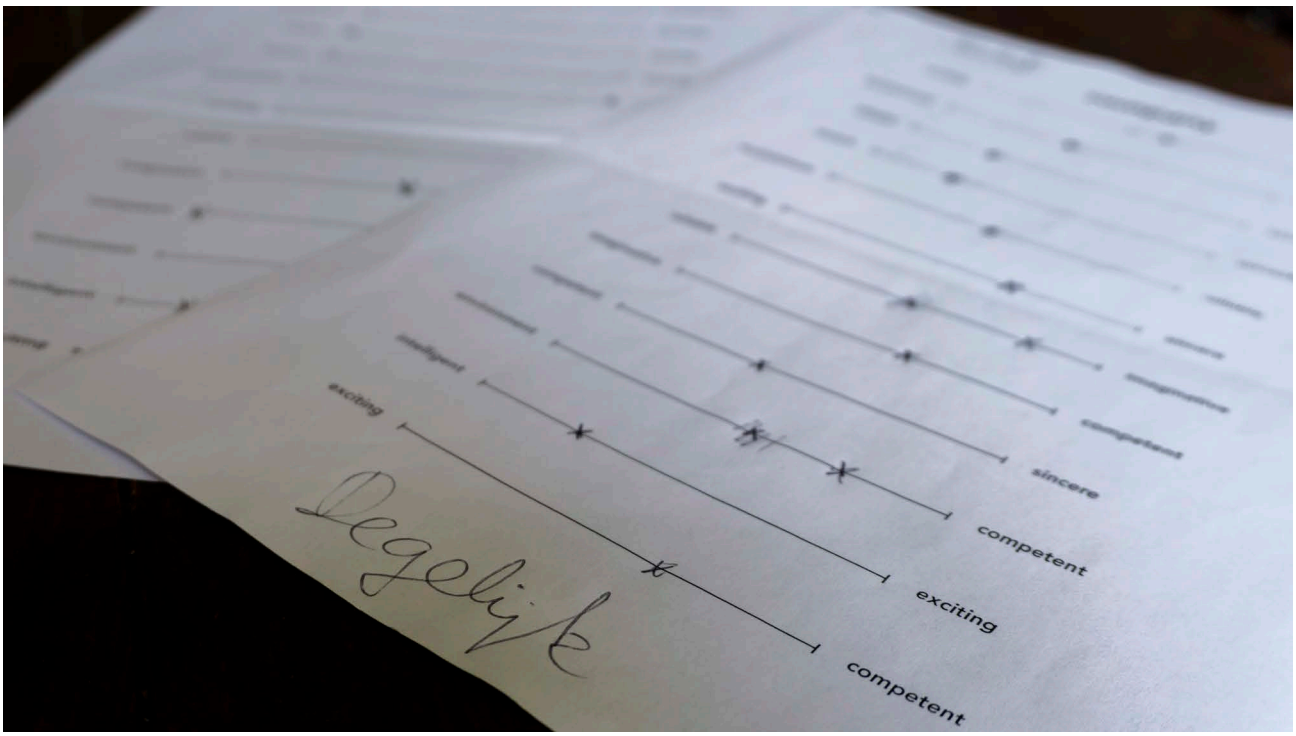


Figure 5.6: *Results of a test were Paul and Warner were asked to indicate which brand personality traits they thought were the most important.*

Table 5.1: *Average scores of brand personality traits test.*

Trait	Score
Intelligent	.92
Competent	.82
Imaginative	.68
Sincere	.64
Reliable	.57
Environment	.39
Exciting	.23
Successful	.08

The results can be divided into two categories: the current brand personality and the personality the brand should develop in the future.

5.3.3 CURRENT BRAND PERSONALITY

As a result of using the Brand Personality Tool, four main personality characteristics were chosen to describe the brand Quantified.

INTELLIGENT

According to Paul Kengen, there hasn't been much innovation in the seed market. The vision is to bring intelligent solutions to the industry on a scientific level. This requires a transition from old to new cutting-edge technologies. Now the company is mainly focused on the agricultural sector, but there is a possibility that Quantified moves to being a company that brings intelligent solution to industries that haven't had innovation for a considerable amount of time.

COMPETENT

Quantified is able to provide solutions for complex problems. Added up, they have a lot of knowledge and expertise. They are capable of developing intelligent products that push industries forward.

IMAGINATIVE

Bringing innovation to uninnovative industries requires a lot of creativity. According to Paul and Warner, they always have an abundance of ideas to solve the many problems they find during the product development process. This translates to an imaginative brand personality.

SINCERE

As stated by Warner, honesty and sincerity are of paramount importance. They do not pretend that results or products are better than they are. This is crucial to build sustainable relations with other parties.

5.3.4 FUTURE BRAND PERSONALITY

In the conversations about the brand personality, there also was a clear vision was expressed about the future of Quantified's brand personality.

RELIABLE

Since the brand and the products are rather young, they haven't yet been able to build up a reputation of providing reliable products. However, as is the case for every company that produces technical products, it is important of being reliable.

SUCCESSFUL

Quantified wants to be a company that successfully pushes the boundaries of industries.

EXITING

As expressed by Quantified, there is the wish that the customers experience excitement with the use of the product. The problems the products solve should make working procedures much more convenient for users and really add value. A concrete example is that researchers do not repeatedly have to manually count and classify seeds, but that this is done automatically. "It would be great if customers really like working with us."

ENVIRONMENTALLY FRIENDLY

Quantified makes products that optimize the efficiency of seed and plant growing. This will reduce the water and energy use. Moreover, Quantified wants to have a higher recyclability of future products.

5.3.5 DISCUSSION

While doing the test, the participants were asked to comment on the choices they made. The most notable comments are shown below.

We need to show that we're competent. We're competent and we don't just have fun and exciting ideas.

Being successful doesn't say a whole lot. Am I better than my neighbor?

We make sensors that have to be reliable. Excitement is therefore inferior.

The focus should be on the environment instead of being successful. The latter will follow later.

Imaginativeness invites people to work with or for you and is therefore more important than reliability.

Sincerity is something for the long term; to build sustainable relationships.

Excitement is less important than the other traits, because it will follow later.

In summary: we are decent, calm, thoughtful and intelligent.

Figure 5.7: *Quantified's climate sensor.*

5.4 CURRENT PRODUCTS

Quantified's main product is the FireFly (Figure 5.7), a climate sensor used in greenhouses and in the field. In the product brochure, it is described as follows:

"Know what is best for your plants to improve quality and optimize costs with real time insights into the conditions over your entire growing area. This will help you decide what to do to improve growing conditions and therefore yield and quality. The measured data will help you to reduce the use of water, energy, crop protection chemicals and nutrients and therefore reduce your costs."

"The Quantified Firefly is a wireless distributed climate sensor that measures air temperature, relative air humidity, barometric pressure and radiation (PAR) coupled with GPS coordinates. This opens up the route to dynamic heat maps. Its robust design, with safely embedded electronics, enables application in the most demanding environments. Specific external sensors can be connected through the IP67 connector."

TAKEAWAYS FOR QUANTIFIED

- Several brand personality tests have been conducted.
- The most important brand personality traits were found to be intelligence, competence and imaginativeness.
- Traits, such as excitement and successfulness, will follow over time.

CHAPTER 6

Quantified's Project Vision

The demand for the supply of food pushes the industry to its limits. The seed growing industry has been using germination tables to optimize the seed growing process. Despite the technological progress in the world, the germination tables have hardly changed and are still labor-intensive. Quantified wants to develop the germination table of the future: the QIEM-Array. It should be able to control and measure conditions, automate most human actions and provide detailed analysis using machine learning algorithms. In this chapter, Quantified's project vision is discussed.

6.1 THE REASONS FOR THIS PROJECT

With the ever increasing food supply demand and decreasing quality of available agricultural land, innovations in the agricultural sector will play an increasingly crucial role. Increasing productivity, improving quality and increasing the nutritional values of the end products are key in combating the problems (Cunningham, 2013).

In the horticultural sector, germination tables have been used for decades. These tables can be divided in two types: constant-temperature tables and temperature gradient tables. The former are used to determine the germination power of seeds. The latter are used to determine the optimal temperatures for seed germination (see Figure 6.1 on page 52).

Despite the technological progress in many other sectors, germination tables have hardly changed in recent decades. The basic principle of these tables is that the temperature is controlled with a water tank that is kept at temperature by a thermostat. Seeds are placed on or in growing media on top of the surface. When sufficient water is provided, the germination process can start.

The use of these tables is very labor-intensive and the number of possible settings is very limited. Seeds have to be selected, counted and placed on the table manually. The results of the germination period have to be evaluated by trained personnel to draw conclusions about the process. Quantified saw an opportunity to bring innovation to this sector (Venstra, 2019).

Quantified's R&D document for this project stated the following:

> *Research has shown that the use of temperature gradient tables, and selection of the best seeds and growing conditions can increase the productivity in horticulture by up to 15%, depending on the type of crop, and thus play an important role within the sector. The optimal climatic conditions vary from species to species and also depend on the conditions of the mother plant. These are therefore ideally determined per seed batch. (Venstra, 2019)*

6.2 QUANTIFIED'S INITIAL VISION OF THE QIEM-ARRAY

Quantified wants to develop the germination table of the future; the Quantified Array (QIEM-Array). The QIEM-Array can monitor and control the germination process in a fully automated way in order to determine the ideal germination conditions.

The QIEM-Array makes the germination tests more efficient and improves the quality of the seeds.

6.2.1 CONDITIONS

The temperature and light of individual positions can be controlled. This allows for the use of complex climatic profiles. Furthermore, the individual positions can be sprayed with specified amounts of water, nutrients and pesticides.

6.2.2 ANALYSIS

The QIEM-Array will have automated photography of the developmental stage of seeds. The QIEM-Array generates an enormous amount of data that would be nearly impossible to analyze analytically. Especially when looking for multidimensional connections in the data. For example, connections between moisture level, temperature and light with different non-linear profiles over day and night. Therefore, analysis will be done using neural networks.

6.2.3 PLACING SEEDS

The QIEM-Array will have faster setup and higher reproducibility of tests due to automated placement of seeds. The seed counting will also be automated, saving a tremendous amount of labor for the researchers.

6.3 PROJECT STARTING POINT

Prior to this project, research into Peltier elements has been done by graduate student Gerben van den Berg (2020). A Peltier element is an electrical component that can be used to transfer heat from a cold place to a warm place or to generate an electrical current from a difference in temperature.

Figure 6.1: *Test setup of a Peltier element with temperature control (in Quantified's lab).*

In this research project, it was found that, in addition to heating and cooling, the Peltier element can also be used to measure temperature. Figure 6.1 shows a test setup of this project.

6.4 THE ASSIGNMENT

The original assignment given by Quantified is the following:

In this assignment you will design x-y array robot hardware. The 2Drobot should be as cheap as possible and service a x-y flat surface. The robot will need to be able to periodically take images of the seed germination progress. Later the images will need to be analyzed using AI-algorithms. Furthermore seeds will need to be picked and placed as well as being sprayed with fluids. The system will need to be controlled for positioning, taking pictures as well as spraying individual cells.

As an initial test, you will simulate the germination process influenced by various watering and temperature conditions. When time is still available you can also apply AI pattern recognition techniques to the acquired images, implemented in Python / OpenCV, to quantify seed information such as the number of seeds, their size distribution and the stage of germination.

6.5 PRODUCT ENVISIONING TOOL

To help the creation of a more concrete product vision, the Product Envisioning Tool was used. This resulted in a list of product traits. A wide variety of existing products were presented on cards. Paul Kengen and Warner Venstra were asked to tell about their associations with the products and relate them to their image of what the QIEM-Array should be (Figure 6.2). The associations were used to form a vision about the QIEM-Array. The results are shown in Figure 6.3

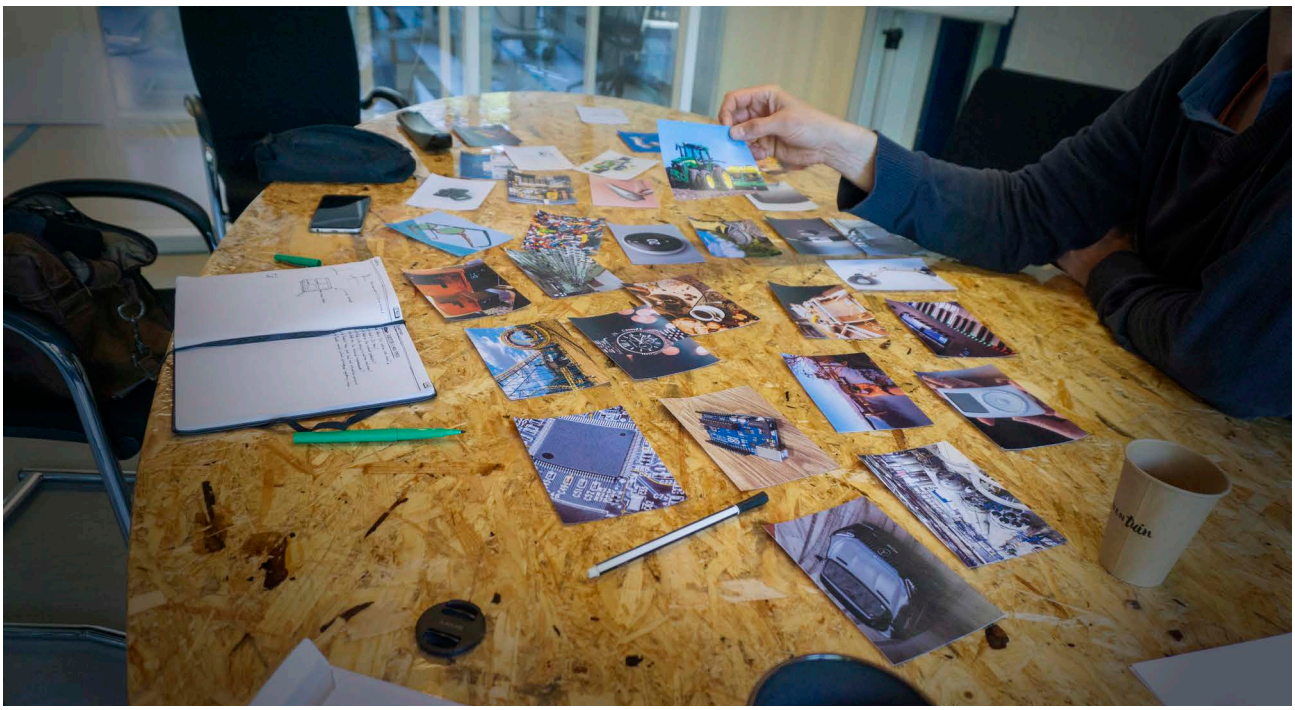


Figure 6.2: *Warner using the Product Envisioning Tool.*

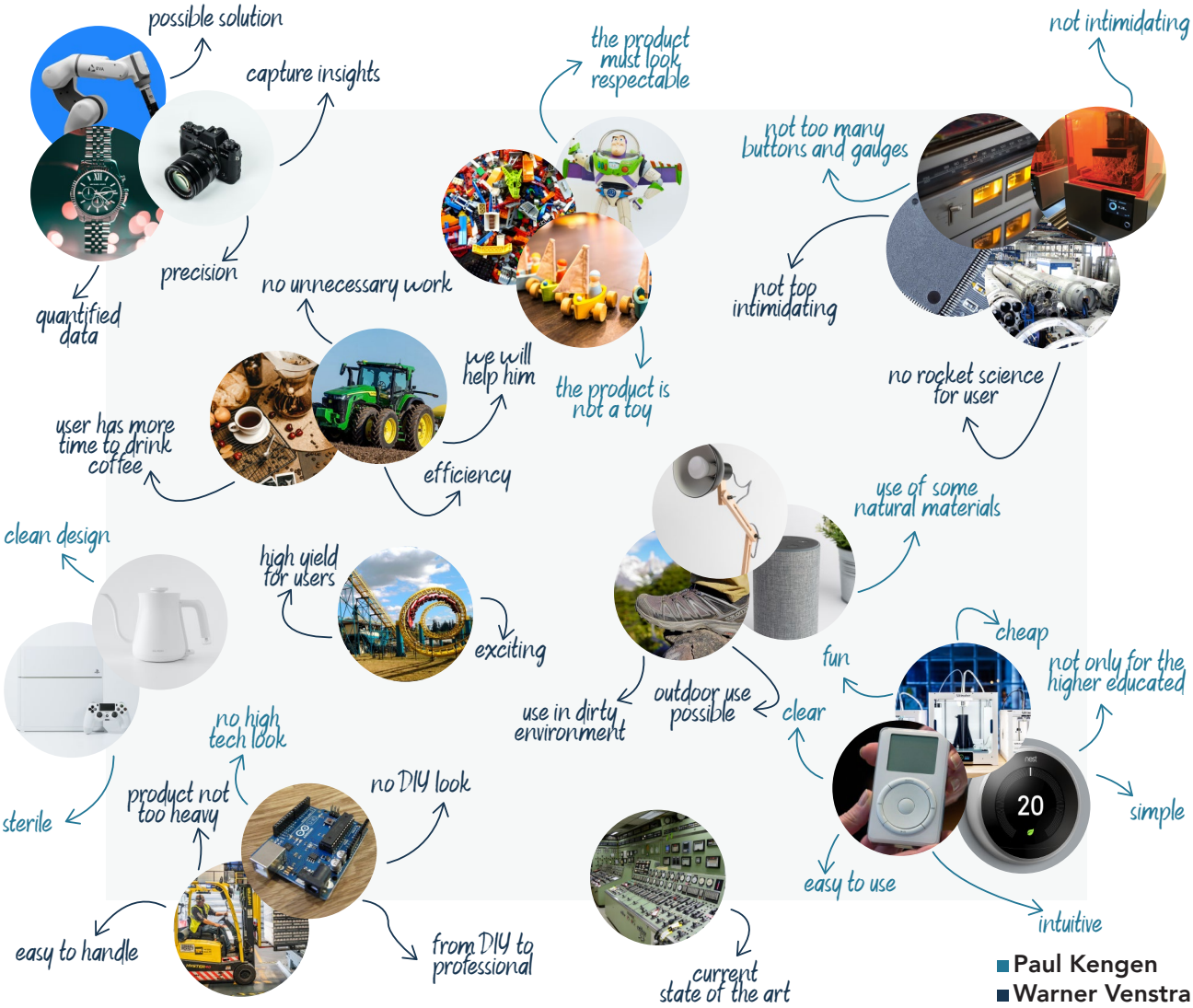


Figure 6.3: *Results of Product Envisioning Tool.*

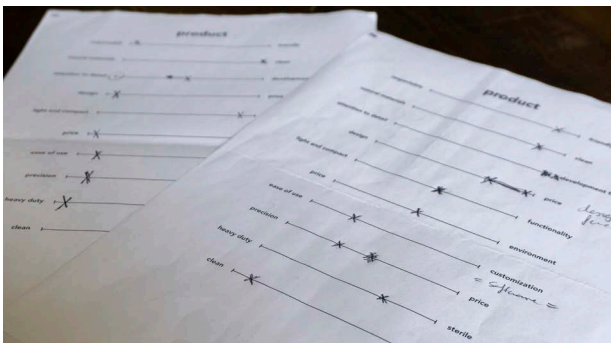


Figure 6.4: *Results of a test were Paul and Warner were asked to indicate which traits they thought were the most important.*

6.5.1 MAKING CHOICES

Products can't have everything. Often, compromises have to be made. For example, it is near impossible to make products with Apple-like design and performance, while also being the cheapest. These conflicts make the product development process interesting. The most notable and conflicting traits were evaluated one-on-one by Paul and Warner (Figure 6.4).

The test resulted in a two sheets of paper with product traits rated against each other. The two participants rated differently in terms of extremes. Therefore the results were normalized before averaging them, to give the scores of the participants equal weights. This was done with the following equations:

$$\text{trait right} = \frac{d - \min}{\max - \min}$$

Table 6.1: *Average scores of product traits test.*

Trait	Score
Ease of use	.86
Precision	.84
Clean look	.72
Functionality	.70
Low development time	.67
Heavy duty	.65
Respectable	.58
Good design	.52
Exciting	.47
Price	.47
Friendly	.42
Sterile	.35
Attention to detail	.33
Light and compact	.30
Environment	.24
Customization	.14
Natural materials	.09

$$\text{trait left} = 1 - \text{trait left}$$

Here *d* is the distance measured in mm, *min* the minimum score (in mm) given by the participant and *max* the maximum score (in mm) given by the participant. Finally, the scores for all the traits were averaged. The results are shown in Table 6.1 and Figure 6.5.

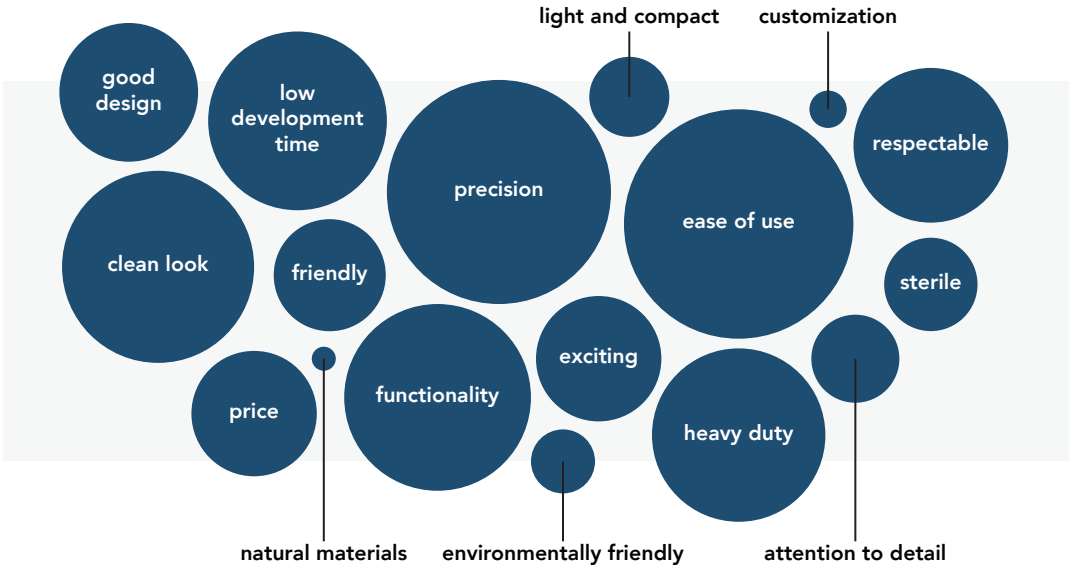


Figure 6.5: *Visualization of the scores of the Product Envisioning Tool. Larger means more important.*

6.6 QUANTIFIED'S PROJECT VISION

From the conversations about the project, the R&D vision document and the product envisioning tool, Quantified's vision of the project started to become clearer. The QIEM-Array should be the germination table of the future. It should be able to control and measure conditions, automate most human actions and provide detailed analysis using machine learning algorithms. The functions desired by Quantified are summarized in Figure 6.6

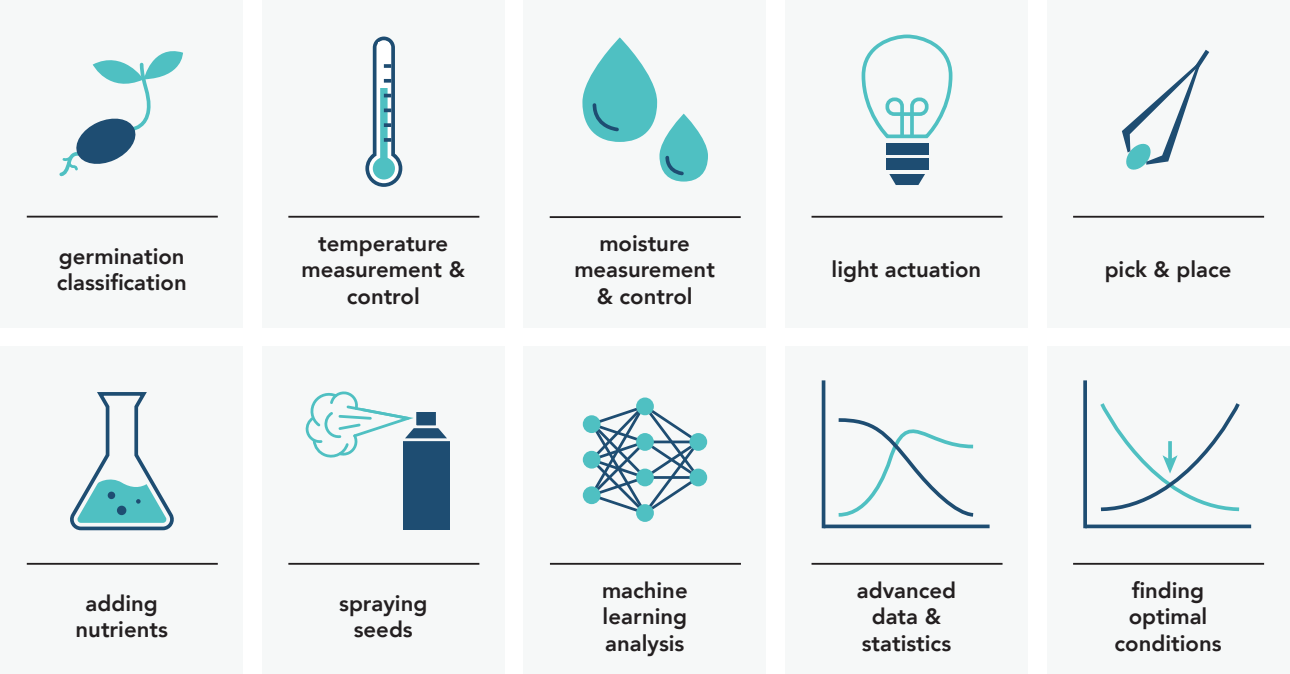


Figure 6.6: *Functions of the QIEM-Array desired by Quantified.*

TAKEAWAYS FOR QUANTIFIED

- Quantified's vision of the QIEM-Array was studied in several ways.
- The most important traits for the envisioned product were found to be ease of use, precision, clean look, functionality and low development time.
- According to Quantified, the major product functions include temperature, humidity and light control; pick and place, adding nutrients and spays to the seeds; and advanced analysis and optimization using machine learning.

CHAPTER 7

Trends & Developments

Currently, the seed industry uses low-tech germination tables and cabinets. There are several companies and organizations that have been developing smarter germination systems. However, there is none that completely automates the process. The seed market as a whole has experienced growth over the past decades and this expected to continue for the foreseeable future. However, there is an increasing demand from authorities and consumers for more environmentally friendly products, that could cause difficulties for the industry.

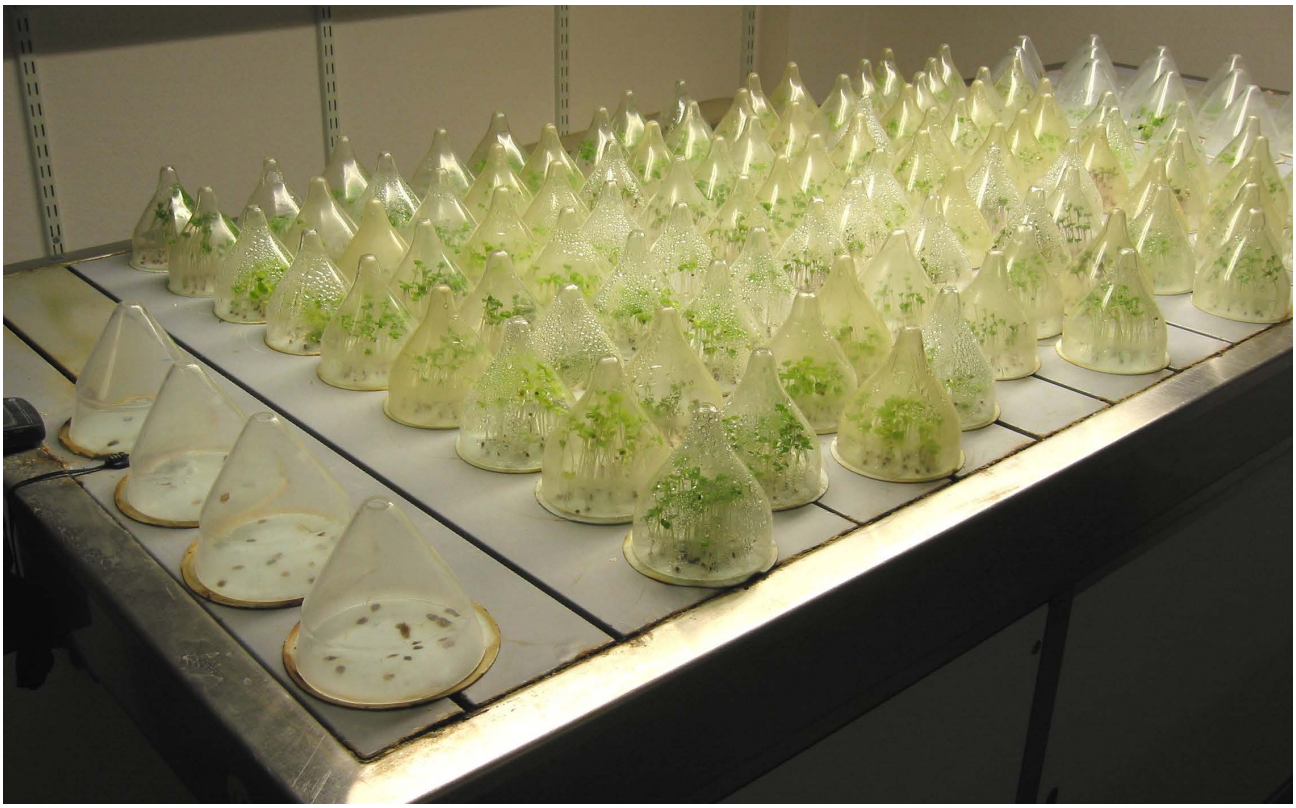


Figure 7.1: *Jacobsen table.*

7.1 ESTABLISHED GERMINATION TESTING PRODUCTS

The seed industry tests seeds according to the ISTA regulations (Chapter 9 on page 66). The two major ways germination tests are performed are with germination tables and with germination climate cabinets. In addition, to simulate more realistic conditions, germination tests are also performed in trays in greenhouses.

7.1.1 JACOBSEN TABLES

Jacobsen tables (or germination tables) come in two types: with a constant temperature (Figure 7.1) and with a temperature gradient. The first type has a water tank that is kept at a constant temperature with a thermostat. The water is then pumped around to heat a surface, on which the seeds are placed. The latter type has two water tanks that are kept at different temperatures. This is how a temperature gradient is created at the surface. The paper on which the seeds are placed, are in contact with the water, and are therefore always moist.

The advantage of existing germination tables is that users in the industry are familiar with the products, since they have been in use for a long time. However, they are very labor intensive and test results are often inaccurate. They cost around € 60.000.

7.1.2 GERMINATION CLIMATE CABINETS

Next to germination tables, germination climate cabinets are often used by the seed industry (Figure 7.2). These cabinets have temperature control, for which day and night temperatures can be set. Additionally, they have light control. As opposed to the seed Jacobsen tables, the seed media are not in contact with a water source. Therefore, water has to be added manually if it gets too dry.

Figure 7.2: *Germination Climate Chamber.*

7.1.3 TRAYS

Plants are often grown in greenhouses. Although the ISTA regulations provide a consistent way of germination testing for the seed industry, it often doesn't match the real conditions close enough. Therefore additional tests are often done in trays in greenhouses (Figure 7.4). These trays have plugs which contain media, such as soil or rock wool. Depending on the species, nutrients can be added. Usually, one seed is placed per plug.

Figure 7.4: *Trays used in greenhouses.*

7.2 NEW DEVELOPMENTS

There are several products that have been developed to help with classification in the germination process. A lot of research has been done on the classification of seed germination with image recognition (Chapter 11 on page 72). Few of them have resulted in actual products. A selection of seed germination classification systems are discussed below.

7.2.1 KWS - GERMINATION ROBOT

The GESA is a highly specialized robot, that tests the speed at which sugar beet seeds germinates (Figure 7.3). The seeds are placed in trays under regulated temperatures and humidities. Photos are taken at defined time intervals and analyzed automatically and intelligently (KWS, n.d.).

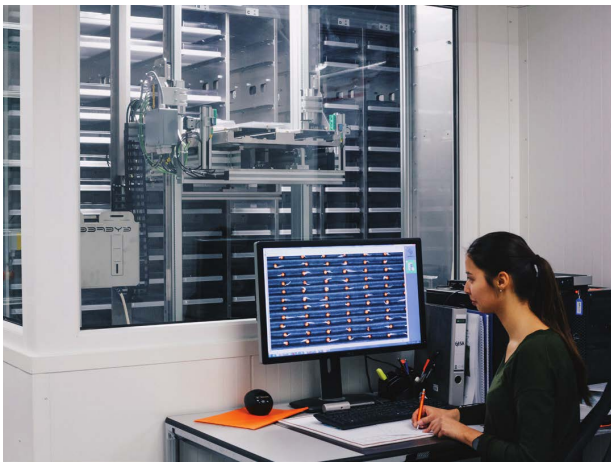


Figure 7.3: *KWS's germination robot.*

7.2.2 PHENOSEEDER

The Phenoseeder (Figure 7.5) enables handling and phenotyping of individual seeds of different sizes. It has 2D and 3D imaging capabilities, seed weighing and space for adding further sensing equipment. The Phenoseeder can be used to place seeds onto paper for germination tests.

7.2.3 ARIS GERMINATION VISION SYSTEM

This system is made for the phenotyping of plants It is not suitable for on-paper germination tests according to the ISTA regulations. It is rather used in greenhouses on plants that grow in trays (Figure 7.6).

7.2.4 FAST TECHNOLOGIES - AUTOMATIC GERMINATION ANALYSIS SYSTEM (CASE STUDY)

In recent years, the first systems appeared in which counting and classification are automated using cameras and image recognition software. These systems can usually be found in research setups in an academic setting. By measuring the morphology (shape and dimensions), the germination system from FAST (Figure 7.7) can

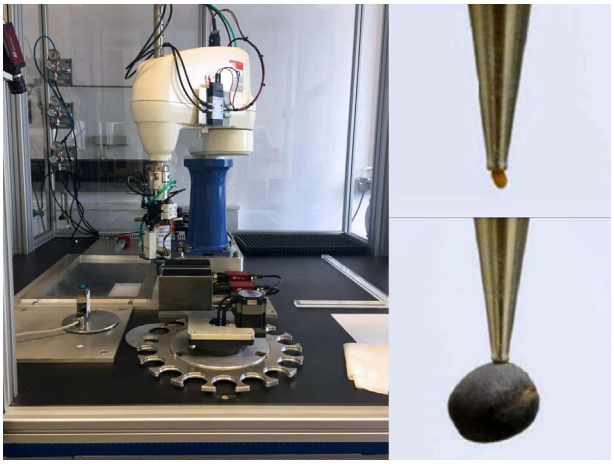


Figure 7.5: *The Phenoseeder.*

Figure 7.6: *Aris Phenotyping Vision System.*

Figure 7.7: *FAST's germination system.*

obtain information about the course of the germination process even before the germination occurs. Image recognition modules are available for maize, wheat and a limited number of other crops (FAST Technologies, 2015).

7.3 TRENDS

The seed industry is growing and modernizing by using new technologies. Furthermore it is pushed by governments, retailers to move towards sustainability.

7.3.1 MARKET TRENDS

The two market trends in are the growth of the seed industry and the corporate concentration.

SEED MARKET GROWTH

The global seed breeding market was valued at 60 billion USD in 2018 and expected to be 90 billion USD in 2024. This corresponds to a compound annual growth rate (CAGR) of 7.9%. The drivers of the market growth are the increasing demand in the agriculture sector, and growing number of research and development initiatives to improve the potential and yield of seeds (Mordor Intelligence LLP, 2019). The global seed treatment market was valued at 3.9 billion USD in 2016 and is expected to grow to 5.6 billion USD by 2020. This corresponds to a CAGR of 9.6% (GVR, 2017).

MULTINATIONALS

The seed industry is controlled by a handful of multinational seed companies (Taggar, 2018). Over thee past decades, the seed industry has experienced corporate concentration trends. Concerns have been raised by various stakeholders about the availability of seeds and the risk of creating an oligopoly (Bonny, 2017).

7.3.2 TECHNOLOGICAL TRENDS

The two technological trends in the seed growing market are the use of biotechnology and the move towards the industry 4.0.

BIOTECHNOLOGY

In the last few decades, the use of various modern biotechnology techniques has increased. This includes hybridization, micro-propagation, mutagenesis, protoplast fusion and genomic selection. This has caused a significant increase in seed yields (Bonny, 2017).

INDUSTRY 4.0

The networking of production facilities and machines is seen as the fourth industrial revolution. This produces large amounts of data. The data is initially presented in an unstructured way. Intelligent algorithms are required for effective analysis and explanation of the data. The use of big data in the agricultural industry is an ongoing trend (Hoeren & Ophues, 2020). An

example of this is the use of drones to monitor growing plants and using the data to locally improve conditions.

7.3.3 REGULATORY TRENDS

Increasing regulation of pesticides by the government, and even more so by supermarkets, can cause difficulties in the seed breeding industry. According to Spruijt (2008), new EU crop protection regulation would have major economic consequences for the Netherlands. Due to the fact that in certain cases hardly any crop protection products will remain, a yield decrease of more than 50% was expected as a direct effect for some crops, which would make these crops unprofitable in the Netherlands and extreme consequences for the production and international trade in these crops. The European Union also focuses its policy on risk reduction. The objective in the Seventh Environmental Action Programme (Mihajlov & Pokimica, 2013) for the European Union is that, by 2020, the use of plant protection products must not lead to any impact on human health or to an unacceptable impact on the environment (Tiktak et. al., 2019). The seed breeding industry must constantly come up with solutions to work around the regulations. This causes a constant search for new chemicals and growing processes that can help to increase the yield of seeds.

7.3.4 CULTURAL TRENDS

An increasing number of people came to understand that we need to sustainability manage our the planet's ecosystems and resources. Over the past decades, the public environmental awareness has been rising. Governments and corporations have been pushed by environmental activists to pay more attention to the industry's impact on the environment and health. An example is the use of GMOs by the seed industry. It has lead to controversy and public distrust, and this has caused a negative view of the seed industry in the media and in a large part of the population. The public opinion has played a major role in the regulation of ongoing innovations in the seed sector (Bonny, 2017).

TAKEAWAYS FOR QUANTIFIED

- The Jacobsen table is widely used by the seed industry for germination tests, as well as germination cabinets.
- There are some companies that have been developing automation solutions for germination tests.
- There is no product on the market that automates the whole germination test process.
- Market, regulatory and cultural trends push the seed industry to move to sustainability, and therefore innovation is required.

The goal is to turn data into information, and information into insight.

Carly Fiorina (2004)

PART C

Analysis

In this part, the analysis phase of the project is discussed. To kick-off the literature research phase, a brainstorm was done with Warner Venstra to map the areas of research. A mindmap was made with the word 'QIEM-Array' in the center. All the major aspects and their unknowns were written down. The results were used as a guide while searching for literature. The topics of the research included: the germination process, automatic classification with image recognition and machine learning, temperature measurement and control, moisture measurement for germination tests.

Furthermore, several potential users were interviewed and visited, to see how they perform germination test, and what their requirements and wishes are. What kept coming back in the literature and among potential users were the ISTA regulations. These regulations specify how the germination tests should be performed. The regulations are leading for the entire seed industry.

Quantified's original assignment for the QIEM-Array was to design a 2D robot movement system. During the analysis phase, it became clear that such product would not solve the design problem. Therefore, it was necessary to take a step back. At the end of this part, the redefined project vision is given.

CHAPTER 8

Seed Germination

In this chapter, the seed germination process is explained, as well as the factors that influence it. The influencing factors are water, temperature, light, nutrition and salinity. Several examples are given of the effects of the given factors.

8.1 THE SEED GERMINATION PROCESS

With the germination of seeds, the next generation of a plant begins. The seed contains the embryo, which is a miniature version of the plant. It contains food reserves (cotyledons) to sustain the growing seedling until it becomes self-sufficient. The embryos of most seeds are surrounded by layers, such as the seed coat (testa) and the endosperm (Figure 8.2).

The uptake of water marks the start of the seed germination process. The process can be divided into three phases (Figure 8.1). The phases are characterized by the increase of mass of the seeds, mainly caused by water absorption. The first phase is characterized by the rapid absorption of water and is also referred to as *early imbibition*. The second phase has very limited water absorption. The third phase is started with another increase

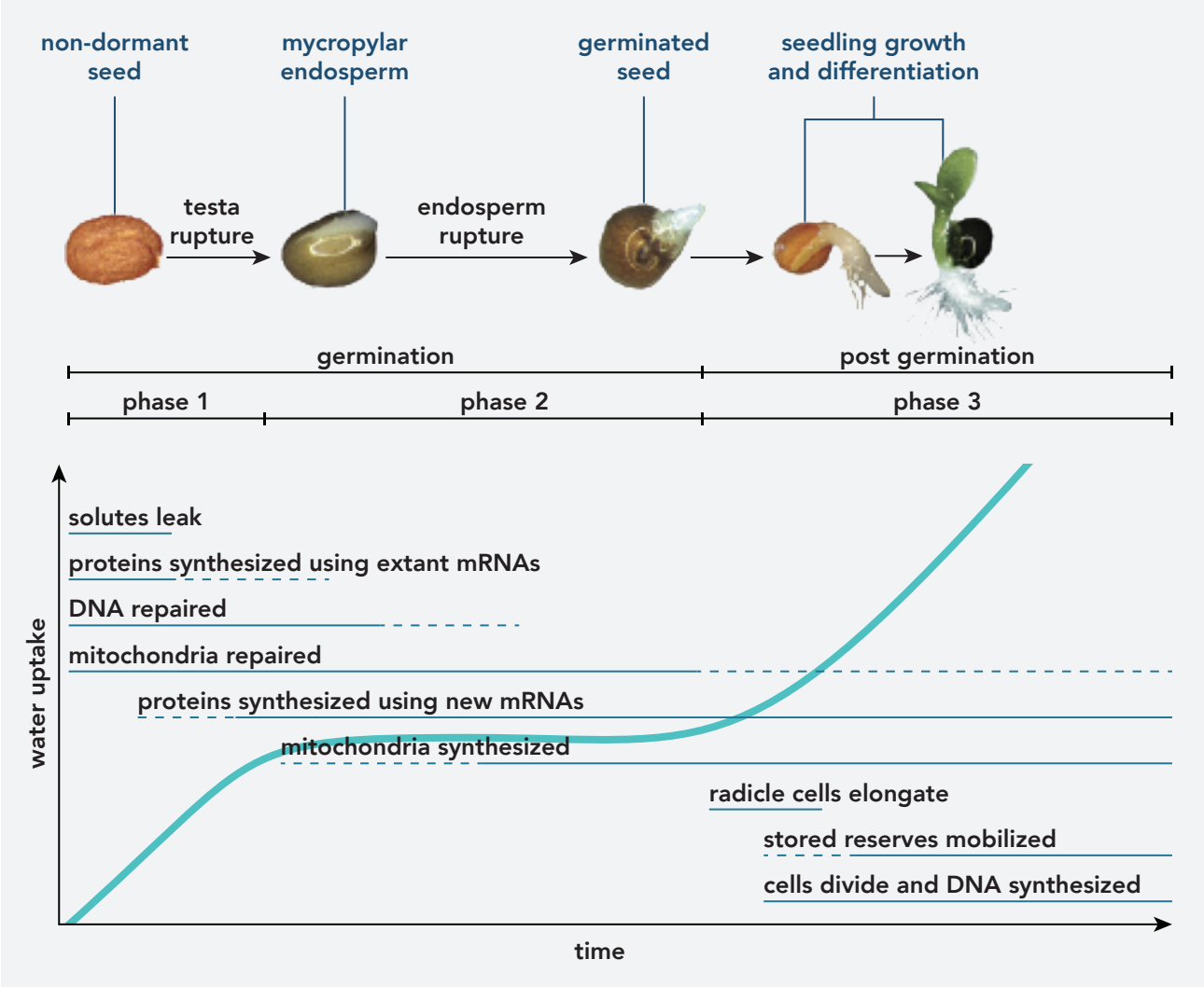


Figure 8.1: *The major germination events over time. The time for the events varies from a few hours to several weeks, depending on the plant species (Bewley, 1997; Weitbrecht et al., 2011).*

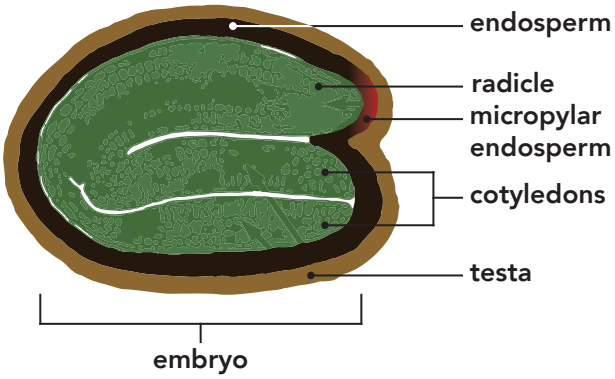


***Figure 8.2:** Morphology of a mature plant seed (Weitbrecht et al., 2011).*

of the seed's moisture content and mass (Bewley, 1997; Lev & Blahovec, 2017).

Seeds do not germinate freely, because it may not be advantageous in all situations. For example, germination in the spring gives the plant plenty of time to mature, whereas germination in the fall could leave the plant susceptible to the harsher winter conditions. Dormancy optimizes the germination of seeds over time. However, dormancy may not be a favorable treat in the agricultural sector, since rapid germination and growth are required.

8.2 WATER

The moisture levels of surroundings of the seed play a role in both the after-ripening and the germination process. After-ripening is a prolonged period of dry storage of freshly-harvested mature seeds. Different species have different optimal moisture contents for after-ripening, which is determined by testing. This can be expressed in a moisture sorption isotherm, as can be seen in Figure 8.3. Region 1 represents strongly bound water (mono-layer) which is unavailable for water-dependent biochemical reactions. Region 2 represents weakly bound, multi-layered water, which leads to a limited availability for water-dependent biochemical reactions. Only water represented in region 3 is freely available and may allow molecular biochemical events that occur during seed imbibition (Weitbrecht et al., 2011).

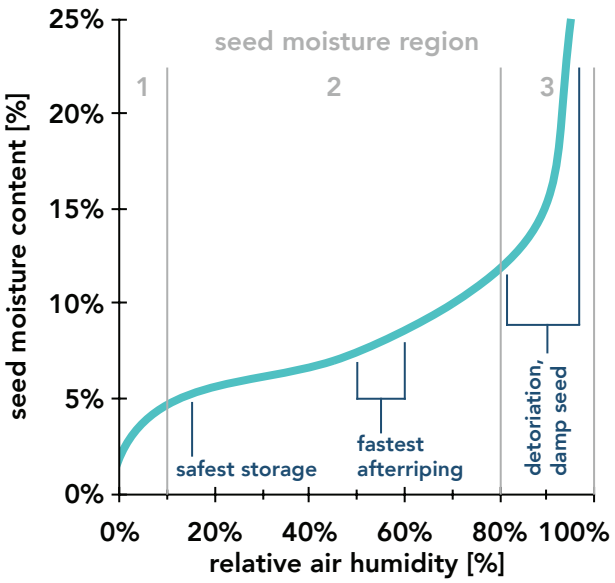


***Figure 8.3:** Typical moisture sorption isotherm of an oil seed at room temperature (Weitbrecht et al., 2011).*

For the germination process itself, according to the ISTA regulations (Chapter 9 on page 66), the growing medium should have the capacity to hold sufficient water to provide water to the seeds and seedlings in a continuous matter (ISTA, 2015). However, exact humidity levels and seed moisture contents are not specified.

8.3 TEMPERATURE

ISTA have specified temperatures per species for seed germination tests (ISTA, 2015). For some species, one temperature is given. Figure 8.4 shows two examples of the effects of a constant temperature on the germination percentage. For other species, two temperatures are given, which have to be reached for a specified time in cycles. However, these may differ from the optimal

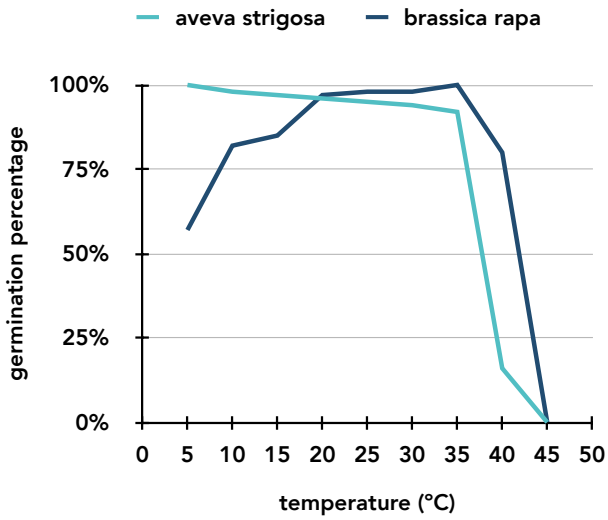


***Figure 8.4:** Influence of temperature on germination percentage on germination percentage (Tribouillois et al., 2016).*

conditions. Research suggests that complex temperature profiles may be beneficial for the yield of the seeds (Young et al., 1981).

8.4 LIGHT

Lighting can play an important role in the germination of seeds. Some crops have an initial light requirement for germination, while others only seem to germinate in dark conditions.

8.4.1 FLUENCE

In a study from Milberg, Andersson, & Thompson (2000), the light requirements for 54 species were investigated. They stated that seeds could use the absence of light as an indication of burial, since light can only penetrate the soil for a few millimeters. Light would, in turn, indicate a location on or near the surface. Large seeds can successfully emerge from greater depths, making light a less-important cue for germination.

The seed's response to light depends on several factors: the photon fluence, its spectral composition and the temperature. In a study from Milberg (1997), the response of the photo fluence was tested the seeds of *C. fontanum*, *R. obtusifolius* and *S. noctiflora*. Seeds were exposed to fluences up to 78000 µmol m^{-2} in varying times, ranging from 1/250 s to 240 s. To put this in perspective, a daylight can be around 2000 µmol m^{-2} s^{-1} during a clear Swedish summer day. It was concluded that there is a linear response to the logarithm of photon fluence of the seeds of *C. fontanum* and *S. noctiflora* (Figure 8.5). *R. obtusifolius*, however, had a threshold of 500 µmol m^{-2} under which germination was prevented.

8.4.2 SPECTRUM

Another specification for light is the color. The wavelength of light can influence the germination process (Lal & Sachan, 2017; Byun et al., 2014). An example of this effect can be seen in Figure 8.6. ISTA, however, have specified that the light color should be cold white for germination tests (ISTA, 2015).

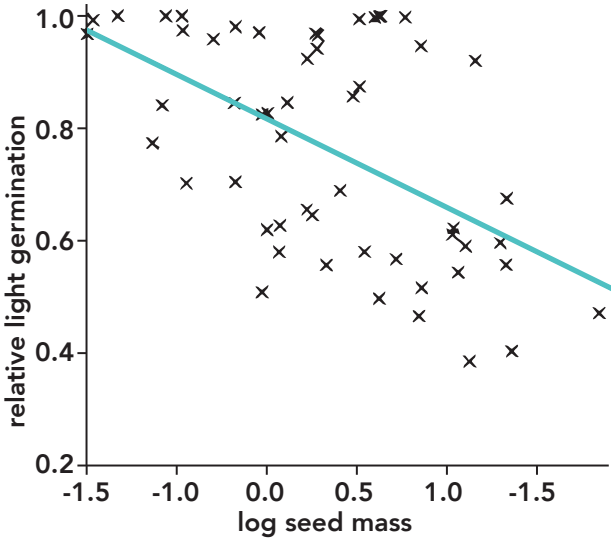


Figure 8.5: *Relation between seed mass and relative light germination (Milberg, Andersson, & Thompson, 2000).*

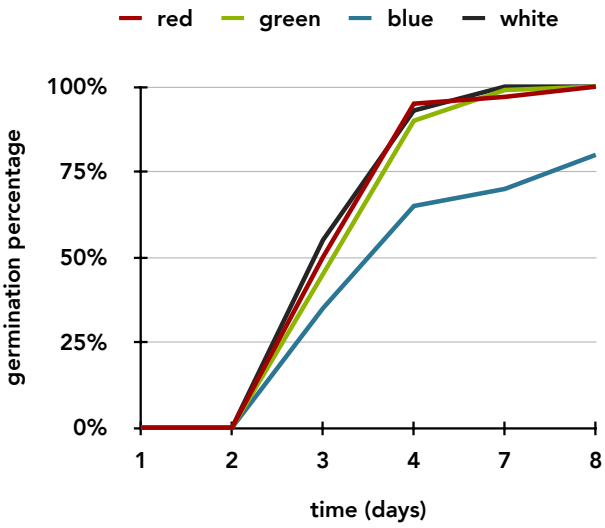


Figure 8.6: *Effect of different light colors on the germination process (Byun et al., 2014).*

8.5 NUTRITION AND SALINITY

There is the possibility to add nutrients to the plants seeds during the germination process. The salinity of the grow medium can be controlled as well. There is a vast number of studies of the effects of certain nutrients to species. For example, Yang (2018) studied the effects of nitrogen, phosphorus and potassium fertilizer on growth and seed germination of Capsella *bursa-pastoris (L.) Medikus* (Figure 8.7). There is a large number of nutrition types that can be tested, as well as the volumes added, and how and when these are added.

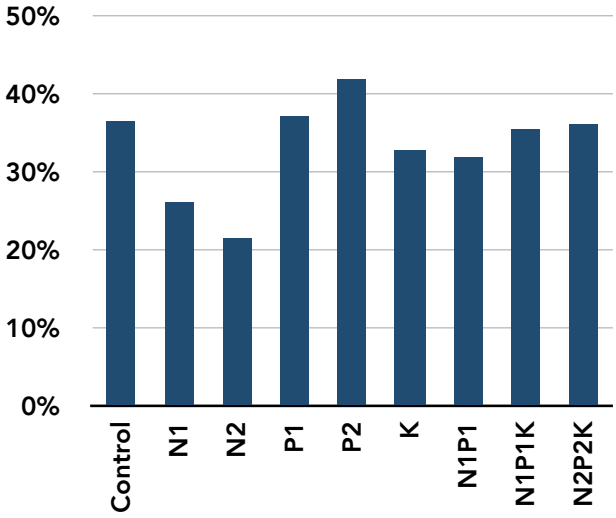


Figure 8.7: *The effects on germination of different combinations of nutrition of different combinations of nutrition (Yang, 2018).*

TAKEAWAYS FOR QUANTIFIED

- The factors that influence the germination process are water, temperature, light, nutrition and salinity.
- It is near impossible to analyze the effects of these factors analytically, as well as combinations of them.
- The QIEM-Array could be of great help in quantifying the effects of the different factors.

CHAPTER 9

International Rules for Seed Testing

In this chapter, the regulations for seed testing of the International Seed Testing Association (ISTA) are discussed. The definition of the different seedling structures is given, and the requirements for growing media and apparatus are given. Furthermore, the procedures, test conditions and evaluation are discussed.

9.1 ISTA

The ISTA is an independent organization supported by experienced seed scientists, analysts and laboratories. The duties is the development of internationally agreed standard procedures for sampling and testing of seeds. ISTA-certified tests are accepted by trading partners of the World Trade Organization (WTO) and international seed traffic (ISTA, n.d.). The ISTA regulations are mentioned in the vast majority of scientific articles about seed germination research. These regulations are published annually in the ISTA Handbook on Seedling Evaluation (ISTA, 2015).

9.2 GERMINATION

According to the ISTA regulations, a germination test is the emergence and development of the seedling. The essential structures must indicate whether or not it is able to develop into a plant under favorable conditions in the field. The germination percentage indicates the percentage of seeds that have been classified as normal within a certain time.

The seedling consists of one or more of the following structures, which are essential for its development into a plant:

- Root system (primary root; in certain cases seminal roots).
- Shoot axis (hypocotyl; epicotyl; in certain Poaceae mesocotyl; terminal bud).
- Cotyledons (one to several).
- Coleoptile (in all Poaceae).

9.3 GROWING MEDIA

Growing media have to provide sufficient pore space for air and water in germination tests (Figure 9.1).

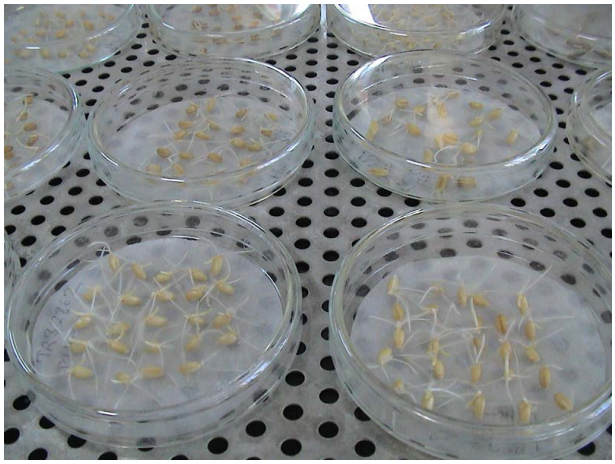


Figure 9.1: *Example of a seed growing medium.*

9.3.1 COMPOSITION

With paper as the base medium, combinations of growth media are prescribed by ISTA per species. These can include sand or a mixture of organic compounds with added mineral particles.

9.3.2 WATER

The growing medium should have the capacity to hold sufficient water to provide water to the seeds and seedlings in a continuous matter. Moreover, it should also provide sufficient pore space for aeration required for optimal germination and root growth. The use of demineralized, deionized, tap and spring water are permitted.

9.3.3 PH

The pH value must be in the range of 6.0-7.5.

9.3.4 SALINITY

The salinity must be as low as possible and not exceed 40 millisiemens m^{-1}.

9.4 MATERIALS AND APPARATUS

All kinds of plastic, glass, metal or pottery containers are permitted, as long as they have no toxic effects, are clean and do not carry micro-organisms.

9.4.1 THE JACOBSEN TABLE

The Jacobsen table (Figure 9.2) consists of a germination plate, upon which filter paper substrates with seeds are placed. The substrates are kept moist with a wick, which are in contact with a water bath under the germination plate. The substrate is covered with a bell jar to prevent drying out. The temperature is regulated by heating or cooling either the plate or the water in the water bath.

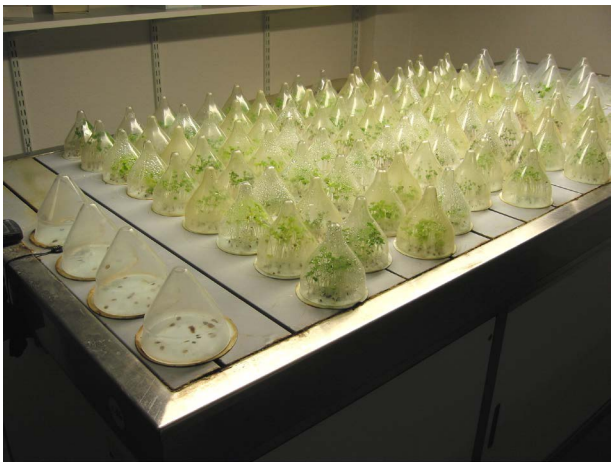


***Figure 9.2:** Jacobsen table.*

9.4.2 THE GERMINATION INCUBATOR AND THE ROOM GERMINATOR

The incubator is used for the germination of seeds or for pretreatments of seeds to break dormancy. The room germinator is similar to the incubator, but is large enough to allow workers to enter and perform tests within it. Incubators are equipped with heating and cooling systems, and the temperature must be evenly distributed.

9.5 PROCEDURE AND TEST CONDITIONS

A sample of 400 seeds are taken at random from a well-mixed pure seed. The seeds must be spaced uniformly and with adequate spacing on a moist substrate. Replicates of 100 seeds are used normally, but in some cases replicates of 50 or even 25 seeds are necessary to provide adequate spacing.

9.5.1 MOISTURE AND AERATION

The amount of water added should be adjusted to the needs of the species and the capacity of the medium. Subsequent watering should be avoided whenever possible.

9.5.2 TEMPERATURE

The temperature to which the seed is exposed on or inside the substrate is specified per species by ISTA. The variation in temperature most not be more than ±2 °C. When alternating temperatures are indicated, the lower temperature should be maintained for 16 h and the higher for 8 h. When a temperature range is given, no tolerances may be applied to the upper and lower limits.

9.5.3 LIGHT

Seeds will germinate in either light or darkness, but illumination of the substrate is generally recommended. Seedlings grown in complete darkness are more sensitive to attack by micro-organisms. In some cases, light may promote germination of dormant seeds, but in other cases, light may prevent germination. The illuminance should be between 750 and 1250 lux from cool white lamps. Cool white light is defined as light with a color temperature between 6000 and 7000 K. The spectrum of daylight corresponds to a light temperature of 6500 K. A commonly used standard for lighting is the Standard Illuminant D65 (Figure 9.3), defined by the International Commission on Illumination (CIE) (Schanda, 2007; Lovetskiy, K. et al., 2018).

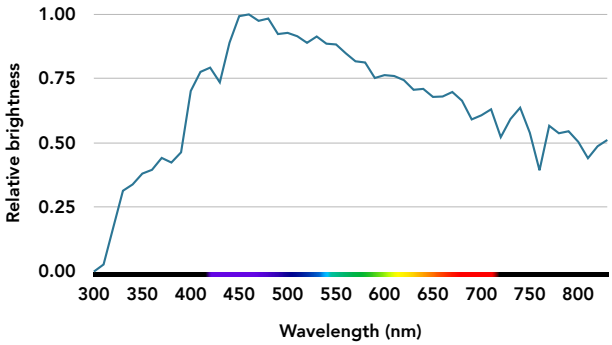


***Figure 9.3:** Relative brightness per wavelength of Standard Illuminant D65.*

9.5.4 DURATION OF THE TEST

The duration of the test for individual species is specified by ISTA. These range from 5 to 42 days.

9.6 EVALUATION

When a seedling has all essential structures (as stated in "9.2 Germination" on page 66), it must be removed from the test at the first count. Additionally, badly decayed seedlings should be removed, since there is a risk of secondary infections. A unit is counted as one in case it produces more than a normal seedling.

For the evaluation of cotyledons and primary leaves, the 50% rule is applied. Seedlings are considered normal as long as half or more of the total cotyledon and primary leaf tissue is functional. More detailed germination evaluation specifications can be found in the specifications by ISTA (2020).

9.7 CALCULATION AND EXPRESSION OF RESULTS

The results of the germination test are expressed as percentage of normal and abnormal seedlings.

TAKEAWAYS FOR QUANTIFIED

- Seed test require samples of 400 seeds.
- The temperature and light requirements are defined by ISTA.
- Seeds should be placed uniformly and with adequate spacing.
- Subsequent water during the test should be avoided whenever possible.
- The light should be cool white (CIE D65) and between 750 and 1250 lux.
- Seeds should be removed after germination or when they are badly decayed. This should happen at counting instances.

CHAPTER 10

Potential Users

The goal of the QIEM-Array project is to develop an innovative seed germination testing apparatus. The main functionalities, as defined by Quantified, were: picking and placing of seeds, advanced temperature and humidity control, adding nutrients, spraying with pesticides and seed germination classification. The envisioned purpose of the QIEM-Array would be to find optimum germination conditions for different plant species. To validate Quantified's assumptions and to gain knowledge about the seed industry, a number of companies were interviewed and visited (Figure 10.1). The coronavirus situation made it a bit more difficult, since many companies have imposed restrictions regarding visitors and many people were working from home. Therefore, most interviews were conducted on phone. The interview results can be found in Appendix C on page 176.

10.1 APPROACH

The first potential users were found by using Google and Google Maps. Search terms, such as 'plant seeds' and 'seed grower', were used. Then these companies were called and asked who to talk to about seed germination research. When the right person was reached, questions were asked, such as:

- How do you conduct seed germination research?
- What is important to measure?
- What is important to control?
- What is done manually and what is automated?
- Have you ever considered automating (parts of) the process?
- How do you find optimum seed germination conditions?
- Would you want to add nutrients or pesticides during the tests?
- Of what importance are the ISTA regulations?
- In an ideal situation, how would seed germination tests be conducted?
- Are there any other companies or organizations worth talking to?

The interviews took about 45 minutes. Many insights were gained. The interviewees gave tips about other companies to call. Most of them were very interested in the project and wanted to be kept informed.

10.2 SUMMARY OF INSIGHTS

At the start of the project, the main goal of the QIEM-Array was to find optimum germination conditions. However, it can be concluded from the interviews and visits that most potential users want to automate the ISTA tests instead. Usually, the plants are eventually grown in greenhouses or on land. The conditions depend, therefore, largely on the weather. For them, there is no point in finding the optimal conditions.

Almost all of the companies conduct seed germination research manually. This includes picking and placing of seeds, counting and classification. This takes them a lot of time. Moreover, since different people are involved in the tests, there is some variance in classification, because it is somewhat subjective. Automation of the process could save them a lot of time.

Now, they have set counting and classification moments (e.g. after 7 and 14 days for tomato seeds). Many indicated that it would be valuable for them to have germination data in between those moments, as well as condition data. Furthermore, several interviewees also said that they would want to be able to detect abnormalities.

In addition to the ISTA tests, many companies also conduct seed germination tests in trays greenhouses. This is done to simulate realistic growing conditions. Plantise was the only company that didn't perform ISTA tests. They are more interested in the percentage of usable plants and optimization of the conditions.

The full interview results can be found in Appendix C on page 176. The desired functions of the QIEM-Array extracted from the interviews and visits are shown in Figure 10.2.

Figure 10.1: *Companies interviewed and visited.*

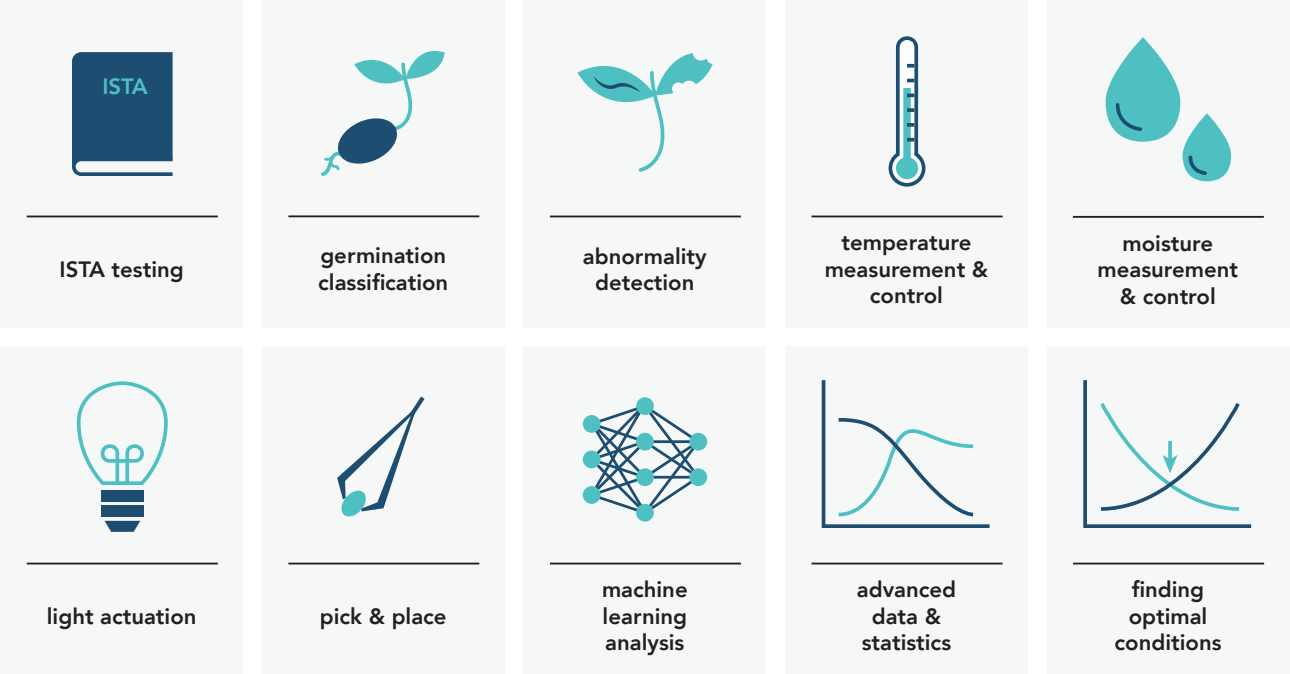


Figure 10.2: *Functions of the QIEM-Array desired by the users, extracted from the interviews and visits.*

TAKEAWAYS FOR QUANTIFIED

- ISTA tests are very important for companies and organizations in the seed industries.
- Germination tests are done manually. This is time-consuming and not consistent.
- Import conditions temperature, humidity and light.
- They want to classify seed germination and detect abnormalities in plants.
- They don't want to add nutrients or spray seeds during the germination process.
- Finding optimal conditions is not important for most companies.

CHAPTER 11

Imaging

A desired function of the QIEM-Array is advanced germination classification with intelligent image analysis. In this chapter, the imaging requirements are explored. Furthermore, different camera kinds are compared and a choice is made that suits this application best.

11.1 CAMERA REQUIREMENTS

Different cameras and lenses were used in previous studies on seed germination imaging. It is important that the resolution of the images provides enough details for the analysis.

11.1.1 BODY & LENS

A wide variety of cameras en lenses were used in previous studies into seed germination imaging. In some cases, specialized machine vision cameras were used, such as the Sony XC-033P (Figure 11.1 (a)) by Ducournau et al. (2004). In other cases, DSLRs were used, such as the Canon 450D (Figure 11.1 (b)) by Lev & Blahovec (2017).

Figure 11.1: *Different cameras used for seed germination imaging. Left: Sony XC-033P; right: Canon 450D.*

A telecentric lens was used by Dell'Aquila (2009). A telecentric lens produces an orthographic view of the subject, meaning that they don't have a change of magnification if the distance to the subject is changed. However, it provides no advantages compared to a regular lens if the distance between the camera and subjects are constant.

11.1.2 RESOLUTION

If the resolution of the camera is too low, important details can be missed. On the contrary, a resolution that is too high, could potentially make the image analysis too slow. In previous seed germination image analysis experiments, a pixel density between 86 px/cm and 272 px/cm was used (Dell'Aquila 2005; Joosen et al., 2010; Škrubej et al., 2015; Zhang et al., 2018).

11.1.3 BACKGROUND

In previous studies, different specifications of paper as grow medium have been used. The choice of color is always motivated by obtaining the highest possible contrast. This has lead to two approaches: a blue paper color to maximize the color contrast (Ducournau et al., 2004) or black paper color to maximize the luminance contrast (Škrubej et al., 2015) (Figure 11.2).

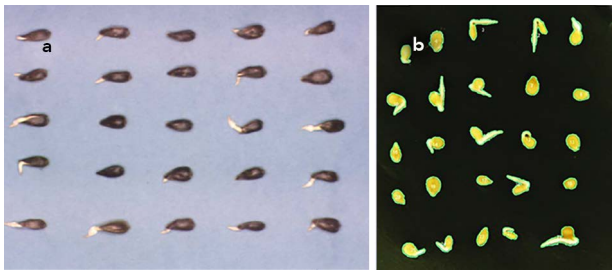


Figure 11.2: *Blue (a) and black (b) paper growing media.*

11.2 ILLUMINATION

Illumination as an significant factor in obtaining a high-quality image. It is important that the colors of the image correspond to the real colors (Ureña et al., 2009). In previous studies different lighting methods have been used. Ureña et al. (2009) used a LED panel to illuminate the scene. Black fabric was used by Howarth & Stanwood (1993) to eliminate the effect of ambient light on the germination process. However, light was turned on for 30 seconds when the photos were taken. Joosen et al. (2010) used two vertically placed fluorescent lamps while taking photos. They stated the importance of preventing any reflection, since it can interfere with the image analysis. According to Ureña et al.,

(2001), it is important to diminish shadows for the same reason.

11.3 FREQUENCY

The frequency at which photographs are taken is an important factor. On one hand, if the frequency is too low, important data could be missed. On the other hand, if the frequency is too high, the system could end up with too much data. From previous studies into digital image analysis of the germination process, a frequency of 1 photograph per hour seems to be the optimum (Dell'Aquila 2009; Dell'Aquila 2005; Ducournou, 2004; Howarth & Stanwood, 1993). But this has to be tested once the product is finished.

The performance of seeds can be described with a germination curve. The curve describes the percentage of seeds that have germinated over time (Figure 11.3). It was argued by Joosen et al. (2010) the number of germination assays could be reduced. In their experimental setup, they placed germination trays under a camera manually. They developed an automatic curve fitting algorithm using the *four parameter Hill function* (El-Kassaby et al., 2008). This meant that fewer measurements were required to form the germination curve. However, this method can be less accurate when screening large populations with different germination times and rates.

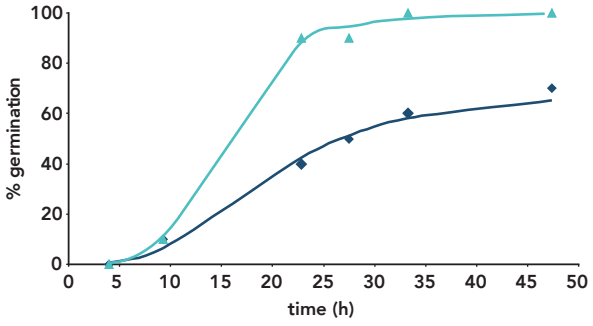


***Figure 11.3:** Example of seed germination curves. In this case the basilica seed (Joosen et al., 2010).*

11.4 CLASSIFICATION

After the photo of the seeds is taken, it needs to be analyzed by a computer to determine, for example, the germination rate or the number of abnormalities. This can be done using machine learning algorithms. This is further explained in Chapter 12 on page 76.

11.5 CAMERA CONCEPTS

At the very start of the project, the idea was to use a moving camera that would move over the cells and make a photo of a single cell at a time. Several other possibilities were explored. Some of the sketches made are shown in Figure 11.4. For example, the camera could be static or moving; or it could capture one or multiple cells. After some research and brainstorming, these four options seemed the most viable: line scan camera, moving area camera, static array camera and static cell camera (Figure 11.5).

11.5.1 LINE SCAN CAMERA

A line scan camera moves in a straight line. It can scan all cells in a linear movement. The advantage is that the images would be of very high quality. A disadvantage would be that the cells would have to open every time a photo needs to be taken, making this option relatively complex. Moreover, it would require a moving mechanism for the camera.

11.5.2 MOVING AREA CAMERA

A moving area camera would move to from cell to cell to take pictures of one cell at a time. As the previous option, it would mean that the cells have to be opened when taking photos. Additionally, it would require a x-y movement system for the camera.

11.5.3 STATIC ARRAY CAMERA

A static area camera would have capture multiple cells photos at once. Since the camera is static, this solution would be less complex than the previous ones. Nonetheless, it would still mean that the cells have to be opened for every photo. Moreover, the cell walls would block the view

11.5.4 STATIC CELL CAMERA

With this solution, each cell would have an individual camera. A large numbers of cameras would be needed, but it would require no moving parts. Photos could be made without the cells opening.

11.5.5 EVALUATION

The different options were evaluated on cost, image quality and complexity (Figure 11.6). The desired situation is also given. As can be seen, the static cell camera comes closest to the desired situation.

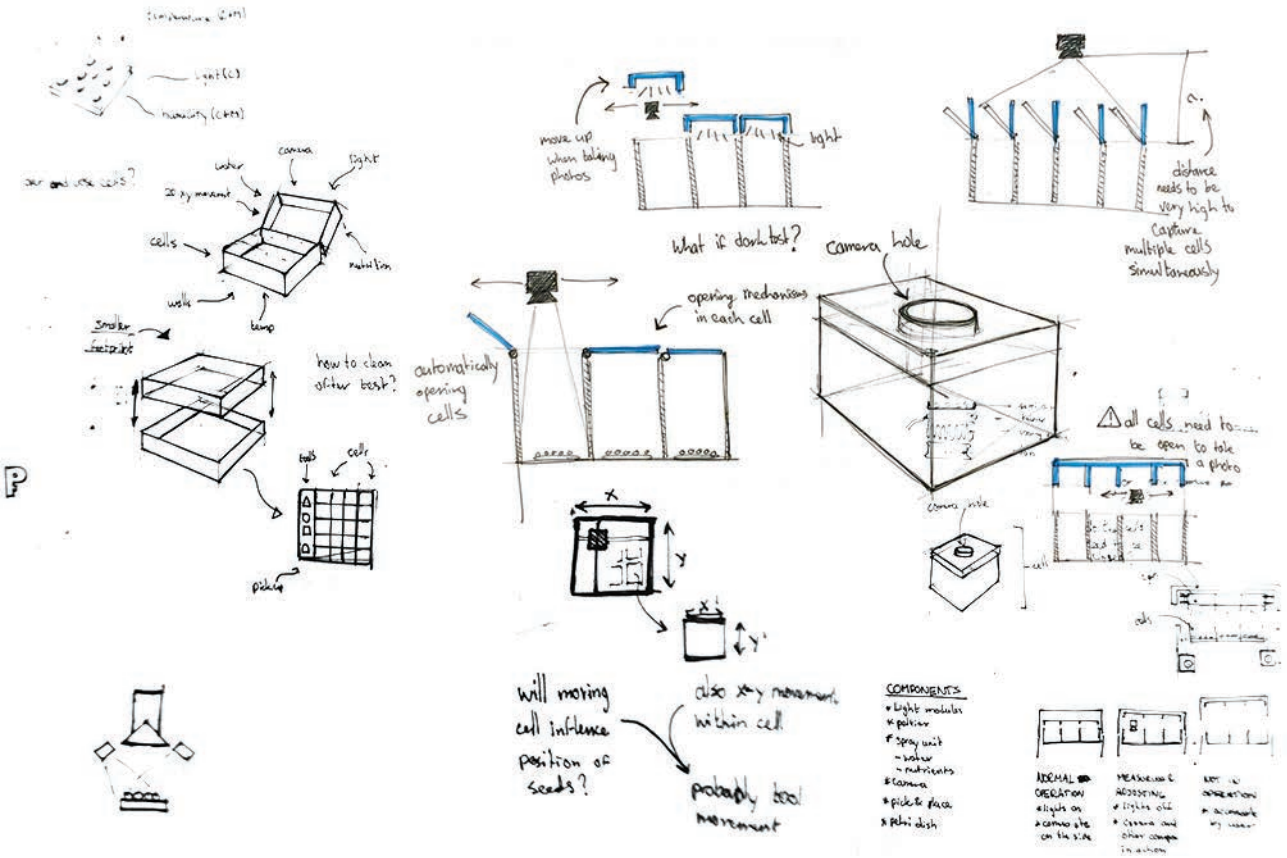


Figure 11.4: *Sketches of various camera options.*

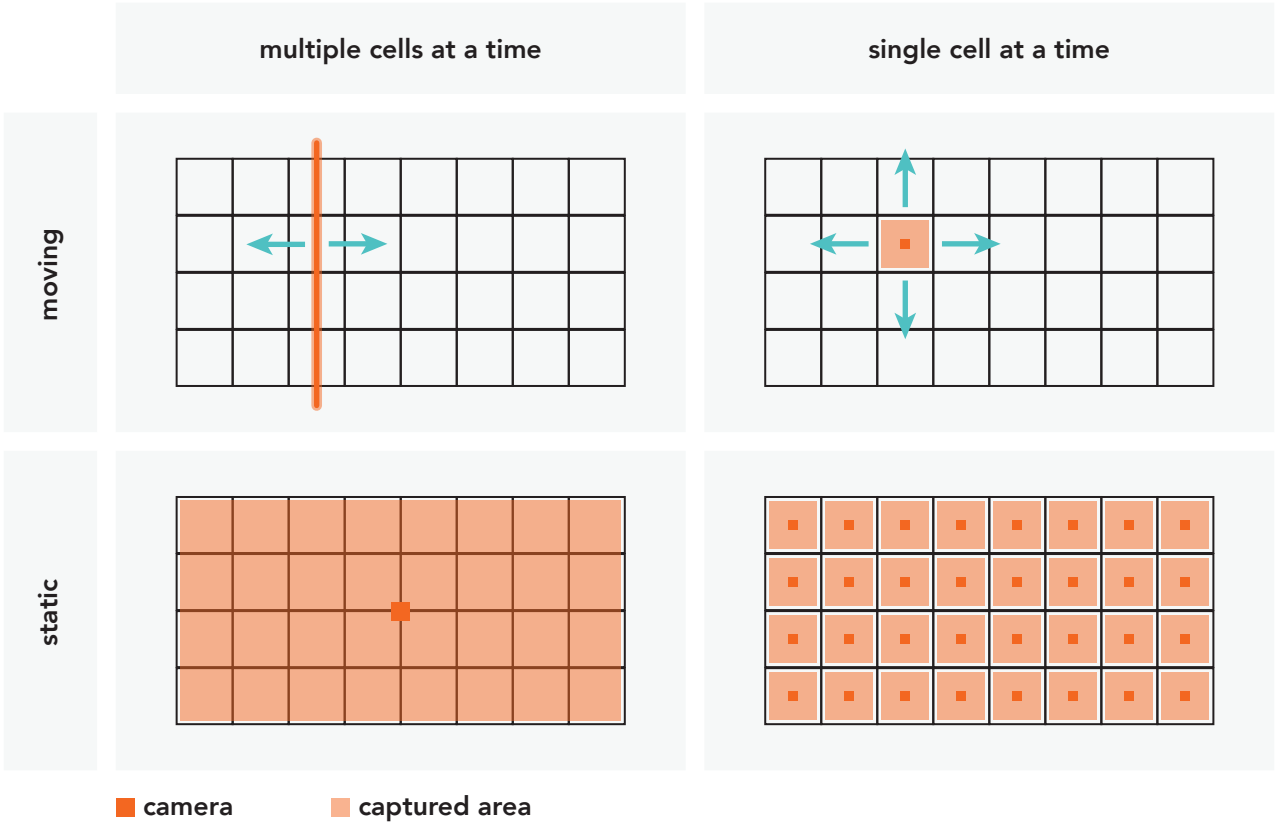


Figure 11.5: *Schematic representation of the different camera concepts.*

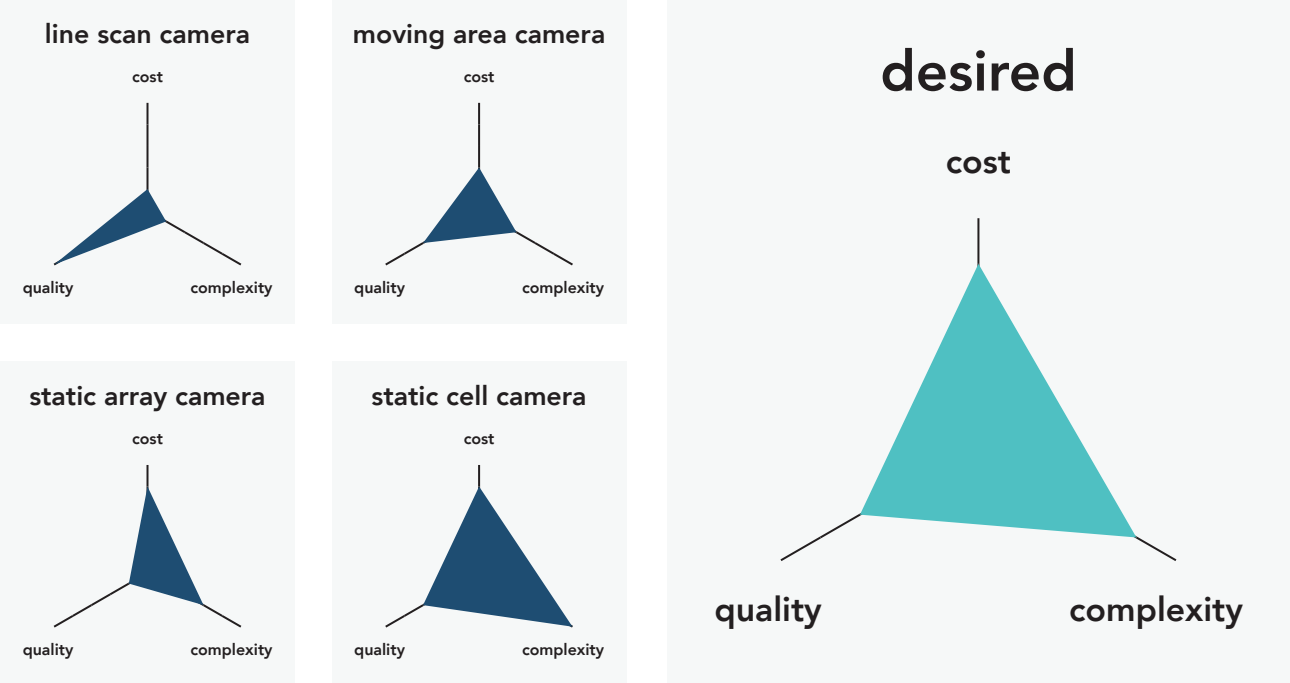


Figure 11.6: *Comparison of the different camera concepts.*

TAKEAWAYS FOR QUANTIFIED

- The type of camera not significant, as long as the quality of the photos is sufficient.
- There should be enough contrast between the seeds and the background.
- The frequency of one photo per hour is sufficient.
- Image analysis using machine learning classifiers is discussed in Chapter 12 on page 76.

CHAPTER 12

Machine Learning

In this appendix, machine learning classifiers are compared for the application of germination image analysis with artificial intelligence.. Artificial intelligence (AI) is a technique in computer science that creates intelligent machines that mimic human behavior. Machine learning (ML) is a subset of AI that uses statistical techniques that enables machines to improve at tasks with training. Deep learning is a subset of ML that consist of artificial neural networks (ANN) composed of multiple layers (Figure 12.1). **MACHINE LEARNING CLASSIFIERS**

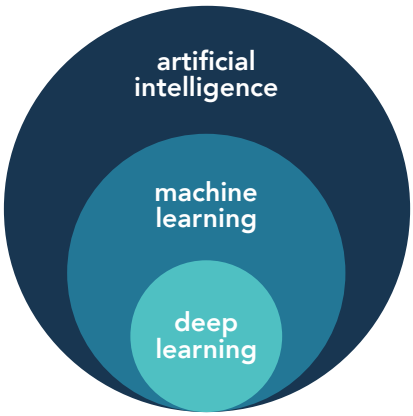


Figure 12.1: *The relation between AI, ML and DL.*

Classification is the process of assigning a class to data inputs. There are different classification algorithms. In a study from Škrubej et al. (2015), the performances different classifiers were compared for automatic assessment of the germination rate for tomato seed.

12.5.1 NAIVE BAYES (NB)

The NB classifier (Figure 12.2) uses the Bayes probability theory under the assumption that the attributes are conditionally independent. Even though this assumption is not valid on most cases, it performs reasonably well. The NB classifier is easily scalable to large data sets and, due to the assumption, has relatively low computational costs.

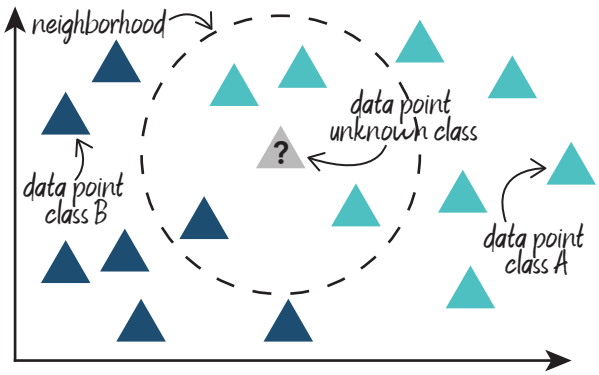


Figure 12.2: *Illustration of the NB classifier.*

12.5.2 K-NEAREST NEIGHBOR (KNN)

The kNN classifier (Figure 12.3) stores all training data in an *n*-dimensional space. When an unknown input is given to the classifier, it is placed in the space and compared to it's nearest neighbors. It is then classified with the most common class of its *k* nearest neighbors, where *k* is an integer given by the user. The algorithm is simple to implement when there is a lot of training data, but it can be computational-intensive, since all distance to the neighbors have to be calculated.

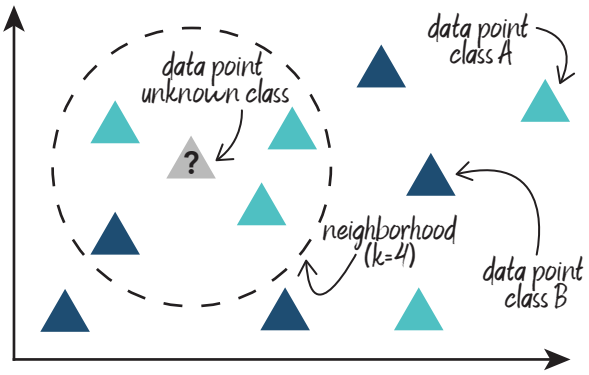


Figure 12.3: *Illustration of the kNN classifier.*

12.5.3 DECISION TREES (DT)

The DT classifier (Figure 12.4) makes binary splits on input data, based on rules learned sequentially using training data. The model is easily visualized as a tree-like model. A disadvantage is that the DTs can become very complex and therefore unstable.

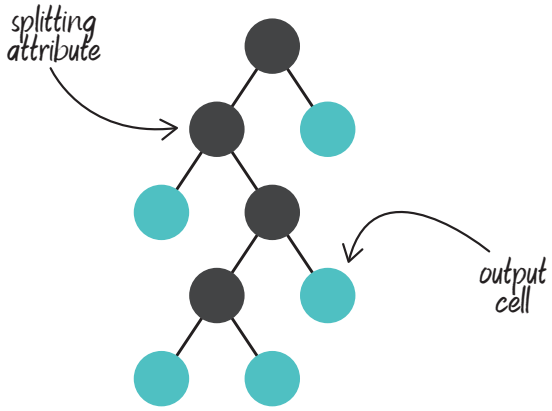


Figure 12.4: *Illustration of the DT classifier.*

12.5.4 SUPPORT VECTOR MACHINES (SVM)

The SVM classifier (Figure 12.5) maps training data in a multi-dimensional space. The space is then separated into categories by finding the largest gaps as possible. Unclassified data is classified by placement in the space and therefore automatically categorized. The classifier is memory efficient, but it uses computational-expensive cross-validation.

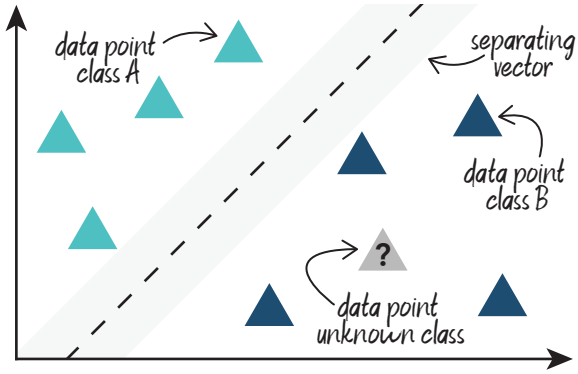


Figure 12.5: *Illustration of the SVM classifier.*

12.5.5 ARTIFICIAL NEURAL NETWORKS (ANN)

An ANN classifier (Figure 12.6) is a network layers of input/output nodes that are connected with weighted connections (neurons). The weights are determined with training data. The ANNs have proved to have impressive performance in real-life applications. A major disadvantage is the poor interpretability of the models, compared to, for example, the DT.

12.5.6 EVALUATION OF CLASSIFIER PERFORMANCE

The performances mentioned classifiers were compared on accuracy, precision, recall and f-measure.

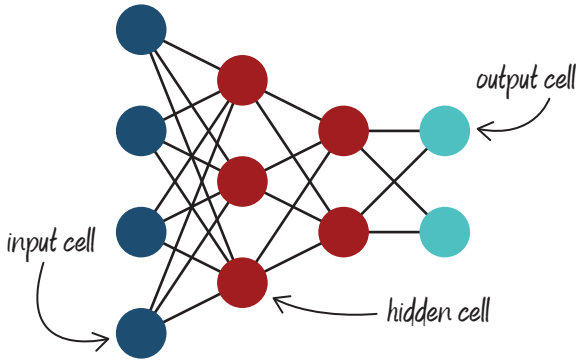


Figure 12.6: *Illustration of the ANN classifier.*

ACCURACY

The accuracy gives the percentage of correct predictions made when compared to actual classifications. It is calculated with the following equation, (Witten & Frank, 2005):

$$\text{accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \times 100\%$$

TP stands for *true positive*, TN for *true negative*, FP for *false positive* and FN for *false negative*.

PRECISION

The precision describes the proportion of actual positive predictions among the total number of positive predictions. It is calculated with the following equation (Witten & Frank, 2005):

$$\text{precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

RECALL

The recall (or sensitivity) is the ratio of the TP over the sum of the TP and FN, and is calculated with the following equation (Baeza-Yates et al., 1999):

$$\text{recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

F-MEASURE

The F-measure is the harmonic mean of the precision and recall, and is calculated with the following equation (Baeza-Yates et al., 1999):

Table 12.1: *Test results of the performances of classifiers for the assessment of germination of tomato seeds (Škrubej et al., 2015).*

Classifier	Accuracy (%)	Precision	Recall	F-Measure
NB	87.89	0.9535	0.8755	0.9120
kNN	91.66	93.07	0.9569	0.9432
DT	93.66	0.9569	0.9551	0.9556
SVM	93.09	0.9498	0.9555	0.9523
ANN	95.44	0.9722	0.9652	0.9684

$$\text{F-measure} = \frac{2 \times \text{precision} \times \text{recall}}{\text{precision} + \text{recall}}$$

12.5.7 RESULTS OF CLASSIFIER COMPARISON TEST

The five machine learning classifiers were tested by Škrubej et al. (2015) for the assessment of the germination of tomato seeds. As can be seen in Table 12.1, the ANN classifier proved to have the best performance for this application. In this specific setup, a feed-forward multilayer perception architecture and a back propagation algorithm was used for training.

To make the classifier work for a larger variety of seeds, more research has to be done. There are different parameters (such as the number of layers and classes, the learning rate and momentum rate) that can be optimized for the desired application.

12.5.8 COMPARISON TO OTHER TESTS

It is hard to make a fair comparison between tests, since there are so many variables that can affect the results. Therefore, this comparison has to be taken with a grain of salt.

Shadrin et al. (2019) designed a low-power sensing system with the AI on board with a special focus on the application in agriculture. A convolutional neural network (CNN) was designed, which is a type of ANN. A CNN has one or more layers of convolution units. Such a unit receives inputs from multiple units from the previous layer. Therefore, the input units share their weight. The accuracy on classification of seed germination was 97%.

A computer vision tool to classify germination of *Striga* seed was developed by Masteling et al. (2020). The classifier used is the 'You-Only-Look-Once' (YOLO) CNN. It consist of an image classifier, followed by object detection layers. The classification accuracy was 94.51%.

Awty-Carroll et al. (2018) used a kNN classifier to classify germination of *Miscanthus* seeds. The method achieved a maximum accuracy of 89%.

De Medeiros et al. (2020) used a linear discriminant analysis (LDA) to classify the germination of seeds. LDA is comparable to SVM, with the main difference being that LDA finds the mean vectors of each class and then maximizes the separation of means, while SVM finds a linear separator that separates the classes with the least error. In this particular test, the accuracy of seed germination classification was 93.93%.

12.1 ARTIFICIAL NEURAL NETWORKS

It was concluded that artificial neural networks (ANN) are the best performance for the classification of seed germination. However, in the this category of classifiers, there is a wide variety of possible architectures. The four most commonly used in machine learning applications are discussed below (Aggarwal, 2018).

12.1.1 RADIAL BASIS FUNCTION NETWORKS (RBF)

RBF networks (Figure 12.7) typically use only use two layers. The first layer is constructed in an unsupervised way, whereas the second layer is trained using supervised methods. The RBFs are mainly used for system control, classification, function approximation and time series prediction.

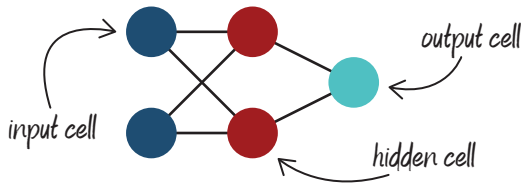


Figure 12.7: *Illustration of the RBF.*

12.1.2 RESTRICTED BOLTZMANN MACHINES (RBM)

RBMs (Figure 12.8) are often used for unsupervised modeling and dimensionality reduction, although they can also be used for supervised modeling. However, since they were not naturally suited to supervised modeling, the supervised training was often preceded by an unsupervised phase.

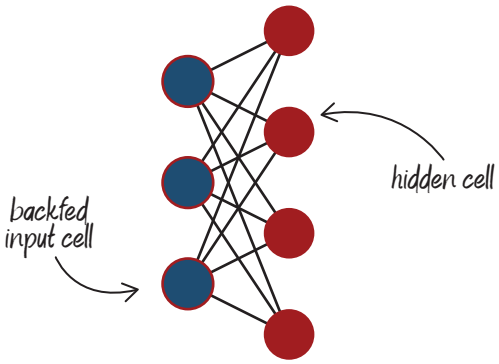


Figure 12.8: *Illustration of the RBM.*

RBMs are used in applications, such as dimensionality reduction, classification and feature learning.

12.1.3 RECURRENT NEURAL NETWORKS (RNN)

RNNs (Figure 12.9) are designed for sequential

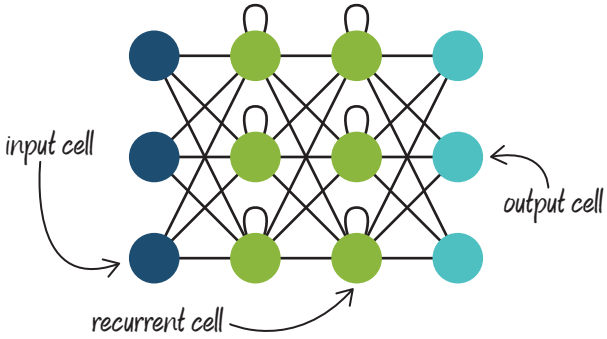


Figure 12.9: *Illustration of the RNN.*

data like text sentences, speech and handwriting recognition, time-series, and other discrete sequences like biological sequences. RNNs use their internal memory to process sequences of input.

12.1.4 CONVOLUTIONAL NEURAL NETWORKS (CNN)

CNNs (Figure 12.10) are biologically inspired networks that are used in computer vision for image classification and object detection. The images are divided into subsets of smaller images. This input window is sliding over the image, pixel by pixel. The data is then processed in convolution layers.

For image and feature recognition, CNNs are the most commonly used. Therefore, this is the

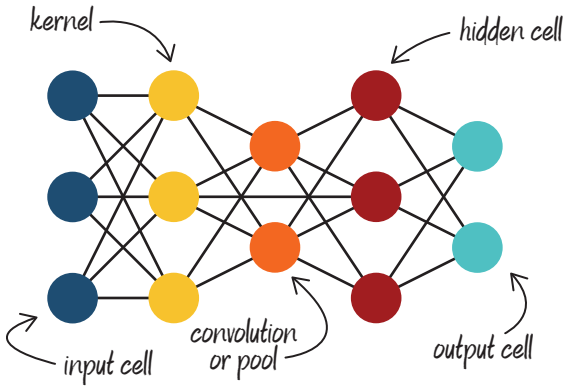


Figure 12.10: *Illustration of the CNN.*

preferred architecture for seed germination analysis. As stated before, a lot of research has been done on germination with image recognition. CNNs were also often used in these studies (e.g. Shadrin et al., 2019; Masteling et al., 2020).

12.2 OTHER CLASSIFICATION METHODS

Besides machine learning, other ways have been used for the classification of seed germination. Here are some of these researches that are worth mentioning.

Most of these classification methods use a color thresholding algorithm to separate the seeds from the background, where after the seeds are counted and the germination rate is analyzed. Experiments have shown that a change in RGB color density can mark the start of germination (Dell'Aquila, 2009). Not much information on the performance of these methods compared to the evaluation by trained technicians is given.

In a study by Dell'Aquila (2009), a multi-color-thresholding algorithm was used for the separation of the seeds from the background. Using the Image-Pro software package, object contours were placed around the seeds, number of seeds were counted and the number of pixels per seed were calculated to determine the size.

Lev & Blahovec (2017) had a similar approach. A blue threshold was set to separate the seeds form the background on the images. The analysis was

done with OpenCV, a software library aimed at computer vision. The development of the seed cross-area, length and width was evaluated by calculating a time derivative.

In a study by Joosen et al. (2010), after separation with color thresholding and image enhancement, the images were analyzed using an Microsoft Excel script. Differences in X-Y movement and color were compared between subsequent images. Classification was done based on user-defined thresholds for these parameters.

Franco et al. (2020) calculated the areas and centers of gravity of seeds after color thresholding. Thereafter, the length of the radicle is calculated with the distance between the center of gravity and the first and the last pixels in the connected region. This is done by locating the corners.

A fuzzy logic-based classifier was used in a study by Ureña et al. (2009). In fuzzy logic, classification happens based on probabilities, rather than true or false statements. The fuzzy logic evaluations closely matched those of trained technician.

TAKEAWAYS FOR QUANTIFIED

- Several image classification algorithms were discussed.
- Artificial neural networks proved to be the best classifier for the classification of seed germination image analysis.
- Within the domain of artificial neural networks, it was found that the artificial neural networks were the best classification method for this application.

CHAPTER 13

Temperature Measurement and Control

For the germination tests, the seeds have to be kept at certain temperatures, as defined by the ISTA regulations (Chapter 9 on page 66). The seeds are placed on a wet piece of paper on a flat surface. The temperature of the surface has to be controlled. In this appendix, different temperature controlling methods are compared. Furthermore, an experiment with temperature control with a Peltier element is discussed.

13.1 WAYS TO CONTROL THE TEMPERATURE OF A SURFACE

Different methods of temperature control are explained below.

13.1.1 WATER RESERVOIR WITH A THERMOSTAT

Conventional germination tables use a water reservoir with a thermostat to control the surface temperature. The biggest advantage is that the reservoir also provides water to the paper the seeds are growing on. A major disadvantage is that it takes long for the reservoir to cool down. Therefore, cold water has to be pumped in, as is done with existing germination tables. Moreover, after each test, the reservoir has to be opened to be cleaned thoroughly, to prevent diseases of mold from growing.

13.1.2 HEATING ELEMENTS

Heating elements convert electrical energy into heat. Current is flowing through a high-resistant element, after which heat is dissipated. These elements can be made from different materials in various shapes. The materials include metals, ceramics and conductive PTC rubber. The main disadvantage is that heating cannot be cooled. The minimum temperature is, therefore, the temperature of the surrounding environment. Figure 13.1 shows an example of a heating element.

13.2 PELTIER ELEMENTS

The Peltier element (Figure 13.2) consists of two ceramic plates between which semi-conducting metal rods are placed. When a power source is connected, a current naturally starts to flow. The electrons can only pass through the semi-conducting material in one direction, so energy is carried in only that direction. The side of the element where the electrons come from becomes cold. The side of the element where the electrons move to then becomes warm. The fact that it can heat and cool is a big advantage of the Peltier element.

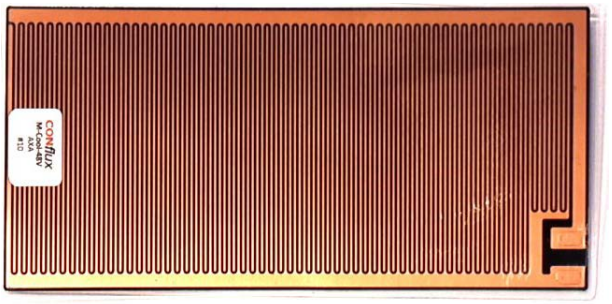


Figure 13.1: *PTC heating element.*

Figure 13.2: *Peltier element.*

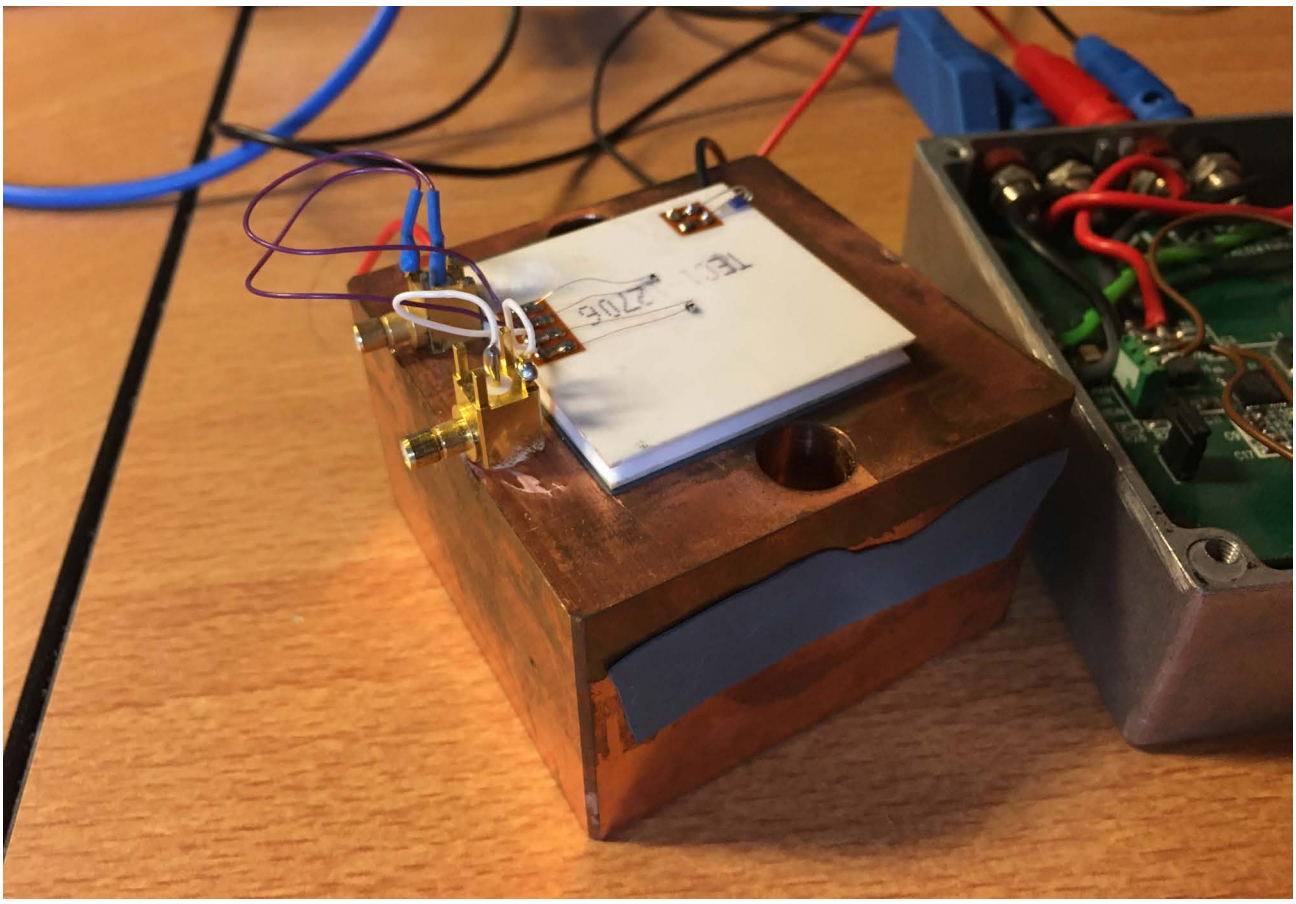


Figure 13.3: *Peltier element temperature control experiment.*

13.2.1 CHOOSING THE TEMPERATURE CONTROLLING METHOD

The three mentioned methods of heating are all widely used for a wide variety of applications. There is, however, one crucial criterion in this choice: the temperature range. According to the ISTA regulations, the temperature has to be between 10 °C and 35 °C. With both a water reservoir with a thermostat and with heading elements, it is impossible to reach temperatures lower than the ambient temperature without complex cooling systems. Therefore, the Peltier element is the best option for this application.

13.3 TEMPERATURE CONTROL WITH A PELTIER ELEMENT

For this project, a test setup has been built to control the temperature of a Peltier element (Figure 13.3). The element has a cooling block to dissipate its heat. On the top surface are temperature sensors to monitor its heat. The temperature is controlled with the *MAX1978 Evaluation Kit*. It is specifically designed to control the temperature of a Peltier element using a PI or PID controller.

In the experiments, it was found that temperatures between 0 °C and 70 °C could be reached with this particular setup and power supply. However, experiments with a more representable setup are necessary with a larger surface with a wet growing medium on it, to see how it performs in germination tests.

13.4 COOLING THE PELTIER ELEMENT

When the seed bed has to be cooled to its minimum temperature, the bottom of the Peltier element has to dissipate a lot of heat. Therefore it has to be cooled. The two most common ways to cool Peltier elements are liquid cooling and air cooling. Research was done into the two cooling methods. According to Han et al. (2018), the water's heat transfer coefficient is tenfold that of air. However, in practice, the heat transfer area for the liquid-cooling systems (which are typically confined in a narrow micro channels and manifolds) is much smaller compared to the air-cooling system heat transfer area. A Peltier element cooling expert from Alflex Technologies was contacted and the design problem was explained. After the literature research and expert consult, it was concluded that the most optimal

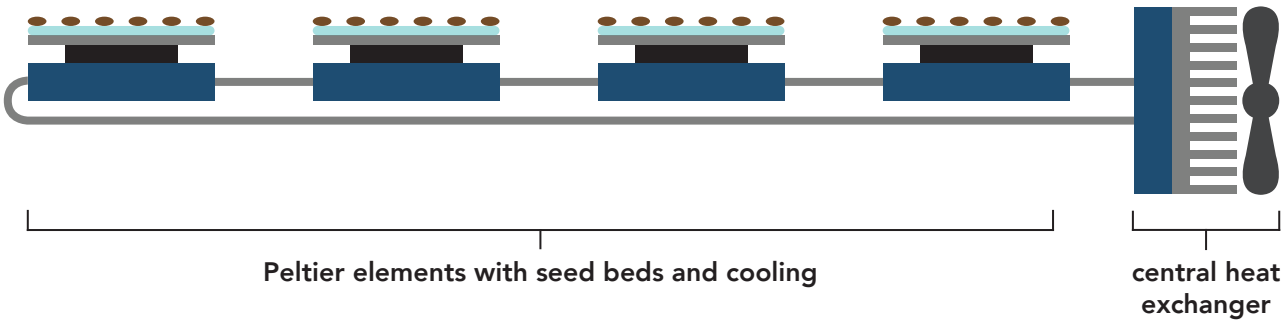


Figure 13.4: *Chosen cooling concept for the QIEM-Array.*

solution for the QIEM-Array would be to have liquid cooling. The cooling of the cells can then be linked and a central heat exchanger can be used (Figure 13.4).

TAKEAWAYS FOR QUANTIFIED

- Different methods of controlling temperature of a surface for germination tests were compared.
- It was found that temperature control with Peltier elements is most suitable for this application.
- A test setup was made with a Peltier element. The temperatures reached was within the range specified by ISTA.
- Further research is needed with a more representable setup.

CHAPTER 14

Moisture Measurement

In the QIEM-Array, moisture of the surface on which the seeds are placed for measurement needs to be measured. As was told by different seed germination testing experts (Appendix C on page 176), moisture level of the surface has to be measured, rather than the humidity of the air surrounding the seeds. Two moisture measurement sensors suitable for this applications have been compared: resistance and capacitive sensors.

14.1 RESISTANCE SENSOR

A soil moisture sensor (Figure 14.1) can measure the moisture content of a soil based on the change in resistance between two conducting plates. When the moisture levels are high, electricity will conduct more easily, reducing the resistance. For dryer conditions, the resistance will increase. Therefore, the moisture content can be measured by measuring the resistance.

14.2 CAPACITIVE SENSOR

Capacitive sensors (Figure 14.2) can detect if a medium has a different dielectric constant than air. An example of an application are touch screens, where the dielectric constant of fingers is detected. These sensors can also be used to detect moisture.

A capacitive sensor works like a capacitor. A charge continually changed in a sensing surface. The amount of current required to change the voltage is measured and indicates the amount of capacitance between the probe and the target. In this case, the target is water.

14.3 CHOOSING THE MOISTURE MEASUREMENT METHOD

Because it's corrosion resistance, capacitive sensors are chosen to be the best method for measuring moisture. Moreover, Quantified is currently developing a capacitive moisture sensor for another application. This gives the possibility of sharing knowledge and hardware.

Figure 14.1: *Resistance sensor.*

Figure 14.2: *Capacitive sensor.*

TAKEAWAYS FOR QUANTIFIED

- Different types of moisture sensors were compared.
- It was found that capacitive sensors are most suitable for this application.

CHAPTER 15

Distilled Project Vision

At the start of the project, Quantified's brand and their project vision were analyzed. In the next phase, research has been done into different areas, such as: seed germination, seed industry regulations, imaging and machine learning, and climate control. A large number of potential customers were interviewed about their germination test procedures, and their requirements and wishes. This chapter summarizes those insights into a design vision.

15.1 THE SEED GERMINATION PROCESS

With the germination of seeds, the next generation of a plant begins. The uptake of water marks the start of the seed germination process. There are different factors that play a role in the germination process. The most notable are temperature, light and moisture. More information about the germination process can be found in Chapter 8 on page 62.

The International Seed Testing Association (ISTA) is responsible for the development of internationally agreed standard procedures for sampling and testing of seeds. ISTA-certified tests are accepted by trading partners of the World Trade Organization (WTO) and international seed traffic (ISTA, n.d.). Regulations for seed germination tests are published annually in the ISTA Handbook on Seedling Evaluation (ISTA, 2015). More information about the ISTA regulations can be found in Chapter 9 on page 66.

15.1.1 TEMPERATURE

The optimum temperatures for the germination process vary per species. Some species require a constant temperature, while others require different day and night temperatures. The temperatures are specified per species by ISTA. The QIEM-Array should be able to reach temperatures between 10 °C and 35 °C, since those are the minimum and maximum specified by ISTA. The tolerance for the temperature is ±2 °C. The temperature will be controlled with a Peltier element (Chapter 13 on page 81).

15.1.2 LIGHT

Lighting can play an important role in the germination of seeds. Some crops have an initial light requirement for germination, while others only seem to germinate in dark conditions. The temperatures are specified per species by ISTA.

The illuminance of the QIEM-Array lights should be between 750 and 1250 lux from cool white lamps. Cool white light is defined as Standard Illuminant D65.

For seeds germination tests in general, there are two lighting methods used: fluorescent and LED lighting. Both types can meet the ISTA requirements. However, it was chosen to use LED lamps for this application. LED lights have a higher lifespan, are more efficient, cheaper and more flexible in use, compared to fluorescent lights

15.1.3 MOISTURE

The moisture levels of surroundings of the seed play a role in the germination process. The ISTA regulations don't provide exact moisture requirements, as long as the growing medium has the capacity to hold sufficient water to provide water to the seeds and seedlings in a continuous matter. When the water content of the growing medium gets insufficient, water should be added. The QIEM-Array should be able to monitor and adjust the moisture levels. Different moisture measuring methods were compared, and it was chosen that a capacitive sensor is the best option for this application (Chapter 14 on page 84).

15.1.4 TESTING PROCEDURES

A minimum of 400 seeds should be tested, with a maximum of 100 seeds per cell, as is specified by ISTA. The QIEM-Array should be able to place seeds on the growing media with adequate and constant spacing. It should also be able to remove the seeds after germination or if they are badly decayed. The germination tests can take from 5 to 42 days, depending on the species.

15.2 GERMINATION ANALYSIS

The QIEM-Array should be able to take photographs of seeds that can be used for image analysis in a future stage of the product.

15.2.1 IMAGING

The requirements for the imaging process were explored (Chapter 11 on page 72). From this research followed requirements for the camera setup, background, lighting and frequency.

CAMERA AND LENS

A wide variety of cameras en lenses were used in previous studies into seed germination imaging. It was concluded that the type of camera and lens doesn't play a big role on the results, as long as it can capture all seeds and the resolution is adequate. However, more compact cameras can be beneficial in certain situations. In previous seed germination image analysis experiments, a pixel density between 86 px/cm and 272 px/cm was used (Dell'Aquila 2005; Joosen et al., 2010; Škrubej et al., 2015; Zhang et al., 2018).

BACKGROUND

It was found that there should be enough contrast between the seeds and the background. This can be achieved in two ways: color contrast (Ducournau et al., 2004) or luminosity contrast (Škrubej et al., 2015).

LIGHTING

Lighting plays an integral part in the imaging process. It is important that the colors of the image correspond to the real colors (Ureña et al., 2009). Joosen et al. (2010) stated the importance of preventing any reflection, since it can interfere with the image analysis. There are several methods that can be used, but a LED ring seems to be the optimal way (Ureña et al., 2001).

FREQUENCY

From previous studies into digital image analysis of the germination process, a frequency of 1 photograph per hour seems to be sufficient (Dell'Aquila 2009; Dell'Aquila 2005; Ducournau, 2004; Howarth & Stanwood, 1993).

15.2.2 MACHINE LEARNING (FUTURE)

The QIEM-Array should be able to analyze the germination process autonomously. This requires image analysis as well as condition optimization. There have been several studies exploring germination analysis using image recognition (e.g. Ducournau et al. (2004) and (Lev & Blahovec, 2017)).

Research was done into machine learning algorithms (Chapter 12 on page 76). A variety of machine learning algorithms were compared for the application of seed germination analysis. According to previous studies, artificial neural networks (ANN) are the best classifiers for this application (e.g. Škrubej et al., 2015).

Within the domain of ANNs, there is a large number of different configurations. From research into ANNs for image analysis in general and specifically for the application of seed germination analysis, it was found that convolutional neural networks (CNN) are best suited for this application.

The machine learning algorithms allow for functions, such as:

- Advanced data and statistics.
- Germination classification with image analysis.
- Abnormality detection with image analysis.
- Advanced temperature control.
- Finding optimal conditions per species.

15.3 TARGET GROUPS

The target groups include companies and organizations that perform germination research. The first target group are the *seed breeders*. They invest large amounts resources into developing seeds. The second target group are the *seed growers*, who want to know the performance of the seeds and optimal growing conditions. The third target group is *research institutions and universities*

15.3.1 USER INTERVIEWS AND VISITS

To validate Quantified's assumptions and to gain knowledge about the seed industry, a number of companies and organizations from all target groups were contacted. Eleven interviews were conducted and three companies were visited. More can be found in Chapter 10 on page 69.

The interviews and visits proved to be very valuable for this project. It gave a lot of insights in the protocols, equipment used, problems and desires of the potential users.

At the start of the project, the main goal of the QIEM-Array was to find optimum germination

conditions. However, it can be concluded from the interviews and visits that most potential users want to automate the ISTA tests instead.

Almost all of the companies conduct seed germination research manually. This includes picking and placing of seeds, counting and classification. This takes them a lot of time. Moreover, since different people are involved in the tests, there is some variance in classification, because it is somewhat subjective. Automation of the process could save them a lot of time.

It was also assumed that users would want to add nutrients or spray with pesticides during the tests. However, when asked, none of the potential users said that they would want this.

15.4 CONCLUSION

The functions of the QIEM-Array are shown in Figure 15.1. Figure 15.2 shows a summary of the technical requirements and Figure 15.3 shows a summary of the complete vision.

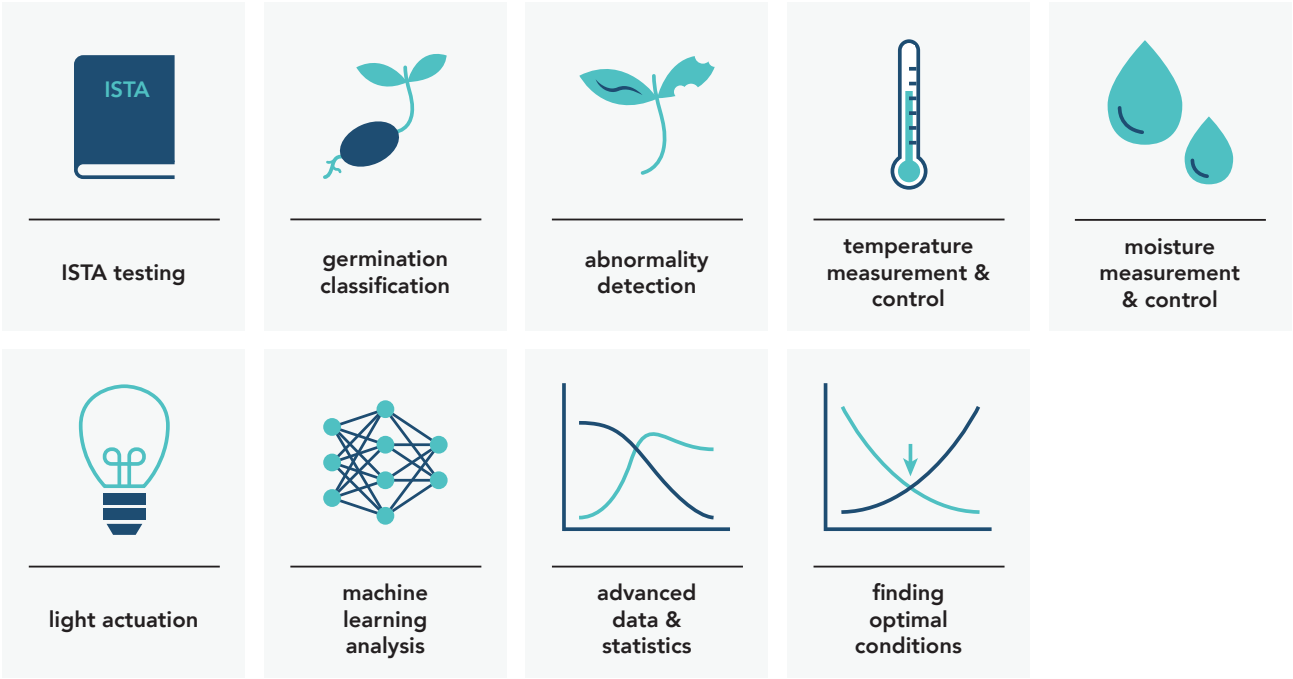


Figure 15.1: *Functions of the QIEM-Array.*

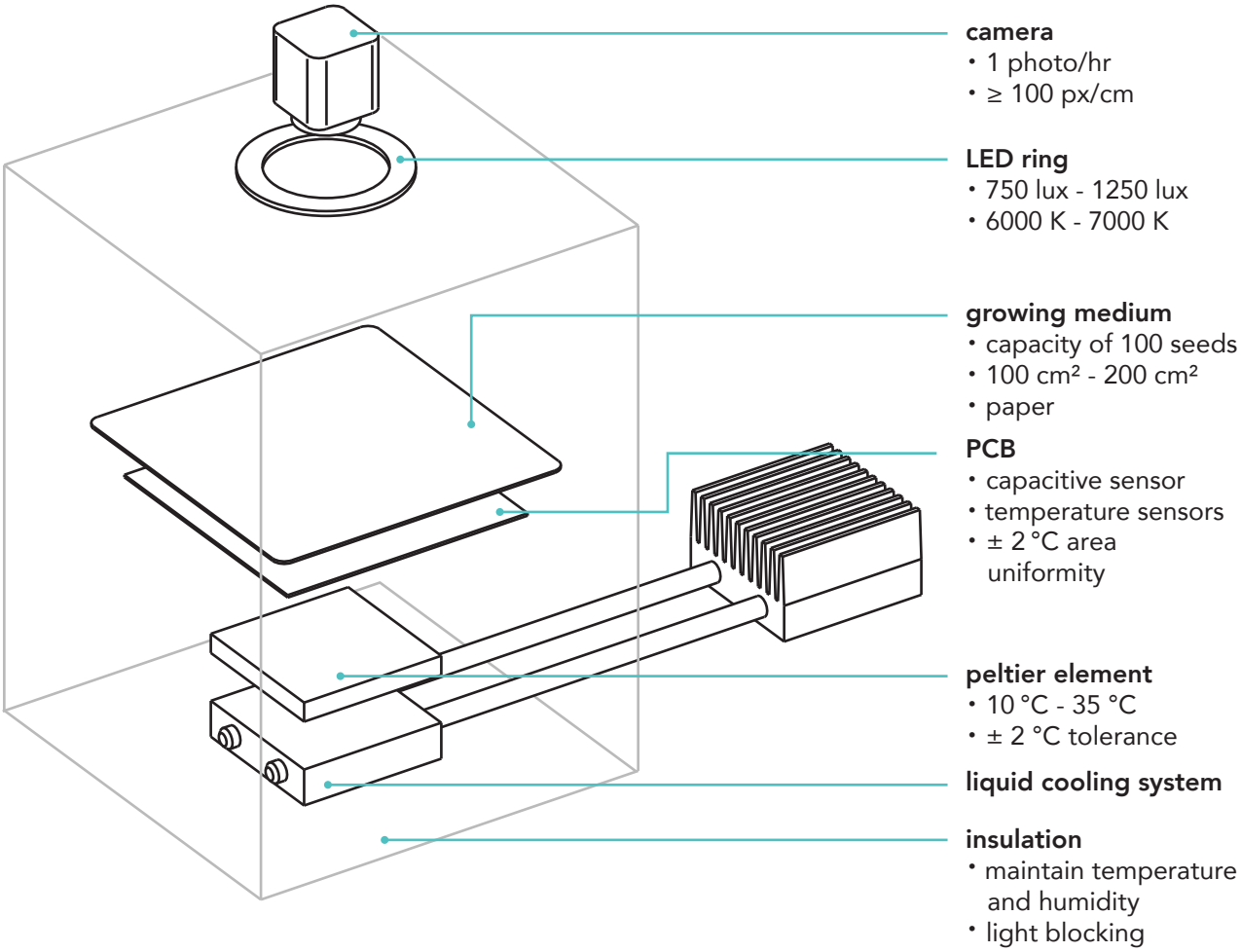
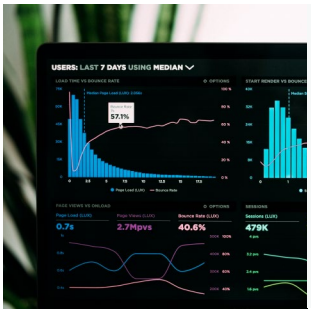


Figure 15.2: *Summary of the technical requirements of the QIEM-Array.*

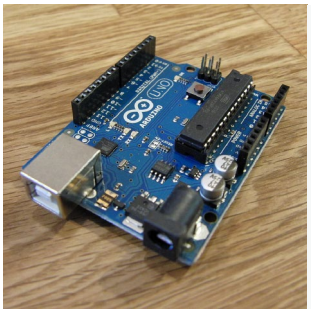


INTELLIGENT AND PRECISE
The QIEM-Array should should have precise control of the climatical conditions in the cells. Compared to the state of the art (Jacobsen tables and climate cabinets) this is a big leap forward. It also reduces the amount of variables, because the cells provide insulation from the outside world. A large amount of data can be generated during the germination tests, since the climatical conditions will be logged using various sensors.

EASE OF USE
The QIEM-Array should be intuitive to use. This means that the product should not look overly complex. The control and data gathering software should be easy to understand.

CLEAN LOOK
The QIEM-Array should have a clean look. This means that no non-essential components should be visible. This includes things, such as electronics, structural components and fastening matereials.

IMAGINATIVE
During one of the feedback sessions, Paul Kengen said: "*It would be nice if the QIEM-Array looked like something new and revolutionary. Like a big step beyond the Jacobsen table.*" The QIEM-Array brings innovation to a field that has remained static for years. Low-tech is being replaced by high-tech. Therefore, the product must look like something new and more high-tech than the Jacobsen table.



LOW DEVELOPMENT TIME
Warner Venstra said in one of the interviews: *"We would rather have a product that is ready quickly and can be tested and improved quickly, than one that is in development for a long time and takes a long time to get results."* Therefore, the QIEM-Array must be a product that could be developed quickly.

Figure 15.3: *Summary of the QIEM-Array vision.*

TAKEAWAYS FOR QUANTIFIED

- Many insights have been gained throughout the project with a company analysis, project analysis, literature research and user interviews.
- These insights have been combined into a project vision.

“

Run, Forrest, Run!

Jenny Curran (1951)

PART D

Design Sprints

Once the in design vision was formed, the design phase could begin. There were many aspects where solutions had to be found, such as the imaging, temperature control, measurements with the sensors, light and other electronics.

The design phase was divided into design sprints, but more loosely interpreted than the traditional sprint method. In each sprint a problem was tackled. The sprints influenced each other, for example, the dimensions of the seed bed influenced the electronics and the shape of the whole device. Throughout the whole design process, prototypes were made and evaluated.

The final design of the QIEM-Array has nine cells in a stepped arrangement. It consists of an aluminum frame with insulated walls. Each cell has a camera and three custom-designed PCBs, temperature regulation and water drainage. The frame, the sheet metal for the walls and the PCBs were manufactured externally. At the end of this phase, a prototype of the QIEM-Array was built.

CHAPTER 16

Form 1

Insights from the research were used in the design process of the cell. Over time the germination cell concept began to take shape. A quick-and-dirty prototype was built to get a sense for the size and to be able to do a test scenario (Figure 16.1).

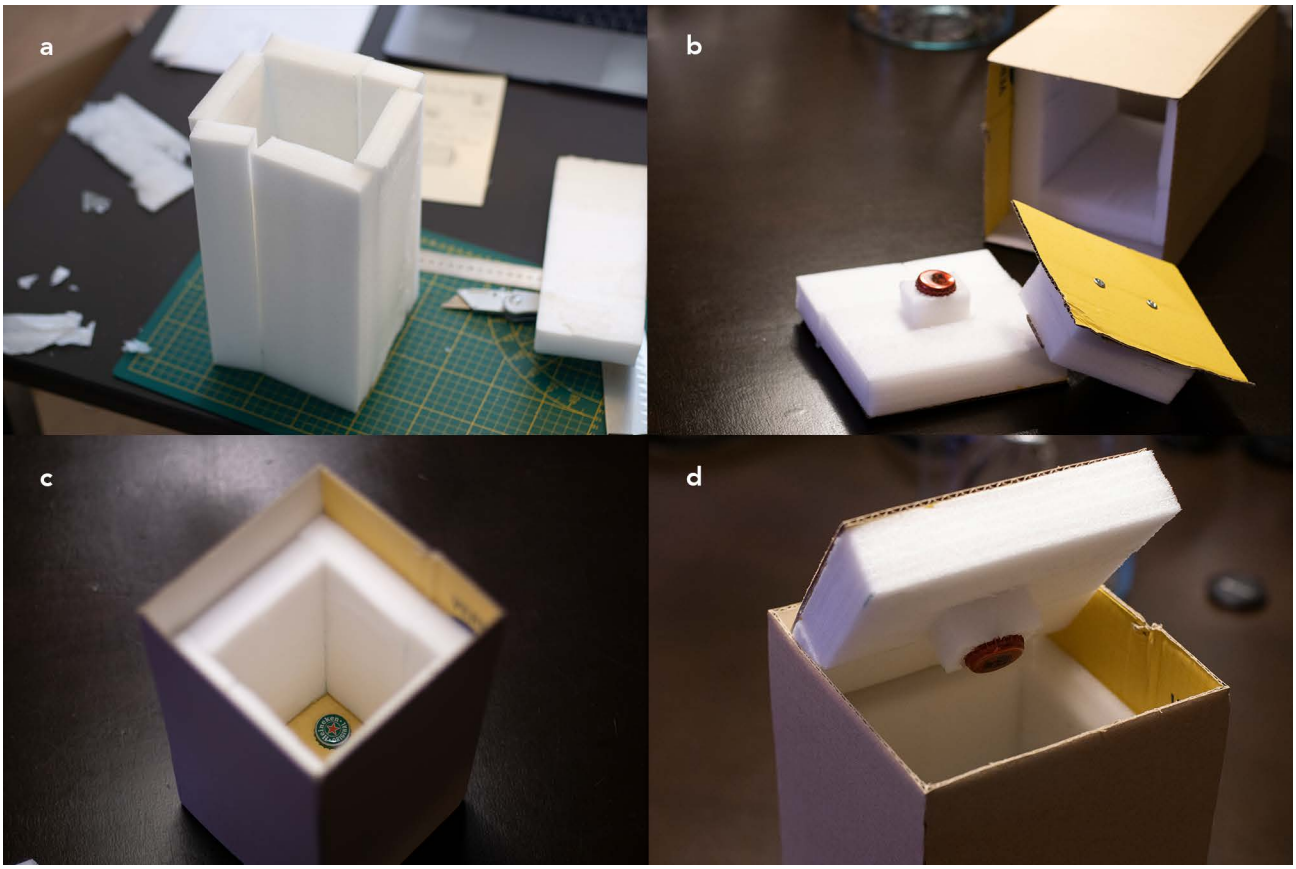


Figure 16.1: *Quick-and-dirty prototype of the germination cell. a: The insulation material. b: the lid with camera, the seed bed with peltier and cooling (yellow part) and the cell walls. c: View into the cell with seed bed. d: Lid with camera.*

16.1 SCENARIO

With the prototype, a test scenario was performed. The scenario was determined based on the insights of the interviews and visits to potential users (Chapter 10 on page 69). It consisted of the following activities:

Opening cell, placing seeds, closing cell.

1. Opening cell, removing germinated seeds, closing cell.
2. Opening cell, cleaning cell, closing cell.

16.2 PROBLEMS FOUND

While playing out the scenario, several problems with the model were found.

16.2.1 USER'S VIEW INTO THE CELLS

The first problem that was found, was the viewing angle of the user into the cell. Depending of the height of the table, the height of the cell walls, the user's length and the user's distance from the table, the user might not be able to see in and reach the cell with their hand (Figure 16.2). The model was expanded to test this more extensively ("Form 2" on page 97).

16.2.2 CLEANING THE CELL AFTER THE TEST

A step in the scenario with the prototype was to clean the cell after the test. This is where a problem occurred. The seed bed has to be cleaned, it is

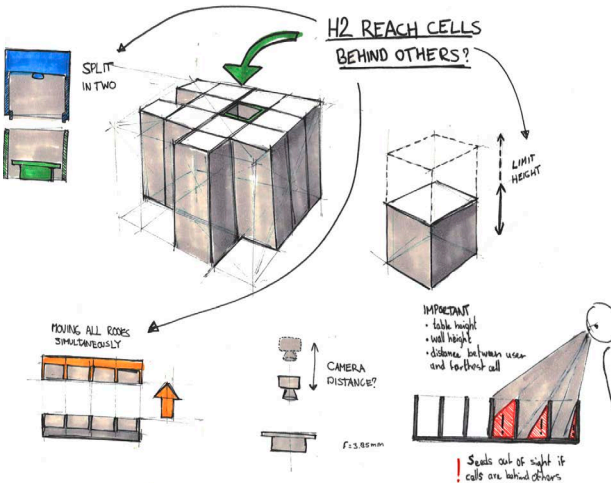


Figure 16.2: *How to reach into cell behind others.*

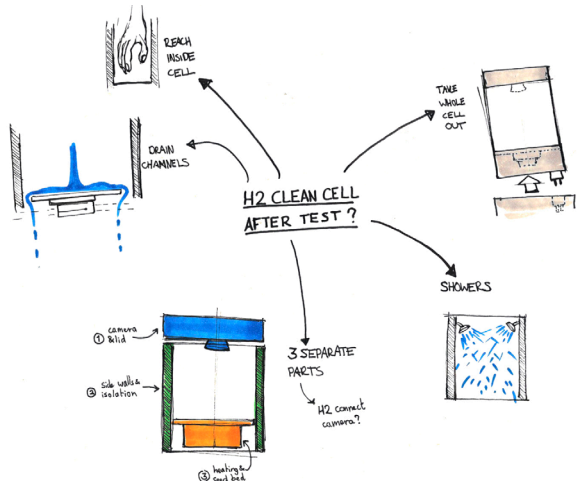


Figure 16.3: *How to clean the cell after the test.*

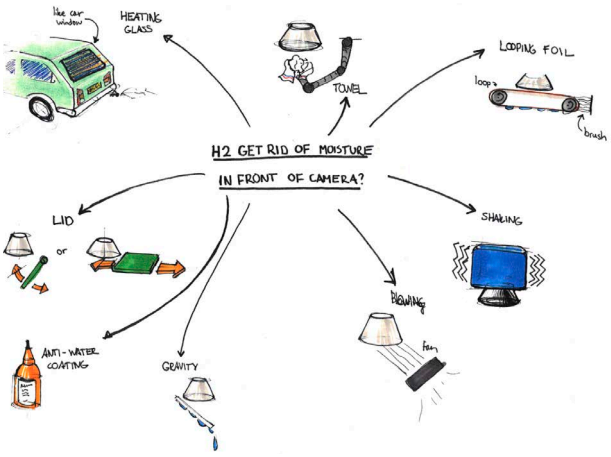


Figure 16.4: *How to get rid of moisture in front of camera.*

connected to the electronics and cooling. Therefore it cannot be taken out. When cleaning the cell from the top, it would be difficult to extract water or other fluids from the cell (Figure 16.3).

16.2.3 MOISTURE ON CAMERA LENS

The humidity in the cell during the test will be very high. A likely problem would be that the camera would not be able to take proper pictures because there is moisture in front of the lens. Ideas for possible solutions are shown in Figure 16.4.

16.3 CONCLUSION

In addition to the issues mentioned, several other (smaller) issues were found. With the insights gained and solutions found, a concept sketch was made (Figure 16.5). The top of the cell includes the camera and LED ring. When the user has to get to the seed bed, the user has to take the top of. The seed bed can be cleaned without the need to take it out. The liquids can be collected under the cell and drained away through a channel. Insights from the model building, scenario and ideation sessions were used in the rest of the design process.

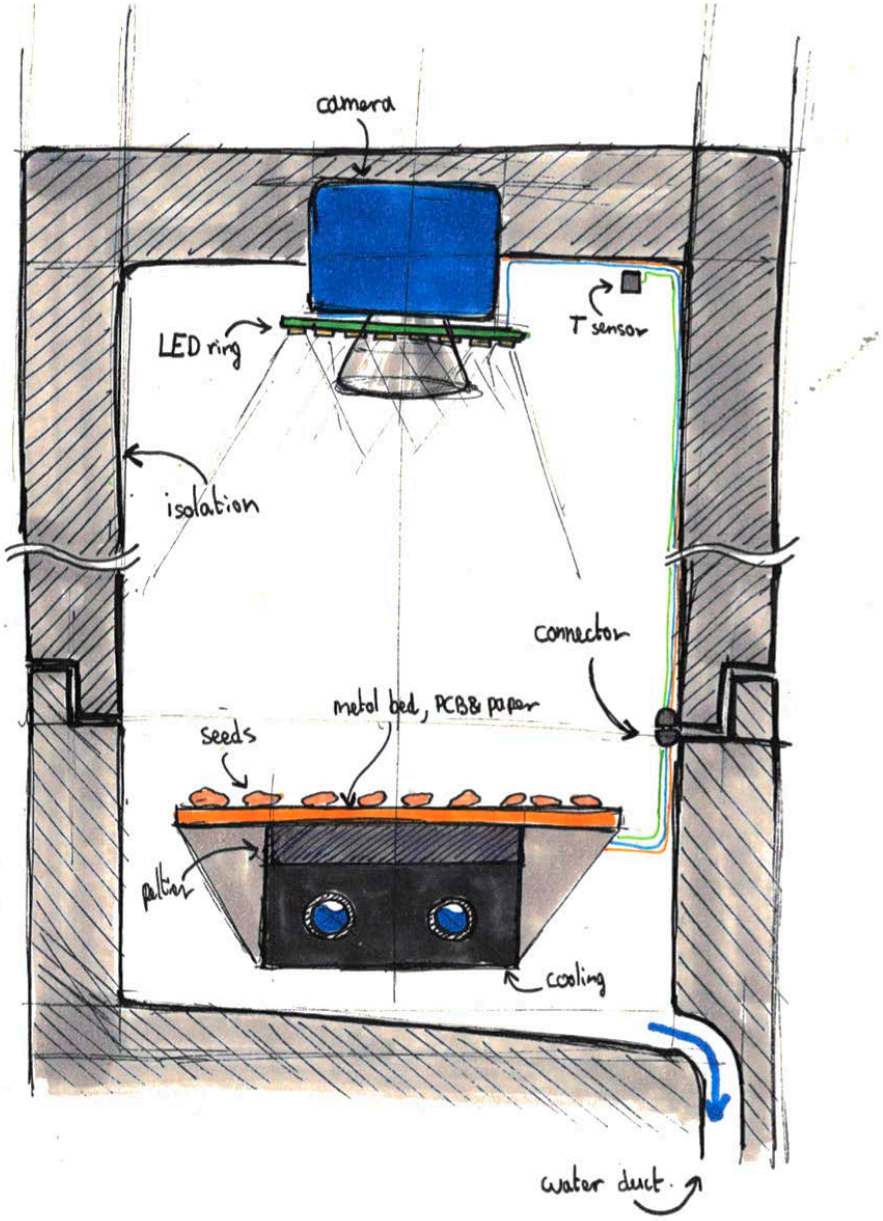


Figure 16.5: *Concept sketch of the cell.*

TAKEAWAYS FOR QUANTIFIED

- A quick-and-dirty prototype of the germination cell was built and used in a test scenario.
- There were several problems found, such as the cell walls obstructing the user's view, the ability to clean the cell after the test, moisture on the camera lens.
- Insights gathered from this test were used in the conceptualization.

CHAPTER 17

Electronics 1

The goal of this design cycle was to get familiar with the water sensor and temperature sensor, as well as to get a sense of what happens over time with a damp piece of paper, similar to the seed bed. A test setup was build and sensor data was collected.

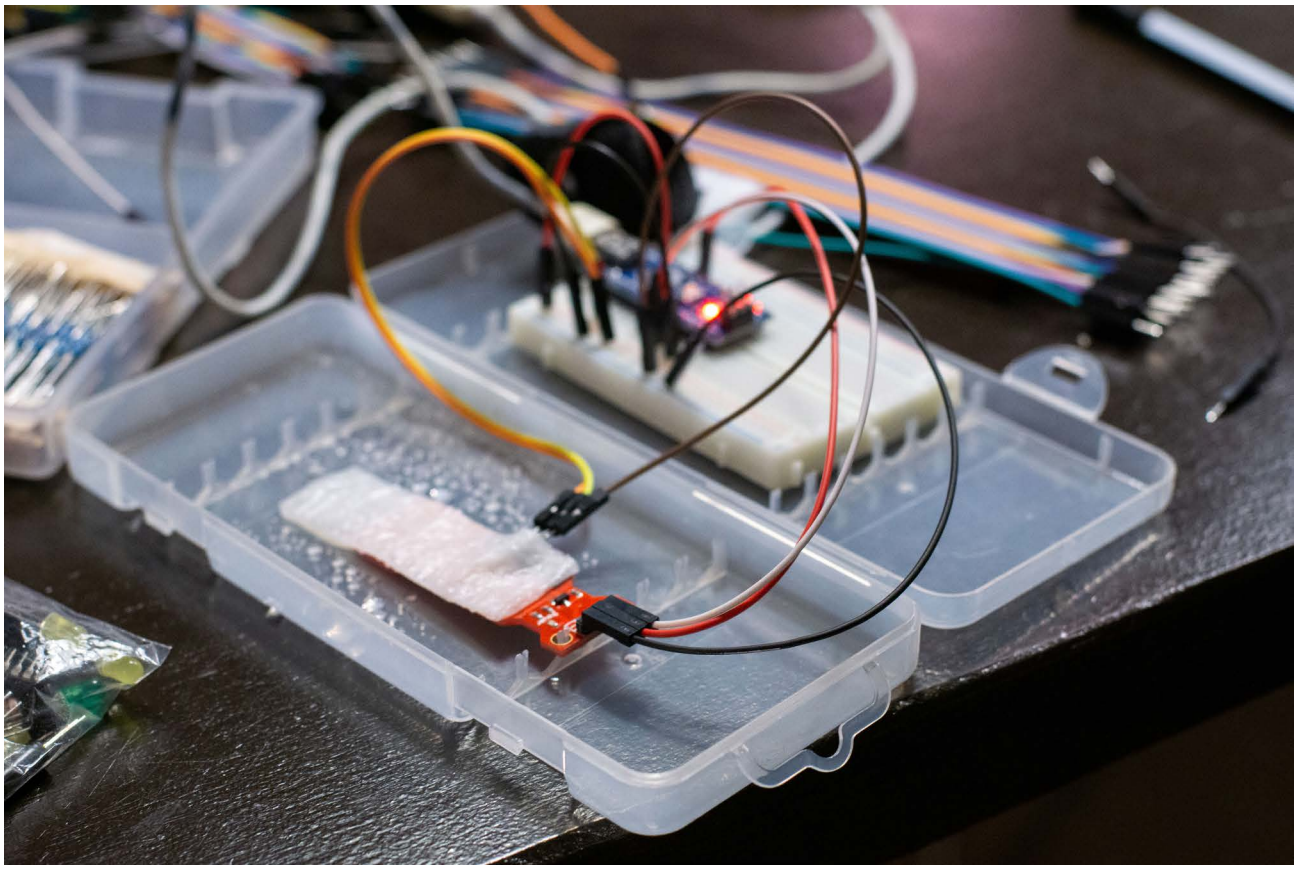


***Figure 17.1:** Moisture and temperature measurement setup. A water sensor and temperature sensor are connected to an Arduino Nano.*

17.1 TEST SETUP

The tools used for this test were an Arduino Nano, resistance moisture sensor and a temperature sensor (Figure 17.1). The sensor used measures resistance, which decreases when exposed to a conducting medium. The transistor was used to measure temperature.

17.2 THE EXPERIMENT

The sensors were connected to the Arduino and the test was started. The first measurements were done while the piece of paper was still dry to get sensor readings in dry conditions. After a few minutes, the paper was moistened. At the twelve hour mark, the paper was moistened a second time. The sensor data was recorded and can be seen in Figure 17.2.

17.3 EVALUATION

The temperature line in the graph follows expected behavior. Right after the paper was moistened, there was a slight drop in temperature. The behavior of the water sensor was different than expected. It was expected that there would be a slight drop in conductivity, due to evaporation. However, the conductivity decreased to a level similar to that of dry conditions, while the piece of paper did not seem to have gotten dryer. Soaking it again at the twelve hour mark confirmed that there was something wrong with the sensor.

After expectation after the test it appeared that the sensor was strongly corroded, hence the unusual values. Therefore, it can be concluded that a resistance sensor is not optimal for measuring moisture.

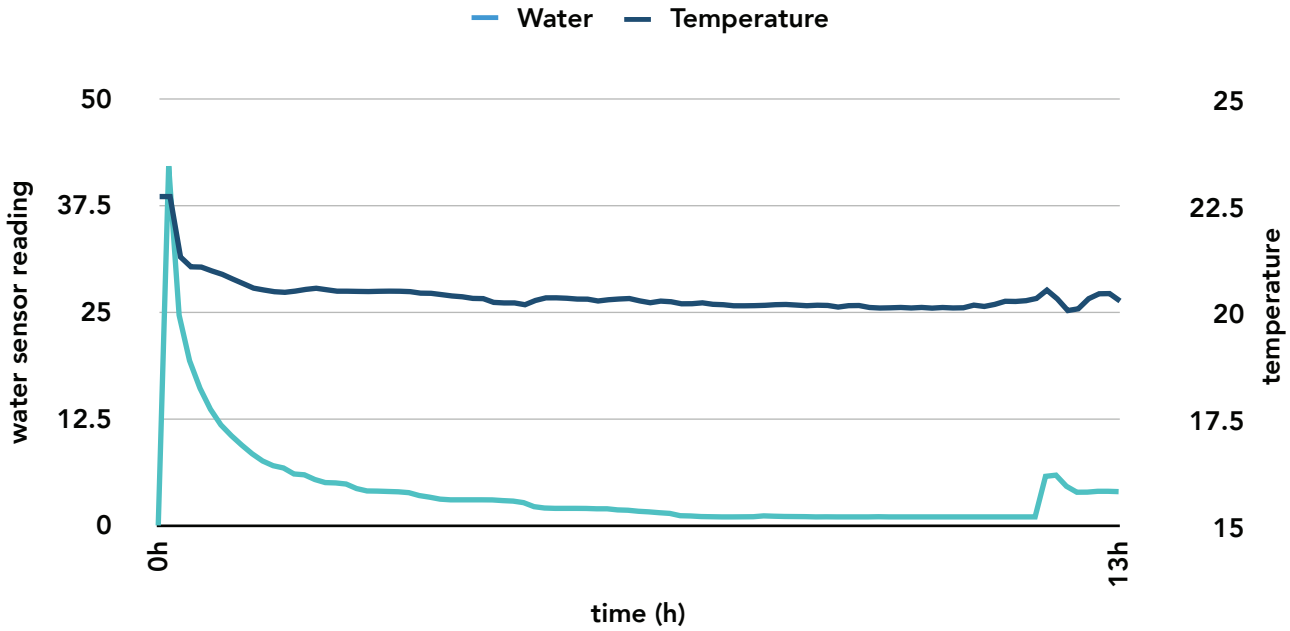


Figure 17.2: *Moisture and temperature over time.*

TAKEAWAYS FOR QUANTIFIED

- A test setup was build to test a water sensor and a temperature sensor.
- Using a resistance sensor to measure moisture is not a suitable option for this application.

CHAPTER 18

Form 2

It was found that the walls of the cells could obstruct the user's view into cells ("Form 1" on page 92). The cardboard-and-foam model that was built to perform the user scenario, was expanded to test this problem. It was found that with the dimensions used for this model, the user can have a clear view in up to rows of three cells.

Figure 18.1: *a: User looking into cell behind walls of other cells. b: User's view in a cell behind one other cell. c: User's view into a cell behind two other cells..*

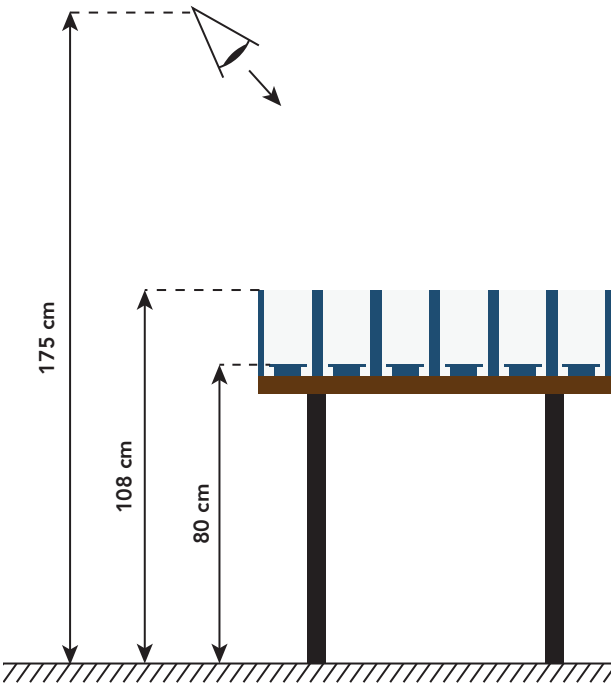


Figure 18.3: *Schematic representation of the test scenario, with cells placed on a table.*

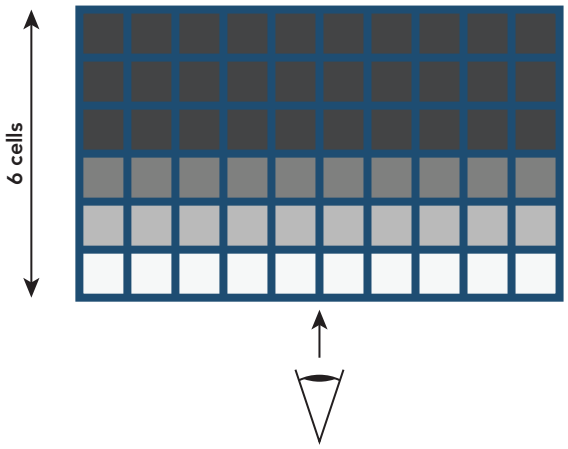


Figure 18.2: *User's view into cells from one side. Lighter color indicates better vision.*

18.1 THE MODEL

The prototype was expanded to test if this was an actual problem. Four walls were built around the cell to represent other cells. Then the cell was placed on a table with the maximum possible distance to the user (in a 6 by n matrix of cells). In this test, distance from the floor to the test bed was 90 cm, the cell wall height was 25 cm and the user was 175 cm. Figure 18.1 shows the user's view into the cell and Figure 18.2 shows a schematic overview of a matrix of cells.

18.2 CONCLUSION

The seed bed was almost completely visible. However, in this stage of the design process, it wasn't clear what the final dimensions of the cell were going to be. Therefore, it was chosen to put this issue to rest.

TAKEAWAYS FOR QUANTIFIED

- The model used to for the user scenario was expanded to test the user's view into cells.
- It was found that the user can view properly in up to the third cell behind other cells.

CHAPTER 19

Electronics 2

A PCB was designed to measure the temperature and humidity of the seed bed. Research has been done into a communication protocol and capacitive sensing. Different sensors have been selected for this PCB design. Several problems have been found with the design.

19.1 FUNCTIONS OF THE PCB

The PCB should have the following functions:

- Measure temperature.
- Measure humidity.
- Control the peltier element.
- Turn LEDs on and off.
- Communicate between sensors and actuators, and computer

Because the first version of the cell was going to be used for experiments during the design process, it was chosen to have a larger number of sensors than there would be in the final concept.

19.2 COMMUNICATION PROTOCOL

In the germination cell concept, as well as the QIEM-Array, the number of senors would be quite high. To limit the number of cables drastically, it was chosen to use the I²C protocol (I2C Info, n.d.), Which can also be used by a Raspberry Pi.

With the I²C protocol, only two wires are required to communicate with the sensors (Figure 19.1). The first is the clock signal (SLC) that comes from the Raspberry Pi. The second is the serial data signal (SDA) that is a has bidirectional communication between a Raspberry Pi and the sensors.

19.3 SENSORS

The PCB design is equipped with different sensors to measure temperature and humidity.

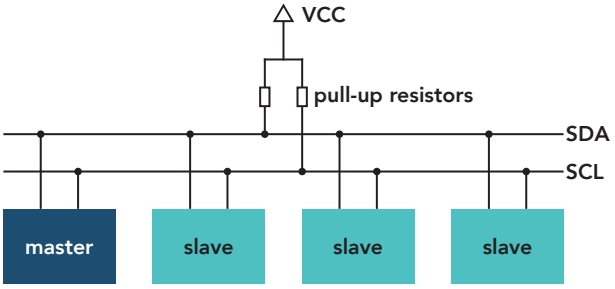


Figure 19.1: *Schematic overview of the I²C protocol.*

19.3.1 AD7747 ADC

The AD7747ARUZ is a 24-bit High Resolution Capacitance to Digital Converter with temperature sensor (AD7747ARUZ, n.d.). It has the option to use an external temperature sensor (2N3906BU PNP transistor).

19.3.2 CAPACITIVE SENSOR

A capacitor is an electrical component in which electrical charge can be stored on one side, with simultaneous storage of the opposite charge on the other side. For a capacitor with overlapping plates, the following equation can be used to calculate the capacitance (C):

$$C = \epsilon_0 \frac{A}{d}$$

Where ε_o is the electric constant; A is the area of overlap of the two plates, in square meters, and d is the separation between the plates in meters.

When building a custom capacitive sensor, the permittivity of the material between the poles influences the capacitance. The relative permittivities of air and water at room temperature are 1 and 80, respectively (Li et al., 2019). Therefore, capacitive sensors can be used as moisture sensors.

Interdigitated electrode capacitive fringing field senors have been utilized in numerous applications. Although various technologies are used to realize these types of sensors, printed circuit board technology is particularly advantageous for realizing this type of sensor through fabricating the interdigitated electrode structures in the patterned Cu foil (Dean et al., 2012).

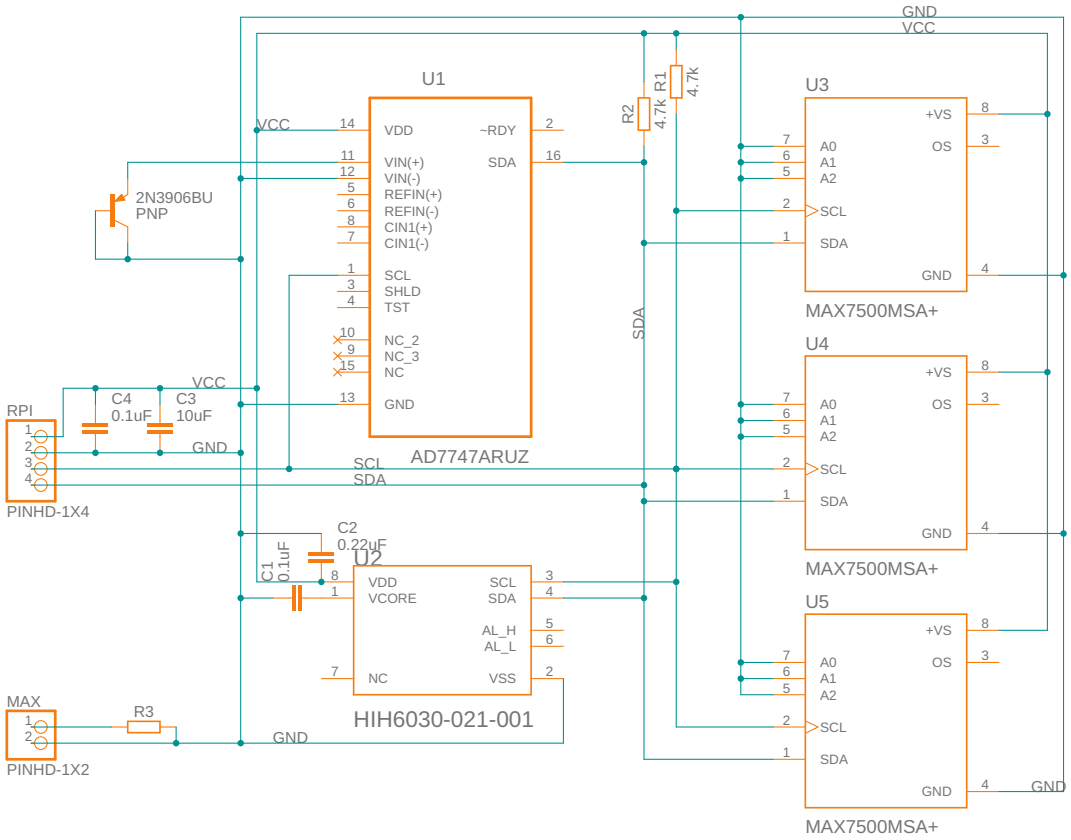


Figure 19.2: *Schematic overview of the first PCB design.*

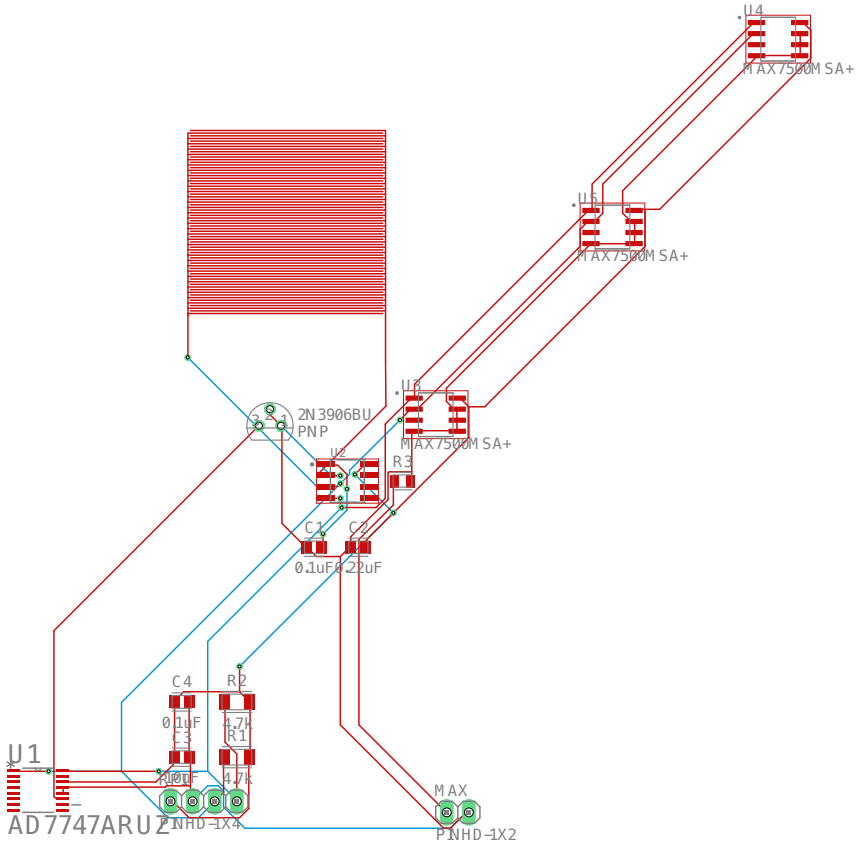


Figure 19.3: *Footprint of first PCB design. The red lines represent the top layer and the blue lines the bottom layer.*

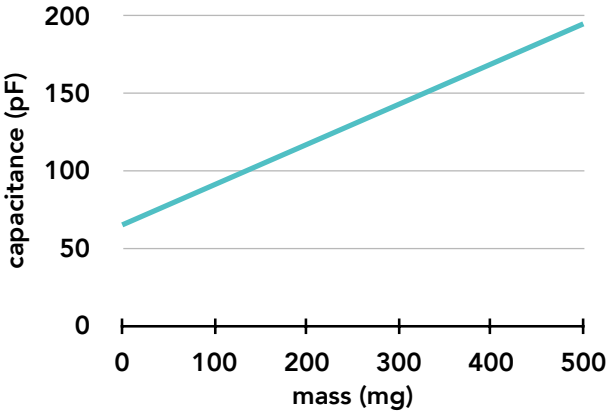


Figure 19.4: *Capacitance of sensor used by Dean et al. (2012).*

For this PCB, it was chosen to use the capacitive sensor designed by Dean et al. (2012). It's characteristics are shown in Figure 19.4. The capacitance of the sensor can be calculated with the following equation:

$$C \cong \frac{(n-1)\epsilon\alpha\gamma}{d}$$

Here, n is the number of interdigitated electrode teeth, ε the permittivity of the dielectric material and γ the fringing scale factor.

19.3.3 HONEYWELL HIH6063 HUMIDITY SENSOR AND TEMPERATURE SENSOR

The HIH6030 is a sensor that can measure both humidity and temperature (HIH6030, n.d.). It can communicate via the I²C protocol.

19.3.4 MAX7500 TEMPERATURE SENSOR

The MAX7500MSA+T is a digital temperature sensor that can communicate via the I²C protocol (MAX7500, n.d.).

19.4 PCB DESIGN

A PCB design was made in Autodesk Fusion 360. Figure 19.2 shows a schematic overview and Figure 19.3 shows the footprint of the PCB.

As can be seen in the footprint design, the three different temperature sensors, as well as the HIH6030 humidity sensor are placed in the center of the PCB. Two other MAX7500 temperature sensors are placed on the PCB to measure temperature uniformity of the surface. Furthermore, the circuit includes some capacitors to reduce noise and two 4.7 kΩ pull-up resistors for the SLC and SDA channels.

19.5 CONCLUSION

Although the I²C protocol allows communication between a large number of sensors, it also has its limitations. For example, the number of unique addresses the sensors can assume is very limited, thus making it impossible to read out all the sensors with one computer. Another problem is the control of the peltier module. With this design, a separate peltier controller would be necessary.

After discussion with Warner from Quantified, it was concluded that having a dedicated microcontroller per cell could solve a large number of the issues found with this design.

TAKEAWAYS FOR QUANTIFIED

- A PCB was designed for the seed bed to measure temperature and humidity.
- It was chosen to redesign the PCB. The redesign would have a dedicated microcontroller per cell.

CHAPTER 20

Seed Bed 1

The testing surface area and the seed size, determine the maximum number of seeds that can be tested in the cell. The area taken up by different batches of seeds were measured to determine the seed bed size of the germination cell.

20.1 THE SEED BED

The ISTA regulations specify that 400 seeds have to be tested in batches no larger than 100 seeds (ISTA, 2015). Having a large test area has the advantage that the cell can have bigger seeds. However, a disadvantage can be that it could have a lot of empty space if the seeds don't take up that much space. Therefore there is an optimum.

20.2 SURFACE AREA

Figure 20.1 shows different plant seeds in different configurations. a and b show 100 seeds on a standard growing medium. This size is most frequently used. Its surface area is 7850 mm². c and d show the areas taken up by seeds of different sizes.

The standard growing medium size from Figure 20.1 provides enough space for the majority of tests. However, to give the user more flexibility, a testing surface area of (100 mm)² = 10000 mm² is chosen for the germination cell. In case larger seeds have to be tested, the batch can be split and divided over more germination cells.

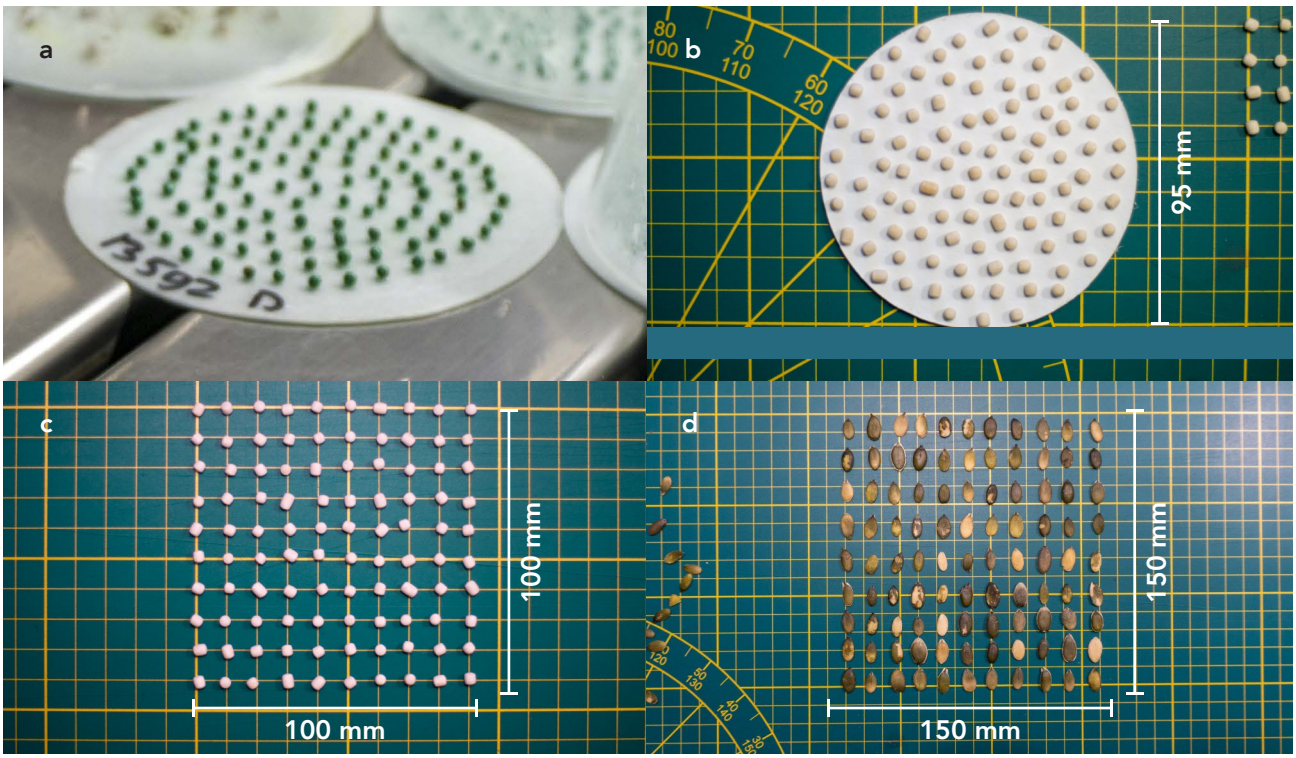


Figure 20.1: *a: Seeds (2 mm diameter) on a standard paper growing medium at Nak Tuinbouw. b: 100 seeds (4 mm diameter) on a standard paper growing medium. c: 100 plant seeds (4 mm diameter). d: 100 seeds (15 mm length).*

TAKEAWAYS FOR QUANTIFIED

- The area taken up by batches of 100 seeds of different kinds of seeds were measured.
- De decision was made to make the seed bed 100 mm × 100 mm.

CHAPTER 21

Camera 1

Earlier in the project, it was chosen to use a static color camera for the photography of the seeds during the germination tests. In Chapter 11 on page 72, the camera requirements were stated. In this sprint, different camera options were compared and a choice was made based on the requirements.

21.1 REQUIREMENTS

As stated in Chapter 11 on page 72, the image analysis requires a pixel density of 100 px/cm or more. A seed bed of 10 cm × 10 cm was chosen. ("Seed Bed 1" on page 102) This means that the minimum image size of the camera should be 1000 px × 1000 px. Since the array is going to have a large number of cells, each with a dedicated camera, it is desirable that the camera is not too costly.

21.2 OPTIONS

After online research, a number of camera options with different communication protocols were found (Figure 21.1). The most notable are described below.

21.2.1 USB CAMERA MODULE

A USB camera is possibly the simplest option. Generally, USB cameras plug-and-play devices. However, since the total number of cells could be well above 50, scalability could be a problem, due to the USB device number limitations.

21.2.2 RASPBERRY PI CAMERA MODULE

There are a number of camera modules available for a Raspberry Pi. Since it was used in this project, this seemed like a viable option. Nonetheless, scalability could be a problem, because then every cell should have its own Raspberry Pi. This could become costly with a large number of cells.

21.2.3 SPI CAMERA MODULE

SPI is a communication protocol that is used for short distance communication and primarily used in embedded systems. SPI allows for communication to a large number of devices with a limited number of connections. However, it is more difficult to work with than the two other options mentioned above. In the sprint "Electronics 2" on page 99 it can be seen that it was chosen to use a microcontroller in each cell. This type of camera is able to communicate directly with a microcontroller.

21.2.4 STANDALONE CAMERA MODULE

Standalone camera modules come in the most compact form of the options. However, the number of connections generally large and they are by far the most complex. Like the SPI camera, the standalone camera module is able to communicate with a microcontroller.

21.3 CHOOSING THE CAMERA TYPE

The camera options were evaluated on three different criteria: complexity, scalability and cost. Because of the limited time for the project, the camera should not be too complex. Because there will be a large number of cells, the scalability and

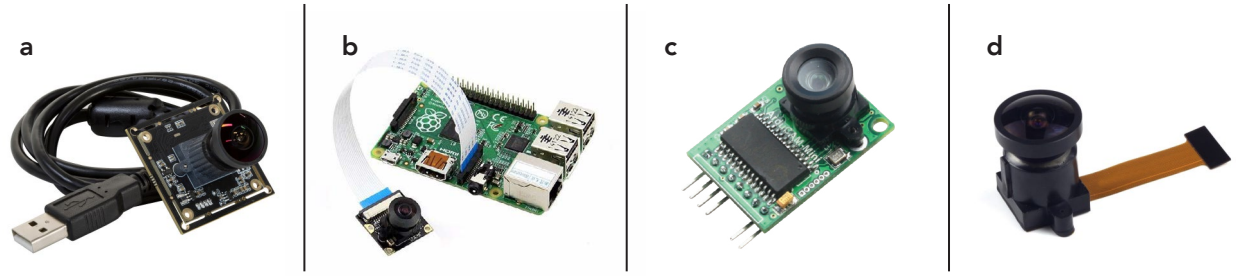


Figure 21.1: *Different kinds of camera modules. a: USB camera module. b: Raspberry Pi camera module. c: SPI camera module. d: Standalone camera module.*

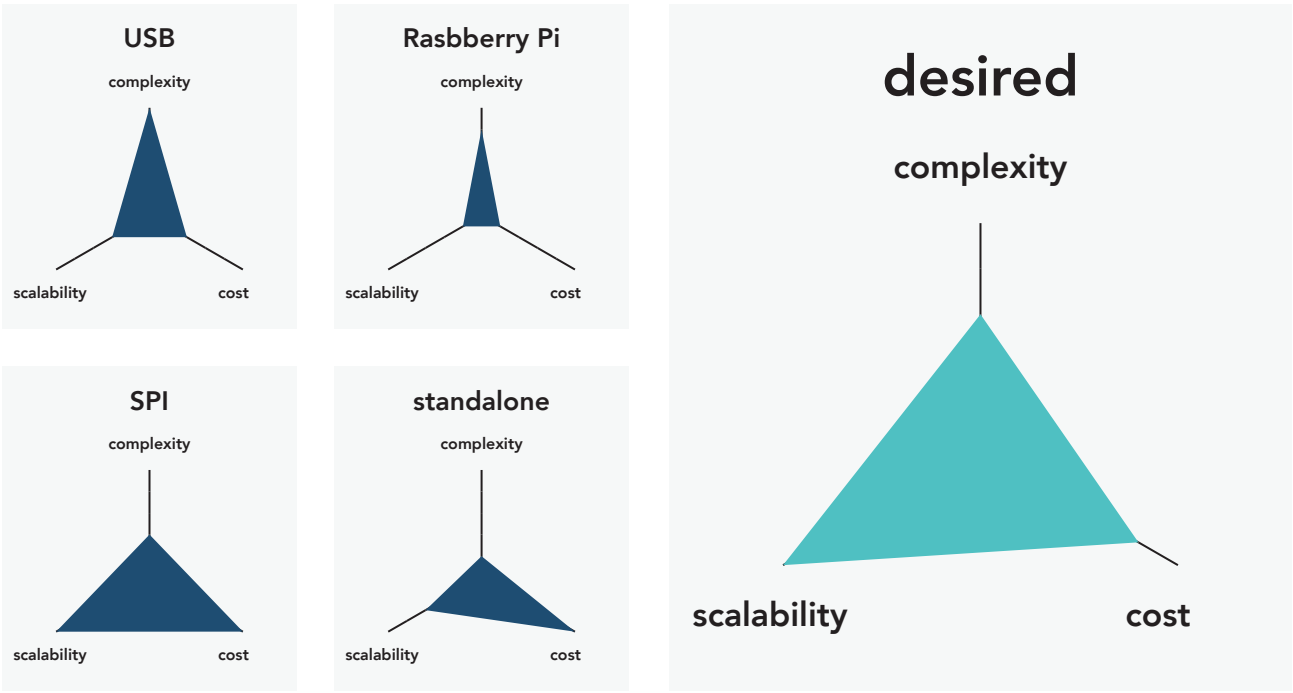


Figure 21.2: *Comparison of the different types of cameras.*

costs are important factors as well. The results of the comparison are shown in Figure 21.2

21.4 CHOOSING A CAMERA

After the requirements were clear, it was time to choose a camera. After research on the internet, the Arducam Mini Module Camera Shield 5MP Plus OV5642 Camera Module for several reasons (Figure 21.3):

The resolution is adequate.

- It uses the SPI communication protocol.
- There is extensive documentation available.
- There is a large library of open source software available on GitHub.
- It has an on-board JPEG compression functionality, which drastically reduces the file sizes, thus the file transfer times.

Figure 21.3: *Arducam OV5642.*

TAKEAWAYS FOR QUANTIFIED

- Several camera types were compared.
- It was chosen to use a camera that utilizes the SPI communication protocol.
- The Arducam OV5642 camera was chosen for this project.

CHAPTER 22

Electronics 3

Previously, a test was done with a resistance moisture sensor. However, for this project, Since it was concluded that such a sensor did not perform adequately for this application, another solution had to be found. In this sprint, several tests with capacitive sensors were done.

22.1 CAPACITIVE SENSING

As explained in the sprint "Electronics 2" on page 99, moisture can be measured with a interdigitated capacitor. The relative permittivities of air and water at room temperature are 1 and 80, respectively (Li et al., 2019). With ε being the permittivity of the dielectric material, the capacitance can be calculated with the following equation (Dean et al., 2012):

$$C \cong \frac{(n-1)\epsilon\alpha\gamma}{d}$$

22.2 CAPACITIVE SENSOR TEST

A custom capacitive sensor was to be designed for this project. Before that point and to be able to perform experiments, a standard water sensor was acquired. To get a sense of the workings of the sensor, it was connected to an Arduino in a test setup (Figure 22.1). The test was successful and showed a difference in measured capacitance between water and air.

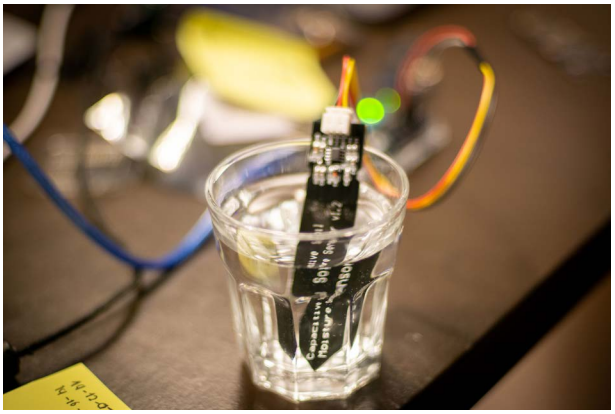


***Figure 22.1:** Test setup with a capacitive water sensor in a glass of water.*

22.3 MEASURING CAPACITANCE WITH A MICROCONTROLLER

The first PCB design used a analog-to-digital converter to measure capacitance of the capacitive sensor and communicate to the computer or microcontroller ("Electronics 2" on page 99). However, it is possible to measure capacitance directly from a microcontroller (Reverter, 2012). Larger capacitors take longer to charge. By measuring the time constant, the capacitance can be calculated (Figure 22.2).

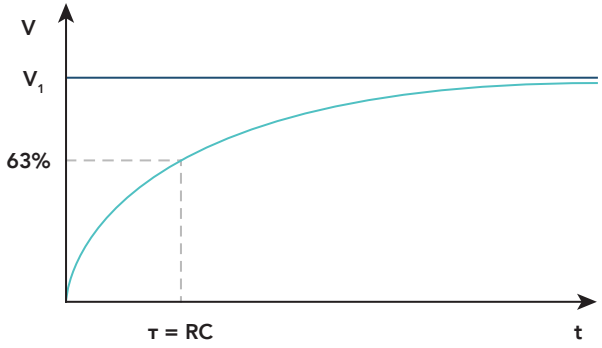


***Figure 22.2:** Voltage change when charging a capacitor.*

The capacitance an be calculated with the following equation:

$$C = \frac{\tau}{R}$$

Here τ is the time constant and R the resistance of the circuit.

22.4 CAPACITIVE SENSOR TEST

In the sprint "Electronics 1" on page 95, a resistance water sensor was tested for this project. The advantage of this sensor is that it has interdigitated fingers, similar to some capacitive sensors. The difference is that fingers of the resistance water sensor are directly connected

to the water, while that is not the case with capacitive sensors. However, by modifying the resistance water sensors, they can be used as capacitive sensor.

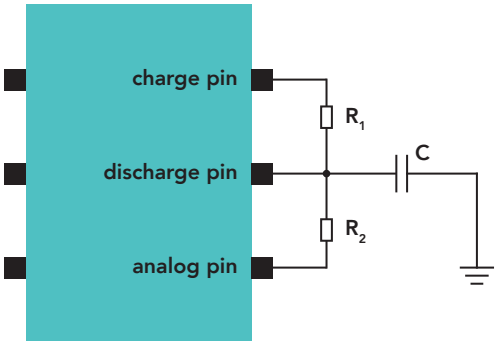


Figure 22.3: *Schematic overview of the capacitance measuring test setup.*

22.4.1 MEASURING STANDARD CAPACITORS

The first step was to build a capacitance testing circuits and test capacitors with known capacitance (Figure 22.3). The charge pin is used to charge the capacitance. The analog pin measures the time constant of the capacitor. Thereafter, the discharge pin discharges the capacitor. In this setup R_1 was 10 kΩ and R_2 330 Ω.

As can be seen in Figure 22.4, the setup was able to measure the capacitance fairly accurately.

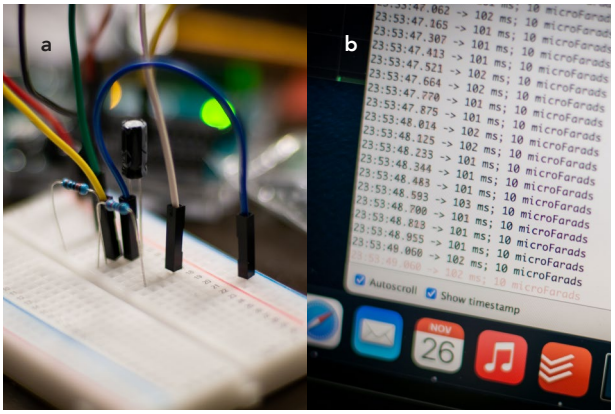


Figure 22.4: *a: Photo of the capacitance measuring test setup. b: Capacitance measuring results.*

22.4.2 MEASURING IMPROVISED CAPACITIVE SENSOR

As can be seen in Figure 22.5, a resistance moisture sensor (as used in the experiments of the sprint "Electronics 1" on page 95), has been modified to be a capacitive sensor. The on-board transistors and resistors have been bypassed and connected directly, according to the overview of Figure 22.3.

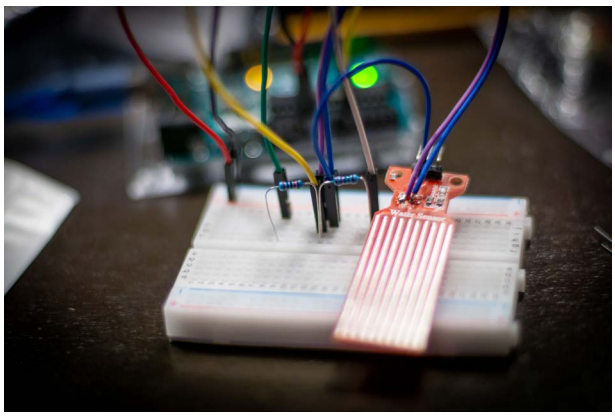


Figure 22.5: *Improvised capacitive sensor connected to the capacitance test setup..*

The sensor was then tested in a glass of water (Figure 22.6). The conducting fingers must not be in contact with water and are therefore shielded with plastic. Unfortunately, the change in capacitance was not large enough for the measurements. Changing the circuit resistance also did not seem to work. This could have multiple reasons. As can be seen in the equations on page 105, the

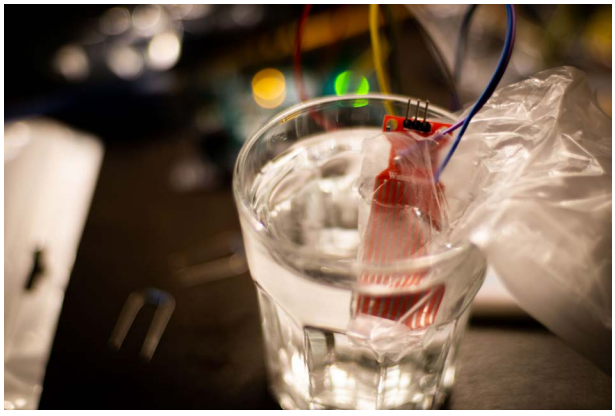


Figure 22.6: *Testing the improvised capacitance sensor in a glass of water. The sensor is shielded directly from water with plastic.*

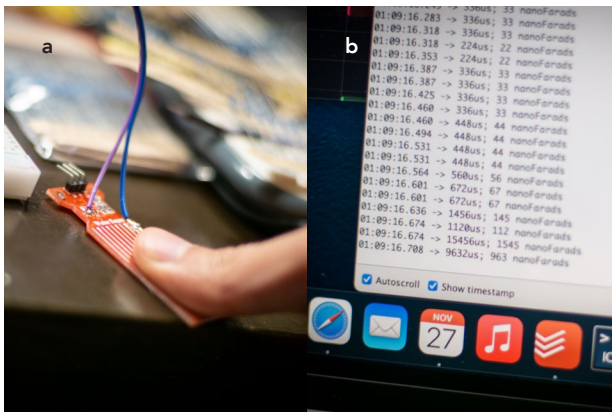


Figure 22.7: *a: Photo of the capacitive sensor. b: Measured capacitance upon finger touch.*

capacitance is influenced by the number of fingers and distance between them. In this particular setup, these weren't adequate. However, the sensor was able to measure touch of the touch of a finger, as can be seen in Figure 22.7.

22.5 CONCLUSION

Although it was proven that a microcontroller can be used to measure capacitance, the capacitor design has to be optimized for this application.

TAKEAWAYS FOR QUANTIFIED

- Capacitive sensors can be used to measure moisture.
- Capacitance can be measured directly from a microcontroller, without any additional sensors or components.

CHAPTER 23

Camera 2

The Arducam OV5642 camera module was chosen for this project ("Camera 1" on page 103). After the camera was ordered, it was tested to determine the field of view, height from the seed bed, file size and file transfer speed.

23.1 TEST SETUP

The camera was first connected to an Arduino UNO (Figure 23.1). Then a software package was acquired form GitHub (Lee, 2015/2020). After a few hours of tweaking the code, the camera started capturing photos.

Next, a test setup was built (Figure 23.2). On a table, a square of with sides of 100 mm was made to represent the seed bed. Thereafter, the camera was mounted to a camera tripod. Photos were taken and the height was adjusted, until the edges of the square touched the edges of the photo.

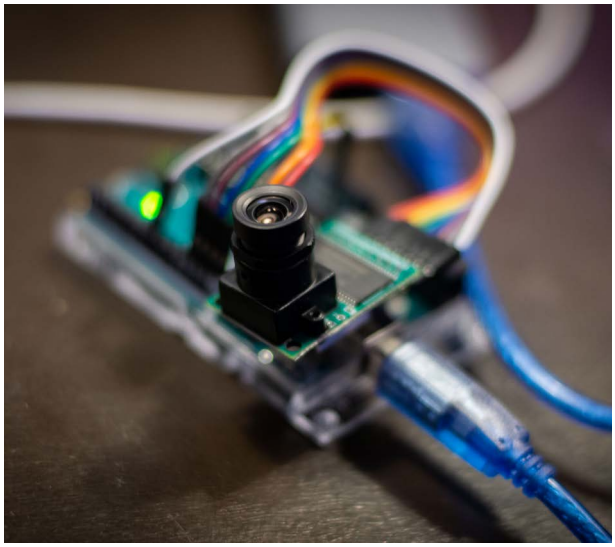


Figure 23.1: *OV5624 camera module connected to an Arduino UNO.*

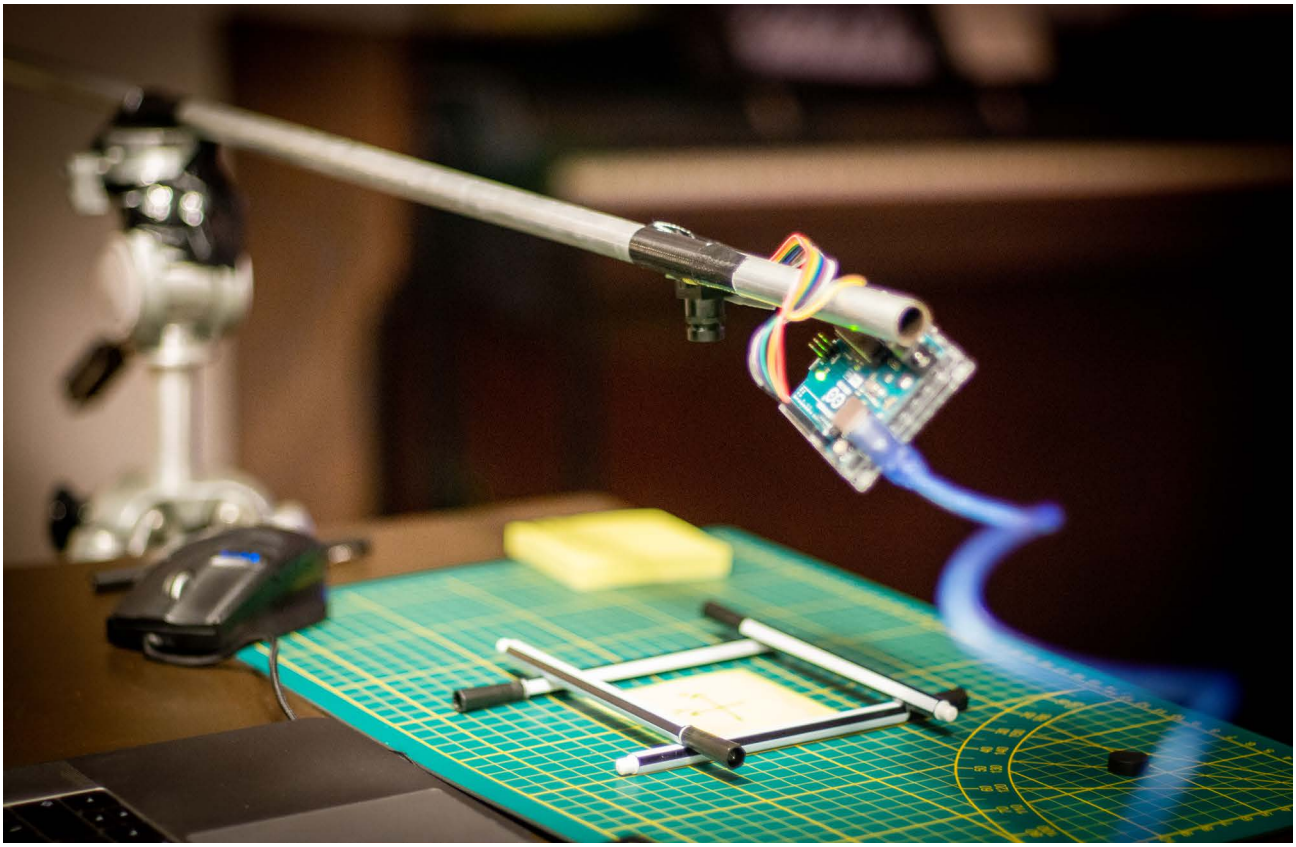


Figure 23.2: *Test setup. The camera module is capturing photos of a 100 mm × 100 mm test surface. It is attached to a height-adjustable tripod.*

23.2 TEST RESULTS

To get the full seed surface in the photo, the distance between the test surface and camera should be 150 mm. This corresponds to a distance between the test surface and camera sensor of 173 mm. This height is key in the final dimensions of the cell.

The average photo size of the photos was 260 kb, with a maximum of 360 kb, after on-board JPEG compression. The transfer time of the files was usually below 6 seconds.

Figure 23.3 shows a photo taken with the camera module.

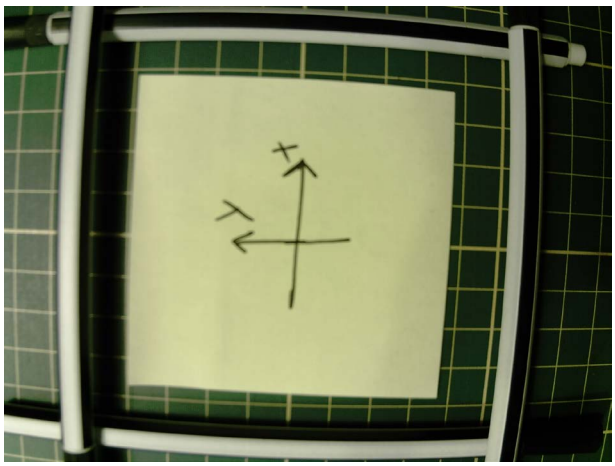


Figure 23.3: *Image captured by the OV5624 camera module.*

TAKEAWAYS FOR QUANTIFIED

- The camera Arducam OV5624 camera is able to take photos and transfer them with the SPI communication protocol.
- The distance between the camera and test surface should be 150 mm.
- The maximum size of the photos is 360 kb and the transfer time is usually below 6 seconds.

CHAPTER 24

Electronics 4

In the sprint "Electronics 2" on page 99, it can be read that the choice has been made to have a dedicated microcontroller in each cell. Moreover, the PCB functions are stated. In this sprint, choices were made about the electronics layouts, PCB configuration and communication protocols.

24.1 CONCEPTS

When combining insights from preceding design sprints, research and discussions, concepts for the electronics were made. Figure 24.1 shows a basic overview of the components and their connections. The following concepts are the result of several iteration cycles, with the last concept being the most developed, and therefore the chosen option.

24.1.1 CONCEPT 1: FOIL PCB

Since the PCB was to be positioned between the Peltier element and the seed bed. Therefore, it had to be able to transfer adequate heat. After exploring the options and a discussion with Warner from Quantified, a foil PCB came forward as a viable option (Figure 24.2). It would be placed

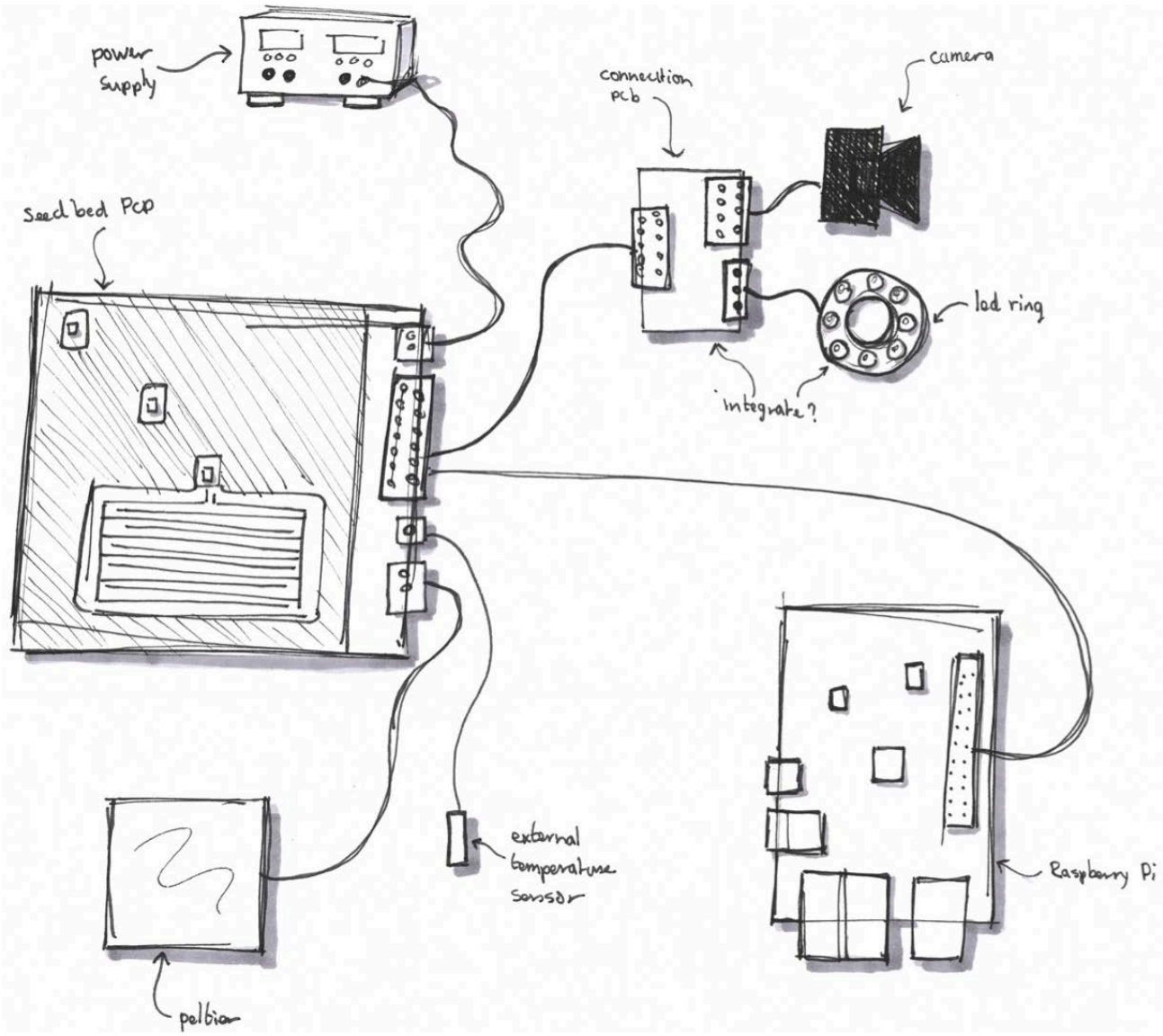


Figure 24.1: *Concept sketch of the electronic components.*

on a metal plate that would divide the heat from the Peltier over the whole seed bed area.

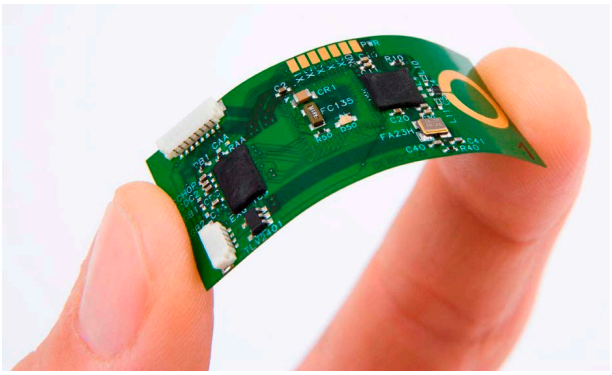


Figure 24.2: *Foil PCB.*

24.1.2 CONCEPT 2: FOUR-LAYER PCB

After some further brainstorming, the idea arose of integrating the heat distribution into the PCB. This could be done with a four layer PCB. The central layers would be used to connect the components. The top and bottom layers would be connected through vias to transfer the Peltier heat through the PCB (Figure 24.3). Vias are vertical copper connections from between different layers of a PCB.

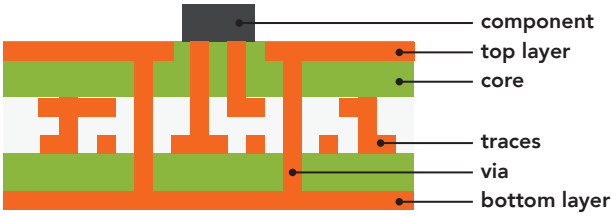


Figure 24.3: *Schematic representation a cross-section of a four-layer PCB configuration.*

24.1.3 CONCEPT 3: PCB-ON-PCB

When the requirements for the PCB and electronic components were clear, a meeting was scheduled with Electronics Engineer Marcel Flipse from the company M91200. In this meeting, the components were chosen and decisions about the their placement were made.

It was chosen to split the seed bed PCB into two. The seed bed PCB would have the following functions:

- Transferring heat from the Peltier to the seed bed.
- Measuring the temperature of the seed bed. Measuring moisture on the seed bed.

The other PCB would be the *brain* of the cell, because it would hold the microcontroller. Its functions include:

- Gathering data from the humidity and temperature sensors.
- Triggering the camera and collecting its data.
- Controlling the LED ring
- Controlling the Peltier element.
- Communicating between the cell and computer.

The second PCB would be connected to the seed bed PCB with Micro-MaTch connectors, like the example in Figure 24.4 (Micro-MaTch, n.d.).

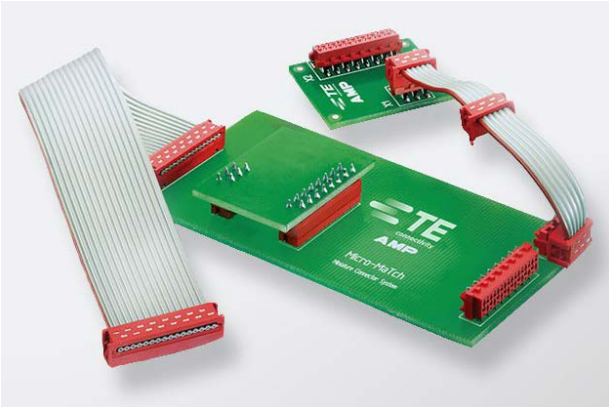


Figure 24.4: *Micro-MaTch connectors.*

24.2 LED RING PCB

In addition to the seed bed PCB and microcontroller PCB, each cell would have a third PCB. Its function would be to hold and control the LEDS. It would have a circular shape and be placed around the camera lens.

24.3 ELECTRONICS SYSTEM OVERVIEW

Figure 24.5 shows a sketch of the electronics of one cell. The big square in the center is the seed bed PCB with its temperature and moisture sensors.

Attached to the seed bed PCB is the microcontroller PCB. In addition to the microcontroller, it would have the MAX1978 Peltier element controller. It has two ethernet connections, with which cells can be linked together. The ethernet connections handle the communication between the cells and computer via the RS485 protocol. This PCB also has a connection to the power supply, to the camera via I^2C and SPI, and a to the LED ring.

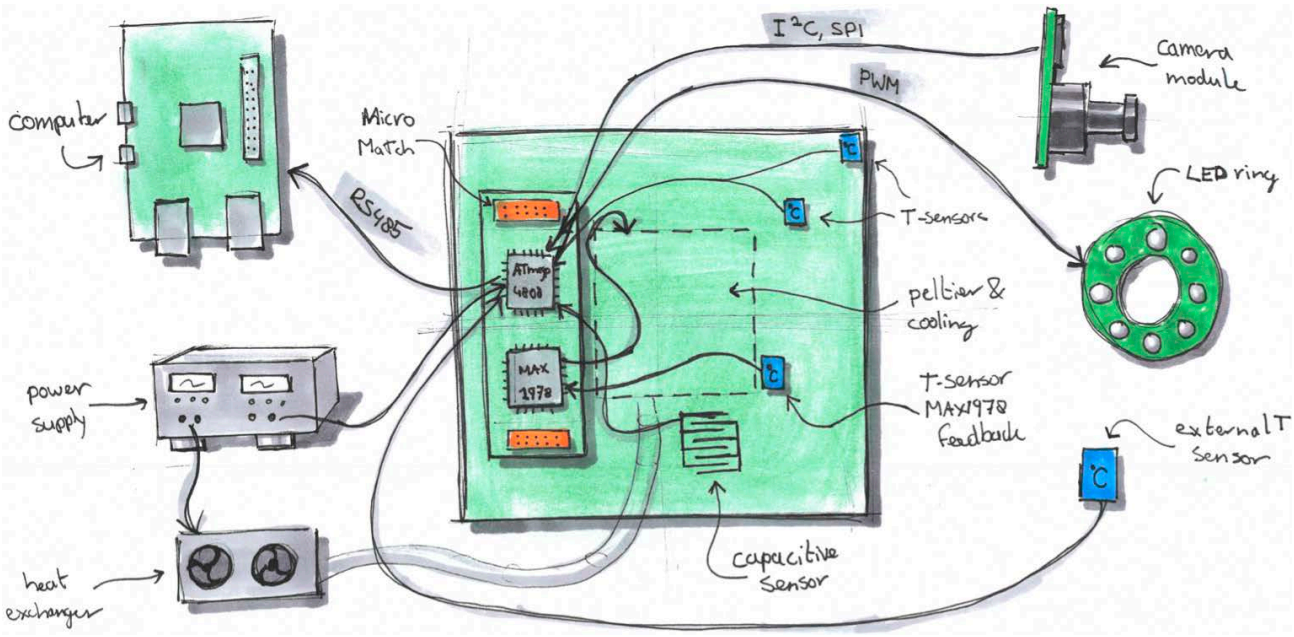


Figure 24.5: *Electronic components overview.*

TAKEAWAYS FOR QUANTIFIED

- Different electronics were made and a concept with three separate PCBs per cell was found to be the best option for this application.
- The seed bed PCB measures the temperature and moisture levels of the seed bed.
- The microcontroller PCB controls the cell, gathers data from the sensors, controls the camera and LED ring, and communicates with the computer.
- The LED ring PCB controls the LEDs.

CHAPTER 25

Camera 3

This design sprint is about the design of the camera housing. The camera was to be attached to the lid of the cell. Since the lid would have the ability to be opened, a solution had to be found for the camera.

25.1 CONCEPTS

Different concepts were considered (Figure 25.1). The first one is a lid with camera that completely detaches from the cell. This is also more or less the concepts that was shown at the end of the sprint "Form 1" on page 92. The problem with this concept is that the electronics have to be attached when the cell is opened. This could cause difficulties for the user.

The second concept has the camera attached to the wall. When the camera hangs from the side, instead of the center, the maximum angle at which the seeds are photographed is twice as high (Figure 25.2). In this stage in the QIEM-Array project, it was still unclear if this would work for the image

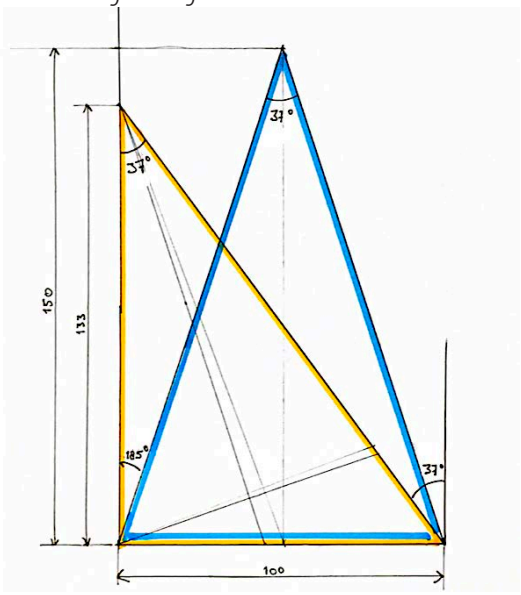


Figure 25.2: *Field of view of the camera when attached in the center (blue) or on the side (orange).*

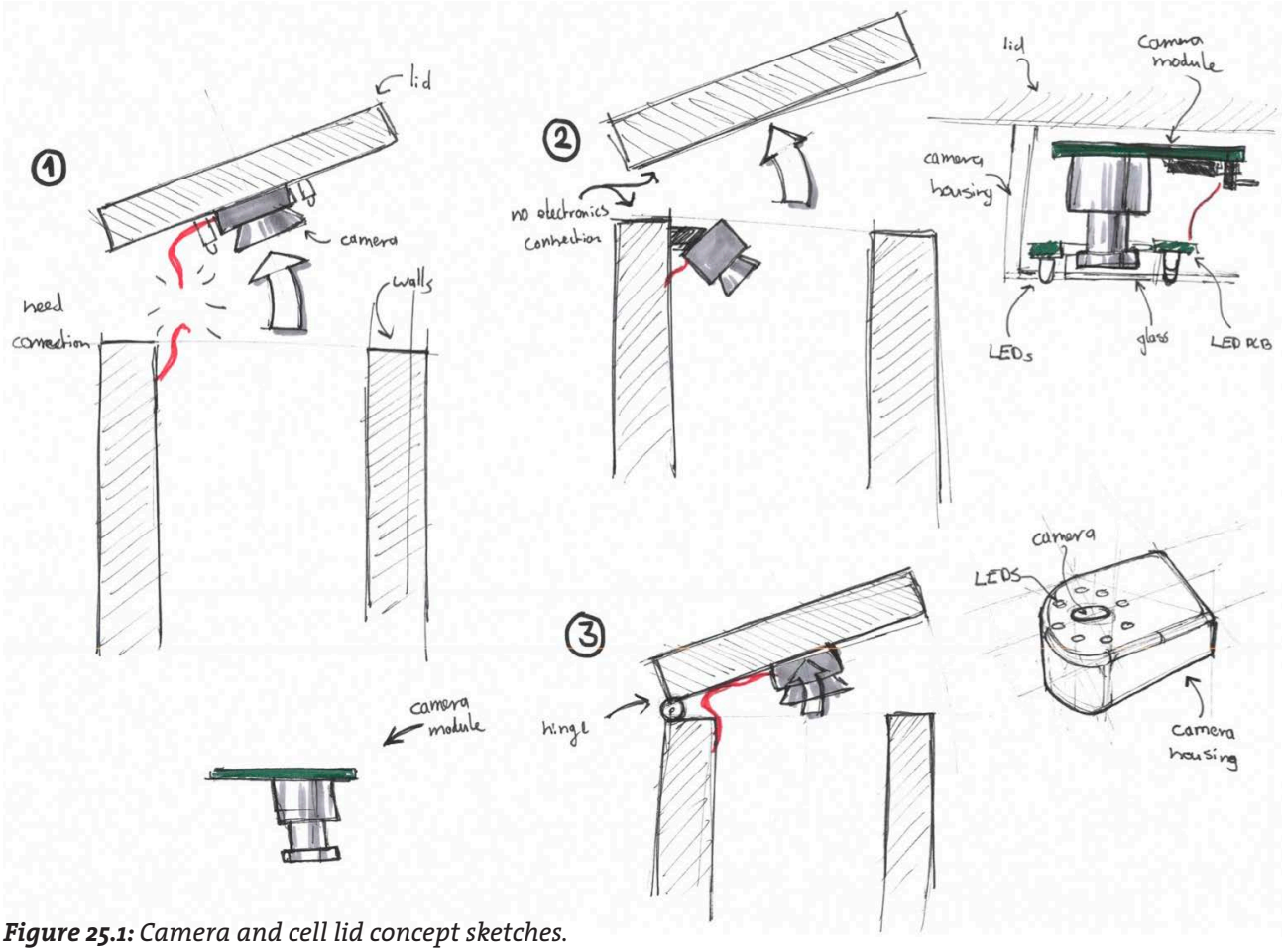


Figure 25.1: *Camera and cell lid concept sketches.*

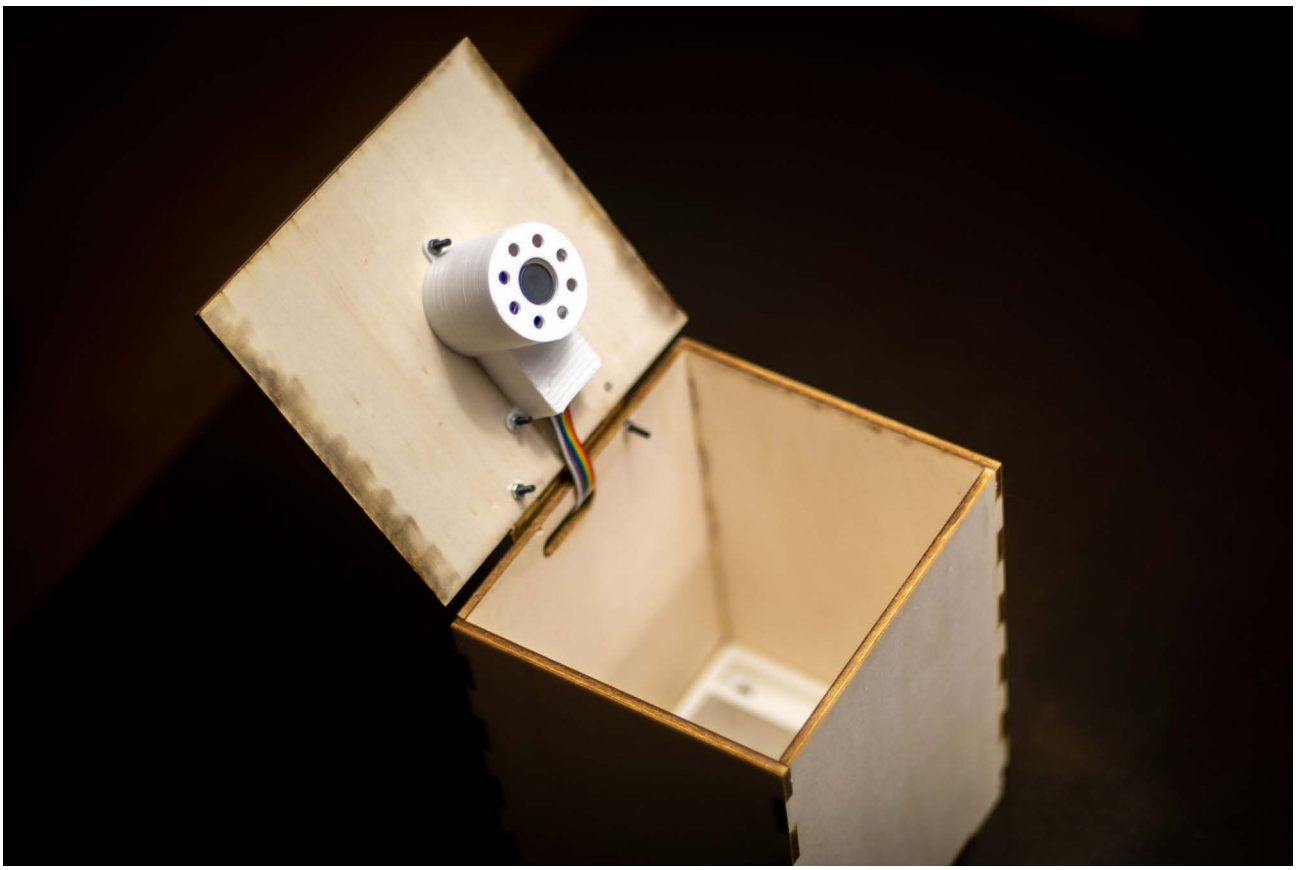


Figure 25.4: *Camera housing attached to lid.*

classification. In preceding researches into seed image classification, the cameras were all centered (Chapter 11 on page 72). After discussion with Warner from Quantified, it was chosen to keep the camera in the center of the cell.

The third concept shows the camera attached to a hinging lid. The other sketches in the Figure 25.1 show concept drawings for the camera and LED case.

25.2 MODEL BUILDING

The insights were combined and used in CAD. Thereafter, the camera housing was 3D printed (Figure 25.3). As can be seen in Figure 25.4, the camera case has holes for the LED ring. At this

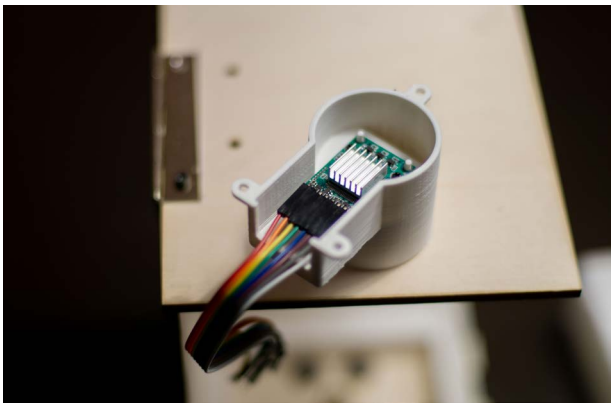


Figure 25.3: *Camera housing with camera module.*

stage of the project, the LED PCB was yet to be designed. Further insights from this model are discussed in the sprint "Form 3" on page 119.

TAKEAWAYS FOR QUANTIFIED

- The camera is to be attached in the center of the cell.
- A 3D printed model of the camera case was made.

CHAPTER 26

Seed Bed 2

The goal of this design sprint was to design the mounting for the seed bed and cooling components. A sketch of the basic concept can be seen at the end of the sprint "Form 1" on page 92. In this sprint, ideation done with a combination of design sketching, CAD modeling and rapid prototyping.

26.1 DESIGN SKETCHING

The first design had a tray that would be attached to the PCB (Figure 26.1). It would hold the Peltier element and cooling block in place.

The user needs to be able to clean the cell after the tests, and therefore it was chosen to include a water drain in the cell ("Form 1" on page 92). In the next sketches, this is included (Figure 26.2). In some sketches, the water drain and mounts are integrated in the bottom part, while in others, these parts are separate. Figure 26.3 and Figure 26.4 on page 117 show various iterations of the concept.

26.2 MODEL BUILDING

The ideas were eventually combined and developed further in CAD and thereafter laser cut 3D printed (Figure 26.5 & Figure 26.6 on page 118). In the center, there are stand to hold the Peltier element and cooling block in place. The 3D printed part has a square recess to hold the PCB and an angled gutter for the water. In the latter of the two photos, a PCB placeholder can be seen. It has four mounting holes in the corners. There is a little extra space around the edge for waterproofing.

Further insights from this model are discussed in the sprint "Form 3" on page 119.

TAKEAWAYS FOR QUANTIFIED

- Ideas for the seed bed were combined and concepts were sketched.
- The insights were combined and used in CAD and model making.

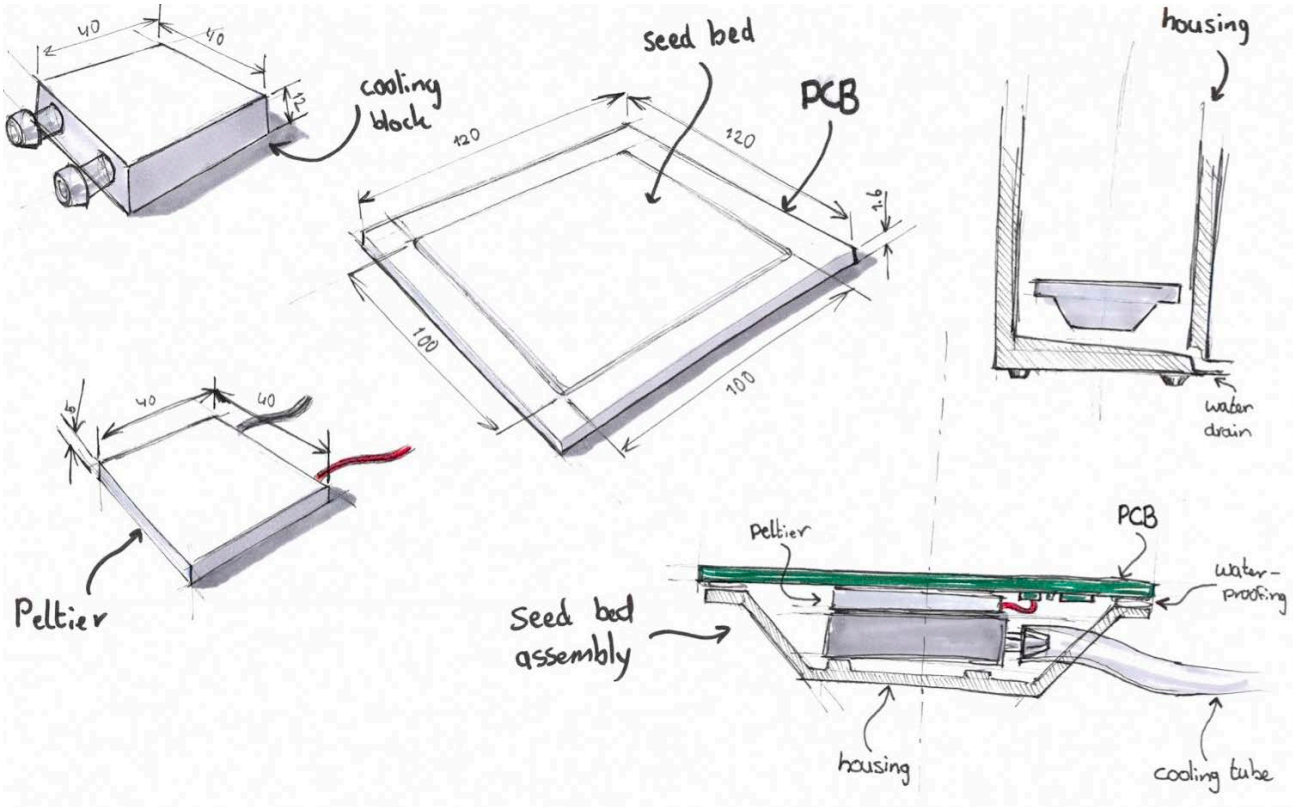


Figure 26.1: *Drawing of various components and the assembly of the seed bed.*

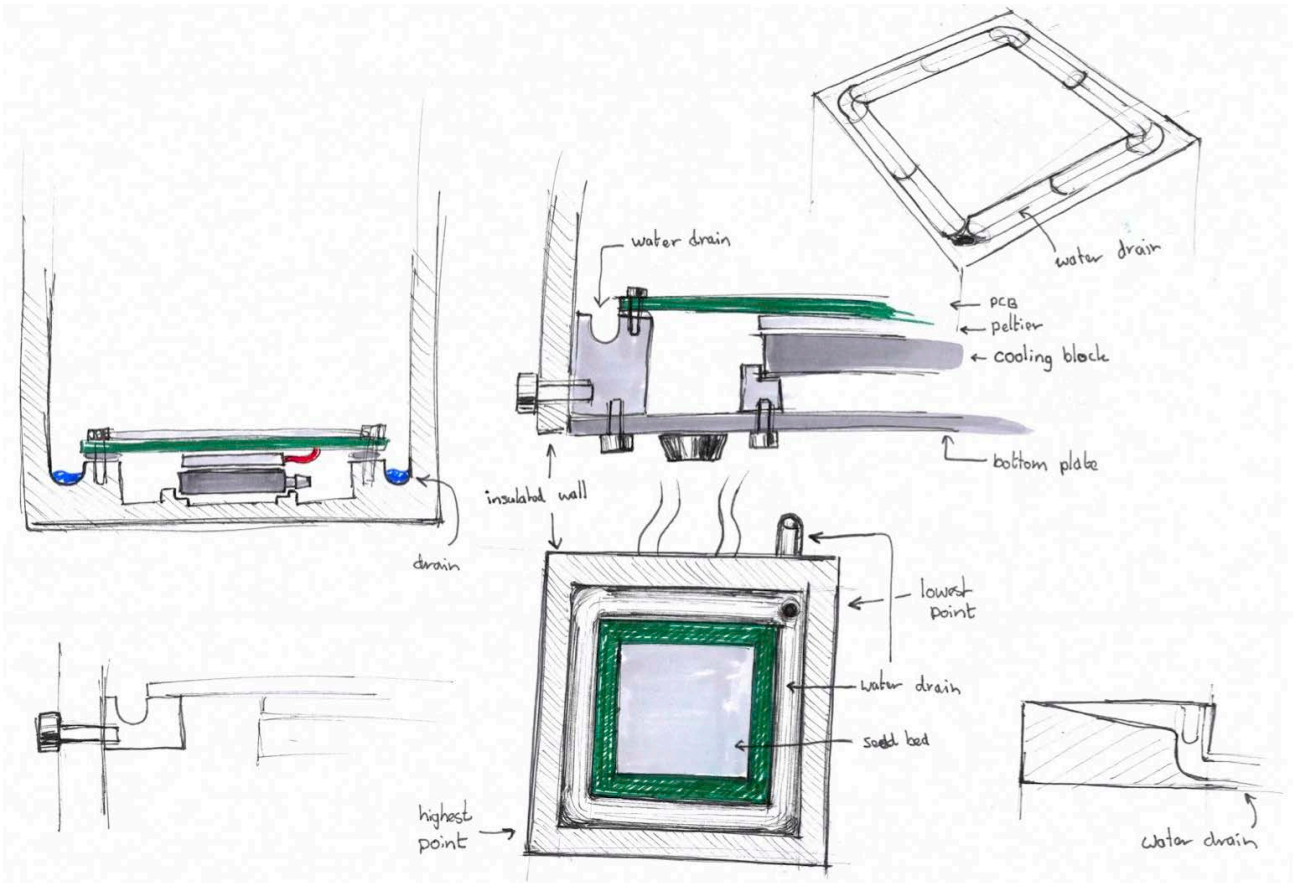


Figure 26.2: *Drawing of various options for the seed bed and water drain.*

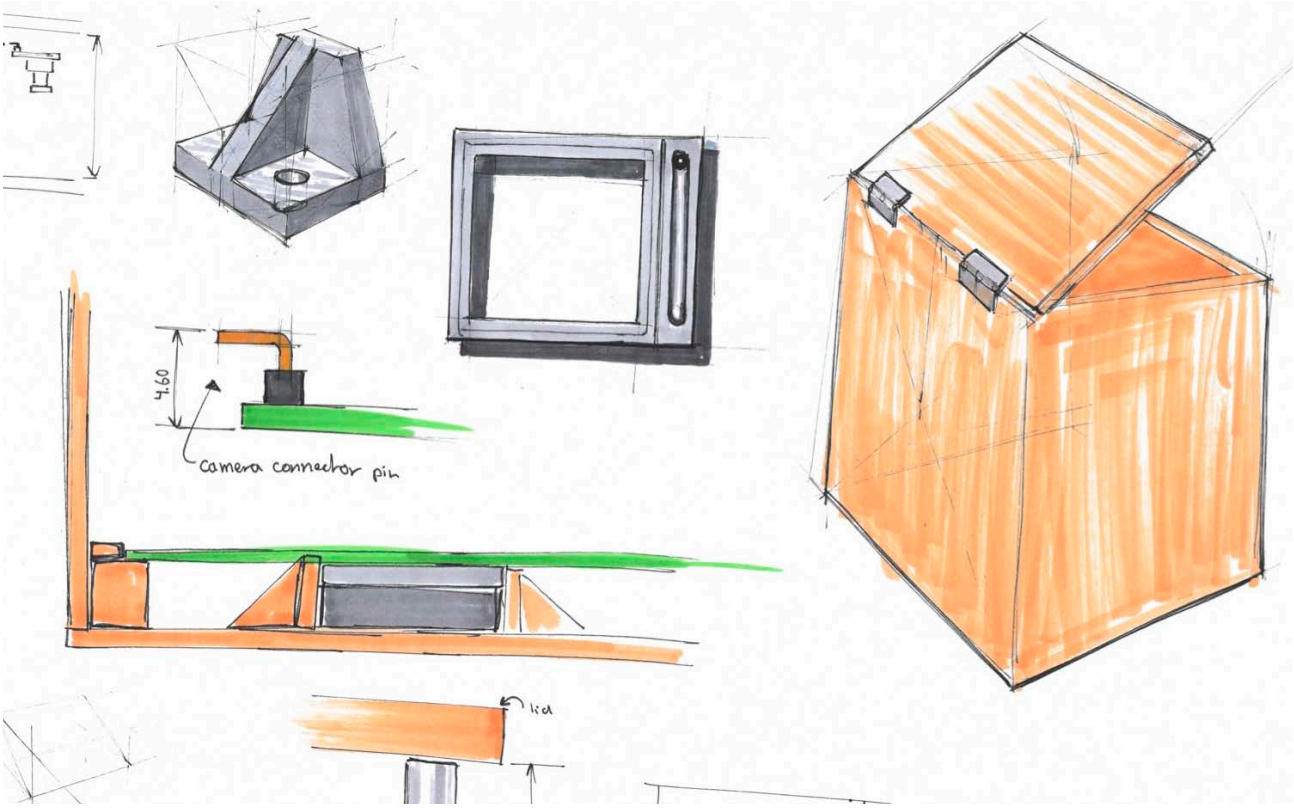


Figure 26.3: *Drawing of various components and the assembly of the seed bed and housing.*

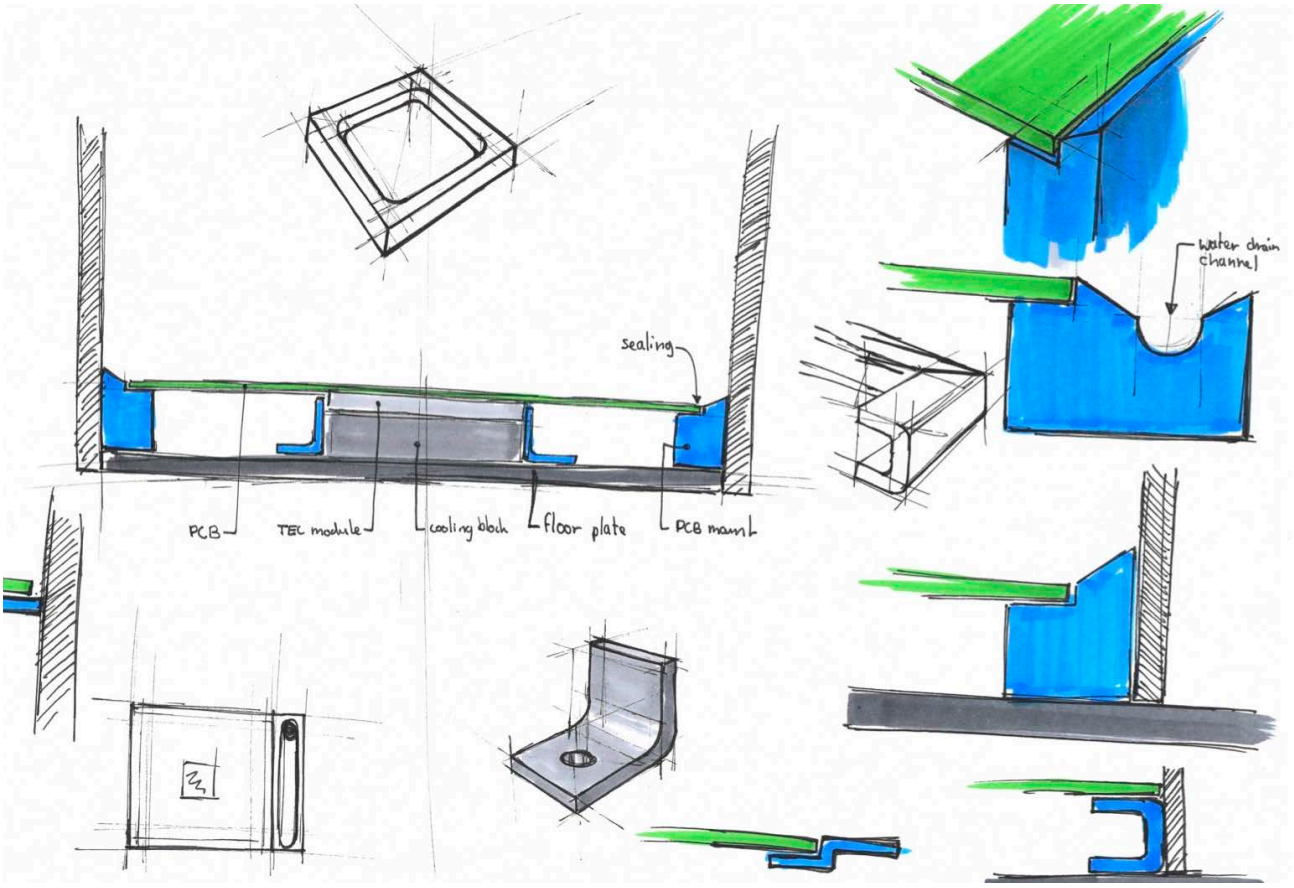


Figure 26.4: *Drawing of various options for the seed bed and water drain.*

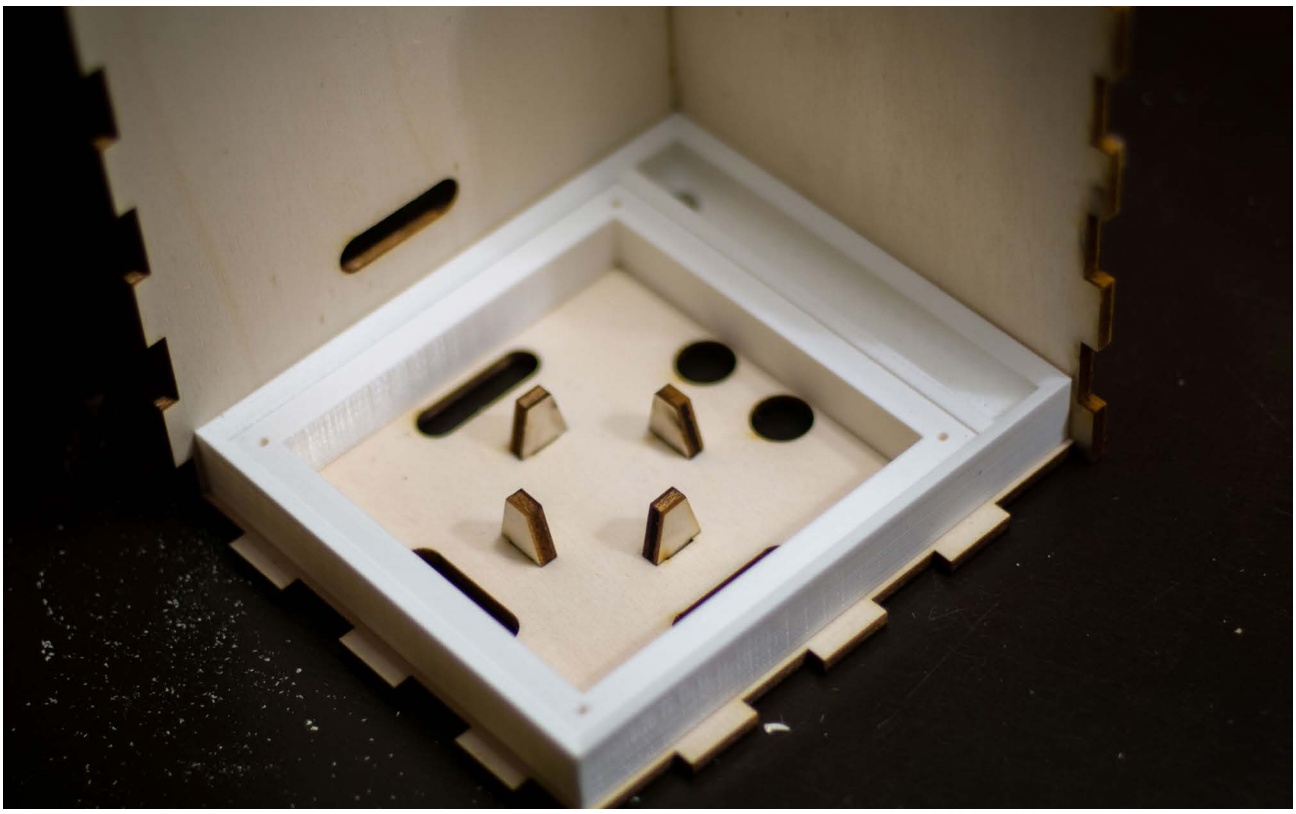


Figure 26.5: *Prototype of PCB holder and water drain.*

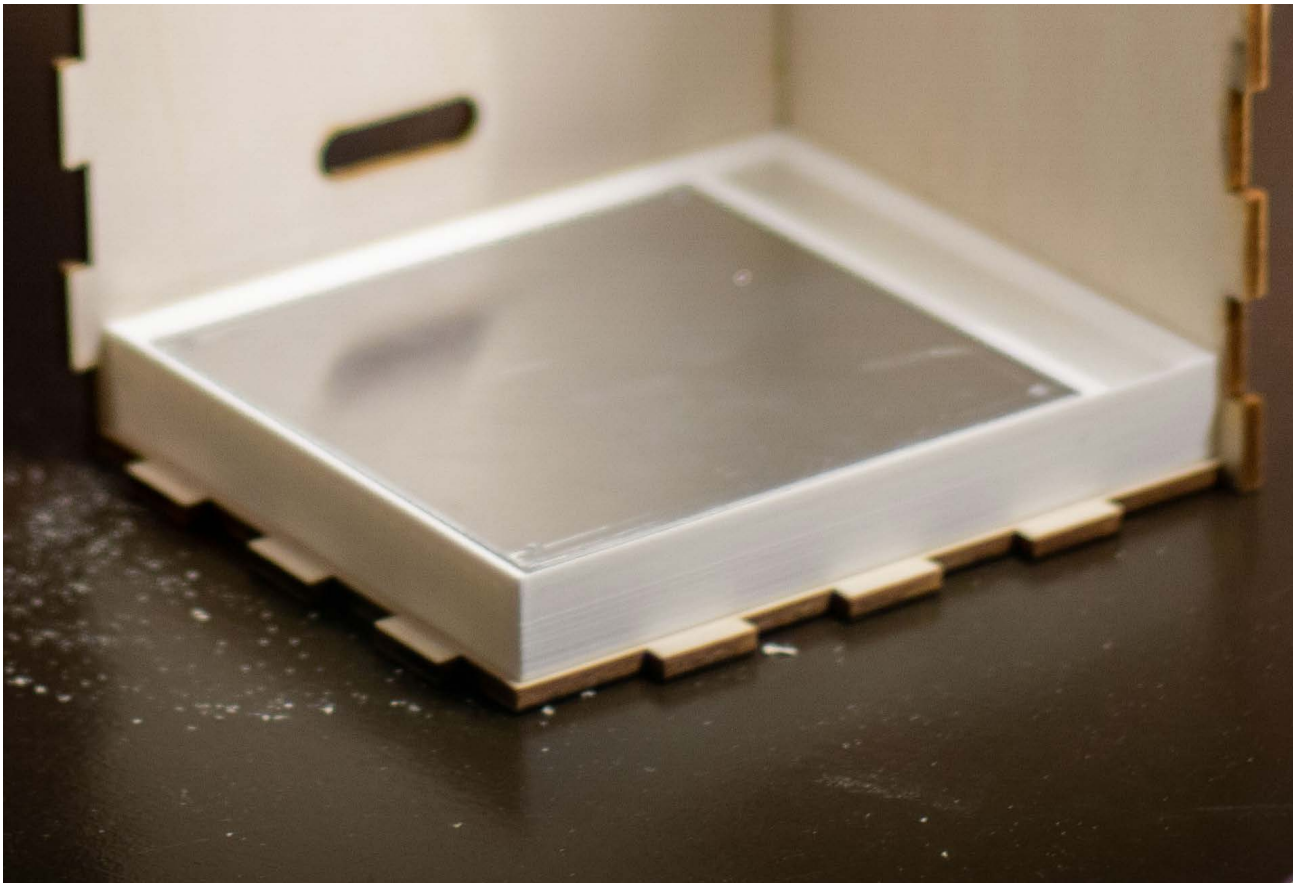


Figure 26.6: *PCB placeholder.*

CHAPTER 27

Form 3

The field of view of the camera and the seed bed size, defined the dimensions of the cell ("Form 3" on page 119, "Seed Bed 1" on page 102, "Camera 2" on page 108 & "Camera 3" on page 113). In the sprint "Seed Bed 2" on page 115, the configuration of the seed bed was chosen. The sprint "Camera 3" on page 113 shows the design of the camera housing. In this sprint, the designs and insights were combined into several germination cell models.

27.1 CONCEPT REVIEW

The concept sketches (from the sprints "Electronics 4" on page 110, "Camera 3" on page 113 & "Seed Bed 2" on page 115) were presented in a company meeting about the QIEM-Array project. In addition to the people form Quantified, an electronics engineer from M91200 and two software engineers from Idematica, who are also involved in the QIEM-Array project, were present as well. The concept was reviewed and the input was used to in the concept development.

27.2 CARDBOARD MODEL

As the shape and dimensions of the concept became more concrete, a new cardboard model could be made (Figure 27.1). This helped to get a better sense of the shape and size of the concept, which is difficult to get from sketches alone. As can be seen in the figure, the model has a white square that represents the seed bed. Behind the seed bed, there is a water drain. The camera is attached to the lid.

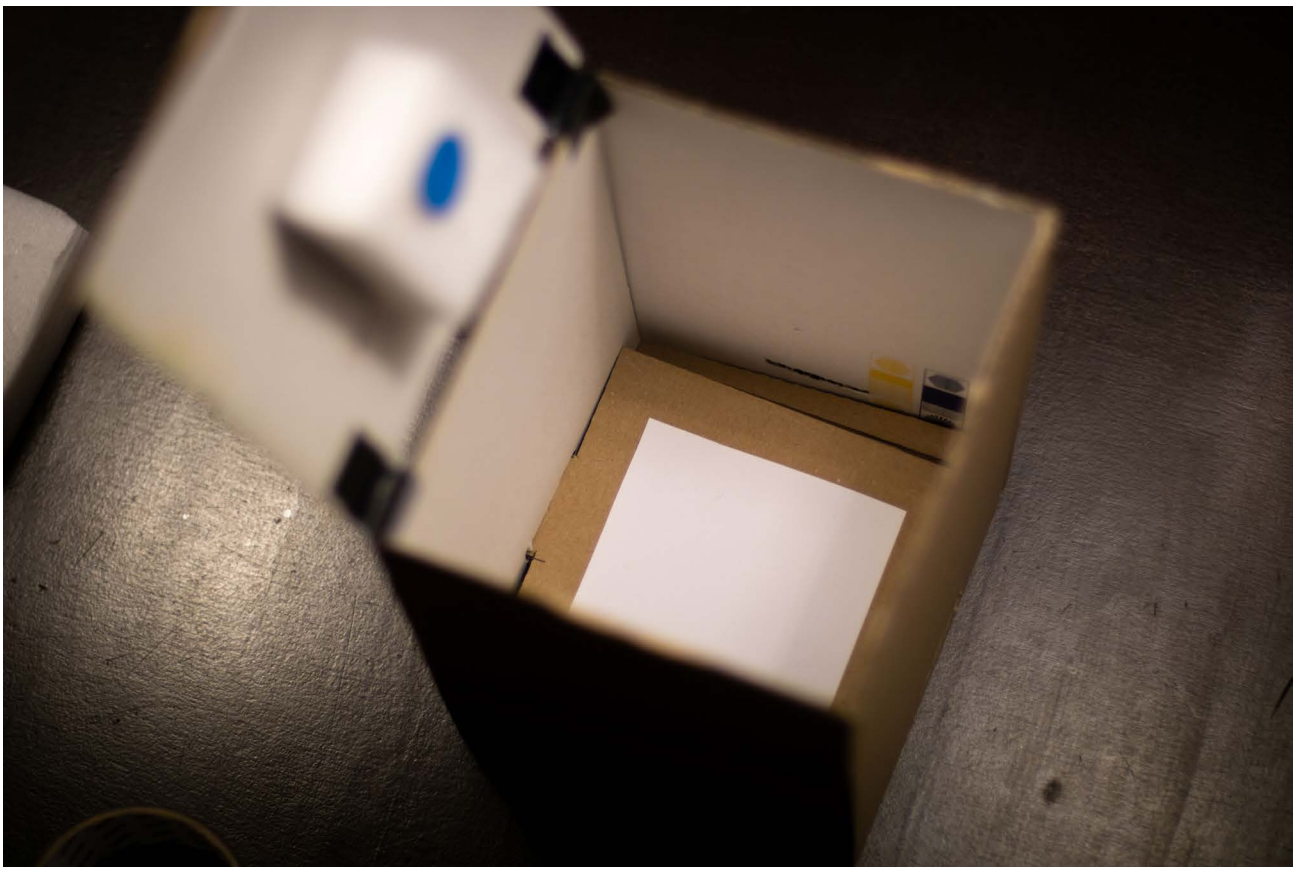


Figure 27.1: *Cardboard and foam model of the cell. The white square represents the seed bed. In the back of the cell, there is a water drain. The blue circle represents the camera lens.*

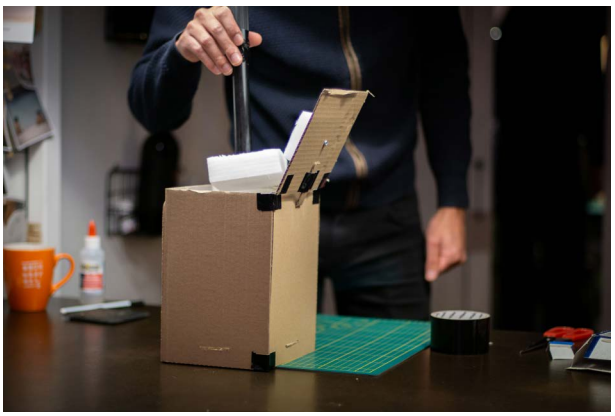


Figure 27.2: *User testing seed placing with a mockup of a vacuum seed placer.*

Figure 27.3: *Building the model of the cell.*

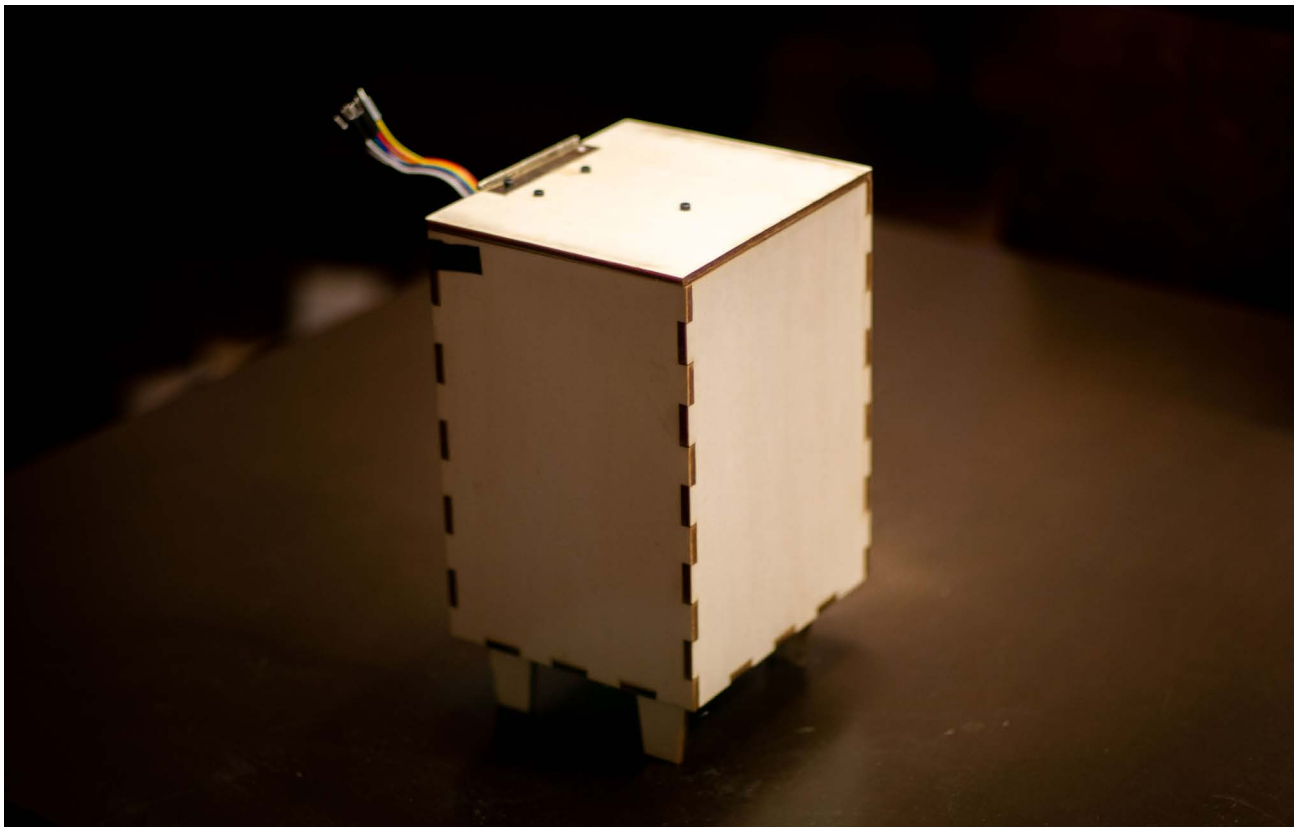


Figure 27.4: *Model of the cell from the outside.*

Figure 27.5: *The inside of the cell with a PCB holder and PCB, water drain. The camera is also attached.*

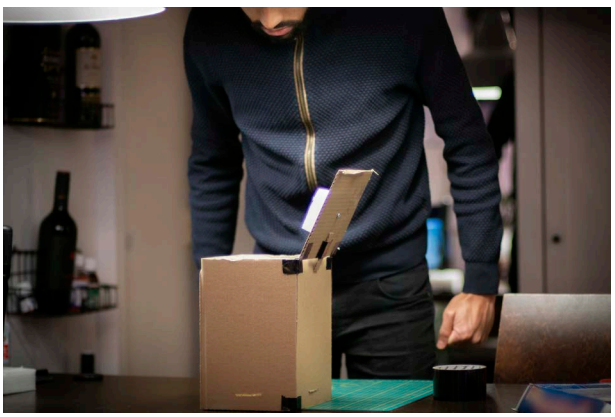


Figure 27.6: *User looking into the cell with a distance if it were behind two other cells.*

27.3 TESTING

When the model was built, a test scenario could be done, similar to the one in the sprint "Form 1" on page 92. It consisted of the following activities: Opening cell, placing seeds, closing cell.

1. Opening cell, removing germinated seeds, closing cell.
2. Opening cell, cleaning cell, closing cell.

The seeds were placed with a mock-up of a vacuum placer, as will be done in the final version of the QIEM-Array (Figure 27.2).

27.4 WOODEN MODEL

In addition to the cardboard model, a wooden model was built (Figure 27.3). It also included the camera housing from "Camera 3" on page 113 and seed bed from "Seed Bed 2" on page 115 (Figure 27.5). In this model, the designs of the components were made even more concrete. Figure 27.4 shows the model from the outside.

27.5 PROBLEMS FOUND

When the models were built and the scenario was played out, several problems have been found.

27.5.1 USER'S VIEW INTO THE CELL

In the sprint "Form 2" on page 97, it was stated that the user's view into the cell could be a problem. In that stage of the project, the dimensions of the cell were much more unclear. With these models, more representative tests could be done. The distance form the table edge was measured and the cell was placed at a distance as if it were behind two other cells (Figure 27.6 & Figure 27.7). With these cell dimensions, the user was able to see the entire seedbed, but only if he bent over. This was not optimal.

27.5.2 REACHING INTO THE CELL

When performing the test scenario, it was concluded that there was little space for hand movement in the cell. This could be problematic when the user has to perform actions on 100 seeds on a small surface area, as well as when they want to clean the cell.

27.6 RETHINKING THE DESIGN

A part of the wall of one of the cells was cut away and the cells were placed stepwise. This resulted in a small improvement on the problems found earlier. Nevertheless, it needed to be elaborated.

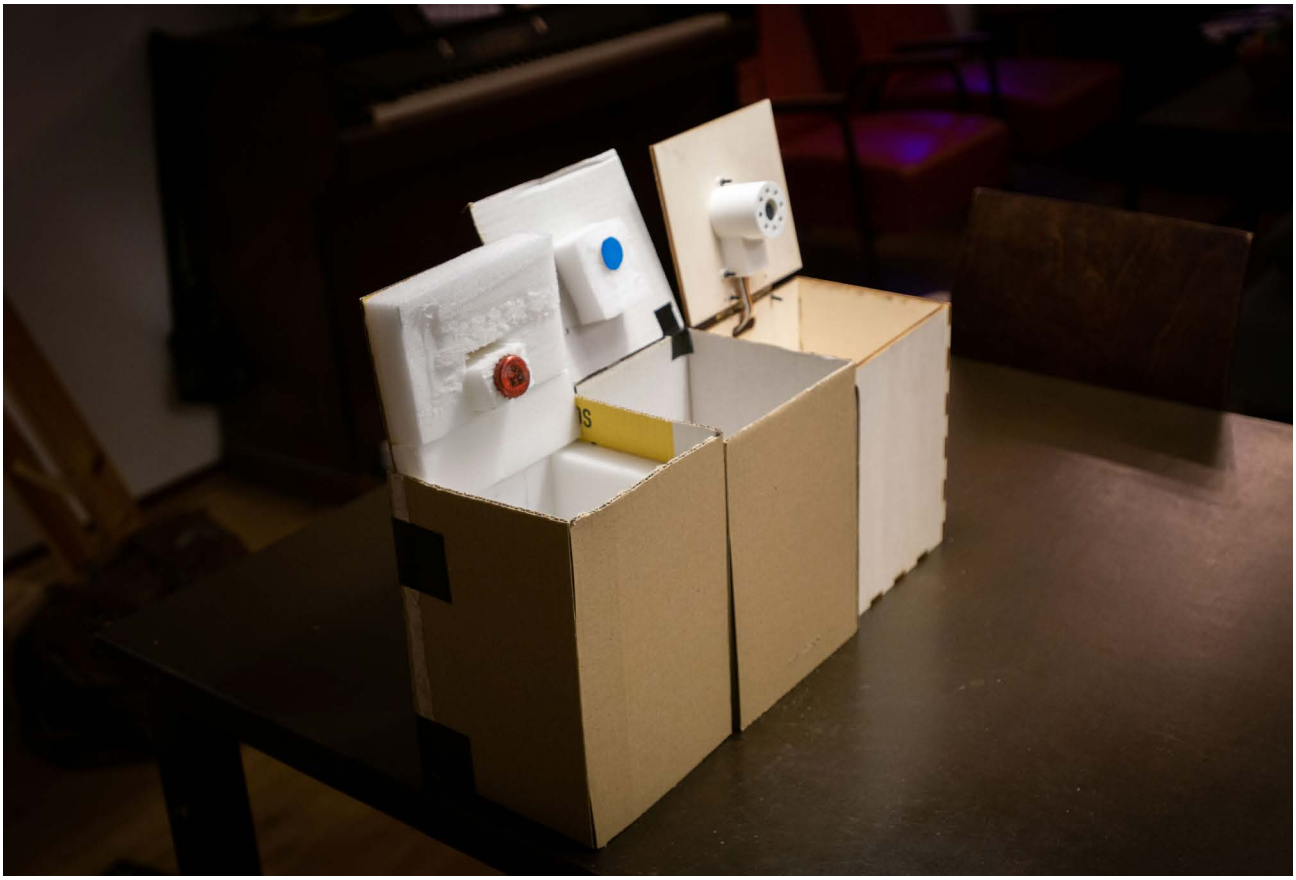


Figure 27.7: *Three models of the cells behind each other.*

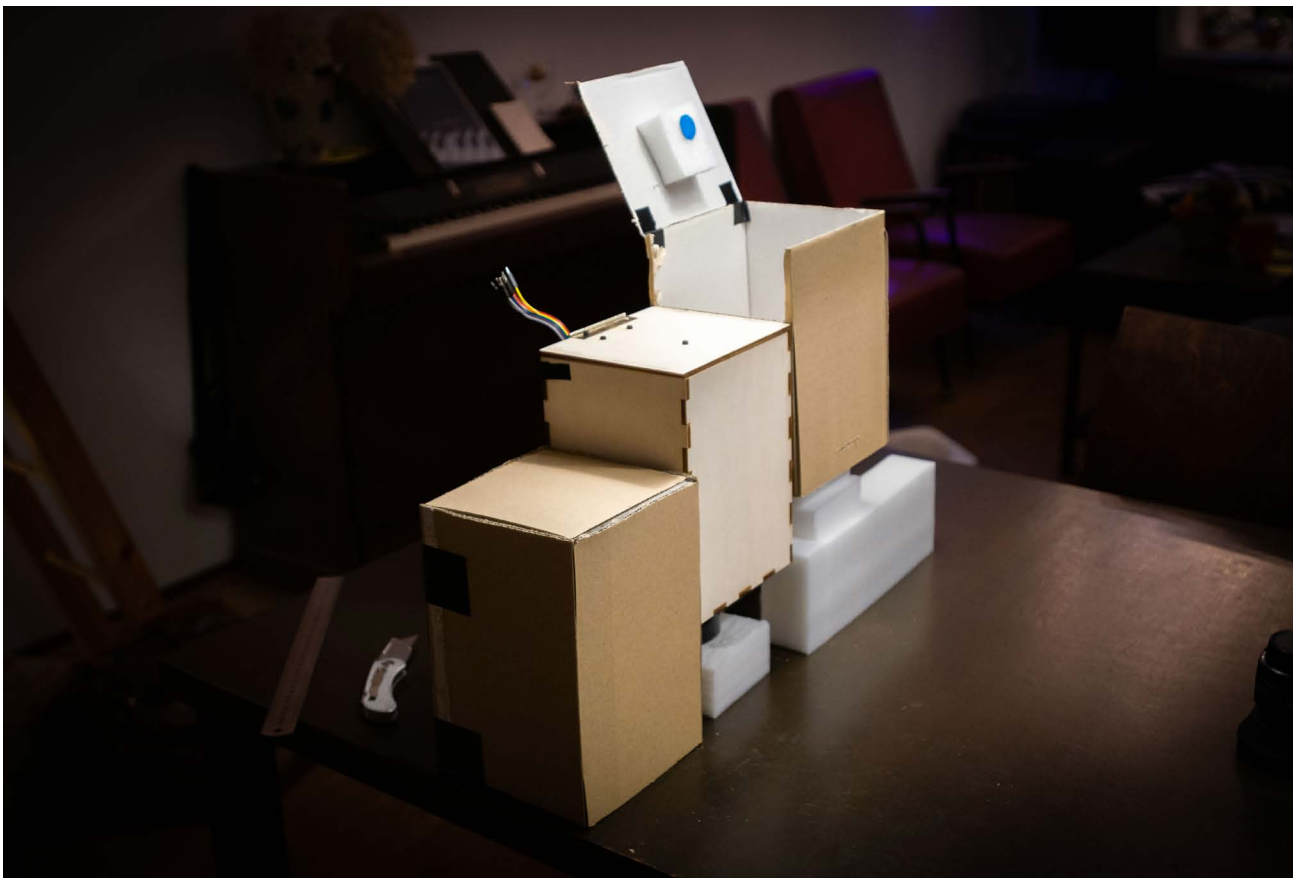


Figure 27.8: *Three cells, stepwise.*

TAKEAWAYS FOR QUANTIFIED

- The findings form the research that was done, the sketches that were made, the models that were built and the feedback that was given, converged into a design for the cell.
- Two models were built and tested in a scenario.
- The cell designs had some shortcomings, particularly the user's view into the cell. It was also difficult for the user to perform actions in the cell.

CHAPTER 28

Form 4

In the sprint "Form 3" on page 119, it was concluded that the cell design had some shortcomings. The problems were namely that it was difficult for the user to look inside the cells. It was also difficult for the user to perform actions in the cell. At the end of that sprint, the idea of a stepwise cell configuration emerged (Figure 28.1). Here, this idea is developed further.

28.1 IDEATION

This sprint started with several ideation sessions. The cardboard cells from Figure 28.1 were cut on different sides to explore the possibilities. Placing the cells in a stepwise configuration means that the user would also have access to the front of the cell, rather than only the top. As can be seen in Figure 28.2, a number of concept sketches were made to explore the options. This was mainly focused on the different types of doors.

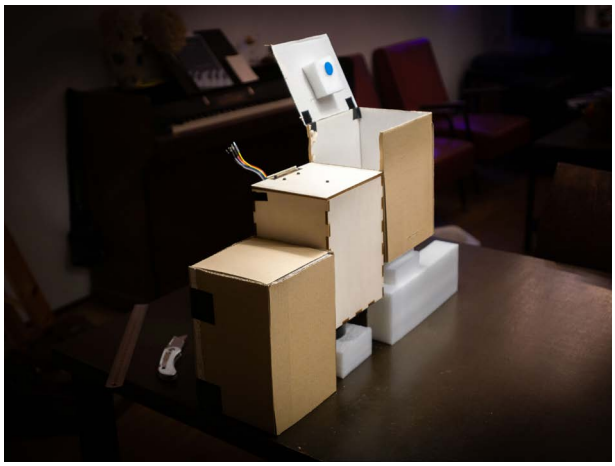


Figure 28.1: *Three cells, stepwise.*

28.2 PROTOTYPING

To test the different options, a framework of three cell was made. Then, various models of door-roof

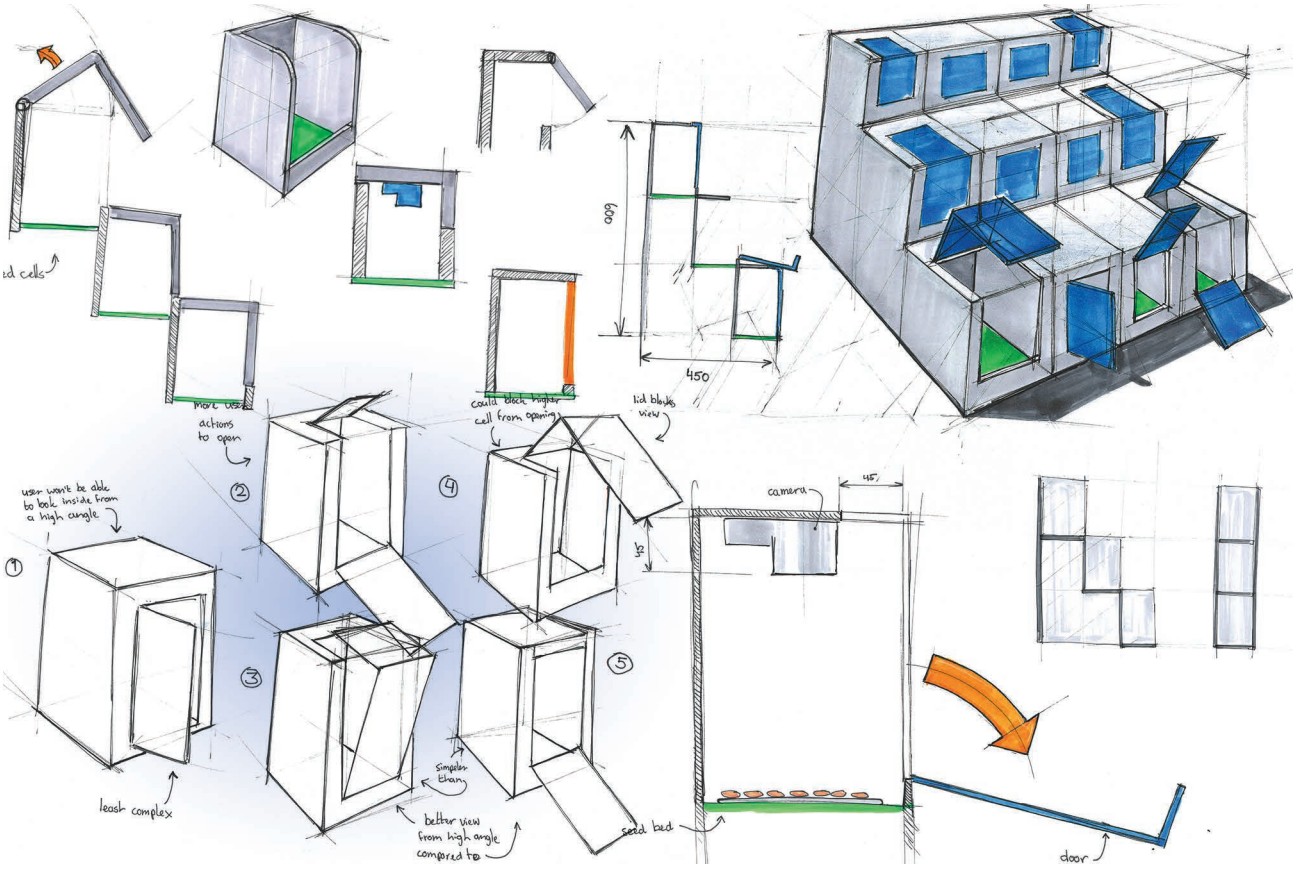


Figure 28.2: *Various concept sketches.*

Figure 28.3: *Cardboard models of the stairs concept.*

a: Three cells on three different levels, used to test different doors and roofs. The white squares represent the seed beds.

b: Cells with different kind of doors. From the top down: door hinged at top; door hinged at the bottom; door hinged at the left.

c: Cell with a door hinged at the left. The user's view is blocked by the roof.

d: Stairs concept with doors hinged at the top, with two doors open.

e: The upper door can't be closed or opened if the lower door is open.

f: Cell with a door hinged at the left, with a roof cutout.

g: Various door-roof combinations.

combinations were made, based on the preceding ideation sessions (Figure 28.3).

The doors were placed on different heights and evaluated on aspects, such as the usability and the user's view into the cell.

The door hinged at the left (c) seemed like the least complex option. However, the roof was blocking the user's view in that configuration.

Another promising configuration was the one hinging from the top (d). When opened, the door could rest on the rest of the roof. When closed, gravity would keep it in position. Nonetheless, when a lower cell is open, the one above it cannot be opened without moving the door of the lower one (e).

A possible solution was found in the combination of the left-hinging and top-hinging doors. With this solution, the cells can be opened, without getting in the way of others. However, because of the design is more complex than the two other solutions.

28.3 EVALUATION

The concepts are evaluated on three criteria (in order of importance): user's view, convenience and simplicity.

28.3.1 USER'S VIEW

This criterion evaluates how well the user is able to look into the cell. During the tests, the cells were placed on different levels (Figure 28.3). For example, the visibility was limited when the left hinging concept was placed on the lowest level (c).

28.3.2 CONVENIENCE

This criterion evaluates the convenience for the user when opening and closing the cells. For example, the view into the top hinging cell is very good, but the cell doors could block others, forming an inconvenience for the user.

28.3.3 SIMPLICITY

This criterion evaluates the simplicity of the concept and how easy it would be to build.

28.3.4 COMPARISON

The strengths and weaknesses of the concepts were evaluated using Harris Profiles (Daalhuizen et al., 2014). As can be seen in Figure 28.4, the *left hinging with cutout* concept has the best score, with the *take-out door with a roof cutout* being a close second. A photo of the concept can be seen in Figure 28.3 (f).

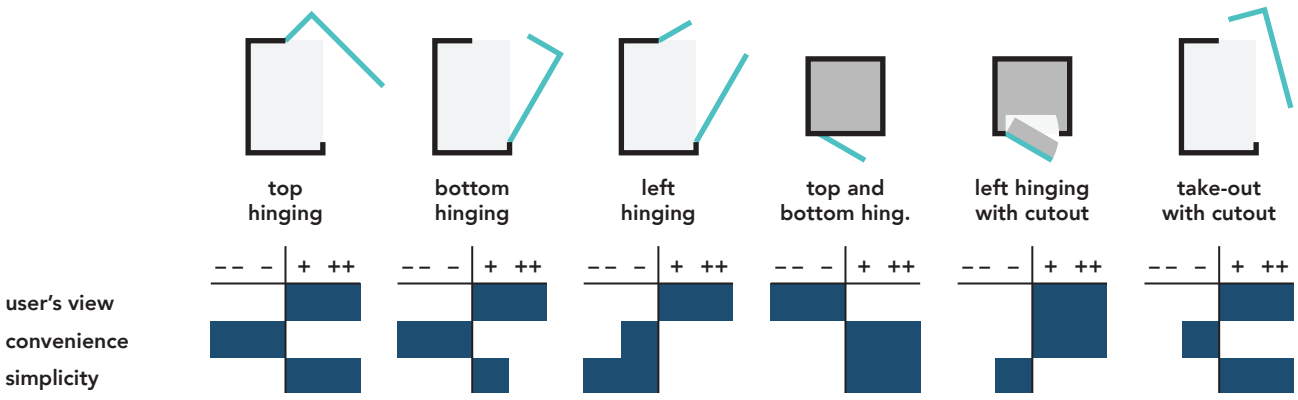


Figure 28.4: *Evaluation of the different cell door concepts with Harris Profiles. The left three cells are cross-sections viewed from the side and the right two from the top.*

28.4 SYSTEM OVERVIEW

The insights from this sprint and the preceding sprints, the concept became increasingly concrete over time. The insights were combined into a system overview, as can be seen in Figure 28.5.

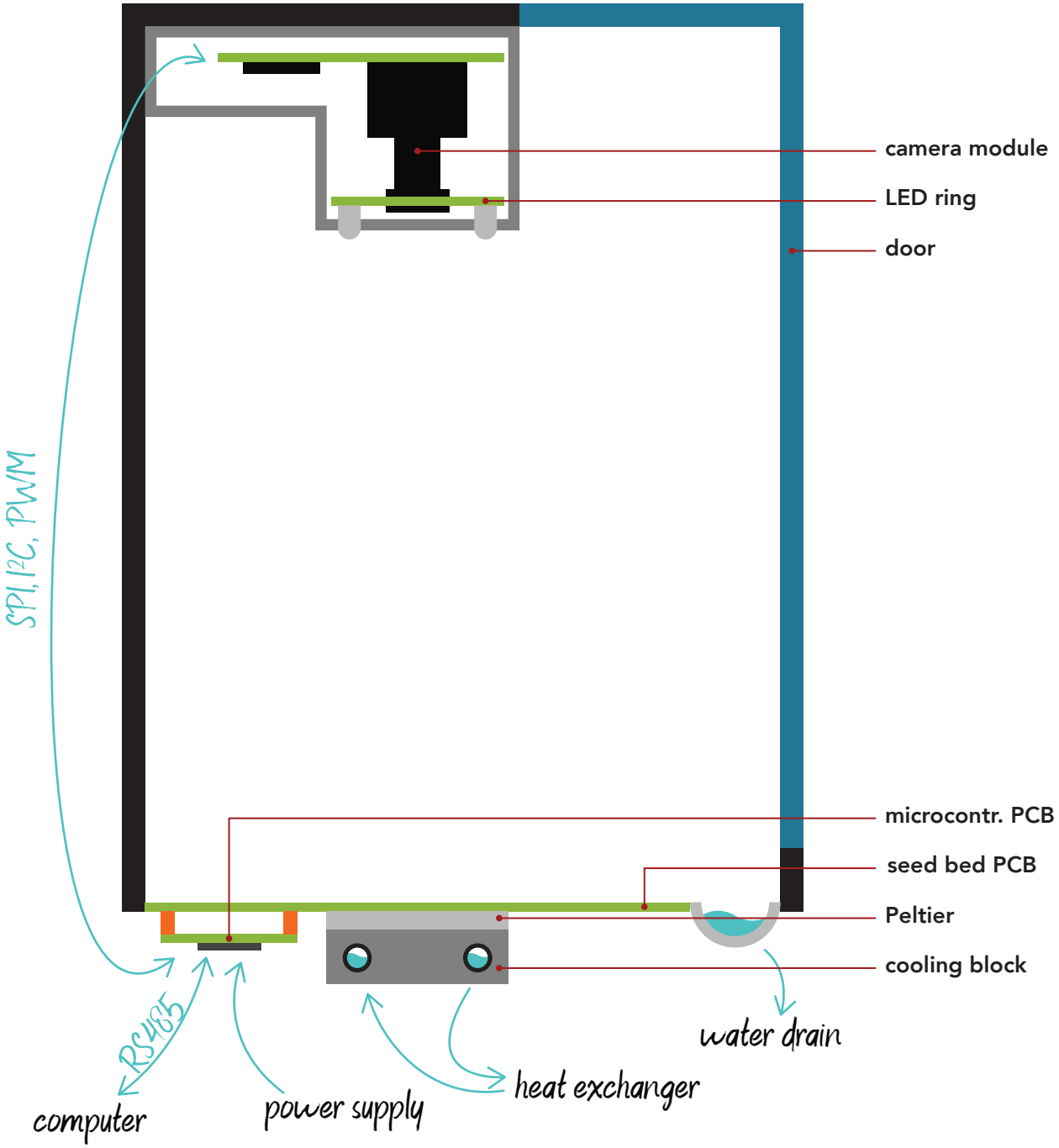


Figure 28.5: *System overview of one cell.*

TAKEAWAYS FOR QUANTIFIED

- The cell designs had some shortcomings, particularly the user's view into the cell.
- The choice was made to use a stepwise cell configuration.
- In several ideation sessions, sketches and cardboard models were made to explore various solutions.
- The solutions were evaluated. A left hinging cell door with a roof cutout scored best.

CHAPTER 29

Camera 4

As can be seen in on the photos of the seed germination tests in Chapter 10 on page 69, the humidity is high around the seeds, causing condensation. This could be a potential problem for the camera. To counteract that problem, several options were considered.

29.1 THE OPTIONS

Research has been done on how to keep a window free of moisture. Several possibilities have been found, such as:

- Heating the window (like a car window).
- Heating the window with warm air.
- Spraying with a hydrophobic spray (like deep-sea divers keep their googles condensation-free).
- Hydrophobic film (as is sometimes used on car mirrors).

The first two options are far more complex than the last two. The last option, the hydrophobic film, seems to be the simplest and cheapest. If this were successful, there would be no need to look at the other options. Therefore, a hydrophobic film was ordered.

29.2 THE EXPERIMENT

The hydrophobic film was applied to an acrylic sheet and suspended above a work surface (Figure 29.1). Then a container was placed under it with boiling water (Figure 29.2). The plate immediately began to fog up, but the view through the film remained clear. The hot water was replaced every two minutes with freshly boiled water to ensure maximum condensation. This was repeated for half an hour.

Figure 29.1: *The test setup, with an acrylic plate with a hydrophobic foil applied. Here, there was no hot water in the tray.*

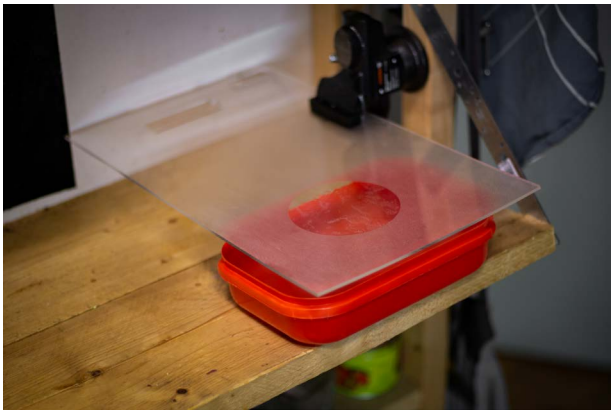


Figure 29.2: *The test setup just after the tray is filled with hot water.*

The droplets around the film grew larger and larger, but the film remained virtually drip-free. The only place on the film where a droplet formed was the lowest point (Figure 29.3). There, a drop slowly formed and dripped down every other minute or so.

As can be seen on Figure 29.4, it is still possible to read through the film, even after half an hour. Since this test was successful, there was no need to look at other options.

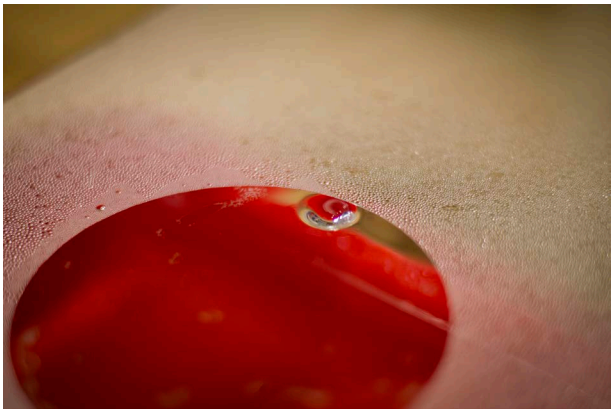


Figure 29.4: *Large drop forming at the lowest point of the film.*

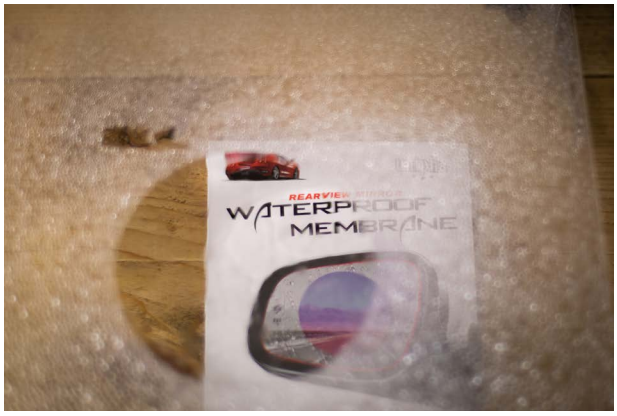


Figure 29.3: *Text can be read through the film easily.*

TAKEAWAYS FOR QUANTIFIED

- Several options were found to prevent condensation in front of the camera.
- It was found that a hydrophobic film is a cheap and simple solution to counteract this problem.

CHAPTER 30

Climate 1

A material for the cell walls had to be found, that had to be resistant to the climate in the cells, as well as provide adequate insulation to maintain the desired climate. Several materials were compared.

30.1 HOUSING MATERIAL

The housing material has to be resistant to the climate conditions in the cell. This means that it has to be resistant water, (cleaning) chemicals and temperatures between 0 °C and 40 °C (ISTA regulations with a safety margins of 5 °C). A selection of materials have been compared, based on the availability at manufacturers and the possibility of laser cutting. All these materials can be used within the required temperature range. The materials were further compared on the water absorption (lower is better), price (lower is better) and chemical resistance (higher is better), as can be seen in Table 30.1.

***Table 30.1:** Material properties of plastics.*

Material	Water absorption	Chemical resistance	Price
ABS	low	medium	medium
HDPE	*low*	*high*	*low*
PA	high	low	high
PC	medium	low	high
PETG	low	high	medium
PMMA	low	medium	high
POM	medium	low	medium
PP	low	high	low

(Crawford & Martin, 2020; ASM International., 2003; Chemical Resistance Chart | Plastics International, n.d; Kunststofsoorten | Vink Kunststoffen, n.d.; Polymer Properties & Chemical Resistance of Plastics, n.d.; Walda, n.d.; Kunststof Lasersnijden Voor De Industrie, n.d.)

Based on the material comparison and export input, HDPE has been found to be the best option.

30.2 HDPE CALCULATIONS (?)

With the wall material chosen, calculations were made to determine the required wall maximum heating power of the Peltier element is 70 W (Hebei I.T. (Shanghai) Co., Ltd., n.d.). Heat transfer through the housing can be calculated with the following equation:

$$Q = \frac{\lambda A \Delta T}{d}$$

The heat transfer coefficient (λ) of HDPE is 0.38 W/mK (Kunststofsoorten | Vink Kunststoffen, n.d.). The housing from the sprint "Form 4" on page 123, has a surface area (A) of 0.1008 m^2. In a extreme scenario, the temperature difference (ΔT) between the inside of the cell and the outside, could be up to 30 °C. With a wall thickness of 5 mm, the heat transfer from the inside of the cell to the outside, would be 230 W. This is out of the capabilities of the Peltier element. It would be an option to use thicker walls, but HDPE that would be thick enough, are simply unavailable. This would also be the case with the other materials that were considered. Therefore, another solution had to be found.

30.3 COMBINING MATERIALS

Research into different insulation materials was done. Several options have been have been considered. EPS was chosen for this application, for its insulation capabilities, inexpensiveness, wide availability (at every construction market), and water resistance. The heat transfer coefficient is 10 times higher than that of HDPE. A disadvantage of EPS is that it is not strong enough to be used as the sole housing material. Therefore, it was chosen to use a combination of EPS and HDPE. The HDPE would provide the resistance to the inner-cell conditions, while the EPS would provide the insulation.

If a 10 mm thick EPS plate is placed between two 3 mm thick layers of HDPE, the heat transfer though the walls would be 31.4 W, and thus lower than the maximum Peltier heating power. With a EPS layer thickness of 20 mm, the heat transfer would be 21.1 W.

TAKEAWAYS FOR QUANTIFIED

- Several materials were considered as housing materials.
- Heat transfer calculations were made to determine the insulation requirements, based on the Peltier element capabilities.
- It was chosen to use a combination of HDPE and EPS for the cell walls.

CHAPTER 31

Seed Bed 3

In the sprint "Seed Bed 2" on page 115, a seed bed and heating-and-cooling combination was designed and a model was built. A disadvantage of the system, was that it required several custom-designed parts. The use of off-the-shelf parts, instead of custom designed ones, is advantageous for various reasons, e.g. lower costs and less complexity.

31.1 CPU COOLING SYSTEMS

When doing research into small-scale cooling systems, a PC CPU cooling system was starting to seem like a viable option to cool the Peltier. A major advantage of these systems is that they are widely available in a large number of varieties (see, for example, Figure 31.1). Moreover, the mounting systems are standardized. The Intel Socket S1156, with M3 holes and a distance of 75 mm, seemed to be the most widely used. It would also provide adequate space for the 40 mm wide Peltier element.

Figure 31.1: *CPU water cooling.*

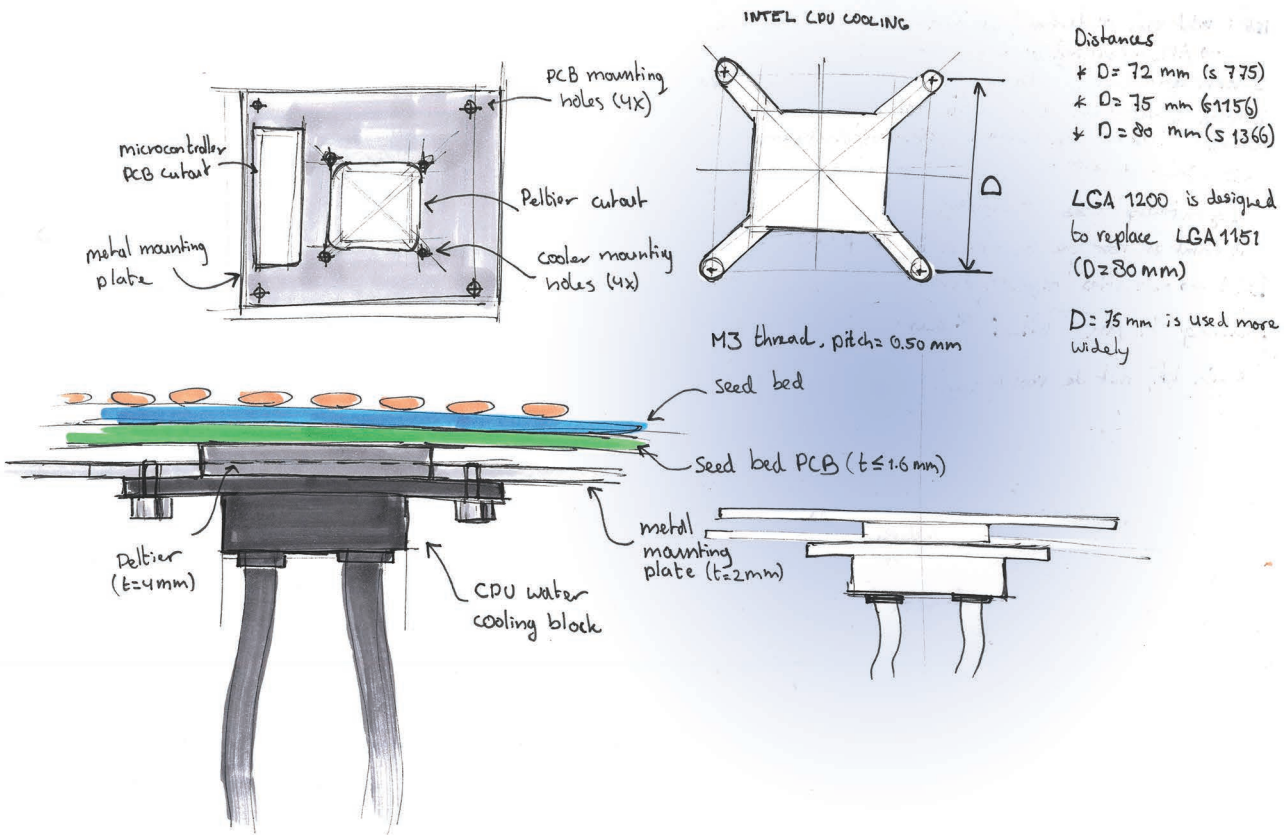


Figure 31.2: *Sketches of the seed bed and cooling components.*

31.2 THE DESIGN

Inspired by the CPU cooling system, some sketches were made in the design process (Figure 31.2). The base of the design is a 2 mm thick metal plate with threaded M4 holes. The seed bed PCB is placed on top of the plate, with a 2 mm spacing. On the bottom of the bottom plate, the CPU cooling can be mounted directly.

TAKEAWAYS FOR QUANTIFIED

- The seed bed design was simplified in a redesign.
- The choice was made to use a standardized CPU cooling system (Intel Socket S1156).
- Insights from this sprint were used in the rest of the design process (“Form 5” on page 133).

CHAPTER 32

Form 5

In the sprint "Climate 1" on page 129, it was decided that the cell walls should consist of a layer of EPS between two layers of HDPE. In the sprint "Form 4" on page 123 it was decided that the cells would be placed in a stepwise configuration. In this sprint, the concept was developed further, from the design of one cell to an array.

32.1 BASE FRAME

After several design sketches and prototypes have been made ("Form 4" on page 123), it was time to develop the concept further in CAD. In the sprint "Form 5" on page 133, a cell model was built. This model used interlocking teeth to connect the walls (Figure 32.1). It was a possibility to use this system for the whole array, but it was soon concluded that it would become unnecessarily complex. Therefore, a base frame was designed (Figure 32.2).

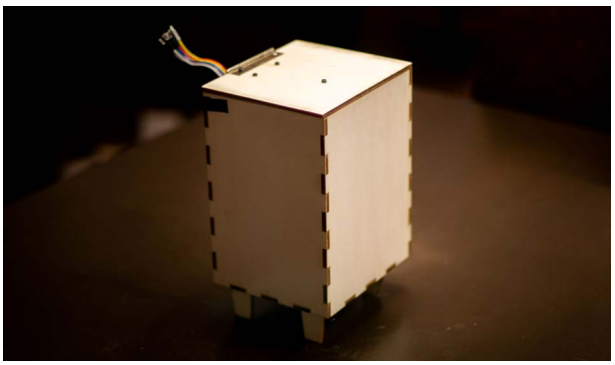


Figure 32.1: *Model of the cell with walls with interlocking teeth.*

32.2 CAMERA HOUSING

In the sprint "Camera 3" on page 113 a camera housing was designed. With the cell walls gaining thickness, due to the integrated insulation, The idea came about to integrate the camera in the cell roof (Figure 32.3). This could reduce the number of parts and make waterproofing easier.

Figure 32.2: *Basic design of the frame.*

32.3 FRAME SYSTEM

After considering the options and discussions about the concept, the choice was made to use aluminum extrusion profiles. These provide a way to make inexpensive frames with a great flexibility.

Several different profile systems were considered. Around the cell, the HDPE plates were to be attached to the frame, on both sides of the beams, with a layer of EPS in between. There is a wide variety of profile systems available on the Dutch market, but only the smaller ones were considered (maximum beam diameter of 25 mm), since large profile systems would make the QIEM-Array unnecessarily bulky.

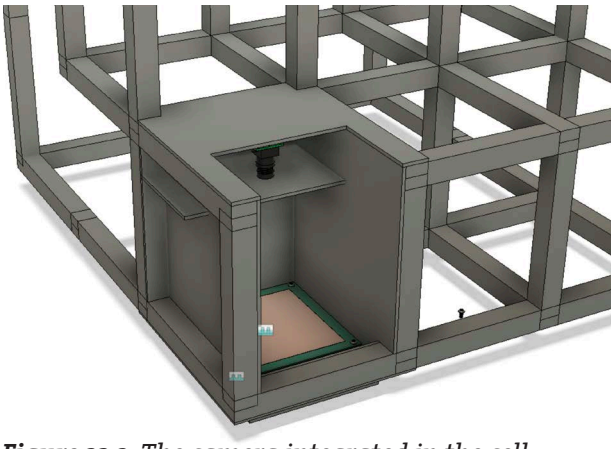


Figure 32.3: *The camera integrated in the cell housing.*

32.3.1 MAKERBEAM

The MakerBeam system (Figure 32.4) was seen as a viable option. The width of the profiles is 10 mm, providing enough space for the EPS insulation plates ("Climate 1" on page 129). However, the MakerBeam system was found to have some

disadvantages. It was found to be rather expensive compared to other profile systems. For example, the cost of 25 M3 nuts was €14.25. Furthermore, the variety of different components was relatively limited, thus limiting the flexibility. Therefore, another option had to be found.

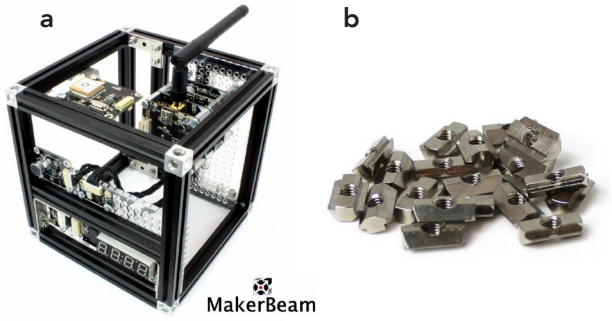


Figure 32.4: *The MakerBeam profile system. a: Example of a MakerBeam frame. b: MakerBeam M3 nuts.*

32.3.2 ALUXPROFIEL

Aluxprofiel is another profile system with a wider variety of connection components (Figure 32.5). Moreover, the components are much cheaper than those of the MakerBeam system. The base profile with is 20 mm. It was found that the minimum width of EPS plates available at Dutch construction markets is also 20 mm. There were other profile systems found with roughly the same dimensions. In case another supplier has to be found, a compatible system would not be hard to find.

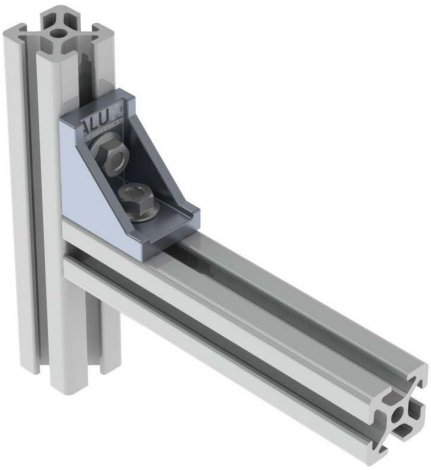


Figure 32.5: *The Aluxprofiel system.*

32.4 TESTING THE CELL DIMENSIONS

One of the existing cardboard models was adjusted to the new cell dimensions (Figure 32.6). The cell had a 120 mm × 120 mm seed bed PCB. It was immediately concluded that there was not enough space a hand to move around in the cell. Therefore, it was chosen to increase the width by 30 mm, making the PCB dimensions 150 mm × 120 mm.

Figure 32.6: *Test with a 120 mm wide cell.*

32.5 CAD AND TESTING

After the dimensions of the seed bed and the profile system was chosen, a CAD model could be made.

32.5.1 CAD

A basic model with the Aluxprofiel system was made in CAD. Other components, such as the camera, Peltier element, cooling block, and water drain were also placed in the model (Figure 32.7).

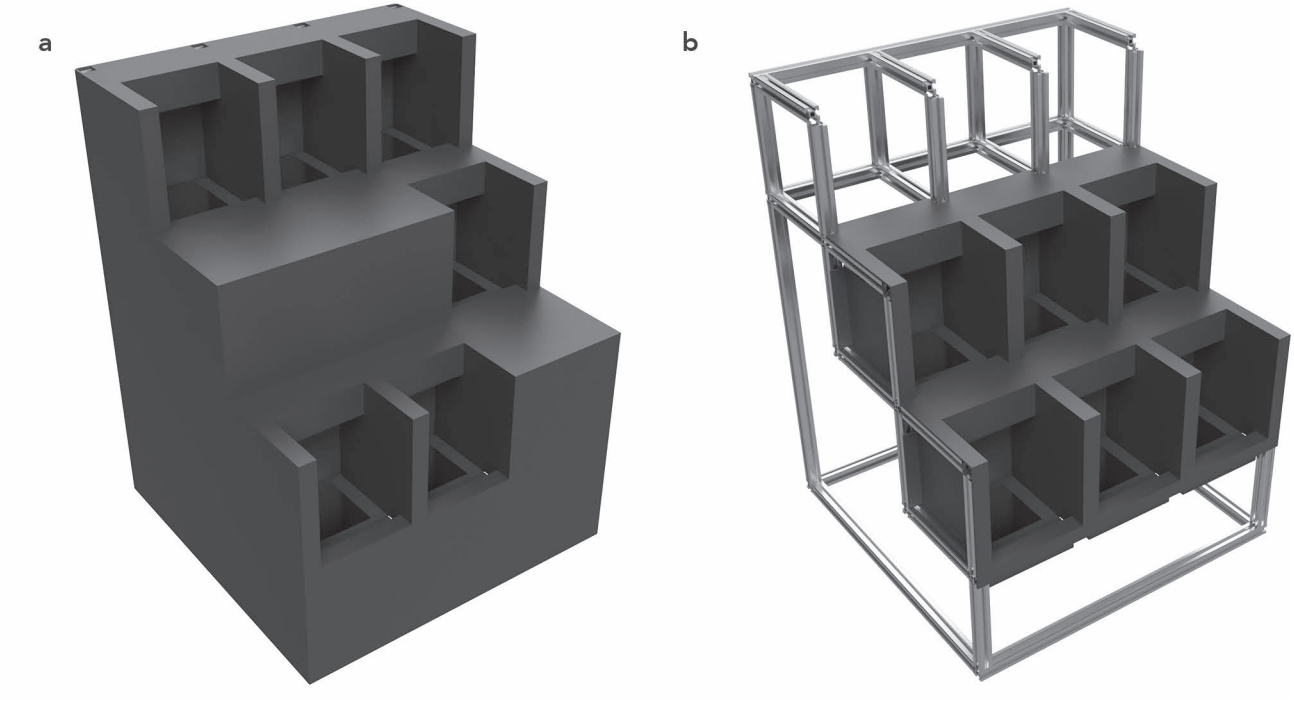


Figure 32.7: *Renders of the array frame. a: Outside of array. b: Array with part of the construction.*

32.5.2 TESTING THE NEW CELL DIMENSIONS

A card model of the cell with the new dimensions was built (Figure 32.8). Thereafter, a test scenario, similar to the one in the sprint "Form 3" on page 119, was performed (Figure 32.9). It consisted of the following activities:

1. Opening cell, placing seeds, closing cell.
2. Opening cell, removing germinated seeds, closing cell.
3. Opening cell, cleaning cell, closing cell.

It was concluded that the cell, with these dimensions, provided a good view into the cell in all positions, had enough space for the user to perform actions, while still being compact.

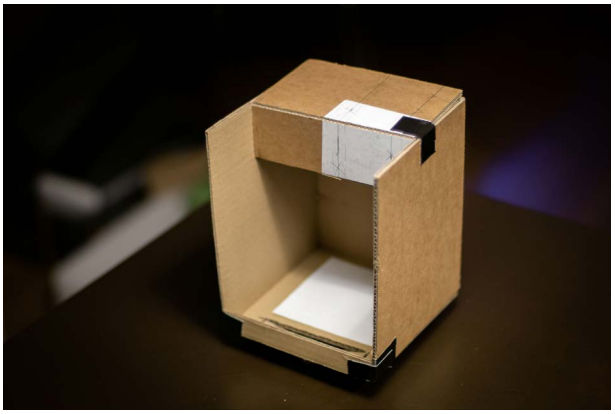


Figure 32.8: *Cardboard cell model with the dimensions that followed from the CAD design.*

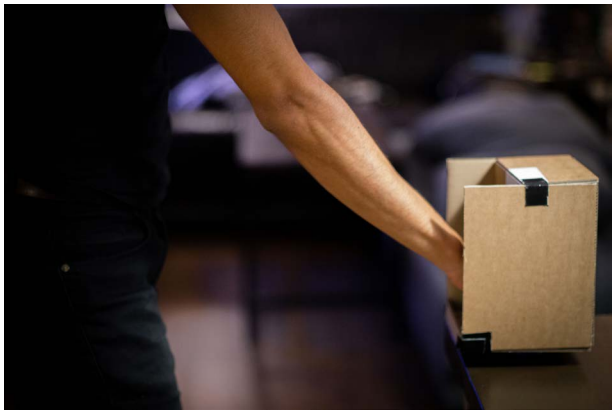


Figure 32.9: *The cell model was tested in different ways. Points of attention were the user's view into the cell and the user's ability to perform actions on the seed bed.*

32.6 FEEDBACK SESSION

A feedback session was organized with Warner from Quantified and a R&D engineer working with Koppert Cress. Both the cardboard and the CAD model of the cell were evaluated. The most important points from the discussion are given below:

- For the germination process, **uniformity is key**.
- In an ideal world, the temperature gradient table, would be used for each seed batch.
- Germination tests are labor-intensive.
- **For germination tests, you want constant climates. With Jacobsen tables, there are still a lot of variables.**
- For germination tests, highly-educated people perform a lot of repetitive tasks.
- In the greenhouses, some parts have active cooling.
- It is a serious consideration to perform the germination process in closed-off climate cells.
- Controlling the temperature could be very interesting. What would work best? A constant temperature or fluctuations?
- Before the germination tests, the medium is soaked completely. The humidity during the tests is close to 100%.
- **There are not a lot of indication that the type of light has a large influence on the germination process.** Turning light on or off is more interesting than the spectrum.
- Cold white light is good for our germination experiments.
- **This product could have a high price.**
- **This product is many steps ahead of the temperature gradient table.**
- **I am convinced that this product is a huge win. It is an ideal experimentation platform.**

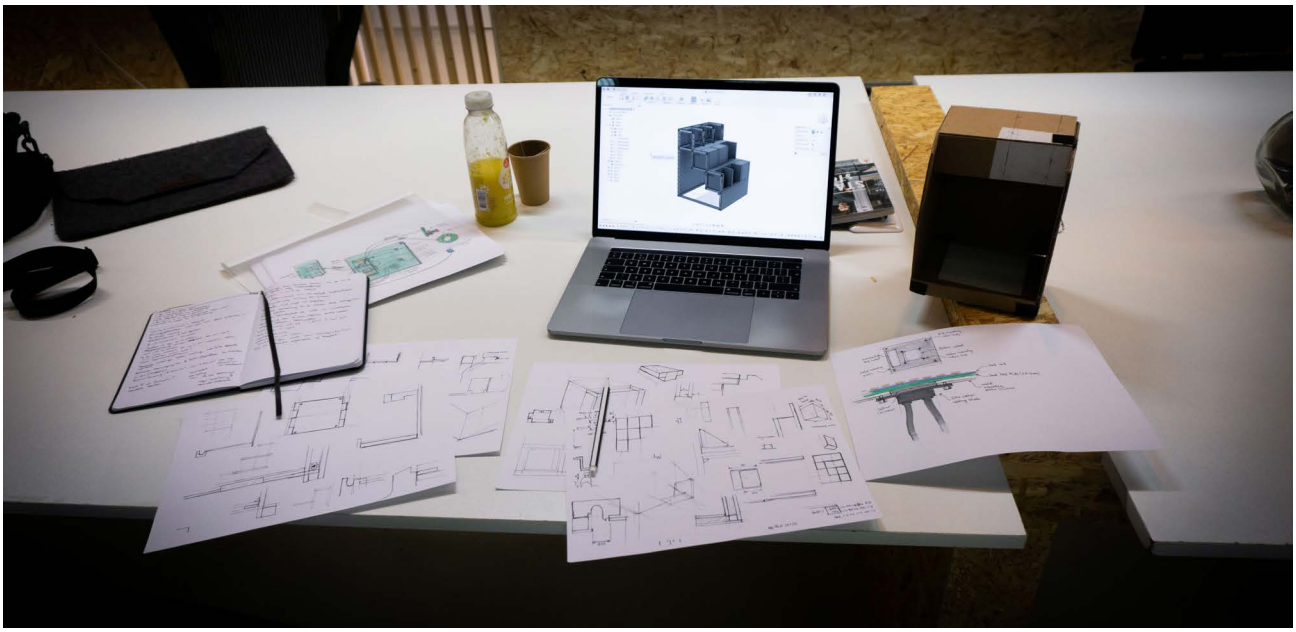


Figure 32.10: *Photo from the feedback session with Warner from Quantified and the R&D Engineer from Koppert Cress.*

TAKEAWAYS FOR QUANTIFIED

- The stepwise array concept was developed further in CAD.
- The camera has been integrated in the cell roof.
- The Aluxprofiel aluminum profile system was chosen as base frame for the QIEM-Array.
- The seed bed PCB size was increased to 150 mm × 120 mm.
- A CAD model and a cardboard model were made and evaluated in a feedback session. The concept was found promising by an expert.

CHAPTER 33

Build 1

In the sprint "Form 5" on page 133, the choice was made to use the Aluxprofiel aluminum profile system as the base for the array frame. Moreover, a basic model was made in CAD. In this sprint the design was detailed. A model was made and tested to find the last shortcomings.

33.1 FROM CELL TO ARRAY

In an early stage of the project, it was decided to limit the scope of the project to the development of one cell. In a discussion with Warner from Quantified, the choice was made to broaden the scope and to develop an array of 3 × 3 cells. The complexity of the concept would not increase significantly, but it would offer several advantages, including:

- Simultaneous tests with different climate conditions.
- More advanced climate tests. For example, determining the required cooling power when the cell is surrounded by warm cells.
- The ability to test the scalability of the system with, for example, the cooling system or the data communication.
- It would also be great to be able to present an array, rather than a single cell, to potential customers, to give them a better idea of what the final product might look like.

33.2 CAD

The insights from the preceding sprints were used to develop the CAD model. While modeling, to help the process, a large number of quick sketches were made (Figure 33.1). The different design steps are shown in Figure 33.2.

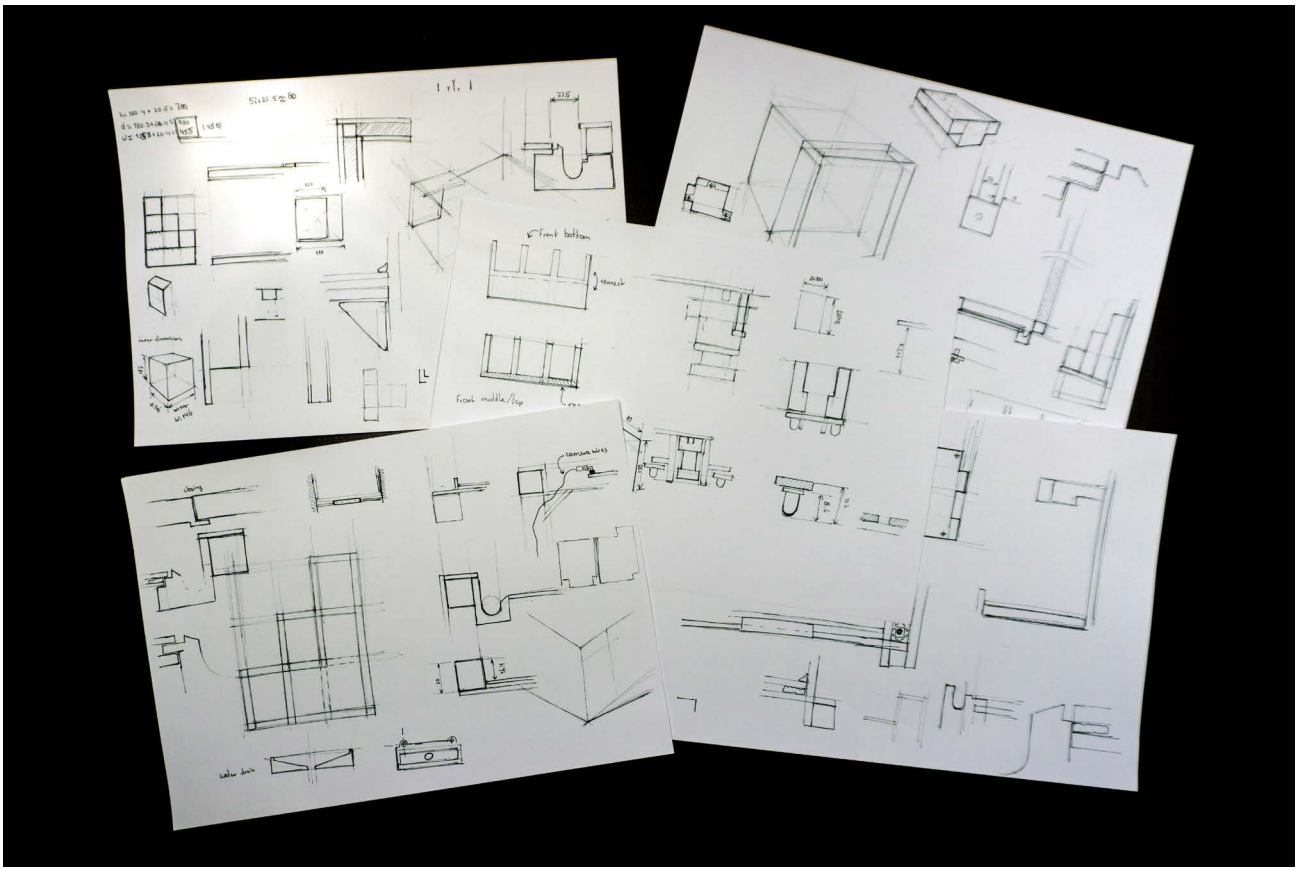


Figure 33.1: *Sketches made to aid the CAD work.*

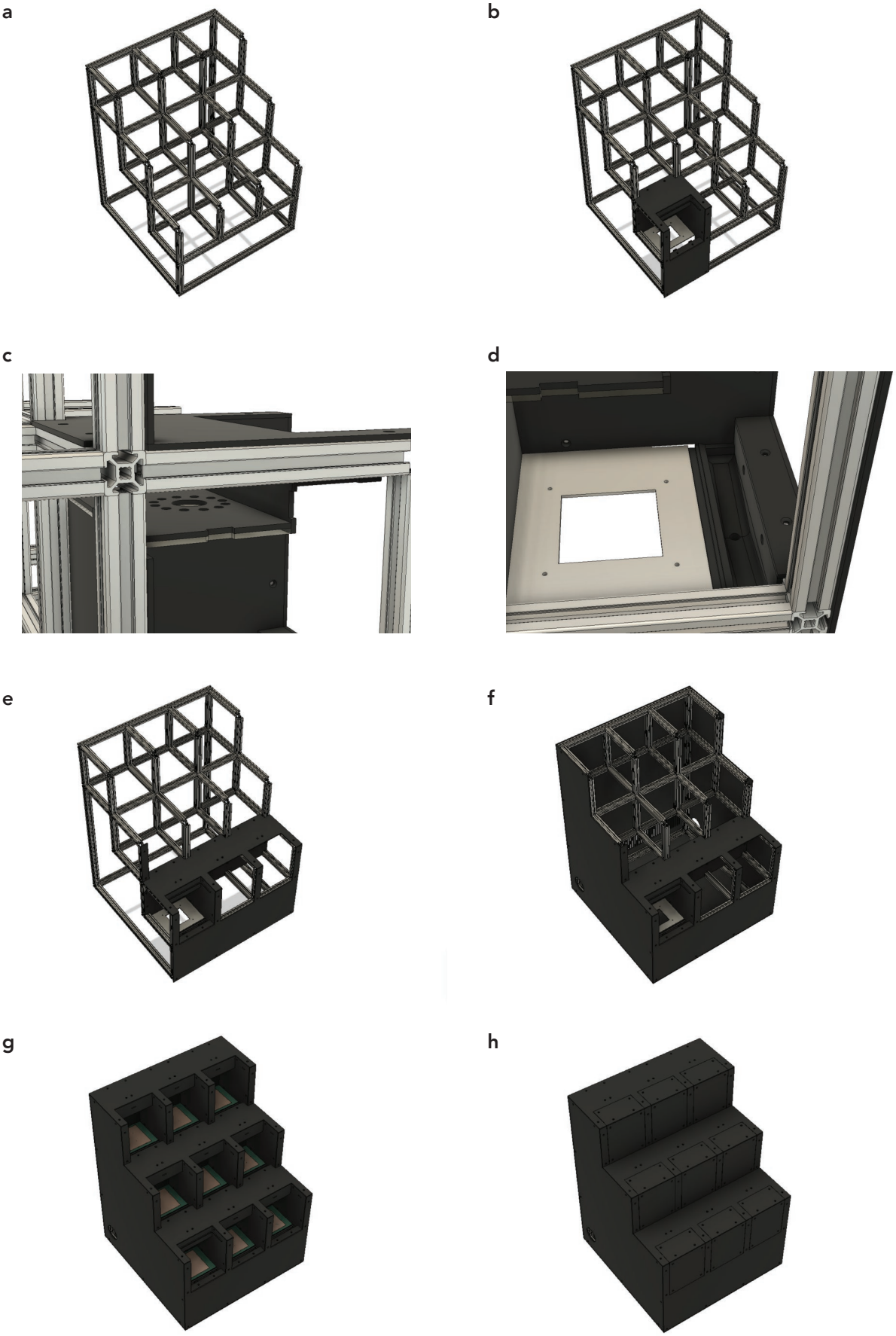


Figure 33.2: *Design of the QIEM-Array. a: Extrusion profile system. b: Cell bottom plate and walls. c: Camera housing integrated in the cell walls. d: Drain. e: Combining cell walls of adjacent cells to reduce number of parts. f: Outer walls of QIEM-Array. g: Copying cell elements to whole array. h: Cell doors.*

33.2.1 CONNECTING COMPONENTS

The Aluxprofiel system provides different methods of connecting the profiles. In this design, internal frame connectors are used (Figure 33.3 (a)). External frame connectors were also available, but these would get in the way of the HDPE wall plates on many places. To connect the wall plates to the profiles, M3 frame nuts and countersunk M3 bolts are used (Figure 33.3 (b)). Countersunk bolts were chosen for two reasons: to minimize the gap between components (e.g. the door and the cell walls) and for aesthetic reasons.

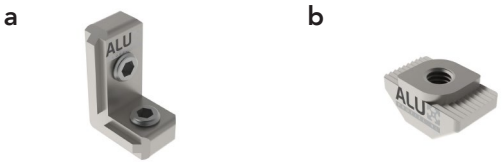


Figure 33.3: *Aluxprofiel parts. a: Frame connector. b: M3 nut.*

33.2.2 FRAME DESIGN

In the design of the frame in the sprint "Form 5" on page 133, it was found that the frame elements in the x, y and z direction had roughly the same lengths. To reduce complexity and costs of the concepts, it was chosen to use one length of 150 mm (50×) in all these three directions around the cell. The cells are supported by beams of 530 mm (9×). There are four outer frame beams of 490 mm. Thus, the number of different frame profile components was limited to three.

33.2.3 CELL BASE

Figure 33.2 (d) shows the cell base plate. The center hole is for the Peltier element and the four smaller holes to mount the cooling block. In this phase of the project, the PCB designs were not, finished yet.

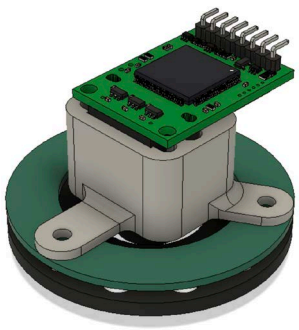


Figure 33.4: *Camera assembly, with (from the bottom up) the light protector, LED PCB and camera module.*

Later more cutouts were to be made for the other electrical components.

33.2.4 CAMERA

Figure 33.2 (c) shows the camera housing integrated in the cell roof. The bottom of the housing consists of two plates. The upper one has holes for the LEDs and camera lens. The lower one is transparent and acts as a water barrier. A hydrophobic film can be applied on this plate to prevent condensation ("Camera 4" on page 127). Since the mounting options for the camera are limited, due to the lack of space around the mounting holes of the module, a mount was designed. The camera mount also functions as a mount for the LED PCB. To protect the camera from direct LED light, a light protector was designed, which is a HDPE ring with holes for the LEDs and camera. The camera assembly is shown in Figure 33.4.

33.2.5 CELL DOOR

In the sprint "Form 4" on page 123, a left-hinging door with a roof cutout came forward as the best option for the cell door. However to reduce the complexity of this model, it was chosen not to use a hinge. Instead, the user can take out the door and put it down on top of the cell.

The first door design did not use the aluminum profiles. It used interlocking teeth that would have to be glued. However, it was discovered that HDPE is difficult to glue. Therefore, it was decided to use aluminum frames in the door.

33.2.6 CROSS SECTION VIEW

To give a better idea of where the components are placed in the cell, a cross section was made. This can be seen in Figure 33.5.

33.3 PROTOTYPING

To find the last shortcomings, before ordering from the manufacturers, another prototype was made.

33.3.1 THE PROTOTYPE

Figure 33.7 shows different components of the prototype. The camera assembly was 3D printed and laser-cut. The rest of the components were also laser-cut.

Almost everything about this model was right. Two minor adjustments were made. In the door,

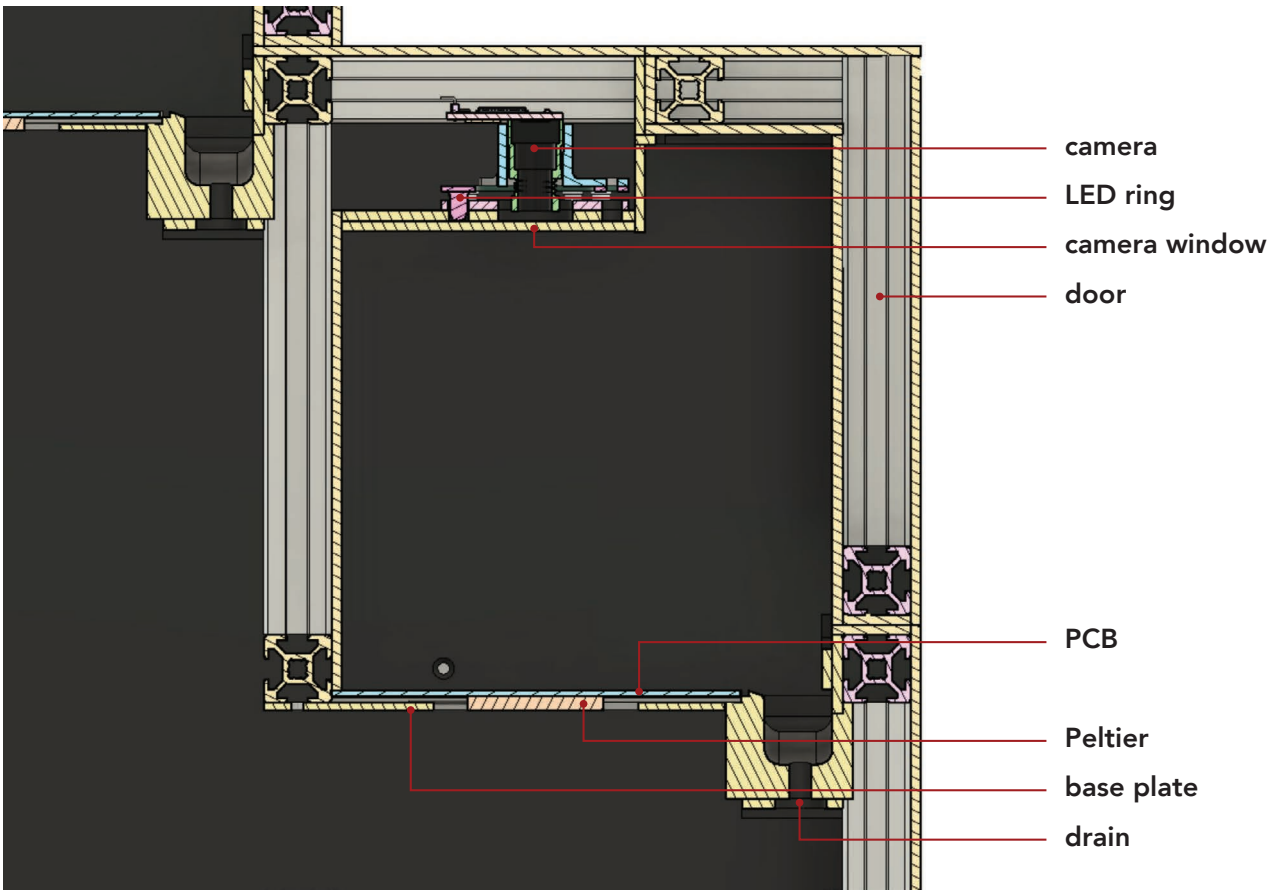


Figure 33.5: *Cross-section of one cell.*

two components were merged into one. The other modification was a door stop. As can be seen in Figure 33.7 (j), the door can tilt because it is only held in place at the top. Therefore, a small door stop was added at the bottom (Figure 33.6).

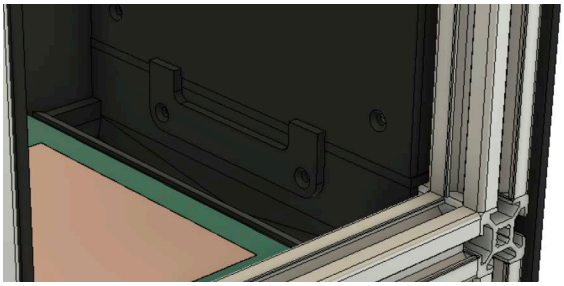


Figure 33.6: *Door stop to prevent the door from tilting.*

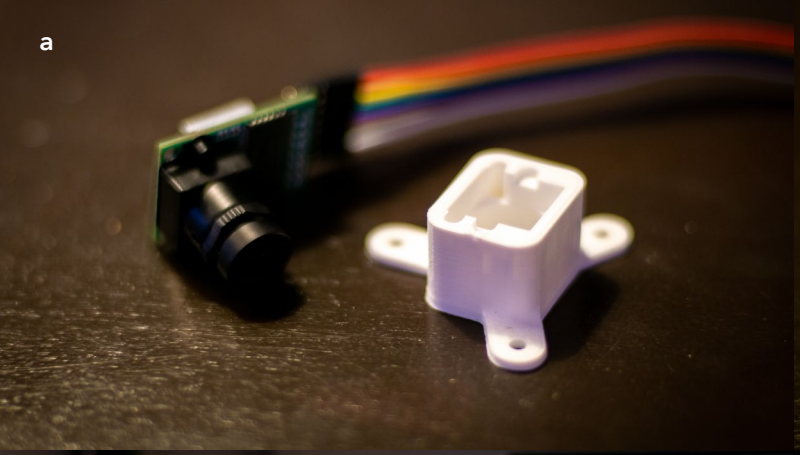
33.3.2 TESTING THE PROTOTYPE

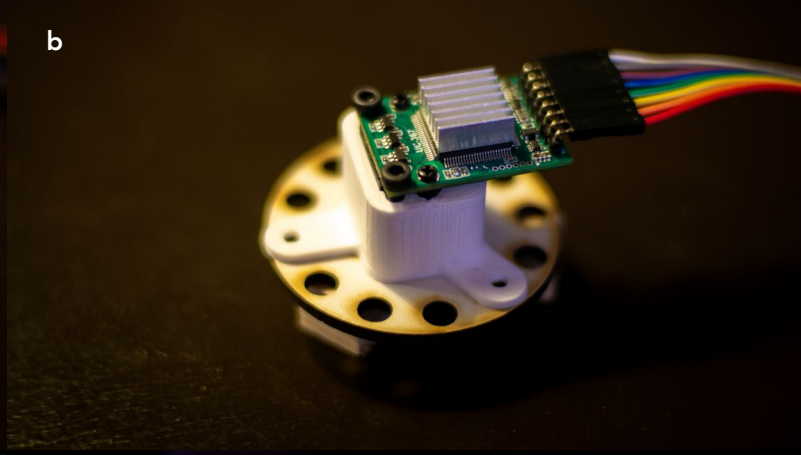
To validate the quality of the concept, a test scenario was performed (Figure 33.8, Figure 33.9 & Figure 33.10). It consisted of the following activities: Opening cell, placing seeds, closing cell.

1. Opening cell, removing germinated seeds, closing cell.
2. Opening cell, cleaning cell, closing cell.

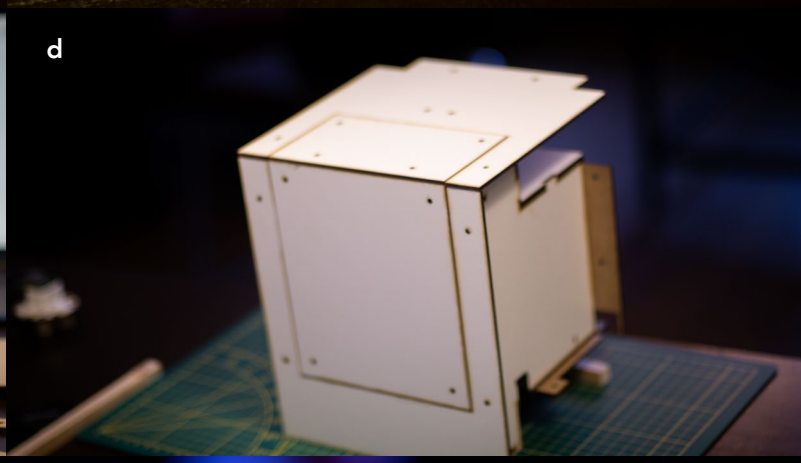
The model proved to work well. No major errors were found. This meant that the components could be ordered.

Figure 33.7: *[ON NEXT PAGE] Building a prototype of one cell. a: Camera mount. b: Camera mount with camera. c: Assembling the cell and the door. d: Assembled cell. e: Cell with open door. f: Close-up of door rest. g: Back of the cell where the camera assembly is placed. i: Cell from the top with the drain. j: Cell door was able to move, since nothing was blocking it at the bottom.*


a


b


c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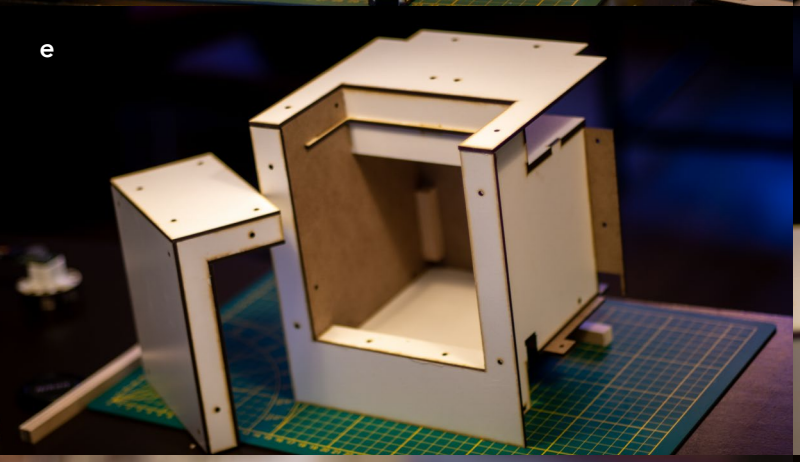
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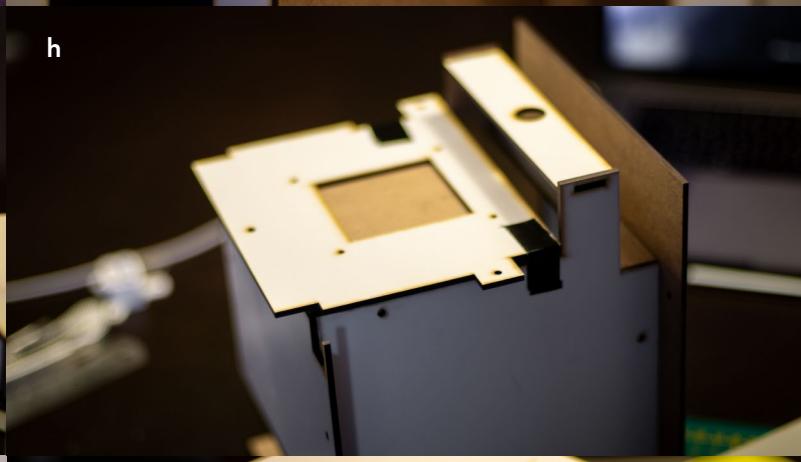
h


i

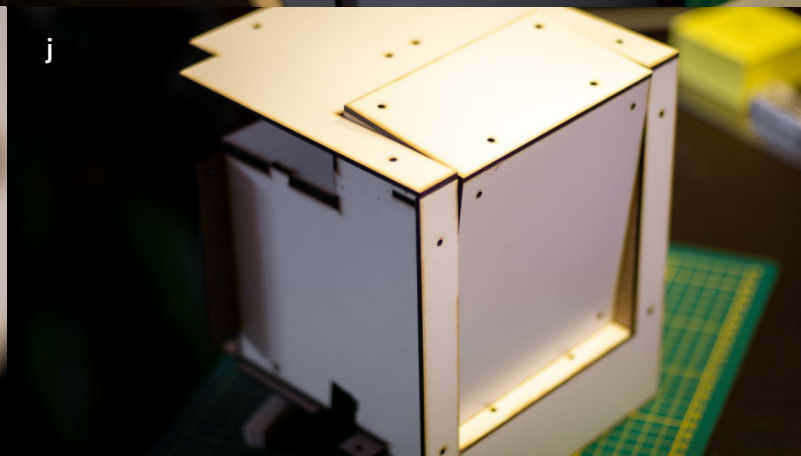
j

Figure 33.8: *Testing the reachability of the seed bed, while the cell door is held in the hand.*

Figure 33.9: *Testing the reachability of the seed bed, while the cell door is resting on the top of the cell.*

Figure 33.10: *Test where plant seeds were placed on and taken of the seed bed.*

TAKEAWAYS FOR QUANTIFIED

- The model was worked out in detail in CAD.
- A test scenario was run with the model.
- Some minor adjustments were made based on the insights.
- After this sprint the components could be ordered.

CHAPTER 34

Electronics 5

The requirements and layout of the electronics were stated in the sprint "Electronics 4" on page 110. In this sprint, the electronics designs were finalized. Then the boards were ordered and the components were soldered on. This was done in cooperation with the company M91200. The first part of this chapter describes the designs of the PCBs. The second part is about several tests that were done to test the electronics.

34.1 PCBS

It was concluded in the sprint "Electronics 4" on page 110 that three PCBs were to be developed for the QIEM-Array. After the PCBs were designed, they were manufactured in a factory. Then the components were soldered on. Figure 34.1 shows a photo these three PCBs.

34.1.1 MICROCONTROLLER PCB

The microcontroller PCB is the brain of the cell (Figure 34.2 on page 144). It gathers data from the sensors and camera, and communicates with the computer. For the communication to the computer, it uses the RS485 protocol. The PCB is mounted to the bottom of the seed bed PCB using two brackets.

34.1.2 SEED BED PCB

The seed bed PCB (Figure 34.3 & Figure 34.4 on page 145) distributes the heat from the Peltier element across the seed bed, and measures temperature and moisture. It is connected to the microcontroller PCB with a band wire. It has six temperature sensors at various places to be able to measure the temperature uniformity.

34.1.3 LED RING PCB

The LED ring PCB (Figure 34.5 & Figure 34.6 on page 146) holds the LEDs that are used to illuminate the seed bed and as a flash for the camera. It is connected to the microcontroller PCB with a band cable. Between PCB and the camera module, jump wires are used. For the communication, both the SPI and I^2C protocols are used.

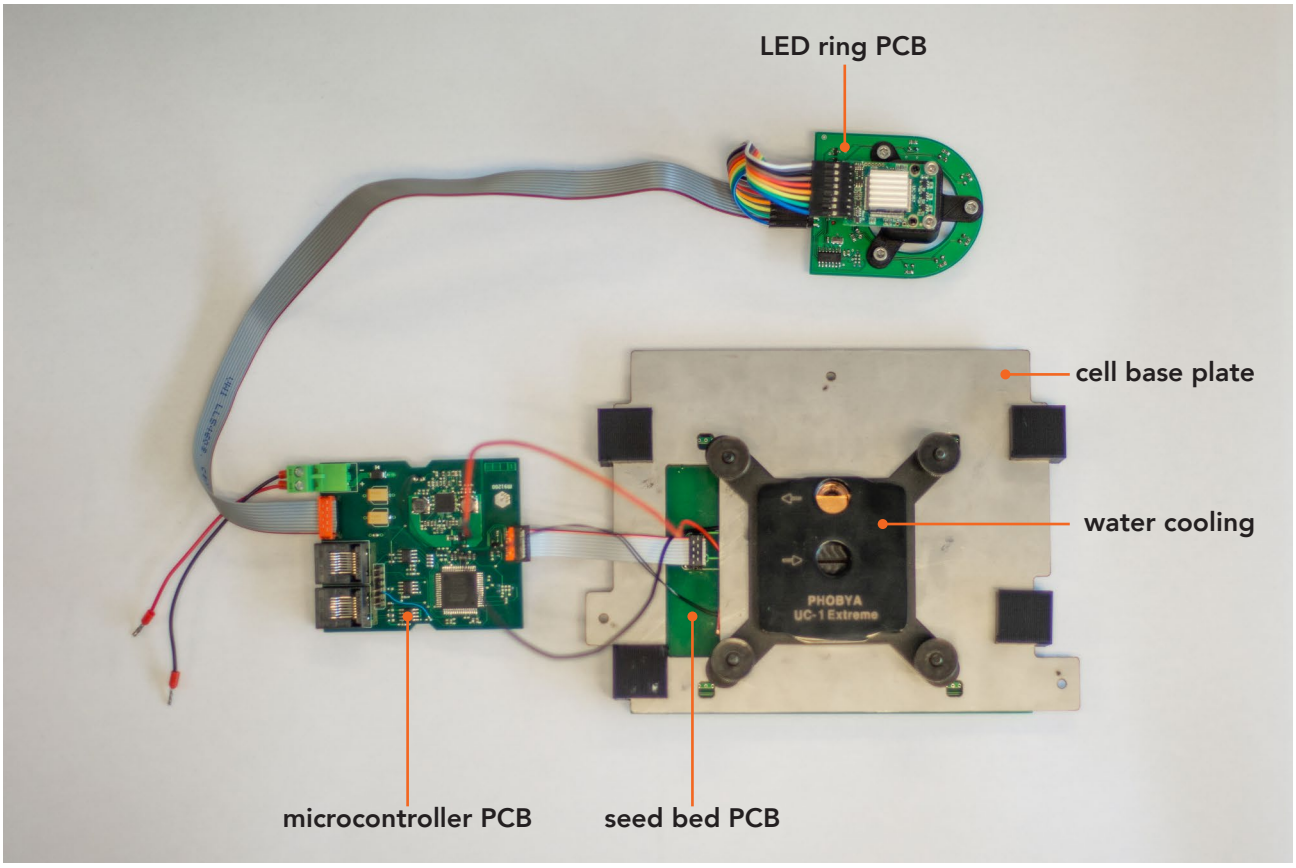

Figure 34.1: *The three PCBs connected.*

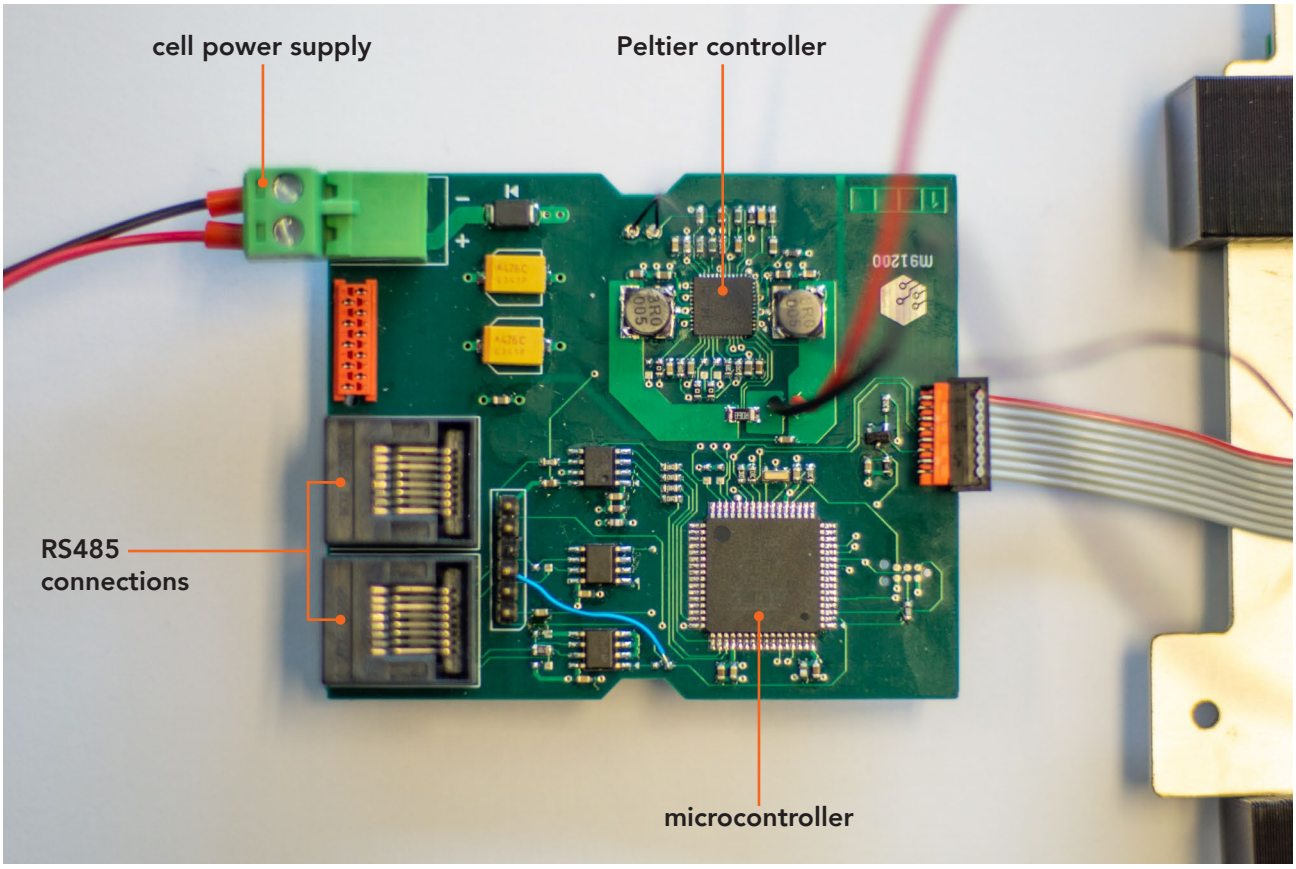

Figure 34.2: *Microcontroller PCB.*

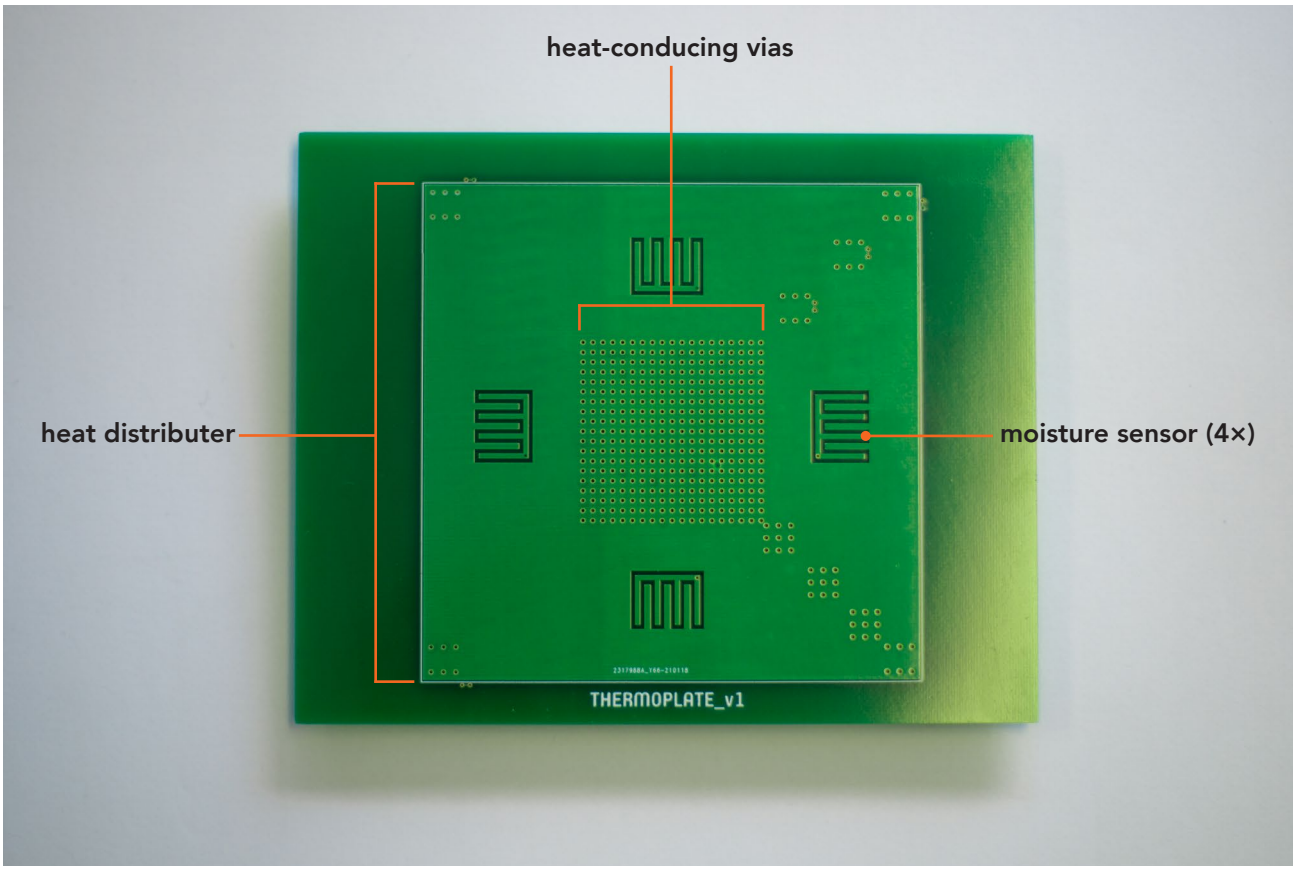

Figure 34.3: *Top of seed bed PCB.*

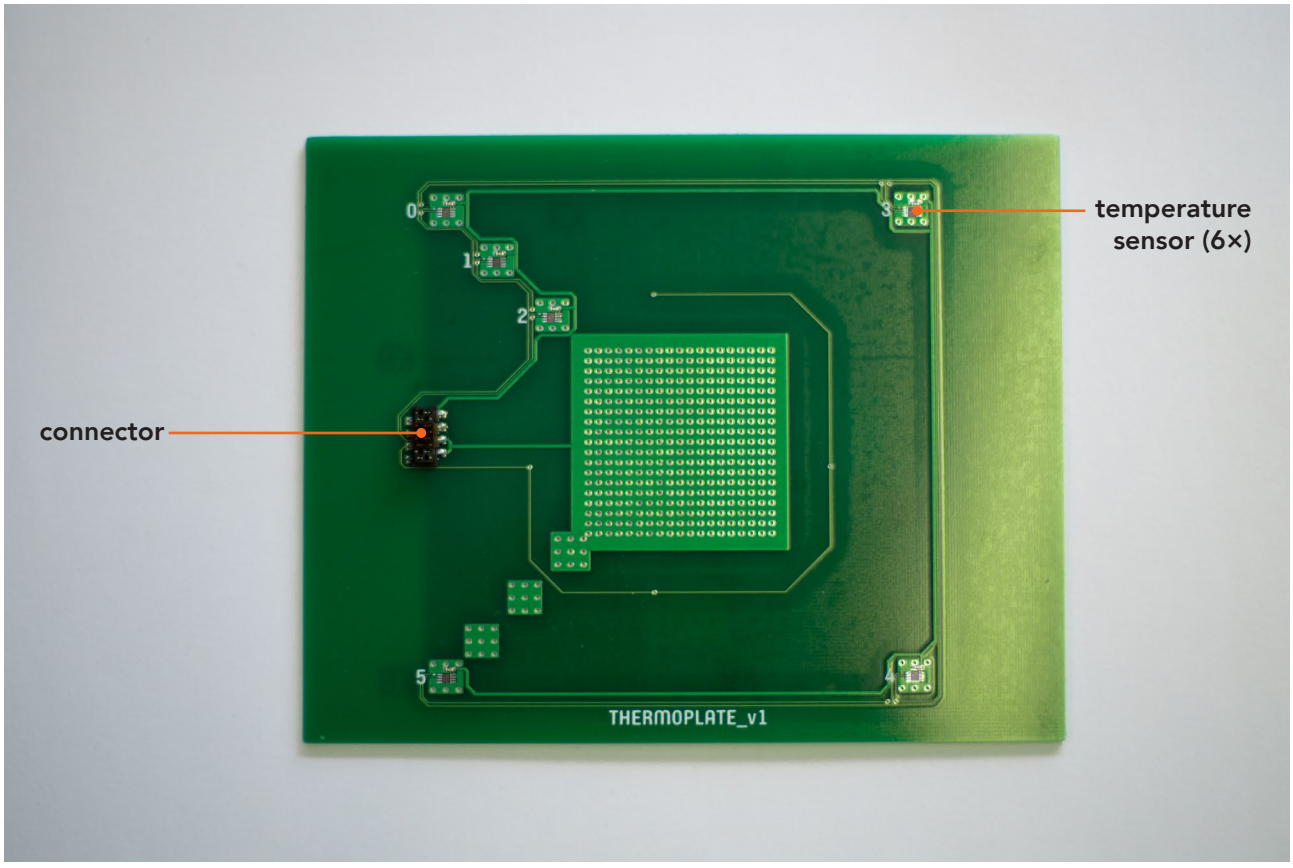

Figure 34.4: *Bottom of seed bed PCB.*

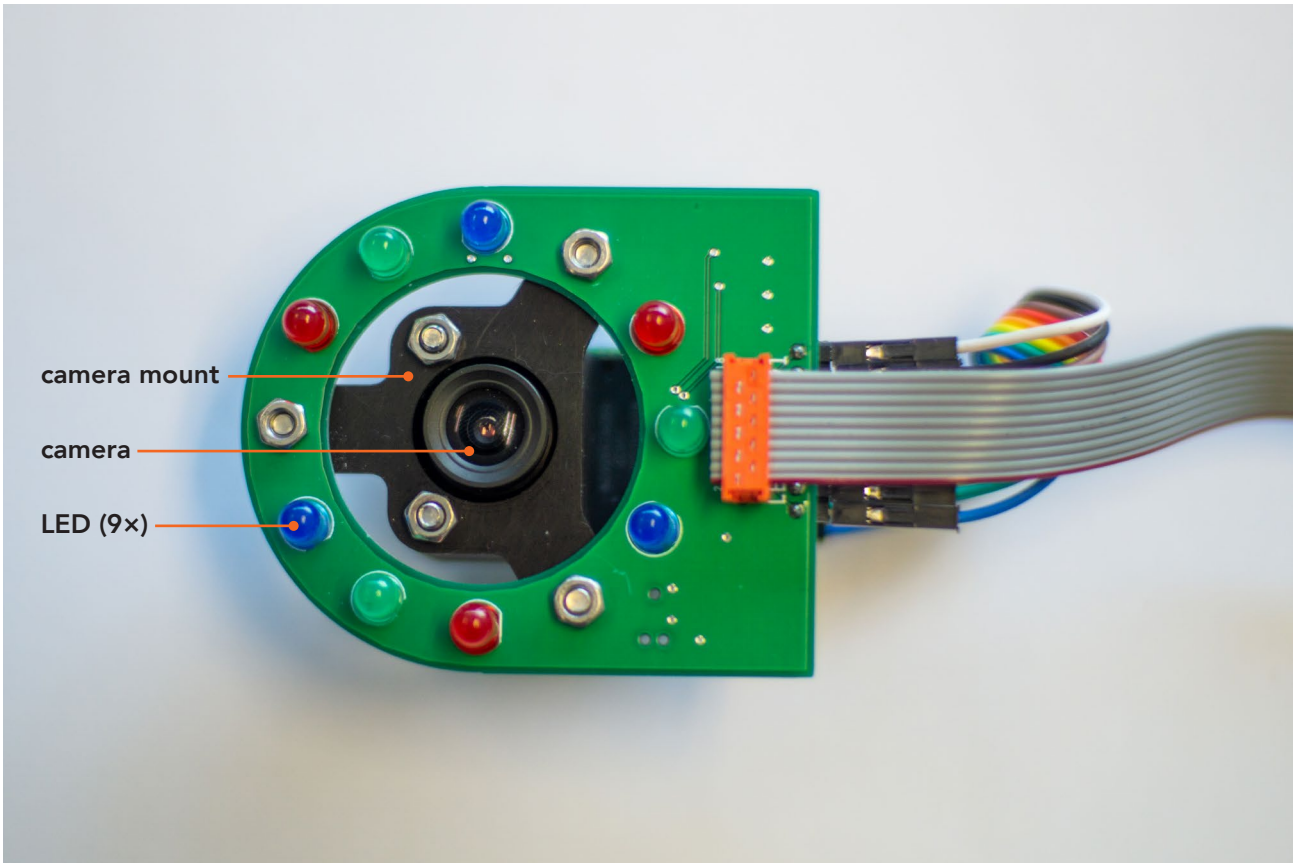

Figure 34.5: *Bottom of LED ring PCB with camera.*

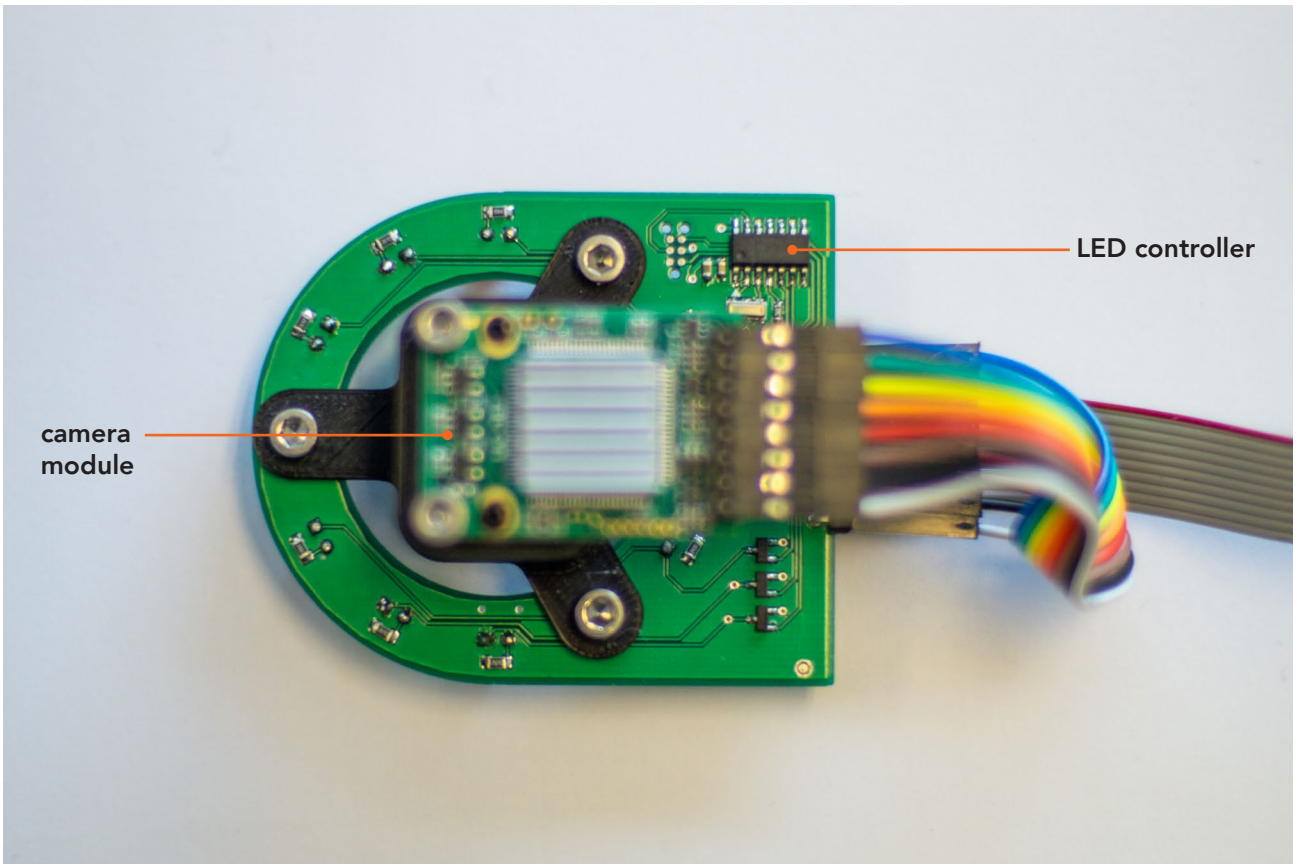

Figure 34.6: *Top of LED ring PCB with camera.*

34.2 TESTS

To confirm whether the electronics worked, tests were conducted with the various components.

34.2.1 TEMPERATURE AND MOISTURE SENSORS

The seed bed PCB has two types of sensors: temperature sensors and moisture sensors. These were tested to validate if they were working. First, the microcontroller PCB was connected to a computer to be able to program it and communicate sensor data to the computer. Next, the seed bed PCB was connected. Then a filter paper was placed on the testing surface of the PCB (Figure 34.7).

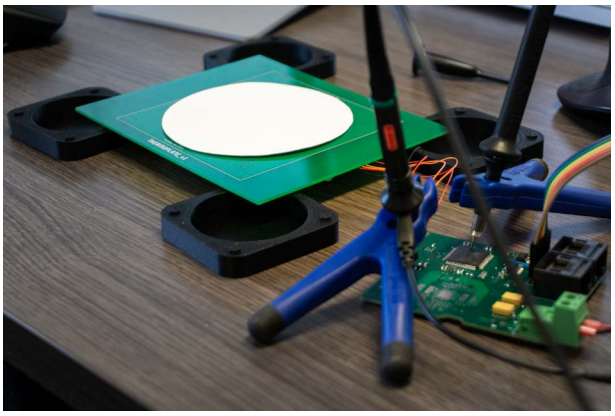

Figure 34.7: *Seed bed PCB sensors connected to the microcontroller PCB.*

For the test, a program was written to read out both the temperature sensors and moisture sensors. Next, the filter paper was moistened. The results could be monitored on the computer (Figure 34.8), which confirmed that the sensors and communication were working.

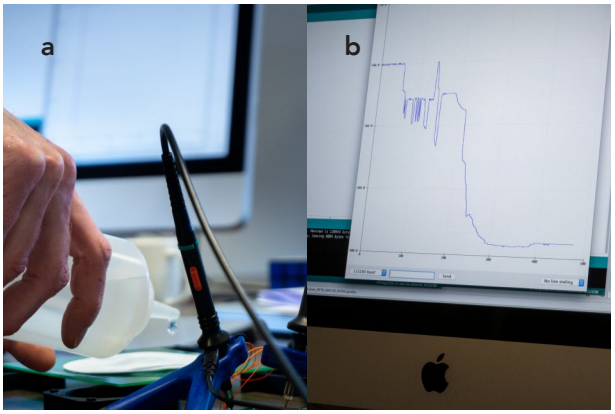

Figure 34.8: *Moisture and temperature sensor tests. a: Putting drops of water on the filter paper. b: Graph showing real-time test moisture measurements.*

34.2.2 CAMERA AND LED RING

To test the camera and LED ring, they were connected to the microcontroller PCB (Figure 34.9). Three different LED colors were soldered onto the ring, to be able to distinguish the different groups. Next, a program was written to trigger the camera sensor, capture a photo, compress the data with a JPEG compression algorithm, and send it to the computer.

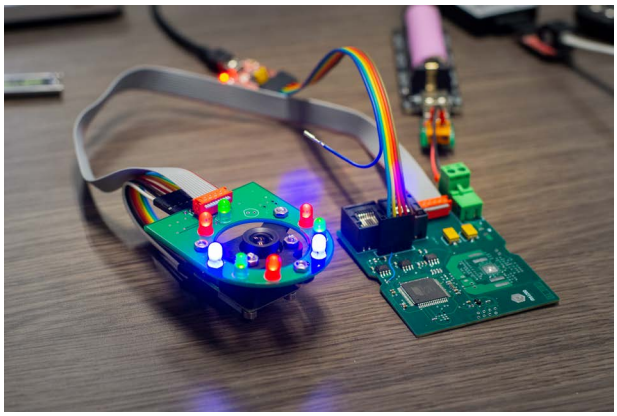

Figure 34.9: *Camera and LED ring PCB connected to the microcontroller PCB.*

34.2.3 HEATING

The next step in the testing of the electronics was to test the temperature control of the seed bed. The goal of the test was to find temperature range, as well as the temperature uniformity of the seed bed surface.

The Peltier element was placed against the seed bed PCB and wired to the microcontroller PCB (Figure 34.10). Then different voltages were applied to the Peltier element to see what the temperature response was. The temperature was measured with a thermal camera (Figure 34.11).

TEMPERATURE RANGE

For this test, the water cooling was not yet connected. Regardless, a wide temperature range could be achieved. According to the ISTA regulations, the minimum and maximum temperatures are 10 °C and 35 °C, respectively (ISTA, 2015). The maximum temperature achieved during this test was 105 °C. Reaching lower temperatures proved to be more difficult, since the water cooling was not connected. Nonetheless, the minimum temperature achieved was only a few degrees above the 10 °C.

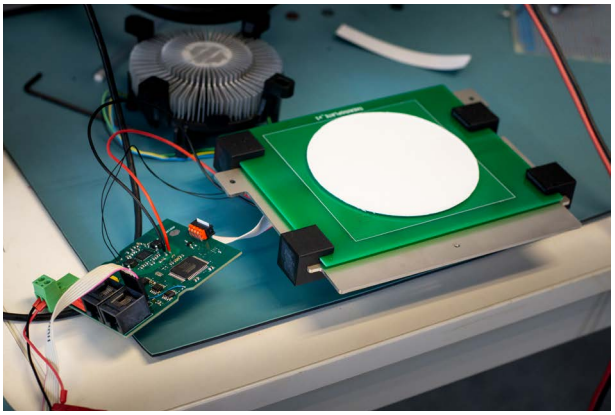

Figure 34.10: *Test setup to test the heating of the seed bed.*

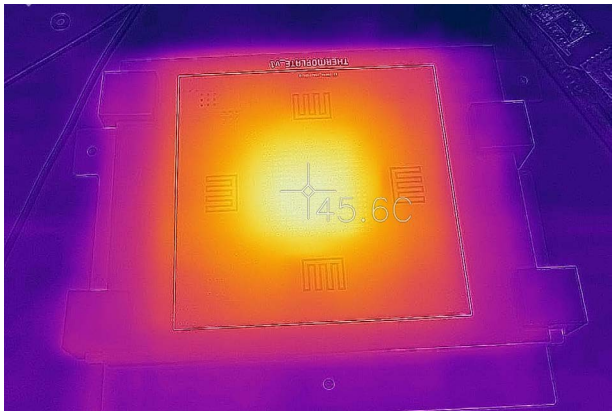

Figure 34.11: *Seed bed PCB surface temperature measurement.*

TEMPERATURE UNIFORMITY

When the current applied to the Peltier element was changed, its temperature changed. On the thermal camera it could be seen that the temperature response was strongest in the center, directly above the Peltier element. In the course of time, the rest of the surface followed. However, the temperature difference between the center and the edges remained up to 5 °C for a significant amount of time. This is outside the requirement of ISTA, which is ±2 degrees. With a damp filter paper on the surface, the uniformity improved. However, more testing would be required to validate if the uniformity requirements can be met with these components. A possible way to improve the uniformity would be to increase the thickness of the copper layer on the top.

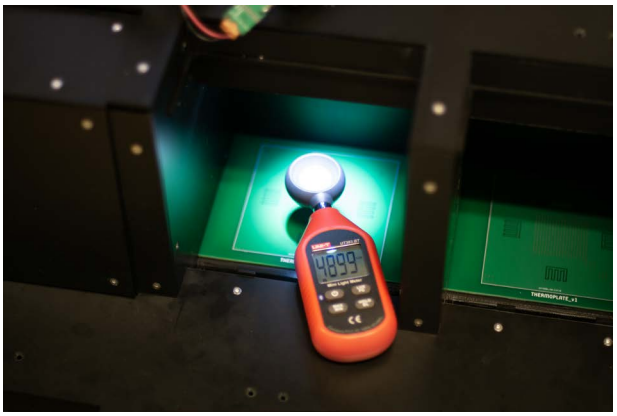

Figure 34.12: *Measuring light intensity. Actual measurements were done with a closed cell.*

34.2.4 LIGHT INTENSITY

The ISTA regulations specify that cold white light of 750 lux to 1250 lux should be used for germination testing (ISTA, 2015). To test if the requirements were met, a LED ring was assembled and placed into the Array. Then the light intensity was measured with a lux meter (Figure 34.12). The results show that an intensity of over 5000 lux could be reached. The intensity can be decreased with pulse frequency modulation, and therefore the ISTA requirements can be met.

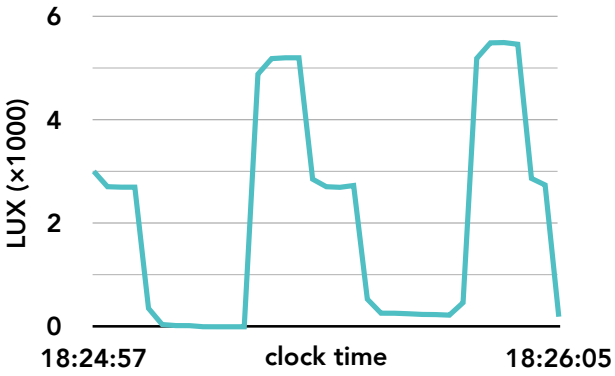

Figure 34.13: *Results of the light intensity measurements at different intensity levels.*

TAKEAWAYS FOR QUANTIFIED

- Three PCBs were developed for the QIEM-Array.
- Several components and functions were tested, such as the temperature sensors, moisture sensors, camera, LEDs and the Peltier Element.
- Most tests were successful.
- The thickness of the copper layer of the seed bed PCB could be increased to increase the temperature uniformity of the seed bed.

CHAPTER 35

Build 2

After it was building and testing the prototype in the sprint "Build 1" on page 137, the components of the QIEM-Array could be ordered. The orders included the aluminum extrusion profiles, the HDPE and EPS wall plates, fastening materials and various electronics. This chapter gives a brief overview of the assembling process. Figure 35.1 shows photos of various steps.

35.1 FRAME AND WALLS

Shown in Figure 35.1: a, b & c. The frame is built up from aluminum extrusion profiles. The profiles are connected with internal connectors that fit in the slots in the profiles. After the frame was assembled, the walls were attached.

35.2 SEED BED

Shown in Figure 35.1: d, e & f. The seed bed PCB is clammed between the HDPE cell walls and bottom plate. After the bottom plate was attached, the Peltier element and water cooling block could be mounted.

35.3 INSULATION

Shown in Figure 35.1: g & h. In addition to the HDPE plates, the walls also consist of a layer of EPS. The EPS was cut to the appropriate sizes and placed between the frame profiles and HDPE plates.

35.4 CAMERA

Shown in Figure 35.1: i & j. The camera is positioned in the top of the cell, directly above the seed bed. The camera is mounted to the top plate of the cell.

35.5 DOORS

Shown in Figure 35.1: k & l. Similar to the frame, the cell doors are also built up from aluminum extrusion profiles. The doors are also insulated with EPS.

35.6 QIEM-ARRAY

Shown in Figure 35.1: m & n. When the assembly of the frame was completed, the insulation was placed, and the walls were attached, the rest of the QIEM-Array could be assembled.

TAKEAWAYS FOR QUANTIFIED

- Insights gained throughout the whole project were combined into a final design.
- The design was detailed and built.
- Building the QIEM-Array enabled elaborative testing and presentation to potential customers.

Figure 35.1: *[ON NEXT PAGES] Photos of the assembling of the QIEM-Array.*


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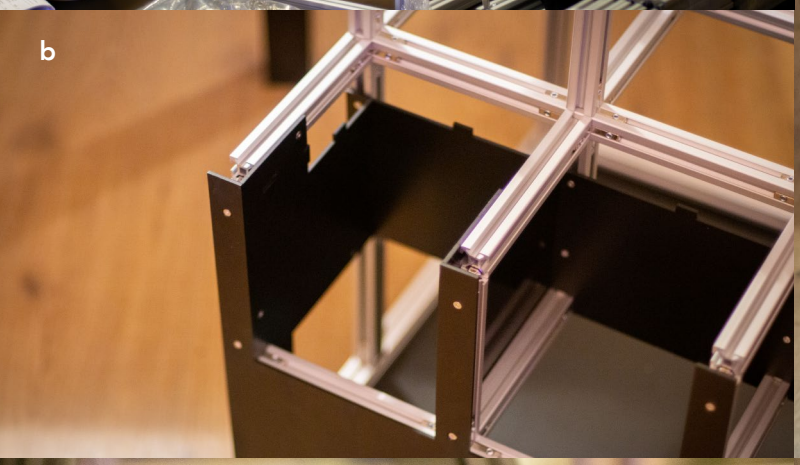
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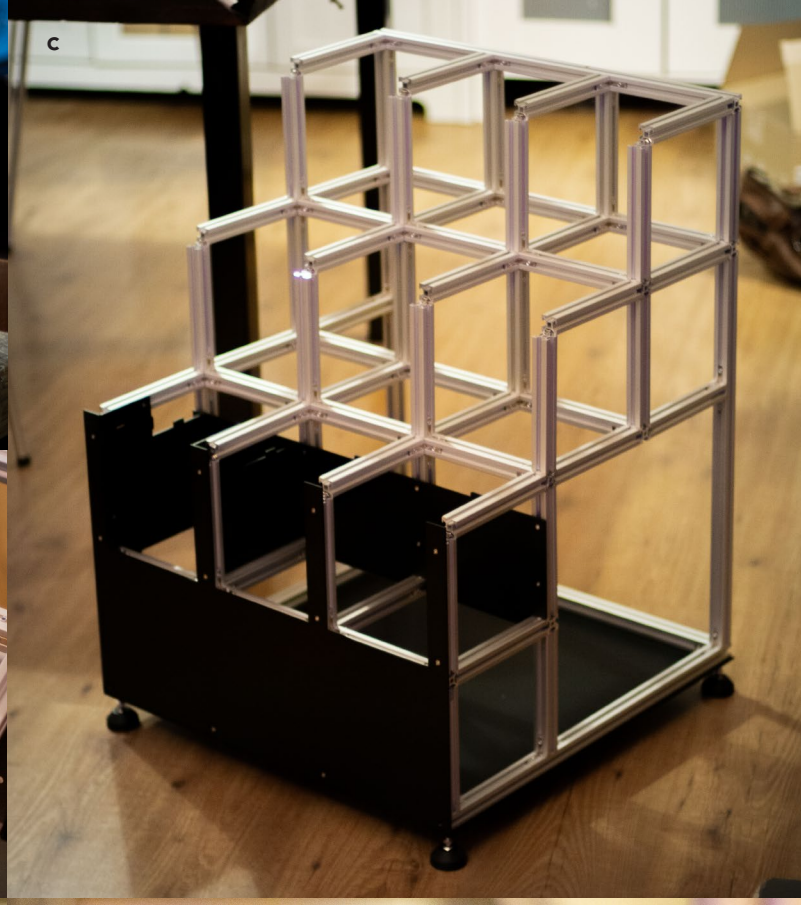
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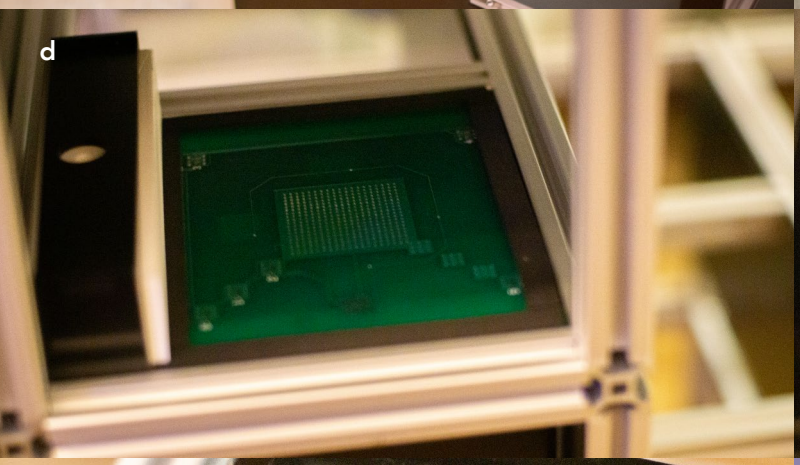
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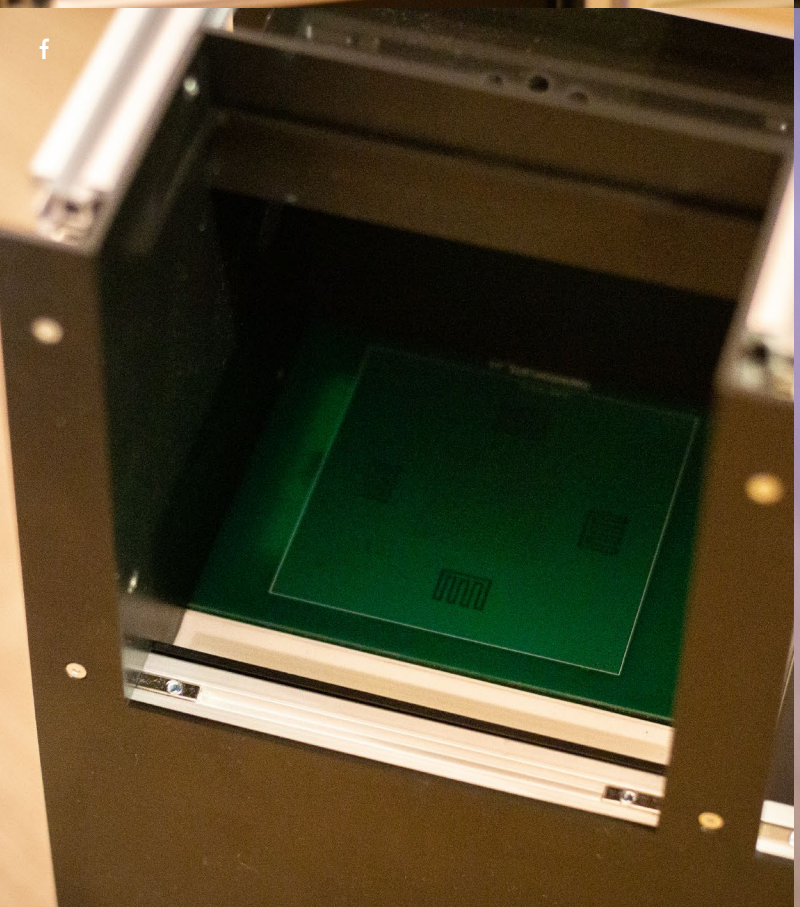
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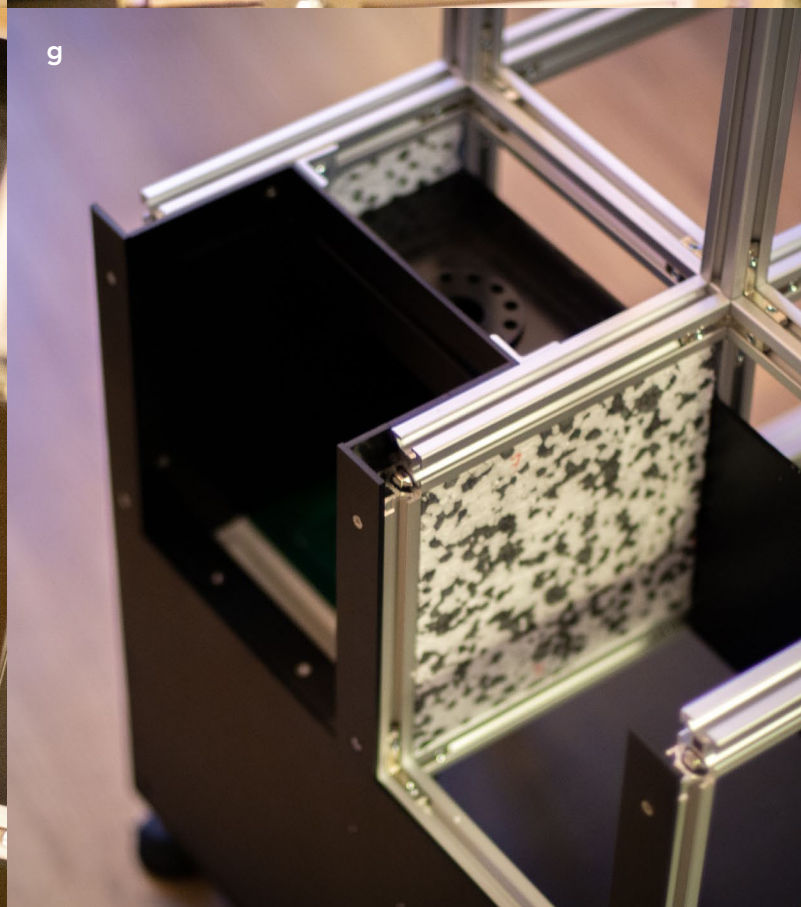
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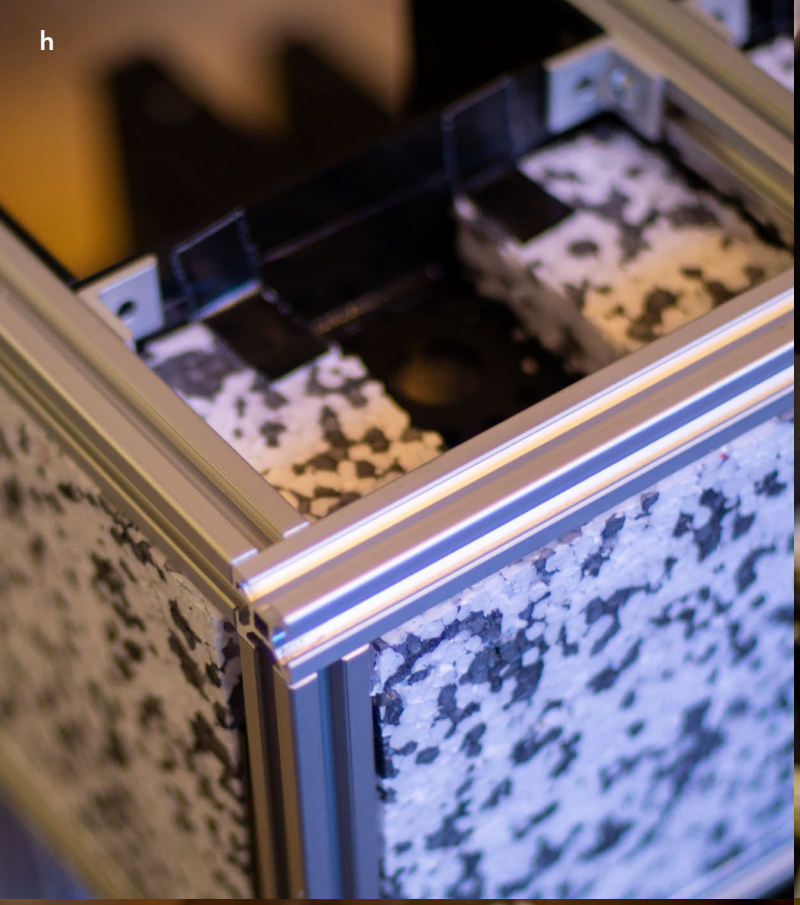
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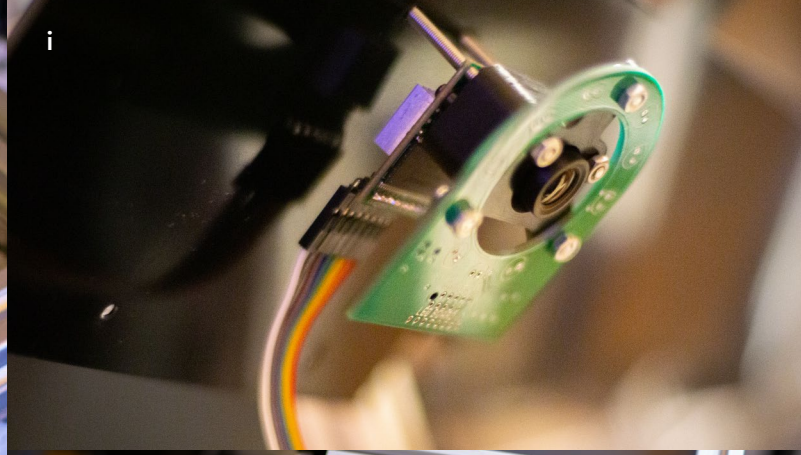
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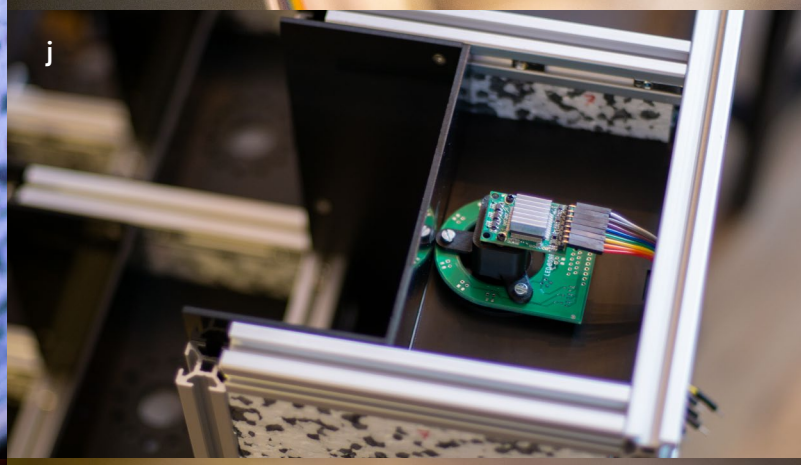
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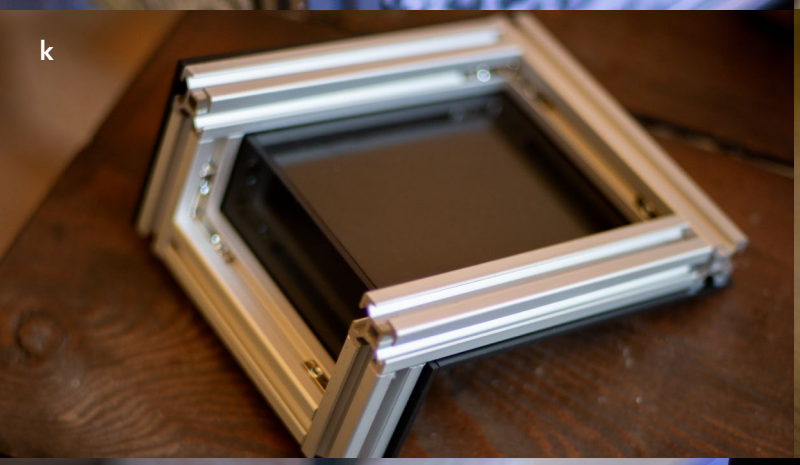
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Stay hungry, stay foolish.

Steve Jobs (2005)

PART E

Evaluation & Recommendation

At the end of the design phase, a prototype of the QIEM-Array was built. Then it was time to evaluate the design. A couple of evaluation sessions with potential users were organized. These are experts who do germination research on a daily basis and know all about it. Their opinion is very valuable because they know exactly what requirements the device should meet.

In addition to the sessions with the experts, a number of user tests were also conducted with other people. Here the focus was more on the usability of the design. Insights from these sessions are summarized at the end of the chapter. In the next chapter, some possible next steps for the QIEM-Array project are discussed.

CHAPTER 36

Evaluating the Design

To evaluate the design, several users were asked to give their feedback on the QIEM-Array in user tests and discussions. These are described in the first part of this chapter. The second part describes possible improvements to the QIEM-Array design. The next chapter contains recommendations for the future of the QIEM-Array.

36.1 USER FEEDBACK

When the QIEM-Array was built, the design could be validated with user tests and discussions. The users that participated in the tests can be divided into two groups: seed germination research experts and other users.

36.1.1 EXPERT FEEDBACK

This group consists of experts who have a lot of experiences with plant seeds and the testing protocols. They know what criteria a seed testing device must meet and, because of all their knowledge, are able to ask in-depth questions.

36.1.2 ONLINE MEETING WITH NAK TUINBOUW

At the start of the project, Nak Tuinbouw was visited to get insights about how germination tests were performed (Appendix C on page 176). When the product was built, the same interviewee was invited to perform a user tests. Unfortunately, due to the corona restrictions, we were unable to organize a physical meeting. Therefore the meeting was organized online. Of course, the user could not directly interact with the device. In those cases the focus was more on the discussion about the product.

QIEM-ARRAY

The interviewee said that it could save a lot of time if the QIEM-Array could automatically classify; then the product could really be helpful in the future. A strict requirement is that the device needs to be able to match the classification of a real user. The interviewee said that a product like this would be new for the industry. Nak Tuinbouw wants to be known as knowledge center. Therefore a product like this could be interesting for them in the future.

CURRENT SITUATION

They currently have five Jacobsen tables, of which two are always set to 30 °C as day temperature and 20 °C as night temperature. The others are changed depending on the test. The interviewee said that this solution lacked flexibility, since they whole table follows the same temperature program. Often, the seeds are not exactly held on the temperatures specified by the ISTA regulations.

TESTING PROCEDURES

Seeds take up a lot of water during the tests. For tests in trays, they add around 50 ml of water for the whole tests, but this changes per species. If the seed bed gets too dry, the test could go wrong. Since the start of the year, the light specifications have been changed to between 3000 K and 4000 K. The advantage of testing in light, is that the plants become green, making it easier to classify. The temperature of the seed bed has to be uniform within a 2 °C range.

OTHER REMARKS

The interviewee also said that seeds like cress and lettuce could be good candidates for first germination tests with this product, because of the low germination times and climate sensitivity.

It was suggested that the seed bed could be heated for the cleaning process. When testing, it was found that temperatures of over 100 °C could be reached. This would have a decontaminating effect.

36.1.3 AXIA VEGETABLE SEEDS VISIT

In the starting stages, Axia Vegetable Seeds was visited (Appendix C on page 176). When the product was built, a feedback meeting was organized at their headquarters. Two of their seed germination researchers were present. A short presentation about this project and the design

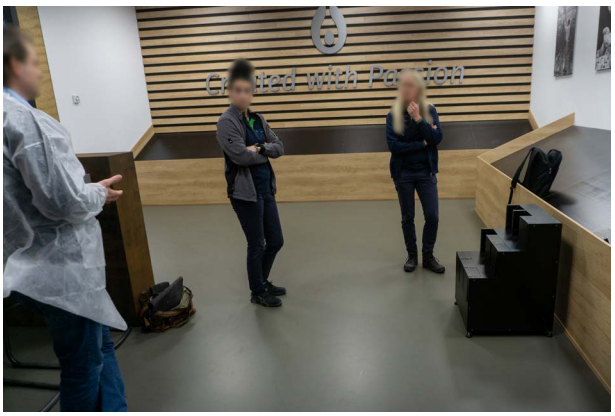

Figure 36.1: *Discussion about the QIEM-Array.*

process was given, after which the QIEM-Array was discussed (Figure 36.1).

QIEM-ARRAY

The QIEM-Array could be interesting for them, because it could save them a lot of time and reduce the number of variables. They were positive about its potential as a research platform. The interviewee had an idea about a possible experiment: *"It would be interesting to see if you could go with day/night cycles of 23 hours, instead of 24 hours. That would save a few hours per test."* She also had an idea about possible moisture tests: *"It would be valuable to start doing tests with different moisture levels in the future, for example. With climate change, it is becoming increasingly important that seeds can germinate with less moisture, so they could also be used in desert environments. With this device, you could, for example, run seven tests in parallel to see what the effect of the moisture is."*

The biggest problem they saw was that the device takes up a relatively large amount of space. Now, the footprint of 3 × 3 cells is 45 cm × 45 cm.

Some seeds have to be taken out of their dormancy. This is done by cooling them for a set amount of time, on around 6 °C. The QIEM-Array would be able to reach such temperatures, unlike their current equipment.

CURRENT SITUATION

Now, they use a couple of climate cabinets do perform their ISTA test (Figure 36.2). The difference with this device, is that it has a smaller footprint. A climate cabinet, that is a bit larger than a large kitchen refrigerator, can hold up to 140 plastic

Figure 36.2: *Climate cabinet with plastic containers with seeds.*

containers with 50 seeds. Therefore, up to 17 simultaneous ISTA tests can be performed.

Many of the tests are done on paper, but the species with the larger seeds, such as cucumber, are done in harmonica filters (Figure 36.3). This would be a problem for the image recognition

Figure 36.3: *Cucumber seeds growing in a harmonica filter.*

functionality of the QIEM-Array, unless a way can be found to provide adequate watering on paper in the cells.

The cleaning of the containers is done with water and chlorine. They said that decontaminating the seed bed of the QIEM-Array by heating it could be a viable option.

OTHER REMARKS

Axia was so kind to invite us to perform further tests in their lab. They suggested doing germination tests in the QIEM-Array and the climate cabinet, and comparing the results.


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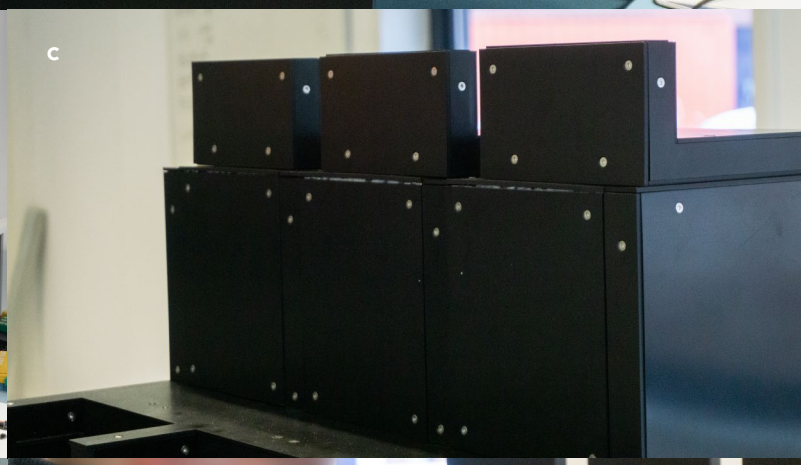
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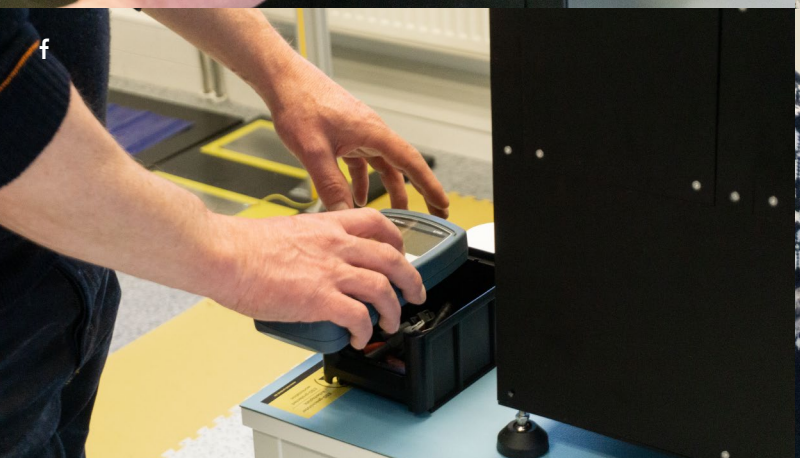
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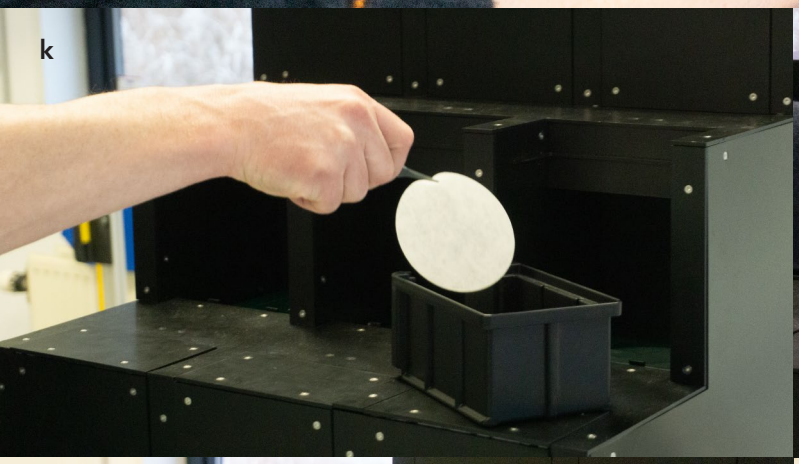
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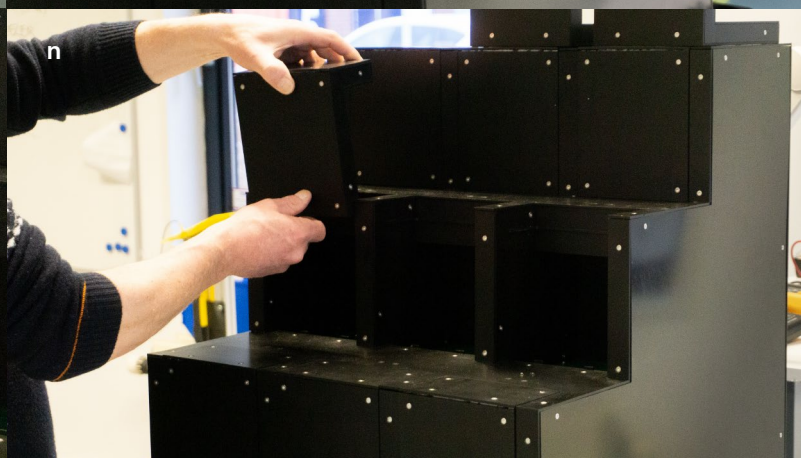
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Figure 36.4: *[ON PREVIOUS PAGES] Photos of user test 1.*

36.2 OTHER USER FEEDBACK

The last group are users that are asked with little to none prior knowledge about seed germination research. Nonetheless, their input on the usability of the product proved to be useful. For the user tests, the participants were asked to perform the same actions as the researchers in the labs.

36.2.1 USER TEST 1

Photos from the test can be seen in Figure 36.4 on page 158. The first action the user performed, was opening the cells. He put the doors of the opened cells on top of another row of cells (a, b & c). Before placing the filter papers in the cell, he put them in front of the cell (d). But then came the realization that they had to be placed in the cell. Next, the papers were moistened (e). Since there were no real seeds and no vacuum seed placer, other objects were used as a replacement (f & g). Then the cell was closed to start the germination test (h).

During the test, germinated seeds have to be removed (i & j). What was interesting, is that the horizontal surfaces of the QIEM-Array were again used to put items on. In this case, it were tweezers and the bin for the germinated seeds.

At the end of the cell, the remaining seeds and the filter paper had to be removed from the cell (k). Then the cell was cleaned with water and a sponge (l & m) and dried with a paper towel (m). Finally the cell was closed (n).

Virtually all actions were performed without mistakes. One unexpected insight was that the surfaces of the QIEM-Array were constantly used to put items on. The user commented that he would like to see real-time data from the cells, so he knows what is going on in each of the cells. Also, he commented that it would be an improvement if the doors could hinge, so don't have to be put aside. Also, he said that he would have liked a little more space in the cell to move his hand around.

Figure 36.5: *User placing seeds with a vacuum head.*

Figure 36.7: *User having some difficulty opening the cell door.*

Figure 36.6: *User not having enough space to put cell doors.*

Figure 36.8: *User drying the cell with a squeegee.*

36.2.2 USER TEST 2

For this user test, the user was asked to perform a germination test. In general, the user was positive about the product. He said that it was easy to perform actions in the cells. However, he had some comments about possible improvements. Figure 36.5 shows the user placing seeds into a cell with a vacuum head.

The user commented that he would prefer hinging doors, instead of doors that can be taken out. If a small number of cells have to be opened, the doors can be placed on other cells. However, when multiple rows have to be opened, there isn't enough space on the QIEM-Array to put the doors (Figure 36.6). But the user also said that he would rather work at one row at a time and that hinging doors could be a solution. Furthermore, the user said he had some difficulty opening the doors (Figure 36.7) and suggested the use of small door handles.

When asked to clean the cell, the user first used water. Then the user picked up a squeegee, which happened to be lying nearby, to dry the seed surface (Figure 36.8).

36.2.3 USER TEST 3

When the test was started, the user opened all the cells. Then the seeds were placed with a vacuum head mockup (Figure 36.9). The user commented that there was enough space to preform actions in the cells on all levels (Figure 36.10). However, she said that it was rather dark inside the cells. She suggested that light could be switched on automatically when the cells are opened.

The user did not make use of the horizontal surfaces of the QIEM-Array. The doors and bowls with the seeds were put away on another surface (Figure 36.11). At the end of the test, she commented that she would prefer hinging doors, so they don't have to be put away.

36.2.4 USER TEST 4

This user chose to preform actions in the cells one by one. What was interesting about this test, is that the user kept the doors close to the cells.

Figure 36.9: *User placing seeds with a vacuum head mockup. All cells were opened simultaneously.*

Figure 36.11: *The user put the doors to the side.*

Figure 36.10: *User picking up germinated seeds with tweezers, while holding the bin in the other hand.*

Figure 36.12: *The user doing actions in the cell, while holding the door. Filter papers rest on a closed cell.*

Figure 36.12 shows the user holding the door in one hand, while placing the filter paper in the cell with his other hand. He used the top of a closed cell to put the stack of filter papers on. Figure 36.13 shows the user again holding the door in his hand while placing seeds.

The user commented that he held the doors in his hand, because there was no space to put them on. He would prefer hinging doors. But he said that placing the seeds with the vacuum head was easy, despite having to hold the doors. He said that the bottom cell was the hardest to reach, but added that it would be easier if the whole device was placed higher. He saw no potential problems for reaching the top row if it were to be placed a bit higher. He also commented that it would be convenient if a light switched on opening the cell.

36.2.5 USER TEST 5

This user performed actions in the cells one by one. He used the top of a closed cell to put the door of the opened cell on. He held the stack of filter papers and bowl with seeds in his hand, while performing actions in the cell (Figure 36.14). He said that there was enough space for his hand in the cells to perform the actions. He added that the middle row was the easiest to reach, but that the others were not difficult either.

He said that it would be convenient if the doors could hinge. He suggested that it would be useful if the seed bed could be taken out, if that was possible.

36.3 GERMINATION TEST

In addition to the user tests, a germination test was performed in one of the cells of the QIEM-Array. A filter paper was placed on the seed bed PCB and wetted with water. Then some cress seeds were put on it (Figure 36.15). A light was switched on and the cell was closed. A control test was run outside the cell. Unfortunately, at the time of the test, the electronics were not fully functional.

The test ran for two days. As can be seen in Figure 36.16, virtually all seeds germinated. During the two days of the test, no water needed to be

Figure 36.13: *User using the shower head while holding the cell door in the other hand.*

Figure 36.14: *The user put the seed tray and door on other closed cells while placing seeds.*

Figure 36.15: *Cress seeds on a moisturized filter paper at the start of a germination test.*

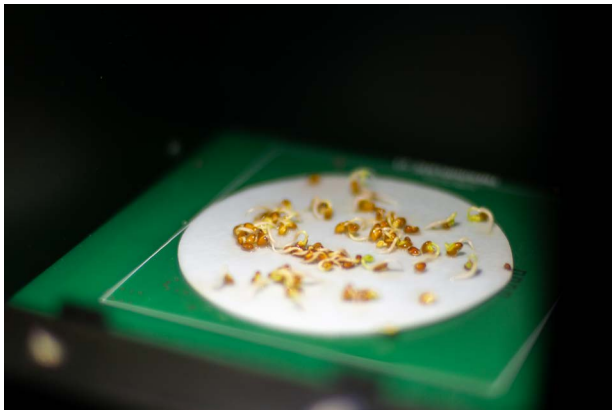


Figure 36.16: *Germinated cress seeds inside the cell.*

added. After the two days, the filter paper was still sufficiently wet. The filter paper from the control test outside the cell dried up much faster. It took no more than eight hours each time before it had to be re-wetted. In this sense, the test inside the cell performed better than the one outside.

36.4 INTERACTION IMPROVEMENTS

This section contains possible improvements for the user interaction with the product.

36.4.1 ON-DEVICE FEEDBACK

When the cells are closed, the user cannot see what the status of the test is. A relatively simple solution could be a status-indicating light. Examples of indications could be:

- The cell is ready to start the test.
- A test is in progress.
- User action is required.
- The test is done.
- The cell is powered off.

36.4.2 DOORS

Several users said that the cells were a bit dark inside, when they performed actions inside. Making the lights switch on when opening could solve that. Some users experienced small difficulties picking while opening the cells (36.2.2). Small door handles could make this a bit easier. The comment that came back the most about the doors is that many users would prefer hinged doors over doors that have to be taken out.

36.5 MECHANICAL IMPROVEMENTS

This section contains possible improvements of the mechanical design of the product.

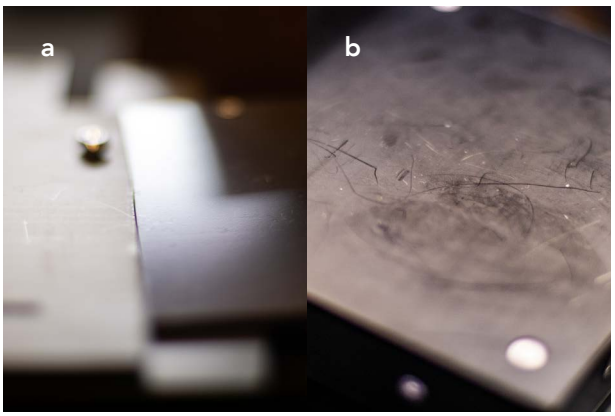


Figure 36.17: *a: Matte and glossy sides of the HDPE plates. b: Scratches on the HDPE.*

36.5.1 FRAME

The aluminum profile system proved to be an relatively simple way of constructing the base frame. However, it required a lot of work to assemble it, since so many connections had to be made. A total of 121 profiles and 202 frame connectors are used in the frame and doors. Simplifying the frame could save a lot of time.

Another disadvantage of this frame was that small irregularities, such as slightly longer profiles or gaps between profiles, can cause the frame to be skewed. When assembling the frame, it was found that some profiles were up to 1.5 mm longer than they should have been. Also, it required a fair amount of work to get rid of the gaps between frames.

36.5.2 WALLS

The laser cut HDPE walls were reasonably easy to work with. The larger plates, with a large number of fastening points, took a some time to attach to the frame, since all screws had to be aligned. It was found that the plates had a matte and a glossy side (Figure 36.17 (a)). A simple solution could be to mirror the CAD files that are used for laser cutting. Another disadvantage is that the HDPE is prone to scratches. There were some minor design mistakes with screw holes not aligning with the profiles, causing some gaps between plates in the doors.

36.5.3 OTHER REMARKS

The addition of hand grips could make the QIEM-Array easier to handle.

36.6 ELECTRONIC IMPROVEMENTS

This sections describes possible improvements of the electronics used in the products.

36.6.1 PELTIER ELEMENT CONTROLLER

To reduce the costs of the electronics, a few things can be done. Firstly, on the microcontroller PCB, the Peltier element controller could be removed. Not only is the controller expensive, but it also requires a lot of additional components. Instead, the Peltier element could be controlled directly from the microcontroller. This would reduce the complexity, hence the costs of the microcontroller PCB drastically.

36.6.2 CAMERA MODULE

Secondly, the camera module could be replaced by an industry grade one, instead of one designed for Arduino hobby projects. This could make the design more compact and further reduce the costs.

36.6.3 NUMBER OF TEMPERATURE SENSORS

Currently, the seed bed PCB has six different temperature sensors. This allowed for detailed insights in the temperature changes and uniformity in the testing stages of the project. However, for a future product, the number of sensors can likely be reduced to one.

TAKEAWAYS FOR QUANTIFIED

- The QIEM-Array was evaluated in user tests and discussions with germination research experts and other users.
- The design was evaluated generally as positive.
- The biggest disadvantage of this design was found by the experts to be its large footprint compared to their current equipment.
- Other possible improvements are the simplification of the base frame, redesigned doors and the removal of the Peltier controller from the microcontroller PCB.

CHAPTER 37

Next Steps

At the end of this project, the QIEM-Array was built. This chapter describes possible next steps for the QIEM-Array.

37.1 GERMINATION TESTS

Now that the QIEM-Array is built, it can be tested extensively. The first tests could be germination tests in the cells. Different species can be used to see if they will germinate in the device. A major improvement over the devices that the industry currently uses, is that all kinds of data can now be logged. For example, the temperature and humidity are measured, one can know what the light strength was at any time, and pictures of the entire germination process can be viewed. In these tests one can also find out if all functions of the QIEM-Array work as they should, and if there are any adjustments that need to be made.

37.2 MACHINE LEARNING

If the germination tests can be done properly in the QIEM-Array, development for the machine learning algorithms can start. Because each cell has a camera and controlled conditions, a lot of data can be generated. In the initial phase, the germination classification algorithms will need to be trained by humans. Over time, the automatic classification will improve and possibly approach the classification standards of humans. Furthermore, the data can be used to let the algorithms determine the optimal conditions for each species.

37.3 USER INTERFACE

Before the QIEM-Array can be put into use by the potential users, a user-friendly user interface must be designed. For this, consideration must be given to what the user should be able to control, and what data is presented and in what way.

37.3.1 ISTA TESTS

Many users will use the device to perform ISTA germination tests. The QIEM-Array itself meets the ISTA requirements. For the germination tests, there is, climate conditions and profiles for each species are specified in the ISTA manual. It would be convenient for the user to be able to choose from a list of species, reducing the amount of manual work. If the classification algorithms become good enough, the device could recognize the species by itself. The user should also be able to enter programs manually and save their custom settings.

37.3.2 FINDING OPTIMUM CONDITIONS

Some of the users will start using the QIEM-Array for finding optimal conditions for specific species. Especially companies specialized in the cultivation of special and exotic, and therefore more expensive, species would be interested in this. The user should be able to set different conditions in several cells at the same time in order to compare them and find the optimum conditions.

37.4 TRIALS WITH POTENTIAL USERS

During the interviews and visits to potential users, there were several companies that were open to using the QIEM-Array for testing. The QIEM-Array used for this project is a smaller version of what the product will eventually become. For initial trials at the companies, a few more of these smaller versions could be built. But the design is flexible, so other sizes could also be built.

These tests could see if the germination of the seeds corresponds to how they perform in current devices. During these tests, pictures can be generated. Since the users have a lot of expertise in the germination process, they could be of great value in training the machine learning algorithms.

37.5 DESIGN ITERATION

If the QIEM-Array has been subjected to many different tests, many insights will have been gathered. These insights can be used for an iteration process.

For example, what could be improved about the QIEM-Array is the complexity of the design. Now

it is made up of aluminum extrusion profiles and sheet metal. The possibility of injection molding the cells, for example, could be explored. This could reduce the frame complexity. One example of comments that came back from several users is that this device takes up a relatively large amount of space. Therefore, concepts that counteract this problem could be looked into, with for example moving trays. Figure 37.1 shows sketches of some examples of possible solutions.

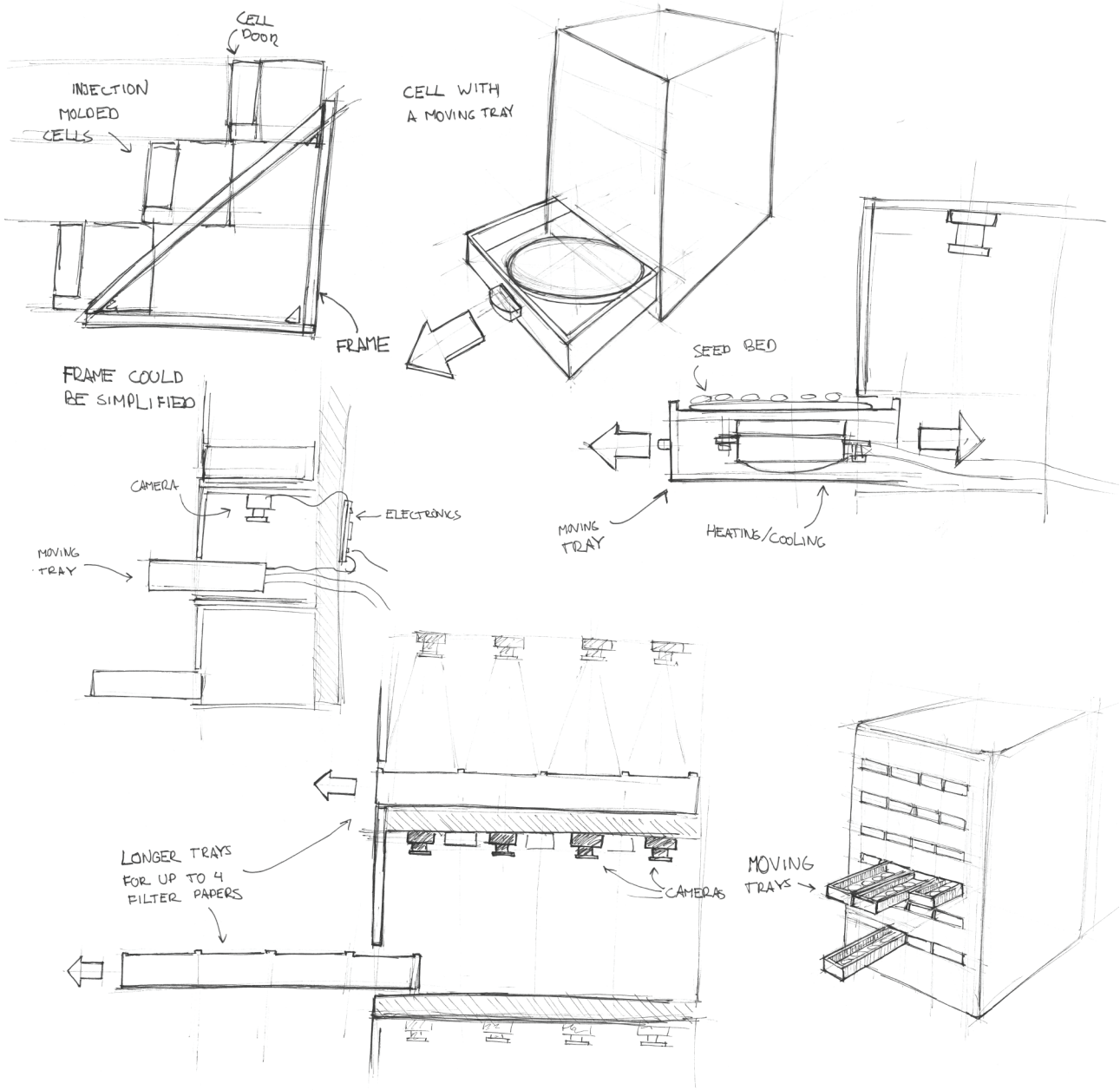


Figure 37.1: *Sketches of possible QIEM-Array improvements in a future iteration of the design.*

TAKEAWAYS FOR QUANTIFIED

- The QIEM-Array is built and ready for tests.
- Photos generated of the germination process can now be used to develop and train the machine learning algorithms.
- A user interface can be designed.
- The QIEM-Array built for this project can be used for test trials with potential users. Some additional ones could be build to be able to test with multiple users at once.
- Insights gained in these phases can be used for a possible design iteration.

Closing notes

With the evaluation of the design and the recommendations, you have reached the end of this report. Thank you for reading. I hope you have enjoyed it.

The project began with Quantified's assignment to design a 2D movement system for the QIEM Array. With the analysis phase, the vision for the product changed significantly. The result of this project was a feasible product was and a working prototype.

Looking back, I can conclude that this project was successful and valuable for both Quantified and myself. The prototype will allow germination testing to be done by customers in the seed industry with more control than they have with the conventional devices, and will give them advanced data on the germination tests. Also, this product is a good start for automatic classification of the germination process with AI. For myself, this has given the opportunity to expand my analysis skills and my design skills. With the amount of time I have spent at M19200, I have greatly increased my knowledge of electronics.

I'm curious where the QIEM-Array project goes next!

Erwin Rietveld

Bibliography

Aaker, J. L. (1997). Dimensions of Brand Personality. Journal of Marketing Research, 34(3), 347–356. JSTOR. https://doi.org/10.2307/3151897

AD7747ARUZ - Analogue to Digital Converter, 24 bit, 45.5 SPS, Differential, Single Ended, 2 Wire, I2C, Serial. (n.d.). Retrieved November 3, 2020, from https://nl.farnell.com/analog-devices/ad7747aruz/cdc-24bit-temp-sens-smd-tssop16/dp/1498726

Aggarwal, C. C. (2018). Neural Networks and Deep Learning. Springer. https://doi.org/10.1007/978-3-319-94463-0

Aris. (n.d.). Aris Vision Systems for grading natural horticulture products and meat. Aris B.V. https://arisbv.nl/en/

ASM International. (2003). Characterization and failure analysis of plastics. ASM International; / z-wcorg/. http://www.books24x7.com/marc.asp?bookid=42631

Awty-Carroll, D., Clifton-Brown, J., & Robson, P. (2018). Using k-NN to analyse images of diverse germination phenotypes and detect single seed germination in Miscanthus sinensis. Plant Methods, 14(1), 5. https://doi.org/10.1186/s13007-018-0272-0

Baeza-Yates, R., Ribeiro-neto, B., Mills, D., Bonn, O., Juan, S., Mexico, M., Taipei, C., Wesley, A., & Limited, L. (1999). Modern Information Retrieval.

Bewley, J. (1997). Seed germination and dormancy. In PLANT CELL (Vol. 9, Issue 7, pp. 1055–1066). AMER SOC PLANT BIOLOGISTS. https://doi.org/10.1105/tpc.9.7.1055

Bonny, S. (2017). Corporate Concentration and Technological Change in the Global Seed Industry. Sustainability, 9, 1632. https://doi.org/10.3390/su9091632

Byun, A., Mao, M., & Sidhu, R. (2014). The effect of different wavelengths on the germination time of Arabidopsis thaliana wild type and mutant type seeds | The Expedition. https://ojs.library.ubc.ca/index.php/expedition/article/view/184793

Chemical Resistance Chart | Plastics International. (n.d.). Retrieved January 11, 2021, from https://www.plasticsintl.com/chemical-resistance-chart

Crawford, R. J., & Martin, P. J. (2020). Chapter 1—General properties of plastics. In R. J. Crawford & P. J. Martin (Eds.), Plastics Engineering (Fourth Edition) (pp. 1–57). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-100709-9.00001-7

Cunningham, M. (2013). Problems in Agriculture: Loss of Land and Decreased Varieties. https://study.com/academy/lesson/problems-in-agriculture-loss-of-land-decreased-varieties-smaller-crop-yields.html

Daalhuizen, J., Boeijen, A., Zijlstra, J., & Schoor, R. (2014). Delft Design Guide.

de Medeiros, A. D., Pinheiro, D. T., Xavier, W. A., da Silva, L. J., & Fernandes dos Santos Dias, D. C. (2020). Quality classification of Jatropha curcas seeds using radiographic images and machine learning. In INDUSTRIAL CROPS AND PRODUCTS (Vol. 146). ELSEVIER. https://doi.org/10.1016/j.indcrop.2020.112162

Dean, R. N., Rane, A. K., Baginski, M. E., Richard, J., Hartzog, Z., & Elton, D. J. (2012). A Capacitive Fringing Field Sensor Design for Moisture Measurement Based on Printed Circuit Board Technology. IEEE Transactions on Instrumentation and Measurement, 61(4), 1105–1112. https://doi.org/10.1109/TIM.2011.2173041

Dell'Aquila, A. (2005). The use of image analysis to monitor the germination of seeds of broccoli (Brassica oleracea) and radish (Raphanus sativus). Annals of Applied Biology, 146(4), 545–550. https://doi.org/10.1111/j.1744-7348.2005.040153.x

Dell'Aquila, Antonio. (2009). Digital imaging information technology applied to seed germination testing. A review. Agronomy for

Sustainable Development, 29(1), 213–221. https://doi.org/10.1051/agro:2008039

Diego Franco, J., Ramirez-delReal, T. A., Villanueva, D., Garate-Garcia, A., & Armenta-Medina, D. (2020). Monitoring of Ocimum basilicum seeds growth with image processing and fuzzy logic techniques based on Cloudino-IoT and FIWARE platforms. In COMPUTERS AND ELECTRONICS IN AGRICULTURE (Vol. 173). ELSEVIER SCI LTD. https://doi.org/10.1016/j.compag.2020.105389

Ducournau, S., Feutry, A., Plainchault, P., Revollon, P., Vigouroux, B., & Wagner, M. H. (2004). An image acquisition system for automated monitoring of the germination rate of sunflower seeds. Computers and Electronics in Agriculture, 44(3), 189–202. https://doi.org/10.1016/j.compag.2004.04.005

El-Kassaby, Y. A., Moss, I., Kolotelo, D., & Stoehr, M. (2008). Seed germination: Mathematical representation and parameters extraction. Forest Science, 54(2), 220–227.

FarmBot. (n.d.). FarmBot | Open-Source CNC Farming. FarmBot. https://farm.bot/

FAST Technologies. (2015). Morphometric Seed Analysis—Automatic Germination Analysis System. https://fasttechnologies.com/solutions/morphometric-seed-analysis/

Grand View Research (GVR). (2017). Seed Treatment Market Size, Share | Industry Growth Report 2012-2020 (No. 978-1-68038-167–2). Grand View Research (GVR). https://www.grandviewresearch.com/industry-analysis/seed-treatment-market

Han, T., Khalighi, B., Yen, E. C., & Kaushik, S. (2018). Li-Ion Battery Pack Thermal Management: Liquid Versus Air Cooling. Journal of Thermal Science and Engineering Applications, 11(021009). https://doi.org/10.1115/1.4041595

Hebei I.T. (Shanghai) Co., Ltd. (n.d.). TEC1-12706 Datasheet. Retrieved January 11, 2021, from http://www.hebeiltd.com.cn/peltier.datasheet/TEC1-12706.pdf

HIH6030-021-001—Honeywell—Temperature and Humidity Sensor, HumidIcon™ Series, Digital. (n.d.). Retrieved November 3, 2020, from https://nl.farnell.com/webapp/wcs/stores/servlet/ProductDisplay?catalogId=10001&langId=31&storeId=10168&urlLangId=31&partNumber=2356755

Hoeren, T., & Uphues, S. (2020). Big Data in Industrie 4.0 (pp. 113–131). https://doi.org/10.1007/978-3-662-58474-3_7

Howarth, M., & Stanwood, P. (1993). Measurement of Seedling Growth-Rate by Machine Vision. Transactions of the Asae, 36(3), 959–963.

I2C Info. (n.d.). I2C Info – I2C Bus, Interface and Protocol. I2C Info – I2C Bus, Interface and Protocol. Retrieved November 3, 2020, from https://i2c.info/

ISTA. (2015). Chapter 5: The germination test. International Rules for Seed Testing, 2020(1), i-1–14. https://doi.org/10.15258/istarules.2020.05

ISTA. (n.d.). About ISTA - ISTA Online—International Seed Testing Association. https://www.seedtest.org/en/about-ista-_content---1--1011.html

Joosen, R. V. L., Kodde, J., Willems, L. A. J., Ligterink, W., van der Plas, L. H. W., & Hilhorst, H. W. M. (2010). GERMINATOR: A software package for high-throughput scoring and curve fitting of Arabidopsis seed germination. Plant Journal, 62(1), 148–159. https://doi.org/10.1111/j.1365-313X.2009.04116.x

Kunststof Lasersnijden Voor De Industrie. (n.d.). BMTEC. Retrieved January 11, 2021, from https://www.bmtec.nl/kunststoffen-lasersnijden/

Kunststofsoorten | Vink Kunststoffen. (n.d.). Retrieved January 11, 2021, from https://www.vinkkunststoffen.nl/kunststofsoorten

KWS. (n.d.). KWS' Germination Robot—Production and Quality Management—Progress: Made by Innovation—Sugarbeet—Products—Home—KWS SAAT SE & Co. KGaA. Retrieved May 14, 2020, from https://www.kws.com/corp/en/products/sugarbeet/progress-made-by-innovation/production-and-quality-management/kws-germination-robot/

Lal, N., & Sachan, P. (2017). Effect of different Visible Light wavelengths on Seed Germination and Photosynthetic Pigment Contents in Vigna unguiculata (L.) Walp. Indian Journal of Biology, 4, 132–136.

Lee. (2020). ArduCAM/Arduino [C++]. https://github.com/ArduCAM/Arduino (Original work published 2015)

Lev, J., & Blahovec, J. (2017). Imbibition of wheat seeds: Application of image analysis. International Agrophysics, 31(4), 475–481. https://doi.org/10.1515/intag-2016-0072

Li, N., Cao, M., Yu, X., Jia, J., & Yang, Y. (2019). High Sensitive Capacitive Sensing Method for Thickness Detection of the Water Film on an Insulation Surface. IEEE Access, PP, 1–1. https://doi.org/10.1109/ACCESS.2019.2929585

Lovetskiy, K., Sevastyanov, L., & Nikolaev, N. (2018). Numerical modeling of color perception of optical radiation. Mathematical Modelling and Geometry, 6. https://doi.org/10.26456/mmg/2018-612

Masteling, R., Voorhoeve, L., IJsselmuiden, J., Dini-Andreote, F., de Boer, W., & Raaijmakers, J. M. (2020). DiSCount: Computer vision for automated quantification of Striga seed germination. In PLANT METHODS (Vol. 16, Issue 1). BMC. https://doi.org/10.1186/s13007-020-00602-8

MAX7500MSA+T - Maxim Integrated Products—Temperature Sensor IC, I2C, Digital. (n.d.). Retrieved November 3, 2020, from https://nl.farnell.com/webapp/wcs/stores/servlet/ProductDisplay?catalogId=10001&langId=31&storeId=10168&urlLagId=31&partNumber=2515642

Micro-MaTch. (n.d.). TE Connectivity. Retrieved December 11, 2020, from https://www.te.com/usa-en/products/connectors/pcb-connectors/wire-to-board-connectors/ffc-fpc-ribbon-connectors/intersection/micro-match.html

Mihajlov, A., & Pokimica, N. (2015). EU SEVENTH ENVIRONMENTAL ACTION PROGRAM: EIA AND SEA ARE EFFECTIVE TOOLS WHEN CORRECTLY IMPLEMENTED. https://doi.org/10.13140/RG.2.1.4206.8962

Milberg, P. (1997). Weed seed germination after short-term light exposure: Germination rate, photon fluence response and interaction with nitrate. Weed Research, 37(3), 157–164. https://doi.org/10.1046/j.1365-3180.1997.d01-16.x

Milberg, P., Andersson, L., & Thompson, K. (2000). Large-seeded species are less dependent on light for germination than small-seeded ones. Seed Science Research, 10(1), 99–104. https://doi.org/10.1017/S0960258500000118

Mordor Intelligence LLP. (2019). Global Seed Market—Growth, Trends, and Forecast (2019—2024). Mordor Intelligence LLP. https://www.reportlinker.com/p05865714/Global-Seed-Market-Growth-Trends-and-Forecast.html

Polymer Properties & Chemical Resistance of Plastics. (n.d.). Retrieved January 11, 2021, from https://omnexus.specialchem.com/polymer-properties

Reverter, F. (2012). The Art of Directly Interfacing Sensors to Microcontrollers. Journal of Low Power Electronics and Applications, 2(4). https://doi.org/10.3390/jlpea2040265

Schanda, J. (2007). CIE Colorimetry. In Colorimetry (pp. 25–78). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470175637.ch3

Shadrin, D., Menshchikov, A., Ermilov, D., & Somov, A. (2019). Designing Future Precision Agriculture: Detection of Seeds Germination Using Artificial Intelligence on a Low-Power Embedded System. In IEEE SENSORS JOURNAL (Vol. 19, Issue 23, pp. 11573–11582). IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC. https://doi.org/10.1109/JSEN.2019.2935812

Škrubej, U., Rozman, C., & Stajnko, D. (2015). Assessment of germination rate of the tomato seeds using image processing and machine learning. European Journal of Horticultural Science, 80(2), 68–75. https://doi.org/10.17660/eJHS.2015/80.2.4

Spruijt, J. (2008). Nieuwe EU-gewasbeschermingsverordening heeft grote economische gevolgen. Kennisakker.Nl 2009 (2008) 5/11/2008.

Taggar, R. (2018). Democratizing plant biotechnology: The case of seed industry.

Tiktak, A., Bleeker, A., Boezeman, D., van Dam, J. D., van Eerdt, M., Franken, R., & Den Uyl, R. M. (2019). Geïntegreerde gewasbescherming nader beschouwd. https://doi.org/10.13140/RG.2.2.28461.64483

Tribouillois, H., Dürr, C., Demilly, D., Wagner, M.-H., & Justes, E. (2016). Determination of Germination Response to Temperature and Water Potential for a Wide Range of Cover Crop Species and Related Functional Groups. PLOS ONE, 11(8), e0161185. https://doi.org/10.1371/journal.pone.0161185

Ureña, R., Rodriguez, F., & Berenguel, M. (2001). A machine vision system for seeds germination quality evaluation using fuzzy logic. In COMPUTERS AND ELECTRONICS IN AGRICULTURE (Vol. 32, Issue 1, pp. 1–20). ELSEVIER SCI LTD. https://doi.org/10.1016/S0168-1699(01)00150-8

van der Berg, G. (2020). Using a Peltier element as a Thermometer. Haagse Hogeschool.

Venstra, W. (2019). MIT Joint R&D t.b.v. De Topsector T&U. Quantified Air B.V.

Walda, J. (n.d.). Kunststoffen die wij lasersnijden. De Laser Frezer. Retrieved January 11, 2021, from https://www.delaserfrezer.com/kunststoffen-die-wij-lasersnijden/

Web of Science. (n.d.). Web of Science. Retrieved May 29, 2020, from https://apps.webofknowledge.com/WOS_GeneralSearch_input.do?product=WOS&search_mode=GeneralSearch&SID=E4JiX3MAA7zJkZNuSPJ&preferencesSaved=

Weitbrecht, K., Mueller, K., & Leubner-Metzger, G. (2011). First off the mark: Early seed germination. In JOURNAL OF EXPERIMENTAL BOTANY (Vol. 62, Issue 10, pp. 3289–3309). OXFORD UNIV PRESS. https://doi.org/10.1093/jxb/err030

Witten, I., & Frank, E. (2010). Data Mining: Practical Machine Learning Tools and Techniques. In Morgan Kaufmann. https://www.elsevier.com/books/data-mining/witten/978-0-12-804291-5

Yang, W. (2018). Effect of nitrogen, phosphorus and potassium fertilizer on growth and seed germination of Capsella bursa-pastoris (L.) Medikus. Journal of Plant Nutrition, 41(5), 636–644. https://doi.org/10.1080/01904167.2017.1415350

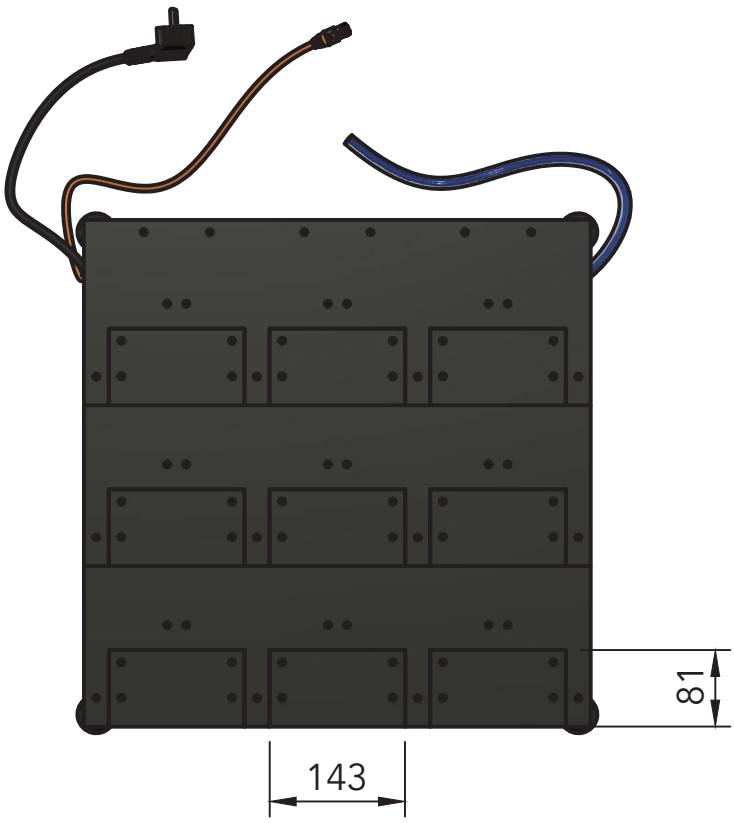
Young, J., Eckert, R., & Evans, R. (1981). Temperature Profiles for Germination of Bluebunch and Beardless Wheatgrasses. Journal of Range Management, 34, 84. https://doi.org/10.2307/3898117

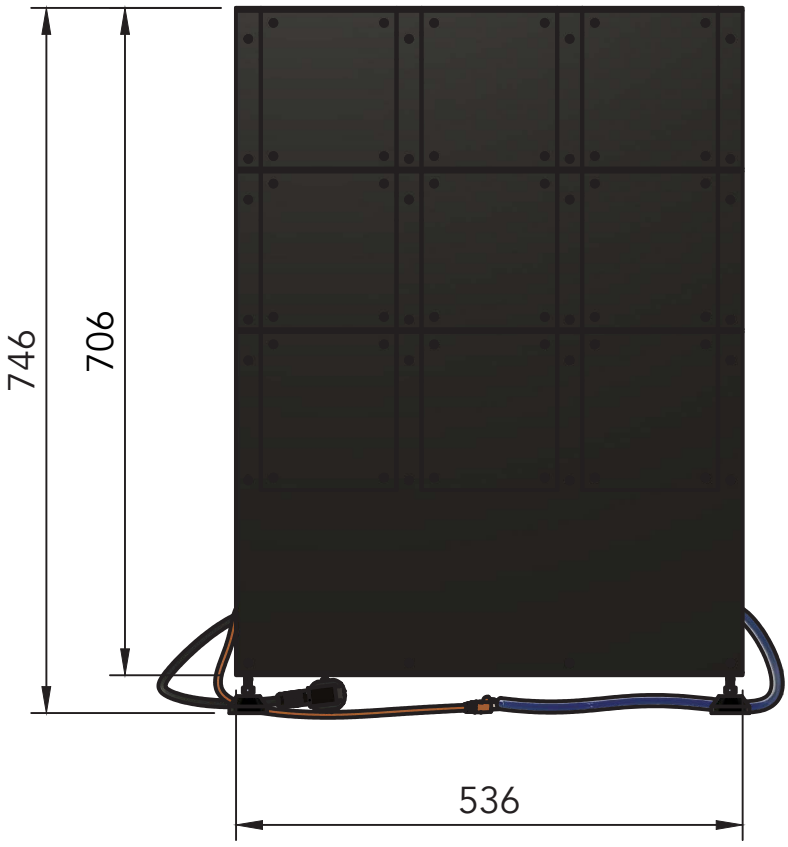
Zhang, C., Si, Y., Lamkey, J., Boydston, R. A., Garland-Campbell, K. A., & Sankaran, S. (2018). High-Throughput Phenotyping of Seed/Seedling Evaluation Using Digital Image Analysis. Agronomy-Basel, 8(5), 63. https://doi.org/10.3390/agronomy8050063

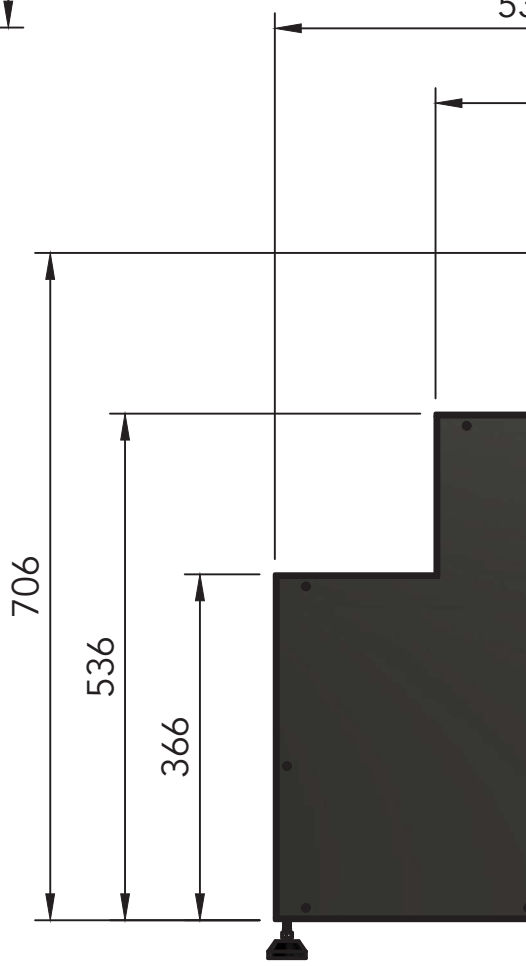
Appendices

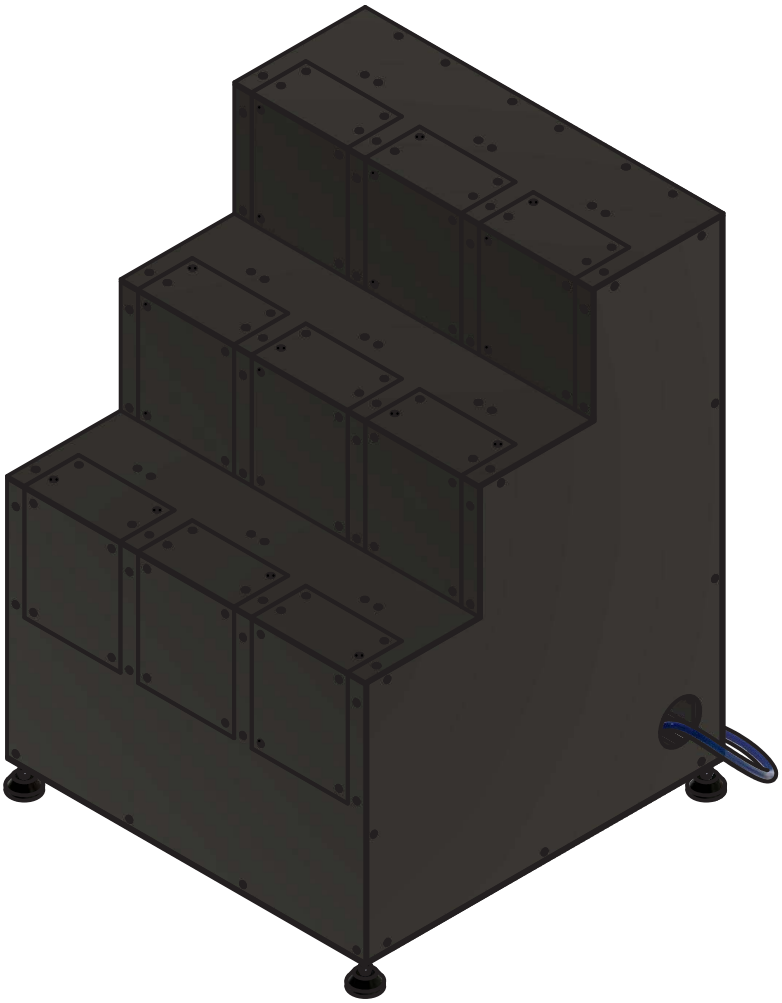
APPENDIX A: **QIEM-Array Outer Dimensions**

REFERRED TO IN CHAPTER 1 ON PAGE 12










366
196

APPENDIX B: **Bill of Materials**

REFERRED TO IN CHAPTER 4 ON PAGE 40

Component	Material	Qty	Price/pc	Price
Assembly:				Subtotal:
▼ Walls				**€ 258,93**
Cell left inner wall	HDPE	18	€ 2,06	€ 37,08
Front frame cover drain	HDPE	12	€ 0,44	€ 5,28
Camera window	PC	9	€ 0,70	€ 6,30
Camera housing bottom	HDPE	9	€ 1,31	€ 11,79
Camera housing front	HDPE	9	€ 0,40	€ 3,60
Drain holder	HDPE	9	€ 0,44	€ 3,96
Door support	HDPE	9	€ 0,10	€ 0,90
Door stop	HDPE	9	€ 0,30	€ 2,70
Door bottom	HDPE	18	€ 0,42	€ 7,56
Door top	HDPE	9	€ 0,70	€ 6,30
Door roof	HDPE	9	€ 0,61	€ 5,49
Door back	HDPE	9	€ 1,49	€ 13,41
Door front	HDPE	9	€ 1,60	€ 14,40
Door left	HDPE	18	€ 0,74	€ 13,32
Light protector	HDPE	9	€ 0,50	€ 4,50
Cell back wall	HDPE	3	€ 7,00	€ 21,00
Cell top	HDPE	2	€ 5,96	€ 11,92
Front frame cover narrow	HDPE	8	€ 0,54	€ 4,32
Cell front	HDPE	1	€ 8,76	€ 8,76
Array top	HDPE	1	€ 5,90	€ 5,90
Left array wall	HDPE	2	€ 11,68	€ 23,36
Back array wall	HDPE	1	€ 28,52	€ 28,52
Bottom array plate	HDPE	1	€ 10,01	€ 10,01
EPS foam 20 mm thick	EPS	1	€ 1,50	€ 1,50
M3x8 CS	Stainless steel	451	€ 0,02	€ 6,77
M3x10 CS	Stainless steel	18	€ 0,02	€ 0,29
▼ Electronics				**€ 2630,01**
Arducam	-	9	€ 33,89	€ 305,01
LED PCB	-	9	€ 33,00	€ 297,00
Seed bed PCB	-	9	€ 67,00	€ 603,00
Microcontroller PCB	-	9	€ 150,00	€ 1350,00
Wiring	-	1	€ 50,00	€ 50,00
Power supply	-	1	€ 25,00	€ 25,00

Component	Material	Qty	Price/pc	Price
▼ Camera				**€ 26,26**
Camera mount	PETG	9	€ 2,38	€ 21,38
Hydrophobic film	-	9	€ 0,24	€ 2,16
M3 washer	Stainless steel	45	€ 0,00	€ 0,18
M3x45 CS	Stainless steel	18	€ 0,07	€ 1,22
M3 nut	Stainless steel	45	€ 0,01	€ 0,54
15x3.5x6.3 spacer	PA	18	€ 0,04	€ 0,78
▼ Seed bed				**€ 512,83**
Drain	PETG	9	€ 9,50	€ 85,50
M3x10 socket	Stainless steel	54	€ 0,02	€ 1,08
M3 washer	Stainless steel	27	€ 0,00	€ 0,11
TEC module	-	9	€ 4,48	€ 40,32
Cooling paste	-	1	€ 0,00	€ 0,00
Cooling block	-	9	€ 19,99	€ 179,91
Cell bottom plate	Stainless steel	9	€ 4,23	€ 38,07
EPDM tape 10mm x 4 mm	EPDM	1	€ 1,20	€ 1,20
Water cooling tube fitting	-	18	€ 1,13	€ 20,30
M5 insert	Brass	9	€ 0,23	€ 2,07
SMC drain tube fitting	Brass/plastic	18	€ 1,35	€ 24,26
CPU water cooling	-	1	€ 120,00	€ 120,00
▼ Frame				**€ 348,54**
T-slot nut M3	Stainless steel	469	€ 0,15	€ 70,35
Door frame A	Aluminum profile	9	€ 0,51	€ 4,59
Door frame B	Aluminum profile	18	€ 0,54	€ 9,72
Door frame C	Aluminum profile	18	€ 0,21	€ 3,78
Door frame D	Aluminum profile	9	€ 0,36	€ 3,24
Array frame A	Aluminum profile	54	€ 0,56	€ 30,24
Array frame B	Aluminum profile	9	€ 1,98	€ 17,82
Array frame C	Aluminum profile	4	€ 1,83	€ 7,32
Leveling foot	Rubber/Stainless	4	€ 1,65	€ 6,60
Aluminum verbindingshoek 2020	Aluminum	18	€ 1,40	€ 25,20
Binnenhoek T-sleuf 6	Stainless steel	202	€ 0,84	€ 169,68
TOTAL				**€ 3776,57**

APPENDIX C: **User Interviews**

REFERRED TO IN CHAPTER 10 ON PAGE 69

To validate Quantified's assumptions and to gain knowledge about the seed industry, a number of companies were interviewed and visited (Figure C.1). The interview results are shown below.

C.1 EMINENT SEEDS

Location	Poeldijk, ZH, Netherlands
Company size	10-50 employees
Specialty	special tomatoes, sweet peppers and chili peppers
Website	https://www.eminentseeds.nl

C.1.1 INTERVIEW 19 JUNE

Interviewee	[name omitted]
Function	Managing Director

- We sometimes use a **temperature gradient table** from Evantia Seeds.
- We do two kinds of tests: on **paper** and in **trays**.
- We count on two moments during the germination process.
- We want to know the **germination power and speed, and the visiological abnormalities.**

C.1.2 INTERVIEW 23 JUNE

Interviewee	[name omitted]
Function	Plant Pathologist

- We primarily work with tomatoes.
- **We have a germination test with temperature control**; a warmer day temperature and a colder night temperature, according to **ISTA**.
- We do two kinds of tests: in **trays** and in a **seed germination cabinet**.
- The tray tests are in a growth cell, with **humidity and temperature control**.
- The germination test is **top-of-paper**. The germination cabinet is made by Seed Processing: https://seedprocessing.nl/en/17/121/seed_quality_control_equipment.html.
- **The most important for customers to know is how many seeds germinate and how uniform that is.**
- We work with specials. It is fine to have a germination rate of 85%. For commercial species, you have to have 99%.
- We have used a **temperature gradient table** (TGT) before, to find out which temperature works the best, but that's more for the flower industry.
- **The ISTA requirements are lower than our own.** The customers want tests in trays and not from paper. That is more representative.
- **Optimization of temperature and humidity are not important.** This would only be important for companies that require a germination rate of around 99%.
- **It depends very much on the species what you want to measure.** For tomatoes it is less precise. If the temperature is roughly okay and there is some light, the seeds will germinate.
- Tropical plants, for example, germinate completely different compared to tomatoes, under normal greenhouse conditions.
- At the start of the test, we make sure **the paper is wet enough**. Then the air also remains humid.
- **We classify manually**, but that is fine for the moments. We don't do a lot of tests, since we're a small company.
- **Seed placing machines exist.**
- **It important to have detailed statistics of tests. If there are abnormalities of failures, you can see where it went wrong and what the impact is.**
- **We never add nutrients** or something alike during tests.
- You can **pillate** seeds, but that is not so interesting for the flower industry.
- You can call back if you have more questions.

C.1.3 CONCLUSIONS

Eminent Seeds do two different kinds of tests: on paper (according to ISTA) and in growth cells. The ISTA tests are done to give a guarantee to the customer, while the others are done to give more realistic image. The placing of seeds and the classification is done manually. They would be interested in having detailed statistics of the tests.

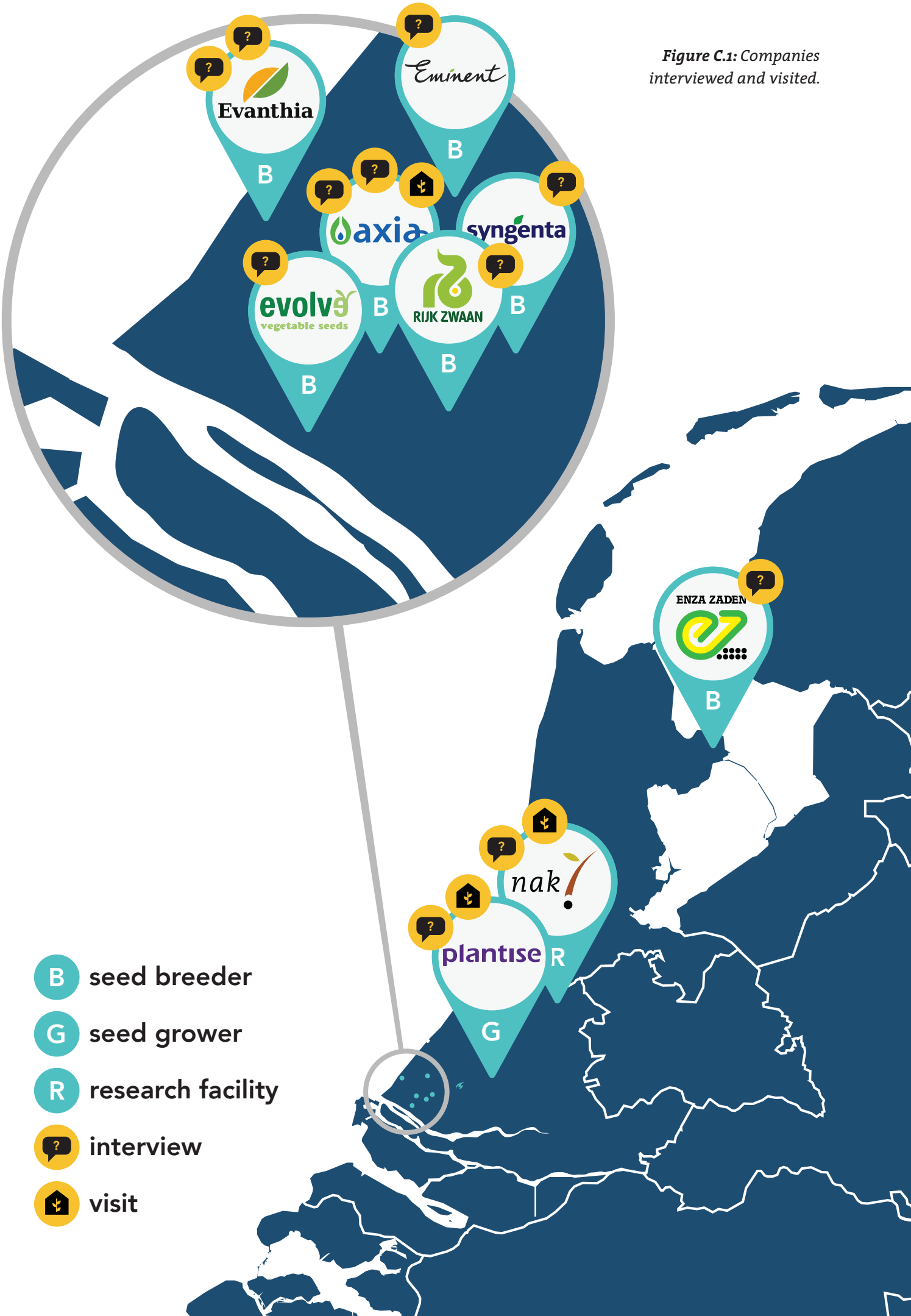


Figure C.1: *Companies interviewed and visited.*

C.2 EVANTHIA

Location Monster, ZH, Netherlands
Company size 10-50 employees
Specialty flowers, pot and bedding plants, and tropical plants
Website https://www.evanthia.nl

C.2.1 INTERVIEW 23 JUNE

Interviewee [name omitted]
Function Sales Representative

- We have a **germination lab**, but we lack the knowledge.
- **We don't do research.** We re a trade company. We test if the incoming seeds meet the **quality requirements** that we want to deliver to our customers.
- **We generally don't germinate according to the ISTA regulations.** Sometimes we use them to see how certain species germinate and what the requirements are. Instead, we try to **imitate realistic conditions.**
- ISTA is only on paper. **We also test on soil.** With the ISTA standards, the tests are generally more positive than with realistic conditions.
- **We look further than only germination.** We also look at 'usable plants'. How many small plants or abnormalities are there?
- Each company has their own standards. Sunflowers, for example, have to have a germination rate of 90%.
- **The germination rate doesn't say anything about the number of usable plants.**
- **ISTA is used as a backup.** If there is a customer complaint, we can say: "This species has a germination rate of 98% and it is ISTA-certified." ISTA is being used as a standard by the leading companies.
- Our germination lab is service-oriented. They do it to get **information about the incoming seeds**. They don't really research new germination methods.
- Seeds of **tropical plants** come from Third World countries. They do not germinate as well as the seeds that are cultivated here in a regulated manner. They're taken from the trees there. **For this type of plant, it's interesting to know which germination method performs best. We're just trying things out.**
- We try temperature, substrate, run off with vermiculite or something else.

C.2.2 INTERVIEW 24 JUNE

Interviewee [name omitted]
Function Foreman Seed Technology

- We are a small company and rather limited in possibilities. We are growing slowly. We are only six years old.
- We have a **small self-built germination lab**. **We control the temperature with an air conditioner. We don't have humidity control.**
- **We have a rack with shelves and LED lights. Nothing is automated.**
- We have a **temperature gradient table** (TGT), but over the last three years, it's been used only three times. **We don't have the knowledge.**
- **99% of germination tests are done on soil.**
- **We work according to ISTA regulations.** We do the most general germination test. Sometimes we cool with a germination cabinet (a kind of refrigerator).
- We lack the knowledge for more advanced germination tests.
- The customers are dependent on the weather. **It doesn't make sense to develop a unique germination method with a 95% germination rate, if it is much lower in reality.**
- **It would be interesting to look at automatic classification in the future.** For now, we are too small for that.
- **What we want to measure and control: temperature, humidity, light** (long or short days).
- **We don't want to add nutrients** or anything like that. This does not correspond with reality. But it can be interesting for specific tests.
- Biological pesticides. When pre-treated with bacteria, the seed gets wet. If it becomes dry again, will the bacteria die? There is nothing known about what it does to seed. It might be interesting to add that during the germination process, but you don't know what it does on the seed before and after. The big companies are working on that.
- Companies that can give more input: Rijk Zwaan, Axia, Zakata, Taki, Benari, Enginetics, Panam Seeds.
- You can call back if you have more questions.
- You can come by for a visit, after the corona measures have been eased.
- **We are very interested in the results of the project.**

C.2.3 CONCLUSIONS

Evanthia test primarily in soil to get more realistic data of the performance of the seeds. However, they also do tests, according to the ISTA standards. This is done so they can give certified statistics about the seeds. They said that they would be interested to look at automatic classification in the future. They want data on temperature, humidity and light.

C.3 ENZA ZADEN

Location	Enkhuizen, NH, Netherlands
Company size	1000-5000 employees
Specialty	vegetable seeds
Website	http://www.enzazaden.com/

C.3.1 INTERVIEW 25 JUNE

Interviewee	[name omitted]
Function	Supervisor Germination Laboratory

- **We don't have a lot of automation. We do everything by hand and eye.**
- **We seed using a vacuum head.**
- For the cabinet, we have a sowing machine.
- We use **germination cells**, not a temperature gradient table. We have a room with a rack shelves, cells, and LED lights.
- We germinate on **paper and soil**, according to **ISTA**.
- **Soil is closer to what the customer expects.**
- We determine per species what kind of test we do. Some on paper, some on soil and some on both.
- We have set counting days. For example, tomatoes are counted after seven days. **Counting takes a lot of time.**
- **Automation would give you the ability to sow, count and classify on set times. You would take away a lot of variables.**
- There are **abnormalities** that you have to classify. The differences are very small. For example, the camera has to detect yellow nerve for tomatoes.
- **Important conditions: temperature, humidity and light (intensity and spectrum).**
- **We do not add nutrients** during the germination process. We have done a anti-fungal test once.
- The tests take from 4 days to 3 weeks. Then we dispose of the plants.
- We switched to LED two years ago. It contains a bit too much red. That doesn't work for all species. **The spectrum does something different per species.** Spectrum tests would be interesting.
- **Important to measure: size of the leaves, area of cotyledon, abnormalities.**
- We have 8 cells. We do 1000 tests per week.
- **We are curious where the project is going and the results.**
- You can call back if you want.

C.3.2 CONCLUSIONS

At Enza Zaden, they perform tests according to the ISTA regulations. They don't have a lot of automation, but they do have a vacuum head to pick and place the seeds. Counting seeds takes them a lot of time. They are interested in automation, because it could save time and it could make the tests more consistent. They want to measure and control temperature, humidity and light. Furthermore, it is important to detect abnormalities. They never add substances to the seeds during the germination tests.

Axia seeds

Location	Naaldwijk, ZH, Netherlands
Company size	50-200 employees
Specialty	tomatoes
Website	http://www.axiaseeds.com/

C.3.3 INTERVIEW 25 JUNE

Interviewee	[name omitted]
Function	Lead Molecular Lab

- We don't do a lot of research. We just want to know what the **germination power** is.
- Germination tests are done according to **ISTA** regulations.
- **We count manually.**
- We do tests to give a guarantee to the customers.
- We have to kinds of tests: on paper and on rock wool.
- With tests on **paper**, we test the germination power.
- With the test on **rock wool**, we test the **size** and **abnormalities** of the plants. These are performed on trays.
- **Manual classification takes a lot of time**, but are too small for automation.

- **As a company, we are generally interested in AI and automation.**

C.3.4 INTERVIEW 26 JUNE

Interviewee [name omitted]
Function Lead Germination Lab

- The Copenhagen table works, but is very limited. You want to determine the optimal conditions.
- **ISTA is maybe not optimal**, but they use it for all tests.
- We are mainly specialized in tomatoes.
- There are 1000 different kinds of tomatoes. **It is impossible to determine the optimum for all species**. We use average conditions for all tests. Moreover, we have 100 new species every year.
- We use **ISTA**. The germination percentage is pretty high, because these are optimal conditions.
- We also do a realistic test in the greenhouse.
- **We manually classify.** We are a small company.
- Seeds are primed sometimes. We don't do it ourselves. Seeds are stirred through liquid for a few hours in the priming process.
- **What you want to measure: temperature and humidity of the paper.**
- **Seed germination processes don't go well in closed-off environments.**
- Nak Tuinbouw has a lot of germination tables. They work according to ISTA.
- **Light is sometimes important for ISTA**, but sometimes it isn't. It depends on the species. We use a day and night rhythm.
- Lighting with LED lamps, ISTA spectrum.
- Interesting companies: Bayer, Rijk Zwaan, Beyo Zaden, Nunems Zaden, Syngenta.
- Priming makes the germination process uniform.
- We want to show the performance of a batch to the customer.
- **We count on day 7 and 14. If you had a camera, you could produce data in between. That would be a valuable addition.** Then you can spend your Saturdays at the beach.
- We put the seeds at fixed distances.
- We pick up 50 seeds simultaneously.
- We have a climate cabinet with temperature and light control. Humidity is not controlled.
- The problem with the Copenhagen table is the water reservoir underneath. If a bacteria gets in, it has to be cleaned very thoroughly.

C.3.5 VISIT 26 JUNE

After the telephonic interview, [name omitted] was so kind to invite me for a visit.

First, she showed me a big book with an enormous variety of seeds. The book contained pictures of seeds of around 1800 species. These were only species grown in the Netherlands. What struck me, was the variation on shapes, dimensions, colors and other features.

Next, she gave me an explanation of the ISTA regulations and classification of seeds during the germination process. It was mainly about what the distinction of good plants and plants with abnormalities. There is often a very thin line between the two.

Next we walked into the greenhouse. There they test how seeds perform when grown on a bed of rock wool. Finally, we went into the germination lab. There they test seeds according to ISTA regulations. They have one large temperature- and light-controlled cabinet. There they test the performance of all different species. The seeds are placed in small plastic containers on paper with a vacuum head. When seeds have germinated, they are taken out. When the paper gets too dry, water is added during counting moments, according to ISTA.

They primarily test tomatoes, but also some other vegetables, such as peppers and cucumbers. They have a large variety of species, with a large number of new ones every year. One of the main research goals for the company is to make the species resistant to different kinds of diseases and climates. The tomato seeds are expensive and customers expect a germination rate of at least 98% in greenhouses. Photos from the visit can be found in Figure C.2.

Figure C.2: *[ON NEXT PAGE] Photos from the Axia Seeds visit. a: The germination cabinet. b: A plastic container with germinating seeds. c: Seeds in an early stage of the germination test. d: A vacuum had to pick up and place seeds. e: Another vacuum head that can pick up more seeds. f: Germination test with tomato plants in the green house . g/h: A small selection of different tomatoes Axia Seeds grow.*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C.3.6 CONCLUSIONS

At Axia Seeds, they perform tests according to ISTA. They do it manually and count on set time intervals (day 7 and 14 for tomatoes). They said that it would be valuable to have data in between these moments. They want to measure and control temperature, humidity and light. [name omitted], the germination lab expert, showed a book with photos of 1800 different seeds, to show how many there are and how different they are from one another. Another important thing learned from the visit is that the germination process doesn't go well in a completely closed-off environment.

C.4 EVOLVE VEGETABLE SEEDS

Location	Maasdijk, ZH, Netherlands
Company size	10000+ employees
Specialty	vegetable seeds
Website	https://www.evolveseeds.com

C.4.1 INTERVIEW 2 JULY

Interviewee	[name omitted]
Function	-

- We don't have a specific seed testing department. We are too small to have this.
- We let Nak Tuinbouw test all our seeds.

C.4.2 CONCLUSIONS

They said that they are too small to have their own seed testing lab, so they outsource their testing. However, perhaps having their own germination testing machine could save them money in the long run. Especially when the company grows.

C.5 SYNGENTA SEEDS

Location	De Lier, ZH, Netherlands
Company size	10000+ employees
Specialty	vegetable seeds, crop protection
Website	https://www.syngenta.nl

C.5.1 INTERVIEW 2 JULY

Interviewee	[name omitted]
Function	Lead germination lab

- We test in **soil** and on **paper**.
- All tests are based on the **ISTA** regulations.
- We test in **climate cabinets** and **germination cells**. We have two cabinets with two temperature settings.
- **We do everything manually, but we are looking for automation. We want to buy a machine for this.**
- There is a wide variety of plants in the lab. **It would be really helpful to have a machine that can classify automatically.** It would be even more helpful if it's up to 9 different crops, for example.
- We sow seeds that go to the greenhouse automatically in the lab. We want to place the machine in the greenhouse in the future.
- **During the germination test, you want to monitor the development of the seeds.**
- **We want to know the germination numbers and abnormalities.**
- For certain storage times, the quality deteriorates. Tomato seeds are quite expensive. Can we still sell them at quality grade 1 after three years of storage or is the limit only 1 year? So we want to test the effects of storage on the seeds.
- **We want to measure temperature and humidity during germination tests. Then you know what causes abnormalities.**
- **We want to know the usable plant percentage.**
- **Measurements in between the defined ISTA measurement moments is very interesting. How uniform is the seed germination?** This is also interesting for customers.
- **The machine should sow, evaluate, test soil.**
- We would like to receive the report after this project finishes. **We think this project is very interesting.** Automation is the future.
- We want to be involved. You can always call back.
- **We would be interested in testing an early prototype.**

C.5.2 CONCLUSIONS

They do a lot of tests, but have little automation. However, at Syngenta, they are very interested in automation. They were very interested in automation. Amount the things they want to measure and control are temperature, humidity and abnormalities. They think the project is interesting ant want to be involved. They are even open to testing an early prototype of the product.

C.6 NAK TUINBOUW

Location	Roelofarendsveen, ZH, Netherlands
Company size	20-500 employees
Specialty	horticulture quality control
Website	https://www.naktuinbouw.nl

C.6.1 INTERVIEW 3 JULY

Interviewee	[name omitted]
Function	Lead Germination Lab

- We have five **Jacobsen tables** that are in use most of the time.
- We sometimes use **vacuum pumps** to place the seeds, but we also do it manually. It depends on the seeds.
- **We would want to measure temperature and humidity.** On the Jacobsen table, the paper is in contact with water. Therefore it takes up as much water as it needs.
- The temperature of the water reservoir underneath the table is being regulated in cycles.
- Light is controlled separately. It is set on 12 hours at the moment.
- **In the future, machine learning could help with classifying.**
- They are working on a project with the University of Wageningen to determine usable plants with AI.
- Automation of our tests could certainly help.
- We remove germinated seeds.
- **ISTA** is the foundation of our tests.
- You can visit us if you want.

C.6.2 VISIT 10 JULY

After the telephone interview, I asked if I could visit Nak Tuinbow to see how the tests are performed in real-life. I also asked if Warner wanted to come along.

At Nak Tuinbouw, they perform a large number of quality tests on plants. In the facility we visited, they tested the purity of batches of seeds and they performed different kinds of germination tests; in soil, on Jacobsen tables, in climate cabinets and in trays. [name omitted] give us a tour around and explained about the operations in the facility.

At the start of germination tests, the seeds have to be placed on a growing medium. They demonstrated how they place the seeds with a vacuum head. It is basically a flat plate with a grid of small holes to which the seeds stick when a vacuum is applied.

Next, we visited the lab with the Jacobsen Tables and climate cabinets. The tables have two temperature settings: a day and a night temperature. The seeds are grown on paper, which is in connection with the heated water between the slits. The seeds have transparent covers with holes in the tops. These covers keep the humidity high, while still allowing exchange air with the environment. According to [name omitted], this is crucial for the germination process. The tables have white lamps at the top. All tests on the tables are performed according to the ISTA regulations. The tables are worth €60.000 per unit.

[name omitted] shared some interesting information about ISTA. They are able to give ISTA certifications. The ista regulations are updated annually. They also have an annual vote about new species to be included in the regulations. Classifications of the seeds is done manually, but by different people. They have to prove that they classify consistently. [name omitted] thinks that automation could solve this problem. However, he thinks that it would be a big task to make this work for all different species.

Photos from the visit can be found in Figure C.3.

C.6.3 CONCLUSIONS

At Nak Tuinbouw, they perform quality tests for the seed industry. They have a lot of Jacobsen tables and climate cabinets, with which they constantly perform tests. They perform many of the testing actions manually. They are very much interested in automation.

Figure C.3: *[ON NEXT PAGE] Photos from the Nak Tuinbouw visit. a: Jacobsen tables. b: Vacuum head to pick and place seeds. c/d/e: Surface of the Jacobsen table with seeds growing on paper. The seeds get water through the slits. f: Seed tests in a climate cabinet. g: Seed tests in a climate chamber.*


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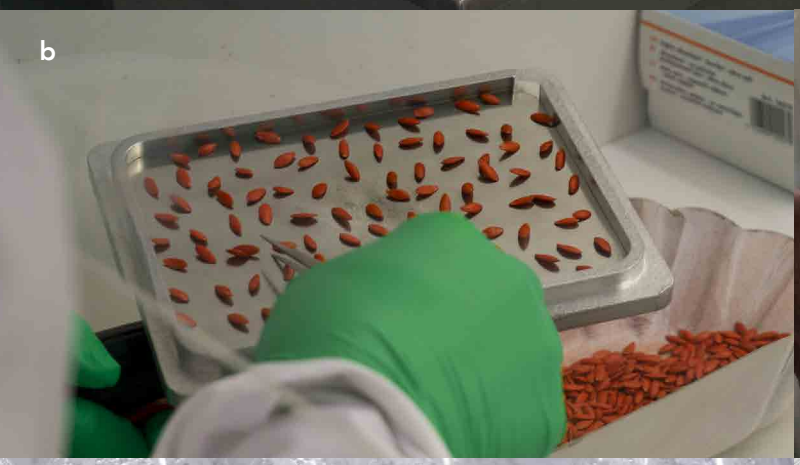
KTA 09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C.6.4 RIJK ZWAAN

Location De Lier, ZH, Netherlands
Company size 1000-5000 employees
Specialty vegetable seeds
Website https://www.rijkzwaan.com

C.6.5 INTERVIEW 8 JULY

Interviewee [name omitted]
Function Operation Manager R&D

- We seed in two ways: traditionally and with a machine.
- **We have an advanced system with machine that sows automatically, takes photos and classifies. The machine is developed in-house. The development time was 3 years.**
- **You have to have constant conditions, uniformity and reproducibility.** If these are constant, you measure only germination.
- We test large quantities; about 100 trays per week.
- **We want to measure germination, usable plants and abnormalities.**
- Trays are taken out automatically and photographed.
- You can't come by for a visit, because this machine gives us a **competitive advantage**.
- You can call back if you have further questions.

C.6.6 CONCLUSIONS

They already have an automatic germination testing machine at Rijk Zwaan. The machine autonomously sows, takes photos and classifies. They are reluctant to share information about the machine, since it gives them a competitive advantage. The seeds are, however, sown in trays (as can be seen in Figure C.4 (f)).

Plantise

Location Bleiswijk, ZH, Netherlands
Company size 200-500 employees
Specialty seed grower
Website https://www.plantise.com

C.6.7 INTERVIEW 8 JULY

Interviewee [name omitted]
Function Cultivation Specialist

- **It sounds like music to the ears if a germination robot becomes reality.**
- We sow in plugs, but mostly in rock wool.
- These are soaked in water and fertilizer.
- We keep the temperatures of the pots and plugs we sow in around 25 °C. This is easier in winter. We use germination cells in summer when the batch isn't too big.
- **Moisture and temperature are most important.**
- We sometimes cover plugs with plastic if the temperature gets too high.
- **It would be ideal to know the ideal conditions per species.** It also depends largely on the weather. In summer, the temperature inside the greenhouse can get over 30 °C. Then we try to cool as much as possible during the night.
- For plug germination, the plants are sorted, potted and grown through. But this depends on what the customer wants.
- We test incoming seeds in trays in the greenhouse. For the different lot numbers, we perform germination tests and check for abnormalities.
- After the initial test, the rest of the batch is sown 2 to 3 weeks later.
- **We don't test according to ISTA. The breeders provide us with data**, such as the germination percentage. They provide the statistics.
- **We only test in the greenhouse, since that gives a more realistic image.**
- **We count and classify everything manually.**
- You can come to visit us, if you want.

C.6.8 VISIT 14 JULY

Three companies have recently merged to form what is now Plantise. Their main activity includes the breeding of seeds. I got a tour around the germination facilities.

They test all batches of incoming seeds, because they want to know the germination power. When they know the percentage of usable plants, they know how much extra they need to seed to get the numbers required by the customers. For example, for some batches, they seed 20% extra. It is very important to know if this number is correct. Sometimes they find out later that the percentage needed to be different. This can be costly, since seeds are expensive. Some tomato seeds cost around € 1 each.

Visit 14 July

Three companies have recently merged to form what is now Plantise. Their main activity includes

the breeding of seeds. I got a tour around the germination facilities.

The seeds are sown in trays in rock wool growing media. This process is automated by a sowing machine. Per batch they test two trays on average, which sums up to a total of 252 seeds. Classification is done manually. According to [name omitted], this takes a lot of time. Another problem is that it is subjective. Different people classify differently. They want the test to be less time-consuming and more consistent. As [name omitted] said on the phone, they don't perform test according to the ISTA regulations.

They test all batches of incoming seeds, because they want to know the germination power. When they know the percentage of usable plants, they know how much extra they need to seed to get the numbers required by the customers. For example, for some batches, they seed 20% extra. It is very important to know if this number is correct. Sometimes they find out later that the percentage needed to be different. This can be costly. Tomato seeds can cost up to € 1 per piece.

The knowledge about the optimal climate conditions for the species is in people's heads. They only recently started writing protocols. The conditions they use change constantly as more knowledge is gained. The optimization process is based on trial and error. [name omitted] said that it would be of great value to know the optimal conditions for each species.

The weather plays a big role in the climate conditions in the greenhouses. For each species, they have desired conditions. But on warm days, they don't have a lot of influence on the temperature. They can warm the greenhouses, but cannot cool them. The climate is controlled by a computer. After a warm day, the system automatically compensates with a cooler day.

They have started experimenting with germination tests in a daylight-independent environment. Here they have complete control over the climatic conditions. However this is rather expensive, compared to germination in regular greenhouses.

[name omitted] told that they are very interested in automation of the germination tests and are open to collaboration.

Photos from the visit can be found in Figure C.4.

C.6.9 CONCLUSIONS

Plantise are seed growers. This means that ISTA tests are less important for them. They want to measure the performance of each incoming batch of seeds in greenhouse conditions, i.e. in trays with rock wool plugs.

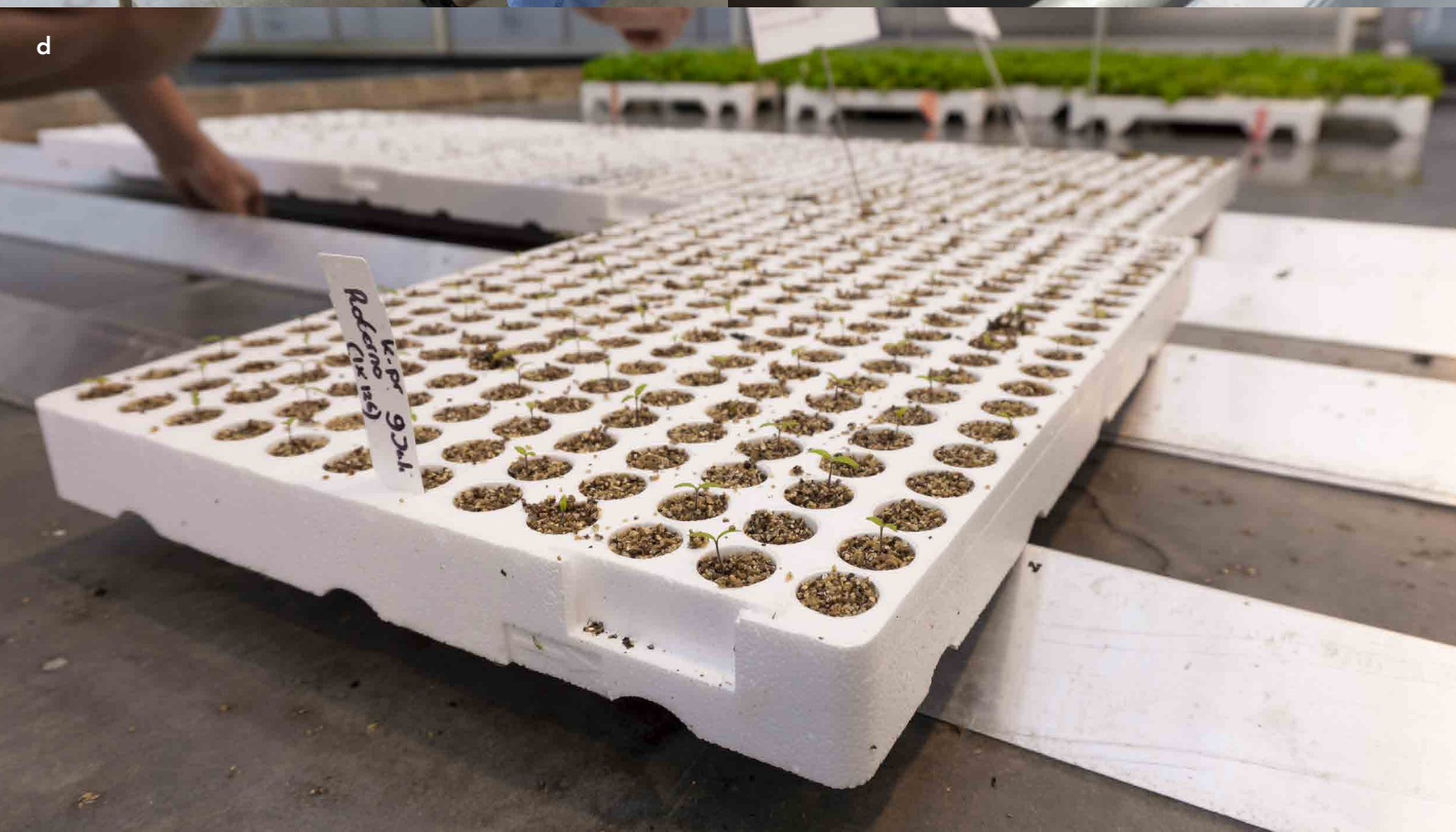
They were very interested in automation of the germination tests, because it could save them a lot of time and it would make it more consistent. Moreover, they want to be able to determine optimum germination conditions for the plant species they grow. Currently, this is determined by trial and error, but they don't have a structured optimization protocol.

Figure C.4: *[ON NEXT PAGE] Photos from the Plantise visit. a: Sowing machine that can sow seeds in trays. The trays are made from polystyrene and have rock wool growing media. The rock wool is sprayed with water and nutrients, where after the seeds are placed. The seeds are covered with a layer of vermiculite to protect the seeds against overheating and drying out. b: Tray with rock wool growing media. c: Vacuum placing roll. d: Germination test in trays in a greenhouse.*


a
Warning!
Several different batches in this box!


b


c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