AeroAlarm

Final report

Food sustainability & resilience of households through urban gardening in today's global crisis

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Abstract

Aeroponic farming requires fewer resources, produces higher yields, and is located in urban areas which reduces the reliability of global food supply chains. Most industrial farms only grow leafy greens. But why do systems for more nutritious food like potatoes not scale up?

The technology-savvy aeroponic potato farmer faces the challenge of a high fragility of the aeroponic system while having a low knowledge of plants and limited visibility. The extensive root system of the potato plants is hidden in closed modules. Thereby, the farmer easily misses if issues come up with the plants. Additionally, human monitoring only increases the risks of spreading pests in the system and damaging the plants. At the same time, the plant can die within minutes if the water or nutrient supply fails. The farmer is in need of reliable and continuous insights on the health of the potatoes without human interaction as well as support in identifying the cause and applying treatment efficiently to prevent crop loss.

In our solution, we apply the *IALL* lens technology which is a flat lens that can focus on high speed without manual control through the application of electrical fields. We combine this flat lens with camera technology into a holistic IoT system. In this system, the camera records the roots of the potatoes in the aeroponic modules and sends the image to a cloud where it is processed into data. Based on the processing results, the farmer receives alarms if there are issues with the plant as well as reaction recommendations in an app. Thereby, we provide the opportunity to react fast and efficiently to prevent damage to the plant and the system. Overall, *AeroAlarm* makes aeroponic potato farming on an industrial scale more reliable, profitable, and thereby scalable.

The project is conducted with *ATTRACT* as a partner which is an EU research consortium on science innovations. Also, the project is part of the global innovation design network *SUGAR*.

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1. Introduction

This design thinking project started in October 2022 with the initial design challenge “Re-design ‘the kitchen garden’ for 21st century food self-sufficiency and resilience, while drawing inspiration from the *IALL* technology”. The project is conducted with *ATTRACT* as a partner who is an EU research consortium on science innovations. Also, the project is conducted as part of the global innovation design network *SUGAR*. Throughout iterations during 9-months of design thinking, the team finalizes the project with a solution to the challenge “How to scale up aeroponic potato farming”.

Aeroponic potato farming is a technique with which potatoes are grown by hanging in boxes in air and being sprayed with water through nozzles in intervals. This water contains all nutrients the plants need. Although this solution has many advantages like requiring less resources than other farming techniques, producing higher yield, and reducing the reliability on global and fragile food supply chains, the system does not scale up. Most companies do not even grow potatoes but focus on leafy greens only. But these do not feed the population.

After over four months of problem space exploration and applying a wide range of design thinking methods like prototyping, futures thinking, or anthropology research, the team identified user problems of the professional aeroponic potato farmer which explain drawbacks of these systems. The aeroponic systems are fragile and need close monitoring to identify issues at an early stage. Clogged nozzles are a common issue to the system which leads to a dehydration rapidly. The plants can start to die within a couple of minutes already. The biggest limitations to identify these issues are that the tech-savvy farmer lacks expert plant knowledge to identify the issues, has limited visibility as the roots are hidden in a closed module, and increases the risk of spreading pests with human interactions. Thereby, the monitoring options especially on an industrial scale are limited. Human monitoring is time-intensive and increases the odds for crop loss on a large scale.

With *AeroAlarm*, the team developed a solution which provides the farmer with insights on the plant health at any given time. Also, it sends out alarms on critical issues including precise action recommendations to apply treatment as efficiently as possible. *AeroAlarm* is an IoT system which is a technology that is established in smart farming today. The *IALL* lens is combined with imaging technology which is located within the aeroponic growing modules to record images of the roots. These images are pushed to the cloud where they are processed into data and turned into valuable insights to the farmer’s app. Now, the farmer always knows what is going on in the aeroponic potato farm without the risk of spreading pests through human monitoring. In addition, he can react quickly and is target-oriented on upcoming issues.

In the following report, the background is given on the project itself, the IALL lens and imaging technologies, as well as different urban farming approaches (section 2). Also, the problem space exploration through design thinking is explained (section 3) as well as the solution (section 4) before ending with the conclusion and future outlook (section 5).

2. Background

Project background

During the 9-months-long runtime of the project, the team explored a wide range of urban farming approaches as well as application cases for the *IALL* lens technology to discover a meaningful human-centered problem to innovate towards. A central pivoting point in the project was when the team realized that they could not identify critical issues from the perspective of the community-based farmer, especially when it comes to a solution with technology. Therefore, the team focused on the professional urban and tech-based farmer in aeroponics as a focus user for the solution. The two evolved focus areas are thereby *imaging and monitoring technology* to apply the *IALL* lens as well as *professional aeroponic farming*. In the following the background is explained to understand the variety of urban farming techniques as well as the field of imaging technologies.

IALL lens and imaging technologies

The *IALL* lens is a tuneable lens technology based on liquid crystals (Geday, 2022). With liquid crystals, the speed of light passing the lens can be altered with an electrical field. This enables that *IAll* can work like a fast and agile magnifying glass and is characterized by its flat shape. Combined with an imaging technology, it can adjust the focal length in high speed without manual zooming to catch images (Figure 1). Usual lenses have a convex shape and mut be adjusted manually which requires more time to adjust. The *IALL* lens It is used in microscopy, as it can focus without moving parts with a response time less than 0.1 seconds, making is specifically suitable to combine with hyperspectral imaging (Geday, 2022). Other use cases of *IAll* include telescopes, digital cameras, and LIDAR (light detection and ranging). According to the inventors, manufacturing the *IAll* lens is simple, and its size can vary from microscopically small to several centimetres (Geday, 2022). It is important to understand that the technology is a lens and needs to be combined with an imaging technology to record images.

*Figure 1 Functionality IALL lens (Source: (*Cemdatic Develops Flat Lens*, 2020))*

Some aeroponic startups like *Infarm* do use sensor technologies for utilizing biofeedback to learn about their plants (Infarm, n.d). To apply the *IALL* lens in a purposeful manner, the team focused on visual imaging instead of biofeedback sensors. Imaging itself is a broad field as different technologies exist to image a range of images across the light-spectrum, from infrared to ultraviolet (Figure 2). Where inspections of a plant in the visual light spectrum (800nm-400nm) are limited to the level of human vision, the application of ultraviolet imaging (400nm-100nm) can deliver images on a more detailed level because the smaller wavelength leads to the identification of more detailed structures.

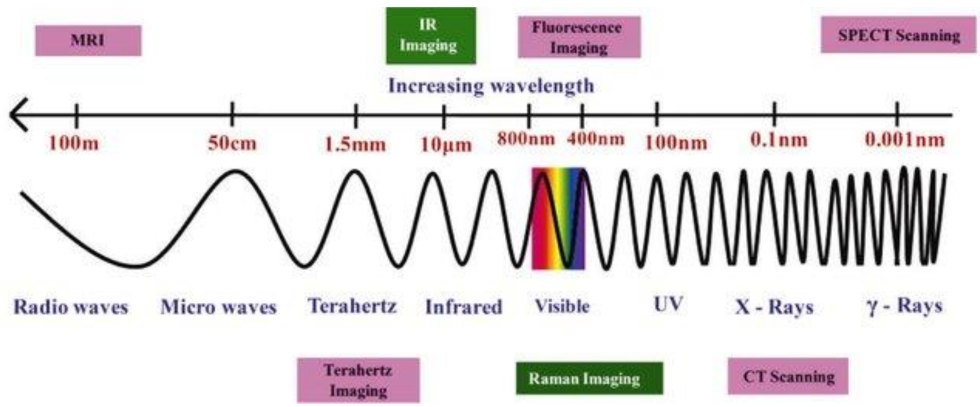

Figure 2 Wavelenghts for different imaging technologies (Source: (Gautam et al., 2015))

In the medical field, diverse imaging technologies are applied. For example, in microscopy, different imaging technologies are used to gain better results (Schultz et al., 2001.). Similar methodology could be implemented in plant monitoring, for example, hyperspectral imaging. Figure 3 shows exemplary results of hyperspectral imaging for skin functionality (*Hyperspectral Imaging*, n.d.).

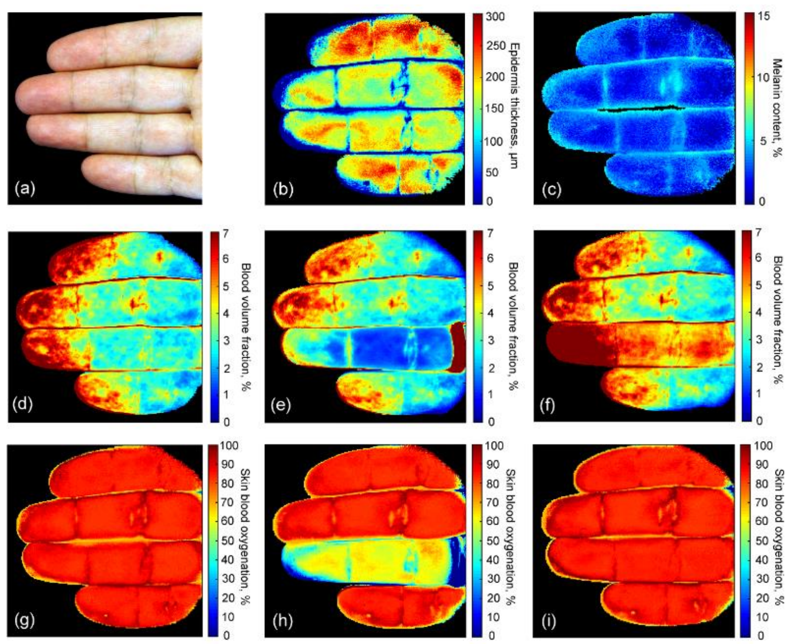

*Figure 3 Example of hyperspectral imaging on skin (Source: (*Hyperspectral Imaging*, n.d.))*

Hyperspectral imaging considers a larger spectrum of light, making it possible to detect changes in the challenging environment. Each light pixel is deconstructed into their own spectral bands which generates more broad information of what's imaged which is especially beneficial in the area of plants and food. Here, the detailed insights on a microscopic level can be leveraged to guarantee a certain level of food quality and detecting issues.

Use cases in urban farming

Community-based or rooftop farming was the first area the team researched as a starting point in community farming, a community which mostly lives around a certain area comes together to maintain a farm in the urban area with shared responsibility. Most often, classic farming techniques with soil are applied. But also vertical or hydroponic farming as the team learned from site visits in the field. During community-farm visits at the *Dodo* farm (Figure 4) or the *Aalto testsite* the team quickly learned that the members value a minimum of technology and enjoy the experience with nature (Dodo urban farm, nd; The Test Site, n.d.). They gain value from enjoying the farm as a space for rest and peace instead of seeing the value in producing food only. The team quickly learned that this potential target group has little interest in improving processes with tech and prefers their own low-tech DIY solutions. The communities are built slowly and emphasize individual responsibility instead of systemic or technological innovation.

Figure 4 Indoor garden house community-farm Dodo (Source: (Smith & Heden, 2012))

Another urban farming approach is modular. This relates to different types of urban gardening as rooftop gardening but also large-scale industrial urban farming. For example, start-ups like the *Urban Green Club* offer growing modules with soil for rooftop or balcony gardens as presented in Figure 5 (Urban Green Club, n.d.). Or the start-up, *Let Us Grow*, offers rolling benches for aeroponic farming on an industrial scale as presented in Figure 6 (*Aeroponic Rolling Benches, n.d.*).

Figure 5Growing module urban green club (Source: (Urban Green Club, n.d.))

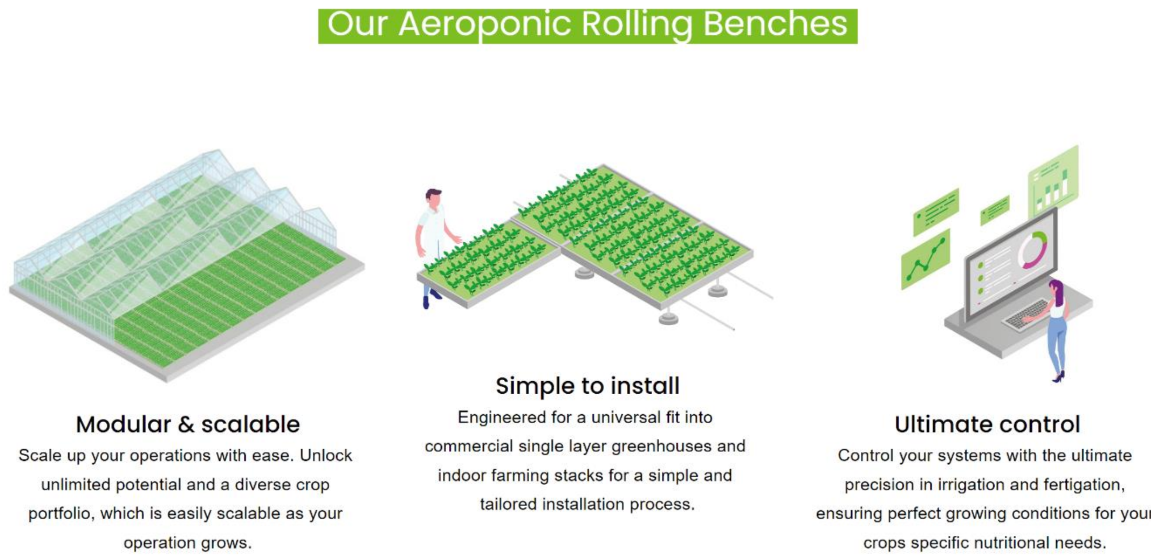

Figure 6 Modular aeroponic rolling benches Let Us Grow (Source: (Aeroponic Rolling Benches, n.d.*))*

With entering the modular urban farming, the team first encountered the large scale and tech-based field of urban farming which seems to have a higher potential for monitoring and a tech-based solution compared to community-based farming for individual communities.

In underwater farming, diverse farming techniques are positioned like algae-farming, fish-farming, or hydroponic and aeroponic farming itself. After a short investigation in the field, the team pivoted away as the field itself showed immense complexity which would have required a deeper time investment which was not possible at the progressed timepoint in the project. However, farming on and around water remains an impactful application case for the future as unused spaces can be leveraged as an alternative to limited geospatial space on land (Figure 7). Also, innovative projects open up new possibilities for farming as the scientists of the *Neo underwater garden* showcase (Figure 8).

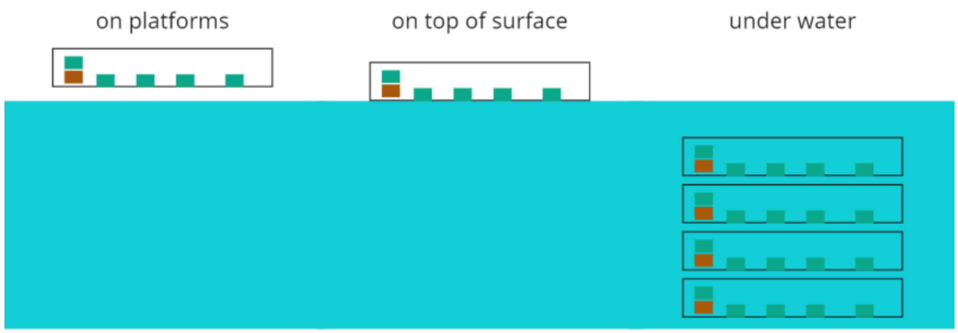

Figure 7 Application cases of farming related to water (Source: Illustration by Alischa Thomas)

Figure 8 Neo underwater farm (Source: (Traverso, 2019))

Despite the various application cases of urban farming, the central applied techniques seem to be *hydroponic* and *aeroponic* farming. Whether applied underwater, in modules in a community-garden, or on an industrial scale in warehouses. In both techniques soilless farming is applied where roots are provided with a nutrient-rich water solution (Figure 9). In hydroponics, the roots swim in a water-solution and in aeroponics roots are sprayed with a nutrient-rich mist.

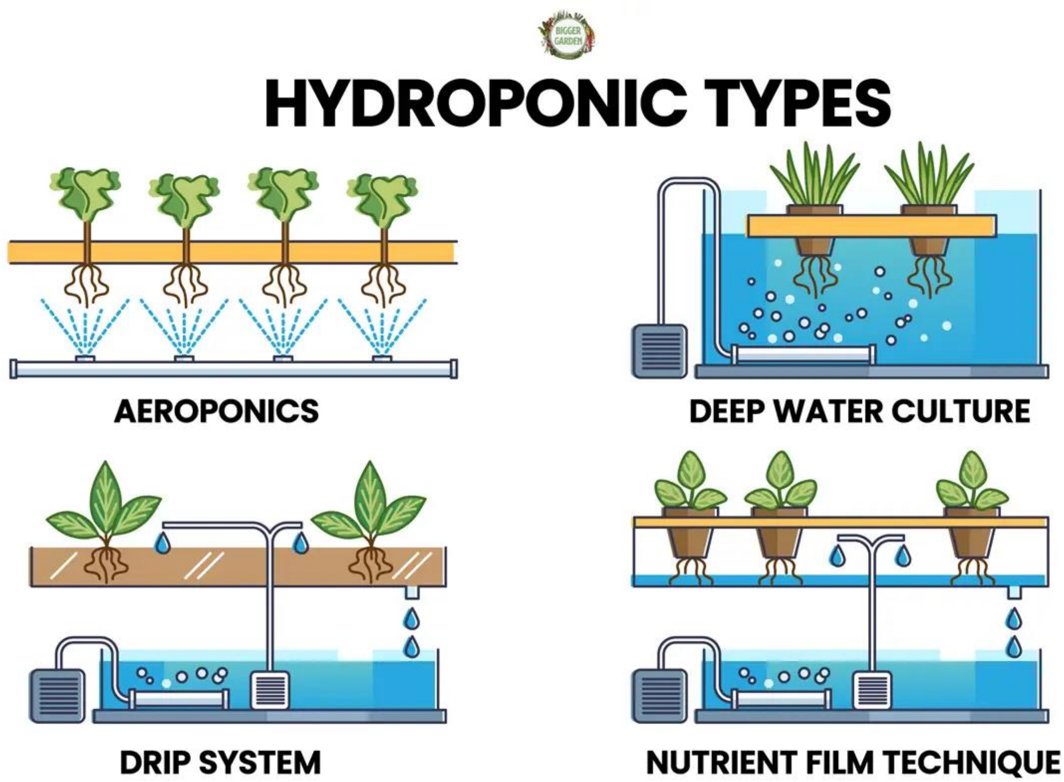

Figure 9 Types of hydroponic and aeroponic systems (Source: (Brock, 2023))

General advantages of both techniques are that they require less resources especially when it comes to soil and can produce higher yield because they grow in a highly controllable and optimized environment. For example, they are provided with the right amount of light, water, oxygen, and nutrients (*What Are the Benefits of Aeroponics?,* 2023). However, the aeroponic system uses even less resources as the water is only sprayed as mist on the roots each couple of minutes whereas the plants must swim in water in a constant flow in hydroponic systems (Klinger, n.d.). But, aeroponics are highly suitable for vertical farming and fitting into urban spaces as shown in Figure 10. Also, the aeroponic system leads to a 22% higher yield outcome compared to hydroponics according to experimental trials of *Let Us Grow (2023).* However, aeroponic systems are much more expensive and complex to initiate as well as maintain. Thereby, hydroponics can easily be installed even in community-based gardens through DIY solutions whereas aeroponics require a higher level of technology expertise. In addition, the system is more vulnerable because the plants rely on a closed cycle of water and nutrient supply. One learning from interviews with experts at the *Urban Farm Lab* at *Metropolia University of Applied Sciences Helsinki* one of the main error-sources in aeroponics are clogged nozzles which lead to a lack in water supply which can lead to plant failure within minutes (*Urbanfarmlab, n.d.*).

*Figure 10 Vertical urban aeroponic farming (Source:(*The Hydroponic / Aeroponic / Aquaponic – Vertical Farming Debate*, 2022))*

In aeroponic and hydroponic farming, a crucial market limitation is currently that mainly only leavy greens and berries are grown. In hydroponics this is explained due to the limitation to small root systems. Big root systems could block the water flow which limits the product range to food with small root systems. In aeroponics, also food with extensive root systems as potatoes can be grown as the start-up *Aeropod* showcases (Figure 11). The potato is one of the most used food plants and also highly used in traditional Nordic kitchen, making it very appropriate use case for the project (Kjølberg, 2021).

Figure 11 Aeroponic potato farming (Source: (Aeropod, n.d.))

In a nutshell, the aeroponic potato farming shows many advantages over other farming systems. For example, it uses less resources, it produces higher yield, and it enables opportunities to grow more nutrient-rich food compared to leafy greens. Still, the system is blocked from scaling up due to the system's fragility. Therefore, the team redefined and crystallized the initial design challenge highlighted in the introduction to "How to scale up aeroponic potato farming?". By tackling this challenge through applying the *IALL* lens, the team contributes towards scaling up a value-adding farming technique. The user in focus of the project is the professional aeroponic potato farmer who has a stronger background in farming technologies than in the food itself.

3. Design Thinking Journey: Problem Discovery

Design Thinking and Prototyping

The basis of the project has been to follow the mission structure outlined in Figure 12. The aim was to split and proceed the phases in more tangible action plans while keeping the essence of design thinking within the project.

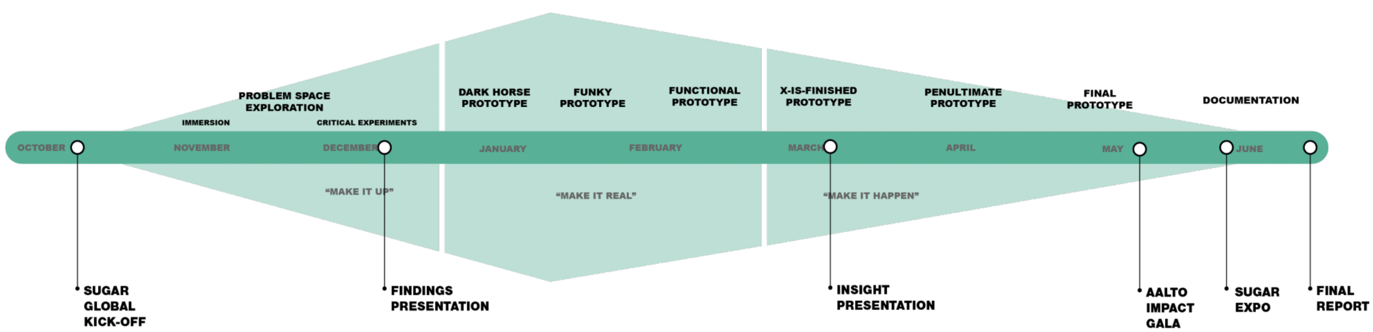

Figure 12: SUGAR Network Shared missions (Koskela, 2022)

Within each mission, the intention was to implement the iterative design thinking circle (Figure 13) to form the action plan. In each mission, the challenge had to be modified to be suitable for the varying context. Then it was important to understand the problem and its stakeholders better, and this was usually achieved through interviews. After that, it was important to create a common alignment for ideation to create a more tangible direction. Prototypes were developed in each mission to serve chosen issue area and each prototype was tested to gather feedback, validation, future ideas and a shared understanding of the topics.

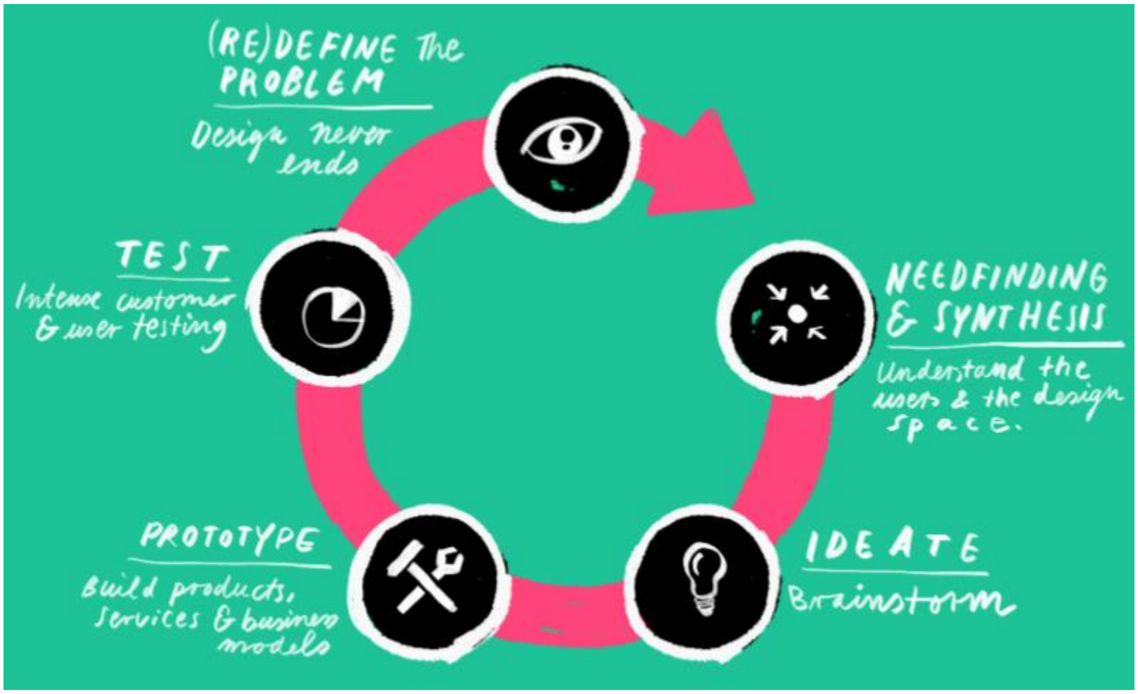

Figure 13: Iterative Design Process (Sugar, n.d.)

The iterative brief was explored through the different type of prototyping approaches which included Early prototyping, Dark horse prototyping, Funky prototyping, and Functional prototyping. By combining the most important and feasible insights gained from these prototypes, the goal was to move into final concept space and its prototyping - what is the final problem and how it is solved. That being the final prototype to be showcased in several expo events.

In early prototyping, the key thing was to briefly explore the areas that started to become clearer. The aim was to get some foundation for the prototyping journey. User experiences and interviews with individuals interested in urban farming provided strong indicators of decision-making and design research. Information was sought to understand urban farming requirements, what interest people in urban gardening activities, what are the biggest challenges with urban gardening and what is the common association with urban gardening. Topic concepts in early prototyping were fresh plant wending machine and hydroponic system integrated in everyday water sources (Figure 14). Along the rapid prototyping journey there were constantly coming new ideas that were interfering with the ongoing work. To solve this, a brain dump was made to keep the value of the ideas and still get them out of the system to be later analyzed and thought more thoroughly with the team.

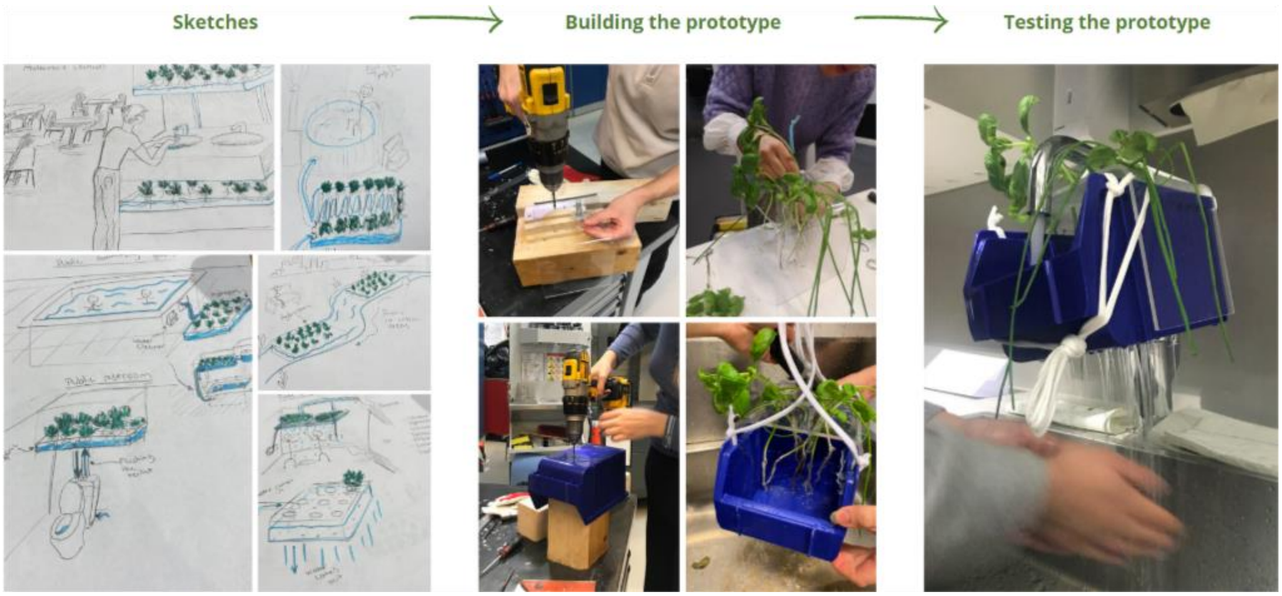

Figure 14: Hydroponics growing implemented in existing water sources

Key learning from the prototyping were that live photo of plant has user value, location for the food should be conveniently close regular life journeys, there is a need for healthy snack options, there is curiosity regarding new technological growing solutions and people do not mind having farms in their everyday lives. Through the learnings, personas were defined, representing different mindsets, including a more hedonistic household and a more utilitarian household. And to balance, three more observing role personas were created: Urban Garden, Food and Earth. Key was to emphasize to understand the topic and the impacts of different type of users.

After the initial prototyping, it was time to unleash creativity and proceed into Dark Horse Prototyping with the aim of forgetting limitations and assumptions – let creativity shine. This way, new concepts and mindsets could be explored, and new kinds of prototyping learned. The prototyping was supported by speculative, proactive, and radical designs through different workshops and exercises. Coming from the convenience of everyday life actions, the first prototype in this phase took it to extreme with delivering plant ingredient straight into kitchens (Figure 15). Important factors were brought up in user testing such as what are the effects and needs in grocery shopping, value in more organic growing and experience, quality should be very good, city infrastructures are opposing.

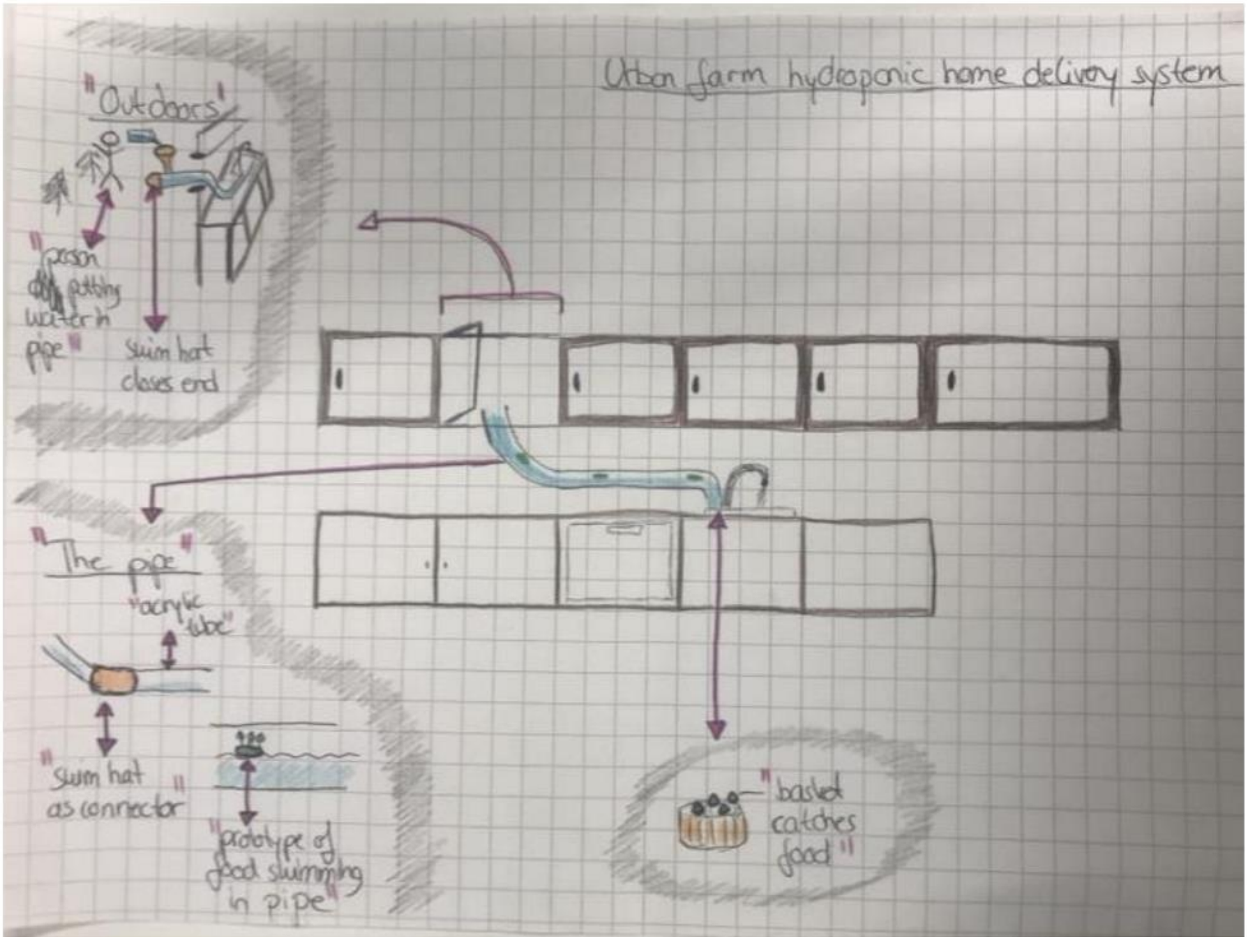

Figure 15: Sketch of ultimate convenience system (Scribble by Alischa Thomas)

Another prototype to broaden up the possibilities over the assumptions was a hyper modular farming block system with automated growing environment (Figure 16). In these modular systems, a new range of different varieties could be cultivated around the year. The systems could be built on top of each other freely enabling positioning in challenging unused spaces and urban areas. App mockup was made to support the modular idea to bring the users to use and create shared value with renting the systems to grow local food and use or distribute them.

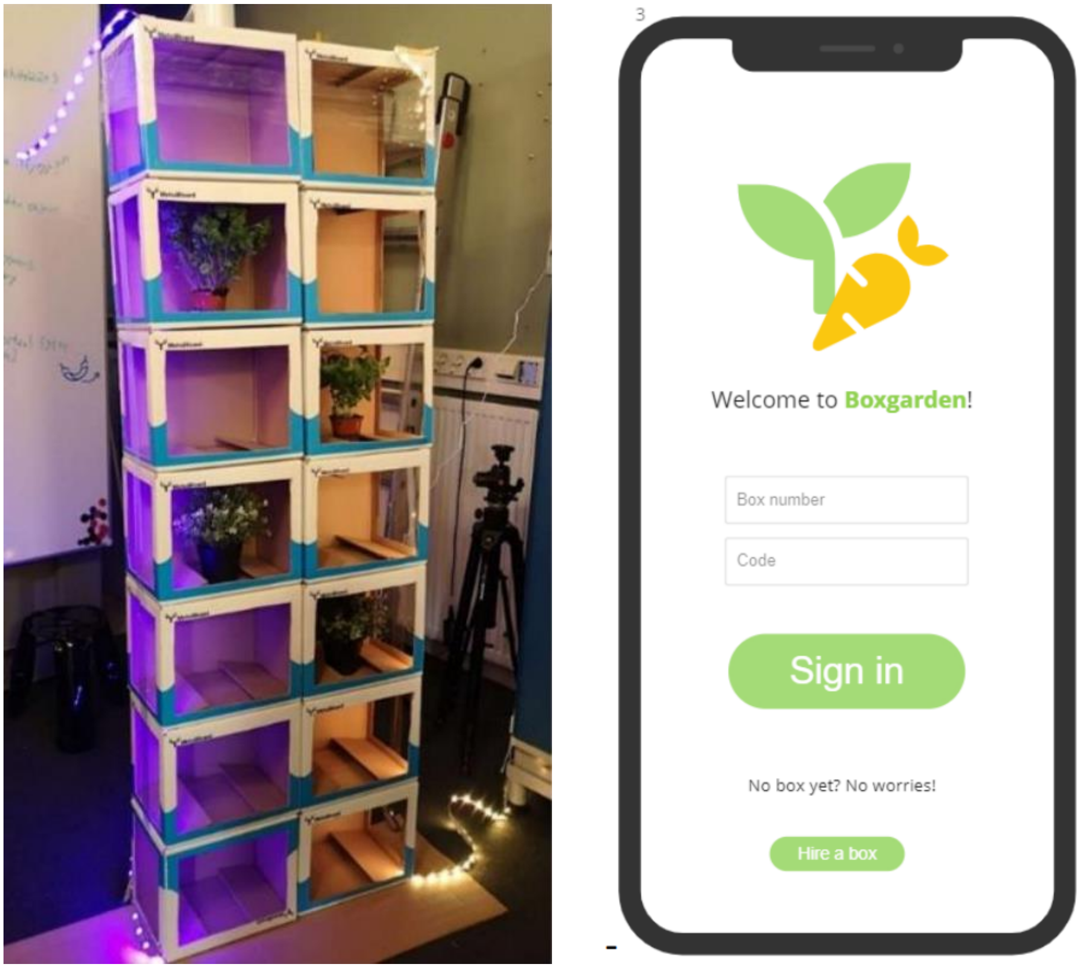

Figure 16: Modular growing system and user app mockup (Image and wireframe by team)

A broader understanding of prototyping was beneficial when it was again time to rationalize and start to prepare a more cohesive concept with actual value and problem-solving in it. FunKy prototyping mission was all about starting to conceptualize and converge. The design thinking aim was to get as much functioning as possible with low costs to represent the wanted concept. In this phase, important aspects were explored and conducted through more expert interviews and site visits to inspire the bigger need for feasibility. Here the journey tried to find its space in the underwater growing systems (Figure 17), which turned out to be a more challenging environment than anticipated, and therefore not continued to further phases.

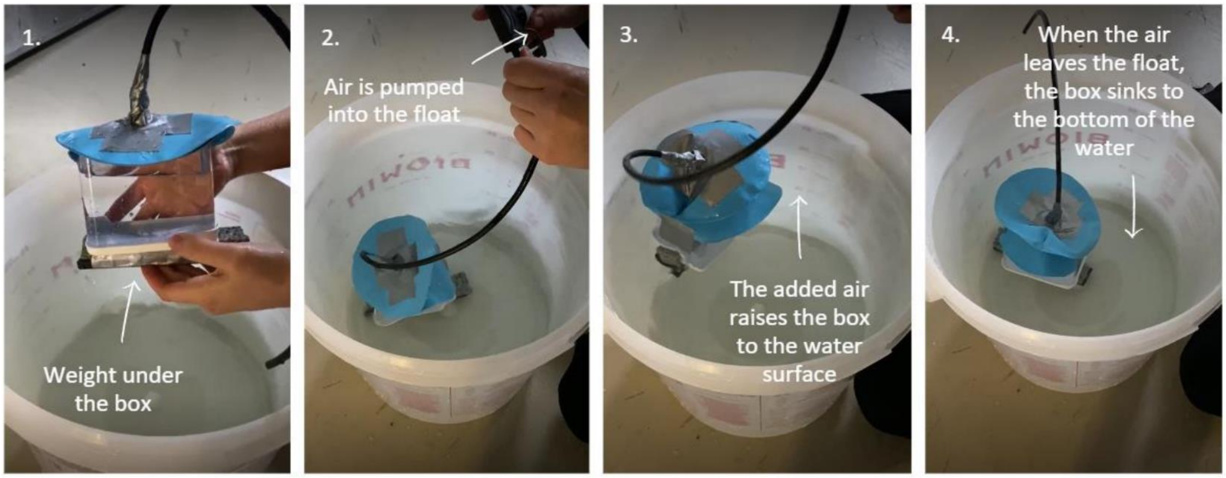

Figure 17: Underwater farm module (Images by team)

Continuing to Functional prototype mission, where the system was aimed to be already fully functional to deliver its value, the decision-making had to be improved. Prototype had to be put in the middle of the topic synthesis and there were multiple differing interest areas. Multiple workshops were designed to find alignment in the problem area. Going back on previous interviews, research, and user tests we distinguished one continuous topic brought up many times in different forms – monitoring of plants. Many users valued quality, convenience and seeing the whole plats status easily. Here the design approach was for the more mechanical side (Figure 18), which turned out to have less notable value to the user than the monitoring itself.

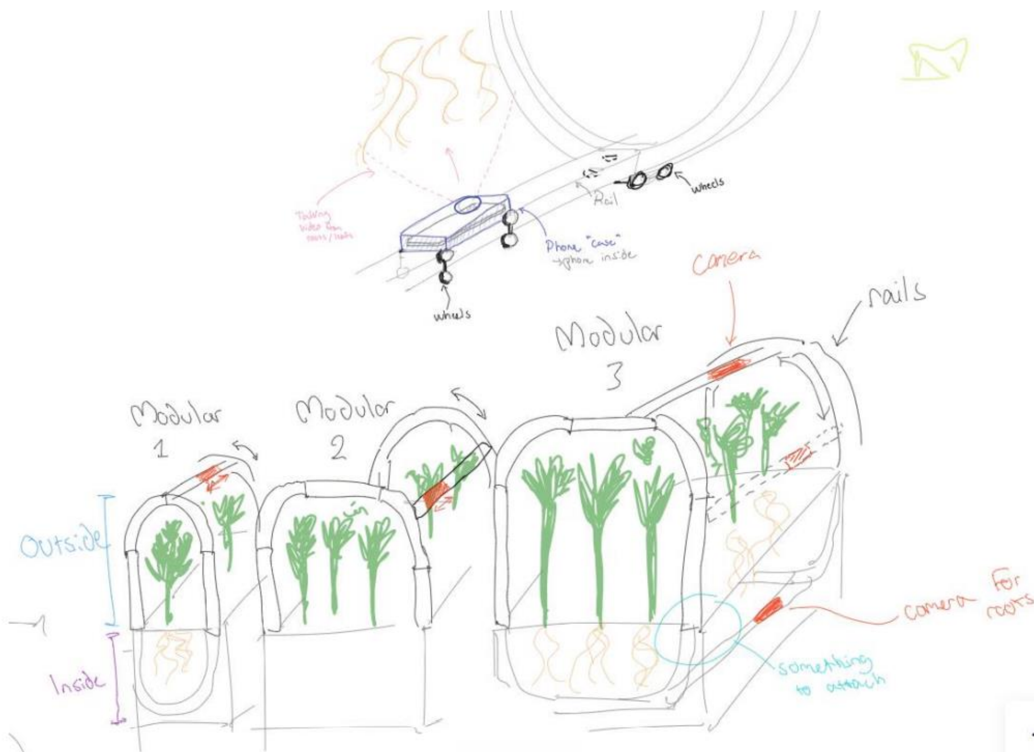

Figure 18: Moving camera system for aeroponic plants (Scribble by Linnea Seeskari)

Then to find out what monitoring actually includes, and what help users would desire, a design workshop was held to get final best possible alignment through different exercises and combining results. For example, crazy 8 method was used to get everybody ideate on the design requirements of the final solution. Following was deconstruction, categorizing and prioritizing the requirements with multiple iterations to plan a realistic and feasible journey.

User problem

Throughout the design thinking journey, the focus lied on understanding the users within the field of urban farming and especially in aeroponic farming. In the beginning of the project, the focus was on community-based farming. A wide range of design research, supported by above presented prototypes, was conducted to understand the different approaches in urban farming. Additionally, interviews, site visits, and co-design workshops were conducted to understand the mindset of different users. In the beginning the focus was on the end-consumer mindset and experience with daily food consumption especially in supermarkets. Also, research was conducted on the experience and problem in community-based farms. The team learned that there is existing problems and needs on the end-consumer side and in urban farming communities. But no valid use case was discovered for the application of the *IALL* lens technology that is feasible, viable, or desirably from the user's perspective. At this point, the team shifted the focus to more tech-based types of urban farming, such as aeroponic farming on an industrial scale. After more site visits, for example, to *the Urban Farm Lab at the University of Applied Sciences Metropolia* in Helsinki, which serves as a start-up development hub for urban farms, or to users of aeroponic growing modules like the *Otaniemi Upper Secondary School*, the team identified the value of aeroponic farming but also relevant user-centered problems.

The team discovered that aeroponic farms on the industrial scale do exist but are limited in product range by mainly focusing on lettuce and herbs (Figure 19). While there are existing aeroponics farms for potatoes, the majority does focus on leafy greens. Thereby, the user problem space crystallized towards the professional aeroponic farmer (Figure 19) and what problems does they face that prevent farms for more nutritious products as potatoes to scale up (Figure 20).

Figure 19 User: Aeroponic professional farmer (Source: (Dongoski, 2019))

Figure 20 Aeroponic potato farm (Source: (Contributor, 2023))

The tech-based potato farmer faces two major challenges. First, little plant knowledge and second, a limited visibility into the growing modules of the aeroponic potato systems. Most of the plant is hidden in the modular boxes and the extensive root systems of potatoes make it hard to see the health status of the plants in every location in the module matrix (Figure 21).

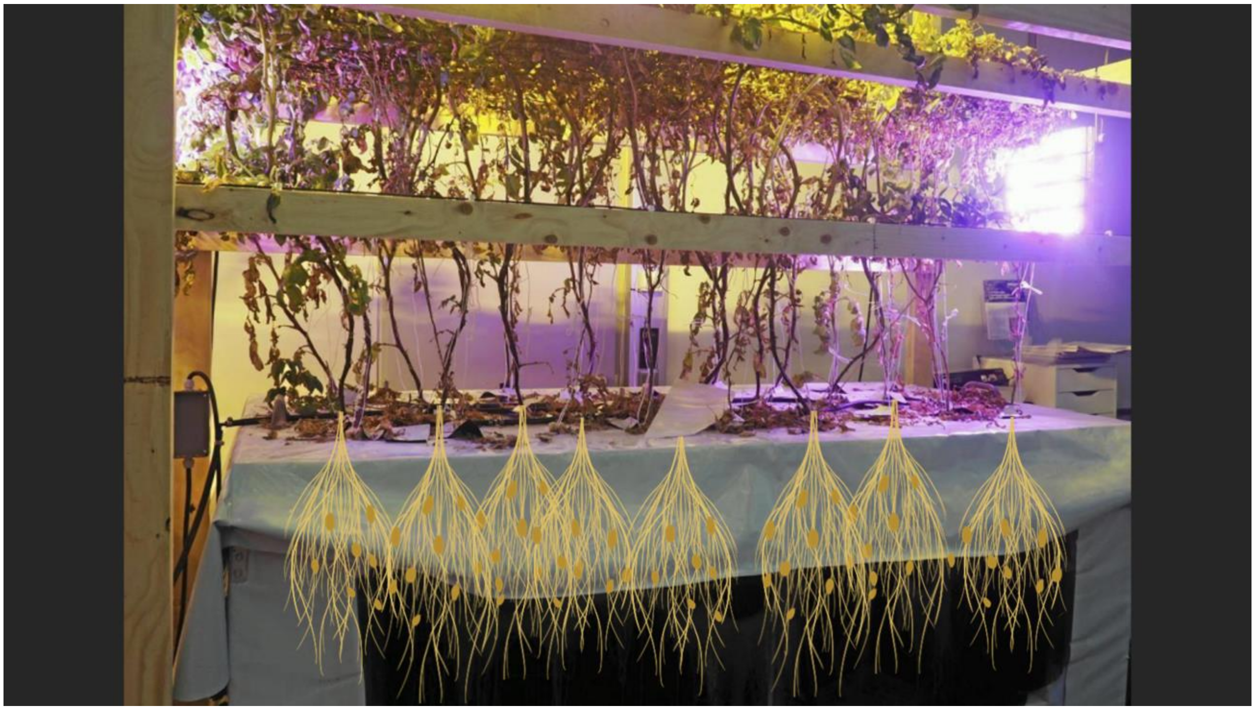

Figure 21 Simulation of aeroponic potato system (Illustration by Linnea Seeskari)

This limited knowledge and visibility becomes critical quickly for farms on an industrial scale. On issues, plants can start to die within minutes according to conducted expert interviews or whole systems can start failing. For example, clogged nozzles are frequently cause a lack of water and nutrient supply due to the salts in the water. Regularly, human interactions when the farmers interact with the plants, bring pests into the systems which can infect the whole crop. Thereby, the tension exists that the farmers need to be aware of the health status of the plants at any given timepoint but increases the odds to put the plants at risk by every human interaction. Even if the farmer notices that there is an issue with the plants, the issue can root from a diverse set of causes. With experience, the farmer might be familiar with the major causes and how to apply efficient treatment. On an industrial scale, employees with a diverse experience level are at work who might lack of knowledge how to react quickly. Also, plants are complex organisms and aeroponic farmers need to reach out to external experts to get consultation on possible causes and treatments. All these steps require time resources which is the crucial factor that leads the plant or the system to be damaged in a critical way.
Overall, we found that there is a need for reliable and continuous insights on the plant and system health as well as support in identifying causes for issues as well as applying treatment efficiently as a professional aeroponic farmer.

4. Solution: AeroAlarm

IoT System Architecture

The solution that helps to detect issues on the aeroponic farm early and supporting the farmer in detecting and treated it efficiently, is an IoT system. IoT systems are already implemented in many farming cases, which is then called smart farming. For example, sensors are used at vast vineyards and send out data via long distance networks to get constant insights on the state of the plants (Lavrut, 2022). In our case we leverage the existing IoT smart farming techniques and design a system architecture in combination with the IALL lens for the use case of aeroponic potato farming. Figure 22 shows how the technical IoT architecture of a smart farming solution looks like by using the IoT platform *Thingsboard*. For the IoT solution of *AeroAlarm*, we orient towards this IoT structure and customize it for the use case of monitoring potato roots in aeroponic modules (Figure 23).

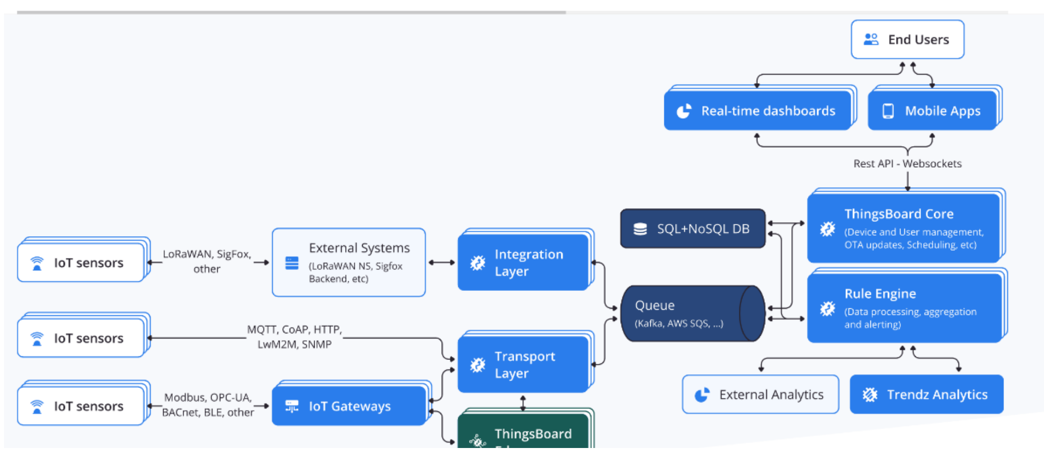

Figure 22 IoT System Architecture Thingsboard for the use case of smart farming (Source: (Thingsboard, n.d.))

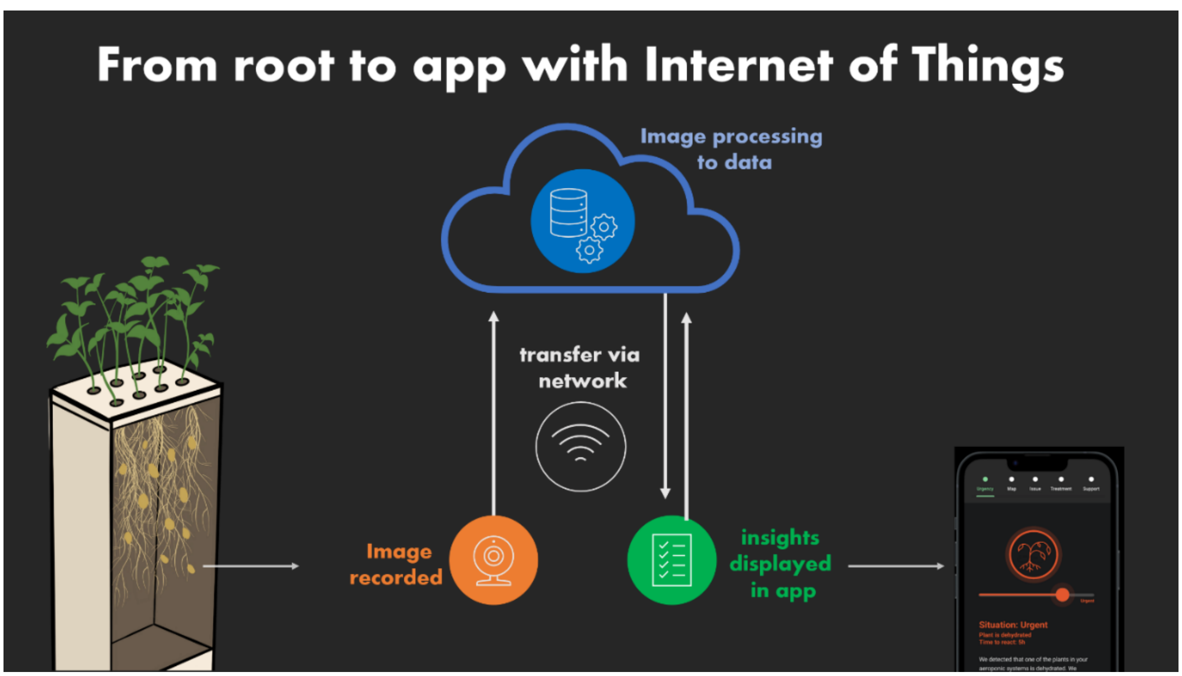

Figure 23 IoT Solution System Architecture (Design by Alischa Thomas)

On a metalevel, the IoT architecture consists of six steps which are introduced below and explained in more details in the ongoing chapter. Steps three – four have been simulated by the team to test for the feasibility of the concept. All other steps have been researched well a use cases have been found which back up the feasibility.

Step 1: Record image with sensor in farm

First, the *Thing* which is the *IALL* lens, which is introduced in section 2, combined with an imaging technology. This imaging technology is located insides the aeroponic potato modules to monitor the roots. Through additional LED lights which flash for the moment the image is taken only, the darkness in the box can be maintained while recording the images of the roots. A live image is not necessary, but images should be taken on a regular interval to create a constant data stream. The flatness of the IALL lens, the high speed of focusing to different points of the roots, as well as low production costs are themselves beneficial features already which enhance existing imaging technologies in smart farming.

Step 2: Send image to IoT Cloud Thingsboard

Second, the images are sent via the installed *LoRaWan Network* to the *Thingsboard* cloud. *LoRaWan* networks as presented in Figure 24 are long range area networks especially used in farming (*LoRaWAN, n.d.*). *Thingsboard* includes relevant IoT features like a rules engine and is applied in smart farming use cases, too (Thingsboard, n.d.).

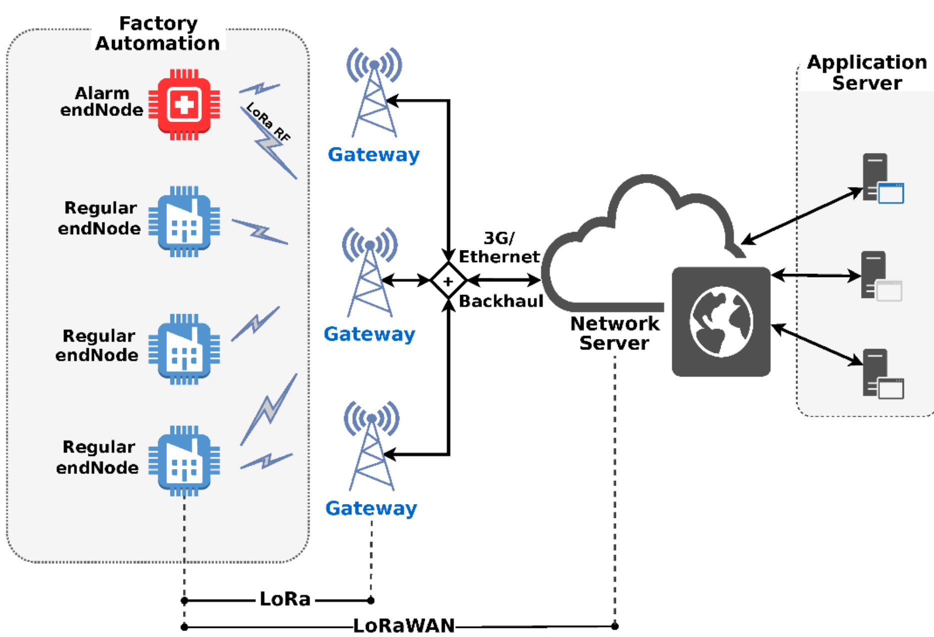

Figure 24 System LoRaWAN (Source: (Filho et al., 2020))

Step 3: Process image with Python script opencv

Third, via an embedded *Python* script in the *Thingsboard* cloud, the API of the cloud-based image processing script *opencv* is utilized (*Opencv-python*, 2023). With *opencv*, the image is processed by recognizing the roots forms and calculating the diameter of the roots system (Figure 25). The results of the image processing, the diameter in cm, is stored in a *JSON* format which the *Thingsboard* can process. Figure 26 shows a simulation of data from the aeroponic module being send to the *Thingsboard* cloud. In the simulation case, the HTTP POST request sends data on the humidity state and the root diameter. Figure 27 shows how this data is accepted and stored in the *Thingsboard* cloud.

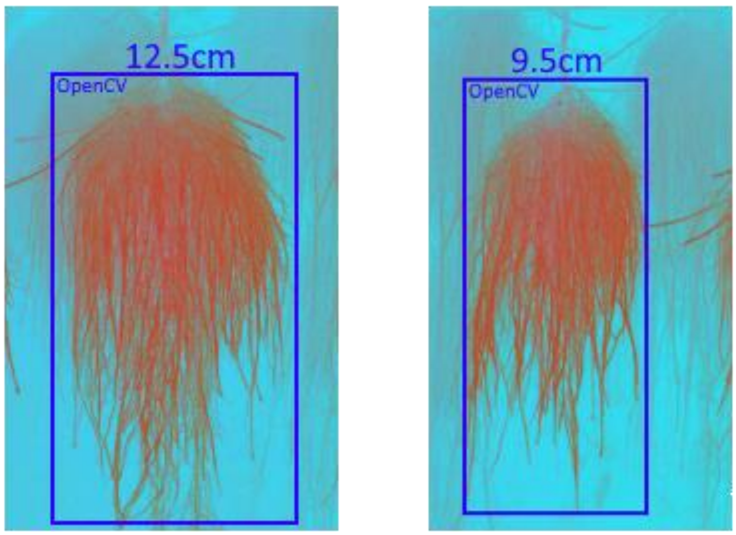

Figure 25 Simulation of image processing in opencv of roots system (potato Images source (Aeropod, n.d.))

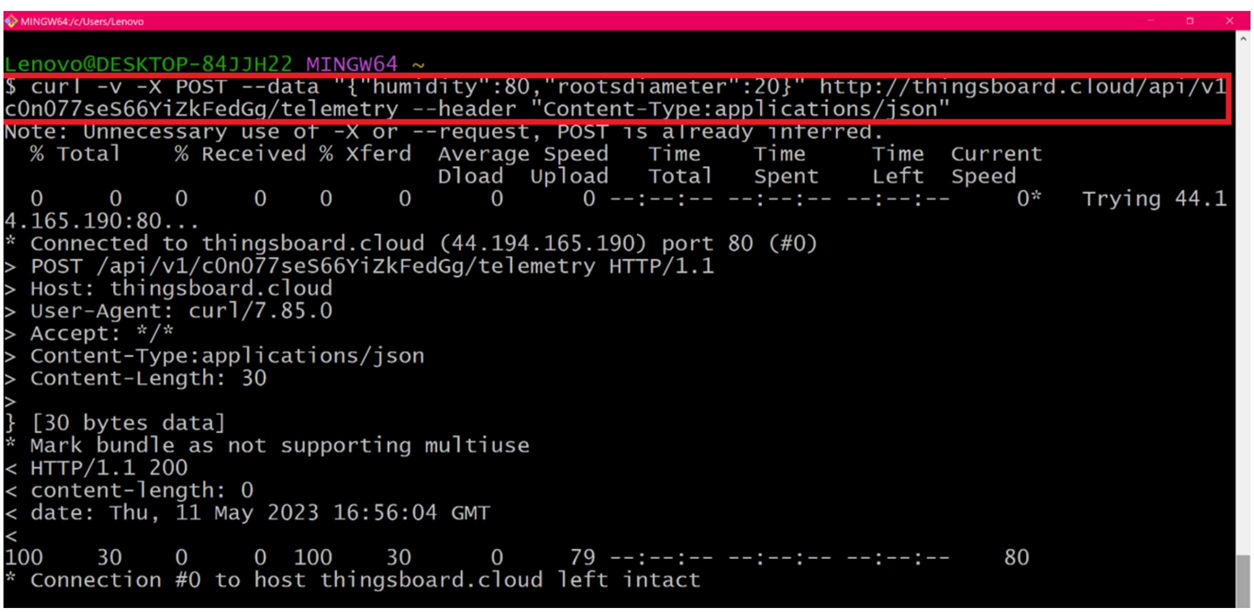

Figure 26 Simulation in Git bash: HTTP Request sending data from farm sensor to Thingsboard cloud (Screenshot Alischa Thomas)

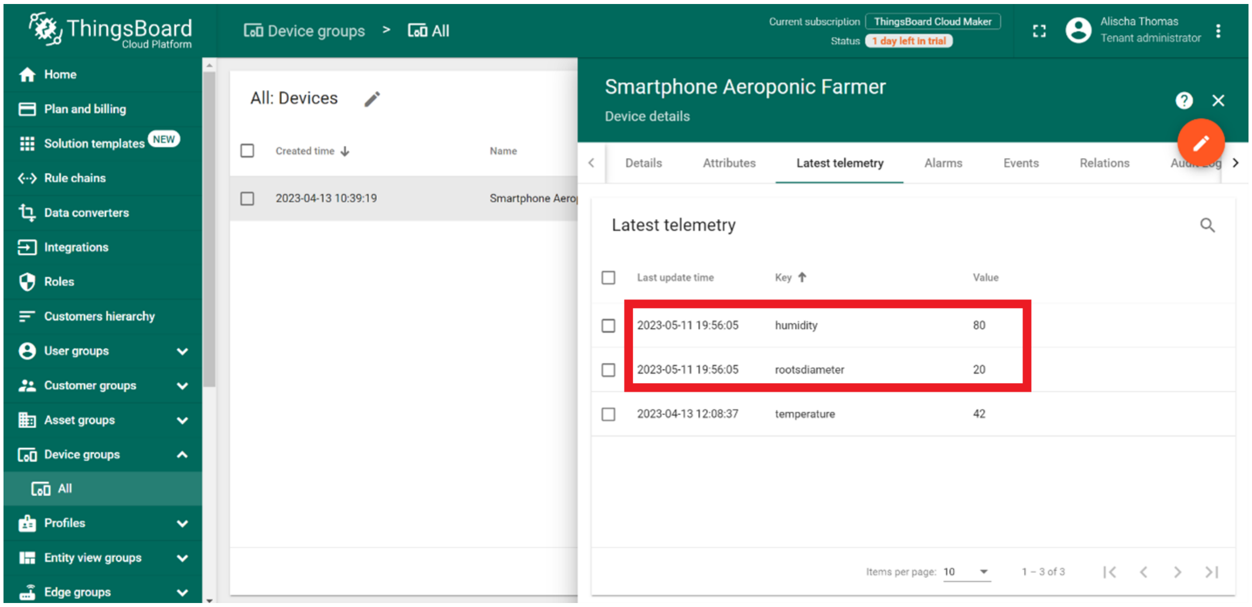

Figure 27 Simulation fetched data Thingsboard (Screenshot Alischa Thomas)

Step 4: Process the data extracted from image with Thingsboard Rule Engine

Next, the *Thingsboard* evaluates based on pre-determined rules whether the data should trigger an alarm or not. For this, the integrated rules engine in *Thingsboard* is utilized. For example: if the diameter of the roots system is too small. In the example in the image below you can see a rule which says that the temperature should not be between 39 and 79 degrees. If not, it returns a message which says "undefined". For our use case of the root system, the rule engine would include rules about the appropriate size of the root system. For example, if the root system is compliant with the size of a healthy root system, the message "root system okay" would be send.

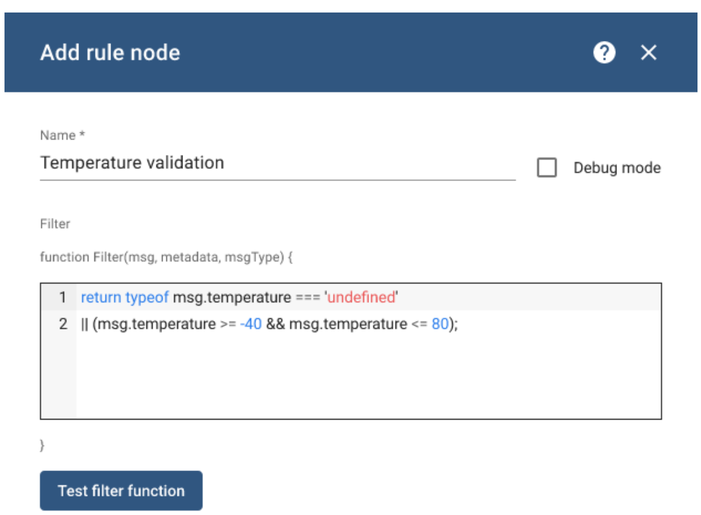

Figure 28 Example of a rule evaluation in rule engine of Thingsboard platform (Source: (Thingsboard, n.d. - b))

Step 5: Actions based on Rules Engine results: sending alarms

Fifth, depending on the outcome of the data processing with the rules engine, results are sent out to the farmer's app respectively. If the data do fulfil the criteria, the farmer can see the positive health status of the plants in the app. Only if the data do not match the criteria, the farmer receives an alarm to the smartphone with a notification indicating the severity of the plant's negative health status.

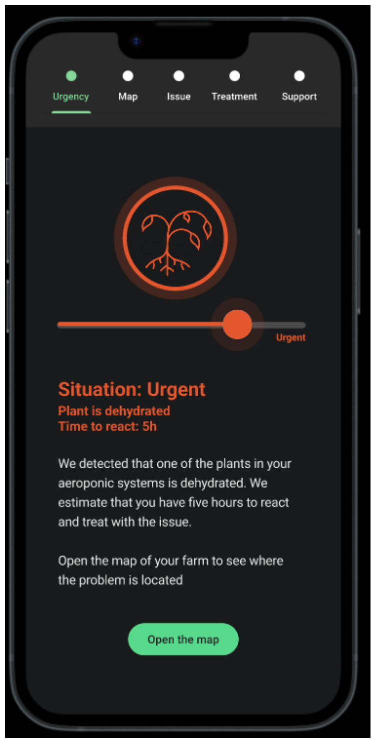

Figure 29 Wireframe of an Alarm in the AeroAlarm App (Source: Design by Linnea Seeskari)

Step 6: Show recommendations and action steps

Sixth, the aeroponic farmer now receives and alarm as presented in Figure 29. Depending on the issue causing the alarm, *Thingsboard* displays relevant recommendations and actions steps to the farmer's app from databases stored in the backend of the *Thingsboard* (Figure 29 - Figure 30). For this, established database systems as SQL can be used. For more client-side related activities, for example, indoor navigation to the correct location of the issue, other APIS can be integrated such as *MapsPeople* for indoor navigation (MapsIndoors, n.d.).

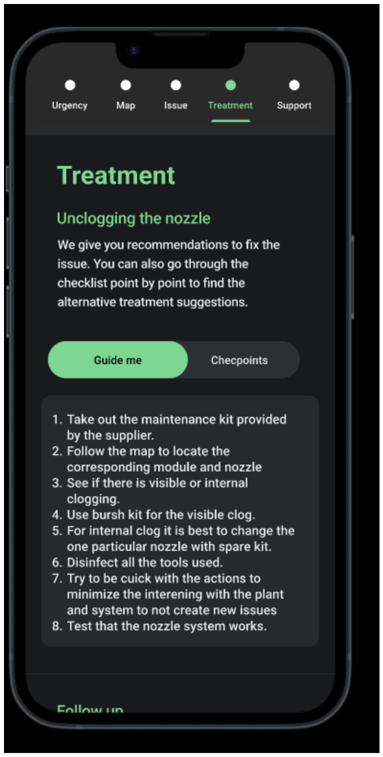

Figure 30 Wireframe of an Alarm in the AeroAlarm App (Source: Design by Linnea Seeskari)

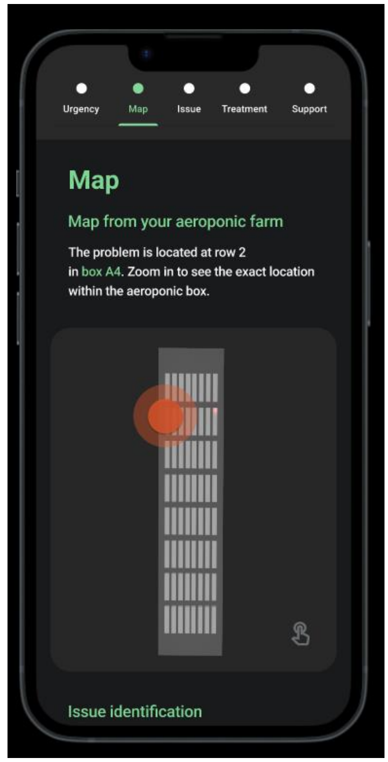

Figure 31 Wireframe of an Alarm in the AeroAlarm App (Source: Design by Linnea Seeskari)

AeroAlarm Application

By deepening our user research and conducting interviews with stakeholders, we gained valuable insights into the goals, motivations and behaviour of aeroponic farmers. Once we had a good understanding of their needs, we designed an application that meets their desires. Our user-friendly and intuitive app called Aero Alarm bridges the knowledge gap, allowing farmers to easily monitor, diagnose and maintain their aeroponic systems.

When designing the app, it is crucial to consider the user's goals, motivations, and behaviours that we have identified through deep research and multiple interviews. The user, in this case, is an aeroponic farmer who has a good understanding of modern technology but lacks in-depth knowledge about plant health and maintenance.

Given the user's tech-based background, the app should be designed to be user-friendly and intuitive, with easy-to-follow instructions and recommendations. The app should allow the user to monitor and track the crops remotely and alert the user when any issues arise.

To minimize the risk of crop losses, the app should be designed to prevent human interaction with the aeroponic system and provide real-time alerts to the user if there are any problems in the system.

The user's pain points are the challenges with diagnosing the plant’s condition and knowing the right treatment. This should be addressed through the app's functionalities, such as providing clear and concise action recommendations, easy-to-follow instructions, and clear visual representations of the plant health status. By addressing these pain points, the app can enhance the user's experience and enable the user to maintain a healthy and productive aeroponic system.

The essential features and functionalities required for an aeroponics app, user flow, and overall layout to enhance its usability of a user-friendly app that helps urban farmers to monitor and maintain their aeroponic system.
The primary aim of the Aero Alarm app is to alarm urban farmers of issues in their aeroponic systems. The app helps to prevent crop losses by providing real-time information from issues in the system and recommendations how to fix the issues. And the steps are designed to be easily followable along the user journey and actions.

The following features and functionalities are essential for the app:

1. Alarms: The app should send alerts to the urban farmer when there is an issue in aeroponic systems. The alarm should show the urgency of the issue, what the issue is and how much time there is to react to it.
2. Map from the users aeroponic systems: The app should have an interactive 2D/ 3D visual representation of the users aeroponic systems. The map enables the user to locate the problem.
3. Issue recommendations: The app should provide issue recommendations to the user, including primary and secondary recommendations based on the plant's health status.
4. Action Recommendations: The app should provide clear and concise action recommendations to the urban farmer on how to address the issues.
5. Support: The app should enable the user to connect to plant experts to get professional help for the issues and the best action plans.

Mapping out the user flow (Figure 32) of the app is crucial in ensuring that the user has a seamless experience. The overall layout of the app should be user-friendly and intuitive, enabling the user to navigate the app's features and functionalities quickly.

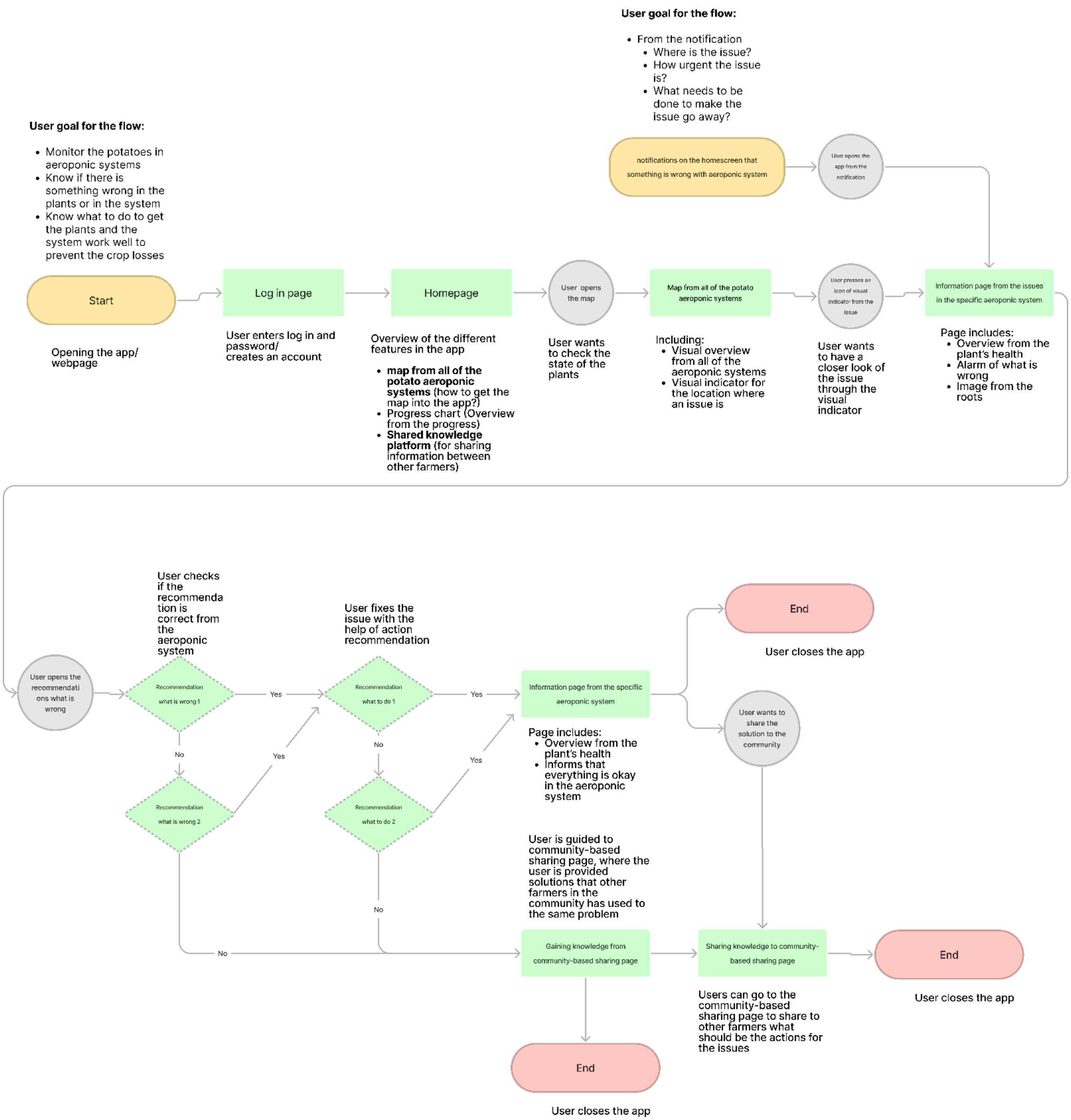

Figure 32: Aero Alarm User flow chart (Concept & Design by Linnea Seeskari)

The user values creation starts when enabling fast and efficient reaction time and treatment from the farmers to prevent rapid crop losses and system damage. The fast reaction time and treatment enable increased yield reliability, profitability, and scalability of the aeroponic farm. By addressing problems quickly and providing appropriate solutions, farmers can effectively maintain the health and stability of their aeroponic systems, even when expanding their operations. The app (Figure 33) not only amplifies the level of yield reliability but also elevates the overall profitability and scalability of the aeroponic farms. By addressing the user's pain points such as plant condition diagnosis and management decisions, our app improves the user experience and promotes a healthy and productive aeroponic environment. Ultimately grasping the impact of increased possibilities and efficiency to grow nutritious food in an urban environment where is no space and means for traditional farming.

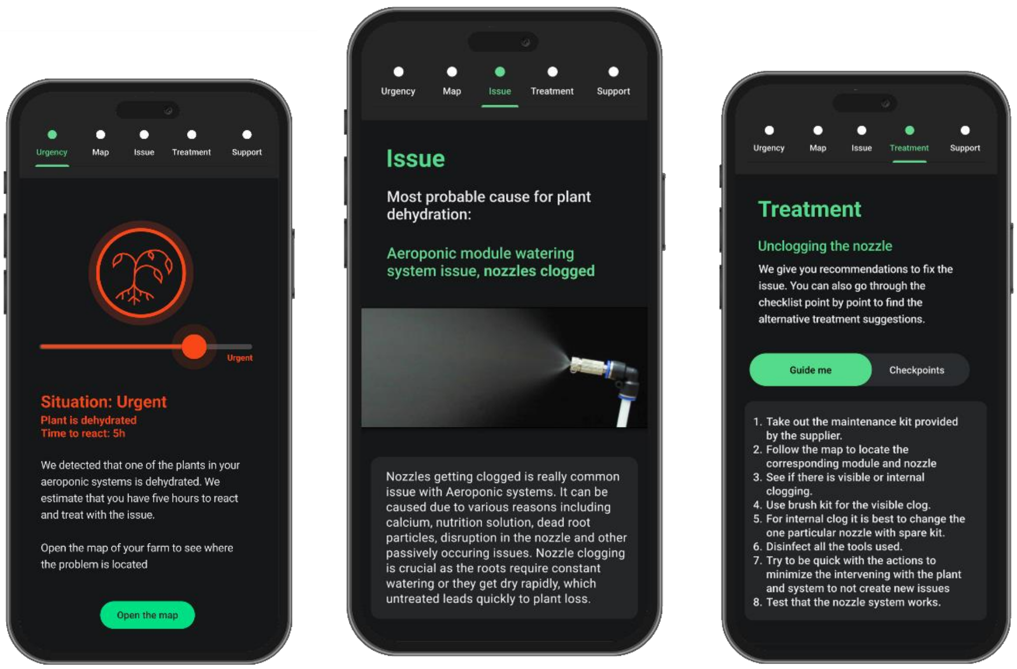

Figure 33: Three screens of Aero Alarm functions (Design by Linnea Seeskari)

To summarise, *AeroAlarm* aims to tackle the most meaningful issues with both the user and the aeroponic farming. By taking off the burden of reaction time and knowledge from the user to be able to maintain aeroponic system to utilise it systematic benefits into food production.

5. Conclusion and Future Outlook

While new tech solutions have revolutionized the world for quite some time, it has more recently just became more normal in the field of farming. While the technology solutions have shown great success in benefits, something is keeping them from scaling up to the general usage. In this report the process journey of different methods of farming and how they can be implemented in the urban environment was separated into different missions and prototypes journeys to end into one solution space while still keeping the similar focus on making impact on urban environment through local food production.

So, the project has shifted topics from more traditional approach to more technology-based field where upcoming technologies and methodologies are developed and utilized for more benefits over older ways of doing things. This also means that many technologies that are developed now can be outdated quickly or developed to the point that some learnings will develop onto something whole different. With newer technologies it is also harder to determine the actual effect on users and compatibility with other technology, especially if you cannot physically prototype with the technologies. Also compared to commercial products, prototypes using new tech can cost a lot and not fulfil the profit needs hoped for. Therefore, while aeroponic farming is struggling now to scale up, the case might be different in few years when the maintaining and production are much cheaper, and parts are more universalised. In addition, the state of the world keeps shifting towards the need for new innovative solutions that can address the challenges in current and future food production. At that point when the benefits of aeroponic farming can be effectively utilized, the actual impact on local food production and food resiliency can be seen more feasible.

While for this project the final solution was final, it truly has more potential in it still and undiscovered opportunities. While for this project our solution was final, it truly has more potential in it still and undiscovered opportunities. While presenting the solution concept, development opportunities were found from fruitful discussions with peers and other professionals. As now the data is gathered and the pictures stored, the data can be utilized for example in Artificial Intelligence to work as a training set to provide even more accuracy and developed solutions in plant monitoring overall and to monitoring other plants. The same data can also be helpful to the people actively driving for better food production and people who are already using aeroponic growing to develop the systems even further and to be more reliable automatically.

An important aspect in the future of aeroponic growing is to get the same method working for even more broader selection of nutritious plants. Some viability with aeroponic has been with maize, rice, beans and berries, giving good opportunities and reason to develop aeroponics further (Tunio, 2020). Bigger reliability and wider production range then can give more means for individual and commercial use cases too. If aeroponics are scaled for singular and size modifiable plant growing modules, same monitoring system approach can similarly bring the trust and value for the farmers, especially if they have little experience with growing plants.

For the partner, Attract, the project provides meaningful use-case for its Liquid crystal-based technology IALL coming from innovative initiatives that follows the SUGAR network principles and approach. While now the fact that the lens was just a theory concept gave its own challenges, it can help a lot when the imaging technologies can be tested with the IALL lens to actually iterate the best working version and setup.

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