UNIVERSITEIT TWENTE.

SMART ENVIRONMENTS PROJECT

DOCUMENTATION REPORT

P.E.B.T.

María Cobo Muñoz

Sven Rozendom

Fran Karlovic

Bart Aarts

Max van den Berg

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Chapter 0: Introduction

To start off this report lets first introduce ourselves. First we have our team leader María Cobo Muñoz. Our programming expert Sven Rozendom. We have Fran Karlovic, who is realizing the 3D prototyping. Bart Aarts, who does background research. Finally, Max van den Berg, who is our main caretaker of the crops and also works on the app implementation.

Our research is to find a solution to the issue of food insecurity and deforestation due to the effects of climate change. Because, according to a report from the European Commission humans are increasingly influencing the climate and the earth's temperature by burning fossil fuels, cutting down forests, and farming livestock.[27]

At first, we mainly focused on deforestation because of agriculture. For this, we came up with several solutions. Sensor networks in current farms to increase longevity and delay field expansion, monitoring reforestation, making use of drones or preexisting mapping satellites which can scan large areas of forest to check where deforestation is happening, Sensor networks in endangered forest areas, and finally vertical farming.

We have chosen to implement a vertical farm for this project as it seemed most feasible to realize and also solves the issue of food insecurity. The latter is an increasing problem as the world population is expanding rapidly. This raises the demand for food, which will cause more intense use of land cultivation in drylands. After cutting down large rainforest areas, at some point, there will be no fertile soil left possibly causing many people to starve. Right now, already 663 million people globally are undernourished.[26]

These issues could potentially be solved with our self-automated vertical farming greenhouse. This makes sure all people can easily access food sources physically and economically. Making it vertical ensures the ability to grow crops in urban areas, which takes up less land and thus prevents desertification of lands. In this report you will find the process of how we came to the solution we currently have and if it worked out as we expected.

Chapter 1: Literature Review

Farming up the city: the rise of urban vertical farms [1]

This article is about the advantages of indoor and vertical farms. The article then states that the main advantage of indoor farming is that the farmer has complete control over the growing climate of the crops. Moreover, growing plants indoors allows giving land that was previously used for farming back to nature. It uses a lot less water and is not affected by the weather.

Agriculture and climate change [2]

The article describes the effects agriculture has on climate change, as well as the impacts of climate change on the present and future of agriculture. It explains how as food consumption increases so does its global impact on climate change. Efforts have been made within the EU to decrease greenhouse gas emissions of the agricultural sector, which yielded positive results but left a lot to be desired. With our reliance on food, a further reduction in consumption is quite challenging, so efforts to improve need to be made on the production side. Furthermore, as the effects of climate change become more apparent, farmers will have to adapt their techniques to the more challenging environments.

Sustainable and Community-Centred Development of Smart Cities and Villages [3]

The article discusses the need to rethink how sustainable smart solutions could be adapted by communities. The article shows several smart solutions for sustainability-related problems and what their impact is on communities. An example of this is the MyWaste solution which tracks the entire lifeline of some garbage which gives users insights on their waste disposal and by this shows community behavior.

Reduction of water consumption and wastewater quantities in the food industry by water recycling using membrane processes[4]

This article is about the renewing and reclining of water using membrane processes. It gives 3 examples of how the process was tested and then goes on to how a pilot-scale experiment was set up: the process begins with pre-treatment, where the water is filtered and disinfected using UV rays. Then the main treatment consists of 2 modules, the first one has a total membrane area of 80 m^2 and filters the water, while the second one uses reverse osmosis for its cleaning. And then followed the post-treatment that was another UV-disinfection. After this process, less water was lost as wastewater.

Bicarbonate produced from carbon capture for algae culture[5]
The article discusses multiple solutions and their pros and cons for capturing carbon dioxide by using certain algae cultures in a closed-loop environment. For example, capturing flue gas and passing this through an alkaliphilic algae culture.

A review of renewable energy sources, sustainability issues, and climate change mitigation [6]

The article describes whether or not renewable energy sources are sustainable enough and analyses why a shift from fossil fuel-based energy sources to renewable energy sources would help reduce climate change and its impact. Examples of renewable energy are bioenergy, hydropower, geothermal energy, solar energy, wind energy, and ocean (tide and wave) energy.

Climate change, nuclear power, and the adaptation–mitigation dilemma[7]

Scientists claim that humans impact the climate by extracting and using fossil fuels that release carbon dioxide into the atmosphere. In contrast, nuclear power does not emit any CO_2 when electricity is generated and the waste is perfectly stored away. Called carbon capture and storage. However, there are also quite some challenges like the large amount of water consumption.

Global warming vs. climate change, taxes vs. prices: Does word choice matter?[8]

This project investigates through three different studies whether word choice matters regarding the user's perception of the seriousness of the problem. The survey examines the terms “climate change” vs “global warming” within European and American participants and compares the results according to their political orientation. The conclusion obtained is that only in the US the use of different words makes a real difference when aimed at Republicans or Democrats.

A Review of CO_2 Capture by Absorption and Adsorption[9]

This article reviews the methods of CO_2 capture through both absorption and adsorption. It first explains the ways that CO_2 could be captured. The first is physical absorption. Where, under Henry’s law, CO_2 is absorbed by reducing the temperature while increasing the pressure. Then there is chemical absorption where a gas mix containing CO_2 is sent through a machine where the CO_2 is absorbed into an absorber and is then reacted within a stripper so that only the CO_2 remains.

Plastic Pollution and Potential Solutions[10]

This article discusses all elements of plastic pollution. It elaborates on the different types of plastic and their composition, the dangers of microplastics, and to what extent humans can prevent this from happening. Possible solutions are hard to find and often consist of governmental action which is hard to achieve, that is why the need for technological solutions to this problem is big.

What is the Relationship Between Deforestation and Climate Change?[11]

The article breaks down the impact of deforestation on climate change, as well as discusses the main causes behind it. It makes a point of deforestation being a triple menace, as the cut/burned down trees do not only stop sequestering carbon but also release all of the captured carbon back into the atmosphere. Moreover, the third aspect of deforestation has to do with the fact that its most common cause is also one of the biggest producers of greenhouse gases: agriculture. This is especially the case for tropical rainforests as the soil in those areas is often extremely poor, so farms need to expand onto new patches of the forest regularly.

Providing personalized energy management and awareness services for energy efficiency in smart buildings[12]
This paper describes the use of an IT ecosystem that improves the energy efficiency of buildings by changing the behavior of its occupants by using new ICT and IoT technology. It makes use of low-cost sensors like Arduino and Raspberry PI to feed information to the data depository, this data is then analyzed and fed into an engine to provide a useful output that can influence the occupant's behavior of the building to increase energy efficiency.

The AI Gambit — Leveraging Artificial Intelligence to Combat Climate Change: Opportunities, Challenges, and Recommendations[13]

The article examines the way how artificial intelligence could help us with combating climate change by delivering much greener, more sustainable, and effective solutions. Also, it could help us understand the climate change issue better than we currently do. For example, the explanation of current and past events, and the prediction of future events could be more accurate when making use of artificial intelligence.

The role of seasonality in lettuce consumption: a case study of environmental and social aspects[14]

The publication studies the CO_2 impact of different types of food consumption. It focuses on lettuce consumption in the UK but some general conclusions can be extracted. The study shows that the production, distribution, and consumption of vegetables locally outside their season can have higher CO_2 costs than the importation alternative. So, seasonality consumption can lower your carbon footprint more than local consumption.

Future Proofing Our Cities With Climate-Smart Solutions[15]

By presenting Singapore as the world's leading smart city, the article discusses the ways cities can take advantage of smart systems to adapt to climate change and minimise their impact on the environment.

Mitigating climate change through green buildings and smart growth[16]

The paper discusses how we can reduce greenhouse gasses by making newly constructed buildings smart and retrofitting older buildings with technologies such as solid state lighting, advanced geothermal heat pumps, integrated energy equipment (with this they mean one unit for cooling, heating, hot water, dehumidification and heat in one piece of equipment). Which according to the paper can save 8% of the expected energy consumption in 2025.

Geoengineering the climate: an overview and update[17]

It describes geoengineering as methods such as releasing materials to the environment (oceans and atmosphere) to remove carbon dioxide or manage solar radiation. Geoengineering would be useful to support but never to substitute cutting global greenhouse gas emissions. It is proven to be technically possible, however, research is too limited due to political, legal, and social reasons.

Future food-production systems: vertical farming and controlled-environment agriculture[18]

The article points out the global trends which lead to a decline in global arable land per person. With the decrease of agricultural resources comes the problem of sustainably feeding the growing population. A proposed way to address some of the issues introduced is the implementation of vertical farming in urban areas. Furthermore, by placing such vertical farms closer to the consumers, also addressed are questions regarding the transportation of food. The article goes on to list some of the benefits of vertical farming as proposed by the modern originator of the idea, Dickson Despommier. These include higher crop yields, all-year-round production, and higher resistance to outside hazards.

Biofuels: An alternative to conventional fuel and energy source[19]

The Paris Agreement is a climate change agreement signed by 178 parties around the world. It is a unified arrangement for the global response to climate change after 2020. The long-term goal of the Paris Agreement is to control the global average temperature rise within 2 degrees Celsius compared with the pre-industrial period, and strive to limit the temperature rise within 1.5 degrees Celsius.The Paris Agreement was adopted at the 21st United Nations Climate Change Conference (Paris Climate Conference) on December 12, 2015, and was signed at the United Nations Building in New York, United States, on April 22, 2016, and became official on November 4, 2016 Implement.On November 13, 2021, the United Nations Climate Change Conference (COP26) concluded in Glasgow, UK. After two weeks of negotiations, the parties finally completed the implementation rules of the Paris Agreement.

Cost-efficient measures in the oil refinery and petrochemical sectors for the reduction of CO_2 emissions under the Paris Agreement and air pollution under the MARPOL Convention[20]

Bioenergy is renewable energy composed of materials from biological sources. Biomass is any organic material stored in the form of chemical energy in sunlight. As a fuel, it may include wood, waste wood, food consumption, organic fertilizer, sugar cane, and other by-products of various agricultural processes. From a chemical point of view, the composition of biomass is C-H compounds, which are similar to conventional fossil fuels such as petroleum and coal. Since coal and petroleum are both converted from biomass for a long period, biomass is the ancestor of fossil fuels and is referred to as green coal for instant use.

Chapter 2: Identification of General Problems and Challenges

Problem/challenge	Number of articles
Lowering production of greenhouse gases	9
Sustainable household energy handling	7
Lack of climate problems public recognition	4
Agricultural effects of increasing land usage	4
Deforestation in ancient rainforest areas	4
Excessive water consumption	3
Capturing CO_2	4
Plastic pollution	1

When categorizing the articles we found that the most common problem is that we should lower our production of greenhouse gasses. This could be done in several ways, such as making use of more sustainable energy sources. Therefore, finding a way to handle energy more sustainably is the second most common challenge on our list. This could be using more solar energy or making use of nuclear energy. From this, the latter one also matches with capturing CO2.

According to the list of article analysis, it can be seen that lack of public recognition is a serious problem. Some people just don't believe that environmental change is a serious problem, or people don't pay much attention to it. At the same time, using new clean energy, such as biomass energy that requires a lot of plants as materials, may directly cause agricultural effects, deforestation, and excessive water consumption. Also, among the articles, there was a mention of plastic pollution, which seems to be easily overlooked.

So in short, we tried to categorize our problems in the best way possible as there were quite some shared challenges in the articles, and some articles matched with multiple problems.

Chapter 3: Identification of Relevant Problems

In this chapter, we will discuss several newly identified problems and discuss a possible solution that could contribute to solving the problem.

1. **Garbage recycling**. Plastic is a huge problem when it comes to pollution, some examples are the plastic soup in every major ocean, the food contamination, and contamination of water with plastic microparticles. The latter 2 even pose a threat to human life and cause health issues in the long team.

   Possible solutions: Bacteria pools which consume (micro)plastics, methane production & management. Both solutions can be measured by sensors and could be smart.

2. **Deforestation because of agriculture.** Farms use a lot of area to grow crops or keep animals and oftentimes forests are cut down to make space for these. Sometimes these forests are even burned down. The former reduces CO_2 capture, while the latter releases a lot of CO_2.

   Possible solutions: Vertical farms could potentially be used to effectively reduce the area used for farming.

3. **Energy storage of renewable energy sources**. Energy is often produced sustainably nowadays, the problem with this is that there often is a mismatch between demand and production. For example, at night there is a higher production than energy demand, but during daytime, the demand is higher than the production. To solve this problem you will need an efficient way of storing energy

   Possible solutions: Smart energy system which stores and emits the right amount of energy when necessary, this could be done in a smart system with different sensors.

4. **Excessive water consumption.** Although the development of biomass fuels is a good way to replace traditional petroleum fuels to reduce carbon emissions. But it is still a waste of water resources. Biomass fuel requires a lot of crops as raw materials, and planting crops requires a lot of water resources, even more, water resources than usual.

   Possible solutions: Surface irrigation can be used to solve the problem of wasting water in agricultural production. The use of high-tech irrigation equipment can more accurately pour water onto each crop. The accuracy of this technology can reach more than 90%.

5. **Methane emissions.** A large number of methane emissions will cause 1 million people to lose their lives every year. At the same time, it is a greenhouse gas with a

huge impact. In the 20-year interval, the potential value of methane to heat up is 80 times that of carbon dioxide.

Possible solution: The main emissions of methane come from the exploitation and use of agriculture, animal husbandry, and natural gas. Rethinking our methods of farming and livestock breeding". This includes using new technologies, switching to a plant-rich diet, and adopting alternative protein.

Chapter 4: Problem Selection and Motivation

We would like to work on the problem of **deforestation** due to **agricultural land usage**. The main motivation for this choice is the broad scope and the multifaceted nature of it. The problem covers not only the issue of the loss of trees but also the side effects including

- Carbon sequestered in trees being re-released into the atmosphere, especially when trees are burned to make space.
- Loss of carbon sequestration capacity
- The forest areas are replaced by agricultural fields, which are related to the toxic chemical release, extensive water consumption, as well as methane and CO_2 production.
- Loss of biodiversity due to animal habitat destruction.

By coming up with a solution for the mentioned problem we are hoping to tackle all of the underlying issues arising with it. Furthermore, with the increase of global food demand due to rapid population growth, the problem is only going to grow in proportions. Moreover, the solution should address the differences in global food availability. A lot of the food produced today is being thrown away, while in other parts of the world communities struggle with year-long access to food. The solution should, therefore, cover not only the agricultural and environmental aspects of the problem but also the social ones.

Problem update

After the feedback session, we have decided to focus on the subproblem of **food security.** We think that our chosen solution could fit better to this than deforestation even though it still tackles it indirectly.

As Ray Kurzweil, Google Engineering Director, said: «The 2020's Will Be The Decade of the Vertical Agriculture Revolution». Nowadays, the agriculture sector is not sustainable. Traditional agricultural techniques take 70% of worldwide water consumption and extensive land, among other environmental problems, which are scarce resources.

By 2050, the world population is estimated to be around 9.000 million. If we take into account the rapid population growth, food availability arises as a problem we will have to face in the next decades.

Climate change will also affect crops, as the new climate conditions will be unsuitable for the production of certain species where they used to be planted. This can also affect seasonal production.

Chapter 5: Potential Solutions

Vertical farms

Vertical farms indirectly prevent deforestation, thus only solving it partially. The basis of vertical farming is stacking multiple growing trays in an enclosed environment. Because the growth space is now mostly vertical, a lot less area is needed to grow the same amount of plants. Furthermore, a lot of water that would normally be either evaporated or soaked too deep in the ground for the plants to use is saved.

It also allows a lot of smaller or less related solutions:

- Allows for genetically modified plants that would usually be too invasive to be grown. This allows for plants that require less water or light.
- Can provide food stability
- Transport costs and CO_2 emissions will be lowered because the farms can now be located in an urban environment or even on location.
- Can provide crops year-round so no energy is spent on preserving off-season crops.

Possible problems we could face tackling this problem:

- The prototype has to be finished early because we have to grow something to prove it works.
- Material usage.

Requirements

Hardware: water and humidity sensors, CO_2/O_2 sensor, temperature sensor(?). Soil. material to build an enclosed area. Pump and ventilator(?) (motors).

Software: monitor and control program.

Humans: -

Crops: Lettuces seeds, soil,

Storage place: University

Vertical farms have the potential to revolutionize farming, as it makes it possible to farm almost anywhere.

The demonstration would be a timelapse of the plant growing on its own.

Sensor networks in endangered forest areas

By setting up a network of microphones that are linked to, i.e., an AI that detects the sound of chainsaws, forest rangers could be alerted to illegal deforestation. Furthermore, infrared sensors could be used to detect forest fires, as deforestation for agriculture often is conducted through setting trees on fire.

Solves the problem partially because once the woodworkers realize the system they might disable it or move to another area, and the rangers have a certain response time in which trees could already have been cut.

Possible problems we could face tackling this problem:

- Creating the network itself.
- Coding the AI.

Requirements

Hardware: microphone, infrared sensor.

Software: sound recognition AI, network

Humans: rangers

Impact: less illegal deforestation

Validate: infrared with a lighter or something, the microphone by finding a woodworker. For both, the network works if it gives us a notification.

Demonstrate: lighter in the demo itself, with a video with the woodworker.

Making use of drones or preexisting mapping satellites (i.e. google maps) which can scan large areas of forest to check where deforestation is happening

By monitoring the patterns in deforestation using images taken by either drones or satellites, you could predict the direction the deforestation would continue in. Rangers could then patrol these areas more often so that illegal deforestation can be caught quicker and more often.

This would solve the problem partially as deforestation isn't stopped but rather predicted.

Possible problems we could face tackling this problem:

- Finding an algorithm to figure out the path of deforestation.
- Access to older satellite images.

Requirements

Hardware: - (drones)

Software: AI, top-down images of forests throughout the years.

Humans: rangers.

Validate: run it and wait to see…

Demonstrate: show the thinking of the AI

Sensor networks in current farms to increase longevity and delay field expansion

By implementing ground quality sensors in existing fields the quality of the earth can be monitored. So that the farmer knows where more fertilizer is needed, where the ground is still quite usable, and how many times he can still grow crops on the same field. Even though this solution doesn't outright prevent deforestation, it would delay it. This wouldn't have a lot of effect in the Netherlands but in i.e. Brazil, the farmers have to cut down a part of the forest every few years because their old land is no longer fertile.

Possible problems we could face tackling this problem:

- A lot of research into ground quality.
- Might have to design our own sensors.
- Not as effective as other solutions.

Requirements

Hardware: ground quality sensors.

Software: monitoring program, network

Humans: farmers

The main impact is that the fields are used longer before more forest is cut down for fields.

Validate: stick the sensor in the ground and have it measure the ground.

Demonstrate: show test results.

Reforestation monitoring

Sensor networks in recently reforested areas that inform on the wellbeing of the healing forest by measuring parameters like humidity, temperature, and air quality. Thus allowing the reforesters to take the right steps to an as healthy as possible forest.

This doesn't solve the problem but instead deals with the aftermath more effectively.

Possible problems we could face tackling this problem:

- Creating the network.
- The network might not have a real effect.

Requirements

Hardware: sensors.

Software: monitoring program, network.

Humans: reforesters.

The potential of this system is to regrow a forest healthier and quicker than just planting a few trees.

Validate the system by monitoring a newly planted forest….

Demonstrate: show the difference between forest grown with and without the system.

Poisonous baby trees that explode and release their poison when cut (joke idea)

By periodically mixing a highly flammable poison into the water we use to grow baby trees, they would become dangerous to the deforesters. The poison alone might not be enough because the woodworkers could start wearing gas masks. Thus we make sure that the poison is flammable. The liquids that a tree uses to grow are stored in cells. The heat from the sawing of the tree would ignite the poison within these cells. And because these cells are in a closed environment, the pressure would start to build. The explosive force of one cell might not be much. But keep in mind that a tree consists of millions of cells.

This solution solves the problem completely as it gets rid of the woodworkers that cut the trees.

Possible problems we could face tackling this problem:

- It is not ethical.
- Trees might not retain their poison.
- Cells might not be strong enough to cause an actual explosion.
- Forest fires caused by natural phenomena spread a lot quicker.

Requirements

Hardware: a poisonous and flammable liquid. Baby trees.

Software: -

Humans: people who are fine with having this on their conscience.

This solution has the potential to completely get rid of the woodworkers.

Demonstrate by bringing a tree to campus, then validate by having someone cut the tree.

Chapter 6: Solution Selection

We have concluded to choose the **vertical farming** solution.

This solution seems the most feasible to carry out for this project as we intend to make a small-scale smart-automated vertical farm, which fits perfectly with the nature of the project: creating a smart environment. It would require sensors to monitor irrigation, light, type of plant, growth…

The solution seems easier to turn into a project compared to our other proposed solutions, as most other solutions require us to build a network ourselves. Furthermore, it is the solution with the most effectiveness as it is the only thing that prevents deforestation preemptively instead of combating deforestation head-on, which will most likely still result in some deforestation. Finally, the solution is the only one that doesn't require human action, thus making it a much more efficient solution.

Furthermore, this solution not only tackles the deforestation problem but also covers multiple problems like combating excessive water consumption. The multi-faceted scope of the solution is one of its most interesting aspects.

The project idea would be to make a modular, small-scale vertical farm to be used in households and/or HoReCa. Thus reducing the need for the agricultural sector to grow plants, which in turn means that less land is used. And with less need for land, deforestation is slowed down.

The remaining part of the project will be managed with an iterative approach where we will go over phases 2 and 3 multiple times to improve on the product. The work distribution will be done by assigning every member certain expertise for which they are responsible. As done in the research phase every team member will research or improve on a topic and will be able to explain this in the general team meetings.

Phase 1: **Research**

Water	María
Monitoring	Bart
Structure and Light	Fran
Plant growth patterns + soil and fertilizers used	Sven
Previous vertical farm & agriculture techniques	Sylvia
Connectivity	Max

Phase 2: **Ideation/design** & Phase 3: **Execution**

The specific roles for the following phases will be determined later as different parts might need more work than during the research phase. We expect to have three areas of expertise, in which we could divide tasks and give the project a modular approach:

Watering system

Monitoring system

Light system

Chapter 7: Methodology

Phases

The project will be divided into 7 modules which each have their own set of goals and purpose for the project. Each module will be linked to a timeslot in which it should be finished to ensure the execution of the module.

Module	Tasks	Persons
1	Team leading, team management, time planning and feedback implementation	Maria
2	Hardware purchase, 3D prototyping	Fran, Maria
3	Programming and Arduino	Sven, Bart
4	Data capture, data validation, data presentation, documentation	Max
5	Research on hydroponics and plants	Bart, Sylvia
6	Final demo, final presentation	Maria
7	App development	Max

Planning

From week five on there will be four weeks of working time left which can be spent on the project. In the table below all deadlines have been recorded and all the phases which have been mentioned are linked to a week to be able to set proper deadlines and to manage the project within the given time.

Week	Module	Start date	End date	Deliverables
5	1	13-12	17-12	Chapter 7
6	1, 5, 4	20-12	24-12	Chapter 0
		27-12	31-12	HOLIDAY
7		3-1	7-1	Hardware arrival
8	1, 2, 3	10-1	14-1	-
9	1, 2, 3 ,4, 7	17-1	21-1	3 minute presentation prototype, chapter 7 improved
10	1, 6	24-1	27-1	Demo, final report

Equipment

- Arduino: Central processing computer, will be located in the base and powered by a battery or plugged in using an adaptor. Reads the data from the water level sensor and multi-sensor, and powers the pump and LEDs.
- Substrate: the material that keeps the plants in place while the water runs past the plants' roots. We will be using rock wool, a kind of insulation, as the substrate.
- Plants: baby plants. Preferably spices.
    - Options:
    - Lettuce
    - Basil
    - Saffron
    - Strawberry
    - Aspergers
    - Celery

  Choice: Basil + Lettuce. We will be growing both, and using the one that sprouts first.

- 3D printed structure: made from PLA plastic. The transparent capsule is a bought transparent tube.
- LEDs (more ambitious projects)
- Water pump: to get the water to the top of the structure. The pump will be activated periodically. It pumps 100mL every 10s.

  https://www.beslist.nl/klussen/d1106331478/LDTR-WG0244_Mini_onderwatermotorpomp_waterpompen__DC_3-6V_100L_-_H_(wit).html?productIdentifier=6ry6QmspT65PUA82EMWMtfqv2op&utm_source=google&utm_medium=free_listings&utm_campaign=klussen

- Pipes: Connect water or water nutrients to the soil. 3D printed structure or store-bought plastic pipes. Depending on the structure of the farm.
- Reservoir: Stores the water needed for watering. It is usually placed at the bottom of the structure.
- Nutrients: Necessities for plant growth, transported by pipeline. Nutrients for hydroponics Plagron. For 1L of water 2,5mL of part A and 2,5mL of part B.
- Sensors: Water level sensor and multi-sensor.

[22-25]

Water level sensor *https://lastminuteengineers.com/water-level-sensor-arduino-tutorial/*

The sensor largely consists of exposed copper strips, with half being power and half being sense traces. The basic working of the sensor is that it acts as a variable resistor. If the sensor is submerged, the water will conduct power between the power and sense traces, if it is barely touching the water, less power can be conducted, thus increasing its resistance.

The sensor only has 3 pins, a signal pin, a VCC pin, and a GND pin. The signal pin has to connect to one of the analog inputs on the Arduino. The VCC is recommended to run between 3.3 and 5 volts, on a digital output pin.

CCS811 multi-purpose sensor

https://opencircuit.nl/product/Luchtkwaliteit.-CO2.-temperatuur-luchtvochtigh

This sensor measures the air quality, CO2 equivalent, temperature, and humidity in one unit by combining 2 sensor chips. It runs on a voltage of 3.3V DC. It can measure a temperature between -40 and 85 degrees Celsius and a humidity between 10 and 95%, both with a 2% error factor. The chip communicates by use of the I2C protocol.

With I2C you can connect multiple ‘slaves’ to a single ‘master’. Where the masters are the controlling devices, and the slave takes instructions from and feeds data back to the master. I2C only uses 2 wires for communication. The SDA or Serial Data for the transmission of data, this wire is used in both directions, and the SCL or Serial Clock. This line only goes from the master to the slave. The data is sent by serial communication.

The data is sent in ‘messages’. These messages are broken up into ‘frames’ of data. Each message starts with a start condition and then an address frame that tells the slaves to which slave the message is sent. After which the data frames are sent before finally the slave receives a stop condition. After every frame of data (and the initial address), the receiver sends back an acknowledgment that the frame has been received.

The use of the CCS811 requires an additional library
How to connect and read CCS811 can be found in the Appendix under [1]

This was the sensor we wanted to buy. However, a miscommunication problem resulted in receiving a different model which functions in the same way but measures volatile organic compounds (TVOCs), including equivalent carbon dioxide (eCO2) and metal oxide (MOX) levels. Of which we will only be using CO2 and TVOC. For air humidity and temperature, we added:

DHT11 humidity sensor

https://create.arduino.cc/projecthub/pibots555/how-to-connect-dht11-sensor-with-arduino-uno-f4d239

The DHT11 is a digital humidity and temperature sensor. It uses a capacitive humidity sensor, measuring the capacity of the air to determine the humidity. And a basic thermosensor for measuring temperature. The chip has 3 pins. A VCC that can run between 3 and 5V, a data pin, and a ground. To measure the data, the DHT library is required. Humidity will then be given in percentages and temperature in degrees C.

Data

For this project it is important to be able to track the progress of growth of the plants. In the ambitious scenario, we try to measure the impact of our actions on the plant through sensors and try to adjust actuators based on the data given. This is fairly complicated and hard to achieve within the given time.

For this reason, we implement the basic data measurements first which are growth process tracking, humidity, temperature, $C0_2$ and we would like to display these measurements in some sort of application either on mobile or pc. When for example we see that the humidity is fairly low we can add water or do something else based on our measurements.

For the ambitious scenario, we would like to measure what impact do actions have on the growth rate of the plant. For example, would adding more water in some situations speed up the growth process, or does the plant grow quicker in a warmer climate. These things we would like to measure and log so the most optimal growth climate can be developed and the highest efficiency can be achieved.

Water pump data

To be able to make some decisions on how to control the watering system, we measured the volumetric velocity of the pump. This was done by measuring the time it takes for the pump to fill a bottle to a 100ml mark. The measurement was done 9 times, and the average calculated as 9.58 s/ml, with a 0.08 s/ml error margin. The data tables can be found in the appendix.

App development

For the project we decided to make an application in which you can check the data and adjust for example the intensity of the light. The application will probably be a web application since it has to retrieve data and display this. Most likely we would use Android studio for this since there are many sources on how to connect this to Arduino and it is easy to use and learn. Features that could be included in the application would entail checking the actual plant, checking plant growth progress, checking humidity

Minimum viable product

For the minimum viable product we should implement some of the most essential features and define what a successful project would look like. For our project to reach its goal, we should be able to measure the enclosed environment and check what is going on with the plants. So the plants should be in a fully enclosed environment combined with sensors that can track the environment and plant growth. If the following requirements are met we reached our minimum viable product.

- Measure humidity
- Measure $C0_2$
- Measure temperature

- See data on application either on mobile or laptop
- Enclosed environment for plant

Chapter 8: Validation

In order to verify whether our enclosed smart environment works we need a form of validation. Since this project is mainly based on the growth of plants in our smart environment, the main validation would be to see whether the plants grow quickly in the prototype. Besides, we could validate whether the sensor values influence plant growth and whether they display logical values.

Plants

To prepare for the growth of plants some plants were seeded during the holidays to already have some sprouts. This was done on the advice of a company called Optimus Garden which is a developer of vertical cultivation technology and was contacted for the project to retrieve some information about hydroponics. They advised to already have some sprouts since they grow better than seeds in hydroponics. The plants we chose to use are microgreens which are smaller versions of the original plants which grow quicker and can be harvested in an early stage. In the table below all plants used are listed in combination with the necessary information. These seeds sprouted very quickly and became grown plants in about two to three weeks. Once the prototype was finished the seeds could also be planted in the actual prototype. In the prototype, the seeds are planted in Rockwool which is known to be a good material for growing plants in combination with hydroponics and was chosen on the advice of Optimus Garden. These seeds sprouted at the same pace as in the dirt in which it was planted during the holidays and displayed fast growth. After using the prototype a couple of times per week, the plants were hydrated and grew to their full potential.

Plants	**Growth time**	**Temperature**
Spicy mix	6 days	16-22 C
Mizuna	1-2 weeks	8-18 C
Lemon Basil	2 weeks	26 C
Lettuce	3 weeks	16-20 C

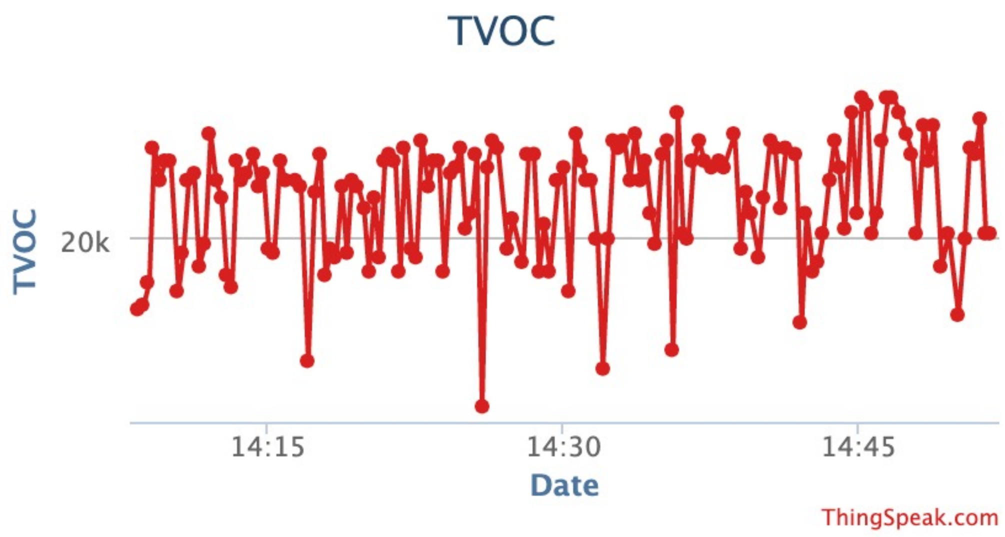
Sensors

For the project we used four different sensors which measured five values in total. The sensors were not calibrated since most of the measured values were as expected and the accuracy of the sensors did not have to be extremely accurate because we have no actuators connected to them. For each sensor, there is a graph attached with the measured data and a description with the necessary information.

Sensor	Min value	Max value	Expected value	Unit	Accuracy
CCS811 (TVOC)	0	32768	750	ppb	-
CCS811 (CO2)	400	29206	1000	ppm	-
Water level Sensor	0	520	150	Resistance	-
Humidity sensor	20	90	30-50%	RH	+5%
Temperature	0	50	20	C (Degrees)	+2%

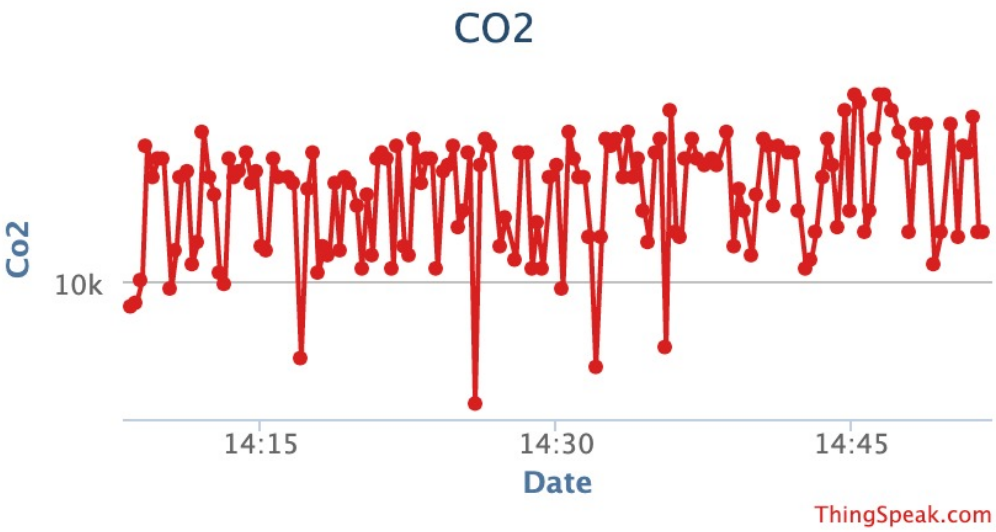
Tvoc

The TVOC represents the measurement of the overall amount of VOCs in a certain room or space. It stands for Total Volatile Organic Compounds (TVOC) and can be used to determine air quality. A higher TVOC represents a higher polluted air and a lower TVOC indicates that a space is barely polluted. A normal value of a room should be around 0.75 ppm which is 750 ppb. Looking at the graphs the values are way too high, however, we believe these values are inaccurate. Mainly because often we also get readings around 1500 ppb which makes more sense for a lab setting in which the amount of VOC would be higher than the average of 750 ppb in a normal setting. We believe that the sensor is either of low quality or that it should be calibrated.



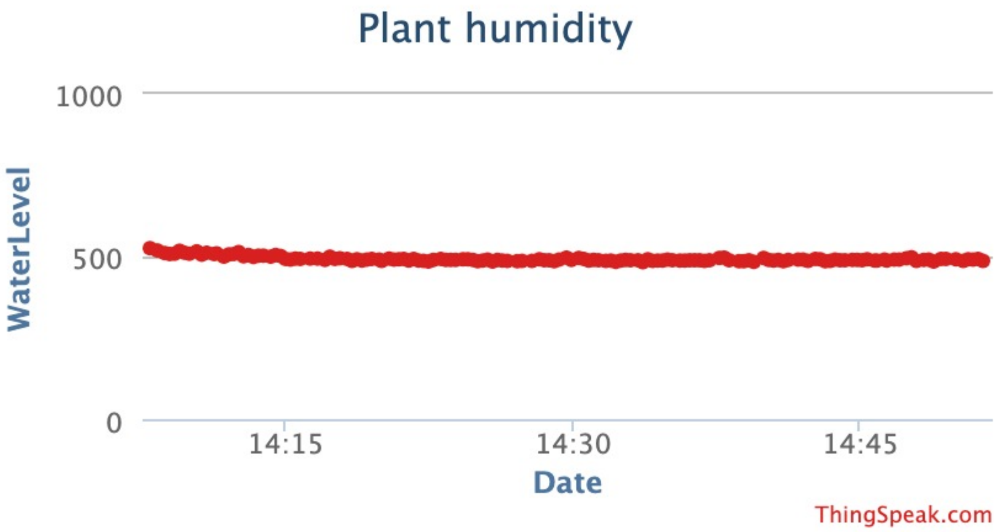
CO2

CO_2 represents the concentration of CO_2 molecules in a room. The sensor can sense values from 400 to 29206 ppm. Plants need CO_2 to survive and grow but too much CO_2 is known to be harmful to plants. For that reason, the average value for a common room can be adapted since plants can grow in this environment which is around 1000-2000 ppm. Looking at the graph the values are around 12k, however, these values are incorrect. The average measurements we got were around 2000 ppm which was correct but sometimes the sensors incremented these values by almost 10k which happens for still unknown reasons. We found out during the testing phase that the wrong sensor was ordered by one of the group members which could be one of the issues.



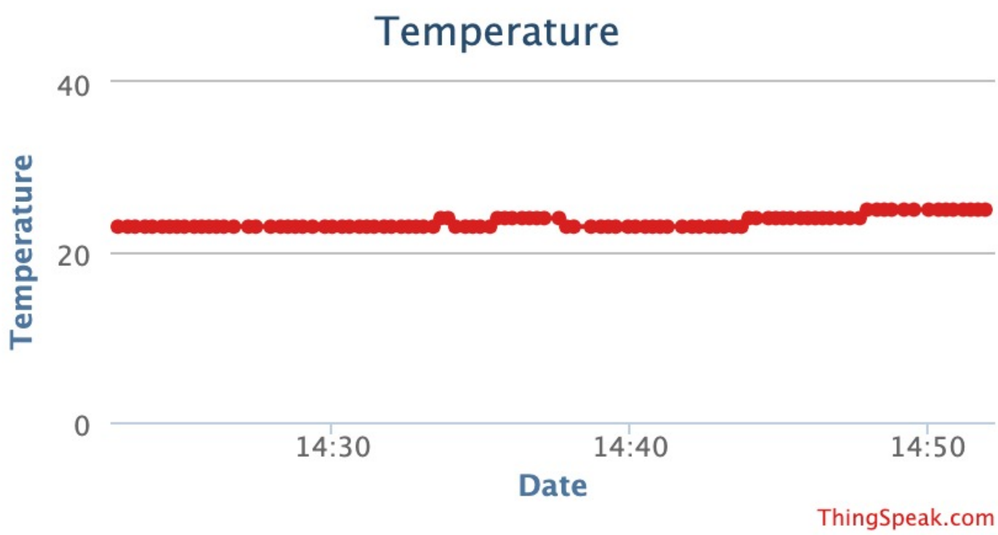
Water level sensor

The water level sensor used the conductivity of the water to sense the resistance on it to determine the water level. Resistance of 520 means that the sensor is almost dry and resistance of zero means that the sensor is fully wet and in the water since the conductivity of water is so the resistance is low. An expected value would be 250 since the sensor should sense some moisture but not be fully wet. This sensor was placed inside of one of the plant baskets to check the root's humidity. The values measured were mainly around 520 since the sensor was at the bottom of the Rockwool which did not fully get wet so this value seems correct.



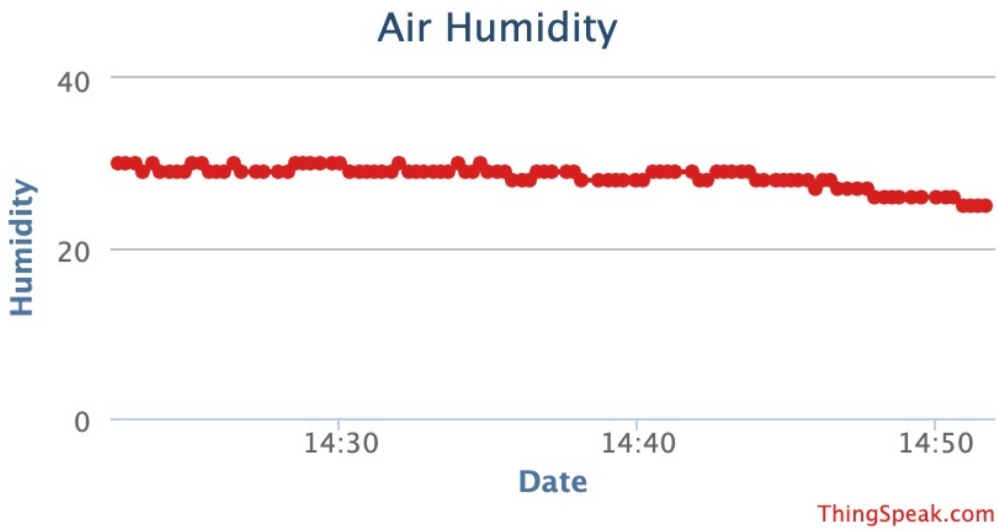
Temperature sensor

The temperature sensor measures the temperature in the room in degrees. Plants need on average a temperature of 20 degrees to grow. Each plant requires a different temperature so this is a variable that should be taken into account carefully. The sensor can sense a maximum of 50 degrees and a minimum of 0 degrees. Looking at the graph it is clear that the value is around 22 degrees which is the same as the temperature inside SmartXP where it was measured, this indicates that the value is correct and right for the plants to grow in.



Humidity sensor

The humidity sensor measures the humidity of the air in RH which stands for relative humidity. The relative humidity is the measure of how much water vapor is in a water-air mixture compared to the maximum amount possible. An expected value would be 30-50 % in a healthy environment which indicates that the plants will be able to grow. Looking at the graph it is clear that the value is around 30% which indicates a healthy environment for the plants to grow in.

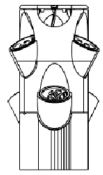


Chapter 9: Results and Conclusion

The product as it is now is an enclosed smart environment for plants to grow in. The user can determine which plants they want to grow and can put the seeds or seedlings in the basket. Once they have been planted the user will only need to pour water and nutrients and power the product, and it will start by watering the baskets. Once the baskets contain enough water the pump will stop and the water level will remain stable. When the plants run out of water the water sensor will sense this and start to pump water again. The user can see on the following website, https://portfolio.cr.utwente.nl/student/cobomunozm/PEBT.html, what the values are of for example the air quality which is determined by the TVOC, CO_2, and air humidity levels. Apart from this, the user can see the temperature to check whether the plants are growing in the most optimal condition. If the user is satisfied with the product he can order more modules to stack upon the base set, this way they can grow more plants.

Technical aspect

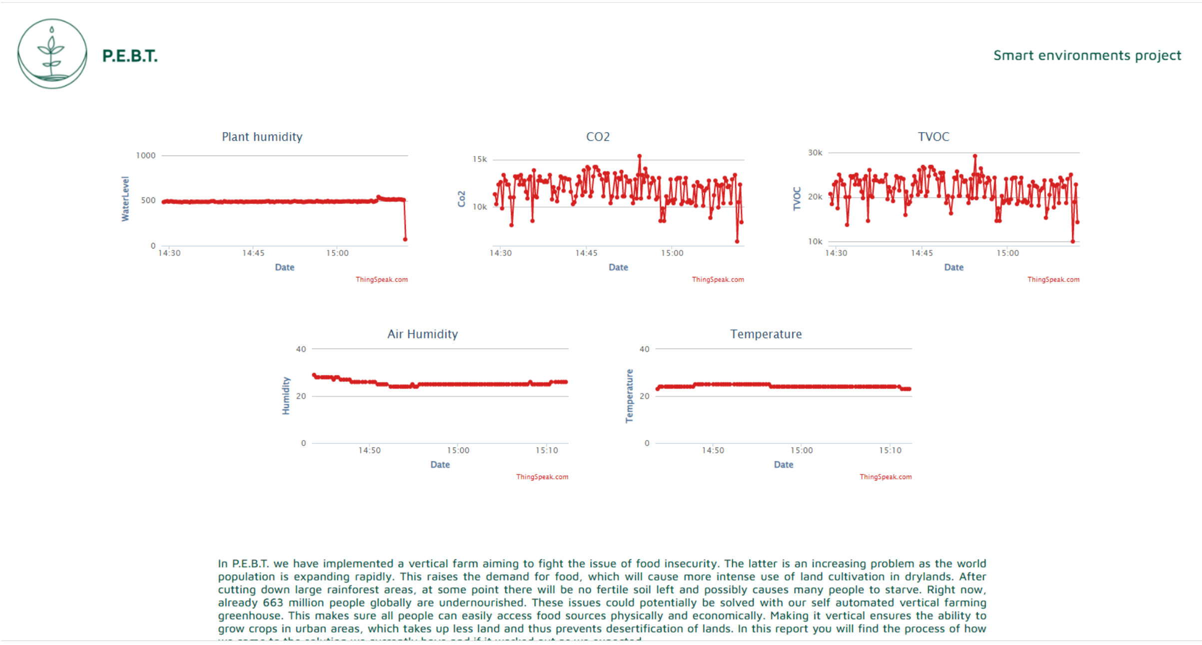
The base structure, as well as the baskets, have been 3D printed out of PLA plastic, which will later prove to be one of the most problematic decisions. When designing the main form and developing the concept, inspiration came from the way some orchids grow from the hollows of other trees.



This formation naturally gave guidance for the watering system being placed on the inside of the structure. The water is being pumped from the bottom, and at the top divided into 6 streams, each flowing to one of the baskets in the module. The excess water is collected at the pool in the base, from where it is pumped back into the system when needed. To prevent leaks, the base is waterproofed with rubber lining, plastic sheets, and epoxy. The outside s, hell is constructed out of two square pieces of acrylic, held together in a circular shape by three laser-cut acrylic rings. The structure is closed at the top with a round piece of laser-cut acrylic with an engraved logo.

As mentioned above, PLA has proven to be an inadequate choice of plastic in regards to water isolation. As PLA is composed of biodegradable molecules, quite big in size, it slowly lets water molecules pass through, in a process that resembles sweating. This means that, even when we made all the holes and contact points water-tight, water still does slowly penetrate the structure when dripping along the inside walls. To prevent this, the structure should be sprayed with a water-resistive spray, or printed out of a different type of plastic (like PETG or nylon).

Three sensors in the structure measure in total five different values, a pump that circulates the water through the structure and a wifi module that allows wireless communication. All the sensors, the pump, and the wifi module are connected to a small breadboard and Arduino UNO as can be seen in the fritzing graph below. The wifi module allows sending values to an API running on an external website called Thingspeak. The app retrieves and stores the values sent and graphs them, these graphs can be exported and used on an external website. In this case, the website is run on the portfolio server of the University and shows the data which is graphed by Thingspeak. Thingspeak has been chosen since this allows to easily plot and store data without any costs or advanced programming experience.



Business aspect

The product as it is now is already a marketable product but it can be improved even more in the future to make it suitable for a broader market than we can reach now. The product is modular and can be marketed as a base set which you can order and expandable modules which you can stack onto the base.

The target group for the product would mainly be companies and specifically restaurants and food related companies. These companies can grow fresh herbs and plants in spaces that were originally unoccupied. Besides the fact that this is very effective it can also be very aesthetically pleasing and very decorative.

Also other companies can benefit from this product in a way that it is very aesthetically pleasing and it can be used by employees. The product as it is now can already be used in such situations after some fine tuning. The structure can be made around pillars in buildings and can also be redesigned to fit walls and other shapes.

The last option to market the product can be as a kind of concept like FEBO, where you can open departments of the structure where you can grow your own plants upon scanning your application or entering a certain code. One modular compartment of the structure can be used as a dispenser for people to retrieve seeds and other necessary material. This concept would require some redesigning and can become quite expensive but also has some potential.

Future work

Looking at the prototype it is clear that there are still some minor issues or potential improvements that could be made. One issue is still that it is hard to distribute the water evenly over all the different plants and navigate the water through the structure. In the current prototype, the water is not evenly distributed since the surface of the 3D printed part is still too rough. Apart from that the water often drips down through the inner walls of the structure which can cause weak walls after a long period since the 3D printed parts are not waterproof.

An improvement that could be made is that we have more actuators that can control airflow, air humidity, and light-based on sensor values. In this prototype, we only have a few sensors and actuators but this can be expanded eventually.

Furthermore, LEDs could be added to better stimulate plant that, and implement individual sensors for every basket. Another feature that should be addressed in the further development of the product is making a case for the electronics and properly waterproofing all the inner wires and sensors.

Conclusion

When comparing the final prototype with the minimum viable product defined in the previous chapter it is clear that the goal has been met. It is possible to measure the humidity, CO2 and temperature, and some other parameters. The data that is retrieved from the sensors is visible on an external website which is visible to anyone with the right link. Also, the structure is fully enclosed since this was a requirement of the minimum viable product. So concluding the project itself was a success since the goals have been met and it contributes to the solution of the problem described earlier.

Looking at the problem of deforestation which causes climate change and food insecurity, the project itself can certainly contribute to the solution of the problems mentioned. The product can produce amounts of food which helps prevent food insecurity and enables every household and company to provide a part of their food supply. By growing crops closer to the final consumer it saves transportation which in its turn reduces CO_2 emissions.

Dealing with incidents

During our project we had to cope with some struggles. Originally, our project group consisted of 7 people but two fellow teammates had decided to quit studying creative technology. Therefore, we were only left with 5 and had to divide the tasks in a very efficient way. Also, because some of our team members had to be in quarantine for a while we could not meet physically very often. This meant solving physical issues, when we discovered that our structure was not entirely waterproof for example, was quite difficult. Luckily, due to good communication, we managed to create an amazing end result.

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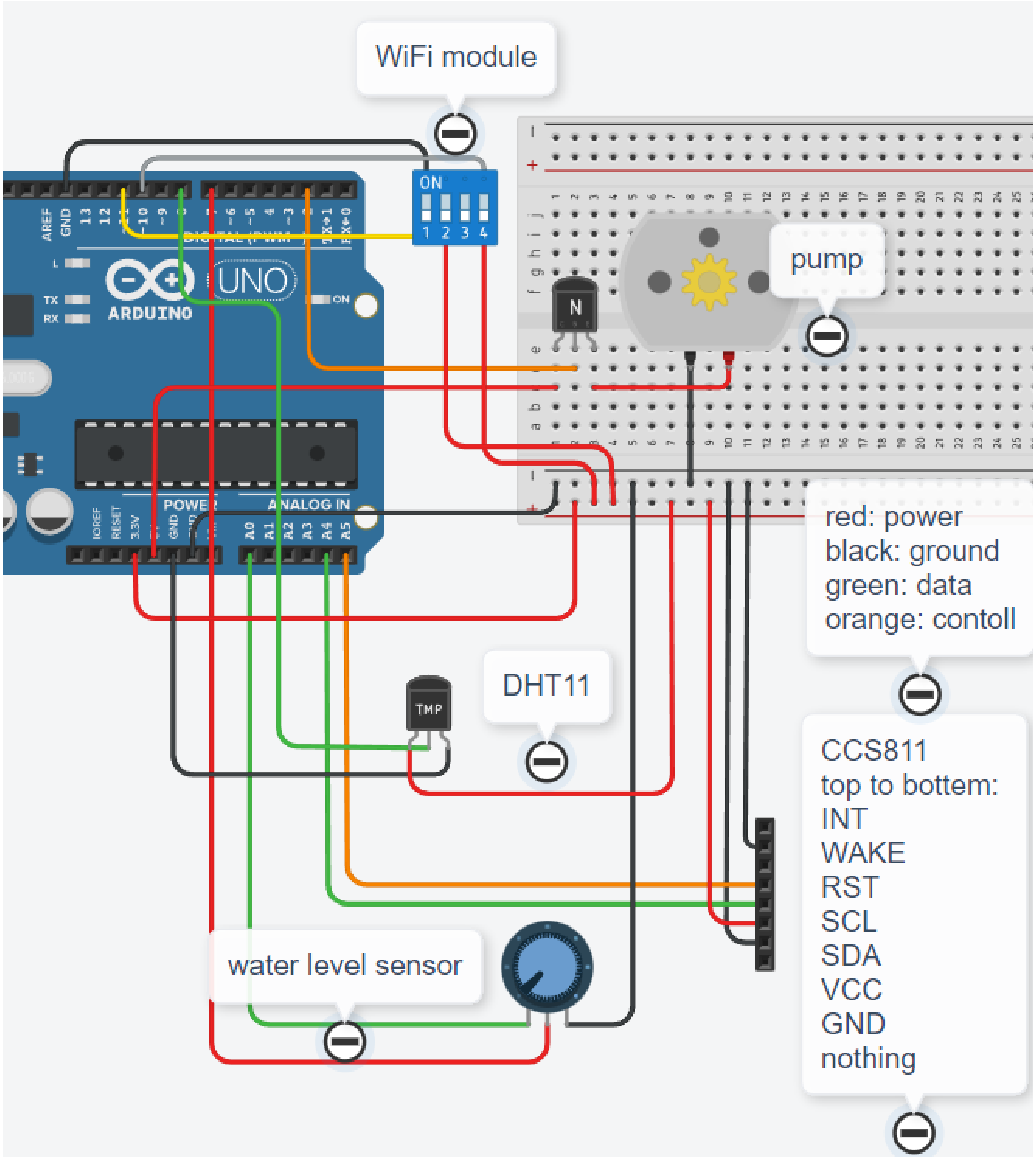
Appendix A: Electronics schematic



Note that up to 4 water level sensors could theoretically be attached if you rerouted power through the breadboard. And because the CCS811 uses I2C, multiple could be connected, again rerouting the connections through the breadboard. Furthermore, the pump needs to be connected to the 5V output pin of the Arduino, thus we are using a transistor to regulate it. The code run on it can be found in appendix D. The Wifi module is depicted in such a way that the 1,2,3,4 side of the chip correlates with the side of the chip that the pins are on.

Appendix B: Code for CCS811 sensor

Within sensor.setMeasCycle these commands can be used to change when and how often the sensor activates:

eClosed,	Idle (Measurements are disabled in this mode)
eCycle_1s,	Constant power mode, AQ measurement every second
eCycle_10s,	Pulse heating mode IAQ measurement every 10 seconds
eCycle_60s,	Low power pulse heating mode IAQ measurement every 60 seconds
eCycle_250ms	Constant power mode, sensor measurement every 250ms

```
#include <CCS811.h>

//CCS811 sensor(&Wire, /*IIC_ADDRESS=*/0x5A);
CCS811 sensor;

void setup(void)
{
    Serial.begin(115200);
    /*Wait for the chip to be initialized completely, and then exit*/
    while(sensor.begin() != 0){
        Serial.println("failed to init chip, please check if the chip
connection is fine");
        delay(1000);
    }
    sensor.setMeasCycle(sensor.eCycle_250ms);
}
void loop() {
  delay(1000);
    if(sensor.checkDataReady() == true){
        Serial.print("CO2: ");
        Serial.print(sensor.getCO2PPM());
        Serial.print("ppm, TVOC: ");
        Serial.print(sensor.getTVOCPPB());
        Serial.println("ppb");
    } else {
        Serial.println("Data is not ready!");
    }
    /*!
     * @brief Set baseline
     * @param get from getBaseline.ino
     */
    sensor.writeBaseLine(0x847B);
    //delay cannot be less than measurement cycle
    //delay(1000);
}
```

Appendix C: Code to read water sensor

```
// Sensor pins
#define sensorPower 7
#define sensorPin A0

// Value for storing water level
int val = 0;

void setup() {
	// Set D7 as an OUTPUT
	pinMode(sensorPower, OUTPUT);

	// Set to LOW so no power flows through the sensor
	digitalWrite(sensorPower, LOW);

	Serial.begin(9600);
}

void loop() {
	//get the reading from the function below and print it
	int level = readSensor();

	Serial.print("Water level: ");
	Serial.println(level);

	delay(1000);
}

//This is a function used to get the reading
int readSensor() {
	digitalWrite(sensorPower, HIGH); // Turn the sensor ON
	delay(10);                                      // wait 10 milliseconds
	val = analogRead(sensorPin);            // Read the analog value form sensor
	digitalWrite(sensorPower, LOW);         // Turn the sensor OFF
	return val;                                     // send current reading
}
```

Here the command analogRead(sensorPin) is the important one as it is the command that actually reads the value. The value itself will rise inversely exponentially, so a converting calculation is necessary to get the correct values. Furthermore, each sensor has its own calibration and gives different measurements, though most average at a maximum output value of 550.

Appendix D: Complete code

```
#include <dht.h>

#include <SoftwareSerial.h>
dht DHT;
#include <dht.h>
#define RX 10
#define TX 11
#include <CCS811.h>
#define sensorPower 7
#define sensorPin A0
#define motorPin 2
#define DHT11_PIN 8

SoftwareSerial esp8266(RX,TX);

String AP = "Fran";        // CHANGE ME
String PASS = "12345678"; // CHANGE ME
String API = "PC0WBRF6EDKPIBI3";    // CHANGE ME
String HOST = "184.106.153.149  ";
String PORT = "80";
int countTrueCommand;
int countTimeCommand;
boolean found = false;


// Sensor values
int co2;
int waterLevel;
int tvoc;
int humidity;
int temperature;

CCS811 sensor;


void setup(void)
{
  pinMode(sensorPower, OUTPUT);
  pinMode(motorPin, OUTPUT);
  digitalWrite(sensorPower, LOW);

  Serial.begin(115200);
```

```
  esp8266.begin(115200);
  sendCommand("AT", 5, "OK");
  sendCommand("AT+CWMODE=1", 5, "OK");
  sendCommand("AT+CWJAP=\"" + AP + "\",\"" + PASS + "\"", 20, "OK");

  /*Wait for the chip to be initialized completely, and then exit*/
  while (sensor.begin() != 0) {
    Serial.println("failed to init chip, please check if the chip
connection is fine");
    delay(1000);
  }

  sensor.setMeasCycle(sensor.eCycle_250ms);
}


void loop() {
  int chck = DHT.read11(DHT11_PIN);
  waterLevel = readSensor();

  Serial.print("Water level: ");
  Serial.println(waterLevel);

  Serial.print("Temperature: ");
  Serial.println(DHT.temperature);
  Serial.print("Humidity: ");
  Serial.println(DHT.humidity);

  if (sensor.checkDataReady() == true) {
    Serial.print("CO2: ");
    co2 = sensor.getCO2PPM();
    tvoc = sensor.getTVOCPPB();
    Serial.print(co2);
    Serial.println("ppm");
    Serial.print("TVOC: ");
    Serial.print(tvoc);
    Serial.println("ppb");
  } else {
    Serial.println("Data is not ready!");
  }
  sensor.writeBaseLine(0x847B);

  String getData = "GET /update?api_key=" + API + "&" + "field1" + "=" +
String(waterLevel) + "&" + "field2" + "=" + String(co2) + "&" + "field3"
+ "=" + String(tvoc) + "&" + "field4" + "=" + String(DHT.humidity) + "&"
```

```
+ "field5" + "=" + String(DHT.temperature);
  sendCommand("AT+CIPMUX=1", 5, "OK");
  sendCommand("AT+CIPSTART=0,\"TCP\",\"" + HOST + "\"," + PORT, 15,
"OK");
  sendCommand("AT+CIPSEND=0," + String(getData.length() + 4), 4, ">");
  esp8266.println(getData); delay(1500); countTrueCommand++;
  sendCommand("AT+CIPCLOSE=0", 5, "OK");
  delay(1000);
  //delay cannot be less than measurement cycle
  if (waterLevel < 300) {
    digitalWrite(motorPin, HIGH);
  }
  else {
    digitalWrite(motorPin, LOW);
  }
}


int readSensor() {
  digitalWrite(sensorPower, HIGH);  // Turn the sensor ON
  delay(10);                   // wait 10 milliseconds
  waterLevel = analogRead(sensorPin);    // Read the analog value form
sensor
  digitalWrite(sensorPower, LOW);   // Turn the sensor OFF
  return waterLevel;             // send current reading
}


void sendCommand(String command, int maxTime, char readReplay[]) {
  Serial.print(countTrueCommand);
  Serial.print(". at command => ");
  Serial.print(command);
  Serial.print(" ");
  while(countTimeCommand < (maxTime*1))
  {
    esp8266.println(command);//at+cipsend
    if(esp8266.find(readReplay))//ok
    {
      found = true;
      break;
    }

    countTimeCommand++;
  }
```

```
  if(found == true)
  {
    Serial.println("OYI");
    countTrueCommand++;
    countTimeCommand = 0;
  }

  if(found == false)
  {
    Serial.println("Fail");
    countTrueCommand = 0;
    countTimeCommand = 0;
  }

  found = false;
}
```

Appendix E: Water pump measurements data table

Time needed to pump 100ml

	time [s]		delta error
1	9.34		-0.243333333
2	8.28		-1.303333333
3	8.77		-0.813333333
4	8.99		-0.593333333
5	9.41		-0.173333333
6	11.46		1.876666667
7	11.28		1.696666667
8	8.12		-1.463333333
9	10.6		1.016666667
Avg:	9.583333333	Max:	1.876666667
		%:	0.195826087
		CI80%:	0.083552464