University of
Southern Denmark

Experts in Team Innovation

Theme 6

5. Semester

Group 2

Engineers without Borders and DIS:
Frugal Innovation in Sierra Leone

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14 December 2022

Executive summary

In collaboration with EWB and DIS, the project group has worked towards developing a planter box used to create a viable business plan for the natives by giving a higher yield in crops. This specific project evolves around the poor country of Sierra Leone.
The project proposes three designs each containing its own business case defined per income per square meter.

To begin with, the group gathered knowledge about Sierra Leone as a country. The specific examination was focused on the nature, size of the country, population, living conditions, economy, agriculture and climate. These topics helped the group establish a foundation and narrowing in on requirements for the project. The team also created a function-means table, which served as the overall design specification for the product. From a calculations chapter it was concluded to iterate on the first concept as it did not live up to requirements. Before moving on to the new creative phase including CAD drawings, new calculations were made to secure the product viability.
The final design comes in different constellations depending on the business case the intended recipient wishes to investment in. One design is constructed to be a cheap investment, whereas the two other designs are constructed to increase profits. The first product being a short-term investment and the two products being long term investments.

In the end of the project, the group brings forward an investment offer intended farmers in Sierra Leone. It concludes that the solution named "One Box solution" is the best short-term investment, as the payback period on this product is 2.5 years. It costs approximately 6,000 Dkk in production and yields 2,337 Dkk in theory.

As the entire development of the product is calculated and constructed under presumed perfect circumstances a future perspectives chapter has been added. In this, problems that might arise by using the solution as it is described in the report are defined.

Table of Contents

Table of Figures

Introduction

Sierra Leone is a country in West Africa with a rich history and diverse culture. It is known for its natural beauty, including its beautiful beaches and forests. However, the country has faced numerous challenges. In recent years, Sierra Leone has made significant progress in rebuilding its infrastructure and economy. One organization that has played a crucial role in this process is Engineers Without Borders (EWB), a non-profit that works to improve the lives of people in developing countries by providing engineering and technical assistance.

EWB has been active in Sierra Leone for many years, collaborating with local communities and organizations to design and implement sustainable solutions to the country's challenges. Through its efforts, EWB has helped improve access to clean water, electricity, and other essential services in Sierra Leone.

This project is a collaboration between EWB and D.I.S. The goal of the project is to design and implement a sustainable solution, which creates a viable business plan for the locals in Sierra Leone. This solution will be developed through a collaborative process that involves research, consultation with EWB and D.I.S, and testing. The final product will be designed to be sustainable, cost-effective, and easy to maintain, with the aim of making the implementation of the solution as easy as possible. In short, the project's goal is stated through the following problem statement:

"The project aims to propose an incremental solution for creating a viable business plan to the locals in Sierra Leone, by planting specific cash crops in planter boxes, designed for multipurpose use."

Ideation

In the phase one report, the group came to the following problem statement:

"The project aims to propose an incremental solution to the existing agriculture environment, by using the current available crops and natural materials to avoid rainfall from destroying the crops and affecting hunger and level of nutrition."

From the this it was decided to make a brainstorm based on words. 'Flooding in the agriculture sector' was the point of origin from which every group member brainstormed on whatever word came to mind. Once a lot of words had been written down, a classification of the words made sense to get a better overview. See figure 1.

Figure 1: Word Brainstorm

The classifications are as follows:

- Rediverting water
- Construction above the soil/water level
- Barriers
- Materials
- Protection of crops
- How to take advantage of much water
- Alternatives

From the brainstorm of words all group members had five minutes to draw an idea concerning flooding in agriculture. From this exercise seven rough sketches were drawn - see appendix A.

Once having rough ideas on how to help farmers not to suffer from excessive rainfall destroying

Criteria/Idea	A	B	C	D	E	F	G
Feasibility - Attila	4	3	5	4	4	3	2
Feasibility - Rebekka	3	3	4	2	4	1	1
Feasibility - Malte	3	2	4	4	2	3	2,5
Feasibility - Peter	5	1	5	3	3	3	1
Feasibility - Sum	3,75	2,25	4,5	3,25	3,25	2,5	1,625

Figure 2: Rating table of ideas

their crops, a criteria table for all ideas was created. As this was the first part of the ideation phase, the group did not know much about solving the problem for which reason 'feasibility' was the only criteria utilized for sorting ideas.

In the criteria table for the generated ideas, idea A and C was given the highest scores. When looking at the drawings of the two they look very similar, which might be why they both score high. The difference between the two ideas is that they both protect the crops by allowing the crops to be located above ground level. Because they look very much alike, they are tied together as one idea.

To further define the chosen concept from the point system in figure 2 a morphology chart is utilized to highlight means for functions.

	Mean					
Functions	1	2	3	4	5	6
Fixation	Pole	Robe	Wall	Anchor	None	
Framework	Wood	Metal	Concrete	Composites	Plastic	
Shape	Cirkular	Quadrangular	Triangular	Rectangular	Oval	
Draining of water	Small holes	One way material	Heating	Spring	None	
Bottom shape	Triangular	Bowl	Flat	Wave shape		
Size	5m2	10m2	20m2	50m2	100m2	200m2
Shielding	Glass	Greenhouse	Plastic bags	None		
Floating	Plastic	Bottles	Barrels	Sheetmetal/ship	Polystyrene	None

Figure 3: Morphology chart

The different functions in the morphology chart above is defined as follows:

- Fixation: Fixation is how the construction is supposed to be mounted to the ground and held in place.
- Framework: Framework is describing the construction of the solution and in which kind of material it shall be constructed.
- Shape: Shape can either be circular, quadrangular, triangular, rectangular or oval. This is important to consider depending on the location.
- Draining of water: Draining of water is how the solution is supposed to get rid of excessive water.
- Bottom shape: This differentiates shape by considering root depth from crops.
- Size: Size defines the expected feasible size for the solution.
- Shielding: Shielding describes what kind of "protection" should be implemented into the solution.
- Floating: Floating defines how the floating mechanism of the solution is supposed to work and how.

From the combination of means to the different functions an initial solution was defined. It turned out that the means to the different functions described idea C from the creativity exercise about drawing for five minutes very well. Due to this no additional drawings were made. See figure 4 for idea C.

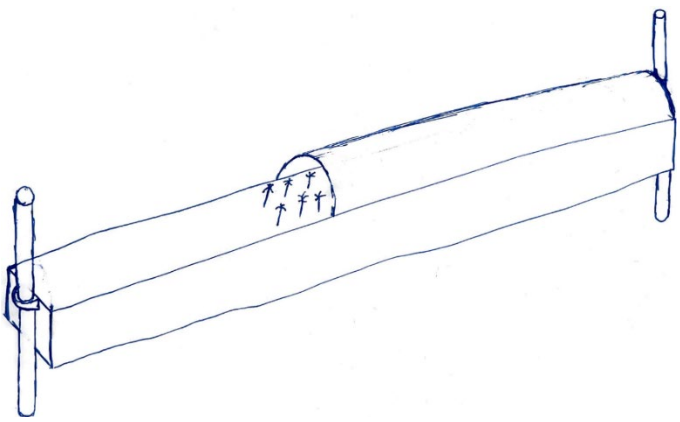


Figure 4: Idea C

Objective tree

As seen in appendix B, the project slightly shifted after the meeting with DIS and EWB, which resulted in making a *Problem Tree* and an *Objective Tree*, to get a clearer overview of the desired future situation in Sierra Leone once the problems have been identified and resolved.

As mentioned above, the project shifted from focusing on ensuring that smaller families can feed themselves, to focus on creating a viable business. Therefore, the Problem Tree is centred around *Poverty in Sierra Leone* and how to reduce this. As poverty is a rather large topic and can be solved in many ways, this project aims to solve it through farming. The problems identified regarding creating a business around farming, are *flooding of crops/excessive water*, *lack of space*, and *dirt as a scarce resource*. The latter and *lack of space* are concerning the people living in city areas, where they are living closely together, thus not being able to have a larger field for farming and where dirt is a rather scarce resource. The matter of *flooding of crops* concerns the people living in tight areas near the ocean, where it could be argued that dirt also in some cases is a scarce resource. As seen on the "*Problem Tree"*, some additional higher effects of the problems have been identified.

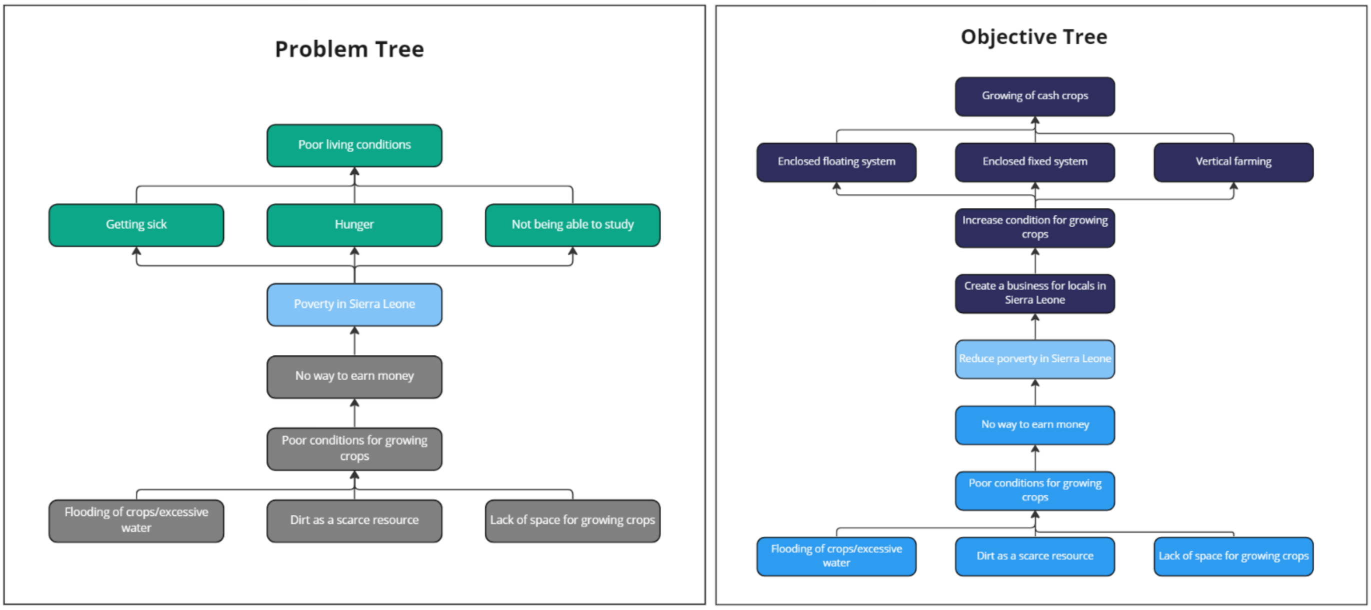


Figure 5: Problem & Objective tree

From the "*Problem Tree",* the causes are then turned into means, and some objectives were found as "ends" to the "means". The objectives are based on the solution to the previous situation and have been identified as *an Enclosed floating system, an Enclosed fixed system, Vertical farming,* and *the growing of cash crops.* These objectives should thus be the focus of the project and would combined create the product to be made.

Cash Crop analysis

The three cash crops, onion, tomato, and potato seem possible to plant in the box and will all give an approximately income. Tomatoes will immediately be the most effective cash crop because it has the shortest production time, the highest amount of production per $10m^2$ and the highest price per kilogram. Onion and potatoes are also okay to plant as they produce the second highest crop income. The three cash crops and their different needs are considered in the "Concept development". See appendix C for full Cash crop analysis.

The following table gives an overview of the three cash crops.

	Onion	**Tomato**	**Potato**
Production time	80 days	67 days	80 days
Production amount/10m^2	28 kg	50 kg	40 kg
Money/kg	1,6 $	4,05 $	2,3 $
Money/year/10m^2	204.6 $	1103.17 $	419.75 $

Concept development

In the cash crop analysis, it turned out that tomatoes, potatoes and onions need no more than 200mm of soil depth for their roots. EWB argued that the concept can be utilized in different ways. Because of this, the concept is built on a modular basis, consisting of the planter box as the primary module, a module for floating, poles for fixation, and a cover. This section gives a better description of the develop concept.

Concept specification

The concept can be modified into several constellations depending on the need and the environment it is being implemented in. Three main constellations are identified as: vertical farming, floating, and one box solution. The constellation to be used depends on the chosen cash crop and the environment it is being implemented in.

<u>Vertical farming definition</u>: Multiple planter boxes mounted on top of each other all fixated to pillars.
<u>Floating:</u> The bottom planter box sits on the ground but is constructed with plastic bottles allowing it to float in excessive water periods.
<u>One box solution:</u> This is one planter box fixated to supporting pillars in the ground.

When the group initially brainstormed on the concept, it was decided to draw the concept in CAD to give a better overview of how the product will look. Being able to orbit around the product in CAD opens new possibilities and difficulties arise.
The concept is dimensioned according to the functions and means table and the cash crop analysis, 10000x1000x200mm. These dimensions describe only the soil container though. The height of the entire construction is not yet to be known as CAD will show us how much space is required for the bottles. In addition, a cover for the concept has been developed to accommodate for the meeting with EWB. The initial concept drawn in CAD looks like figure 6 and 7 beneath. Figure 7 shows the concept as it looks to the eye. Figure 6 shows the bottle compartment. See next page for pictures in further detail.

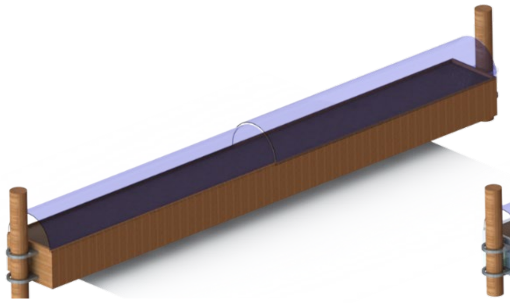


Figure 7: Concept to the eye

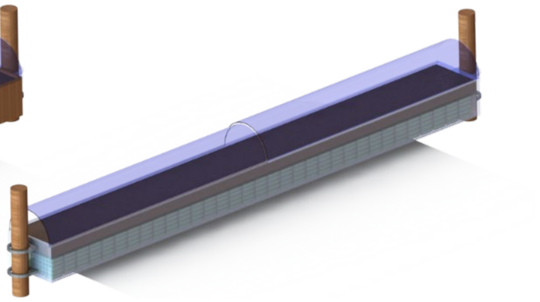


Figure 6: Concept with bottle compartment

On drawing 8 beneath is shown the concept in full size with dimensions. The length shows 10100mm but that is due to the material thickness of 50mms being added.

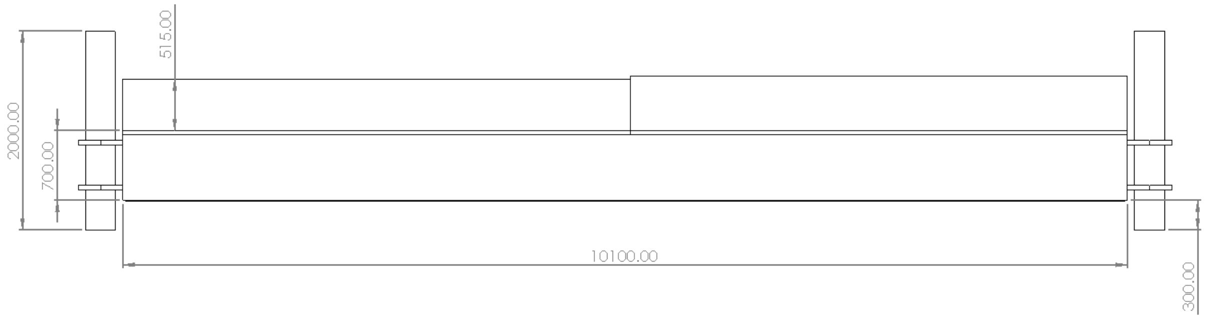


Figure 8: Full size concept with dimensions

On figure 9 beneath the net on the bottom holding the plastic bottles can be seen:

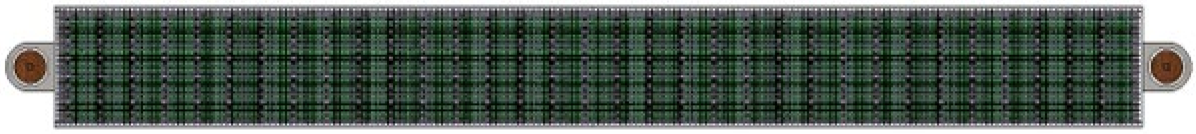


Figure 9: Bottom of the concept with net

At figure 10 at right is shown a section cut of the concept. The cover developed for heavy rainfall, theft and hungry birds has a radius of 515 millimeters. Those can be added to the soil container height of 200 millimeters and the bottle compartment height of 400 millimeters. The height for the bottle compartment was found by filling up the compartment with bottles lying perfectly in order and thereby seeing how much space they would require.

The total height of the concept will end up being approximately 1.2 meters. This is to heigh if it shall be able to float and have a fixed planter box above it for the natives to reach.

The final concept without cover will be 10000x1000x700mm. See figure 11 beneath for a transparent look of the concept from the side.

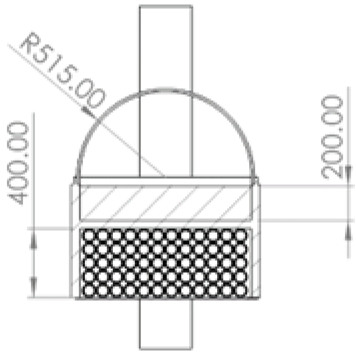


Figure 10: Section cut of the concept

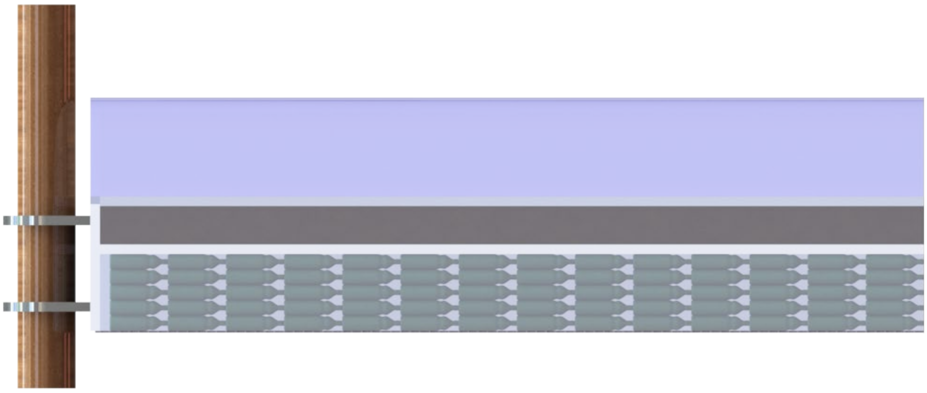


Figure 11: Transparent picture of the concept from the side

Material specification

This section describes which materials are needed for the concept, the buoyancy and how to keep the bottles under the box.

The box

The box is the one that must hold both the soil and the plastic bottles. It must be durable, and partially nature/water safe. That means for optimal use the material of the box should not be naturally degradable, for which reason plastic is found to be the best material, as it is easy to obtain and work with.

The plastic consumption in Sierra Leone is immense, and since plastic is non degradable it is probably not something needed to be replaced in the short term. On the contrary, wood is cheap and easy to work with. In the small villages, natives can get materials from nature/forests. In cities wood can be bought on the market. The disadvantage of wood is the naturally degradable substance and would thus need maintenance at some time. But that is not considered a big problem as wood should be good for a couple of years, even if it is submerged in water.

The price for timber in Sierra Leone at the size 20x120x1500 mm is around 54.000 Leone, which corresponds to 3 American dollars. (Anon., 2021).

The buoyancy

The buoyancy must be cheap and have a lot of power. It should be easy to obtain and easy to handle. The thought is to use water bottles as a lifting force on the box. It is free to collect from the river, and due to the air inside it has buoyancy. In addition, it will remove plastic from the streets and rivers.

Containing the bottles

To contain the bottles, a container is built beneath the soil. To make it easy for the natives to access the bottle compartment, a net is used to hold the bottles in place. If more buoyancy is required and bottles is be to added to the compartment, the net can easily be removed.

Conclusion

If it’s a floating solution it could be done with plastic or wood, both would be reasonable solutions. But if it’s a fixed solution over the ground, it should be wood, because plastic is too fragile to withstand the large load of soil.

Floating calculations

To find out whether the concept is feasible or not, some calculations were made on how much buoyancy is needed to lift the solution above the ground when floods hit the area.
The soil in the concept is what will weigh the most, so that will be the basis line for the calculations.

Dimensions of soil container:

- 10 meters long
- 0.2 meter heigh
- 1 meter wide

Dry soil weighs between 1.2 and 1.6 tons. (Toolbox, 2008)

On average that is:

$$\frac{1.2 + 1.6}{2} = 1.4\, metric\ tons$$

Amount of soil the soil container holds:

$$10m \cdot 0.2m \cdot 1m = 2m^3$$

Weight of dry soil:

$$2 \cdot 1.4\, tons = 2.8\, metric\ tons$$

Wet soil weighs 1.776 metric tons per cubic meter. The solution includes two metric tons (Delaware, 2015):

$$1.776 \cdot 2 = 3.552\, metric\ tons$$

As plastic bottles were thought to create buoyancy, the most common plastic bottle type, 1.5 liters, are calculated upon. A 1.5-liter plastic bottle will provide 1.5 kg of buoyancy (Anon., u.d.).

In the solution, the compartment for the plastic bottles has a height of 400 mm. This is enough space for 1,980 plastic bottles. These 1980 plastic bottles create a buoyancy of:

$$1980 \cdot 1.5 = 2.970\, metric\ tons$$

Looking at the calculations, the 1980 bottles aren’t enough to lift the solution as of now. The bottles need to lift additional 582 kilos:

$$3552 - 2970 = 582\, kg$$

So, how many extra bottles are needed for 582 extra kilos in buoyancy?

$$\frac{582}{1.5} = 388\ bottles$$

388 bottles will add 80 mm to the height of the bottle compartment. These calculations do not take the position of the bottles in the compartment into consideration nor the size of the bottles. The locals will not be able to find bottles of the same size, so for now the calculations are theoretical. Furthermore, the materials' weight used in manufacturing the solution isn't included.

Conclusion

The floating calculation showed that the dimensions of the container and the number of plastic bottles needed for it to be able to float didn't add up. Therefore, the idea of a floating element is cancelled, leading on to the other two constellations, namely vertical farming and one box solution. To still counteract the possibility of flooded crops the boxes are lifted from the ground.

New concept

As concluded in the calculation chapter above, a new concept is in its place. This will still have to benefit the idea of being useful in heavy rain periods.

The thought about vertical farming was concluded to be interesting and useful having the excessive water flows in mind. It now made sense for the group to stack multiple planter boxes leaving no boxes touching the ground.

One team member thought of building a vertical farming as some companies build tables and shelfs in one. See figure 12 (Talk, n.d.) Each shelf is supposed to represent a planter box. By stacking the boxes, the natives will be able to utilize their space better and by turning the shelfs, still be able to reach and fertilize the soil.

Figure 12: Table and shelfs in one

Dimensioning:

The first concept was dimensioned 10000x1000x700mm including space for the bottles and a soil container.

If the new solution should be relatively small, handy in places with narrow spaces, easy to build and easy to set up, those dimensions must be changed radically. From the calculation chapter, soil is proven to be very heavy, and for a long construction to withstand that load, it requires some reinforcement in the middle. Otherwise, it will break.

Because of this, the length of the planter boxes is chosen to be built in one third of the length of the first concept, 3000mm. Much longer is thought to be unwise do to handling of the product.

Calculations to the new dimensions

The soil container dimensions for the new concept will look much like the first concept with the only difference being length. The new measurements will be 3000x1000x200mm. Those are the inner dimensions of the soil container. Outer dimensions are determined based on the thickness of the material used.

For the calculations it only makes sense to consider wet soil as this is heavier. From the calculation chapter above, it is known that the most common wet soil has a weight of 1.776 metric tons per cubic meter.

The new soil container will contain the following cubic meters:

$$\frac{3000mm \cdot 1000mm \cdot 200mm}{1000 \cdot 10^6} = \frac{3mm^3}{5} = 0.6\ m^3$$

0.6 cubic meters will weigh:

$$0.6 \cdot 1.776 \approx 1.0656\ metric\ tons$$

By knowing the force that is being applied to the planter boxes, it is possible to calculate whether the construction is strong enough. The group has determined to use pressure impregnated oak as building material with the standard arial dimensions of 47x250mm (Bauhaus, u.d.).

Figure 13: Impregnated oak plank

Before calculating, metric tons must be converted into Kilonewton:

$$1.0656 = 10.45\ kN$$

The force across the planter boxes will be distributed loading, which is why the following formula is used:

$$V = \frac{wL}{2} = \frac{10.45kN \cdot 3m}{2} = 15.675\ kN$$

Now the shear stress applied to the wooden plank can be calculated:

$$\tau_{max} = 1.5 \cdot \frac{V}{A} = 1.5 \cdot \frac{16.675 \cdot 1000}{47 \cdot 250} \approx 2.128723\ MPa$$

From the calculations it can be concluded that the planter box at the middle and most stressful point will be exposed to 2.13 MPa. (Ashraf, n.d.)

In Figure 14 beneath ￼ (Engineeeringtoolbox, u.d.), the typical oak used in beams can withstand 4.07 MPa when in wet conditions. Oak is weaker when wet, for what reason this value is the one considered. With the amount of soil, the new soil container holds, the solution is 52.3% stronger than required. The amount of weight used in the calculations are based on fully moisturized soil which in reality will not be the case. If the soil is fully moisturized the crops will drown. These calculations are based on worst case scenario.

Maximum Stress (psi) (MPa)						
Wood Species	Bending		Compression			
	Horizontal Shear - τ -		Perpendicular to Grain - σ -		Parallel to Grain - σ -	
	Wet	Dry	Wet	Dry	Wet	Dry
Birch, Yellow	1417 9.77	1668 11.5	477 3.29	715 4.93	960 6.62	1200 8.27
Fir, Douglas	1417 9.77	1668 11.5	417 2.88	625 4.31	1360 9.38	1700 11.7
Larch, Western	1417 9.77	1668 11.5	417 2.88	625 4.31	1360 9.38	1700 11.7
Maple, Red	1271 8.76	1495 10.3	410 2.83	615 4.24	880 6.07	1100 7.58
Oak, Black	1369 9.44	1610 11.1	590 4.07	885 6.1	920 6.34	1150 7.93
Pine, Eastern White	1222 8.43	1438 9.92	223 1.54	335 2.31	960 6.62	1200 8.27
Redwood	1320 9.1	1553 10.7	433 2.99	650 4.48	1200 8.27	1500 10.3

Figure 14: Properties of different wood species

Concept Development 2

Vertical farming

See figure 15 beneath for the new concept. To give an insight into the size of the construction a man with a height of 183 cm has been located next to it.

Figure 15: New concept

When looking at figure 16 the different dimensions can be read. The construction is perfectly quadrant when seen from above. When the construction is positioned as on figure 16 to the left, the planter boxes take up a space of 3488x1094 millimetres. When “folded” out it measures 3488x3488 millimetres. In case that excessive rainfall should saturate Sierra Leones soil, the bottom planter box is positioned 300 millimetres above ground level, in hope that the water will not reach the box. As the concept is constructed in a way where the planter boxes are rotating around each other, the height of the entire construction is relatively heigh for a native to reach for the middle planter box.

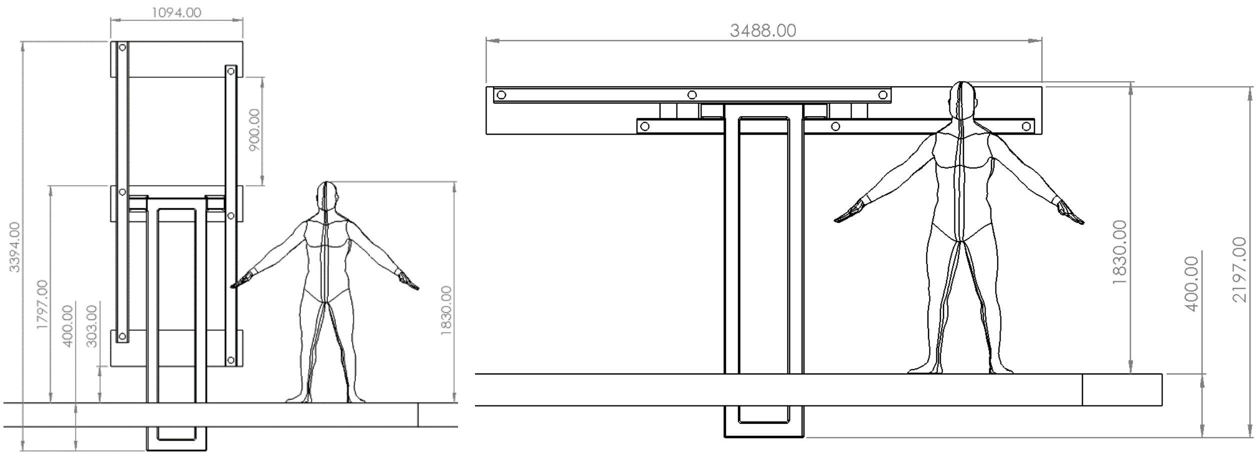


Figure 16: Dimensions of new concept

Unfortunately, the middle box is located at a height of 1797 millimetres which will require something to step on to reach. Between each planter box the height is 900 millimetres.
For the construction not to tip over it requires a solid foundation. On the figures the construction goes 400 millimetres deep into the soil. This has no justification and will require an investigation.

Planter box

A single planter box has the dimensions seen on figure 17. It consists of two pressure impregnated oak planks across with 12 transverse planks mounted in the bottom cut to size. At the ends, two steel structures are designed specifically for the boxes.

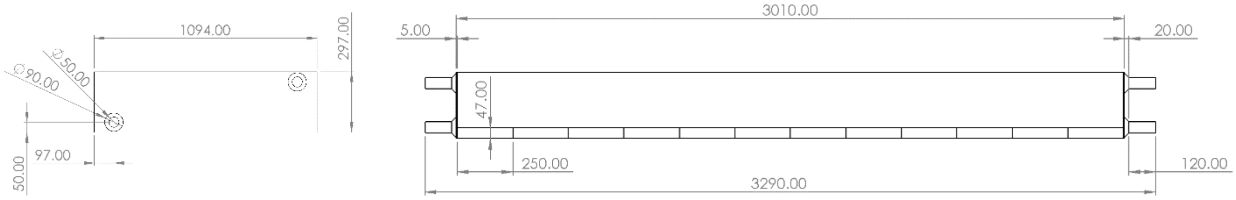


Figure 17: Single planter box dimensions

So what is required for a planter box construction?

Materials:

- 2x impregnated oak planks, 47x250x3000mm
- 12x impregnated oak planks 47x250x1094mm
- 2x steel sheet 5x297x1094mm
- 4x steel pipe Ø50mm
- 6x flat steel 5x50x997mm
- 120 screws

Machinery:

- Metal band saw
- Welding equipment

Imagining a larger vertical farm with 25 planter box constructions would look like on figure 18.

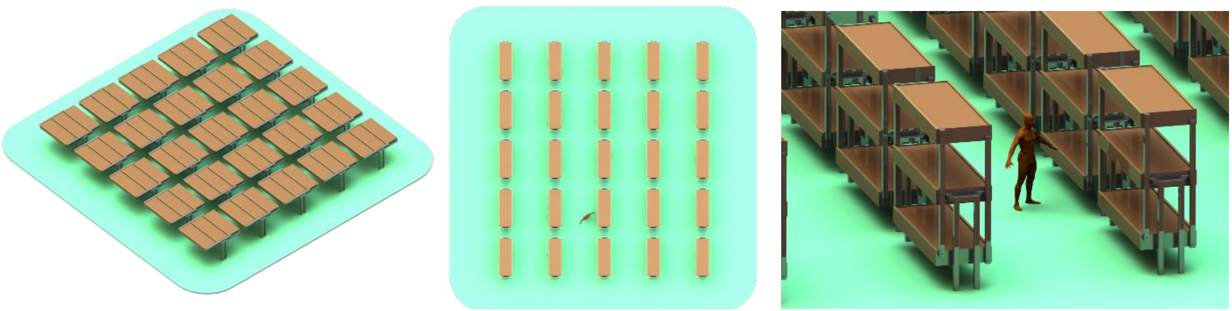


Figure 18: Plantation of solution

Considering the environment in which these are to be implemented, it can be difficult to find the space for one of these in the cities. When they rotate the area which one covers expand.

To accommodate for as many usercases as possible, another constallation in which it doesn't rotate can be constructed. In this case the natives would need a ladder or stool to reach for the middle and top planter box. See this construction on figure 19 at right.

It saves a lot of space and multiple of these would prosper well in crowded areas with minimum farming possibilities.

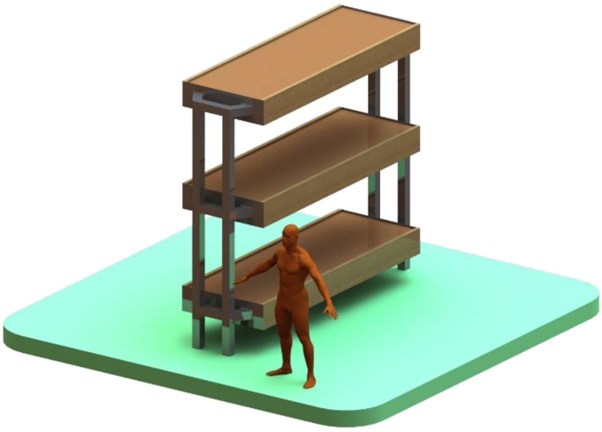


Figure 19: Fixed solution perspective

It is important to mention that only potatoes and onions fit into the vertical farm. Tomatos requires more than 900 millimeters in height, which is why this crop is not suitable.

One Box solution

The one box solution as mentioned in the concept specification chapter, is a single box fixated with pillars into the ground. See figure 20.

This configuration of the construction does not limit crop height. Therefore, tomatos can be planted into these. Also, this solution is cheaper to acquire and not as high. The area this configuration covers is the same though. See the business case chapter for return on investment for all three configurations.

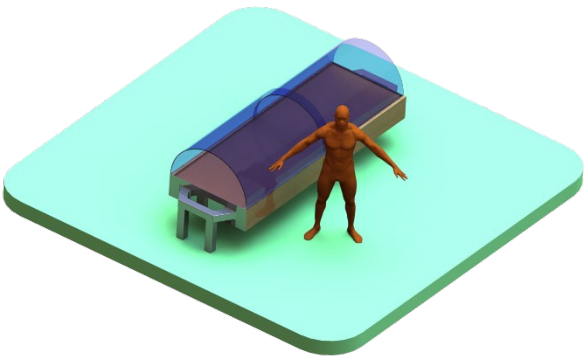


Figure 20: One box solution perspective

As seen on figure 20 the box comes with a plastic cover to protect from hungry birds and theft of crops. The vertical farming concept also comes with these covers. Each cover protects each half of the planter box and can be slided back and forth.

Production Prices

One planter box price

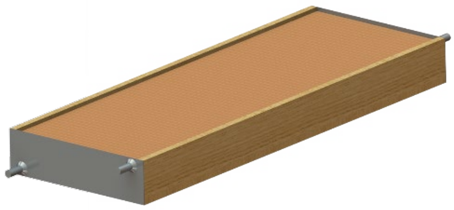


Figure 21: Planter box without shielding

From the material selection chapter, the prize on timber with the dimensions 20x120x1500mm in Sierra Leone is 3 American dollars. The standard timber size is dimensioned 47x250x6000. This is four times longer and twice as thick. Because the timber is twice as thick, the prices per 1500mm is doubled.

$$\frac{6000}{1500} \cdot 2 = 8$$

Price on timber per planter box:

$$8 \cdot 3USD = 24USD$$

One planter box requires 19,200 millimetres in length of timber.

$$Total\ price\ of\ timber\ \frac{19200}{6000} \cdot 24\ USD = 76.8\ USD = 542.36\ Dkk$$

The price of metal is not to be found in Sierra Leone. Therefore, the ratio between the price difference of wood in Sierra Leone and Denmark is used to calculate the price of metal in Sierra Leone. The ratio is 3.184x.

Metal parts are: 4x Ø50mm 140mm pipe, 2x 5x297x1094mm flat steel, 6 x 1000x50x5mm flat Steel

4x Ø50 140 mm pipe price:

$$\frac{390{,}73dkk}{3.184} = 122{,}72\ dkk \cdot 4 = 490{,}88\ dkk$$

2x 5x297x1094mm sheet price:

$$\frac{2280.21dkk}{3.184} = 716{,}15\ dkk \cdot 2 = 1432\ dkk$$

6 x 1000x50x5mm flat Steel:

$$\frac{363.23dkk}{3.184} = 114{,}08dkk \cdot 6 = 684{,}48\ dkk$$

Labour prices in Sierra Leone is not to be found either. Here the same price ratio is used. It is estimated that one planter box will take five hours to build in worst case scenario. A danish smith labour is 525 Dkk an hour. (jtstaal, u.d.)

$$Labour\ Cost: 5 \cdot \frac{525Dkk}{3.184} = 824{,}44\ Dkk$$

Total price of one planter box:

$$\mathbf{542.36 + 490.88 + 1432 + 684.48 + 824.44 = 3974{,}16\ Dkk}$$

One box solution price incl. steel construction

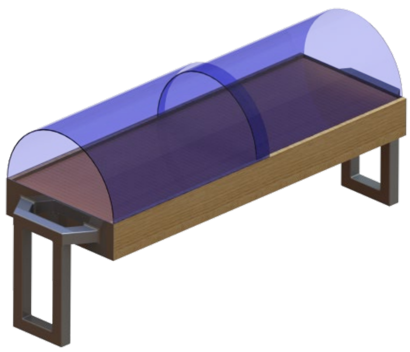


Figure 22: One box solution

The price of the one box solution is separated into three parts, the planter box, the steel construction going into the ground supporting it, and the plastic cover.

Planter box price: 3974.15 Dkk

Figure 23: Steel construction for One box solution

The steel construction is made of profiled pipes with the dimensions 100x100 with a material thickness of 3 mm.

As the construction is made of the same profiled pipes in different lengths, these lengths can be added together: (Stålbutikken, u.d.) (Stålbutikken, 2022)

$$6080mm$$

$$\frac{3387.92dkk}{3.184} = 1064{,}1\ dkk$$

The steel construction is estimated to take 2 hours to cut and weld.

$$\frac{2 \cdot 525dkk}{3.184} = 329{,}77\ dkk$$

The plastic covers are estimated to cost 1000 dkk per piece:

$$\frac{1000dkk}{3.184} \approx 314{,}1 \cdot 2 = 628{,}2\ dkk$$

Total price of the one box solution:

$$\mathbf{3974 + 1064.1 + 329.77 + 628.2 \approx 5996,07}$$

Rotational vertical farming solution price incl. steel construction

The price of the rotational vertical farming solution is separated into two parts, the planter box and the steel construction going into the ground supporting it. The plastic covers can be added as a third part:

Planter box price: 3974.15 Dkk

The steel construction is made of profiled pipes with the dimensions 100x100 with a material thickness of 3 mm.

Figure 24: Rotational solution inclusive steel construction

There are three different lengths to cut which can be added together:

$$Total\ length: 20764\ mm$$

$$\frac{10858.35dkk}{3.184} = 3410{,}29\ dkk$$

The steel construction is estimated to take 3 hours to cut and weld.

$$\frac{3 \cdot 525dkk}{3.184} = 494{,}66\ dkk$$

Plastic covers if needed $628{,}2\ dkk$

Total price of the rotational vertical faming solution with plastic covers:

$$\mathbf{(3 \cdot 3974) + 3410.29 + 494.66 + (628.2 \cdot 3) = 17711.55\ Dkk}$$

Total price of the rotational vertical faming solution without plastic covers:

$$\mathbf{17711.55 - (628.2 \cdot 3) \approx 15826{,}95}$$

Fixated vertical farming solution price incl. steel construction

The price of the fixated vertical farming solution is separated into two parts, the planter box and the steel construction going into the ground supporting it. The plastic covers can be added as a third part:

Planter box price: 3974.15 Dkk

The steel construction is made of profiled pipes with the dimensions 100x100 with a material thickness of 3 mm.

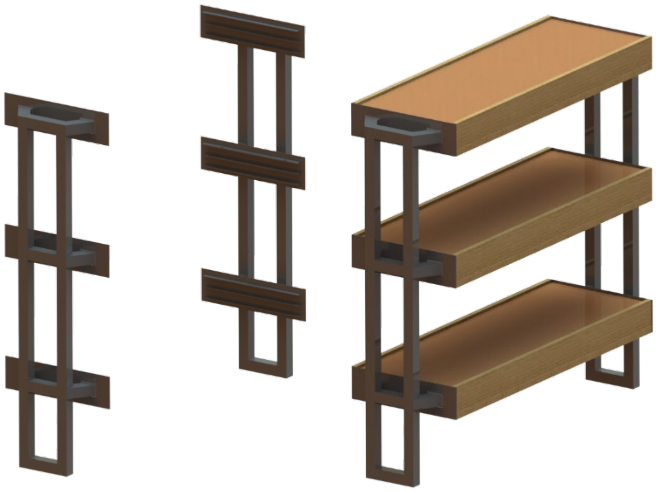


Figure 25: Fixed solution inclusive steel construction

There are three different lengths to cut which can be added together:

$$Total\ length: 18800\ mm$$

$$\frac{10038.37dkk}{3.184} = 3152{,}75\ dkk$$

The steel construction is estimated to take 4 hours to cut and weld.

$$\frac{4 \cdot 525dkk}{3.184} = 659{,}55\ dkk$$

Plastic covers if needed $628{,}2\ dkk$

Total price of the rotational vertical faming solution with plastic covers:

$$\mathbf{(3 \cdot 3974) + 3152.75 + 659.55 + (628.2 \cdot 3) \approx 17618{,}9\ Dkk}$$

Total price of the rotational vertical faming solution without plastic covers:

$$\mathbf{17618.9 - (628.2 \cdot 3) \approx 15734{,}3\ Dkk}$$

Business Case

Crop yield and income overview

One box solution

Production space: $3m^2$

- **Production of onions/yearly**: 35.77 kg
- **Money income per year in onions:** 404.17 Dkk

- **Production of potatoes/years:** 54.75 kg
- **Money income per year in potatoes:** 889.28 Dkk

- **Production of tomatoes/yearly:** 81.71 kg
- **Money income per year in tomatoes:** 2337.17 Dkk

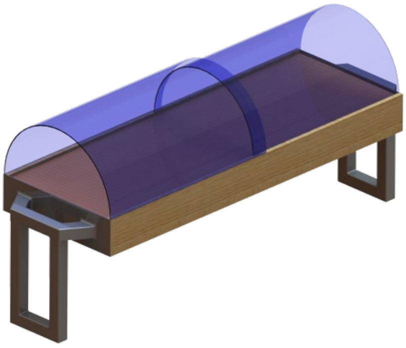


Figure 26: One box solution

Rotational Vertical farming solution

Production space: $9m^2$

- **Production of onions/yearly**: 107.31 kg
- **Money income per year in onions:** 1251.51 Dkk

- **Production of potatoes/years:** 164.25
- **Money income per year in potatoes:** 2667.84 Dkk

Figure 27: Rotational solution

Fixated Vertical farming solution

Production space: $9m^2$

- **Production of onions/yearly**: 107.31 kg
- **Money income per year in onions:** 1251.51 Dkk

- **Production of potatos/years:** 164.25
- **Money income per year in potatos:** 2667.84 Dkk

Figure 28: Fixed solution

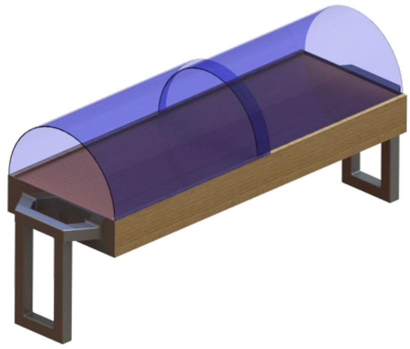
Payback year of investment

The big question is which constellation the natives should choose to invest in. Which will have the fastest return on investment?

One box solution manufacturing price: 5996.07 Dkk

Maximum selling potential of tomatos: 2337.17 Dkk

<u>Payback year on investment: Two and a half years.</u>



Rotational Vertical farming solution price: 17711.55 Dkk

Maximum selling potential of potatos 2667.84 Dkk

<u>Payback year on investment: Six and a half years</u>

Fixated Vertical farming solution price: 17618.9 Dkk

Maximum selling potential of potatos 2667.84 Dkk

<u>Payback year on investment: Six and a half years</u>

Figure 29: All three solutions

Conclusion

When looking at the three different constellations the two vertical farms can produce the highest crop income on a yearly basis. To be specific the fixated vertical farm is the one doing the best job of the two as the manufacturing price is slightly less.

By taking the return on investment into consideration the one box solution shows at much better result. Within 2.5 years it will theoretically have produced enough to earn back the investment. In addition, the natives do not need to invest in a stool to reach for a planter box.

One could argue, that if you're looking to invest on a long term and you are having a limited farming area, the fixated vertical farming solution would do the better job as it in the long run will earn a higher income. It is though, important to consider whether the crops will get an adequate amount of sunlight in the vertical farming solutions.

As Sierra Leone is a country struggling with food production and wealth, the group suggests investing in the one box solution including plastic covers.

Future perspectives for the concept

- When considering the concept there is quite a few unknown parameters which are important to know before producing and selling it. To be able to calculate and produce an in-depth business case, the lifetime of these constructions would have to be known. Wood is something that with time can rot, but since the wood used in these concepts are pressure impregnated, they are capable of lasting up to 20 years when in contact with soil and water. This impregnation will have to be according to the NTR class AB. (Admin, 2012)

- In the vertical farming solution, there is 900 millimetres in between each of the planter boxes. The question is if these 900 millimetres will cover for the sun, so that the bottom and middle planter box crops will not get as much sunlight as required.

- Everything about the concepts that has been described so far, is outlined in perfect shapes and conditions. This is not viable when considering the circumstances under which these concepts shall be produced. The natives should perhaps contemplate the possibility of outsourcing the manufacturing.

- From the calculation chapter it is known that the soil will weigh 1.0656 metric tons. This ton will have to be considered when manufacturing the steel ends for the planter boxes. It is important to know if the welding on the sides will withstand the load.

- It has not been calculated how deep into the ground the construction must go for it not to tip over when affected by wind and nature conditions.

- The material prices and labour are to some extend estimates. It can vary depending on the manufacturer. Also, labour cost can vary depending on the carpenter and the smith. The calculations are not executed based on wholesaler prices, for what reason it is believed to turn out cheaper.

- As of now there is no developed lock system in the rotating vertical concept. This means that if the top planter box is heavier than the bottom one it will rotate by itself.

Reflection

This section contains a reflection on the project, including involvement of DIS and EWB, phase 1 and phase 2.

The project regarding Sierra Leone has been instructive and led to an understanding of what it is like to live in West Africa more closely, Sierra Leone. The Phase 1 report finally led to a formulation of the problem around farming and overfloating, as it was immediately a problem, seen from the external background analysis and literature review. This project's external background analysis could have been set up as a PESTEL analysis, this would make it easier to see where the challenges lay. Although the external background analysis is based on PESTEL, it does not lead to the same overview.

Phase 2 is based on the problem statement. Which entails the idea generation and concept were a solution to prevent the crops from being destroyed during the rainy season. DIS and EWB got an insight into our process, thoughts, and concept at the meeting. DIS and EWB came with good points and a better insight in what country Sierra Leone are and how few resources they have. This better understanding of Sierra Leone would have been useful earlier in the project, so it thought it could be useful to use cooperate/talk more with DIS and EWB in phase 1 and not only in phase 2. This would probably have entailed a more specific and relevant problem statement, which would make our concept better from the start.

The calculations on the first concept, the floating farming box, were incredibly important because it showed that the boxes would not be able to float “just like that”. Thus, we switched to our new concept, these calculations might have been relevant earlier in the concept development, then there could have been more focus on the finally concept and to prof whether that is a good solution or not.

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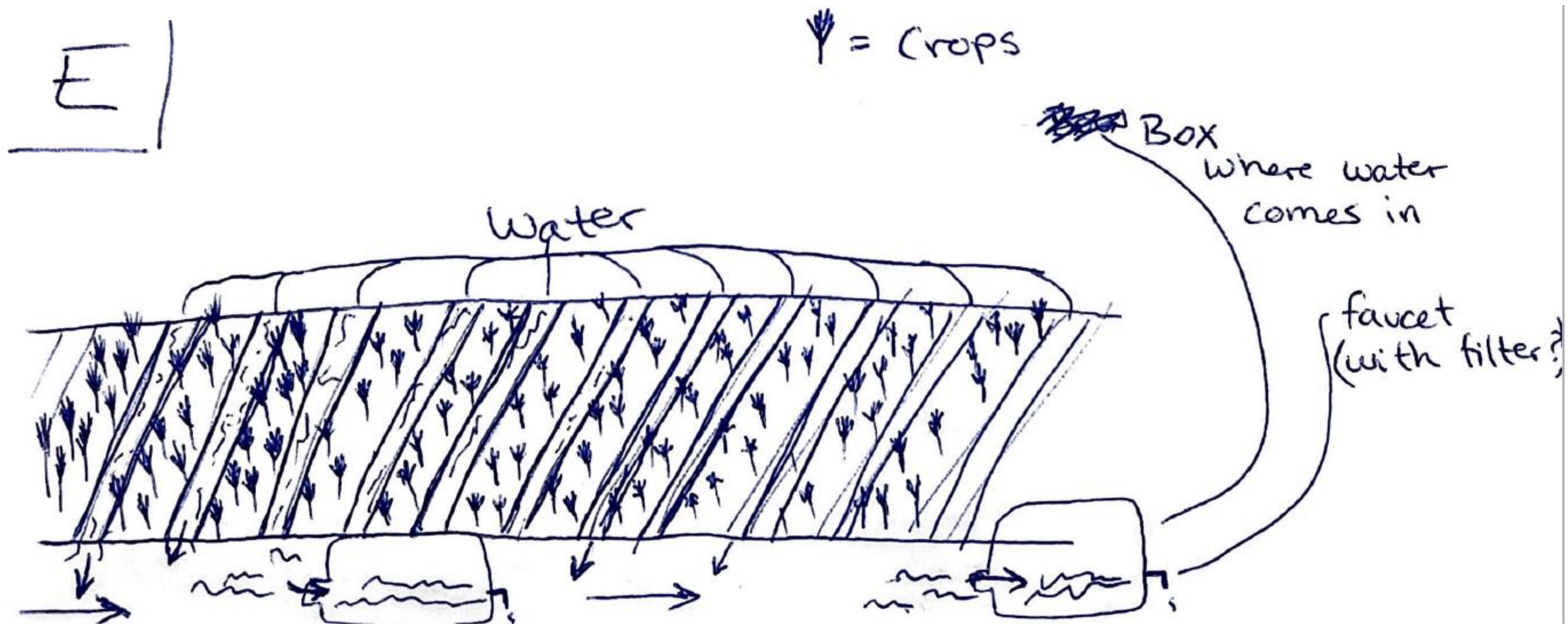
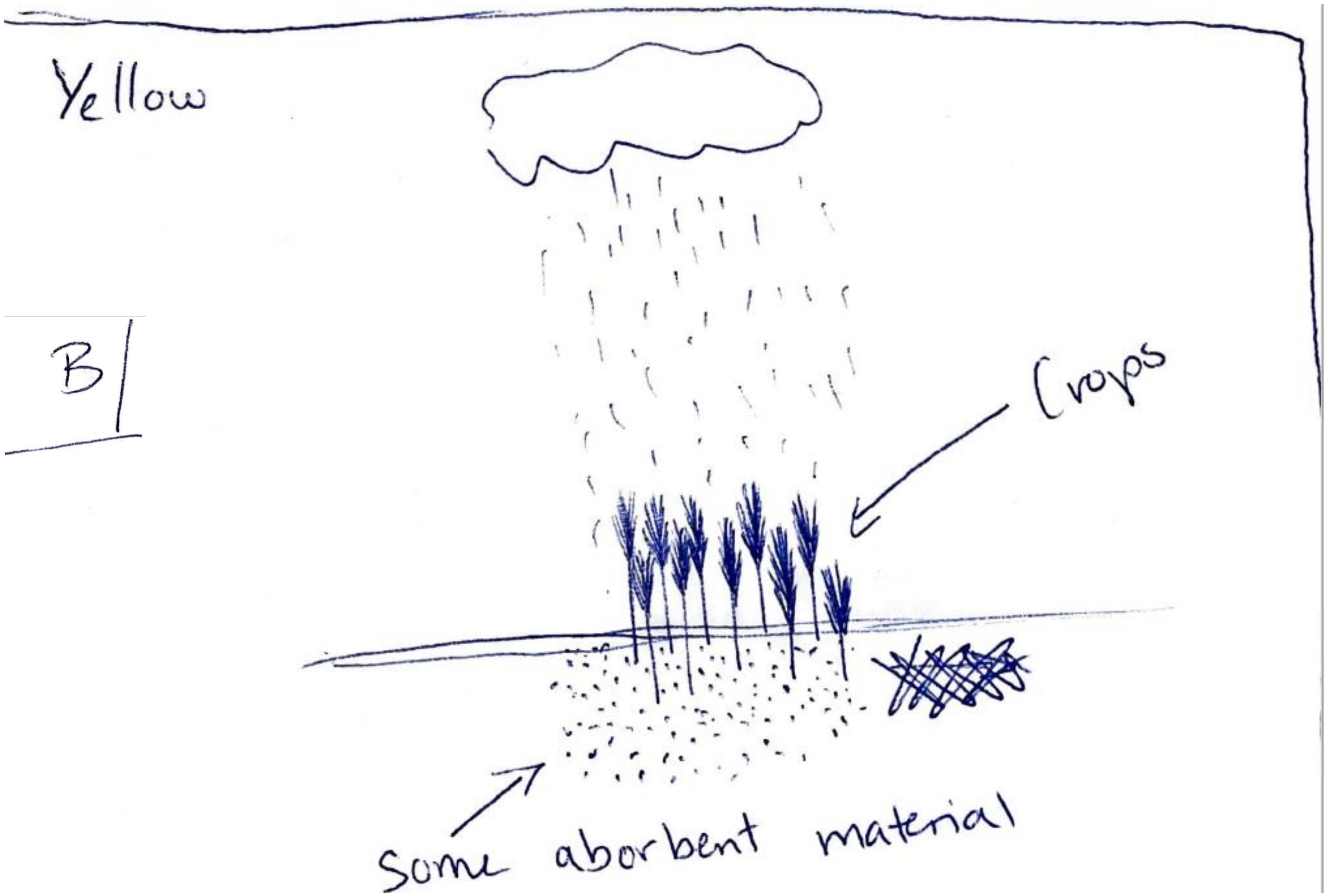
Appendix A

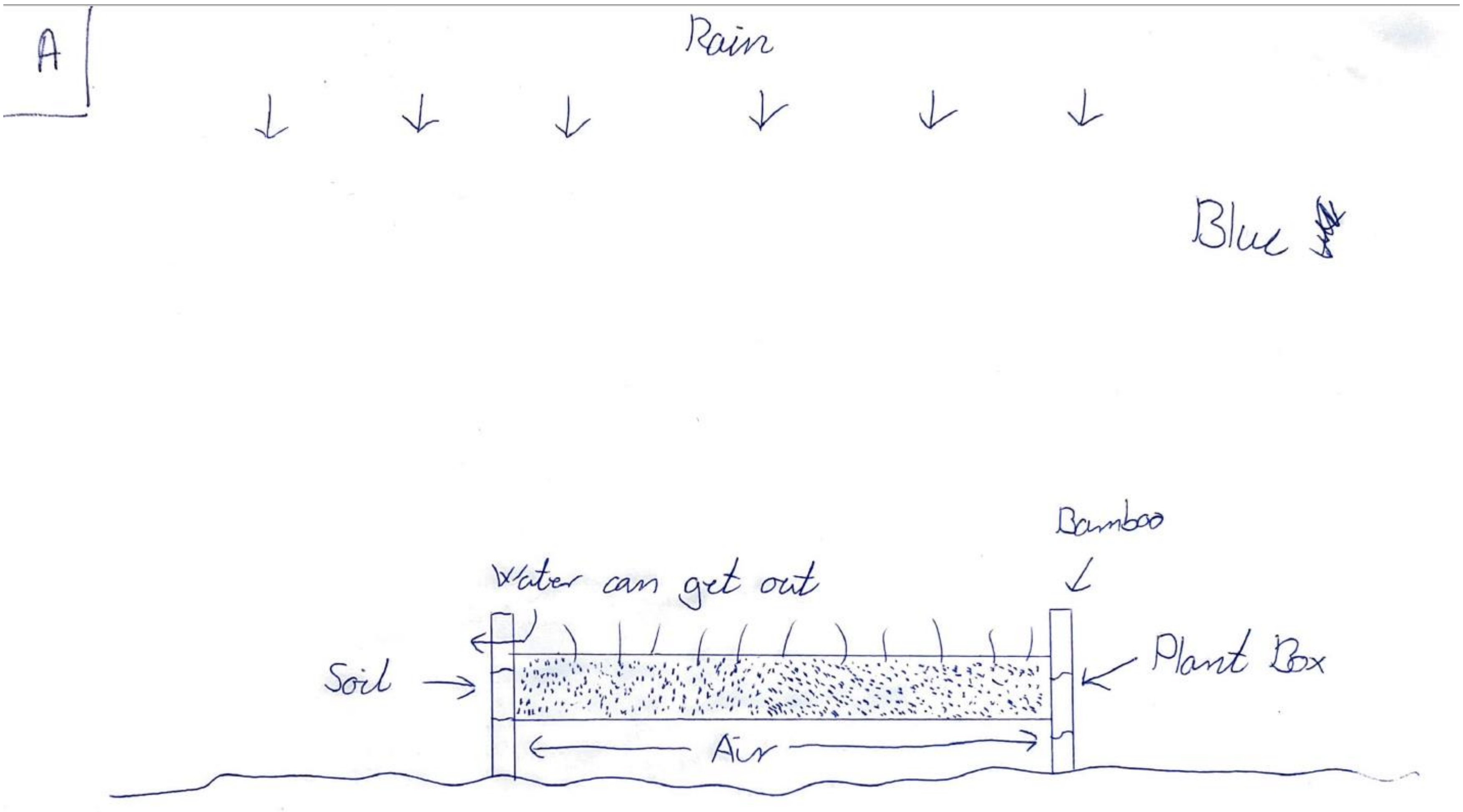
Idea E: Idea E is supposed to illustrate a field with a built-in drainage function. Once the rainfall hits the field, the water will be directed into boxes from where it cannot exit once inside.



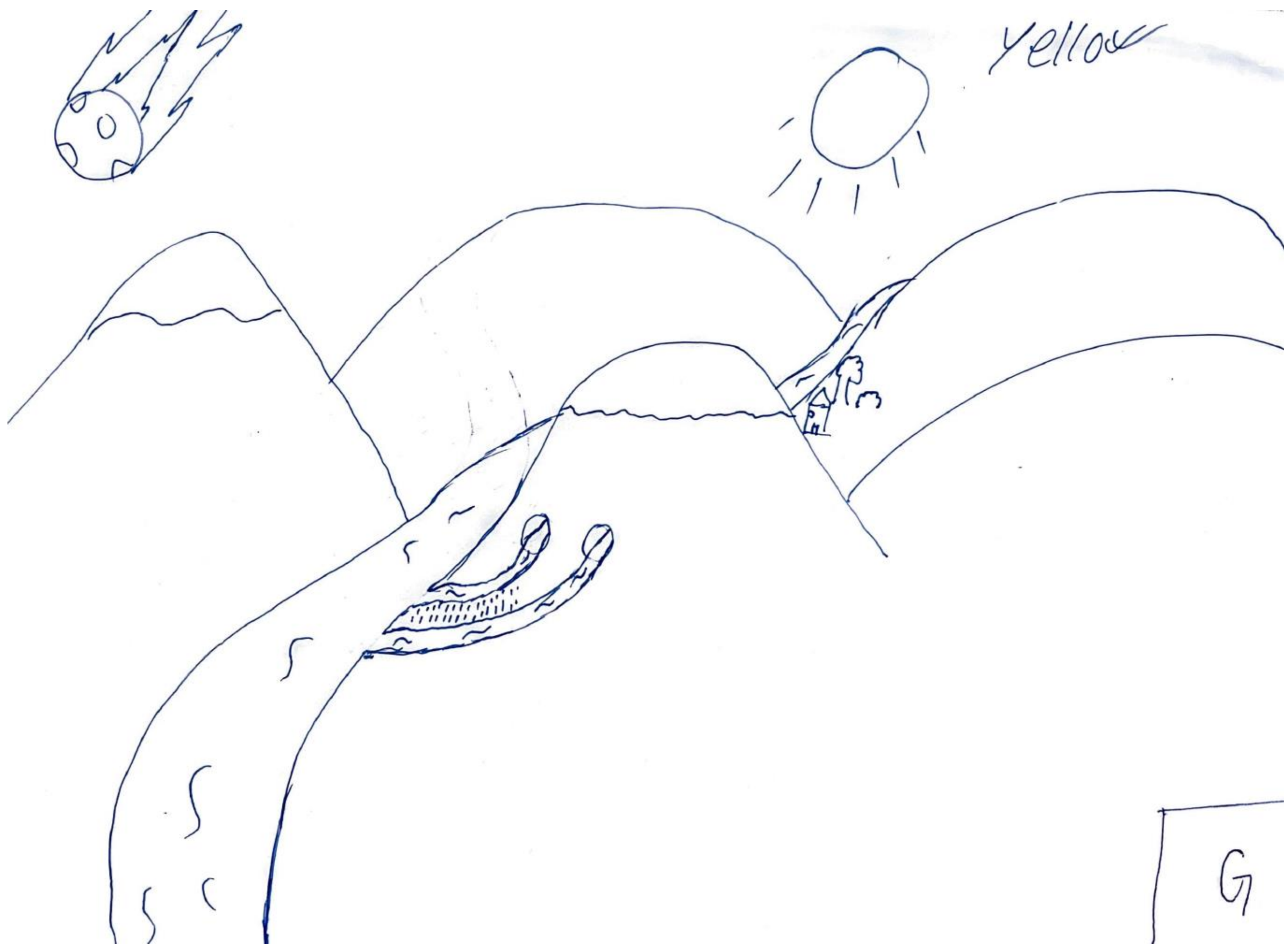
Idea B: Idea B shows a standard farming field but with soil containing water absorbent material.



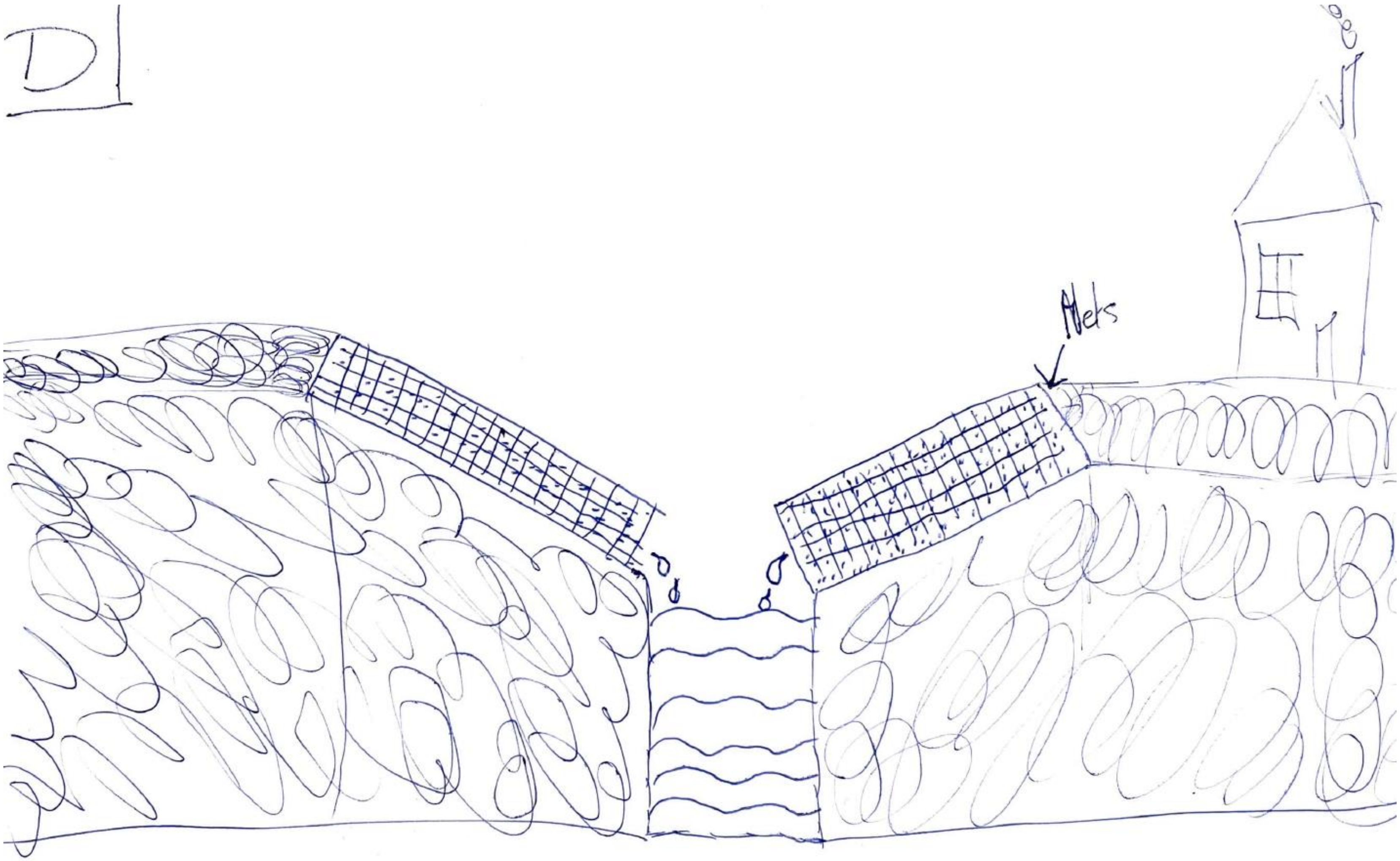
Idea A: The idea is showing a levitated form of a field. It visualizes a fixated box containing soil and not susceptible to excessive water.



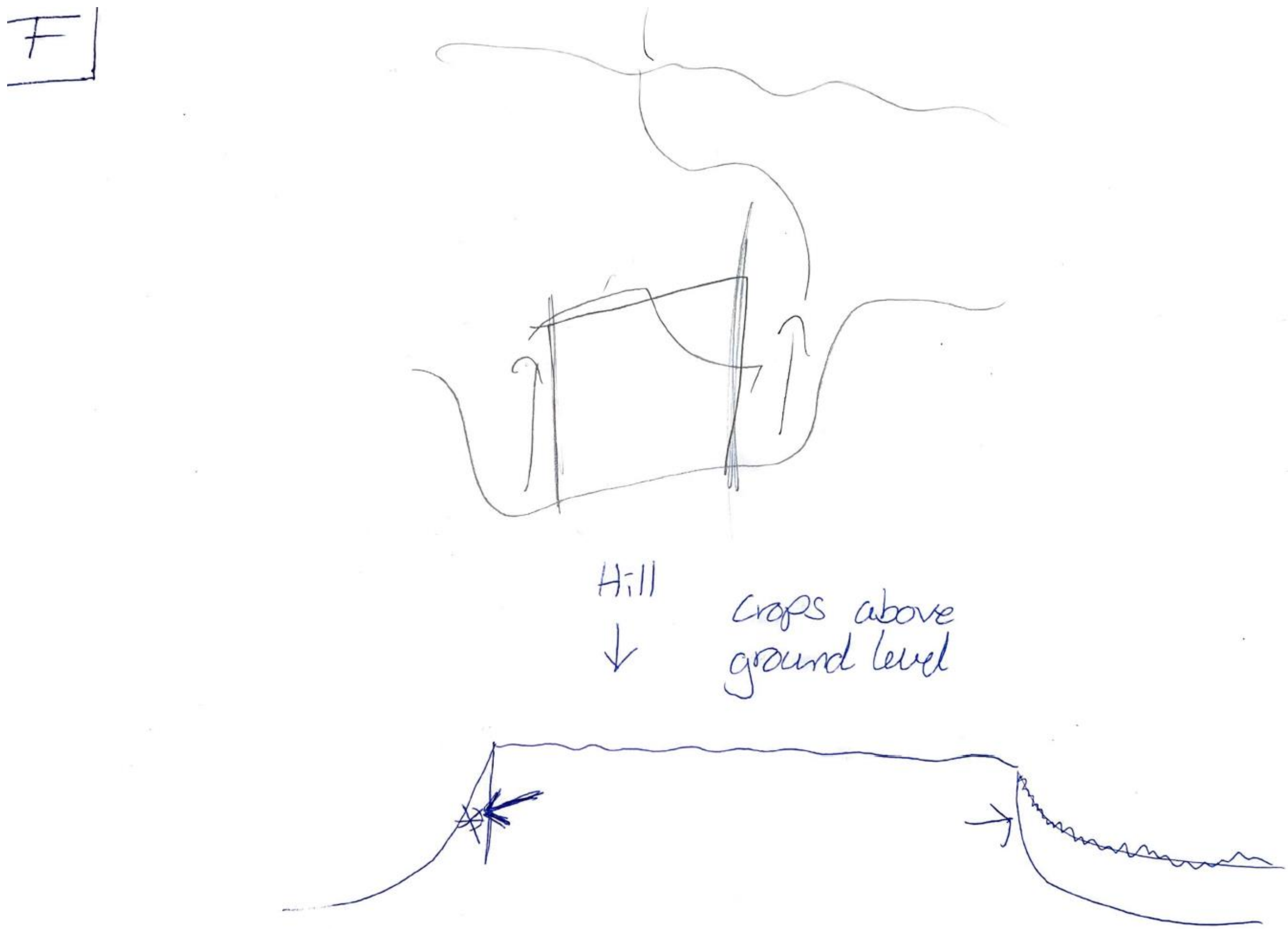
Idea G: Idea G shows the same an idea D - redirecting water by digging trenches into the ground and through hills.



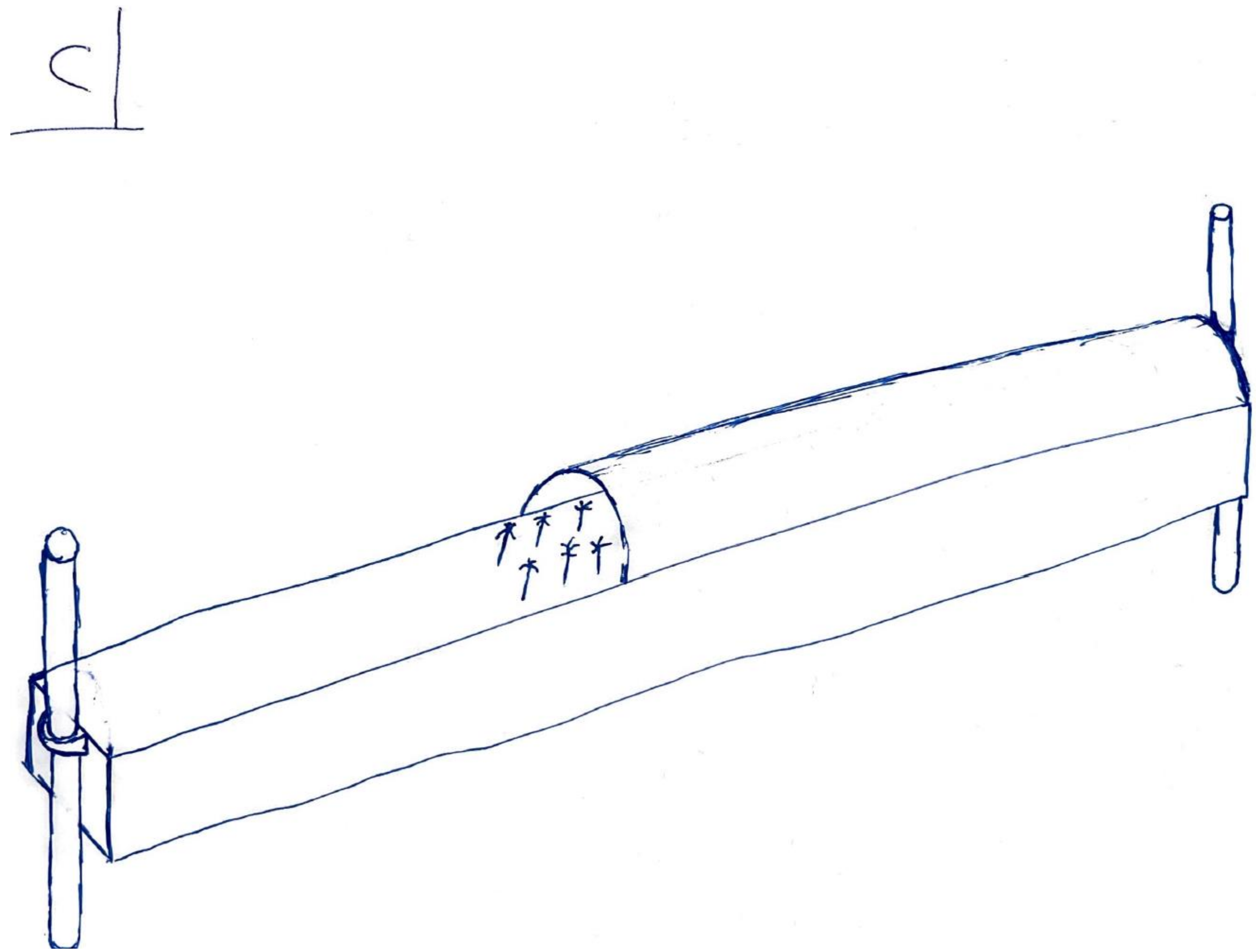
Idea D: The idea shows a trench for the water to be directed away from flooded areas.



Idea F: F illustrates a field landscaped upon a human made rise. When the water enters the ground, it can go into the ground or exit the sides of the field through some one-way particle filter.



Idea C: C visualizes a vertical floating planter box, which whenever areas are exposed to excessive rainfall will float on top of the flooding.



Appendix B

EWB & DIS reflection

From the meeting with EWB and DIS it was possible to collect insight and hear stories from real life experiences from Sierra Leone.
Based on the group's concept of a floating planter, the engineers were able to tell that a lot of water drops, but in certain periods, and that no more than two to three days pass before the water is drawn into the ground. This means that the planter will lie on the ground approximately 95% of the time. Thus, the idea of the floating concept is somewhat lost if it is exclusively intended for farmers in the interior parts of the country.

To be prepared for hungry birds and theft of crops, the engineers suggest that a roof be developed for the solution, so that the crops can be shielded. Also, for periods of excessive rainwater.
Regarding the floating solution, the engineers proposed that several different functions be incorporated into the design. To accommodate people living on riverbanks, the solution must be high and stable enough to handle tides. This can help the surrounding residents to take advantage of the area's typography. In addition, they also believed that the solution can be further developed so that it contains the idea of vertical farming if it is to be implemented on land. This can give farmers in the mainland more space to grow crops.

When it comes to the major cities and the mainland, the group learned that depending on their location, the natives have different means available.
The natives in the cities themselves must buy materials such as wood, while the natives in the mainland can cut their own wood. It can have an impact on the number of takers for the product. In addition, good soil is in short supply in the cities, but no problem in the interior of the country. This is something to consider, as the access to soil has a major impact on which crop the natives can plant and harvest in that specific location. This also means that a farmer in an urban area must have a higher return on investment from their crops than a farmer living in the countryside.

So, the big question for the group is whether the investment in the material a planter box requires, makes sense in relation to the crops that are planted in it.

The return on investment led the group to look for so-called cash crops. Cash Crops are crops that give a high yield measured by quantity. By suggesting the right crop, the group's solution is more likely to create awareness among the locals.

Appendix C

Cash Crop analysis

This section describes cash crops in general and three specific types of cash crops in Sierra Leone which are tomatoes, potatoes, and onions. Cash crops are planted with the purpose of selling to get profit and not for self-supply. The farmers in Sierra Leone plant a lot of crops for self-supply, for example rice. Cash crop are more special crops, which entail they get more money for less crops. The concept in this project have limited amount of space so it could be a good idea to plant cash crops. The cash crops in Sierra Leone are shown in the following table:

Recommended Minimum Amount of Money for food (2400 calories, Western food types)	
Milk (regular), (0.25 liter)	0.57 $
Loaf of Fresh White Bread (125.00 g)	0.17 $
Rice (white), (0.10 kg)	0.09 $
Eggs (regular) (2.40)	0.37 $
Local Cheese (0.10 kg)	?
Chicken Fillets (0.15 kg)	1.12 $
Beef Round (0.15 kg) (or Equivalent Back Leg Red Meat)	?
Apples (0.30 kg)	1.04 $
Banana (0.25 kg)	0.26 $
Oranges (0.30 kg)	0.31 $
Tomato (0.20 kg)	0.81 $
Potato (0.20 kg)	0.46 $
Onion (0.10 kg)	0.16 $
Lettuce (0.20 head)	0.18 $
Daily recommended minimum amount of money for food per person	?
Monthly recommended minimum amount of money for food per person (assuming 31 days per month)	?

Figure 1: Recommended Minimum Amount of Money for food

(numbeo, u.d.)

According to figure 1 the focus are onions, tomatoes, and potatoes. Figure 1 explains all sorts of foods with a few being seeds to plant. Apples and bananas grow on larger trees which cannot fit into a planter box. By looking at the money per kilo, lettuce is not worth planting compared to the three others.

Onion

Onions can grow from seed or from sets, which is small onions. The sets are easier and faster to grow, it takes around 80 days for the sets instead of 100 days for the seed. One set become one larger onion. The seeds should be planted 10-15 cm apart in moisture retentive soil in full sun and planted 2 cm deep. (Anon., 2022)

Tomato

Tomatoes is a great Cash Crops, because it has a high value, compared to how much you get from a plant. For example, a company called Marglobe Tomato says that the average maturation period for a Tomato is 67 days. And the tomato crop yields up to 50 tonnes per hectare (Chou, 2022). Which corresponds to 50 kg per $10m^2$. For new plants, the seeds can be taken from tomatoes they have already grown. So once the first tomato is grown, they don't need to buy new seeds. The tomato plant should have at least 20 cm of dirt in depth, and 50 cm in between the plants. Indeterminate tomato plants will keep producing fruit until disease or frost stops them from doing so. A tomato plant is usually between 90 and 110 cm tall, at which height it usually dies of cold. But because Sierra Leone is in Africa this doesn't happen, and plants grow up to 180 cm tall. (Thefarmdreams, 2020)

Potato

The potato plant requires 30 cm of space in between plants. And 20 cm depth from the surface. You don't need seeds for the potato plant. If you leave a potato in a humble place, it will take root. New potatos will grow from those roots. From you put it into the ground and harvest it, will takes around 80-100 days. A single potato plant will produce at a minimum, 2 kg of potatoes. (Anon., 2022)

The following table gives an overview of the three cash crops.

	Onion	**Tomato**	**Potato**
Production time	80 days	67 days	80 days
Production amount/10m^2	28 kg	50 kg	40 kg
Money/kg	1,6 $	4,05 $	2,3 $
Money/year/10m^2	204.6 $	1103.17 $	419.75 $

Conclusion

All three cash crops (Onion, tomato, and potato) seem possible to plant in the box and will all give an approximately income. Tomatoes will immediately be the most effective cash crop because it has the shortest production time, the highest amount of production per $10m^2$ and the highest price per kilogram. Onion and potatoes are also okay to plant. The three cash crops are in mind in the "Concept development" and their different needs.

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