Design report: Increasing water storage with low-cost urban agriculture

2 designs made for implementing a pilot in Cebu City

Design report: Increasing water storage with low-cost urban agriculture

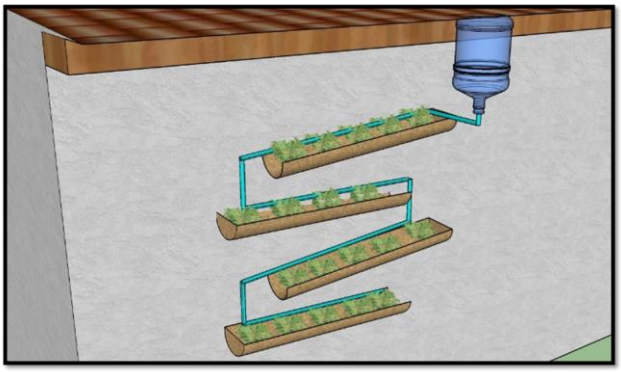
2 designs made for implementing a pilot in Cebu City

Ian Mullens
Timo Hoekstra

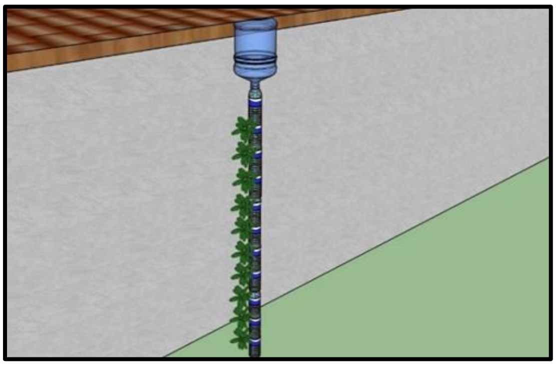
Presidential Commission for the Urban
Rotterdam University of Applied Science
Supervisors: Mr. R. Heikoop (lecturer), Mrs. A. Loois (Lecturer) and C. Osano (Regional director)
The Philippines, Cebu City, December 23th 2014

Summary

For this research 2 designs are made and 1 of those is tested. These designs are given certain demands and requirements which they need in order to succeed. In order to begin with a design we started to brainstorm with help of reference images and a mindmap. This resulted in two designs.



Figuur 1 3d design 1



Figuur 2 3d design 2

These designs catch rainwater from a roof by use of a gutter. The gutter leads the water in a tank. The tank is connected with a tube and is at the end closed so that the tube will be filled with water. In the tube are made tiny holes so that the water will distribute slowly over-time to the vegetation. The vegetation is placed in containers that can be made out of recycled bottles. The biggest difference between the 2 designs is that design 2 is placed vertical.

Design 2 was eventually chosen for the pilot for the following reasons.

- Design 1 is more complicated to build
- Design 2 makes better use of space
- Design 1 is more expensive to make
- Design 2 qualified better in the chosen location Alaska Mambaling school since the pilot could not be made against the wall
- Design 2 has more strong points that respond to opportunities
- Design 2 has more strong points that enable to repel threats.

After creating the pilot the following information about design 2 was gained.

- 156 Less watering days (in 1 year)
- 1400L water is spared (in 1 year)
- 2500L water is slowed down by the system (in 1 year)

Table of content

1. Introduction

For this research 2 designs are made and 1 of those is tested. These designs are given certain demands and requirements which they need in order to succeed. The demands and requirements are placed in chapter 2-3. The designs are made with Sketchup, MS Paint and Adobe Illustrator. For each design is determined what its weaknesses and strengths are with a SWOT analysis.
After the designs are finished and determined whether they qualify for the pilot, one of them will be built and tested. The tests will find place on the chosen location in the location analysis (Alaska elementary school). These tests are done to calculate the water flow of the pilot. This data is placed in chapter 8, the water system analysis.
At first the plan was to make a pilot for both the designs. Unfortunately, due a lag of time we were not able to build 2 pilots. Therefore, there was chosen to build only the design that qualified the most.

2. Program of requirements

There are multiple requirements the pilots must cope with. The designs must meet these requirements in order to be successful.

- **Costs**
  The costs of a pilot cannot be higher than Php300. This project focusses on low-cost urban agriculture so it cannot be too expensive.
- **Water storage capacity**:
  The pilots need to store at least 15L in order to be able to water the plants over a longer period of time.
- **Design lifetime**
  The pilot needs to last at least for 2 years with maintenance. In order to be profitable this is considered to be long enough of a lifetime.
- **Food production**
  The pilot needs to have at least 15 plants to make enough fruit and vegetables to have any effect.
- **Height**
  The plants need to be placed at least 20cm above the ground. Since there is chosen for vertical agriculture it is important that the pilots are designed to be placed at least 20cm above the ground. This to prevent damage from animals, floods, pests, etc.

3. Design functions

The design functions are divided into hard design functions and soft design functions. Hard design functions are functions that the pilot must have in order to function well and be successful. Soft design functions are functions that are optional and not needed.

3.1 Hard design functions

- Design has to storage rainwater
- Design has to make good use of the available space
- Design has space to grow vegetables and fruits
- Construction needs to be firm (flood resistant)
- Design has to slow down the rainwater runoff
- Design cannot hinder people and traffic
- No advanced technology can be used, local people should be able to repair it themselves
- Materials should be available locally
- The design needs to be safe (no sharp edges, no collapse danger)
- It should not weaken adjacent structures

3.2 Soft design functions

- The design connects with the surrounding environment and atmosphere
- The design has to have a positive influence on the environment
- Stored rainwater needs to water the plants continuously over a long period of time
- The design needs to make optimal use of the sunlight
- Add a sign that explains what the design does and how it works, this will educate people

3.3 Solutions

Design has to storage rain water

To storage and catch rainwater a possible solution is to add a barrel. The barrel could store the water and slowly distribute it to the plants. Rainwater on rooftops could also be collected and led to the containers by using pipes for example. This will increase the water storage capacity.

Design has to make good use of the available space

The design will most likely be a form of vertical agriculture. This form of urban agriculture is not very space consuming because it uses space that was unused in the past.

Design has space to grow vegetables and fruits

The design could be made out of bottles connected with each other for example. Vegetables and fruits could be planted inside these bottles. Another solution is to make use of wooden planks or plastic bins.

Construction needs to be firm

The construction need to be firm so it can resist heavy rainfall and other forces of nature. To do this the construction could be attached with nails or other forms of stable construction methods. The materials of the construction will not break down fast and are water resistant.

Design has to slow down the rainwater runoff

Rainwater will be slowed down by the design by catching it on the roofs and slowly watering the plants. After this water is partly consumed by the plants and partly distributed to the sewer system. The soil in the containers will also slow down the water.
Water that falls directly on the vertical agriculture will also be slowed down by the soil and the plants.

Design cannot hinder people and traffic

To avoid this, the design will be placed on locations where it cannot hinder people or traffic. For example on roofs or walls. It will also be taken into account during the designing process so that the structure will not become too wide for example.

No advanced technology can be used; local people should be able to repair it themselves

The design papers need to be as clear as possible so the local people can understand it. Also, the structure will be made using only simple technology. This is also needed to make it low-cost and the people would be able to repair it themselves when broken.

Materials should be available locally

To ensure the structure is only made from local materials, we will build it ourselves. When building it, materials will be collected from local stores, the PCUP and other organizations.

The design needs to be safe (no sharp edges, no collapse danger)

Using sharp edges will be avoided as much as possible, and when sharp edges are inevitable they need to be shielded.

It should not weaken adjacent structures

To avoid this, a few measurements are taken. The structure will not be built against weak buildings or walls. The structure must not weigh too much to prevent structures from collapsing. Caution is permitted while building the structure.

4. Design process

A few steps are taken during the design process. The first step is finding reference images. These are placed below in figure 3, 4 and 5.

Figure 5 Vertical agriculture 1

Figure 4 Vertical agriculture 2

Figure 3 Vertical agriciulture 3

The second step is making a mind map. The mind map is placed below in figure 6. To organize all the possibilities within the brainstorming process a mind map is made. A mind map is a tool used to find as many possibilities and ideas within the designing process of an object or idea. The mind map is also shown in a bigger format in appendix 8.

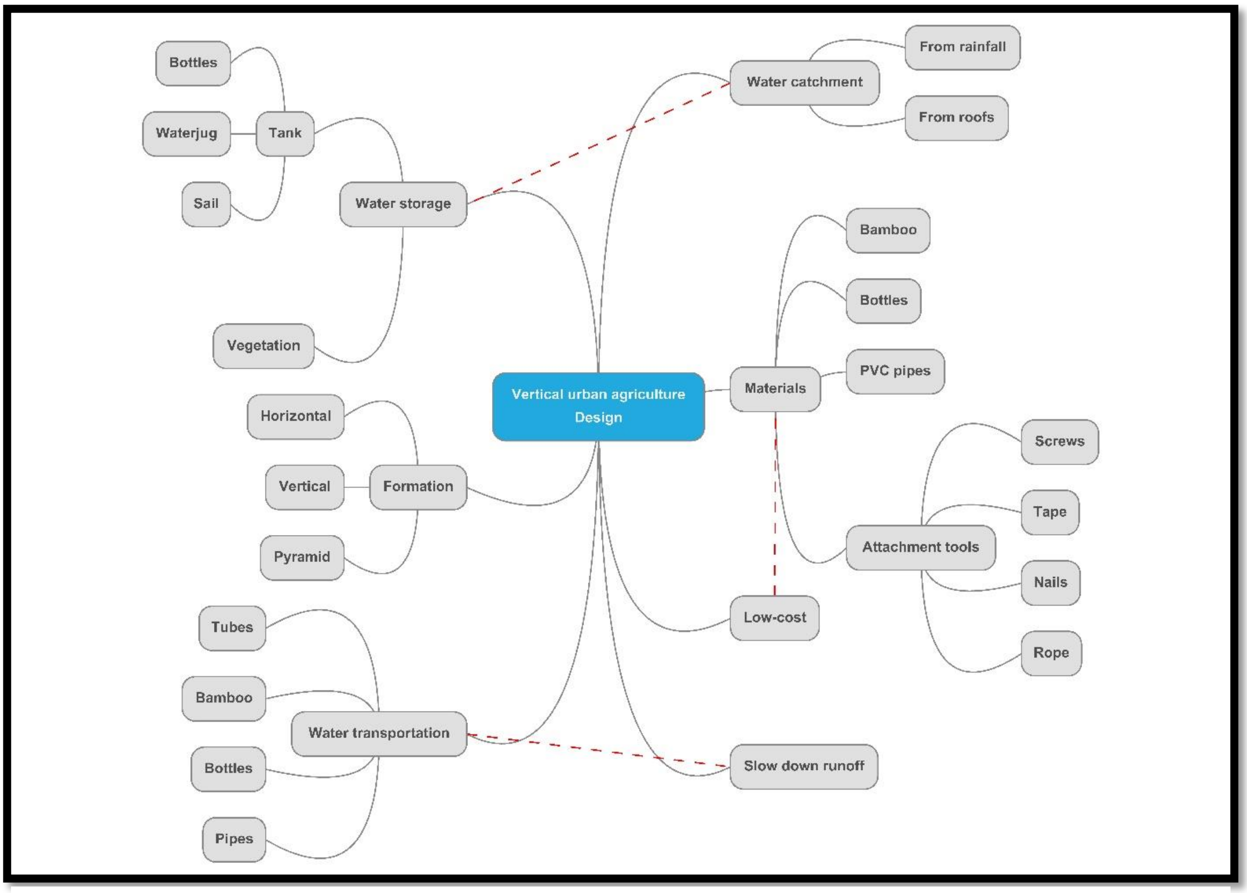


Figure 6 Mindmap

5. Design 1

5.1 Design description

A sketch of the first design is shown in figure 7. A bigger illustration is placed in appendix 1. This design catches water from the roof and re-directs it into a tank by making use of a gutter. The tank is connected to a tube or hose. The tube is closed at the end. This means the tube will also be filled with water. However, the tube has tiny holes so that the water will flow very slowly out of the tube into the vegetation hung beneath the tank. The vegetation is placed in bottles placed horizontally. Multiple rows of bottles are placed beneath each other. The bottles are placed oblique so that water can flow down towards the ground in case of too much water.

This design will store rainwater during rainfall. Since the water can only flow out very slowly, it will water the plants over a large amount of time.

The design can be attached to a selling by making use of ropes or it can be nailed to a wall. This depends on the location. Figure 8 shows an intersection from 2 different angles. With the chosen location the design will have a height of around 2.3 meters.

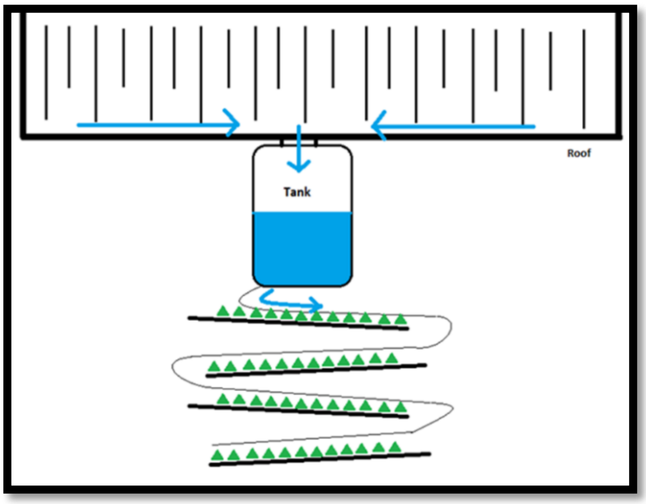


Figure 7 Sketch design 1

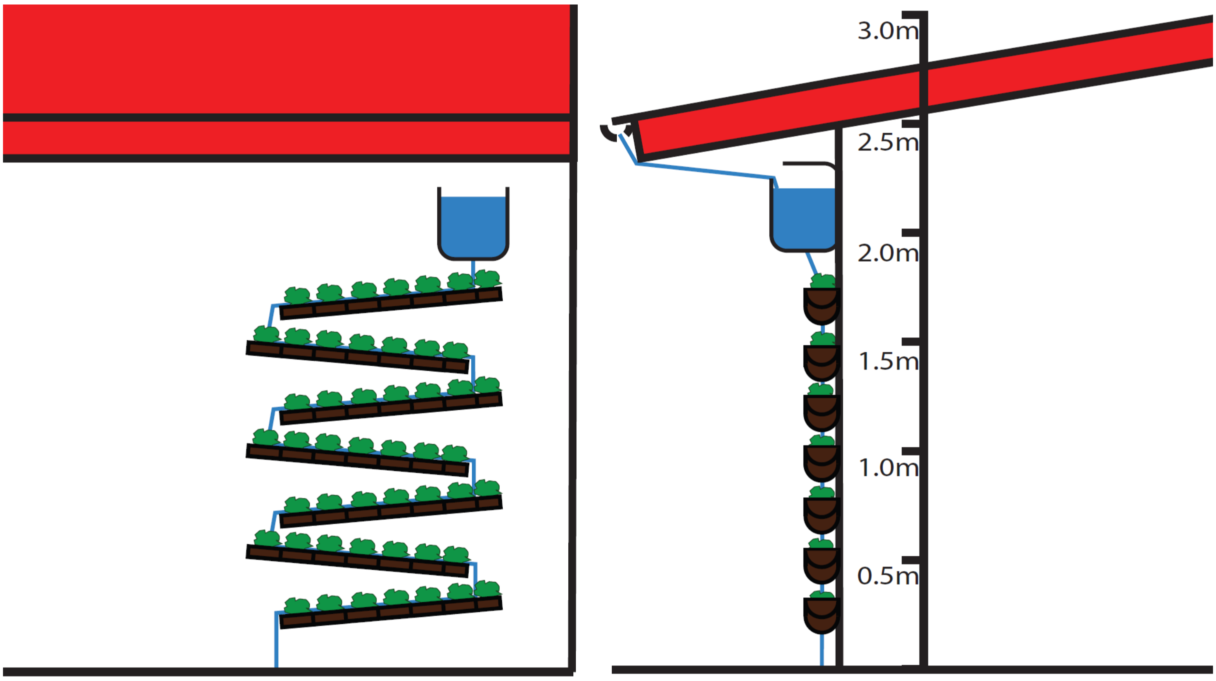


Figure 8 Intersection two different angles design 1

Figure 9 shows a more realistic view of the design to give a good idea what it will look like in reality. All these figures are also placed in the appendix on larger scale.

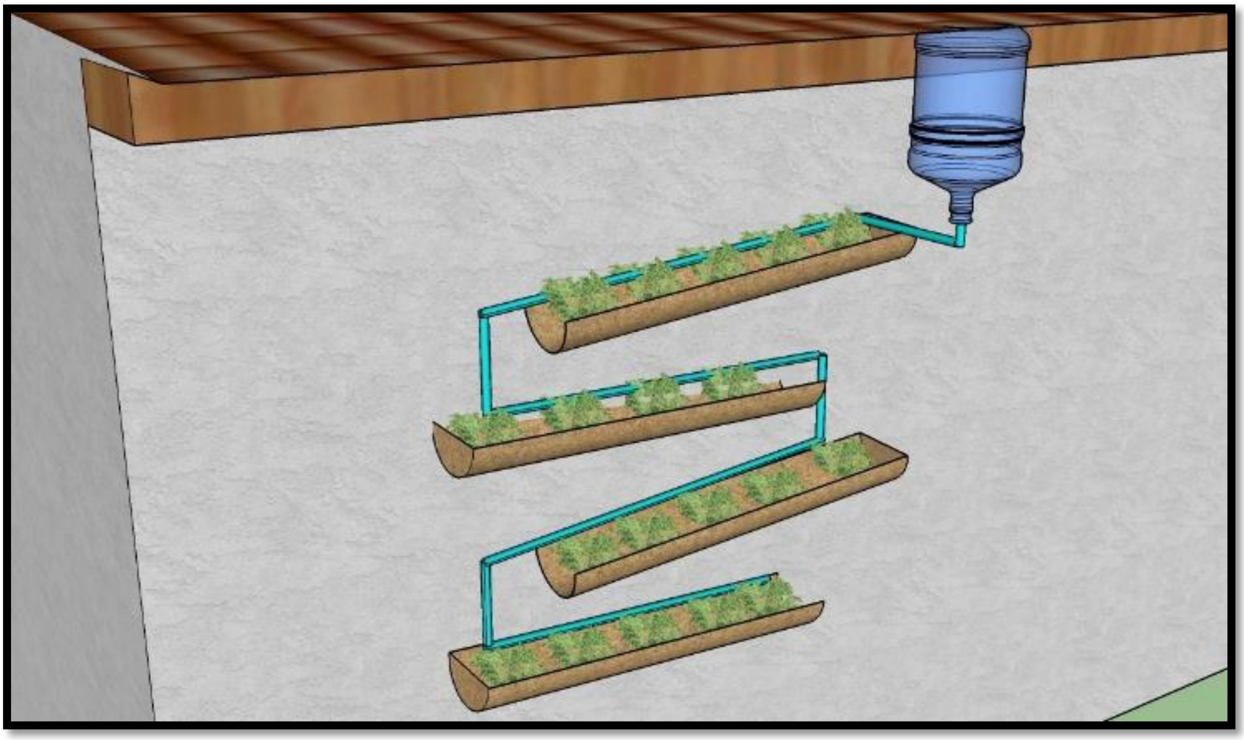


Figure 9 3d design 1

Multiple materials are needed to make this design. The materials needed for design 1 are listed below in table 1 with their costs. Materials that are recycled or provided are considered $0 in costs.

Table 1 Materials design 1

Materials	Description	Unit	Cost ($)
Tank (19L)	The tank is used to store water	1	$0.45
Bamboo (2m)	Bamboo will be cut in half and used as gutter on the roof. The gutter will lead the rainwater into the tank.	1	Recycled $0
Tube or hose (4-5m)	The tube can be a garden hose for example. Tiny holes will be made in the hose so that water slowly drips on the vegetation.	1	$4
Bottles (1.5-2L)	Around 15 empty bottles are needed as a container for the plants. The best size will be around 1.5L-2L. Bamboo can also function as a container for the plants but is more expensive.	49	Recycled $0
Nails or rope	Nails are needed to attach the structure to adjacent buildings. Rope can also be used but is more difficult and probably less stable.	± 10	$0.90
Cork or tape	A cork or tape can be used to attach the tube to the tank. However, tape is probably not as firm as tape.	1	$0.30
Soil	The soil is provided by the City Agriculture Department.	± 20 kg	Provided $0
Seeds	The seeds are provided by the City Agriculture Department.	±50	Provided $0
Total costs			$5.65 (=±300 Pesos)

5.2 SWOT

Table 2 SWOT 1

Strengths	Weaknesses
-Increase water storage -Watering plants over time -People spare water -Room for a lot of vegetation -Cheap -Simple technology -Use of local materials -No obstruction for roads or ways	-Requires more materials (than other design) -Durability -Quite wide
Opportunities	**Threats**
-Locals could learn from design -People will eat more vegetables -Make environment greener -Can be implemented on large scale -Reduce consequences of heavy rainfall	-Could be difficult to attach -Drowning the plants -People will not maintain the pilot -Design failures -Tank can flood with too much rain -Insect pests

Overview of the most important topics

Increase water storage

The main purpose of this design is to storage water. It is an adaptive solution since the water is used for vegetation. The tank on top of the design allows it to storage an amount of rainwater.

Watering plants over time

The plants are watered over time. This is important because main problems in the past with urban agriculture was people not maintaining the plants enough. By watering the plants over time this problem is reduced. Also the plants will slow down the water so that the ground is less likely to be saturated.

Quite Wide

A disadvantage of this design it is quiet wide. This means it is not possible to place many next to each other to catch more rainwater.

Could be difficult to attach

A big threat is that it could be difficult to attach the design to adjacent buildings or walls. This design has many loose parts, each of these parts need to be attached separately.

People will eat more vegetables

After interviewing the City of Agriculture they mentioned that people and especially the children do not eat enough vegetables. This design produces a vast amount of vegetables and could encourage the people to eat healthier.

Confrontation matrix

The confrontation matrix will look at the 'match & mismatch' between the strengths/weaknesses and the opportunities/threats from the SWOT analysis (Marlou Landers, 2013). The confrontation matrix should give clarity to these 4 questions (Marlou Landers, 2013).

- How can strong points respond to opportunities?
- How can strong points be enabled to repel threats?
- How can weak points be strengthened to respond to opportunities?
- How can weak points be strengthened to provide resistance to threats?

Each confrontation will be rated with 0/-/--/+/++. When comparing the points the positive can compensate the negative or the other way around, based on this result it can score + or -.
When counting all the scores the confrontation matrix will show which points are the best opportunities, strength, weaknesses and which one is the highest threat.

Table 3 Confrontation matrix design 1

		Opportunities					Threats						
		Locals could learn from design	People will eat more vegetables	Make environment greener	Can be implemented on large scale	Reduce consequences of heavy rainfall	Could be difficult to attach	Drowning the plants	People will not maintain the pilot	Design failures	Tank can flood with too much rain	Insect pests	
Strength	Increase water storage	++	0	++	+	++	-	-	--	--	-	-	-1
	Watering plants over time	++	+	+	++	++	-	0	+	--	-	-	4
	People spare water	+	0	+	+	0	-	0	+	-	-	0	1
	Room for a lot of vegetation	0	++	++	+	++	-	--	0	-	-	-	1
	Cheap	+	+	0	++	0	+	-	0	-	-	0	3
	Simple technology	+	0	0	++	0	+	0	+	+	0	0	4
	Use of local materials	+	0	0	++	0	0	0	+	-	-	-	1
	No obstruction for roads or ways	0	0	0	++	0	0	0	0	0	-	0	1
Weaknesses	Requires more materials	+	-	-	-	0	-	0	-	-	0	0	-5
	Durability	-	-	-	-	-	-	0	--	-	-	-	-11
	Quite wide	0	0	+	-	0	-	0	0	-	0	0	-2
		8	2	5	10	5	-5	-3	-1	-12	-8	-5	

Important results of the confrontation matrix

- When implementing this design the water storage will increase. This means that the consequences of heavy rainfall will reduce in the future.
- The design is made using simple technology, this could mean that it is more likely design failures can occur and forms a threat for this project.
- When people see that this design will store water and give plants water over time, they could be more interested in learning how it works so that they can implement it themselves.
- The design is made so it will water the plants automatically. Therefore, the people do not have to maintain in that often so the strength can be used to repel a threat.
- When something is built very complicated using advanced technology, the chance of design failures is higher. Since the design is made using simple technology, this is not the case. It will reduce the chance of design failures.
- Durability is the biggest weakness of the design.
- "Design failures" is the highest threat of the design.
- When people see that this design stores water and is made by local materials and simple technology they could be more interested in maintaining the pilot.

6. Design 2

6.1 Design description

The second design is shown in figure 10 below. A bigger illustration is placed in appendix 4. This tank can also be placed beneath a roof to store rainwater. In this design the plants are placed beneath each other. They are connected with each other by use of bottles. A tube is connected with the tank and placed through the soil vertically. The tube also has tiny holes so that it will water the vegetation over a large amount of time. Holes are made in the bottles so that the vegetation can grow towards the sun. The design can be attached with rope to the roof or by nails against the wall, depending on the location. This design is very small which opens up the opportunity to place multiple next to each other. Figure 11 shows an intersection from two different angles. With the chosen location the design will have a height of around 2.3 meters.

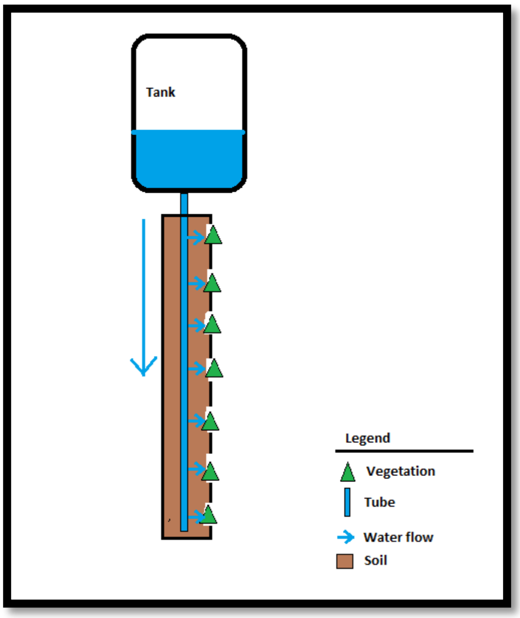


Figure 10 Design 2 sketch

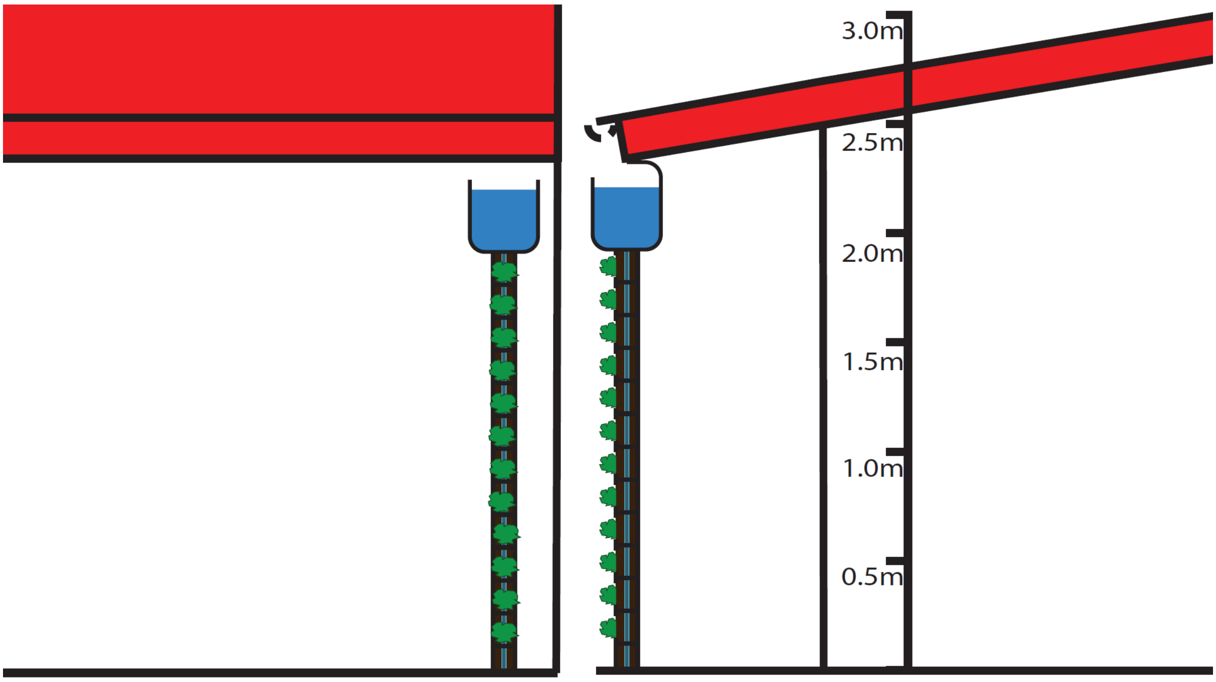


Figure 11 Intersection from 2 angles design 2

Figure 12 shows a more factual view of the design. This design figure is also placed in appendix 5 in a bigger format.

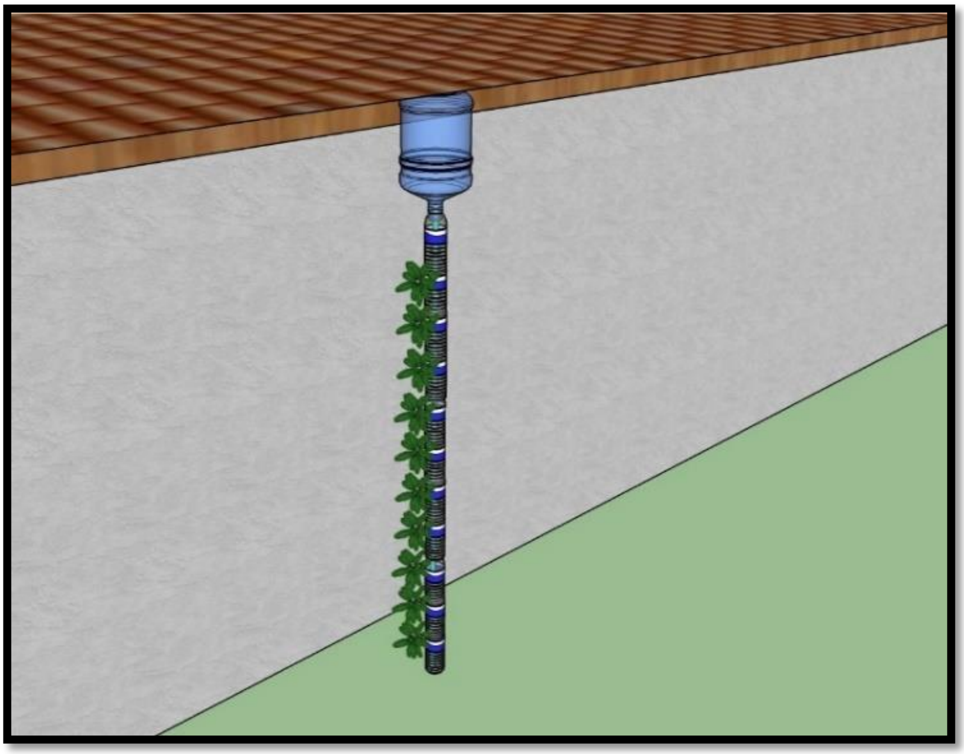


Figure 12 3d design 2

Multiple materials are needed to make this design. The materials needed for design 2 are listed below in table 4 with their costs. Materials that are recycled or provided are considered $0 in costs.

Tablet 4 Materialen design 2

Materials	Description	Unit	Cost ($)
Tank (19L)	The tank is used to store water	1	$0.45
Bamboo (2m)	Bamboo will be cut in half and used as gutter on the roof. The gutter will lead the rainwater into the tank.	1	Recycled $0
Tube or hose (2m)	The tube can be a garden hose for example. Tiny holes will be made in the hose so that water slowly drips on the vegetation.	1	$2
Bottles (1.5-2L)	Around 15 empty bottles are needed as a container for the plants. The best size will be around 1.5L-2L.	12	Recycled $0
Nails or rope	Nails are needed to attach the structure to adjacent buildings. Rope can also be used but is more difficult and probably less stable.	± 5	$0.45
Cork or tape	A cork or tape can be used to attach the tube to the tank. However, tape is probably not as firm as tape.	1	$0.30
Soil	The soil is provided by the City Agriculture Department.	**± 5** kg	Provided $0
Seeds	The seeds are provided by the City Agriculture Department.		Provided $0
Total costs			$3.20 (=±150 Pesos)

6.2 SWOT

Table 5 SWOT 2

Strengths	Weaknesses
-Increase water storage -Watering plants over time -People spare water -Room for vegetation -Cheap -Simple technology -Use of local materials -No obstruction for roads or ways	-Has not that many plants (compared to other design) -Durability
Opportunities	**Threats**
-Locals could learn from design -People will eat more vegetables -Make environment greener -Can be implemented on large scale -Reduce consequences of heavy rainfall	-Drowning the plants -People will not maintain the agriculture -Could be instable -Design failures -Tank can flood with too much rain -Insect pests

Overview of the most important topics

Increase water storage

The main purpose of this design is to storage water. It is an adaptive solution since the water is used for vegetation.

Watering plants over time

The plants are watered over time. This is important because main problem in the past with urban agriculture was that the people would not maintain the plants enough. By watering the plants over time this problem is reduced.

Has not many plants

A disadvantage of this design is that it has not that much room for plants compared to the other design. This could reduce the amount of water it can hold and the amount of vegetation it will produce.

Scalability

A big opportunity of this design is the scalability. The form of this design makes it possible to place multiple of these designs next to each other. Since it is able to do this multiple can be placed under the same roof what will increase the water storage significance.

Stability

A big threat could be the stability of the design. Every bottle needs to be connected firm enough to each other or it might collapse.

Confrontation matrix design 2

Table 6 Confrontation matrix 2

		Opportunities					Threats						
		Locals could learn from design	People will eat more vegetables	Make environment greener	Can be implemented on large scale	Reduce consequences of heavy rainfall	Could be instable	Drowning the plants	People will not maintain the pilot	Design failures	Tank can flood with too much rain	Insect pests	
Strength	Increase water storage	++	0	++	+	++	-	-	--	--	-	-	-1
	Watering plants over time	++	+	+	++	++	-	0	+	--	-	-	4
	People spare water	+	0	+	+	0	-	0	+	-	-	0	1
	Room for vegetation	0	++	++	+	++	0	--	0	-	0	-	3
	Cheap	+	+	0	++	0	+	-	0	-	0	0	2
	Simple technology	+	0	0	++	0	+	0	+	+	0	0	6
	Use of local materials	+	0	0	++	0	+	0	+	-	0	-	3
	No obstruction for roads or ways	0	0	0	++	0	-	0	0	0	0	0	1
	Does not need much space	+	0	+	++	0	+	0	0	0	0	0	5
Weaknesses	Has not that many plants	0	--	--	0	-	+	+	+	0	-	+	-2
	Durability	-	-	-	-	-	--	0	--	-	-	-	-12
		8	1	4	13	4	-2	-3	-1	-8	-5	-4	

Important results of the confrontation matrix

- When implementing this design the water storage will increase. This means that the consequences of heavy rainfall will reduce in the future.
- The design is made using simple technology, this could mean that it is more likely design failures can occur and forms a threat for this project.
- When people see that this design will store water and give plants water over time, they could be more interested in learning how it works so that they can implement it themselves.
- The design is made so it will water the plants automatically. Therefore, the people do not have to maintain in that often so the strength can be used to repel a threat.
- When something is built very complicated using advanced technology, the chance of design failures is higher. Since the design is made using simple technology, this is not the case. It will reduce the chance of design failures.
- A big opportunity is that this design can easily be implemented on large scale. This is due the fact that this design does not need much space, materials and is low-cost.
- Durability is the biggest weakness of the design.
- "Design failures" is the highest threat of the design.
- When people see that this design stores water and is made by local materials and simple technology they could be more interested in maintaining the pilot.
- A weakness is that this design does not have room for that many plants. A threat is that this design could be unstable and could fall out of balance. The fact that there are not many plants reduces the weight and chance that it will fall out of balance. For this reason, a weakness reduces the chance a threat will occur.
- When there are fewer plants, the people have to maintain less.
- The water storage capacity is reduced since this design has not many plants.
- Insects are lured by flowing water and the plants. This design has less room for plants and the vegetation is better hidden in the bottles. This reduces the chance of insect pests.

7. Pilot

This chapter will show the end result of the pilot, what materials are used and the results of testing the pilot.

7.1 creating phase

On December 12, 2014 design 2 has been made and placed at the Alaska Mambaling School. Figure 13 shows the end result of the pilot. There are 2 designs that could be implemented and tested. Due to lag of time we chose to only make 1 design. Design 2 was eventually chosen for the following reasons.

- Design 1 is more complicated to build
- Design 2 makes better use of space
- Design 1 is more expensive to make
- Design 2 qualified better in the chosen location Alaska Mambaling school since the pilot could not be made against the wall
- Design 2 has more strong points that respond to opportunities

Figure 13 Pilot

- Design 2 has more strong points that enable to repel threats.

After all the materials were gathered it only took 4 hours to build the pilot. On the next page a table (7) is shown with the materials that were used to make this pilot.

Table 7 Materials Pilot

Materials	Description	Unit	Cost ($)
Tank (19L)	The tank is used to store water	1	$0.45
Bamboo (2m)	Bamboo will be cut in half and used as gutter on the roof. The gutter will lead the rainwater into the tank. Another bamboo pole is used to attach the bottles to it to make it more stable.	2	Recycled $0
Tube or hose (2m)	A garden hose is used as hose. Tiny holes are made in the hose so that water slowly drips on the vegetation.	1	$2
Pen	A pen is used to plug the end of the tube so it will stop the water. The pen is wrapped in plastic to make it waterproof.	1	Recycled $0
Wooden planks (±30cm)	Wooden planks were used to attach the gutter to the roof	4	Recycled $0
Bottles (5L)	10 empty bottles are used as container for the plants. These 5L bottles are used because they were available at the school.	10	Recycled $0
Nails	Nails are used to attach the structure to the adjacent building.	± 5	$0.45
tape	Tape is used to attach the tube to the tank.	1	$0.30
Copper wire (1m)	Copper wire is used to attach the bottles to the bamboo pole	10	$0.45
Soil	The soil is provided by Alaska Mambaling school	± 10 kg	Provided $0
Alugbati plants	Plants are provided by the Alaska Mambaling school	18	Provided $0
Total costs			$3.65 (=±160 Pesos)

During the creating phase multiple problems occurred. The first problem that occurred was that the whole structure collapsed because there was too much pressure on the lowest bottles. After it was rebuild a bamboo pole was attached (figure 14) to the roof and to every bottle with copper wire. Thanks to this solution the pilot is more stable and will not collapse.
The lowest bottle is closed and empty. The reason for this is that a requirement was that the pilot should be 20 cm above the ground to protect vegetation. Now the lowest bottle is empty so there is no vegetation that can be damaged by pests or floods.
Tiny cuts are made in the lowest bottle so that water that has been gone through the whole system will leave the pilot and go into the ground.
A small hole is made at the back on top of the tank so that water will flow out of the tank in case it rains too heavily. The water will not stream into the opening of the bottles into the plants but instead, it will go towards the ground.
This pilot has room for more than 20+ Alugbati plants. This is more than we expected because of the 5L bottles that are used.

Figure 14 Pilot bottle close-up

7.2 Testing phase

After testing, this pilot can hold 1L of water for a duration of 30 min before it is completely distributed throughout the system. This results in a water flow of 2L/h. This is very high compared to the designs we made beforehand. This is because we made 9 holes in the tube which is too many. From we were able to calculate the water flow of one hole, this is 0.22L/h. Figure 13 shows that with 9 holes there are 165 days per year the people need to water the plants themselves. There is an average of 142 raining days in the Philippines which will then water the plants. And there are 58 days per year that the drainage system provides water for the vegetation. So these 58 days the people will not have to water the plants which they would have without this design. In these 58 days is a total amount of 500 L/year water is spared.
So it is advised to make 3 holes in the hose instead of 9 holes. When making 3 holes the graph should look more like the small circle in figure 15. You can see that in the small circle the drainage day are a lot more and the watering days is significant less.

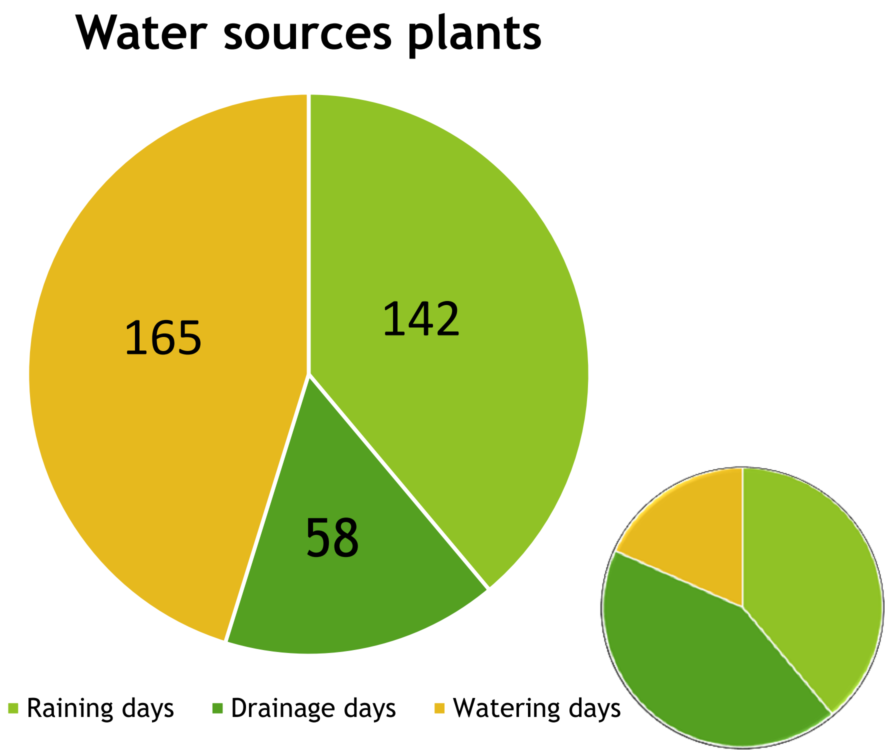


Figure 15 Water sources Pilot

Water flow
The water falls onto the roof and flows into the bamboo gutter. The gutter will lead the water into the tank (18.9L). The tank is attached to a hose which is plugged at the end so it will stop the water. The tube will be filled with water and will be divided onto the vegetation through tiny holes. The water will flow down through the soil and vegetation and will end up after a long period of time in the ground.

8. Water system analysis

To show the water flows in the water system of garden area (appendix 9 shows a top view) a bucket model has been made as you can see in figure 16. Within the chosen school area, the precipitation falls on three different types of surfaces. The water that falls on the paved surface will partly evaporate back into the air, but the biggest part of it will flow to the garden. This water together with the water that fall directly on the garden and a part of the water from the roof will flow to the ground water. A small percentage of the roof is caught by the pilot. This water is drain over a longer amount and this water is partly absorbed by vegetation. The remaining water from the pilot drains slowly to the paved surface. After this the water flows into the groundwater through the garden.

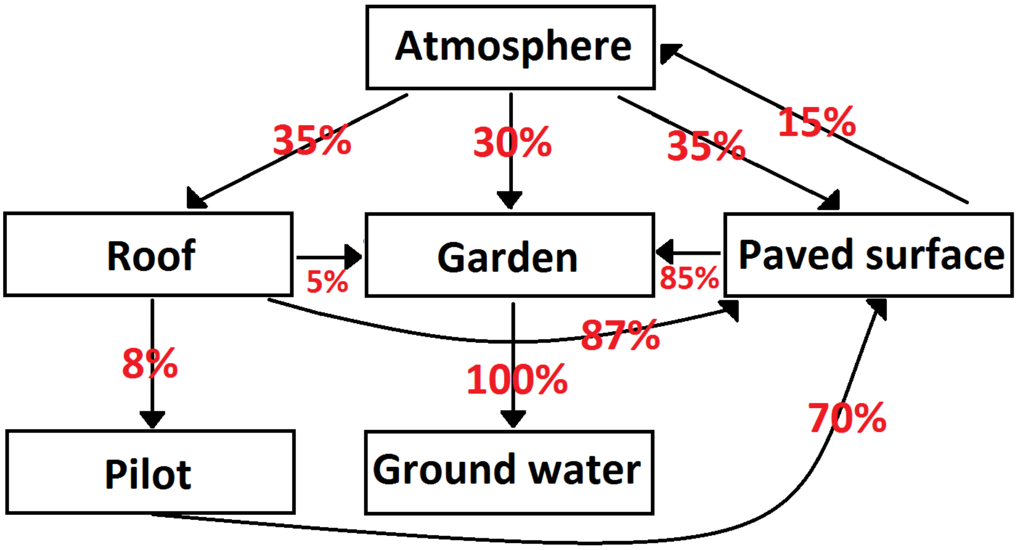


Figure 16 Bucket model

The calculations made in the water system analyses can be split into 3 paragraphs. The first paragraph is “Input”. In the paragraph “Input” is the rain flowing to the tank calculated. The second paragraph is “Storage”. In this paragraph is calculated how much water will be saved by the tank. The third paragraph is called “Output”. In this chapter is the water flow to the agriculture calculated. The last paragraph will show the results of the calculations.

Each of these paragraphs is divided into 3 parts, “Known data”, “Calculated data” and “Formula explanation”. The known data is data that has to be obtained before calculating. Some of this data can be obtained with the help of the internet, but other data are specific for the design situation and need to be obtained by measuring the designs.

Some data can only be calculated with the help of other data. Because of this, data needs to be calculated in a specific order. The order in which data can be calculated is shown by the “stage” of the data. Known data is always stage one because this data is obtained beforehand and not calculated. The calculations can also be found in the chronological order in the example in appendix 7.

8.1 Input

Known data

Table 8 Known input data

Data	Abbreviation	Unit	Source	stage
Number of months	t_y	Months	Common sense	1
Days per month	t_m	Days	Common sense	1
Days with precipitation per month	t_p	Days	(Weatherbase, 2014)	1
Average precipitation per month	P_a	mm	(Weatherbase, 2014)	1
Length of the roof	L_r	m	Measured with steps	1
Width of the roof	W_r	m	Measured with steps	1
Length of the catching area	L_c	m	Measured with tapeline	1
Width of the catching area	W_c	m	Measured with tapeline	1
Average shower length	t_s	min	Estimated based on experience	1

Calculated data

Table 9 Calculated input data

Data	Abbreviation	Unit	Stage
Area of the roof	A_r	m^2	2
Rain catching area	A_c	m^2	2
Average days between showers per month	t_b	Days	2
Precipitation on roof	P_r	m^3	3
Precipitation on catching area	P_c	m^3	3
Precipitation on catching area (average shower)	P_s	L	4
Overlapping day 1	t_{o1}	Days	7
Overlapping day 2	t_{o2}	Days	8
Overlapping day 3	t_{o3}	Days	9
Total overlapping	t_{oTotal}	Days	10

Table 10 input formulas

Abbreviation	Formula
A_r	L_r*W_r
A_c	L_c*W_c
t_b	t_m/t_p
P_r	$(P_a/1000)*A_r$
P_c	$(P_a/1000)*A_c$
P_s	$(P_c/100)/(t_p*100)$
t_{o1}	$t_m*(t_p/t_m)^2*$(if $t_d>1$ then t_d-1 else 0) Days of month * Chance * Wasted days in scenario
t_{o2}	$t_m*((t_p/t_m)^3+((t_p/t_m)^2*(1-(t_p/t_m))))*$(if $t_d>2$ then t_d-2 else 0) Days of month * Chance * Wasted days in scenario
t_{o3}	$t_m*((t_p/t_m)^4+((t_p/t_m)^3*(1-(t_p/t_m)))+((t_p/t_m)^3*(1-(t_p/t_m)))+((t_p/t_m)^2*(1-(t_p/t_m))^2))*$(if $t_d>3$ then t_d-3 else 0) Days of month * Chance * Wasted days in scenario
t_{oTotal}	$t_{01}+t_{02}+t_{01}$

Formula explanation

Most of the formulas stated above are quite simple. Although, the overlapping days need extra clarification. If the raining starts at day one, the tank will also be filled. From the tank water is drained to the vegetation over time. This process can take multiple days in which there is also a chance of rain. If the rain starts for the second time while the water from the tank was still draining, less water can be distributed compared to when the second shower starts after the tank is done with draining. These days that water what should normally be stored in the tank when it is empty, cannot be stored since the tank is still partly full and thus is wasted (figure 17). These days are called overlapping days. To calculate the number of days that have this problem, chance calculation methods have been used.

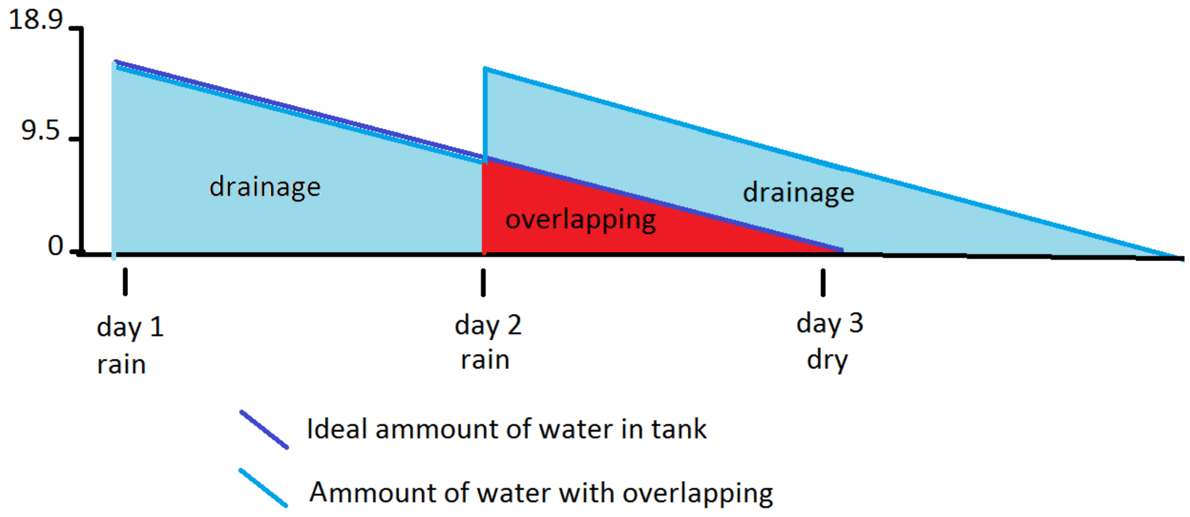


Figure 17 Example, overlapping

To calculate the overlapping of the second day we calculated the chance that it would rain 2 times after each other. At first we need to be able to calculate the chance of raining once a day. This can be calculated by dividing the number of rainy days in the month by the number of days in that month which means t_p/t_m. The chance of this happening two times after each other can be calculated by multiplying this chance with itself which means $(t_p/t_m)^2$. This is the chance that it will rain two times after each other. To calculate how many days in a month this will happen we multiplied the chance by the number of days in the month which means $T_m*(t_p/t_m)^2$. But the drainage can be longer or shorter than one day which means that multiple or no days are wasted. This can also be put in the formula with “if, then, else”. *If* the drainage takes longer than one and a half day to empty the tank *then* the one and a half day are subtracted from the drainage days to get the remaining days *else* 0 which means if $t_d>1$ then t_d-1 else 0. The 0 needs to be there because when the drainage time is less than 1 the overlapping days will not affect volume of the drained water. The formula is multiplied by the outcome of this part which means $T_m*(t_p/t_m)^2*$(if $t_d>1$ then t_d-1 else 0).

8.2 Storage

Known data

Table 11 Known storage data

Data	Abbreviation	Unit	Source	stage
Tank volume	V_{tmax}	L	Tank label	1

Calculated data

Table 12 Calculated storage data

Data	Abbreviation	Unit	Stage
Water in tank (average shower)	V_t	L	5
Drain time (average shower)	t_d	Days	6
Amount of drained water after 24h	V_{24}	L	6

Table 13 Storage formulas

Abbreviation	Formula
V_t	If P_s>V_{tmax} then V_{tmax} else P_s
t_d	$V_t/(Q*24)$
V_{t24}	If $24*Q<V_t$ then $24*Q$ else V_t

Formula explanation

V_t is the amount of water that is stored in the tank after the average shower of the particular month. This is the same as P_s (amount of water fallen on the catching area per shower) except when the amount of water is more than can be stored in the tank. If that is the situation then the total volume of the tank will be V_t which means If P_s>V_{tmax} then V_{tmax} else P_s.

V_{t24} is the amount of water that flows from the tank to the agriculture in one day. This can be calculated by multiplying the water flow by the time of a day (24h). But the amount of water cannot be more than the amount of water that is stored in the tank after a shower. Because of this the "if, then, else" method is used, which results in If $24*Q<P_t$ then $24*Q$ else V_t .

8.3 Output

Known data

Table 14 Known output data

Data	Abbreviation	Unit	Source	stage
Water flow (<0.2L/h)	Q	L/h	Measured per hole with stopwatch at the pilot	1

Calculated data

Table 15 Calculated output data

Data	Abbreviation	Unit	Stage
Watering days (old)	t_{wo}	Days	2
Not watering days (new with overlapping)	t_{nno}	Days	7
Not watering days (new without overlapping)	t_{nn}	Days	11
Watering days (new)	t_{wn}	Days	12
Saved water	V_s	M^3	12

Table 16 Output formulas

Abbreviation	Formula
t_{wo}	t_m-t_p
t_{nno}	t_p+t_p*t_d+(t_p*t_r/60/24)
t_{nn}	If t_{nno}-t_{oTotal}>t_m then t_m else t_{nno}-t_{oTotal}
t_{wn}	t_m-t_{nn}
V_s	((t_p*t_d-t_{oTotal})*v_{24})/1000

Formula explanation

The number of not watering days in the old scenario is the same as the number of rainy days. This is because vegetation in the climate of Cebu needs to be watered every day except on a rainy day. The number of watering days of the old scenario is calculated by subtracting the not watering days from the amount of days in the month.

The number of not watering days (new with overlapping) are calculated by looking at the old not watering days. In the new scenario there is no need to water the plants on a rainy day just as in the old scenario, but now instead of the usual 1 day of not watering, the drainage time is added every shower which means t_p+t_p*t_d. But the shower itself also takes a little bit of time, therefore the duration of the shower is added every time a shower occurs which means t_p+t_p*t_d+(t_p*t_r/60/24).

The number of not watering days (new without overlapping) are calculated by subtracting the number of the total overlapping days of the number of not watering days (new with overlapping). Overlapping occurs when the water tank is filled up before it has drained empty. When this occurs less water can be stored in total which means the drainage will take less time (because there is less water) in total. This number can be higher than the number of days in the month. This means that there is a big chance that the tank will drain every day of the month. But because a month is limited to a number of days the number of drainage days is also not able to be more. This is limited with the "if, then, else" method which means if t_{nno}-t_{oTotal}>t_m then t_m else t_{nno}-t_{oTotal}.

The amount of save/distributed water can also be calculated. To calculate this, the number of draining days per month need to be calculated. This can be done by multiplying the number of rainy days per month with the drainage time or t_p*t_d. After this number of overlapping days need to be subtracted which means t_p*t_d-t_{oTotal}. These are the number of draining days per month. This number needs to be multiplied by the draining time (t_p*t_d-t_{oTotal})*v_{24}. This answer is the amount of water saved by the tank per month in litres. This number is divided by 1000 to get the amount of saved water in cubic metres.

8.4 Results

With the help of the explained formulas it was possible to calculate the different effects that the designs would have on the water system. The two Designs have different effects on the water system because they have a different amount of plants. This means that the designs need to have a different water flow.

To water the 49 plants of design 1 you would need a water flow of about 1.0L/h (0.5L/day/plant). After testing and measuring the pilot project we found out that this could be achieved by making 5 holes in the hoze/tube.
Design 2 has only 18 plants which means that a lower water flow can be used in the pilot. The water flow that is needed for this design is 0.38L/h. This can be achieved by making two holes. However it is better to use 3 holes so the water is more equally devided.

By implementng the first design 2.7m³ of rainwater is stored and slowly drained per year. The ammount of days that the pilot is watering the vegetation is 102 days per year on average (figure 18). This means that about 2500L water is spared in 1 year on average. 2700L water is slowed down by the system.

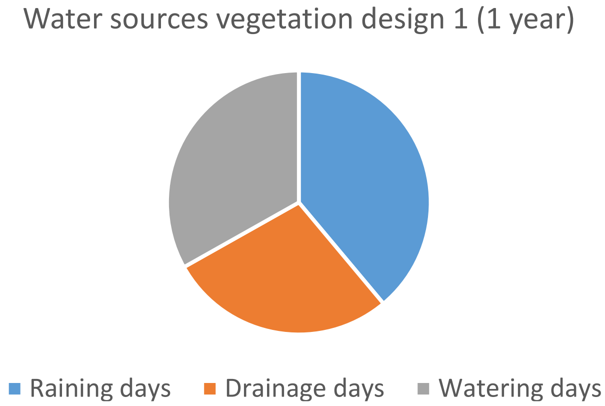


Figure 18 Water sources design 1

By implementing the second design 2.5m³ of rainwater us stored and slowly drained per year. The amount of days that the pilot is watering the vegetation is 156 days per year on average (figure 19). This means that about 1400L water is spared in 1 year on average. 2500L water is slowed down by the system.

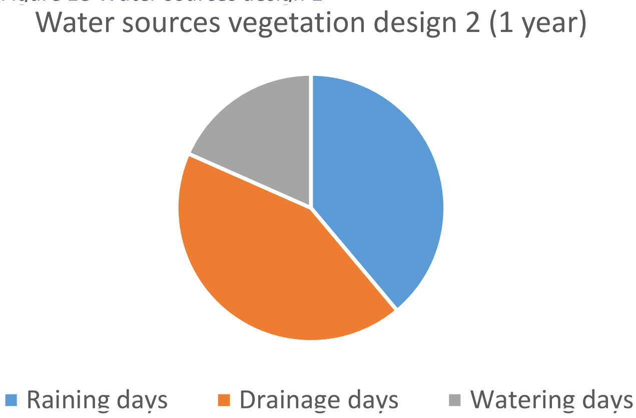


Figure 19 Water sources design 2

The pilot has different results than the design because too many (9) holes where made into the hose which caused a very high water flow of 2L/h. When the water flow is too high the tank is empty faster and there are less watering days. The pilot stores 2.7m³ of rain water a year. The amount of days that this pilot is watering the vegetation is 58 days per year on average (figure 20). This means that about 500L water is spared in 1 year on average. This could be as much as in design 2, but too many holes were made into the tube. 2700L water is slowed down by the system.

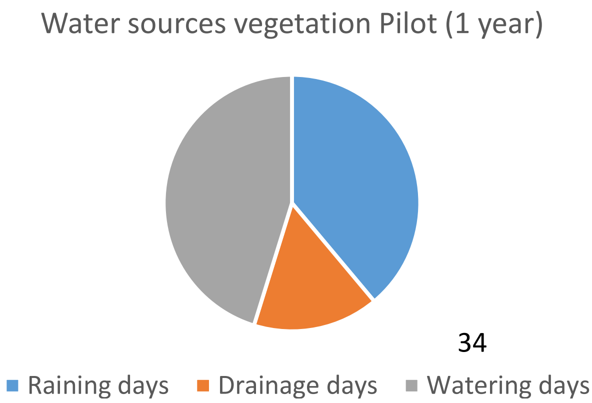


Figure 20 Water sources Pilot

9. Conclusion

There can be concluded that design 2 is a better option than design 1 for Cebu City. Design 2 only costs 150 Pesos, it is made of locally available materials, the design does not use much space, it slows down the rainwater, it produces food and it stores rainwater.
Design 1 is also pretty complicated to build and is more expensive compared to design 2. Design 2 also has more strong points that respond to opportunities and repel threats regarding the confrontation matrix. The amount of days that this pilot is watering the vegetation is 156 days per year on average. This means that about 1400L water is spared in 1 year on average and about 2500L of water is slowed down by the system in 1 year. After testing, this pilot can hold 1L of water for a duration of 30 min before it is completely distributed throughout the system. This results in a water flow of 2L/h. In total the amount of water that is spared is 500 L/year. The 500L water would in a normal situation be given to the plants.

This can be increased by reducing the amounts of holes made inside the tube.

The following details are important to make when implementing this pilot (figure 21).

- Do not make much more than 3 holes inside the tube.
- Divide the holes equally over the length of the tube.
- Add a bamboo pole and attach every bottle to it.
- Place the vegetation at least 20 cm above the ground.
- Make tiny cuts on the bottom side of the lowest bottle.
- Make a small hole at the back on top of the tank.
- Make tiny cuts inside every bottle cap so that only the tube can go through.

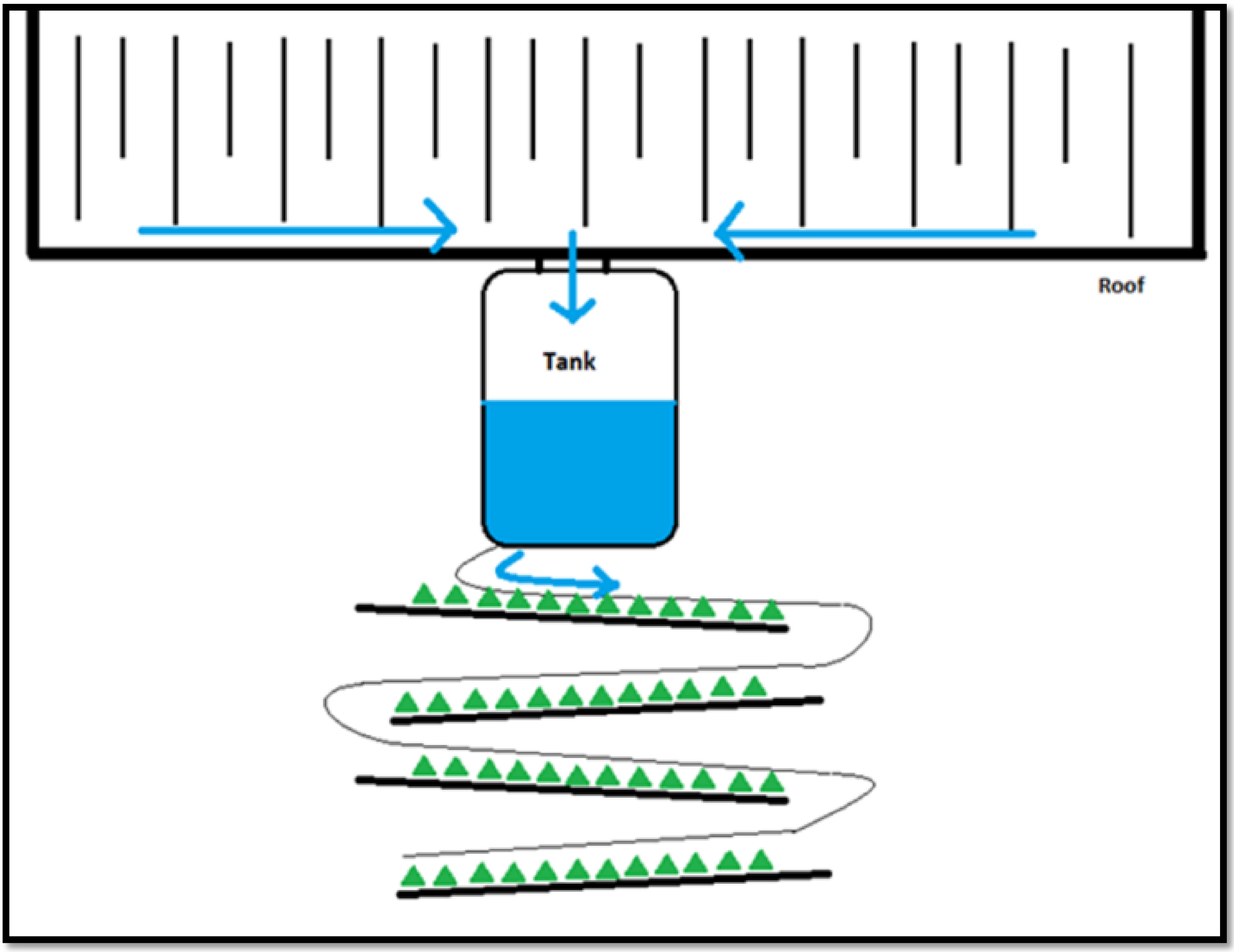
Figure 21 Pilot project finnished

10. Illustrations

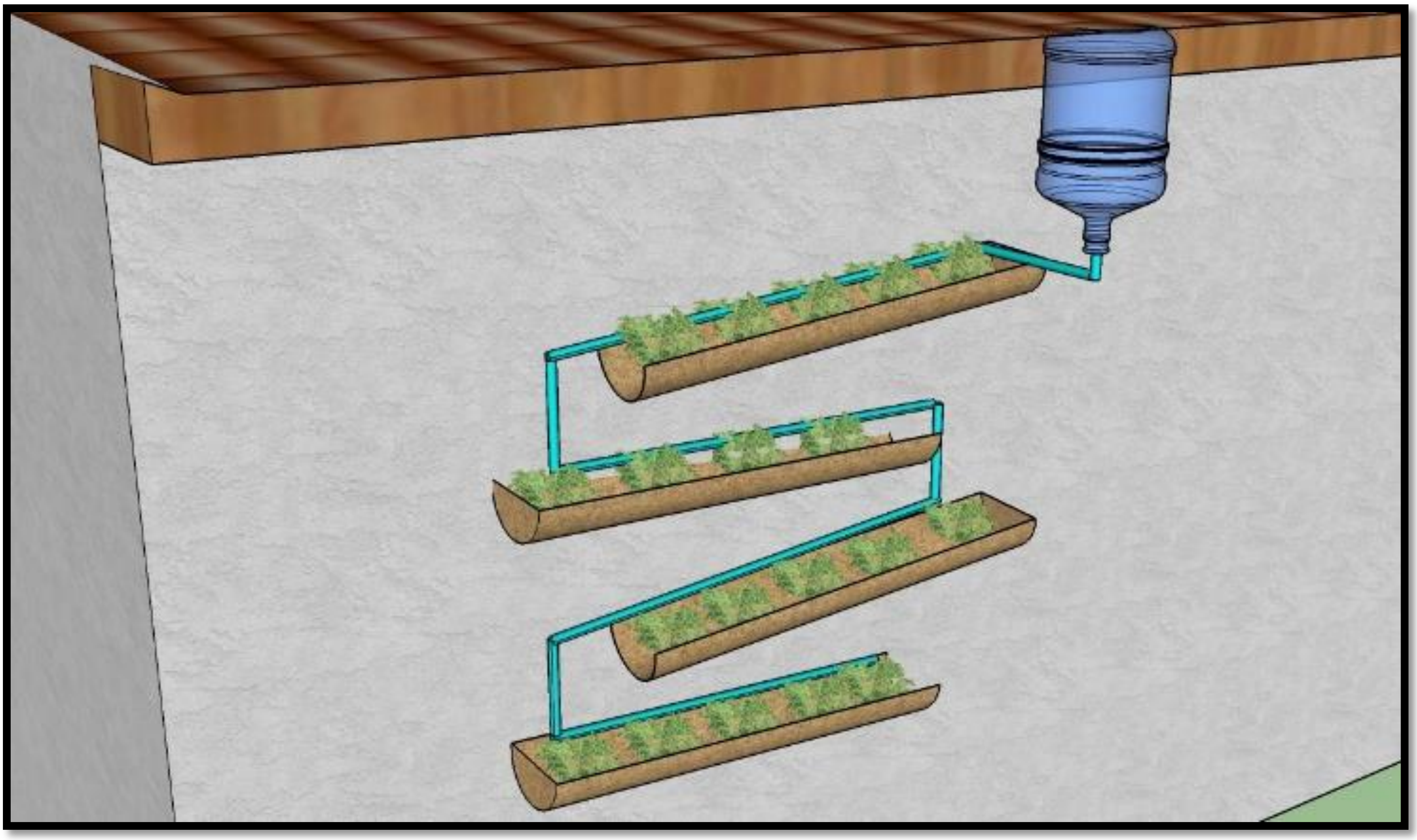
Nr	Description	Source	Date of publication	Author
1	3d design 1	Made with SketchUp	14-11-14	Ian Mullens
2	3d design 2	Made with SketchUp	14-11-14	Ian Mullens
3	Vertical agriculture 1	http://www.inmagz.com/wallbank/1688-vertical-gardening-ideas-with-wire-fence.jpg	24-8-2013	Interior Magazine
4	Vertical agriculture 2	http://meergroenzelfdoen.nl/wp-content/uploads/2013/01/Verticaal-tuinieren-sla-in-dakgoten.png	1-4-2013	Rob van Eeden
5	Vertical agriculture 3	http://www.handmadekultur.de/up/2012/07/window1-600x760.jpg	13-7-2012	Britta Riley
6	Mindmap	Bubbl.us	14-11-14	Ian Mullens & Timo Hoekstra
7	Sketch design	Made with MS Paint	14-11-14	Timo Hoekstra
8	Intersection two different angles design 1	Made with Adobe Illustrator	10-12-14	Ian Mullens
9	3d design 1	Made with SketchUp	14-11-14	Ian Mullens
10	Design 2 sketch	Made with MS Paint	13-11-14	Timo Hoekstra
11	Intersection from 2 angles design 2	Made with Adobe Illustrator	9-12-14	Ian Mullens
12	3d design 2	Made with SketchUp	14-11-14	Ian Mullens
13	Pilot	Photo	12-12-14	Timo Hoekstra
14	Pilot bottle close-up	Photo	12-12-14	Timo Hoekstra

15	Water sources pilot	Water system analyses	15-12-14	Ian Mullens & Timo Hoekstra
16	Bucket model	Water system analyses	11-12-14	Ian Mullens
17	Example overlapping	Water system analyses	4-12-14	Ian Mullens
18	Water sources design 1	Water system analyses	15-12-14	Ian Mullens & Timo Hoekstra
19	Water sources design 2	Water system analyses	15-12-14	Ian Mullens & Timo Hoekstra
20	Water sources pilot	Water system analyses	15-12-14	Ian Mullens & Timo Hoekstra
21	Pilot project finished	Photo	12-12-14	Timo Hoekstra

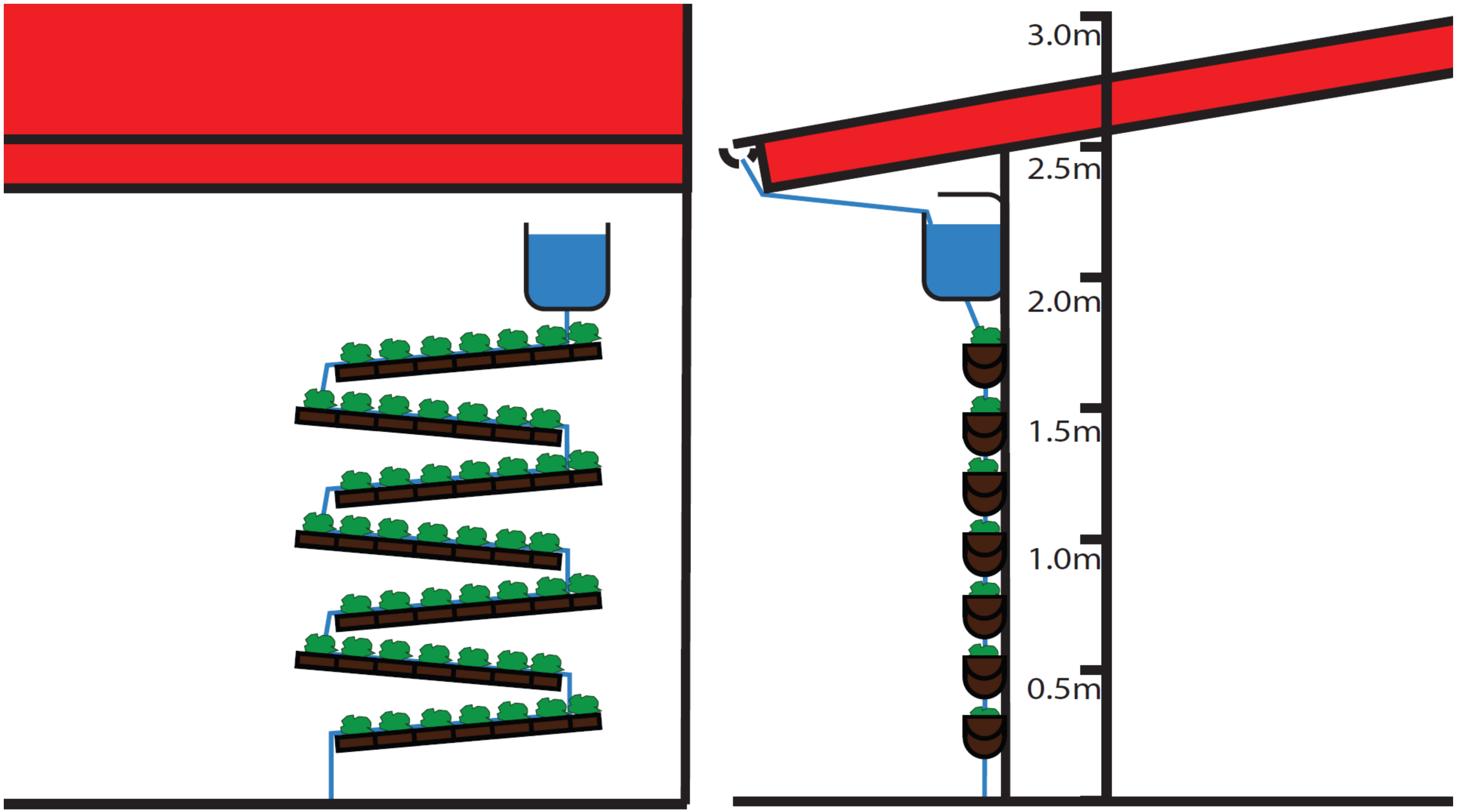
Appendix 1 Sketch design 1



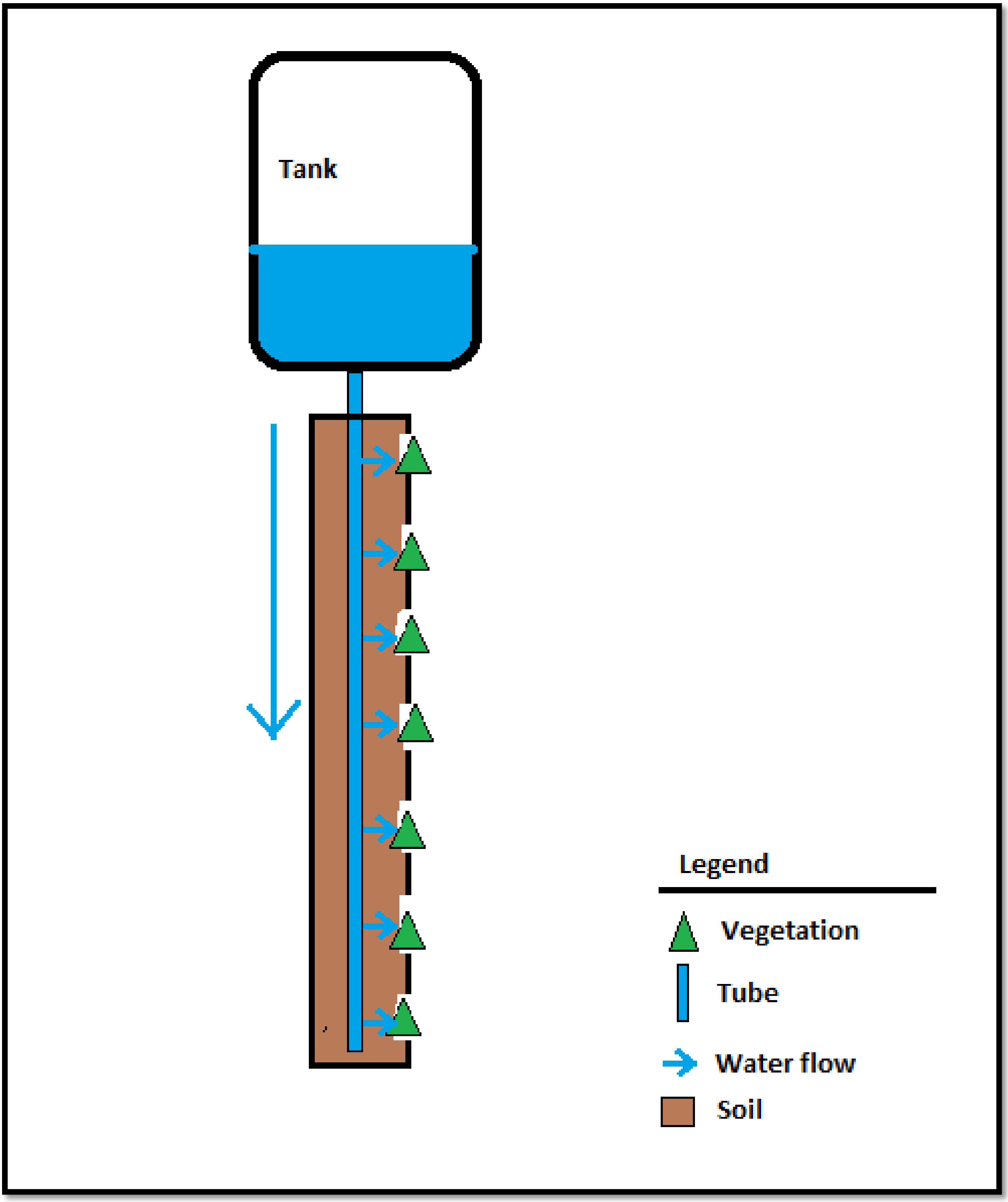
Appendix 2 3d Design 1



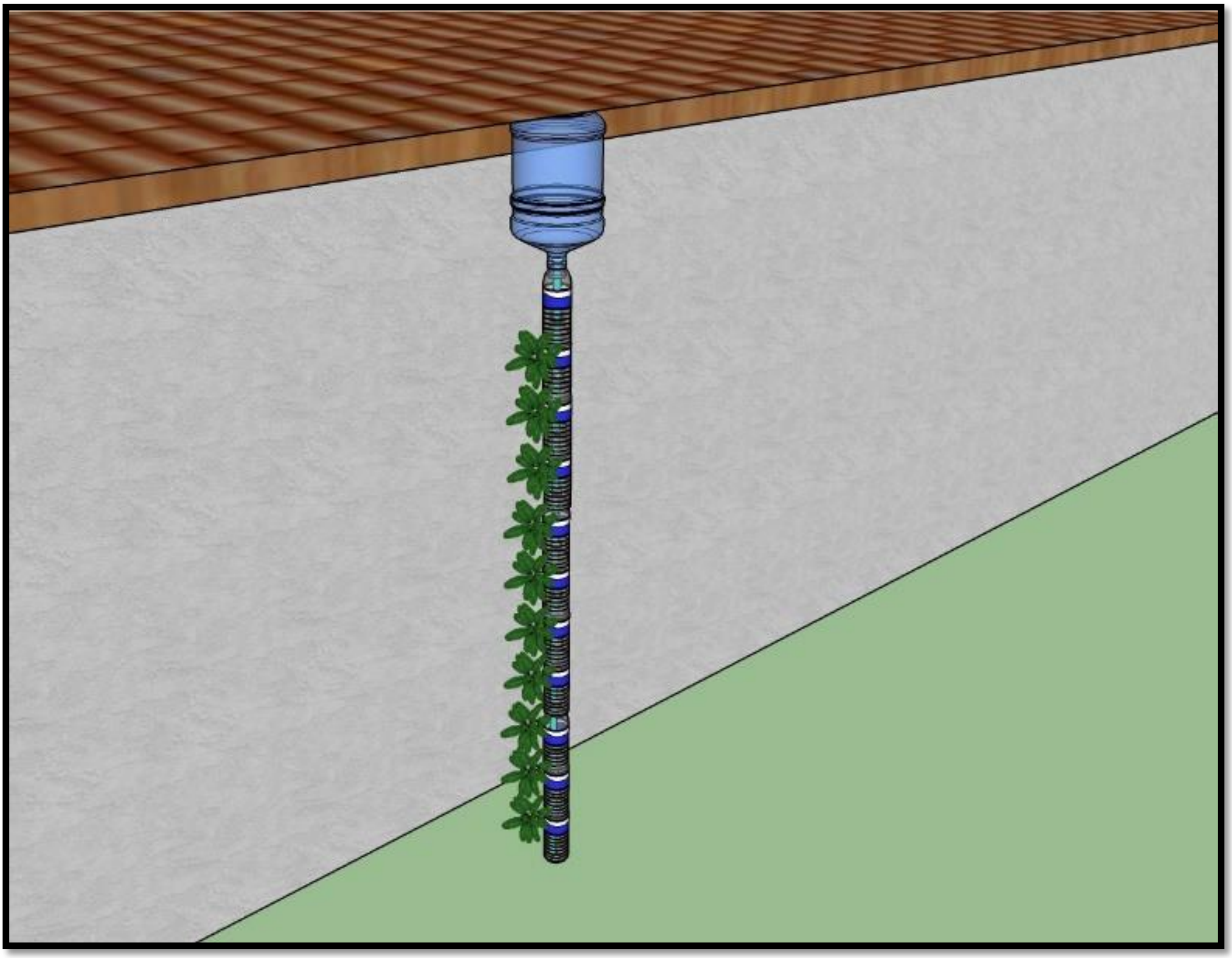
Appendix 3 Intersection design 1



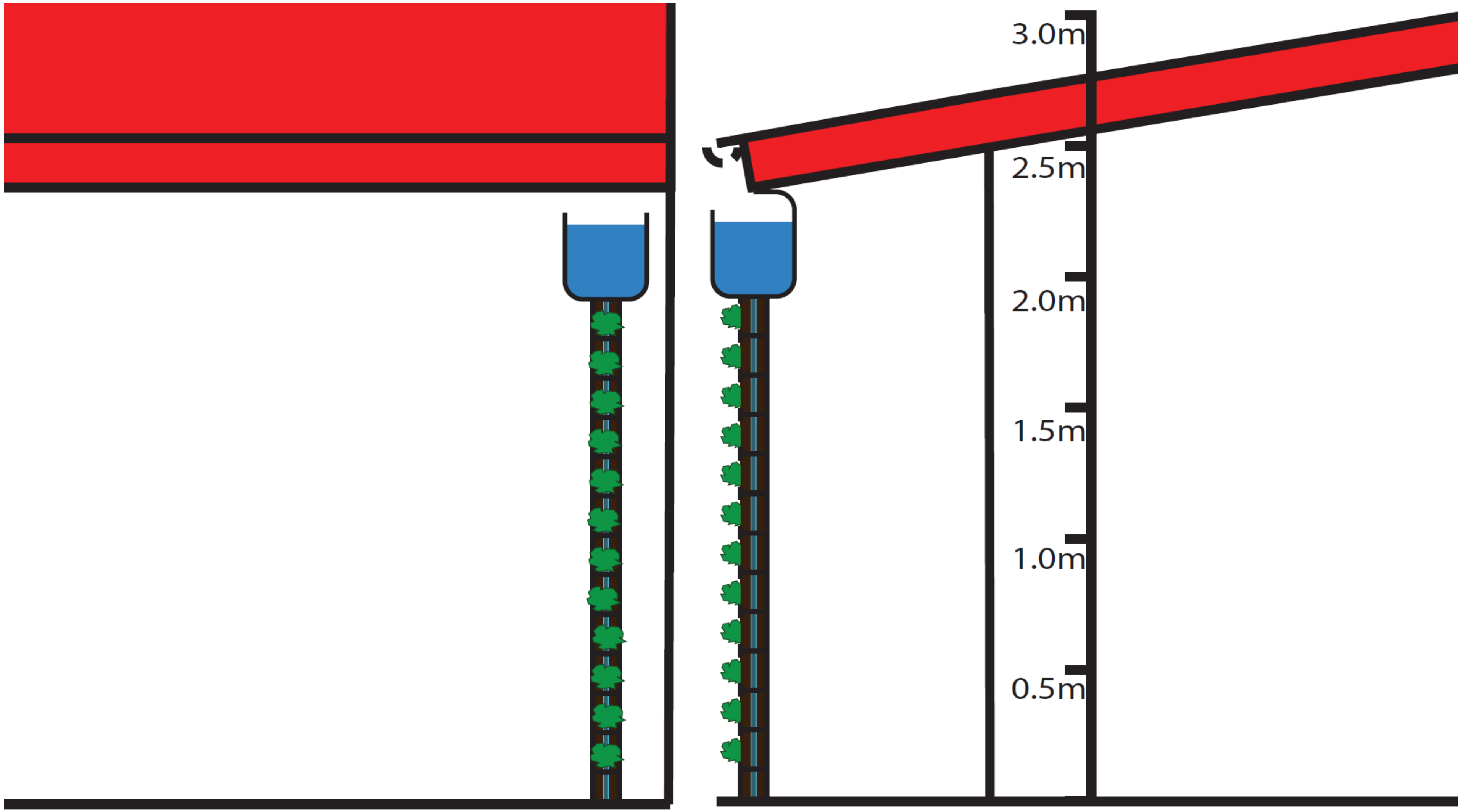
Appendix 4 Sketch design 2



Appendix 5 3d Design 2



Appendix 6 Intersection design 2



Appendix 7 Calculations

Area of the roof (stage 2):

$A_r=L_r*W_r$
$A=35*6=210m^2$

Rain catching area (stage 2):

$A_c=L_c*W_c$
$A=2*3=6m^2$

Average days between showers per month (stage 2):

$t_b=t_m/t_p$
$t_b=31/14=2.21days$

Watering days (old) (stage 2):

$t_{wo}=t_m-t_p$
$t_{wo}=31-14=17days$

Precipitation on roof (stage 3):

$P_r=(P_a/1000)*A_r$
$P_r=(110/1000)*210=23.1m^3$

Precipitation on catching area (stage 3):

$P_c=(P_a/1000)*A_c$
$P_c=(6/1000)*210=0.66m^3$

Precipitation on catching area shower (stage 4):

$P_s=(P_c/100)/(t_p*100)$
$P_s=(0.66/100)/(14*100)=47.1L$

Water in tank (average shower) (stage 5):

V_t=if $P_s>V_{tmax}$ then V_{tmax} else P_s
V_t=if 47.1>18.9 then 18.9 else 47.1=18.9L

Drain time (average shower) (stage 6):

$T_d=V_t/(Q*24)$
$T_d=18.9/(0.25*24)=3.15days$

Amount of drained water after 24h (stage 6):

V_{t24}=If 24*Q<V_t then 24*Q else V_t
V_{t24}=If 24*0.25<18.9 then 24*0.25 else 18.9=24*0.25=6L

Not watering days (new with overlapping) (stage 7):

$t_{nno}=t_p+t_p*t_d+(t_p*t_r/60/24)$
t_{nno}=14+14*3.15+(14*30/60/24)=59.1days

Overlapping day 1 (stage 7):

$t_{o1}=t_m*(t_p/t_m)^2$*(if t_d>1 then t_d-1 else 0)
(Days of month)*(Chance)*(Wasted days in scenario)
$t_{o1}=31*(14/31)^2$*(if 3.15>1) then 3.15-1 else 0
$t_{o1}=31*(14/31)^2*(3.15-1)$=13.6days

Overlapping day 2 (stage 8):

$t_{o2}=t_m*((t_p/t_m)^3+((t_p/t_m)^2*(1-(t_p/t_m))))$*(if t_d>2 then t_d-2 else 0)
(Days of month)*(Chance)*(Wasted days in scenario)
$t_{o2}=31*((14/31)^3+((14/31)^2*(1-(14/31))))$*(if 3.15>2 then 3.15-2 else 0)
$t_{o2}=31*((14/31)^3+((14/31)^2*(1-(14/31))))*(3.15-2)$=7.3days

Overlapping day 3 (stage 9):

$t_{o3}=t_m*((t_p/t_m)^4+((t_p/t_m)^3*(1-(t_p/t_m)))+((t_p/t_m)^3*(1-(t_p/t_m)))+((t_p/t_m)^2*(1-(t_p/t_m))^2))$*(if t_d>3 then t_d-3 else 0)
(Days of month)*(Chance)*(Wasted days in scenario)
$t_{o3}=31*((14/31)^4+((14/31)^3*(1-(14/31)))+((14/31)^3*(1-(14/31)))+((14/31)^2*(1-(14/31))^2))$*(if 3.15>3 then 3.15-3 else 0)
$t_{o3}=31*((14/31)^4+((14/31)^3*(1-(14/31)))+((14/31)^3*(1-(14/31)))+((14/31)^2*(1-(14/31))^2))*(3.15-3)$ =0.9days

Total overlapping (stage 10)

$t_{oTotal}=t_{01}+t_{02}+t_{01}$
t_{oTotal}=13.6+7.3+0.9=21.8days

Not watering days (new without overlapping) (stage 11):

t_{nn}=if $t_{nno}-t_{oTotal}>t_m$ then t_m else $t_{nno}-t_{oTotal}$
t_{nn}=if 59.1-21.8>31 then 31 else 59.1-21.8=31days

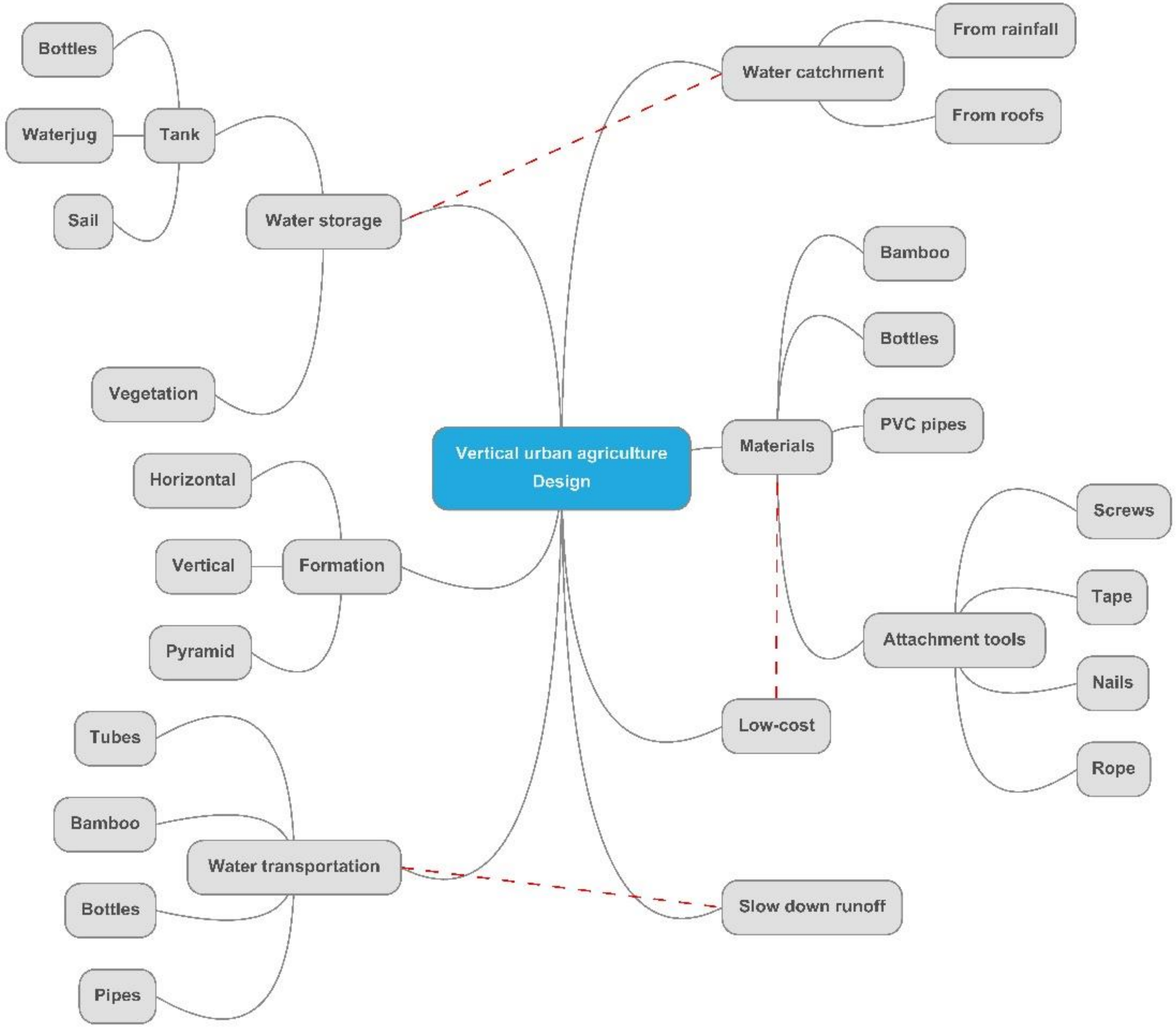
Watering days (new) (stage 12):

$t_{wn}=t_m-t_{nn}$
$t_{wn}=31-31=0days$

Saved water(stage 12):

$V_s=((t_p*t_d-t_{oTotal})*v_{24})/1000$
$V_s=((14*3.15-21.8)*6)/1000=0.13m^3$

Appendix 8 Mind map



Appendix 9 Area usage school garden