Abstract

The echo of the problem of urban congestion has spread in many other fields. It is one of the major problems that leads to the demolition of any country. What made it worse was its association with many other several grand challenges. So, what causes this disaster? Well, many causes ranging from the spread of arid areas and the lack of water resources, which are connected. So, the keyword for solving the problem is water. The project's purpose is making use of wasted rain water. That's why, our chosen solution is building a rainwater collector, which will provide the opportunity of grand scale reclamation projects solving the problem of arid areas and urban congestion. For the collector to meet its original purpose, it must have the design requirements of collecting the greatest amount of water in the shortest time. After conducting the test, the results exceeded the expectations and had a high collection rate. This showed that the prototype can perfectly solve the problem and can be used throughout the country providing a new water resource, which will lead to making people spread in different places and the construction of new lands far from the Nile River and will solve the problem of urban congestion and arid areas. Giving astonishing results far beyond expected. Proving that the project can solve the problem perfectly.

HEXA PROJECT

Group 112

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Introduction

Egypt faces a series of problems, where the most important one of them is urban congestion. It spreads fast as well as the shortage of water and pollution, on the other hand, arid areas are spread in regions that are less Population. The ancient Egyptian people settled around the Nile, and to this day 95% of Egyptian population is still concentrated around the Nile as shown in figure (1), which has led to urban congestion and the spread of arid areas in regions far from the Nile. Finding an alternative water source will make people spread far from the Nile. According to" UN's Food and Agriculture Organization", FAO, the amount of rain that falls on Egypt is estimated at 51 billion m^3 annually, which is equivalent to the country's share of Nile water. However, only 1.3 billion m^3 per year are currently used, where rainwater represents a percentage of 0.050% of fresh water on earth, which is an encouraging percentage. That's why, the chosen solution to make rainwater collection system because of its purity and availability. All of that is to solve the problem of wasted rainwater and to provide a new source of water that makes people spread in different areas away from the Nile which will lead to solving these problems.

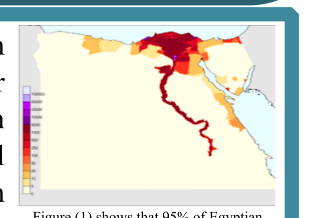


Figure (1) shows that 95% of Egyptian population settle around the Nile.

Many rainwater collection systems were made before. The first and most popular one is the rooftop collector. It uses the rooftop to collect rainwater and then transfers it to a tank by a system of gutters as shown in figure (2). Its advantages are that it provides high-quality water for domestic use and reduces the cost of pumping underground water. The disadvantages are that the water can get contaminated by the corpses of the small animals. Another one is the ground catchment. It uses compacted or cement soil with enough slope to collect the rainwater in an underground tank as shown in figure (3). It is very useful as it can provide water for whole families in a small community rather than individual roof top systems. Its disadvantages are that the maintenance of the underground tank will be difficult, and it can be fairly expensive to set up a pumping system and an underground tank.

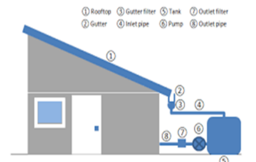


Figure (2) shows the rooftop harvesting system and its components.

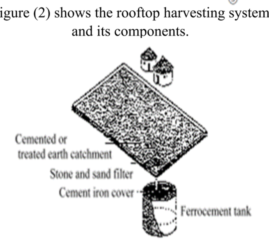


Figure (3) shows cement enforced ground catchment and its mechanism.

The prototype achieved results that exceeded expectations as it was able to meet design requirements of having the greatest collection rate, which is defined as the amount of collected rainwater in an interval of time. This can be tested by calculating the time needed by the collector to collect a liter of water from a shower 1.5m above the prototype and the prototype showed amazing results.

In order to show these wonderful results, the prototype was made from effective materials that can collect water and prevent leakage, and this was one of the most important steps.

Materials

Name	Quantity	Description	Image
Craft Sticks	10 Boxes	They are made of wood where they are 1.7 cm wide, 15cm length and 0.1 cm thick	
Yellow PVA	One	Yellow PVA is the adhesive material that joins craft sticks together.	
Polyurethane Caulk	One	PU caulk is the adhesive that is used to glue the faces together.	
Kemapoxy150	One	Kemapoxy150 is the coating material that is used to protect the craft sticks from water, etc.	
Rough and Smooth wood sandpaper	One - One	It is used to make the edges and the body of the sticks smooth.	
Hardpoint Tenon Saw Straight Handle Serrated Normal	One	It was used to cut the craft-sticks rectangular faces into trapezoidal faces of the prototype.	
Paintbrush	One	It was used to cover all the prototype with kemapoxy150	

Methods

Section one: Preparation

1st Step: The round edges of the craft sticks were cut by the scissors and the body of the stick was glazed as shown in figure (4).

Figure (4) shows the craft sticks after cutting.

2nd Step: Many samples were made to try the glue and the coating material which helped to choose the suitable materials for each use as shown in figure (5).

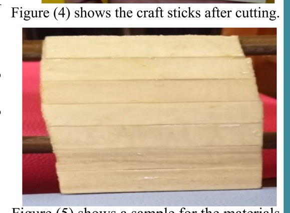


Figure (5) shows a sample for the materials.

3rd Step: The sticks were glued together by the yellow PVA to form rectangular faces of dimensions 40x60cm ,where some sticks are put as horizontal rows and there was another layer with vertical rows of sticks.

Section two: Execution

1st Step: Rectangular faces were cut into triangles with dimensions with a base of 31.5cm and a height of 38.6cm as shown in figure (6).

2nd Step: The produced triangles were cut into trapeziums with dimensions 31.5cm and 3.6cm bases and 34.09cm height by removing a small triangle with an area 8.33x10cm^2 that makes the area of each resulted trapezium=600cm^2.

3rd Step: The trapeziums were made smoother by using sanding papers.

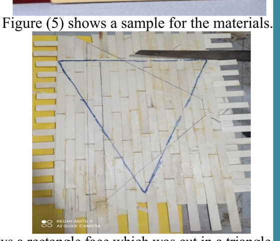


Figure (6) shows a rectangle face which was cut in a triangle

4th Step: The trapeziums were put together and then glued to make the hexagonal pyramid frustum by the PU sealant figure (7).

Figure (7) shows the faces after putting them together by PU sealant.

5th Step: The prototype was supported by gluing some sticks on the external of the prototype to hamper PU sealant's flexibility, then all the external of the prototype was covered by PU sealant to fill spaces between the craft sticks as shown in figure (8).

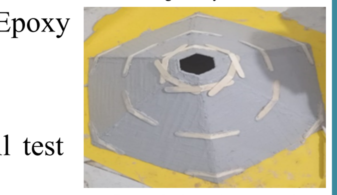


Figure (8) shows the supported prototype after covering by PU sealant and Kempoxy150.

6th Step: The prototype was covered externally and internally by Kempoxy150 (Epoxy Risen) as shown in figures (8) and (9).

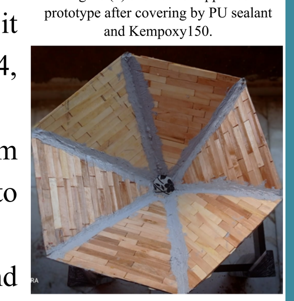


Figure (9) shows the internal of the prototype after covering by Kempoxy150.

Section three: Test Plan

Our design requirement was having a high rainwater collection rate, so a small test station was made by performing these steps:

1st Step: A water bottle with a capacity of 1.2liter was attached to the prototype, where it had a mark each 0.2L to facilitate indicating the time interval indicated to collect 0.2, 0.4, 0.6, 0.8 and 1L.

2nd Step: The shower, which is the water source, was attached at the height of 150 cm above the prototype and the diameter of the shower was calculated and was equal to 6.5cm.

3rd Step: The time intervals of collecting each 0.2L were calculated carefully and recorded in a sheet of paper.

Results

Negative Results

During the test plan, there was a problem facing us. The pressure of the shower's water, which is the water source, wasn't stable. The pressure levels were variant, odd and random, where the pressure must be a controlled variable in the test plan and must be the same during the test plan. That gave us positive results.

Positive Results

After correcting that mistake, the results became positive. First a quantity of 0.2L was dropped into the prototype using the shower and the time was collected. Those steps were repeated for every 0.2L until a liter was dropped. The results were competitive and encouraging for each of 0.2, 0.4, 0.6, 0.8, 1L as shown in table (1). The results remained competitive and gave an average of a liter per 29 seconds as shown in graph (1). That is due to the prototype's great way of construction. That result supports the fact that the prototype can perform good or even better in any real-life application. Also, if the people in Egypt used the prototype, the problem of urban congestion will be eradicated and solved completely.

Quantity	1st trial	2nd trial	3rd trial
0.2L	6 ±1sec	7 ±1sec	7 ±1sec
0.4L	13 ±2sec	12 ±2sec	12 ±2sec
0.6L	18 ±3sec	16 ±3sec	17 ±3sec
0.8L	24 ±4sec	21±4sec	22 ±4sec
1.0L	31 ±5sec	26 ±5sec	28 ±5sec

Table (1): shows the time taken to collect 200, 400, 600, 800, 1000ml in the two trials.

Graph (1): Shows the visualization of the average time interval to collect 1liter.

Analysis

The analysis is one of the major aspects of any project to know the scientific background behind the chosen materials and the obtained results. Also, it helps to know the scientific concepts used in the project which will all be shown in this section.

Prototype Overview:

In physics, the angle of slope and the speed of water are in direct variation, so by increasing the angle the speed of water increases. To achieve the goal of collecting the maximum amount of water in the least amount of time the suitable angle is 45°. Because the percent of the slope at this angle is 100% as shown in table (2). Also if the angle increased by more than 45° this will decrease the amount of water collected as the base of the prototype will decrease. The reason for choosing the hexagon shape is that it is compacted. Which means it has a high area to perimeter ratio. This property is especially important for our prototype. As the design requirement was achieving the maximum collection rate, so by choosing the hexagon the maximum area for water to fall into can be achieved to collect more water while reducing the material used, effort and cost. This idea is symbolized in the honey comb where bees use the hexagon shape to store maximum honey with the least material used to build it as shown in figure (10). By using the angle, 45° and given area, 0.36m^2, the dimensions of the prototype were measured as what will be described.

Percent	Degrees/min/s
0.5	0°17'10''
1	0°35'
2	1°08'40''
5	2°51'40''
10	5°42'40''
20	11°18'36''
30	16°42'
40	21°48'05''
50	26°33'55''
100	45°

Table (2) shows conversion of slope units from percent into degrees.

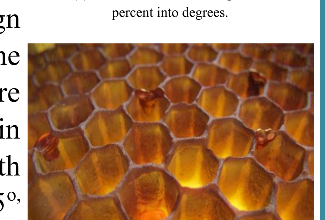


Figure (10): shows the hexagonal structure of honey comb.

The side of the hexagonal base was named (a), the depth of the hexagonal pyramid was named (d) and the height of the side of the hexagonal pyramid was named (h).

From learning outcome (3) in mathematics, it is known that the depth (D) of the prototype with (45°) angle of slope is equal to the vertical distance from the center of the hexagon base on any side of the hexagonal pyramid. Both of them make right isosceles triangle and its hypotenuse is the height of any face of the hexagonal pyramid. All of these are shown in figure (11). From that:

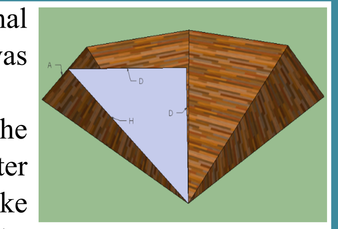


Figure (11): shows a section from the prototype and the given notes from studying that.

$$h = \sqrt{d^2+d^2} = \sqrt{2d^2} = \sqrt{2}\,d$$

On the hexagonal base, there is an equilateral triangle whose side is equal to a and its height is equal to d. It can be concluded that:

$$d = \sqrt{a^2-\left(\frac{1}{2}a\right)^2} = \sqrt{a^2-\frac{1}{4}a^2} = \sqrt{\frac{3}{4}a^2} = \frac{\sqrt{3}}{2}a \quad \text{and} \quad h = \sqrt{2}\,d = \sqrt{2} \times \frac{\sqrt{3}}{2}a = \frac{\sqrt{6}}{2}a$$

The total area of the faces of the hexagonal pyramid frustum is 3600 cm^2. So, the total area of the hexagonal pyramid frustum was put as 3650 cm^2.

The area of any triangular face is $\frac{1}{2}ah = \frac{1}{2} \times a \times \frac{\sqrt{6}}{2}a = \frac{\sqrt{6}}{4}a^2$

and for six faces is $6 \times \frac{\sqrt{6}}{4}a^2 = \frac{3\sqrt{6}}{2}a^2$ and this must be equal to 3650 cm^2.

So, $\frac{3\sqrt{6}}{2}a^2 = 3650$. By using the calculator, a=31.5cm, where $h = \frac{\sqrt{6}}{2}a = \frac{\sqrt{6}}{2} \times 31.5 = 38.6$ cm and

$d = \frac{\sqrt{3}}{2}a = \frac{\sqrt{3}}{2} \times 31.5 = 27.3$cm

To make the triangular face trapezoidal, a small triangle must be cut out of each face and the total area of the small triangles must be 50cm^2. The height was named (k) and side of the base was named (f). The area of one triangular face is $\frac{1}{2}fk$ and the the total area of the triangular faces is $\frac{1}{2}6 \times fk = 3fk = 50\,cm^2$

From the biggest hexagonal pyramid, it appears that $k = \frac{\sqrt{6}}{2}f$. So that, $3 \times f \times \frac{\sqrt{6}}{2}f^2 = 50cm^2$

By using the calculator, $f = 3.6$cm and $k = \frac{\sqrt{6}}{2}f = \frac{\sqrt{6}}{2} \times 3.6 = 4.51$cm

Knowing that the dimensions of the hexagonal pyramid frustum are expressed by both the dimensions of each trapezium and the depth of the prototype as follows: the two bases is 31.5 cm and 3.6 cm. The height was $h - k = 38.6 - 4.51 = 34.09$ cm and the depth = 25.5 cm.

Materials Analysis

Kemapoxy

The coating material used is epoxy coating. An epoxy coating is a compound of two distinct elements. One is epoxy resin and the other is polyamine hardener.When mixed, the resin and hardener engage in a chemical reaction that creates cross-linking of the elements as it cures, where epoxy resins are formed of the reaction of Bisphenol A with epichlorohydrin as shown in figure (12).When it is fully cured, the resulting product is durable, rigid plastic with numerous mechanical and chemical advantages. It is also chemical resistant which is an important property withstand acidic rain. It is also anti-fungus and anti-bacterial.

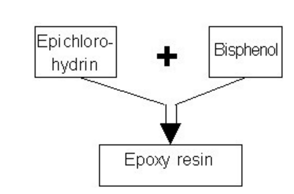


Figure (12): shows the elements forming epoxy resisns.

PU Sealant

Polyurethane is a polymer formed of the reaction of a isocyanate (R–(N=C=O)$_{(n≥2)}$) which has two or more isocyanate (N=C=O) groups and a polyol (R'–(OH)$_{(n≥2)}$) containing two or more hydroxyl group(OH) as shown in figure (13).

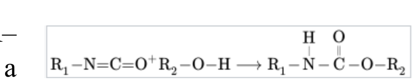


Figure (13): The general form of the reaction forming Polyurethane from two compounds, one with an isocyanate group and the other with a hydroxide group.

Polyurethane is affected by the polyol and the isocyanate forming it, where long chains gives a flexible polymer and chains with a lot of cross-linking gives a rigid polymer. Polyurethane is characterized by its flexibility and a good level of rigidity as it consists of long chains with intermediate cross-linking. Also, PU is recyclable and environment-friendly and it does not soften or melt by heating. It is compatible with wood, too, which makes itself one of the best choices to use.

PVA Glue

PVA (Polyvinyl Acetate) is usually a nontoxic thermoplastic adhesive prepared by the polymerization of vinyl acetate. PVA is a rubbery synthetic polymer with the formula $(C_4H_6O_2)n$ as shown in figures (14 and 15). Polyvinyl acetate is a component of a widely used glue type. It refers to variously as wood glue, white glue, carpenter's glue. Yellow PVA which used is Special as it is water resistant and that made it suitable for water collection system.

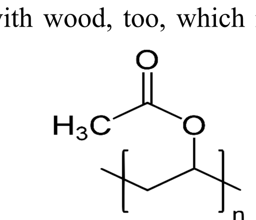
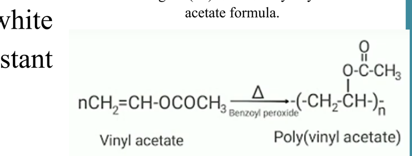


Figure (14): shows Polyvinyl acetate formula.



Figure(15): shows the chemical reaction of formation of PVA.

Learning Transfer

Phy L.O.1

The first learning outcome in physics, which talks about errors, precision and accuracy, was first used by decreasing the error in results by conducting the test plan more than one time and getting the average result to get the most accurate and reliable results. The error of the measuring device was also considered.

Maths L.O.3

The third LO in Mathematics which talked about 3D shapes was used to make a 3D shape for the prototype to know the ability of constructing it in the real-life and helped to measure the dimensions of the prototype.

Chem L.O.1

The first L.O. in chemistry talked about the relation between variables in an experiment and controlled variables. In the test plan, the dependent variable is the amount of collected rainwater in a period of time and the independent variable is making the periods of time of observing water level equal. Studying that learning outcome helped to make the controlled variables as pressure stable to get better results.

Conclusion

According to the results and analysis, the prototype showed high efficiency by achieving the design requirements and collected high amount of water. Also, building it with a large scale can provide the needs of each family in Egypt, which leads to solving the grand challenge.

Recommendation

Materials Recommendation

After completing the project testing and analyzing the results, we concluded that there are materials that can be used that may lead to a better result.

Fiberglass

It will be better to replace the epoxy insulation with fiberglass (illustration shown in figure (16)). It is a type of plastic that is used as a water-proofing material, which will permit collecting more water with less leakage. Fiber glass reinforced plastics are used in a wide variety of piping system applications, Firefighting systems, drinking water systems and gas distribution systems. But among the flaws, that fiberglass becomes damaged by the effect of sun and UV rays.

Figure (16) illustrates fiberglass.

Epoxy Adhesive

Epoxy (illustration shown in figure (17)) can be used as a coating material as in our prototype or as a glue, where it is water-proof and some types have very short drying intervals. It has many positive points as it is both water and solvent resistant, fills gaps and have short bonding time intervals varying from very short time intervals to 24 hours. But, its high price was a great issue preventing its use as a glue.

Figure (17) illustrates Epoxy.

HDPE

HDPE (illustration shown in figure (18)) material will be more useful than craft sticks, as the craft sticks are made of wood and absorb water, on the other side (HDPE) is a water-resistant material. HDPE (High Density Polyethylene) has many positive points as it is safe for drinking water, characterized by long-term reliability, resists corrosion, deposits, flexible during speed installations and is both lightweight, easy to transport and healthy, where most milk bottles are made of it.

Figure (18) illustrates HDPE.

It is recyclable, environment-friendly and suitable for a roof-top collector, due to its heat resistance. In spite of the advantages of HDPE, it is still harmful to humans. But it is the best type of plastic to use as it has the least damage among other types of plastic.

Real-life Application

In Egypt, the recommended region for the rain collector is the Northern Coast. It is the place with the largest rainwater fall rate, which is 200mm/year. It was recommended to have a rainwater collector above each roof. An individual person in the north cost uses around 47 liter per day and the average number of people per household 4.1 person. The rainwater collector should collect 192.7 liter to suffice the needs of the house. If rain will last for 5 minutes with the quantity not changing and the rain not stopping, the hexagonal pyramid frustum must collect 38.54 liter per minute. The prototype, which collects approximately 2 liters per 1 minute must get bigger to collect 38.54 liter per minute. This will happen by multiplying the prototype dimensions 19.27 times. So, the resulting dimensions are 6.07 m for the large base, 0.6937 m for the small base and around 6.56915 m height. The resulting area for the collector is around 266.59 m^2.

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