Research School of Engineering

College of Engineering and Computer Science

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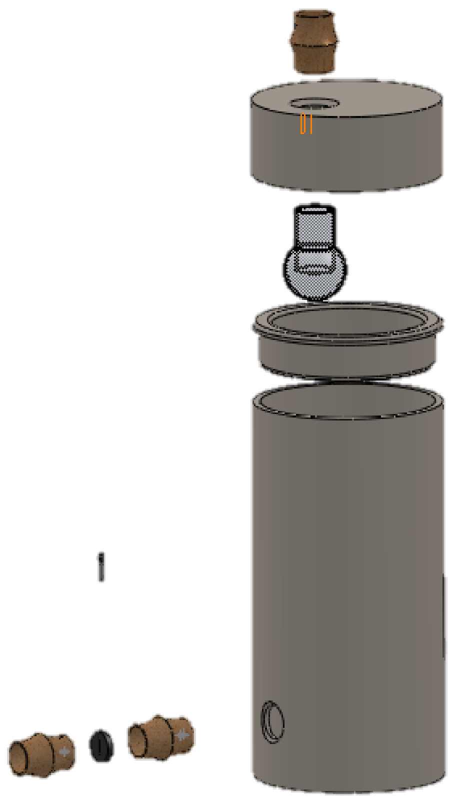
Report Title: Engineers without Borders Challenge-

Water, Sanitation and Hygiene



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Summary

The following report presents a design for a water supply and filtration system to be used in the rural village of Codo in Timor-Leste. The process used to produce this design is outlined in this report. Using research on the region and country, and the needs and requirements of the user, a set of design criteria was developed. This design criterion was used in conjunction with selection matrices and group discussion to develop two different concepts for possible development. These two designs were thoroughly evaluated to determine which design was more appropriate. The chosen concept design was then modelled, drawn, researched and refined to produce the final proposed design. Overall, a “bottom up” approach was taken to the task, by which components were chosen based upon their appropriateness to the context and these were then incorporated into a final design.

The system that resulted from this process consists of two main parts, a system of bamboo pipes, for which slaked lime treatment and silicone rubber jointing are prescribed, and a container which allows for constant filtration of incoming water. The ceramic container based on clay contains a sawdust- clay ceramic filter treated with silver nitrate which removes turbidity, suspended solids and most bacteria including faecal coliform from the water. The flow of water into the filter is constant but is moderated in flow rate by a float which blocks the inlet pipe when the system is full. At the bottom of the container there is an outlet pipe with a simple tap which can be used to obtain clean water at any time. The main outcome of this process is a design that is sustainable, consisting mostly of biodegradable materials, affordable to the members of the village, easy to maintain, and is extremely effective and practical when compared to current water distribution methods.

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1.0 Introduction

A commission has been accepted by the Engineers Without Border (EWB) and Plan to implement a water sanitation and hygiene system in the village of Codo, Timor Leste. This system is intended to take part in the Engineers without Borders Challenge (EWBC), a competition to design an appropriate technology for the village. The aim of this report is to propose a design for this application and outline the process used to generate this design. The current methods used in Codo for transporting water via containers and disinfecting water using boiling are inefficient, slow, unreliable and inconvenient to the people of the village and also have significant environmental impact. The goal of the proposed design is to increase the efficiency and convenience of attaining potable water, while also reducing the environmental impact of water purification through replacing the current piping, distribution and purification methods. The design is also proposed to be as appropriate for the context as possible.

The EWB are unfamiliar with the proposed design so dimensioned drawings, mathematical modelling, a bill of materials and a proposed method of construction and implementation are included as well as a comprehensive life cycle analysis of the system. Background information on the topic of Timor Leste and the issues faced in that context are also included. The approach taken to this design is one of a systematic engineering process and this approach is outlined within the body of the report including the concept generation and selection methods as well as design validation. It could be said that a "bottom up" process was used in the design of this device, in which components were designed and chosen before the system as a whole was designed. The structure of the report is somewhat chronological, beginning with an outline of background research, leading into the preliminary design phases, an outline of the final design and then an analysis and justification of that design.

2.0 Background

Codo is a small village in the Lautém district of Timor-Leste. The current state of the village's water system is relatively sanitary, however it is time and fuel consuming. In Codo, there currently exists infrastructure that sources the water from natural springs from up the mountain behind the village. From here the water is transported via pipes to a number of tap stands around the village. All water and sanitation projects are currently implemented and maintained by a group of volunteers from the village. (Engineers without Borders Institute, 2013)

The water is potable at the source, however it becomes contaminated through the transportation to the village from the pipes, and then more so when the water is transported using unhygienic containers. Because of this, the villagers tend to disinfect water via boiling or frequently buy bottled water, at some considerable cost and environmental impact, as boiling the water consumes plant matter as the fuel and plastic bottles are often add to litter (Engineers without Borders Institute, 2013). Additionally, the area around spring is slowly eroding, and the pipes that transport the water to the village are in high risk to landslides which could potentially destroy them.

Timor-Leste has quite a low education level, a representation of this being that only 47% of people aged 15 and older are literate (The Economist Intelligence Unit, 2010*)*. Income levels are also loe with 17% of the population having no income at all, and only 1% earning more than 989AUD monthly (De República Democrática de Timor-Leste, 2010). There are also certain cultural beliefs that must be taken into consideration, such as rain water being considered sacred, and therefore ruled out as a source of fresh water.

Timor-Leste is a hot and humid tropical country subject to dry and wet seasons, which means it will often be raining heavily for extended periods of time, and then dry and sunny for extended periods of time. The landscape of Timor-Leste is mountainous, with often unstable soil. Timor-Leste is also prone to a number of natural disasters such as floods, cyclones, earthquakes, landslides, storm winds, and droughts. Particularly in rural areas such as Codo, the accessibility to commonly used construction materials is very limited, as transportation of these materials is difficult and expensive. This means that many of the materials used in projects are often sourced on site, such as bamboo, clay for pottery and recycled parts (such as tires and bottles).

3.0 Design Criteria

3.1 Ethical considerations

There are a number of different ethical considerations and responsibilities for the project. This project involves altering and fixing an existing water supply system. This means that there is an ethical responsibility to create a water supply and disinfection system that will not bring the villagers any harm. There is also the ethical responsibility to be sensitive to cultural and religious traditions and to maintain and promote the sovereignty of the people of Codo.

3.2 Generation and Justification of Design Criteria

The topic of design criteria was initially approached though a brainstorming session where background knowledge on the state of water sanitation and hygiene in Codo was shared and this knowledge was assembled into a list of broad knowledge statements. From these, interpreted needs were established.

From this brainstorming session, the interpreted needs were placed into the table seen in ANNEX A, after this stage the interpreted needs were then refined and transferred into a list of design criteria seen in ANNEX B. These design criteria were assigned some appropriate metrics to which marginal and target values were assigned. The design criterion attempts to be both thorough and relevant, with as many quantitative metrics as possible. Suitable marginal and target values were subject to large amounts of research. These values changed as new information came to the fore. It was also decided that metrics should be based upon a percentage input or allocation for each individual such as the units of Litres of water per person per day in the water capacity metric, which was deemed more suitable and easy to conceptualise than a simple litres of water unit. Many of the metric units were decided based upon what would produce an appropriate technology.

Many metrics used such as cost of construction and maintenance, volume and water capacity were found to be standard; used in other similar projects. Some unusual metrics were devised for the context of Codo however. These include the binary of whether or not the technology is integrable with existing technologies. This is important as it is a significant factor in both reducing cost, and ensuring the adoption of the technology. The villagers are far more likely to adopt a new technology if it is similar to or integrates with the technologies they are accustomed to. Design requirements such as being covered were to prevent mosquito larvae contaminating the water, and the prevention of standing water were included to both improve hygiene by preventing algal growth, as well as to appeal to the cultural aversion to water that has been standing. The age restriction metric was included to ensure that the technology was highly accessible to the young population of Codo and to appeal to the major stakeholder Plan which has vested interest in providing child-friendly and child-empowering technologies to the developing world. Education requirements were included with the ultimate aim that the implemented technology would be completely built and maintained by the people of Codo. This is positive in that it can lead to the development of many technical skills amongst the population, can give individuals a sense of ownership and pride (thus leading to higher acceptance of the technology) and can prevent the need for intervention should the device need maintenance. Standard water quality test metrics were included as to ensure that the device is answering the design aim of providing potable water to the people within international health standards. This also relates to the ethical responsibilities outlined in section 3.1. The metric of the water source being ground or river sourced relates to another cultural bias, in that the people of Codo have an aversion to rainwater. The material source metric was included with the philosophy that if the materials are entirely local, the people can replace broken components easily and the technology will flourish. Finally the metrics of a land securing system and the positioning of the device were included to ensure the team took into account the possibility of flooding in the wet season.

4.0 Concept Generation

4.1 Concept Generation Process

The concept generation phase of the EWB project was focused mainly on the development of component concepts to be employed into a larger system. This is a “bottom up” approach. This method was used as the complex situation seemed to present many different problems, each of which needed to be addressed via different methods. There were 4 main problems which were established being: transporting water safely from the source to the village, storing the water or increasing its accessibility, treating the water and pumping the water if required.

The approach taken to generate concepts for this project was one of brainstorming along with synectics. Screenshots of the brainstorming session can be seen in Annex C. Each issue was brainstormed separately with the overall goal highlighted. Many of the concepts were developed before the brainstorming session through individual research. Other options were born out of creativity.

Many of the solutions generated are seen in the selection matricies of ANNEX D. For the issue of transporting water to the village from the source; concepts generated included aqueduct and piping systems with materials considered including Poly vinyl Chloride (PVC) and stainless steel. These materials were considered as they are currently in use in the western world. Other alternatives including treated bamboo were included, as to appeal to the abundance of that material in the region. Disinfecting or fixing the current pipes were considered as options as they would be using current infrastructure which would save on cost. Digging a new bore was proposed so as to ensure we were exploring a large scope of solutions. To address the issue of water treatment, methods included en mass boiling, UV and solar treatment methods, filtration both under pressure and gravity forced and various chemical treatment methods. En mass boiling was proposed as it may be simply a more efficient method than small scale boiling, meaning the locals would already be accustomed and trust the method. UV, solar (SODIS) and filtration were considered as they are employed in some projects in similar developing countries to various levels of success. Chemical treatment was included as to consider a range of solutions. Another idea was to treat the pipes and containers themselves to prevent any microbial growth which was an appeal to maintaining current infrastructure to reduce cost and increase the probability of adoption. To address the issue of water accessibility, having a large centralised water tower was considered as it has been used effectively in other villages of similar size. Small water tanks near homes were considered as it is common in the western world. To this it was added that water tanks should be easily replaced with short lifespans as to prevent microbial growth and the need for cleaning. Developing a hand held container that could be easily produced which resisted microbial growth and a comprehensive education system to ensure hygienic water container usage were also considered as grass roots solutions which would appeal to current methods employed by the people. Finally, in the case of water pumping systems, 6 were considered, the treadle, rope, diesel, solar and wind powered pumps were considered. All of these pumps have been employed to varying success in other developing nations and could theoretically be applied in Codo. The need for a pump was determined to be nullified by the fact that the water source for Codo is higher in altitude than the village, making a gravity-fed system a viable option.

5.0 Concept Selection

5.1 Concept Selection Process

During the concept generation process, many components were generated for use in a wider system. During selection, the components were assessed within the groups as outlined in section 4.1. Each group had its own variation on the design criteria in order to appropriately assess them.

The process began with brainstorming in which the importance weightings (seen in table 1) were determined. These importance weightings were given out of 5, 5 being the highest possible importance. The selection matrices were completed by each group member alone so as to avoid influence from other group members and hopefully gain an objective analysis of each concept. Each member was to fill them out using comparative measurements for the importance ratings; that is, giving score for one concept based on how it compares to the other concepts. These scores were then multiplied by the importance weightings, and then summed to give each concept a numerical ranking.

Table 1: An example of the selection matrix used for the concepts for the treatment of water.

Design Criteria	Importance weighting	Boiling water en mass at storage	UV treatment at storage/ in pipes	Filtration system at storage or homes- fast pressurised	Treat pipes to prevent microbe growth	Disinfect pipes	Chemical treatement at storage/ in pipes	Home chemical treatment packs
Cost of maintenance/ replaced resources	4	3	4	2	2	2	1	1
Cost of installation	5	2	1	2	4	4	3	5
Integratable with existing technologies	3	2	2	1	3	3	3	2
Lifespan	4	2	3	2	2	1	1	2
Prevents mosquitos	3	3	2	2	1	1	1	1
Age restriction	4	3	3	4	2	2	2	2
Education for Installation	3	2	2	3	1	2	2	1
Education for maintenance	4	2	2	3	2	3	2	3
Water Capacity	3	3	3	3	2	3	2	1
Water Turbidity	5	5	4	4	4	4	4	3
Microbial contamination	5	5	4	4	4	4	4	3
Fuel Consumption	4	2	3	3	2	2	2	2
Sum		138	132	133	121	127	111	110

Once each member had filled out their selection matrices, they were brought together and analysed by comparing and contrasting each concept and their numerical ranking. It was then determined which concepts were overall the highest ranking. (See Table 1)

The components selected were as follows. To address the issue of water transport, a bamboo piping system was chosen. This was chosen as it is clearly a low cost option which uses local materials. On further research into the option it was found that treated bamboo aqueduct and piping systems have been successfully installed in countries similar to that of Codo such as Indonesia (Boulton, 2008). To address the issue increasing water accessibility, it was decided that water tanks which were easily replaced and close to homes were superior to a centralised water tank. On research into the geography of the village itself, the team came to the conclusion that easily replaced water tanks which were central for 3-5 houses would be ideal in order to prevent locals from transporting water from the tank in contaminated containers. The use of short lifespan tanks was thought to be best as the maintenance of high quality expensive tanks over long periods in which algal contamination could occur, was seen to be impractical with the education standards of the village and also costly. Although water pumping methods were not employed in the final system, various pumps were compared. The treadle pump was chosen due to its low cost, low maintenance and relatively high water pressure and pumping capacity in comparison to similarly priced pumps. Finally of the water treatment methods, the solar/ UV and filtration methods were initially considered to be most appropriate. This is because they are low cost, require little education, are relatively effective and have no fuel use or age restrictions. Filtration was finally decided upon due to its reliability and the abundance of established technologies available.

The process used can be justified only in that it closely mirrors the design criteria. If we consider the design criteria to be accurate and to embody an appropriate technology, then the concept selection process used should too produce an appropriate technology. Constant redefining of the design criteria and research done throughout the selection process allowed for the concepts chosen to be refined.

6.0 Design

6.1 Notes on Drawings

Drawings are included in Annex E and include the following: A detailed drawing of the system as a whole, an exploded drawing of system to envision the bringing together of the components and finally a detailed view of the tap to cover ambiguity in its construction. Note that the dimensions given on the drawings are only indicative, not real. They are an indication of possible dimensions and scale such that an assembly was possible. The appropriate dimensions depend upon the possible usage of the unit and how many people will be using each unit. Details of this are included in section 6.3 in mathematical modelling. Bamboo sections are included as indicative or joining locations. The unit would also be on a stand of some sort as to be off the ground but this is not included in the drawings. Sketches of preliminary concept designs are seen in ANNEX C as figures 4 and 5.

6.2 The Networked System

Note also that each unit should be joined in a type or array such that when one system is filled, excess water travels to other systems to supplement their water supply. The systems are therefore networked so that water is distributed evenly between them and so that excess water is captured. In the event that too much water is flowing into the system, it expected that the pipes will be able to withstand the backpressure, although some leaking may occur. An emergency outflow pipe is suggested for this purpose to prevent breakage. One system should cater for the houses around it. The number of systems depends upon the size of the system and the population using each system. A concept sketch of this idea is included in ANNEX C as figure 6.

6.3 Outline of Mathematical Modelling

The possible range of dimensions in which the cylindrical water container and filter is explored in the below. The design criteria states that the cylinder must contain enough water to provide between 15 and 75L per person per day. Assuming the cylinder will service a group of 5 to 15, this gives a range of 75 and 1125 litres of water. Furthermore, the limits of x and y are given as 10 and 4m for reference. The range is represented by figure 3 which indicates the range of values which satisfy these criteria depending upon the number of people the system is catering for.

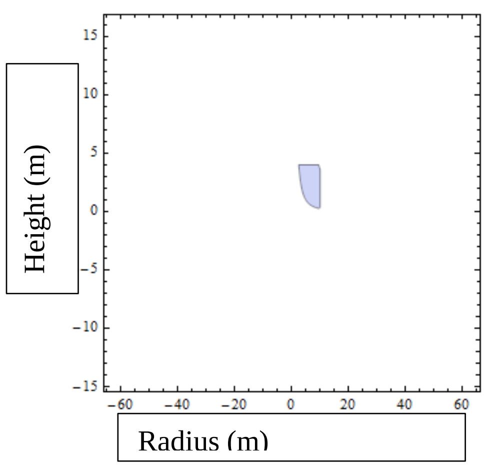

Figure 1. Plot indicating the range of values for the container's dimensions

To determine the flow rate of the pipes the following were taken into account. Pipe Diameter minimum=2.5cm, pipe diameter maximum= 25cm. The standard for most plumbing pipes is a flow velocity of 1.5m/s, we will assume a lower velocity of 1m/s. (Waterfacts, 2013). 1728 Software Systems (2013) gives equation 1.

$$\frac{1}{4}\pi D^2 V = FR$$

Equation 1. Flow rate. (FR) in relation to pipe diameter (D) and flow velocity (V)

Minimum pipe diameter gives a flow rate of 4.9e-4L/s = 1.7L/hr. Maximum pipe diameter gives a flow rate of 0.049L/s =176L.71/hr. Using the above estimates, the flow rate should be between 7.5L/hour and 112.5L/hr. A pipe diameter of 5.2cm will suffice which is within expectation.

The limiting factor is likely to be the filter rate which will be significantly smaller than that of the pipe flow rate. Filter rate is given by equation 2:

$$Q = -KA\left(\frac{\Delta h}{L}\right)$$

Equation 2. Filtration rate (Q) in relation to head (h), hydraulic conductivity (K), thickness of the filter (L) and surface area of the filter (A)

Ideally the filter will be able to supply a household's water supply within one night. It is assumed that accounts for 10 hours of constant filtering; that is the required filtration rate is at least 15L/person in 10 hours. The hydraulic conductivity (K) of a ceramic filter is approximately 0.0617 cm/s. (Miller, T.R, 2010). The head (h) is assumed to be approximately 20cm. The thickness of the filter (L) will depend entirely on the amount of water above the filter. For now it is assumed to be 5cm. Figure 4 indicates a minimum filter radius of approximately 70cm and maximum of approximately 2m to service all the daily water needs during the night. If filtering over the course of an entire day is taken into account, the radius minimum reduces to a more reasonable 30cm.

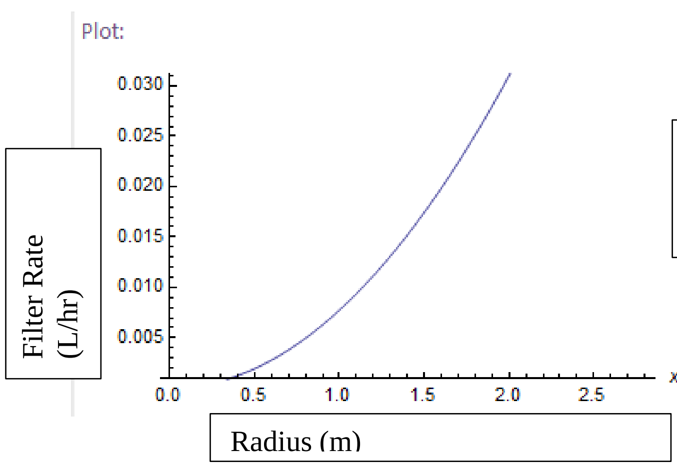

Figure 2: Plot indicating the filter rates for various filter radii.

6.4 Bill of materials including cost and source

A bill of materials is included in Annex F. This bill of materials simply prescribes the ideal or suggested materials for construction. It is likely that other methods and materials will be used given the context of the design.

6.5 Possible construction techniques

Bamboo pipes should be felled and collected approximately 3-5 years into growth so as to be in a hardened state with appropriate mechanical properties. Quickly following felling, the pipes should have the membranes broken by the use of a long pole. Following this, the culms should be submerged in a solution of slaked lime and water for several days and up to 2 weeks. Following this, the bamboo culms exterior should be painted with a very thick coating of slaked lime and water. (Chalet & Bamboo, 2011). Other bamboo culms used to support the above ground bamboo pipes should undergo the same treatment and be connected to the pipes using twine or wines. It is also suggested that local trees be incorporated into the support system for the bamboo so as to reduce the spatial and environmental impact of the piping. (Appropedia, 2013). At the inlet pipe, the entrance to the pipe should be covered by the use of a metal mesh in a cube of approximately 0.5x0.5x0.5metres size around the inlet. This is to both protect the inlet from animals and humans and to prevent leaves or debris clogging pipes.

To join bamboo pipes, cut the bamboo culm with the largest diameter into several parts. This can be used as a sleeve into which smaller diameter culms can slip. Seal the join using silicone. The pipes are suspended by two bamboo lengths which are staked into the ground such that they cross over beneath the pipe. The pipe and supports can be lashed together using vine or twine. To make corners in the piping system, take a section of bamboo and leave the membranes intact before treatment. Attach this to the end of the up steam pipe below the future join. Cut into the upstream culm using a machete to make a hole for the downstream pipe and join the downstream pipe into this pipe by force. Seal using silicone. The membranes will force water back up the up steam pipe and into the downstream pipe. To better preserve the join, seal a piece of rubber of diameter equal to that of the pipe over the membrane using silicone.

To produce the container, firing of clay can be done by local artisans or in dung fires; similarly for the clay lid. However, before firing, the entire container must be coated in a silicon dioxide paint to produce a glaze to ensure that once it is fired the container will be waterproof. These should be formed in order to facilitate the float and filter as well as bamboo pipe connections as seen in the drawings in Annex E. To preserve the strength of the membrane, a rubber seal made using old tire rubber can be constructed and placed into the bamboo below the membrane, then sealed into the bamboo using silicone. The filter itself can be produced using methods which are established in many developing countries. The most common method is the use of sawdust and clay. Firing an approximately 50:50 mixture of sawdust and clay. Silver nitrate can also be painted onto the filter surface as it will improve bacterial removal.(Brown, J., & Sobsey, M., 2007)

The float is simply produced by the use of an old thermoplastic polymer bottle. First, wash the bottle carefully and remove any exterior labelling. A lighter or small flame can be used to soften the plastic at the top of the bottle to shape the bottle without puncturing it so as to plug the inlet pipe. Once the bottle has been formed, the bottle is placed in the guides in the ceramic lid such that when the filter is full, it floats and plugs or slows water flow from the inlet.

The inlet and outlet pipes can then be connected and sealed using silicone rubber. To construct the tap and valve system, firstly the outlet bamboo pipe needs to be cut relatively close to the connection to the container. A hole should be drilled into the top or side of the bamboo close to the outlet end of the outlet pipe. Once this is done, the valve can be inserted. The valve itself should be constructed using 2 thick sheets of stiff rubber such as that from a car tire as seen in the drawing in ANNEX E “Assembly of Tap”. The rubber should be cut into the same dimension as the outlet pipe. The rubber should then be washed thoroughly and heated to above 60°C in order to disinfect the rubber. The tap handle itself can be constructed using stainless steel which should be formed into the required shape as seen in ANNEX E by local blacksmiths, or imported. The first piece of rubber should have adhesive sprayed onto its surface and should be inserted such that it sits tightly in the pipe. The tap handle should then be inserted, and the pin inserted into its hole. The second piece of rubber with adhesive on its surface should then be attached to the surface of the first piece such that it envelops the tap handle and its pin. Adhesive instructions of use should be tightly followed.

Before assembly, the piping system should be washed through with water several times. This is to remove any debris that could clog the filter or pipes. Once everything is assembled and the joins are sealed using silicone, the system should be “flushed” for a day, allowing water to flow through the system to wash any unwanted debris through the system before use. The system may require an additional supporting structure. Such a supporting structure can be easily crafted on location by simply surrounding and stabilising the base with rocks and/or bamboo. (Bambooroo, 2013).

6.6 Running and maintenance costs

Choice of local materials means that the running and maintenance costs of the system are limited. Parts can be reproduced using local materials in the most part. Through the system’s life span certain parts may need to be serviced or replaced, and to do this the sealant must be removed, this can be done easily just by cutting the silicon with a sharp tool such as a machete. Slaked lime may need to be imported at some cost to the members of the village, but considering the pipes should last for roughly 4-5 years, this reduces cost by year significantly. Furthermore, the compound is stable and therefore can be stored for many years without issue, reducing both cost and time. Repair materials such as adhesive and silicone are of small cost. The tap and valve system may undergo some crevice corrosion but it is hoped that the choice of a stainless steel alloy will prevent this issue, thus reducing maintenance costs. Running costs of the device are minimal. There is no need for fuel or any other input that could cost the locals money following the completion of construction. The filter needs to be cleaned regularly using a clean cloth or replaced. This only needs to occur once every 6 months and the filter replaced every 2 years. The container itself should be cleaned hygienically every 3 years or replaced entirely. Overall maintenance cost should be approximately 1% of the village income per year.

6.7 Potential revenue and income streams

Members of the community may be able to produce income by the construction and maintenance of a number of these systems. Whilst aspects of the construction and maintenance would require varying levels of education for the community (which in itself is another potential aspect of employment) in the long term it would provide a greater mean income for the community. The increase in time and cost efficiencies as a result of the system is also an indirect means for greater revenue for the community. An increase in health from cleaner drinking water will boost economic output due to greater efficiency and availability of labour. Furthermore, time will not be taken in the collection of firewood and boiling of water, allowing income generating activities.

7.0 Life-cycle Analysis

Throughout the construction, life span and retirement of the system, it will have environmental impacts. In order to correctly assess the system we must consider the initial resources, manufacturing processes, operation and final retirement of the system separately as well as together. Many factors need to be considered in this type of assessment such as resource depletion, energy, water consumption, greenhouse gas emissions, and waste generation/ disposal. It can be seen in figure 5 that the system has a high resource input in the initial stages, but low in the latter stages and that waste produced is minimal.

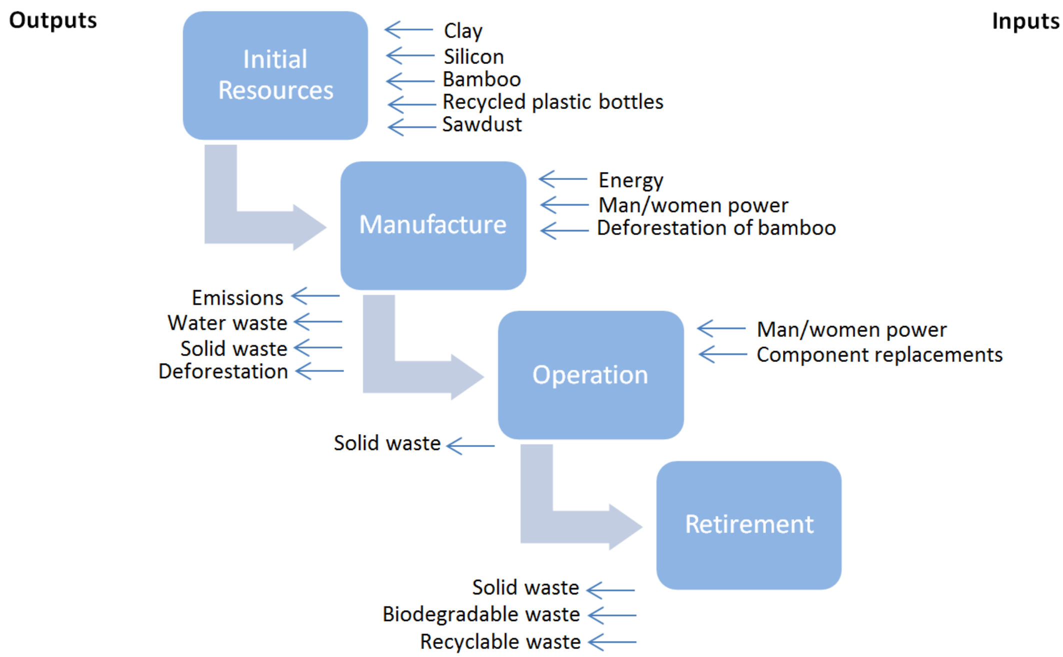

Figure 3. A flowchart of the outputs and inputs of the device over it life cycle

7.1 Initial Resources

The resources of the device were devised to have minimal environmental impact. These are seen in figure 5 of section 7.0 and in the bill of materials in ANNEX F. Clay and bamboo are the highest volume contributing materials. Both of these materials are locally sourced meaning there is a reduced environmental impact which would come from the transport of these materials. Some carbon emissions will occur in the firing of the clay and transport locally; however, this process has far less impact than large scale shipping. As for bamboo, the specific material used is local black bamboo called bambusa Iako (Moffat). The logging of the bamboo culms will require a small amount of deforestation, possibly destroying the habitat of local fauna. This is minimal however as only a small amount of bamboo is required. Furthermore, with the lifespan on the piping being 4-5 years, and bamboo being a fast growing plant, the process is renewable. Furthermore, bamboo can regrow quite easily, and logging the culms rather than removing the plant from the ground will not kill the plant itself. The logging process will require tooling such as machete which can be locally sourced, which will require energy input from locals. Being locally sourced, transportation is negated and as such so are the potential greenhouse gas emissions. The bamboo will need to be treated using slaked lime (Calcium Hydroxide), which is a compound that is can be acquired easily, though may need to be shipped in, which can lead to a high amount of emissions. Slaked lime itself has very low impact on the environment if properly used. The compound naturally forms calcium carbonate which is water soluble and other harmless compounds. Exposure to air means that over several days the alkaline solution drops in PH to neutralise by a process known as recarbonation. There are some issues with the calcium ion increasing the hardness of water, however this will not be an issue in Codo as the effects of hard water will not be noticeable and the concentrations which will leech from the bamboo pipes will be very low.

The system requires silicone caulk and AP 1 Industrial adhesive sealant to be used. These are commonly used in plumbing applications across the developed and developing world. These will have to be transported to Codo and the greenhouse gas emissions as a result of this transport depend entirely on the distance travelled. These are minimal in use however.

Water bottles and rubber valves are both sourced through recycling the material from other uses. This is a sustainable process.

The use of wire mesh and the metal tap will have a minor environmental impact. The steel can be sourced locally and therefore there are few transport impacts. The steel itself used produces greenhouse and other harmful gases such as sulphur dioxide in its production as well as the effects of iron ore mining. Again, the volume used is quite small, reducing the overall environmental impact.

7.2 Manufacture

The manufacturing process for the system is designed to be relatively environmentally friendly however there are still some unavoidable impacts. The clay that is required for the container, lid and filter will need to be fired. This process of firing will require significantly high temperatures to achieve (around 900°C to 1400°C), however, through the use of dry dung fires, these temperatures can be achieved with minimal smoke and emissions and the fuel source is sustainable. The logging and treatment process of bamboo has minimal impact. The sawing and manipulating of the bamboo also has very little environmental impact as it can be done entirely by hand using unpowered tools. Any solid wastes from the bamboo will quickly biodegrade. Slaked lime is used in the treatment of the pipes and as noted in section 7.1 it is almost harmless in the environment. The bamboo piping is above ground and will therefore have little or no impact on the local environment as no digging is required. The joining of materials produces no waste or emissions as left over joining materials should be kept for repair purposes.

7.3 Operation

One of the key benefits of the device is that it reduces overall carbon dioxide emissions. This is because the device is designed to replace the need for everyday boiling of water, which is a source of much carbon emissions. Furthermore, the use of local forest for fuelling fires for this purpose will be reduced, thus reducing deforestation. The replacement of the current piping system with a bamboo piping system will mean potentially environmentally damaging replacements such as PVC piping are avoided in the future. Furthermore, the bamboo system can be more easily replaced without any digging required; meaning that the environmental destruction from digging another replacement piping system in the future can be avoided.

The system itself has no emissions during its operation. Ideally the system is entirely gravity fed, meaning that there is no need for energy input in the form of pumping. Filtration is gravity powered, thus causing zero emissions until the filter needs to be replaced. (Griffin Soil, 2013). The impact of the system upon retirement is covered in section 9.4.

8.0 Design Validation

The device designed for the EWBC has clear benefits to the village of Codo East Timor. Direct comparison to the design criteria is found in ANNEX F which demonstrates that the device clearly meets many of the needs of the community. If the design criterion is sufficiently detailed then the device should be appropriate. The device will be able to be produced with minimal cost and labour by the individuals in the village of Codo if we consider average education. The device will be able to be used by all members of the community equally. The device will produce safe and potable water through a common and tested method. Furthermore, should the decision be made that hygienic cleaning isn't possible, the filter and container can be easily replaced, requiring only local materials and local manufacturing processes. The device is designed to survive the climatic conditions of Codo, having been designed to be hardy and for broken components to be easily replaced. The device is also culturally sensitive, taking into account cultural aversions, traditions and religious practices. The device also promotes local traditions and a sense of sovereignty in the village. This is because it can be fabricated almost entirely on site by the individuals of the village, meaning that the village members will have a sense of pride and responsibility in using the system.

Ultimately it is incredibly difficult to determine whether or not the device will be effective and if use of it will continue into the future. Prototyping and implementation will only provide such insights. Issues such as meeting demand have been modelled, but the modelling could be inaccurate to reality. Supplementing water supply via boiling may therefore be required. Furthermore there may be omissions or failings in the design criteria, potentially sinking the project.

Overall the device clearly reaches the design aim. The system makes clean water more available to the people, removes the need to use the decaying piping system, reduces the time taken to attain clean water and removes the deforestation and greenhouse emissions that occur due to the boiling of water. If the design criteria are correct, the design is valid and appropriate.

9.0 Proposed implementation and next steps:

9.1 Immediate Next Steps

An immediate next steps, is to build and test a prototype of the proposed system using the proposed materials. This would be helpful to demonstrate and visualise an actual physical model and find any design errors. A prototype will identify design flaws and issues which need to be addressed. Use of the actual materials is required to determine their practicability, changes in construction techniques and to attain useful data.

9.2 Recommendations for possible development and use

Following prototyping, the device should be implemented in Codo. The first stage of implementation into Codo is education. Firstly it would be required to teach them how to use the system properly and hygienically. Secondly teaching them how to maintain the system would be required so that it can last for a significantly long amount of time to be economically viable. This would include teaching them how to treat bamboo, how to maintain the pipes in good condition and also how to manufacture and recycle the filters as well as dispose of the system conscientiously on its retirement. The population must be educated on hygienic container use when getting water from the system, hygienic practices with the water containers as well as cleaning techniques should be taught.

The physical construction of the system would require team members to be present so everything can be supervised and to ensure that the system is built under the necessary parameters. This should however be completed by the village members to ensure a sense of sovereignty, trust and pride in the device. Furthermore, it is important that following construction, it is verified that the system is producing potable water. Broad spectrum water testing including PH, microbe, turbidity and total solids tests will have to be implemented. The joins and construction quality of the unit should be critiqued and following this, the system should be self-sustaining for future use.

Following implementation, usage and attitudes toward the technology should be monitored over the course of several months or years. Furthermore, rates of dihedral and other water borne diseases should be monitored. Design development will arise from the results.

9.3 Broader Benefits from Use

The broader benefits of this proposed innovation are numerous. Firstly there will be significant health benefits. Brown et al (2007) report a similar system being applied in Cambodia causing an overall mean reduction of diarrheal disease by 39-44% in users of the system against non users who boil water.

Further health benefits include a reduction of smoke inhalation from constant boiling of water; and as a direct result of this a more child-safe environment. In respect to time, our water system would completely free what time was usually spent in boiling the water leaving greater room for doing other more important things such as cooking, cleaning, time spent with the family, and social life. Further benefits could include that it requires almost no management on a day-to-day basis where filtering is concerned, the water supply is conveniently close to each home. Time need not be taken to fetch wood and boil water allowing for time for other pursuits as seen in section 6.8. There will also be significant environmental benefits. The unit will reduce greenhouse gas emissions and deforestation as the demand on burning wood will greatly reduce. There will also be a reduction of the use of plastic water bottles, as the time constraints of boiling water will be reduced and as will the desire to buy bottled water. This will reduce landfill and littering in the area.

9.4 Retirement, End of life, Recycling and Reuse Considerations

The Retirement Stage of the system's life cycle has a limited environmental impact. Solid waste will be produced in the form of ceramic. This ceramic may be broken down and possibly used as aggregate in other building materials or even the construction of a replacement container. Biodegradable waste will be produced from the bamboo pipes. The slaked lime treatment at this stage in the life cycle will have been neutralised by exposure to air, resulting in the material being harmless to the environment in which the bamboo degrades. The bamboo will easily reincorporate into the environment as mulch. The float polymer will not biodegrade and will form part of landfill, or could simply be reused following cleaning. In fact, there is reason to say that within a reasonable time frame, the system will not need to be retired, so long as components are replaced regularly. Silicone and rubber valve components will need to be removed and will produce landfill. Theoretically these materials can be recycled but it is unlikely in the context. Fortunately, only small amounts of these materials will be required. Metal and rubber components used in the tap may be salvaged and reused if in a suitable condition.

Conclusions

The aim of this report was to propose a design to be implemented in Codo, Timor Leste as part of the EWBC. The aims of the project were to increase the efficiency and convenience of providing potable drinking water to the people and to reduce the environmental impact of this process. In this report the design for a continuous filtration system and water distribution system were presented. The main features of this design are a treated bamboo piping network, which feeds directly in a ceramic container. This container houses a typical sawdust- clay ceramic filter and a float which allow for the constant and moderated filtration of water into a holding container which has an outlet pipe with a tap. The design allows for instant access to drinking water that is purified and safe. The outcome is an easy to construct and maintain system that is cheap and effective in performing its role.

It is felt that this design does fulfil the goals of the project. The design provides a mechanism by which water can constantly be filtered and mathematical modelling shows that within certain bounds, the supply can reach demands. This provides disinfected water to the people, at a location within only several metres of homes without the need for boiling and the wasted time, deforestation, smoke and greenhouse gas emissions that are associated with that process. Furthermore, the device can be deemed appropriate as it is very low cost, uses almost entirely locally sourced materials, is suitable to the climate of the region and is sensitive to cultural, educational and environmental concerns.

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Appendices

Annex A – Interpreted Needs

Background Knowledge	Interpreted Needs
Water Source is reliable, buckets contaminate water	Better water transportation
Community is poor	Cheap to construct
	Cheap to maintain
	Cheap to fuel
Existing tap stand	Improve upon or integrate with current technology
Long distance between tap stand and village	Transportation system must work over long distances
Steep terrain, mountainous landscape- water source up hill	Transport system must be able to transport water from higher altitudes
Frequent sun and rain	Must be durable/ waterproof/ weatherproof
Mosquitoes are a problem	Must avoid stagnant or still water. Sealed container.
Unreliable or non-existent grid electricity	Must be self-contained if electrically powered
Young Population	Can be used by women and children.
Low education standards	Easily constructed
	Easily used by the uneducated- simple education system for use
	Easily maintained

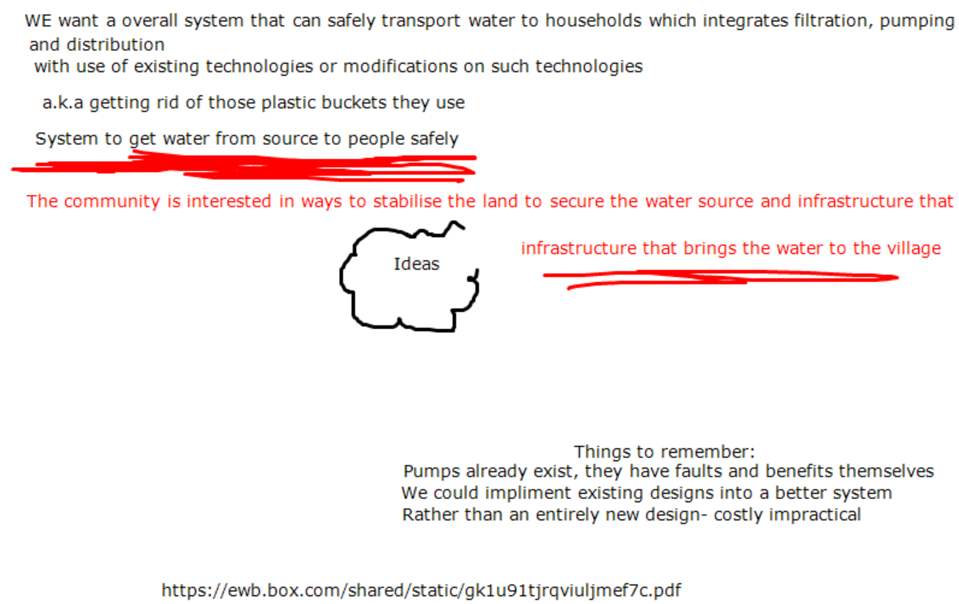
Increasing population size	Accommodate an increase in population
	Can be used by children
Water must be potable when it reaches the village	May require purification system
	Does not make water turbid or disturb sediments during pumping
Current issues with transportation methods contaminating the water supply	Transport method must remain sanitary after many years use
	Education on cleaning practice of components for maintenance
Cultural aversion to rainwater	Must source water from surface or underground
Limited transportation/ poor road quality	Use of local materials during construction
	Independent of fuel, or low fuel consumption
	Must not require heavy machinery or specialised tools in construction
	Can be constructed on site or easily transported to site
Land prone to flooding	Must be firmly secured in ground or able to withstand flood waters/ submersion

Annex B – Design Criteria

Metric	Units	Marginal	Target Value
Cost of maintenance + fuel	%village income/year	< 8	< 5
Cost of installation	%income/pp	< 10	< 7
Integratable with existing technologies	Binary	N	Y
Water supplied directly to houses	Binary	Y	Y
Lifespan	Years	10	15
Covered	Binary	Y	Y
Prevents standing water	Binary	N	Y
Energy source	Subjective	High efficiency combustible	No combustibles required
Age restriction	Years	18+	8+
Education for installation	Subjective	University	High school
Education for maintenance	Subjective	High school	Primary school/redementary
Water capacity	L/person/day	15	50
Water turbidity	NTU	< 3	< 1
Filter system	Binary	N	Y
Microbial contamination	CFU/ml	500	5
Source from groundwater or river	Binary	Y	Y
Materials	Subjective	Cheap importable and local	Local materials
Volume	m^3	8	1
Fuel consumption (if applicable)	L/hr	1	0
Land securing system	Binary	Y	Y
Positioning	Subjective	Sturdy ground	Flat, sturdy ground
Efficiency	%	70	99

Annex C - Brainstorming session

Below are a series of images taken from a brainstorming session completed online using a collaborative white board. These are included to demonstrate the problem definition, communication and concept generation processes that occurred.



System to get water from source to people safely

The community is interested in ways to stabilise the land to secure the water source and infrastructure that t

Getting water from the source to the village- 1
Getting water into households- 2

Ideas

Boling system at the tap stand
solar

New alternatives to pipes

UV treatment at the tap stand/ in pipes

Filtration/ disinfecting system at tapstand

Replace current pipes with new ones pvc

Treat pipes to prevent microbes

Bamboo piping/ aqueduct system

Change location of the spring- dig new bore or rain water

Possible pipe materials?????
PVC
Copper
Bamboo
Stainless steel

Disinfect/ treat pipes

Relocate pipes

duct tape/ fix pipes

From tap stand to the houses

Pump water up to water tower- water tower feeds down to homes

Filter/ disinfectant in water tower
Covered/ agitated to prevent mosquitos

Pumps for that:
Solar
Modified treadle pump
Disel

Automatic boiling machine

Pipes with valves in homes

En mass boiling

Each home has a water tank

Household level filter

EAsily replaced water tanks- replaced when contaminated
Or couldn't be used long enough to become contaminated

Distribute hygenic water containers to people

Who needs water anyway?

en mass UV treatment

Powered water- just add water

Education on correct cleaning and water treatment practices

Chemical treatment- en mass or home packs

Better education on use of current water bottles

Water containers that resist contamination

quick, pressureised water filters

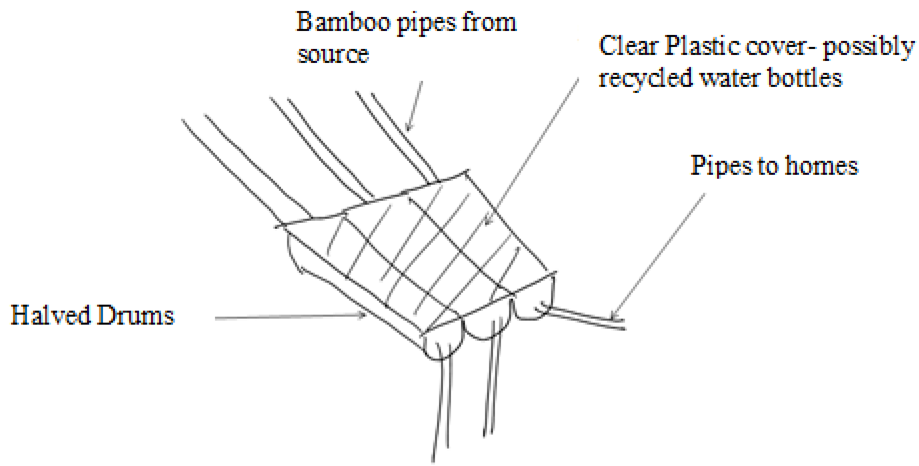


Figure 4: A concept sketch of a possible solar disinfection process.

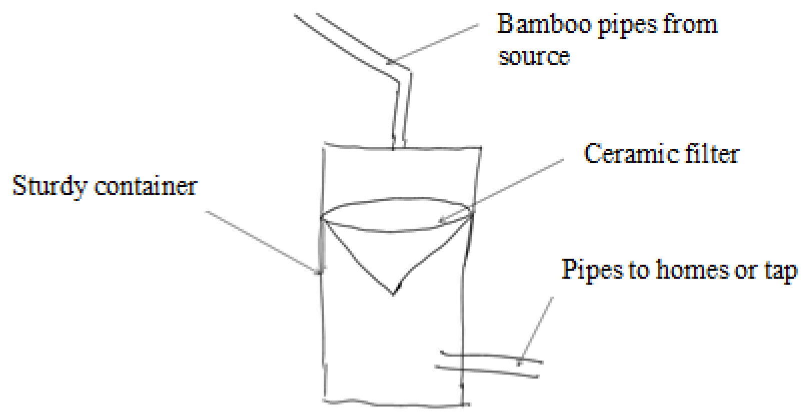


Figure 5: Concept sketch for a continuous filtration system

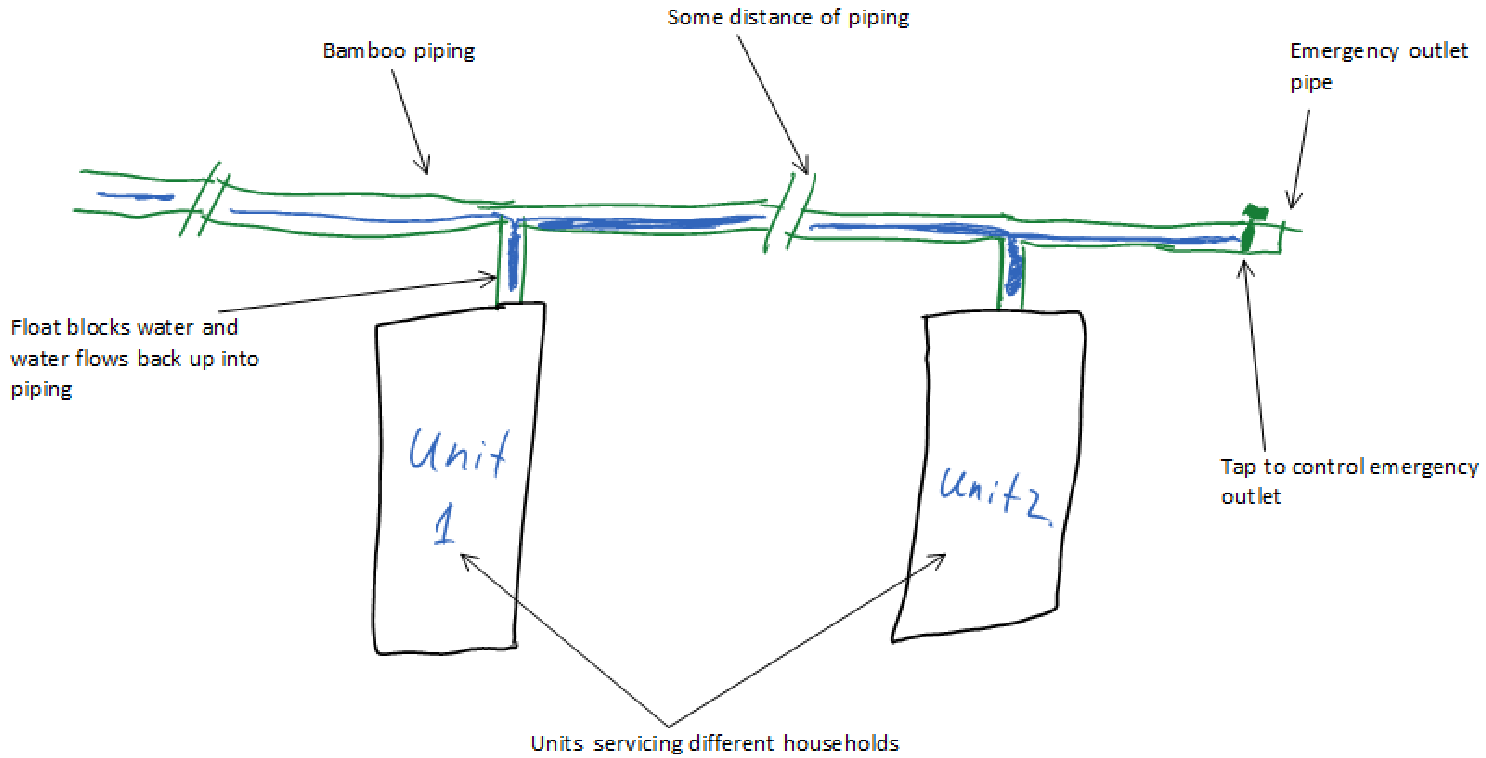


Figure 6: Concept sketch of the networked system.

Annex D – Selection Matrices

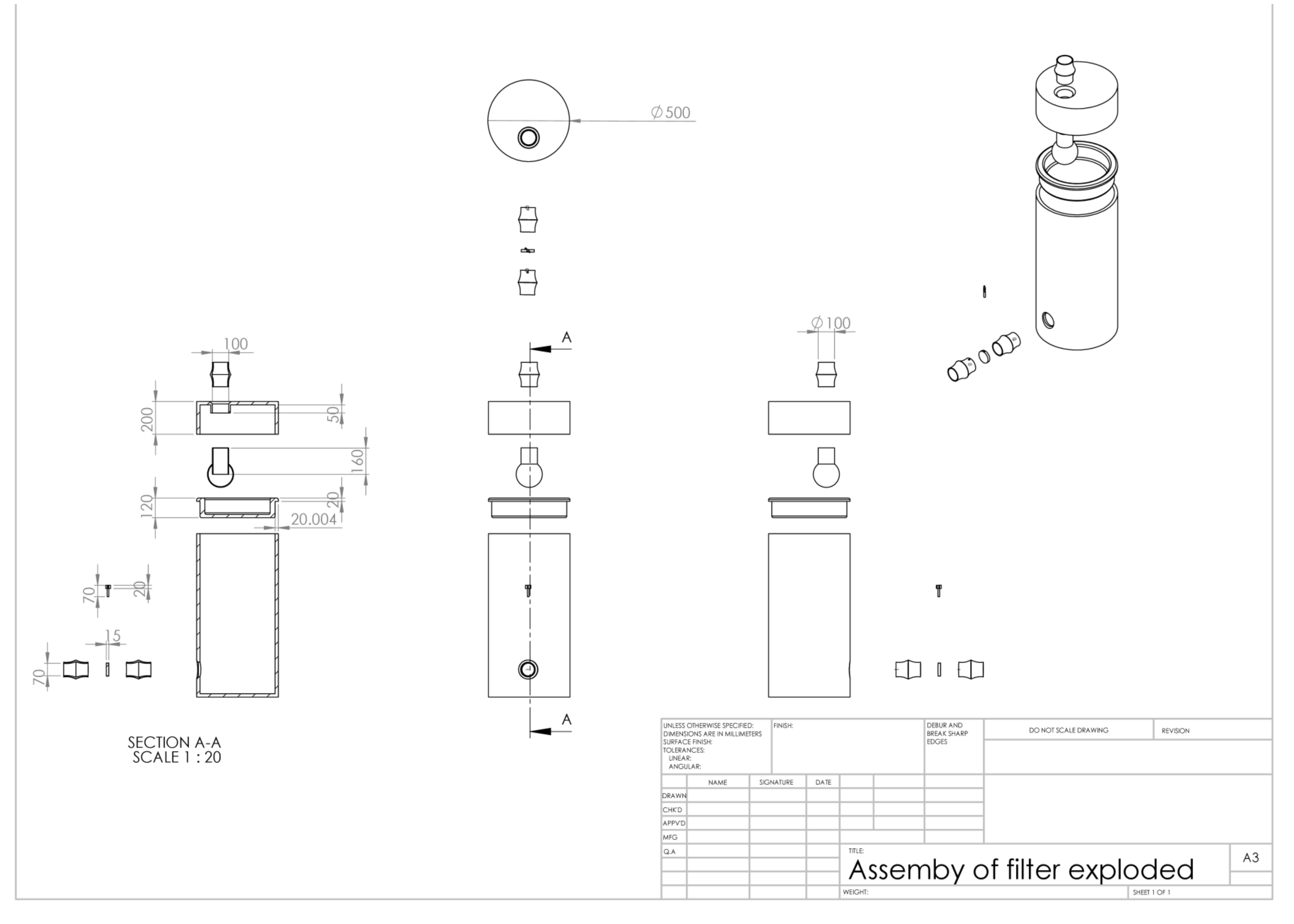
Design Criteria	Importance weighting	Boiling water en mass at storage	UV treatment at storage/ in pipes	Filtration system at storage or homes- fast pressurised	Treat pipes to prevent microbe growth	Chemical treatement at storage/ in pipes	Home chemical treatment packs
Cost of maintenance/ replaced resources	4	4	4	4	3	2	2
Cost of installation	5	1	4	5	4	5	5
Integratable with existing technologies	3	1	2	4	5	5	5
Lifespan	4	3	4	2	1	2	2
Prevents mosquitos	3	4	4	2	1	1	1
Age restriction	4	1	5	5	5	1	1
Education for Installation	3	5	4	4	1	2	1
Education for maintenance	4	4	2	3	1	2	1
Water Capacity	3	3	3	2	5	5	5
Water Turbidity	5	1	5	5	3	1	1
Microbial contamination	5	4	5	4	4	5	5
Fuel Consumption	4	1	4	5	5	5	5
Sum		121	185	182	151	142	135

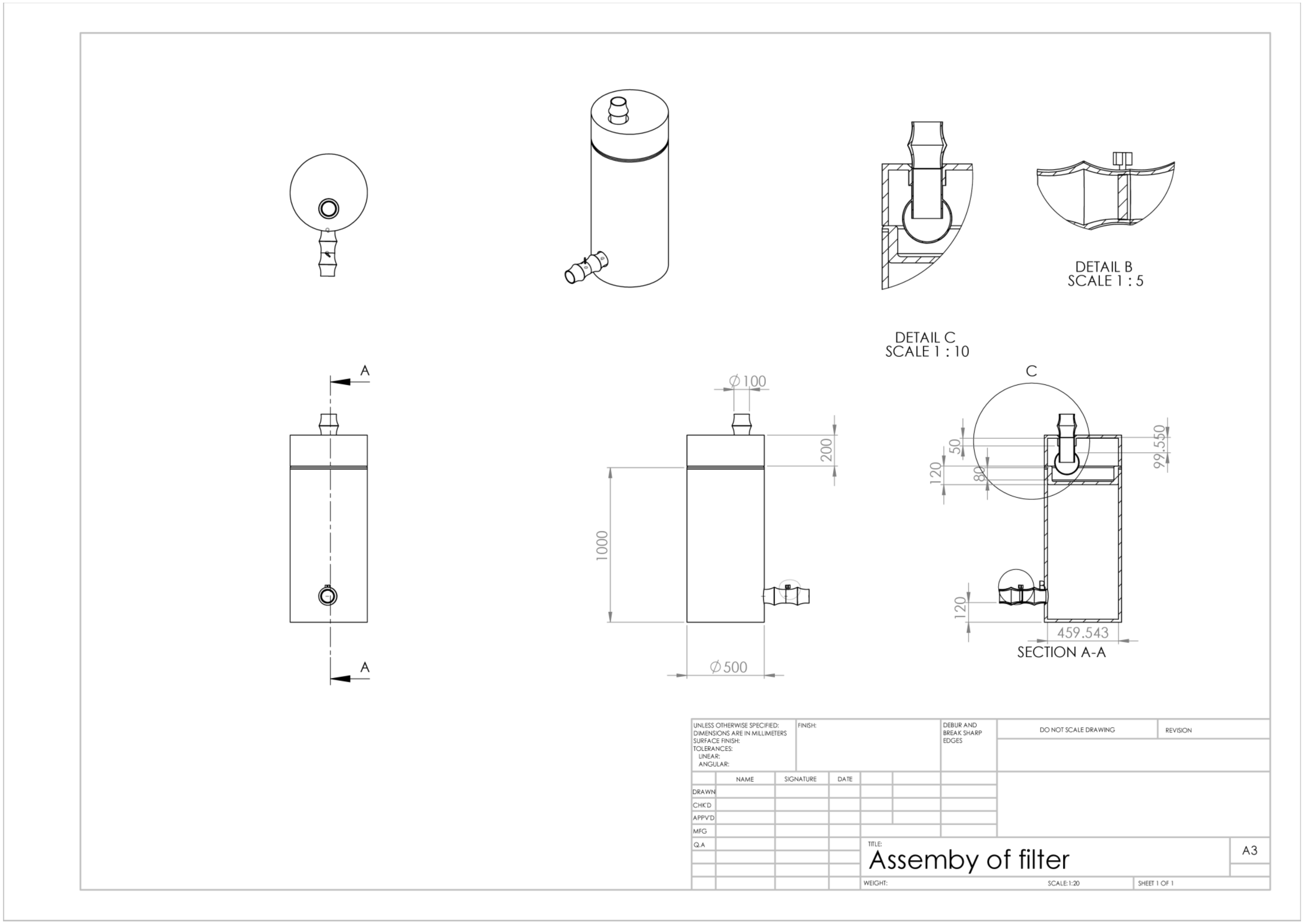
Design Criteria	Importance weighting	Aqueduct system- bamboo	Aqueduct system- PVC	Dig new bore	Piping- PVC	Piping- stainless Steel	Piping- treated bamboo	Fix existing pipes/ treat pipes
cost of maintainence	4	4	4	4	4	3	4	5
Cost of installation	5	4	2	1	1	1	5	5
Integratable with existing technologies	3	3	2	4	1	1	4	5
Lifespan	4	1	4	5	4	4	3	3
Prevents Standing water	3	4	4	3	4	4	4	4
Education for Installation	3	4	2	4	4	4	3	2
Education for maintenance	4	4	3	4	4	4	3	2
Water Capacity	3	2	4	3	5	5	2	3
Water Turbidity	5	3	5	2	5	5	5	3
Microbial contamination	5	2	4	3	5	5	5	4
Local Materials	4	5	1	4	1	1	5	4
Land securing system	4	3	3	1	5	5	5	5
Sum		152	151	144	169	165	194	178

Design Criteria	Importance weighting	Treadle pump	Rope pump	Disel pump	Solar pump	Wind powered pump
Cost of maintenance + fuel	4	5	4	1	4	4
Cost of installation	5	5	4	3	3	4
Integratable with existing technologies	3	4	4	2	2	2
Effective pumping distance	4	3	1	5	4	4
Pumping pressure	4	3	2	5	4	4
Lifespan	4	5	4	4	5	5
Age restriction	4	4	4	3	5	5
Education for Installation	3	4	4	1	1	1
Education for maintenance	4	4	4	3	4	3
Pumping capacity	3	3	2	5	4	4
Water Turbidity	5	4	2	4	4	4
Microbial contamination	5	4	3	4	4	4
Materials	4	3	3	1	1	1
Fuel Consumption	4	5	5	1	5	5
Land securing system	4	4	4	4	4	4
Efficiency	3	2	1	2		
Sum		248	202	193	220	221

Design Criteria	Importance weighting	Large water tower- pipes to homes	Smaller water tanks at homes	Water tanks that are easily replaced- do not foul	Educate people on hygenic container use	Containers that resist microbes
Cost of maintenance	4	3	2	1	5	3
Cost of installation	5	2	1	3	5	1
Integratable with existing technologies	3	2	2	1	5	2
Lifespan	4	5	5	1	1	2
Prevents Standing water/ mosquitos	3	2	1	1	4	5
Age restriction	4	5	5	5	1	5
Education for Installation	3	3	2	2	1	5
Education for maintenance	4	4	2	1	1	5
Water Capacity	3	5	3	3	3	3
Water Turbidity	5	4	3	3	2	2
Microbial contamination	5	5	3	5	3	4
Use of local Materials	4	4	4	2	5	1
Efficiency	3	3	3	3	5	5
Sum		184	140	125	156	159

Annex E – Drawings




DETAIL B
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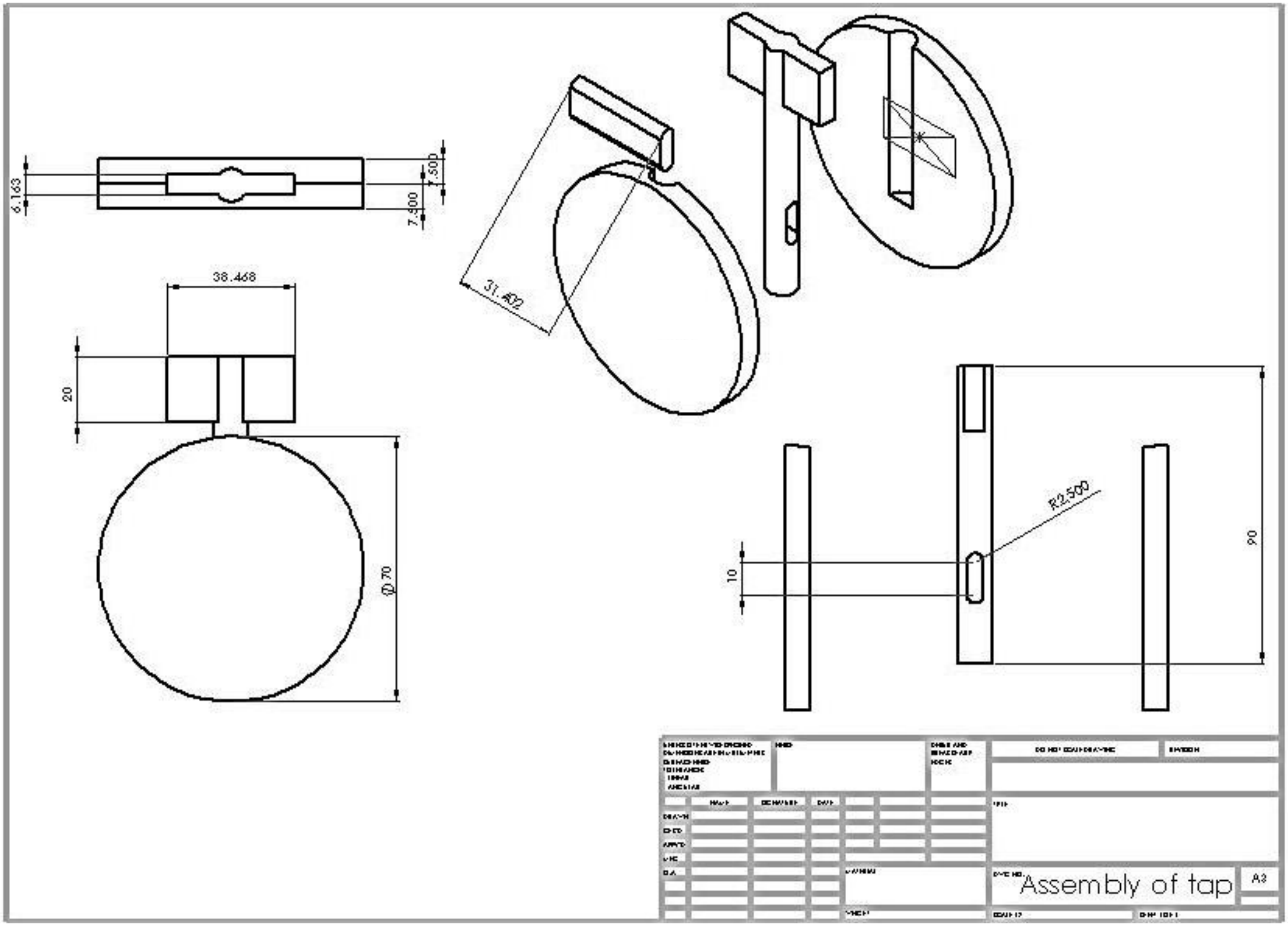
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90
Assembly of tap
A3

ANNEX F- Bill of Materials

Component	Material	Source	Cost (% of village annual income)	Mass for the purposes of transport (kg)
Piping	Bamboo	Local Forest	Negligible	0, Locally sourced
Inlet protection	Wire Mesh	Local or imported	<1%	4-5
Piping treatment	Slaked lime, old petroleum	Import from Australia, or local suppliers	1-2%	10-20
Lashing	Twine or vine	Local	Negligible	Locally sourced
Filter	Saw dust and Clay	Local sources	Negligible. Firing may be at some small cost to villagers (likely <1%)	0, Locally sourced
Container	Clay	Local Sources	1-2% due to firing	0, Locally sourced
Float	Polymer/ plastic	Water bottle- bought locally	<1%	0, Locally sourced
Lid	Clay	Local Sources	<1%	0, Locally sourced
Valves	Rubber	Old Tires or bought locally	<1%	2, Locally cut
Join filler	Silicone	Imported or bought in city	<1%	1
Adhesive	AP1 Industrial Adhesive	Imported or bought in city	<1%	0.5
Tap Handle	Stainless Steel	Local or imported	<1%	1
Clay Glaze	Vitreous enamel	Local or imported	<1%	1

Metric	Units	Marginal Value	Target Value	Probable Achieved Value	Comments
Cost of maintenance+ fuel	%village income/year	< 8	< 5	<2	Maintenance costs are minimal and large scale maintenance need only occur every 4-5 years. Small scale cleaning biannually.
Cost of installation	% income/pp	< 10	< 7	<10	Cost is determined simply as an addition of estimated costs of components and construction.
Integratable with existing technologies	Binary	n	y	n	The system is significantly different to current methods of water treatment with good cause.
Water supplied directly to houses	Binary	y	y	y	Units should be placed within 10-50m of the households using the unit. This is very close and accessible, as was the goal.
Lifespan	years	10	15	15	Piping lasts approximately 5 years, filters 1-2 years but the system as a whole, with routine component replacements could last almost indefinitely.
Covered	Binary	y	y	y	The lid and inlet pipe are sealed to prevent mosquitos from entering the unit or other forms of contamination.
Prevents Standing water	Binary	n	y	y	Constant filtration means that there is an almost constant movement of water through the system.
Energy Source	Subjective	high efficiency combustible	No combustibles required	none	The system is entirely gravity fed. No pumping or energy is required, including human input.
Age restriction	years	18+	8+	5+	Children can easily use the tap mechanism.
Education for Installation		University Level	High school	High school/ skilled labour	Some technical skills are required for the firing of clay but overall construction is designed to require little experience and education.

Education for maintenance	Subjective	High school	Primary school/ rudimentary	Rudimentary / high school	Components which will need to be replaced such as the filter and bamboo pipes but exercise requires no more knowledge than construction.
Water Capacity	L/person/da y	15	50	36	Moderate capacity based on filter rates from mathematical modelling
Water Turbidity	NTU	< 3	< 1	<1	Based on data from Brown et al (2007) ceramic filters are very effective in removing suspended particles from water.
Filter System	Binary	n	y	y	A ceramic filter is the main feature of the design.
Microbial contamination	CFU/ml	500	5	<10	According to Brown et al, (2007) approximately 66% of households had CFU values of this range following ceramic filter implementation in Cambodia
Source from Groundwater or river	Binary	y	y	y	Rainwater is required for the system and therefore aligns with the cultural aversion to its consumption.
Materials	Subjective	Cheap importable	Local Materials	Mostly local	Materials are local excluding some chemicals and metallic components
Volume	m^3	8	1	<1 for the unit	Determined from mathematical modelling.
Fuel Consumption	L/hr	1	0	0	The system is gravity powered.
Weatherproof	Binary	y	y	y	The device is almost water tight, making it weatherproof.
Land securing system	Binary	y	y	y	A bamboo support structure or rocks should be used to support the device.
Positioning	Subjective	Sturdy ground	Flat, sturdy ground	Flat ground	Support structure hopes to ensure a sturdy placement. The device will be very heavy and therefore unlikely to be washed away in flooding.
Efficiency	%	70	99	N/A	There is no energy input to the system.