Effective Laundry:

A design engineering approach for laundry systems in small, off-grid, sustainably minded communities.

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1. Executive Summary

Kalu Yala is a sustainable village hidden in the Panamanian Jungle. The unique location allows inhabitants, researches and explorers freedom to experiment in all fields from Media Arts to Engineering. Since settlement in 2010, Kalu Yala has grown closer to complete town development every year. Part of this path is building suitable facilities for current and future inhabitants to use. While great improvements have recently been made to the shower and restroom facilities, the laundry system leaves much room for improvement. Using the design process of Pahl and Beitz, a new system will be created and implemented at Kalu Yala. The system must both practically allow inhabitants to clean their clothes, but also align with the sustainability vision of Kalu Yala.

2. Methodology

The design process specified by Pahl and Beitz (1984) was used to understand the problem, theorize potential solutions and select a final outcome. Of the many design processes, this one was selected for its known value in engineering systems application[4]. The four main phases are: Task Specification, Conceptual Design, Embodiment and Detailed Design. An overview of this process can be seen in figure 1.

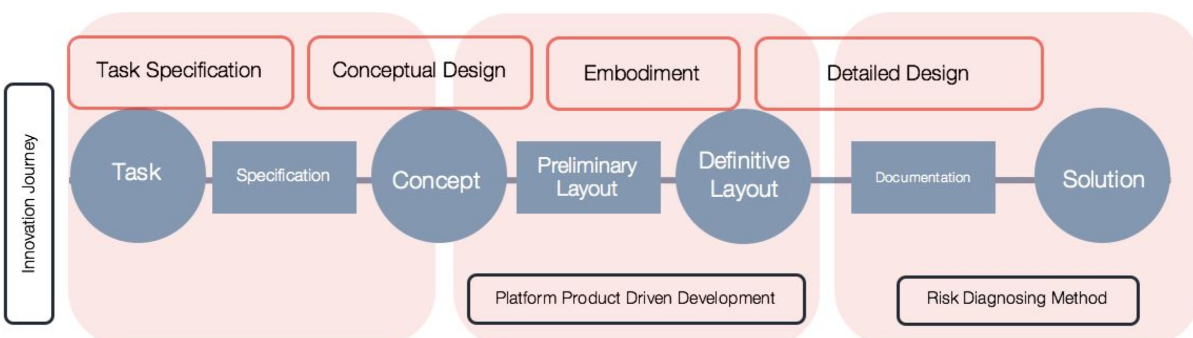

Figure 1: Flow Chart Representing innovation methods used in framework of Pahl and Beitz (1984).

3. Task Specification

How to effectively do laundry, especially during the rainy season, has always been a problem at Kalu Yala. While there are options to send laundry to San Miguel, the ideal situation is that all people staying at Kalu Yala have access to adequate laundry facilities they can use themselves with no cost. Washing by hand is a fine way to do laundry but it is difficult to get all the dirt out and the drying process can take very long. The long term impact of the project will be pushing Kalu Yala towards complete town development. Creating facilities for inhabitants that are both easy to use and environmentally friendly is key to attracting people to the town while preserving its mission. In the near future, Kalu Yala inhabitants will be able to do laundry quickly and thoroughly. The system will be easy to maintain, and be made from modular pieces so that it can be improved in the future.

3.1 Problem Definition

In order to better understand the problem, informal interviews were conducted with various members of the Kalu Yala Community (See Appendix A). Residents overwhelmingly described the laundry process as unpleasant, inconvenient and inadequate. These interviews led to the following problem definition:

1. Inability to clean clothes to a satisfactory level;
2. Failure to dry clothes in a timely matter;
3. Lack of a complete roof over drying area;
4. Lack of drainage system creating muddy pathways/standing area;
5. Inconvenient layout for drying clothes;
6. Lack of infrastructure to wash clothes comfortably.

Each of these problems will be addressed during the design process through the functions and requirements table (see table 1). Literature, personal experiences and history will all be considered when designing a solution.

3.2 Research

Going back in time, early civilizations relied on river systems to launder their clothes. With the boom of the textile industry, people began to own more items of clothing and thus the demand for facilities to wash these clothes increased[2]. This led to a series of inventions over the course of hundreds of years, from beating clothing with rocks to the machines we use today. As effective as modern washing and drying machines are, they use and excessive amount of energy to produce heat and rotational motion. Today, doing a single load of laundry at 60 degrees celsius and drying those clothes, has a carbon footprint of 3.3 kg

CO_2e[1]. This can be compared to washing clothes at 30 degrees celsius and hanging to dry which results in a carbon footprint of just 0.6 kg CO_2e[1]. The problem goes farther than just the carbon footprint of each load of laundry, as producing the machines and transporting them across countries also has a carbon footprint of its own. While newer machines are becoming more efficient and renewable energy sources are able to power the devices cleanly, doing laundry creates an unpredictable demand on the energy grid. The peak hours often do not align with peak production hours of renewable energies such as solar[3]. Because of this, using and electrically powered washing or drying machine will not be a feasible option in the foreseeable future for Kalu Yala, even if there was enough solar production to support it.

There are many examples of washing and drying systems that do not require electricity. One of the most common examples is the bike powered washer or dryer. In these systems, the user pedals a bike to rotate the washer or dryer. Such systems are faster and provide better results than washing by hand and hanging to dry. The drawback of such systems is that they require a working bike, and due to the number of moving parts, are likely to require repairs. These repairs may require the purchase of new parts, or even a new bicycle. Due to the remote location of Kalu Yala and its sustainability mission, it is not feasible to have such a system as getting parts for repairs would be difficult.

In many places around the world, particularly in south/central America, Africa and Asia, rural communities still rely on the same technology the Romans used to launder their clothing: the washboard and clothes wringer. These two inventions have survived the test of time because of their simplicity and effectiveness. They are easy to produce and last a long time. The drawbacks of this system are that they are time consuming and require more effort than simply tossing your clothes into a machine as many people do today. However, when integrated into a more modern system, the benefits of traditional washboards and clothes wringers is increased while its drawbacks are decreased. The proposed system for doing laundry at Kalu Yala will rely on traditional methods but integrate them into a streamline system so that using these technologies is faster and easier.

To further the drying process, clothes can be dried under a clear roof. This both protects clothes left out to dry from rain, as well as speeds up the drying process. Just like a greenhouse, a clear roof will allow sunlight to passthrough, heating the clothes and the air around them. This will increase the rate at which the clothes dry because at higher temperatures, the rate at which liquid water evaporates into water vapor and diffuses through the air is faster. Other factors such as airflow and humidity also affect the rate of drying but are harder to control than temperature.

4. Conceptual Design

Using the gathered knowledge about the current laundry system, a list of functions the final system should fulfil was created. These functions help guide the product design to ensure it is both useful and realistic to the target group. The target group has been defined as those living in Kalu Yala. This includes all staff, students, teaching assistants and independent business owners. It excludes hostel guests who stay for shorter time period and are not likely to do laundry. The main function of the system was defined as: A washing/drying system for a community of 100 people viable in all seasons for long term use. Long term use is intended to mean for a period of 10 or more years. Table 1, shows all other functions the device must fulfill as well as the requirements, or ways that the product achieves the function can be measured.

Function	Requirement(s)		
Remove dirt	Remove 100% of dirt from clothing.		
Dry clothes	Remove 100% of moisture from clothing within 48 hours.		
Provide water	Water is provided by the system.		
Drainage	100% of water used for system is directed away from pathway/standing area		
Protect user from elements (sun/rain/bugs)	Rain does not affect user during use.	Sun does not affect user during use.	User is not overexposed to bugs during use.
Integrate in daily life	Interaction with system does not take more than 30 minutes for 10 items of clothing.	Product does not interfere with daily pattern.	
Aesthetically pleasing	Clothing line is not fraying	Laundry station is well maintained.	
Easy to use	90% of people should understand how to use the system immediately	Presence of an instructional board explaining system.	
Comfortable to use	99% of users are able to use the system without physical discomfort.		
Conserve energy	System is 100% independent from energy grid.		
Conserve water	Presence of a sink plug so water does need to run continually .		
Has large capacity	At least 100 people can wash 10 items of clothing each week.	At least 100 people can dry 10 items of clothing each week.	

Table 1: Functions and Requirements Table for System.

After defining the functions and how they will be measured, a morphological chart was created to express all the possible ways each function could be fulfilled. Creating such a chart before defining anything specific about the system itself allows the design to not be limited but come up with many solutions regardless of their ability to be integrated into the product.

Function	Methods of Implementation					
Remove dirt	Scrubbing	Cylindrical Force	Soap	Soaking	squeezing	
Dry clothes	Cylindrical Force	Hanging	Squeezing	pressing	heat	airflow
Provide water	Sink	Hose	Bucket	Captured rainwater		
Drainage	PVC piping	Metal Piping	Drainage ditch	Large gravel filled hole		
Protect user from elements (sun/rain/bugs)	Umbrella	Overhang-ing roof	Platform to stand on	Strategic foliage (create shade, discourage bugs)		
Integrate in daily life	Takes little time	In area people frequently visit				
Aesthetically pleasing	Organized (creation of system)	colors	Easy to clean	Materials that do not degrade		
Easy to use	Make similar to existing system	Clear instructions	Logical system flow			
Comfortable to use	Standing height table	Able to sit while wash	Place to put clothes/soap	Aisle ways		
Conserves energy	Minimal Maintenance	All done by hand	Installation process			
Conserves water	Drainage plug	Recycle water				
Has large capacity	Multiple sinks	Large sinks	Larger drying space	Multiple levels of clothing line		

Table 2: Morphological Chart

5. Embodiment

Considering the outcomes of the function and requirement charts, potential designs were theorized. It was quickly decided that the final system would make use of as much of the existing system as possible to reduce material demand and ensure the system is easy and convenient for inhabitants to use. The main aspect lacking in the current system is an effective and comfortable method to wash clothing.

The necessary elements/improvements of the system were defined as:

- Construction of a table to elevate clothes and washing soap off the ground;
- Implementation of standing height sink(s) with running water and drainage for washing;
- Integration of a coarse texture to allow user to scrub clothing clean;
- Integration of a clothing press or wring to squeeze water out of clothes;
- Reconfiguration of drying lines to increase accessibility;
- Completing roof with a clear material;
- Pruning of vegetation to increase airflow and light exposure.

5.1 Initial Design

The resulting design utilizes a standing height table with two sinks, a washboard and a clothes wringer. PVC piping will be used for a short extension of the existing waterline so the sinks have a tap with running water. PVC piping will also be used for the creation of a drainage system leading to the leach field previously created for the toilets and showers. The clothing line will be replaced with a stronger plastic material that will not fray or rot. The layout will be kept the same to keep maximum capacity. The wash table will be placed along the backside of the drying area where there is already a partial roof covering. The roof will be finished and extended to fully cover the drying area as well as the wash table. This will be done with clear roofing to allow light through.

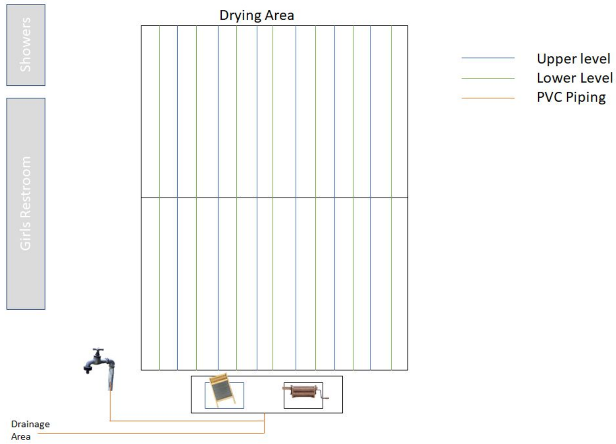

Figure 2: Example System Design

Example of washboard:

Example of clothes wringer:

5.2 Material Selection

In order to align with the sustainability mission of Kalu Yala, special attention needed to be paid to the materials used. The system should use sturdy materials that can be sourced locally and will last for generations to come. It is important to consider each material in the scope of the entire life-cycle of the project as the immediate advantages of one material might not outweigh the long-term advantages of another. While the material properties are important to consider in relation to design choices, given the location of Kalu Yala, availability will also play a large role in the decision making process.

Concrete, Metal, wood, polypropylene and zinc are all materials that were considered for various aspects of the design.

Regarding the roof, a clear material is desired to allow light (and therefore heat) to fall onto the clothes. Currently, corrugated plastic made from polypropylene is being used to cover about 40% of the roof. The rest of the roof is corrugated metal made from zinc.

Polypropylene is a lightweight (density 0.895-0.92 g/cm3) material that is also strong (young's modulus 1300-1800 N/mm2)[5]. It's clear complexion allows light to pass through, which is an important characteristic for this project. However, the chemical structure of polypropylene doesn't support long term exposure to UV radiation. Long term exposure causes bond breakage which weakens the strength of the material and causes discoloration which limits its ability to let light through[5]. This effect is clearly evident in the current uses of Polypropylene at Kalu Yala. Polypropylene is used because it is readily available and easy to transport. Glass would be a much better choice however transportation would be extremely difficult and the cost is also greater. Still, this is considered the ideal choice as glass does not react to UV light in the same way. Based on observing current uses of polypropylene, after approximately two years of use, the material is so badly damaged that it does not allow enough light through to be considered effective. From an economic standpoint, polypropylene is better for the short term but when the capital exists, a glass roof should be considered.

Regarding the sinks, metal and concrete were both considered. Concrete is very durable and requires little maintenance. It has a long lifespan and is resistant to wind, water and rust. However, it is very heavy and difficult to work with when compared to other materials. From an environmental point of view, concrete is attractive because it is made from elements natural to the earth[6]. When it is at the end of its life it can simply be crushed and used in future mixes of concrete. Metal is much lighter and offers more versatility in shaping. The main drawback from metals, such as steel, is that they are likely to corrode over time[7]. Concrete also has a higher roughness coefficient then metal[6], this can be seen as an advantage for the system in question as an integrated washboard made of concrete will be more effective than one made of metal.

Considering the table, wood and concrete were initially options. Once concrete was selected for the sink, it was easier to build the table also of concrete blocks. It would take much more time and skill to construct a wooden table capable of supporting the heavily concrete sinks. Furthermore, even if wood is used as the primary building material, a concrete (or like material) foundation is needed to prevent rotting of the wood. The current structure displays signs of weathering in the forms of rotten and algae covered wooden beams. In such a tropical environment, concrete will have a much longer lifespan than wood.

6. Detailed Design

After creating the initial design, detailed product designs were created for each aspect of the system. This started a feedback loop of testing different system configurations which led to the final system.

The problem of having to duck under clothes line or wooden support beams in order to access the drying area was not solved in the initial design. This problem can be solved in the final design with the creation of aisles. It was discovered that part of the current structure, the part that did not have a complete roof, has started to rot. In order to insure the structural integrity of the building, three beams were selected to be replaced. While doing this construction, two aisles for people to walk down will also be created. Because of the placement of the aisles, the location of the washtable was then also moved to a perpendicular side so inhabitants can easily access the aisles.

Finally, it was decided that the cost of buying enough plastic roofing to cover the entire drying area was too great especially as it is not the ideal material for the function. The current aluminum roofing is in good condition and there are already a few panels of clear roofing. However, the clear roofing is currently having little effect as overgrown trees shade most of the drying area. These trees should be put on a regular maintenance schedule to prevent them from growing over the structure again. Keeping the structure open and clear from overgrowth also allows increased airflow throughout the drying space which will help clothes dry faster.

6.1 Ideal Design

The following figure shows the ideal design. The system has the addition of aisles ways for easy access and the location of the wash tables have been moved to allow for the creation of the aisles.

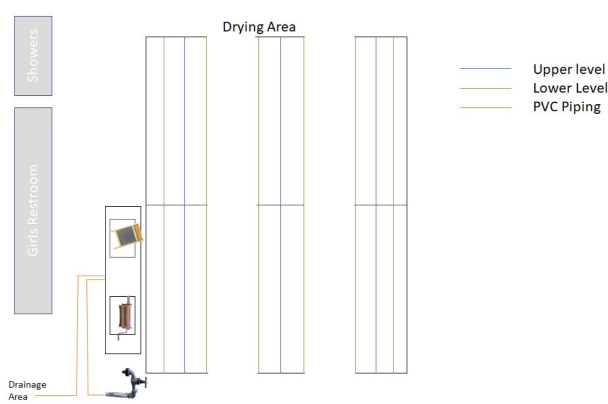

Figure 3: Ideal System Design (not pictures: glass roofing)

7. Implementation and Limitations

The implemented system differs from the ideal design theorized during the design process in numerous ways. Financial, time and material restrictions all contributed to these discrepancies. The implemented system integrates 6 of the 8 points deemed necessary in the ideal design. The points lacking are the glass roof over the drying area and the creation of aisles in the drying area.

7.1 Evaluation

During the design process, twelve functions were defined with requirements as a means to measure how well they were implemented into the final design. The following table shows which functions are included and which still need to be improved upon or tested over a longer period of time. The evaluation was done

Function	Deal Design	Implemented Design
Remove dirt	1	1
Dry clothes	1	0
Provide water	1	1
Drainage	1	1
Protect user from elements (sun/rain/bugs)	1	0
Integrate in daily life	1	1
Aesthetically pleasing	1	-1
Easy to use	NDA	NDA
Comfortable to use	NDA	NDA
Conserve energy	1	1
Conserve water	1	1
Has large capacity	1	1

Table 3: Function Evaluation, Ideal vs Implemented Design. (1-included, 0-partially included, -1-not included, NDA- No Data Available)

As can be seen in Table 3, the Ideal design does a great job fulfilling the requirements set out for the system. However, the system that was eventually implemented lacks in a few categories. In the following section, how to bring the implemented design closer to the ideal design will be discussed. The major discrepancies are seen in the categories of Aesthetically pleasing, Protect user form elements, Comfortable to use, Easy to use and Dry Clothes. The drying area was not completed to the specifications of the ideal design. The roof is still made from two different materials, half polypropylene and half zinc which gives a messy impression. The lack of a glass, or completely clear roof, slows the drying process so clothes of a thicker fabric may not dry within 48 hours. Furthermore, aisles ways were not created which both affects the aesthetics and the comfort to user. However the washing system was implemented at standing height bringing more comfort to the user than the previous system. At this moment, no tests have been done to conclude how users feel about the categories of easy to use and comfortable to use. Overall, the implemented wash system is a large improvement compared to the previous system of simply two buckets and a tap.

Figure 4: (Left) Previous wash system, (Right) Implemented wash system

8. Future Development

In order to maintain the system in the coming years, the system needs to be further developed and regularly maintained. This can be done by future students and current/future staff members. Regarding continual maintenance, the trees around the drying area should be cut seasonally so they do not block light from reaching the drying area. In the near future, the wooden beams supporting the drying area roof will need to be replaced as they are starting to rot from moisture. At this time, the possibility of installing a completely transparent roof should be explored.

The wash basins built during the embodiment phase will require very little maintenance. However, the drainage system is very slow to drain and should therefore be improved upon. This can simply be done with a drill or chisel and widening the hole at the bottom of the sink.

9. Conclusions

The system designed is capable of providing laundry facilities for small, off-grid, sustainably minded communities. The implemented system at Kalu Yala allows inhabitants to wash and dry clothes in an effective and timely manner. The system was created using the four stage design process of Phal and Beitz. The main problems with the previous system were identified and possible solutions were theorized using a morphological chart. The eventual solution was able to alleviate the problems associated with the previous system. The shortcomings of the system are mostly related to implementation issues regarding time, finances and material availability. A continuity plan will help translate the implemented system into the ideal system over time. While the system was designed with a specific community in mind, the final design can be applied in many similar areas.

10. References

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11. Appendix

A. Interview Notes

Questions:

- What has your experience been doing laundry at Kalu Yala?
- What are the aspects you do not like?
- Is there anything about the system that you do like?

Notes

- Unpleasant → has never used laundry facilities because lack of appeal
- Sitting to reach bucket on the ground leads to bug bites
- Has only dont laundry twice in two years because it is so bad
- Washing clothes in the shower/sinks is better than the current system
- Hanging clothes works well in the dry season, is okay in the wet season
- The roof should be completed with clear plastic
- The area is very messy/muddy with buckets of water dumped everywhere
- Would prefer to stand or sit comfortably while washing
- Capacity for drying clothes is very good
- Annoying to duck under clothes lines when trying to hand/retrieve clothes
    - Perhaps make a staggered second level, lower level for big stuff, upper level for small stuff
- Clothes line is sagging and fraying