Development of a Point-of-use Water Treatment System in Nepal

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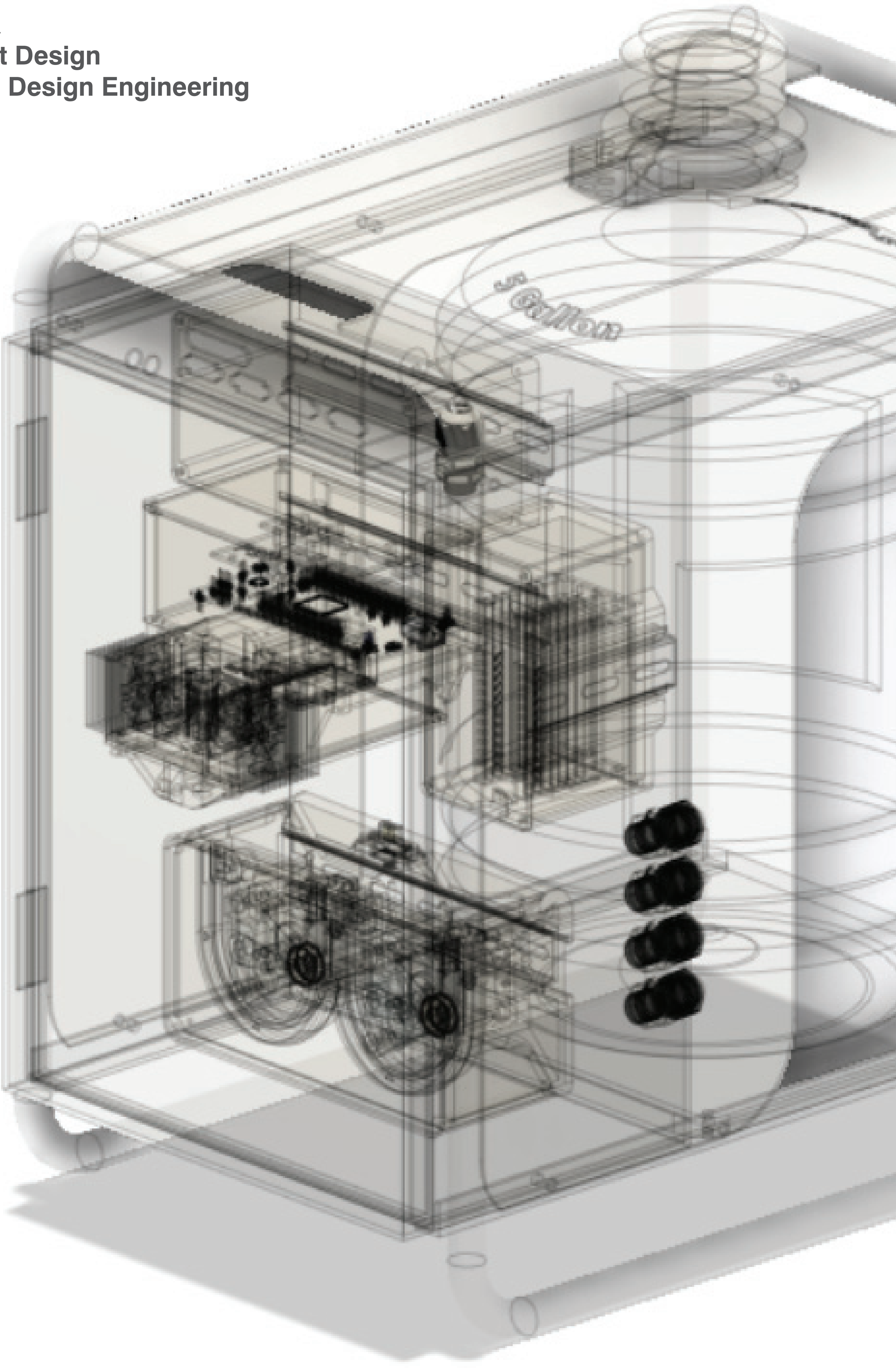
Integrated Product Design
TU Delft Industrial Design Engineering
Masters Thesis
August 2023



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Thank You

To my committee for your support, expertise, and confidence in me throughout this project

To everyone at PRI for your insight and hospitality both in and out of Nepal

To everyone at the Diyalo foundation for connecting me to this project and for an unforgetable experience

To my friends and family, without whom I would have never made it far enough to attempt this project

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Introduction

Chapter 1

1.1 Abstract

This report details the design of a decentralized water treatment system for use in Nepal, which currently lacks improved sanitation for 10.8 million people and a water contamination rate of 71 percent (UNICEF, n.d.). This contributes to the approximately 140,000 deaths per year (O'Neill, 2023v) from diarrheal illnesses caused by such bacterial contamination. To combat this, the Phutung Research Institute (PRI) in Nepal has developed a low-cost optical sensor that can detect pathogenic bacteria in water. This sensor is a vast improvement over existing tools used to assess water quality, such as consumable test kits or laboratory analysis. However, detecting contaminated water is only one of two steps necessary to provide safe water to those who need it - the water must be cleaned. Such is the purpose of this project: to integrate this sensor in a design that both detects contaminated water and purifies it for people in Nepal.

In addition to providing a practical application for PRI's technology, this project applies other areas of design to create a holistic product intended to operate through its complete life-cycle within Nepal. User ethnography was researched to identify a ubiquitous water tank system as the implementation point, allowing for a single design to be applicable throughout Nepal's diverse population. This also yielded additional pain points that are addressed to increase the acceptability of this product design in Nepal. Manufacturing and maintenance research yielded a modular architecture that can be constructed in Nepal as much as possible, thereby shortening supply lines and reducing costs while stimulating the local economy. Such a system also allows for the maintenance of sensitive components in the field without specialist intervention.

These elements were combined to create a TRL 6 prototype designed to detect bacteria within a home's water supply and automatically eliminate it with chlorine treatment. It is intended to both demonstrate PRI's technology and to facilitate field testing in Nepal. This was done while improvising a design method called 'Who, Why, How into What'. A new method was necessary to organize a project in which multiple diverged areas of design development had to occur simultaneously over a short period of time, barring the use of more traditional and better-defined design methods.

1.2 Project Objective

In a broad sense, the objective of this project is the protection and preservation of human life. As such, the result should be a design of practical use in the effort to bring clean water to the third of Nepal's population at risk of contamination. To accomplish this, there are three main areas of focus: Functionality, Manufacturing, and Maintenance.

The functionality objective is to research and understand the human and infrastructure factors that cause this high contamination rate, as well as to integrate PRI's optical engine as an integrated sensor. This will determine what the functional requirements of the design are - what it needs to do to be effective when operating in Nepal

The manufacturing objective is to create a design that can be constructed in Nepal. This includes using Nepali components, companies, and labor whenever and wherever possible in order to shorten supply chains and stimulate the local economy.

The maintenance objective is to create a design that can be deployed all over Nepal and remain there in operation for as long as possible. As such, factoring in repair is essential to creating a piece of infrastructure that provides an essential utility for the user.

These factors will be used to develop a concept product capable of addressing this issue, and generate a TRL 6 prototype to demonstrate this concept. The purpose of this prototype is to not only prove the concept, but also demonstrate the practical applications of PRI's optical engine to potential investors and provide a testing platform for further development. This prototype will be evaluated and used to determine the next steps towards implementation and commercialization.

1.3 Constraints and Scope

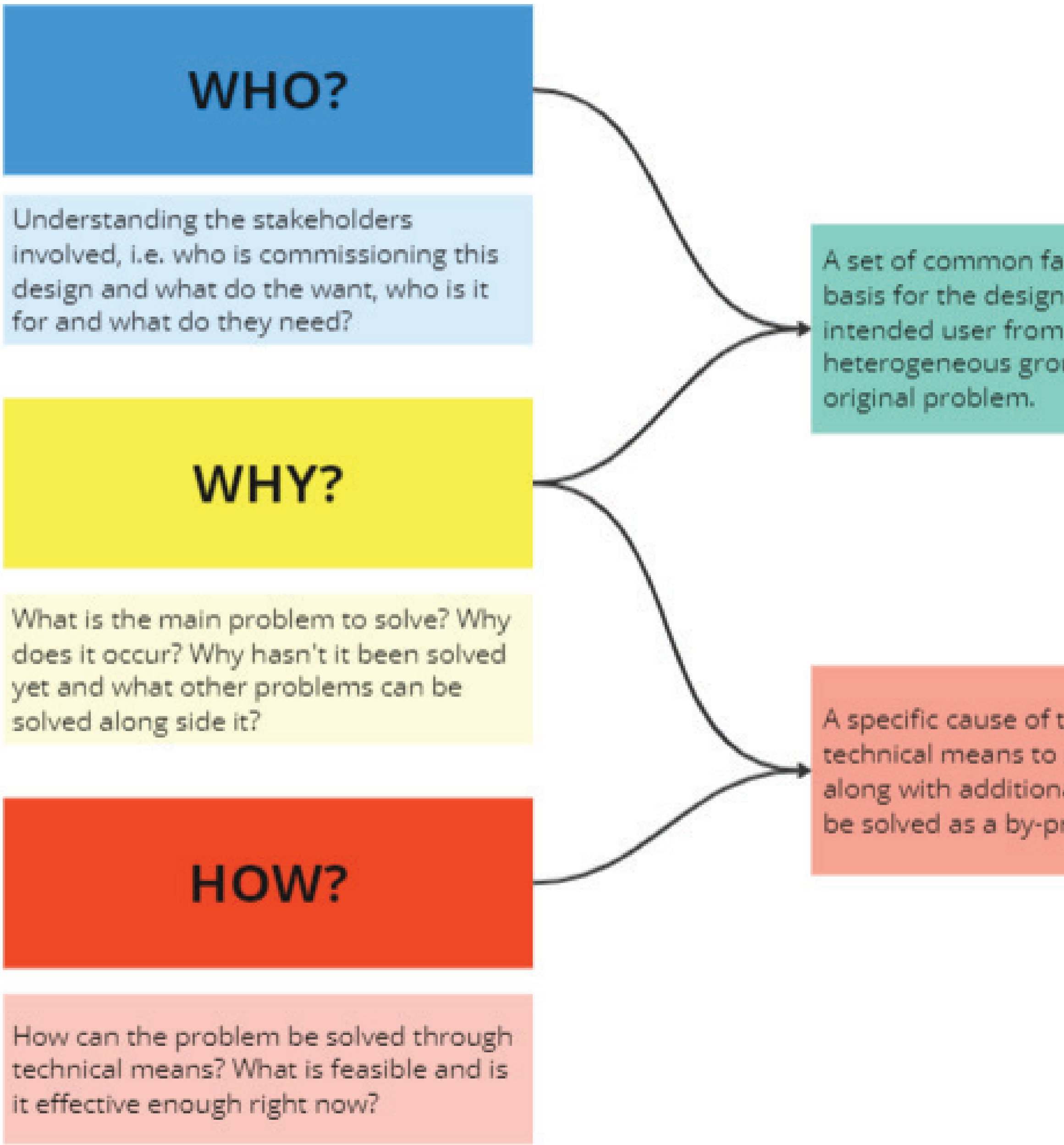
This project covers the research, concept development, and early-stage prototype embodiment of a public health device. Given the breadth of this project's scope, there are several areas related to product development that will not be covered in full. First, engineering and manufacturing optimization will not be conducted as the engineers on staff at PRI are better suited to do this following the completion of this stage of the project. For example, integrated circuits and printed circuit boards will not be fully designed, but will be considered when creating volumetric constraints. This also includes certain parts of prototyping and testing. While a prototype should be constructed to illustrate the design features and requirments, this is not purely an embodiment project and some compromises should be made on a works-like/looks-like prototype in order to facilitate a more holistically complete project and design.

Second, comprehensive ergonomics and user studies with a completed design cannot be conducted due to a lack of access to the target user at this stage of the project. However, secondhand knowledge provided through the client and literature is considered, such as physical ergonomic references (such as DINED).

Lastly, due to the time constraints of this project, long term field testing is also out of scope. This also includes use of a functional optical engine in the later stages of the project. This is because the optical engine design is still evolving and working prototypes are still rare and const prohibitive to be used in this project. Instead, this stage of the project is intended to produce a proof of concept prototype design that can be later integrated with more developed technology and the be used for more comprehensive testing in Nepal.

1.4 Approach and Methodology

Traditional design methods were not used as the basis for this project. This is because the project was subject to several scheduling and logistics constraints - mainly that the technical development of the design and the exploratory user and environment research must be conducted at the same time. This occurred over the course of 5 weeks towards the beginning of the project. For this reason, a traditional 'double diamond' (or similar) design method would not be applicable as the very beginning of the project began in a diverged state with certain research objectives already defined. At first, the use of the 'lean startup method' was proposed, which relied on multiple fast-paced prototyping sprints at the beginning of the project. However, simply generating prototypes would not yield satisfactory research insights into user ethnography and it was necessary to to re-define the research method



Understanding the stakeholders involved, i.e. who is commissioning this design and what do the want, who is it for and what do they need?

What is the main problem to solve? Why does it occur? Why hasn't it been solved yet and what other problems can be solved along side it?

How can the problem be solved through technical means? What is feasible and is it effective enough right now?

A set of common fa
basis for the design
intended user from
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A specific cause of t
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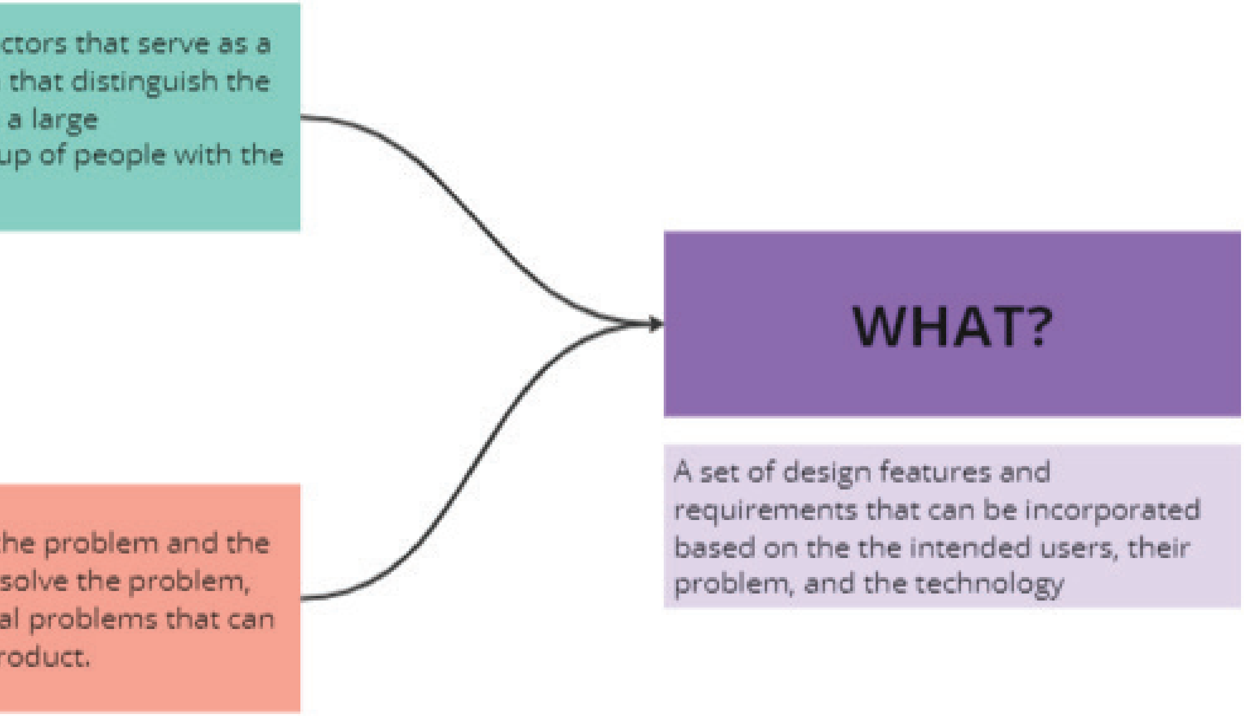
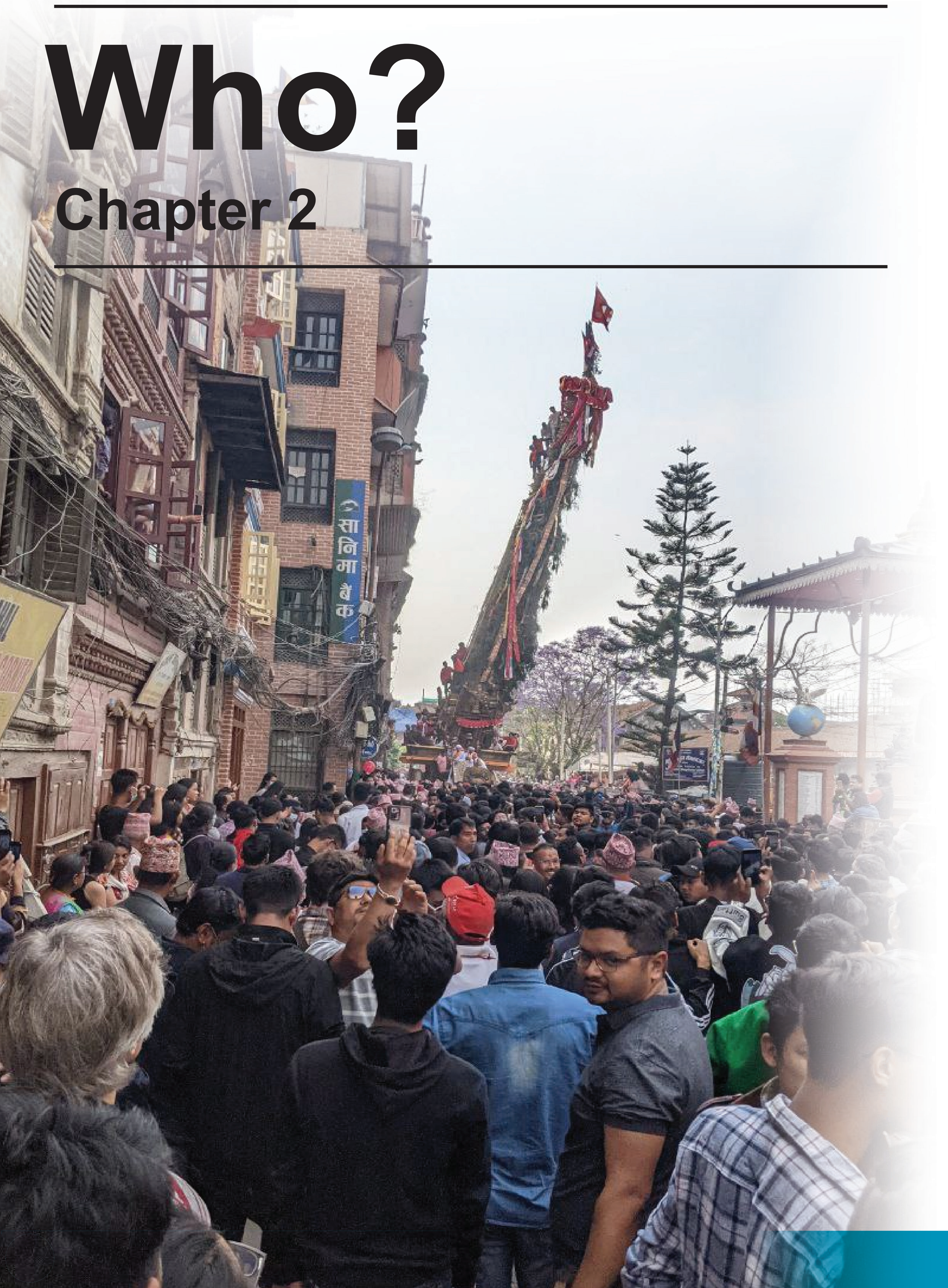
A new method was improvised for this purpose: the ‘Who, Why, How into What’ method, or the WWH method. This approach focuses on answering these questions: ‘Who’ is the user and what is required to meet their needs, ‘Why’ does this problem occur and why it has not been sufficiently addressed yet, and ‘How’ can this problem be solved with the technical means at our disposal. These questions will be researched in parallel over the course of a 5-week immersive sprint, allowing insights from one area to inform the other areas. This results in a cumulative ‘What’ - a justified overview of what the design will consist of. This ‘What’ will be used when generating a prototype which will be used for demonstration and evaluation purposes.This report will also use a similar structure, first detailing the findings from each part in the WWH map and then specifying how they factor into the design specifications. From there, the project will take a more traditional embodiment approach to using these specifications to develop and test a working prototype.

While it has many shortcomings when compared to more established methods, the WWH method proved useful in this specific use case by generating design requirements and scope definitions under heavy scheduling restrictions. In particular, it was essential in defining the user segment due to the ‘Who’ and ‘Why’ being researched at the same time early in the project. This will be further explained in their respective sections



Who?

Chapter 2

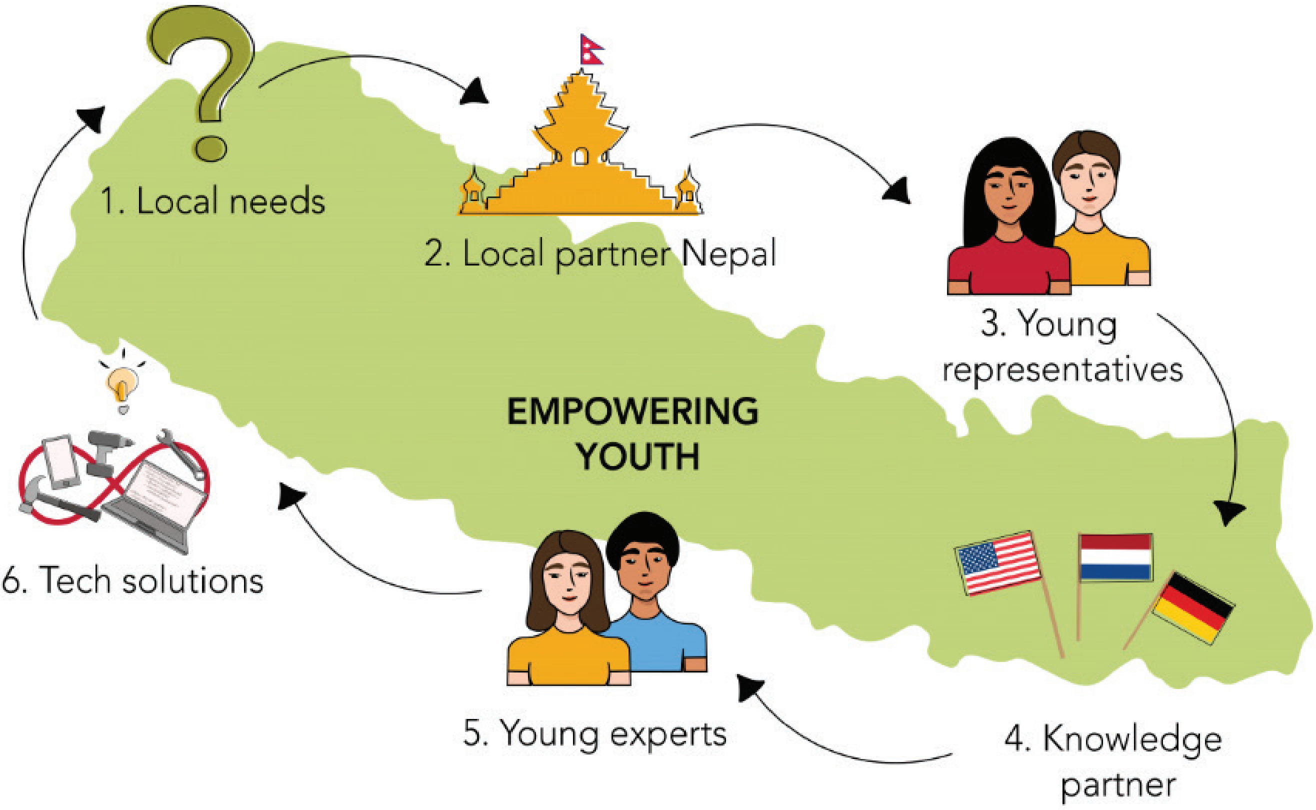


2.1 Stakeholders

The first section of the WWH map is WHO - who is involved with this project and what are their expectations? This will describe the stakeholders involved, including their stated intentions, their implicit desires, and most importantly how we should determine who the end user should be for this design.

The Diyalo Foundation

The Diyalo foundation is the sponsor for this project and others like it. They are a non-profit organization dedicated to promoting innovation in Nepal. They do so by facilitating co-operation between Nepali researchers and organizations in Europe and North America to provide technical expertise on projects that develop infrastructure (usually with medical and public health applications) in Nepal. They also provide funding for research and development projects based in Nepal, such as the development of a water assessment system at the Phutung Research Institute.

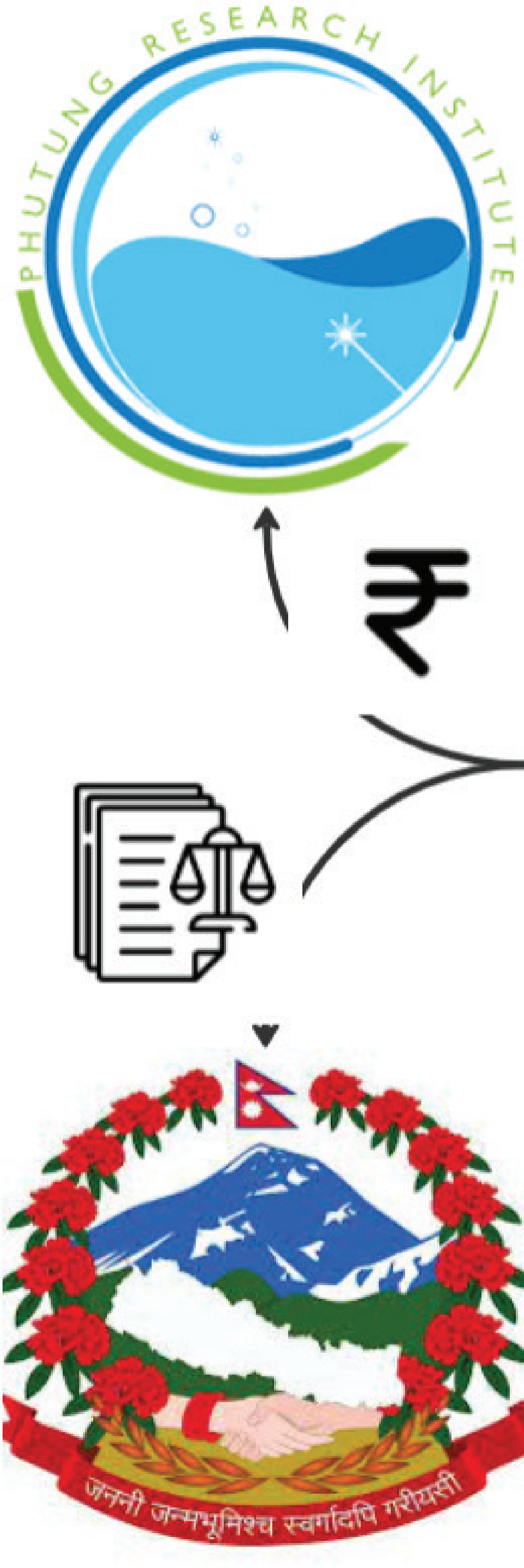


Phutung Research Institute

This project is hosted by the Phutung Research Institute (PRI) - a non-profit organization based in Kathmandu. They have expertise in multiple technical fields including electrical engineering, biomedical science, optics and photonics, and computer vision. However, much of their focus is on using their research to develop cost-effective solutions to improve infrastructure and quality of life in Nepal and other developing nations.

One of the ongoing projects at PRI is the WAS - Water Assessment System. By developing a low-cost (less than one thousand euro) optical sensor, they have created a device that can quantify fecal coliforms in a water sample in less than 1 minute with no additional consumables or reagents. They intend to develop these sensors into a consumer-ready device and market it throughout Nepal, thereby reducing sickness caused by fecal coliform contamination in the water supply. They also believe their device has potential as an integrated sensor within a localized water treatment system and have hosted this project to validate this belief.

For them to accomplish this, however, they require funding. To acquire funding, they need to demonstrate the technology is safe and has potential in consumer devices. Therefore, the appeal to investors, such as the WHO, is just as important as utility for the end user because this technology will not reach the end user without further funding. Because of this, the desired outcome for PRI is a design demonstrating the feasibility of such a system that can be shown to investors and public health authorities to promote their research.



Public Health Authorities

World Health Organization

The intended design is a device related to public health. Therefore the concerns and requirements of public health authorities must be considered as well - specifically the World Health Organization (WHO). The WHO has already expressed interest in this technology and PRI intends to seek funding and other support from them. Therefore keeping subsequent designs within their guidelines is important for establishing future collaboration. Additionally, the WHO is not a technology venture capital firm and may not have the technical expertise to determine the merit of PRI's developments based on the technology alone. Therefore it is important for the design to demonstrate immediate applications to a current public health threat.

Nepali Government

Nepali public health authorities, specifically the Ministry of Health and Population, would also have jurisdiction should this technology be implemented - especially if it involves water treatment. However, the technology would likely not fall into existing legislation. Instead, the design should focus on solving the problem as safely and effectively as possible, increasing the likelihood the government will enact new legislation to permit it. This also increases the importance of a partnership with the WHO, as they have the potential to influence regulation that would permit such a design.

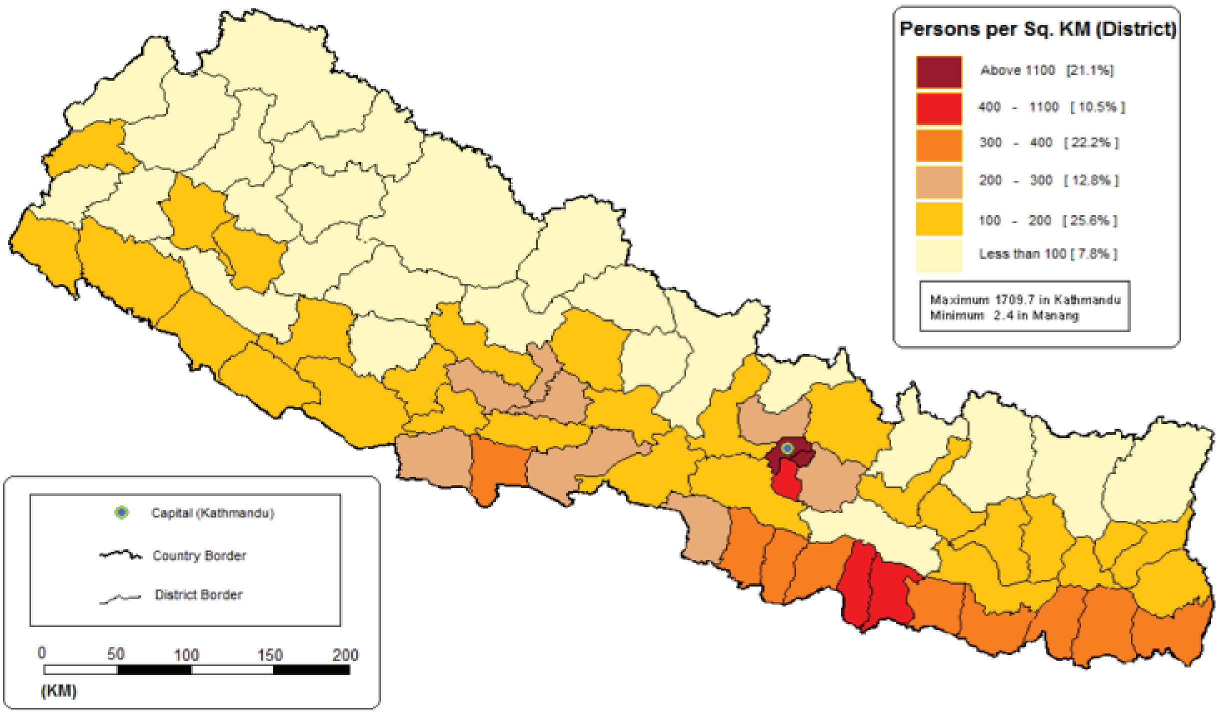
Citizens of Nepal

People living in Nepal without access to clean or treated water represent the end user of the intended device and are therefore the most important stakeholder. As of 2021, it is estimated that 27% of the population has immediate access to properly managed drinking water and 82% of Nepali households are at risk of microbial contamination within their water supply (Rahman, 2021). Such contamination results in diarrhea-related illness that causes almost 6% of the nation's total morbidity, with additional costs from strain placed on the national health system and lost productivity. The dangers of untreated drinking water are known in Nepal, however people do not always know the steps to sanitize it or cannot spare the time or effort to do so. Therefore, the desired outcome for the citizens of Nepal is a solution that treats water with minimal effort on their part.

However, in a country as populous as Nepal, this user group is too large and too diverse for a single design. This population is split between urban and rural areas with multiple languages, monetary incomes, geographic topologies, education levels, etc. For a new technology in a new product class, this user group must be reduced and homogenized. That way, a product can be developed for this group, tested, distributed, and commercialized, thereby allowing the cycle to be repeated for the remaining groups in Nepal. The question is, who should be designed for first?

2.2 Ethnographic Research

The purpose of the initial user research was to determine how to narrow down the user base. This could be done by comparing socioeconomic groups or geographic regions. However, comparing home water infrastructure was the deciding factor. This is because the intended design would likely have to integrate within home water infrastructure, therefore the fewer variables within this infrastructure would simplify the design. Such variables include user pain points, allowing the design to address more than just the lack of purified water within a specific user group. Essentially, the user group was not defined by human factors, but by the infrastructure the user has to interact with.



2.3 Narrowing down user base

At first, researching Nepali water infrastructure does not give much insight into user ethnography. However, a working understanding of such systems will give context on user interactions with their water systems. This allows for the group of potential users to be narrowed down based on their water system so that the user base will have common pain points.

Most areas in Nepal do not have centralized water distribution. Instead, most people rely on naturally occurring water sources such as streams or groundwater. These sources may not necessarily be close to the home, therefore there is a collection process to retrieve the water. Because of this, people store water within their homes to avoid constant retrieval.

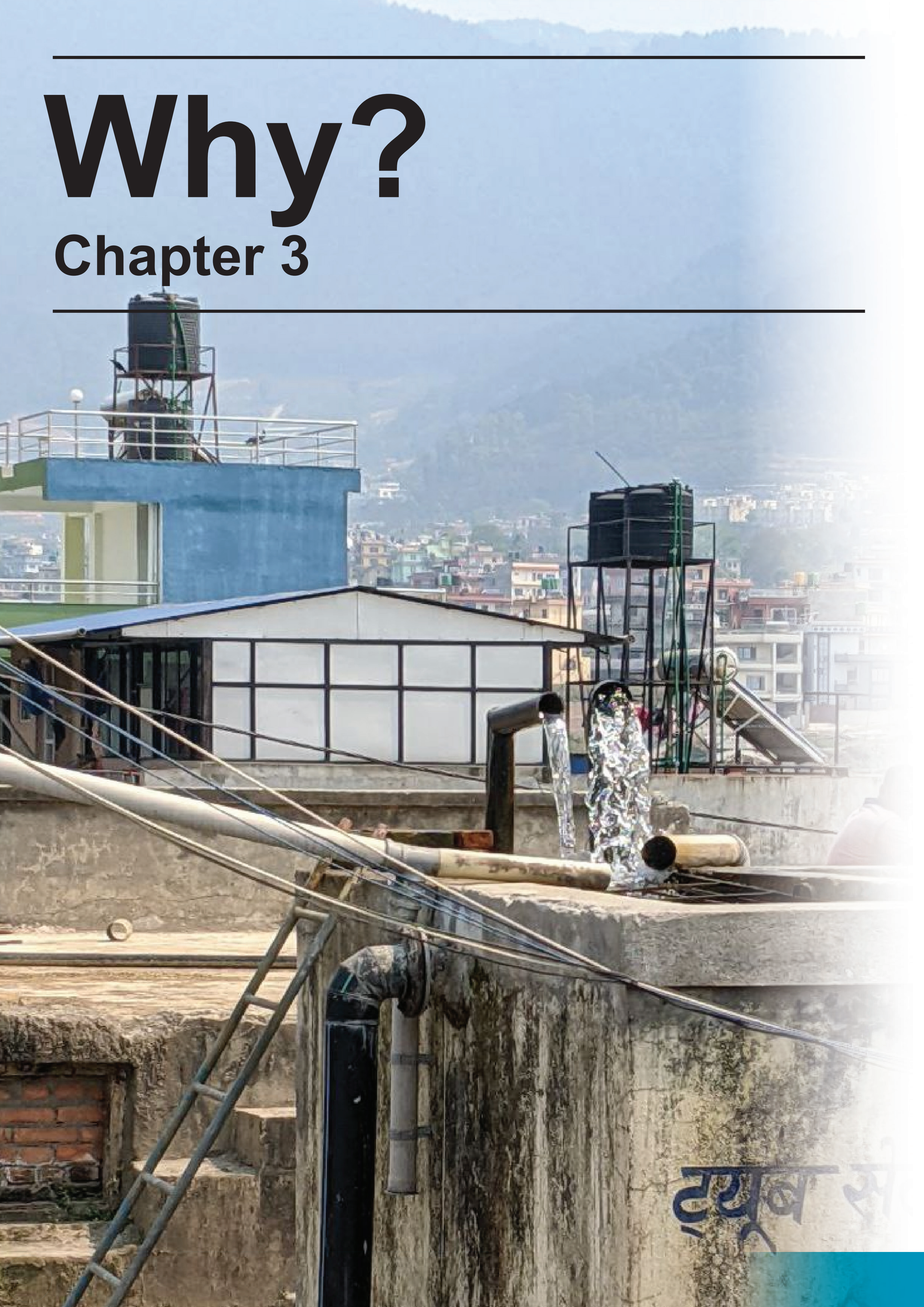
Many buildings in Nepal store water on the roof in tanks ranging from 250 to 5000 liters, with one the most common being 1000 liters. When depleted, the tanks are refiled by the user. In rural areas, this is sometimes done by hand using water transported manually. In areas with improved infrastructure, this is done using a pump using ground water from shallow or deep-bored sites around the building.

People with this type of water system represent a good starting user group. First, they still represent a majority of the Nepali population at risk for water contamination. They also live throughout the varied environments in Nepal. Therefore a system that is designed to work for these potential users can be tested and eventually distributed throughout the country. The barrier between these users and PRI is also very small. In fact, PRI uses this type of water system along with the surrounding areas in Kathmandu, therefore early stage testing can be conducted in close proximity to PRI to reduce the size of the user/maker feedback loop. Because of this, the intended design will focus on users who use roof-mounted water tanks to store water they collect from untreated sources such as rivers or groundwater. They represent the Who in this design map.

Rooftop water tanks are ubiquitous throughout Nepal, giving a common infrastructure system to base a design around

Why?

Chapter 3



Introduction

Now that the target user group has been narrowed down to people who use rooftop water tanks, the next section - Why - will focus on why this problem exists and why the current user situation is far from ideal. This will give insight into what problems the intended design has to solve and what parameters of the current situation can be modified to deliver the ideal experience.

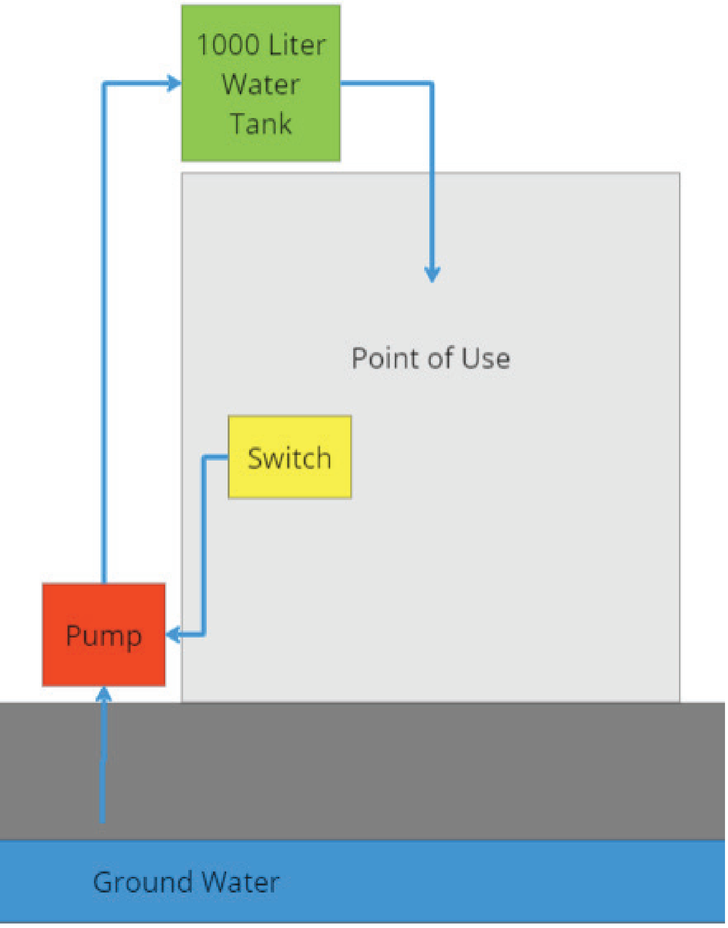
3.1 Problem Cause

The most severe problem faced by users of these water tanks is bacterial contamination, which provided the motivation for this project to exist. Contamination occurs due to untreated water being used from this system coming from untreated sources such as rivers/streams, or groundwater. Biological waste from such areas ends up here, where it can contaminate the water used by the majority of Nepal's population. This waste is a source of fecal coliforms such as E Coli bacteria (Shrestha, 2018), which cause approximately 140,000 deaths per year (O'Neill, 2023) and the hospitalization and financial burden of many more. Due to the severity of this problem, addressing it is the first priority of this project. However, examining other aspects of water management - especially on the user interaction side - uncovers additional aspects to this problem and why it is so severe.

3.2 Target User Habits

Examining the infrastructure available to the target users reveals additional pain points for the intended design to address. That said, there are multiple possible interactions possible within the system, but this examination will assume the simplest ones possible. The reason for this is that this is still an early stage design and optimizing for variations in user interactions is still beyond its scope. Therefore, the design should focus on the 'least common denominator' or the baseline for user interactions that show the pain points experienced by the majority of users instead of pain points specific to a smaller user subgroup.

The system serves multiple people within a building, it is generally operated (when necessary) by a single person. In the case of an automatically activated pump, no user intervention is necessary. However, in a manually activated pump, the user must interact with both the water tank and the pump. A typical interaction is as follows:



Simplified diagram showing the main components of a home water system

The water tank volume is checked regularly. Given the size of the tanks and their height from the ground, this is generally not done visually. Instead, the user knocks on the tank with their hand. They are able to determine the approximate water level by listening to the change in acoustic quality as they knock above and below the waterline.

If the waterline is close to the bottom of the tank, the user will decide to fill the tank using the pump. Users generally try to do this before the tank is completely depleted as there may be sediments at the bottom of the tank. If the tank is used to a very low volume, such sediments may end up in the building water supply.

When the user decides to fill the tank, they activate the water pump, either with a dedicated breaker or a switch on the wall. They generally do not interact with the pump itself apart from installation and maintenance

The user must determine when the tank is nearly full and deactivate the pump manually. This is done either by using the same method they use to determine water level (step 1) or by running the pump for a predetermined amount of time. If the user runs the pump for too long, the excess water is released from an overflow spout near the water tank until the user deactivates the pump.

After filling the water tank, some users take steps to purify water used specifically for drinking. This is done in individual batches - usually through boiling the water.

This Scenario shows three main pain points:

First, the user must intervene when the water tank is low. It is up to the user to determine if intervention is necessary using information that is not readily available. If they do not fill the tank in time, other members of the household will not have water readily available which can disrupt everyday activities. Additionally, sediment can enter the house water supply.

Second, the user must know when the water tank is full and turn the pump off in time. Failure to do so will result in wasted water and possible water accumulation on the roof. This requires them to wait while the water tank fills - a boring task in which they may get distracted.

Third, this process does not reduce the risk of fecal coliform contamination - in fact it can increase it. If a water tank is contaminated and then depleted, the amount of water deliberately left in the tank may contaminate any subsequent batches of water that are pumped in. Such contamination requires the user to manually decontaminate the water - usually through boiling. This consumes both time from the user and fuel that can otherwise be used for cooking. Because of this, some users neglect to treat the water, which results in the high rates of infection and fatality that affect Nepal.

The original design brief is intended to address only the third pain point. The contamination of fecal coliforms is the most pressing problem and the one the client is working to solve. However, the system is also intended to integrate within an existing home water system. This introduces the possibility of addressing the first two pain points as well. For example, a fully automatic system may provide increased desirability over one that requires regular intervention. It may also reduce the risk of unnecessary user intervention in a system that includes PRI's sensitive optical technology. For this reason, addressing these pain points is an integral part of the intended design.

3.3 Existing Solutions

Given that these pain points, mainly the risk of bacterial contamination, are prevalent throughout Nepal, there are already solutions in place to reduce them. By examining these solutions, it is possible to determine what is available, what has already been tried, how it is effective or ineffective, and whether features from these solutions can be incorporated into the intended design to improve it based on known effective features.

As stated in the pain points section, boiling water is a very common means of purifying water within the home and one of the most effective. (Shrestha, n.d.) This requires only a heat source, usually a gas stove or sometimes one fuelled by wood or biomass, and a metal basin in which to hold the water. However, the basin size determines how much water can be purified at a time, which may not be sufficient in some cases. This method also requires active input from the user as drawing attention away from an open fire can present a safety hazard.

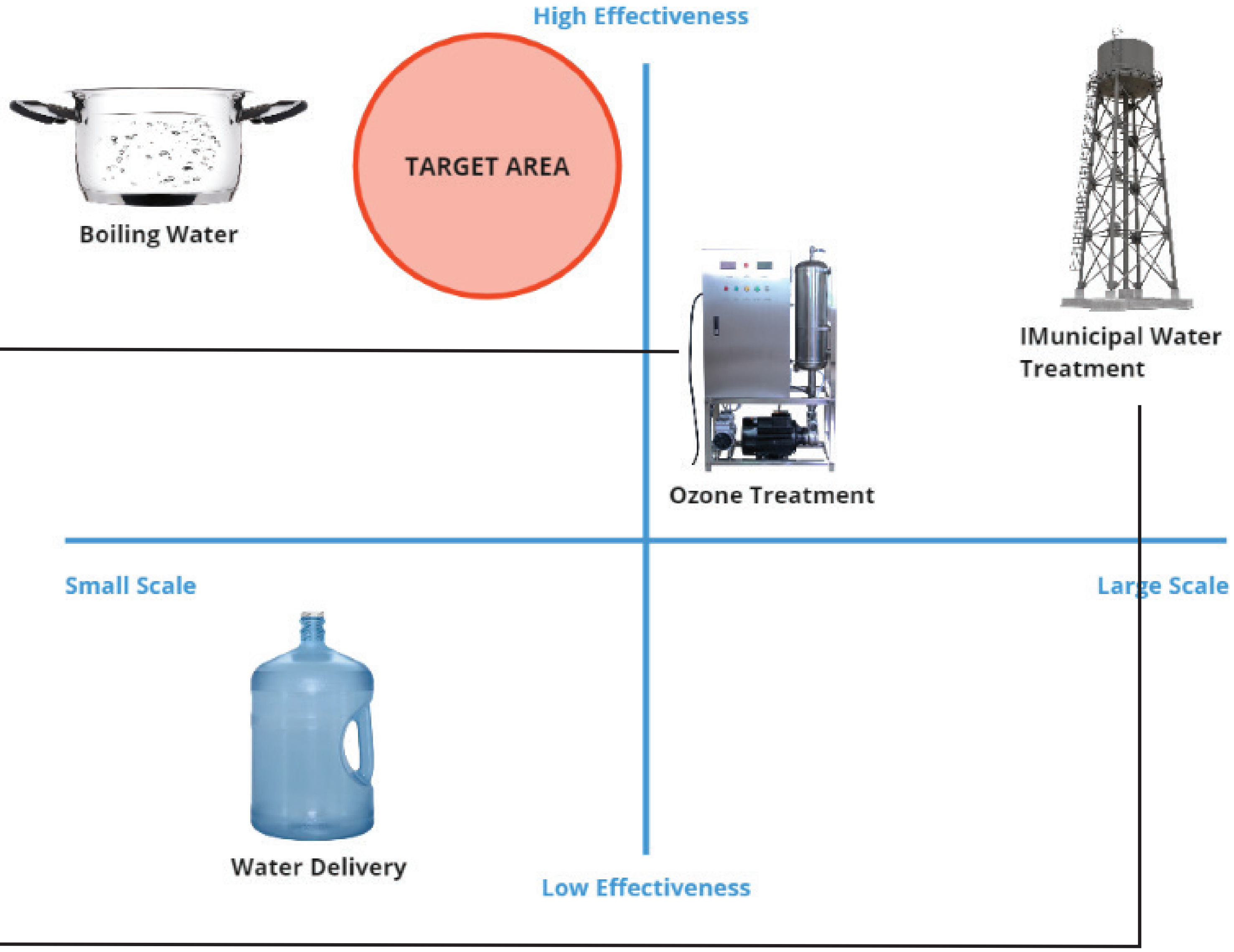
In some locations, the delivery of treated water is possible. Full 5 gallon bottles are distributed by truck and exchanged for depleted bottles, which are re-used. The water is then used directly for drinking or cooking in homes or small restaurants/cafes. In some cases (usually commercial locations) the bottles are inserted into a water cooler/heater unit. The water in the bottles is usually treated with filtration and ozone to eliminate pathogens. However, issues with this process and/or quality control mean this water can still present a hazard (Pant, 2016) - especially to individuals who are not previously exposed to it. As a result, people in Nepal do not always trust this source and elect for additional treatment. Part of the reason cooler/heater units are used is that the heating function brings water to a high temperature for extended periods, thereby killing the hazardous bacteria.

Ozone and ultraviolet light treatment is a common disinfection method used for small-scale public water distribution. Large and well funded buildings may have an ozone treatment system. Public areas may also have portable water treatment systems, especially if crowds are expected. However, these systems are generally not viable for home/small building use due to their high cost and complexity. Additionally, the process is dependent on a high-output power source. This would render it useless in the power outages which are common in Nepali cities.

While the lack of widespread industrial water treatment necessitates this project, it does exist in certain areas. This method operates by taking untreated water from multiple sources, filtering it, treating it with chlorine, and distributing it to an area of a city. The information used in this report comes from the Lubu water treatment facility in Kathmandu. A more detailed analysis can be found in the appendix. These co-ops are funded by the people who receive water from them and are run by those elected by those people. They employ full-time staff to maintain the facility and conduct regular quality checks on the water supply. This ensures that the end consumers are not subject to the bacterial outbreaks that pose a threat to the rest of the area. These plants represent the most desirable option for end users as this requires the least amount of effort for a very low regular cost. However, the high start-up cost and need for dedicated equipment and land mean a water treatment co-op is not viable in many areas throughout Nepal.

3.4 Solution Mapping

These solutions in Nepal mainly differ on two main metrics: effectiveness in eliminating bacteria, and scale. For example, boiling water is highly effective in eliminating bacteria but is only viable when serving an individual or family whereas water delivery/purchase can serve more users but is not as effective or trusted. When all described methods are mapped along two axes (effectiveness and effort) we see the only solution that is highly effective with high volume is industrial water treatment. However, we know that this option is not viable in most situations. Additionally, this solution is not applicable to the target user base (which was already narrowed down in the WHO section). In fact there is no highly effective solution that works on the scale of a 1000 liter water tank which is the intended target area. This leaves a gap in the market for a solution with the same effort and effectiveness as an industrial facility, but on a smaller scale without the startup costs and spatial constraints.



3.5 The Ideal Situation

Even though an industrial water treatment plant is not a viable option, it still gives insight into what the ultimate user experience should be. Ironically, it shows that the best user experience is the near complete absence of a user experience. The customers of an industrial facility do not need to collect water, process it in any way, or operate any device beyond a tap in their home. This is because a facility operates as a service and all aspects of water collection and processing are delegated to this service.

PRI is not in a position to offer water treatment and distribution services. However, it may be possible to design a device that operates like such a service, i.e. providing sanitary water with no retrieval or purification process done by the user. Every pain point (except bacterial infection) is due to the user performing an intervention task with their system - tasks that are absent from the way a user interacts with an industrial facility. Therefore, a desirable design should eliminate user intervention whenever possible.

3.6 Re-Defined Problem and Intended Solution

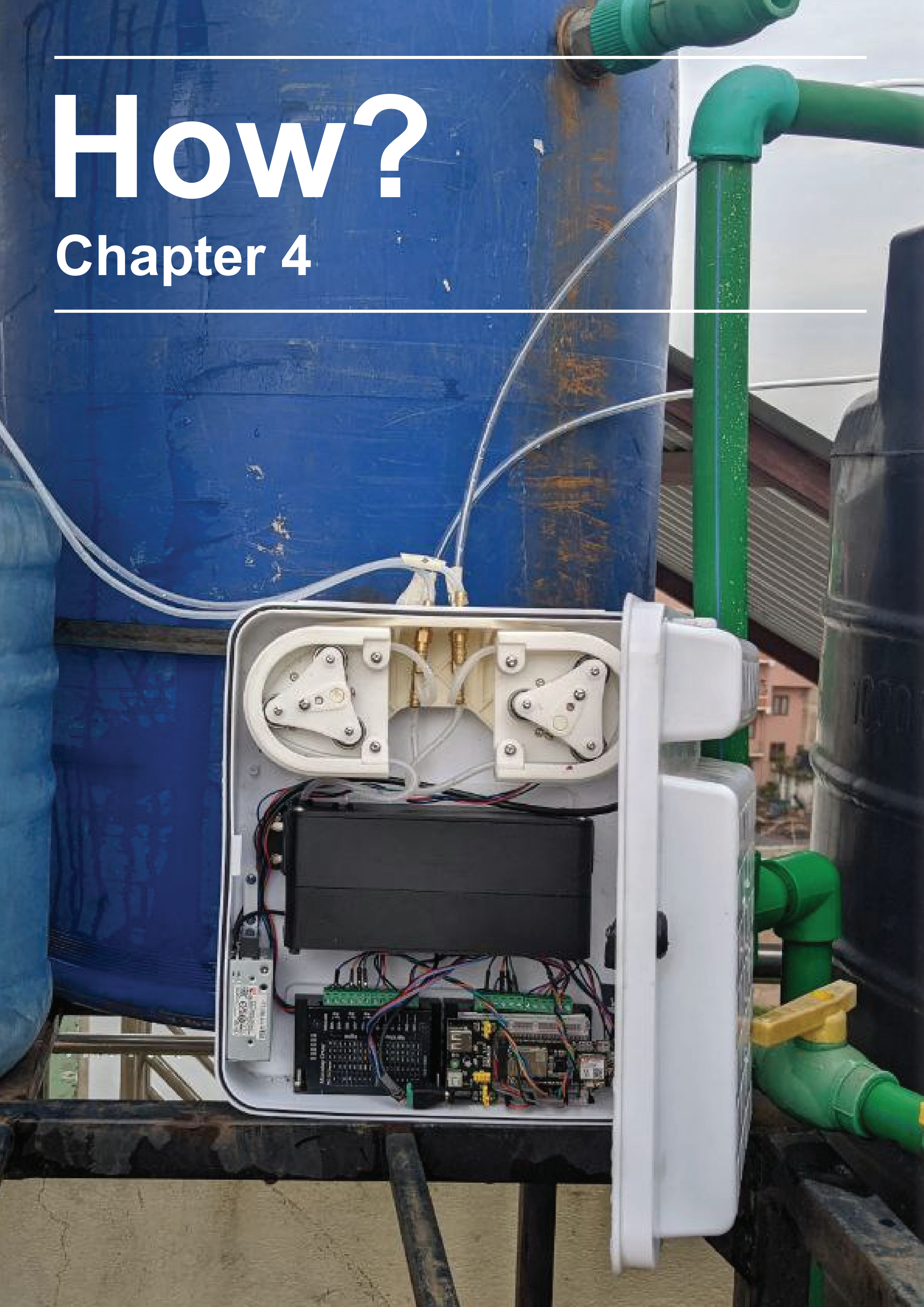
Given these insights go beyond what was issued in the original project brief, it is necessary to re-define the project scope into something that will result in a more desirable design. While reducing bacterial contamination and providing sanitary water is still of the highest importance, the project scope should include aspects of the user experience - or the absence thereof. It should also include the insights from the ‘Who’ section, such as the narrowed user group and that this design must be investor-worthy before it can reach the real intended user. Taking these into account, the revised problem statement reads as such:

“How do we demonstrate a solution that brings the experience and safety of a water treatment plant to a single home using a 1000 liter water tank using PRI’s optical engine technology?”

The water towe and chlorine mixing vessel at the Lubu water treatment co-op in Kathmandu, Nepal

How?

Chapter 4



Introduction

Now that the general scope of the problem and solution is defined, the technical implementation of the design can be explored - ‘How’ can one build a system that does what is required to solve this problem?. This section details the engineering problems associated with such a device and how they can be solved individually. This results in a prototype technology demonstration device that can be used for water testing and purification. This prototype is for technical demonstration only and serves to develop the hardware required to solve the more technical aspects of the problem. Once tested, the same hardware can be incorporated into a more holistic device that delivers the desired user experience. The technology was developed separately from the user experience parameters because the two had to be developed within a 5 week research sprint in Nepal. 5 weeks is already the minimum amount of time to develop the hardware, therefore it could not wait until the user research was complete. Therefore, the two had to be developed in parallel.

4.1 Necessity of a Technical Prototype

Optical engine technology and product category is new, therefore there should be a ‘works like’ prototype to determine what it takes to make the design work. This section also describes how this can work as an exploratory process to learn about domestic manufacturing in Nepal. This prototype is intended to prove the technical feasibility of this design and develop the mechanical hardware that will be implemented in the final design.

4.2 Disinfection Methods and Parameters

The first priority for the intended design is water disinfection. In order to achieve high effectiveness with low cost and effort, the right disinfection method is critical. Multiple methods and mechanisms were evaluated (Appendix: Disinfection Methods and Mechanisms). Most are already used in Nepal with varying degrees of effectiveness, but the pain points and general situation in Nepal show which methods could be more effective than others.

Desirable Qualities

High Effectiveness
The most important aspect of the purification method is its effectiveness in neutralizing fecal coliforms, therefore the solution must, above all else, reliably exhibit this quality throughout a variety of conditions.

Low Energy Consumption
Power outages are common, therefore the solution must have a low power consumption in order to run on either an internal or building-wide battery backup. This would also reduce electricity costs to the user and not over-stress the power grid once scaled to widespread use.

High Throughput
Multiple users are expected to use this system, possibly at the same time and for water-intensive purposes (showering, washing clothes and dishes etc.). Therefore it is important for the method to have sufficient throughput without becoming too large or losing effectiveness.

Acidity and Turbidity Resistance
Many water sources in Nepal have high turbidity and concentrations of dissolved solids. Therefore, the chosen method must be effective in spite of these factors.

Few/Inexpensive Consumables
Having consumables in the system may place an undue burden on the user both in cost and maintenance time. Therefore consumables should be avoided or at least be inexpensive and easy for a user to replace.

Low Effort
The method should not require excessive time or effort commitment from the user, i.e. it should not require the user to be present for it to function correctly beyond occasional maintenance. It should also not require the user to drastically change their existing habits to allow the system to work correctly.

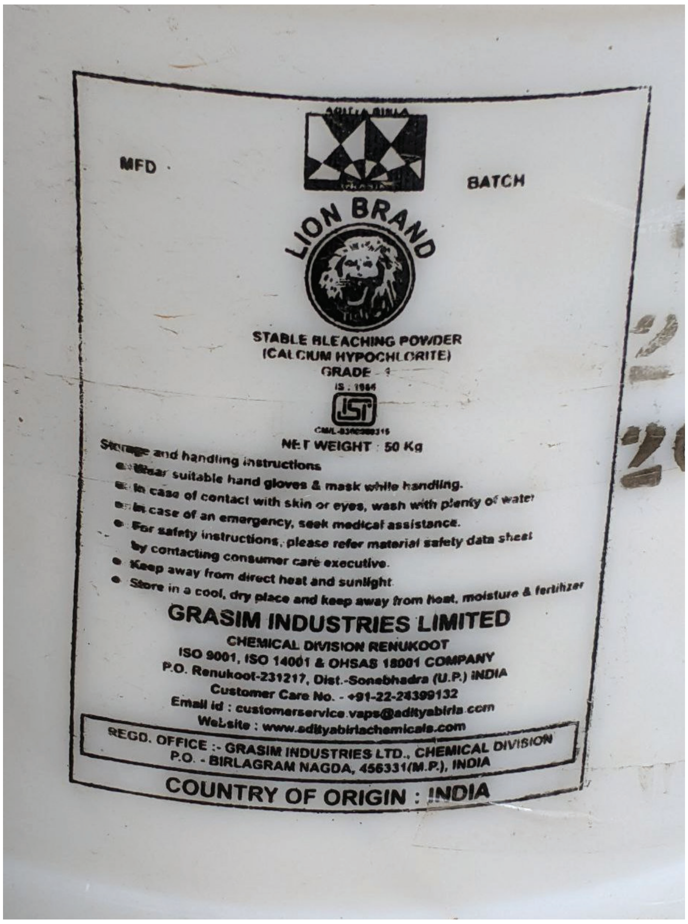
4.3 Disinfection Methods and Parameters

Based on these qualities, Chlorination appears to be the best purification for this system (see Disinfection Methods and Mechanisms in Appendix). Chlorine is highly effective against bacteria even in high turbidity/acidity conditions (though the amount of chlorine required depends on these factors) (Oxfam, n.d.). Additionally, the reaction does not require additional energy to take effect. Chlorine can be added to water containers even beyond the system parameters of 1000 liters and does not require any additional effort from the user. Its effectiveness is proven in industrial capacity by existing water treatment plants both in Nepal and abroad in countries such as the U.S.A (U.S. Environmental Protection Agency, 2022). The chlorine will be distributed as a diluted solution made from calcium hypochlorite powder as it is alreadt commercially available in Nepal. This will allow for a simple mechanism to inject it into the water tank, vs an inherently more complex powder feeder. A dilute solution also reduces the potential hazard to the user by not storing concentrated chlorine in their immediate vicinity.

That is not to say chlorine is the perfect disinfection method. There are several drawbacks. First, the chlorine itself is a consumable substance, though a relatively inexpensive one. Nevertheless, it still puts a burden on the user to purchase and replenish, and safely store a chlorine solution. The concentration of chlorine is also critical to the effective and safe operation of a system. Too little chlorine and some bacteria may survive the disinfection process. Too much will make the water smell strongly of chlorine and presents a health hazard (U.S. Environmental Protection Agency, 2022) to the user. Either would compromise user health and trust.

4.4 Determining Chlorine Content

For the system to be effective, the proper amount of chlorine should be applied. However, the volumetric range of chlorine necessary to purify water depends on multiple different factors such as acidity, and turbidity. Measuring those factors with available sensors (especially pH) will be impossible for the intended use case. Therefore, the device will deliver a constant ratio of chlorine solution to treated water. According to PRI a safe dosage range for chlorine is 2 - 4 milligrams per liter of water using a 1% calcium hypochlorite solution. Based on their internal research, this will yield the safe residual chlorine level of 0.2 to 0.5 mg/l after disinfection (Branz, 2017).Given that the device will not know where in that range the optimal chlorination ratio is (for that given moment) it will instead always dispense 4 mg / liter. This is because not enough chlorine might result in further bacteria growth, but adding the maximum amount (that is considered safe for consumption) will ensure that all pathogenic bacteria is neutralized even in unfavorable conditions.



MFD

BATCH

LION BRAND

STABLE BLEACHING POWDER
(CALCIUM HYPOCHLORITE)
GRADE - 1

NET WEIGHT : 50 Kg

Storage and handling instructions
- Wear suitable hand gloves & mask while handling.
- In case of contact with skin or eyes, wash with plenty of water
- In case of an emergency, seek medical assistance.
- For safety instructions, please refer material safety data sheet by contacting consumer care executive.
- Keep away from direct heat and sunlight
- Store in a cool, dry place and keep away from heat, moisture & fertilizer

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CHEMICAL DIVISION RENUKOOT
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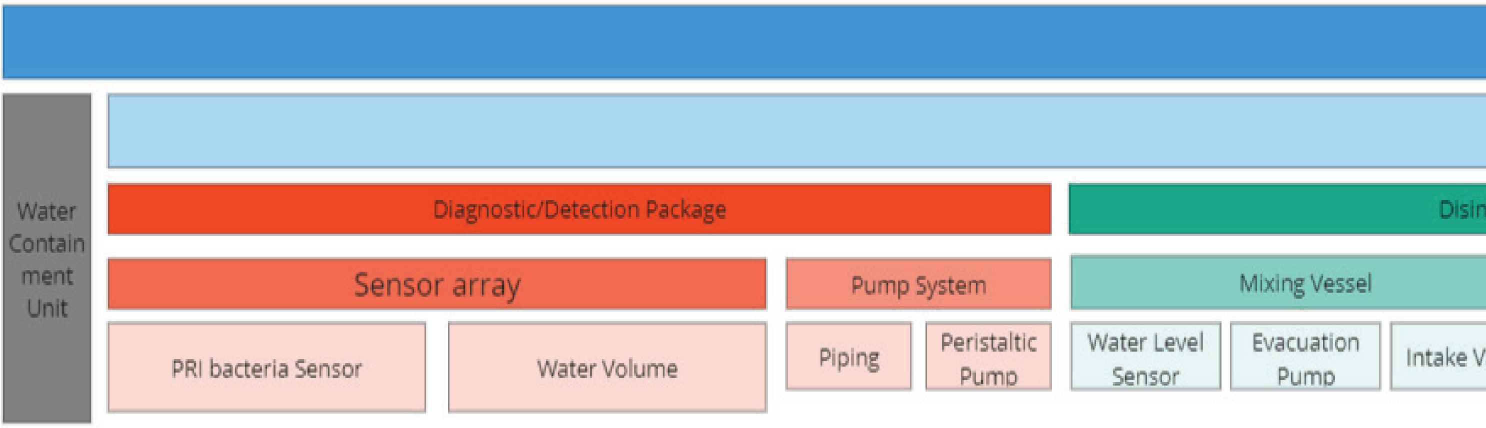
P.O. - BIRLAGRAM NAGDA, 456331(M.P.), INDIA

COUNTRY OF ORIGIN : INDIA

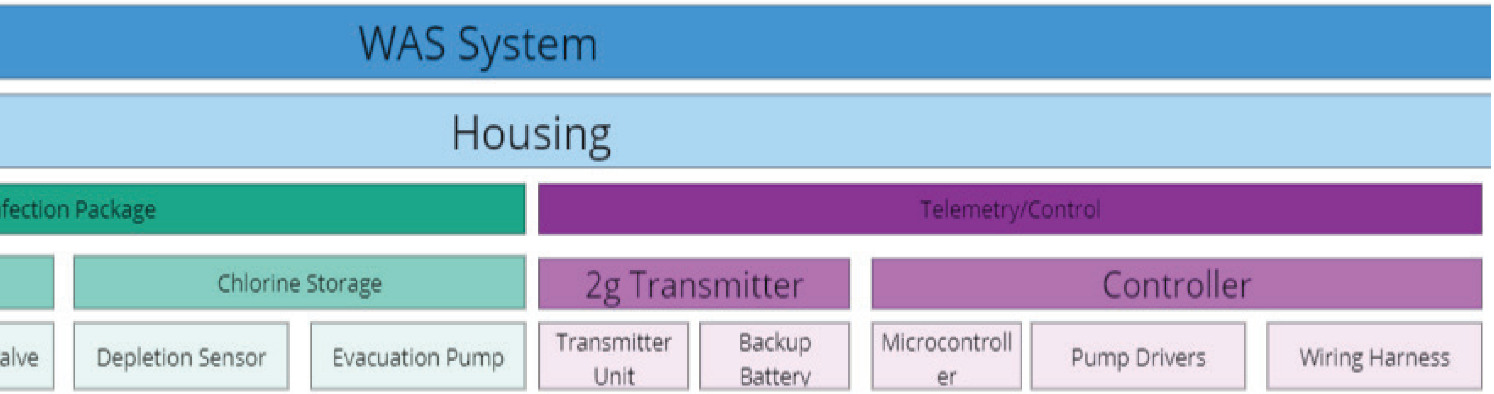
Industrial quantities of Calcium Hypochlorite found at the Lubu Water Treatment plant

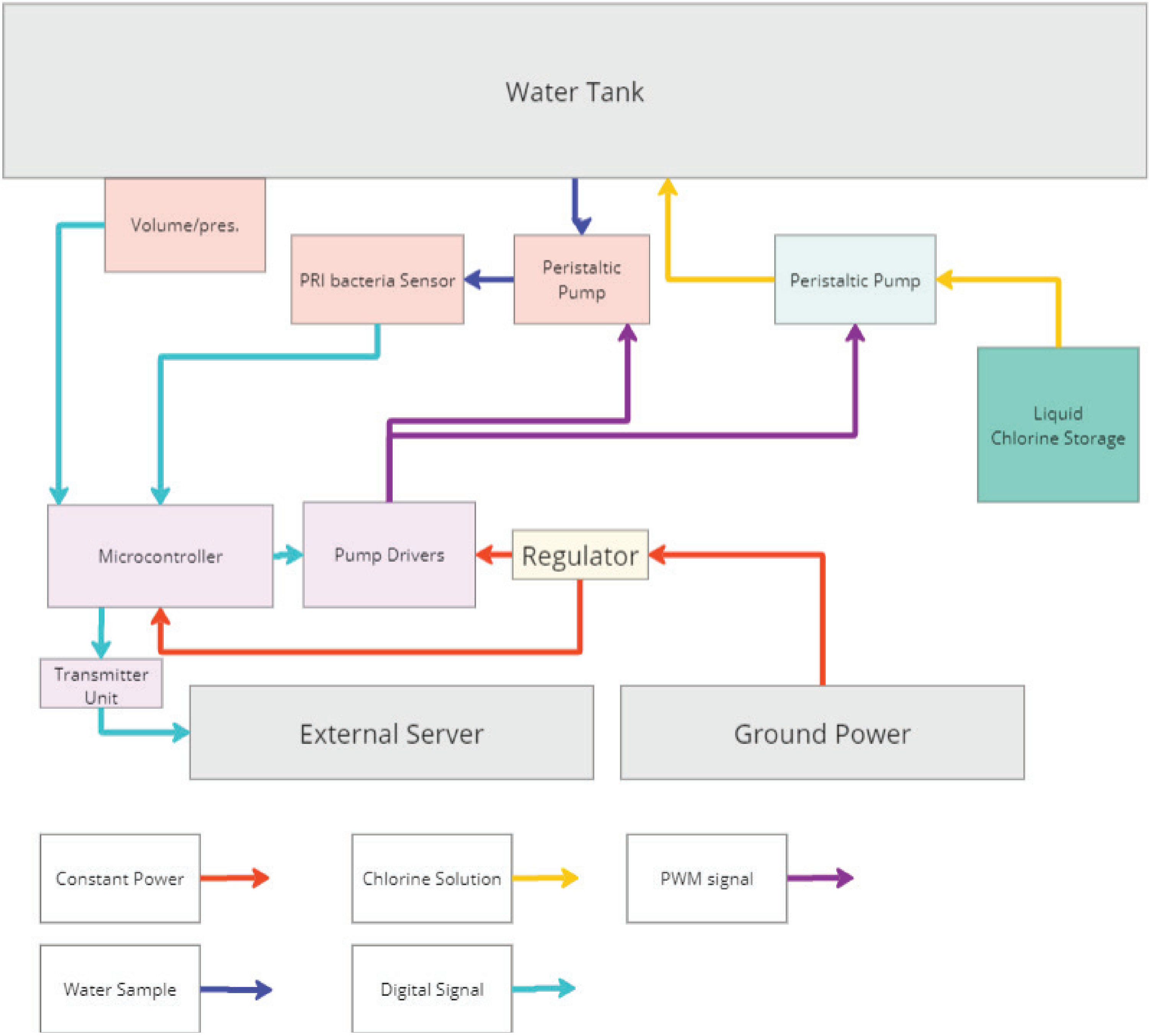


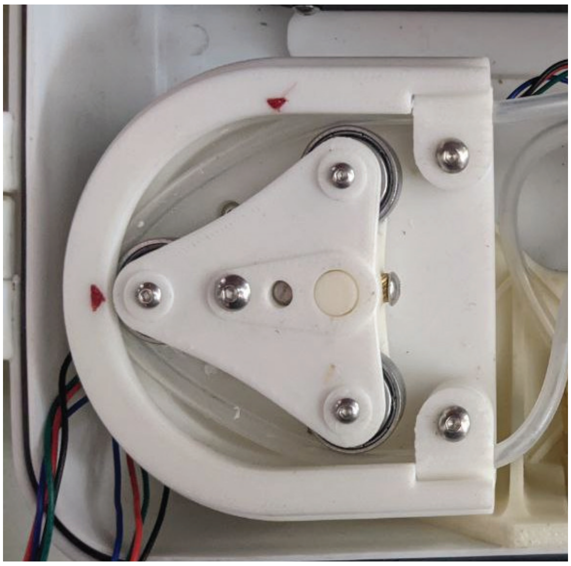
4.5 Initial Prototype Development

Now that chlorination is secured as the purification method, a prototype system can be designed around it. This diagram represents the first prototype iteration. Each component will be further described in their respective sections. Overall, the system operates by using a peristaltic pump to inject a water sample from the water tank into the PRI bacteria sensor/Turbidity sensor. The integrated PRI sensor determines if the bacterial level is over the safe threshold. If so, the microcontroller will determine the water volume inside the tank and use the other peristaltic pump to dispense the appropriate amount of chlorine. In this case, the 2g transmitter unit will send data about the event to an external server and also notify the user their water supply has been contaminated.

This system architecture was used to create a limited scope prototype to test if such a device could dispense chlorine in the required quantities with adequate precision and whether or not the optical engine could return accurate readings when modified to be an integrated sensor instead of as a standalone device as originally intended by PRI. The following sections detail the design process and testing that went into each individual system function/module.


WAS System
Housing
fection Package
Telemetry/Control
Chlorine Storage
2g Transmitter
Controller
alve
Depletion Sensor
Evacuation Pump
Transmitter Unit
Backup Battery
Microcontroller
Pump Drivers
Wiring Harness


Water Tank
Volume/pres.
PRI bacteria Sensor
Peristaltic Pump
Peristaltic Pump
Liquid Chlorine Storage
Microcontroller
Pump Drivers
Regulator
Transmitter Unit
External Server
Ground Power
Constant Power
Chlorine Solution
PWM signal
Water Sample
Digital Signal



4.5.1 Chlorine Delivery

Given that the system will use a liquid calcium hypochlorite solution, a pump must be used to inject it into the water tank. Such a pump must be able to withstand prolonged exposure to chlorine and precisely modulate the output volume based on the amount of liquid to disinfect. Peristaltic pumps offer an ideal solution based on these parameters. Their internal silicone tubes are inherently chlorine resistant and prevent any other components from being corroded. Additionally, their output can be very precisely modulated, they do not require priming, and the output can be reversed.

Unfortunately, such pumps may not always be available in Nepal and the ones that are may not have the precision required. This necessitated designing a peristaltic pump for low-volume manufacture in Nepal. Given the geometry required to make a peristaltic pump, 3d printing was the manufacturing method of choice. There is a precedent for 3D printed peristaltic pumps (Behrens, 2020). However, their use of gear reduction meant that their long-term reliability was not enough for this application. Instead a new peristaltic pump was designed for this purpose using a direct drive setup and components that are commonly found in Nepal.

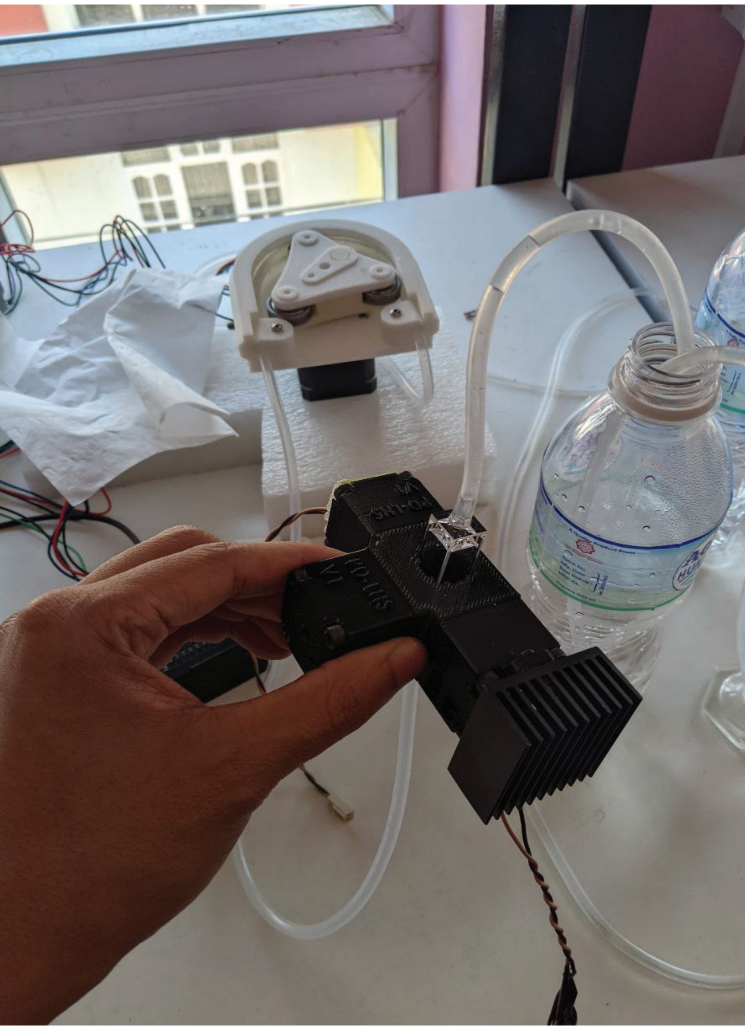
The pumps went through three iterations before arriving on a geometry that worked sufficiently. At first, a two-rotor design was used in order to reduce the torque needed to turn the pump. However, this was prone to leaking and would not hold pressure above 20 cm of head. To fix this, the distance between the bearings and outer wall was reduced, but the problem remained. Next, a three-rotor design was used. This drastically increased the power needed to turn the pump, but made it capable of holding more than 200 cm of head.

Top to Bottom: The 3d printed pump described in Behrens, 2020. The first iteration of the peristaltic pump for this project. The final iteration of the pump used in this project.

Right: First test setup to demonstrate feasibility of a flocell in an optical engine instead of an open cuvette

4.5.2 Pump Testing

Using a graduated cylinder, the output was calculated to have a resolution of 0.1 ml - more than sufficient for this application. This test was also able to determine that the pump requires 2000 steps per milliliter. Given that the prototype would require two pumps - one to collect the sample and the other to dispense chlorine, a bracket was constructed to hold them in place within the casing. This created a modular pump assembly that could be inserted into any box so long as an outlet was placed at the bottom for the input and output hoses. The pumps have since been tested for close to 8 non-consecutive hours so far at the tolerances remain sufficient to hold 200 cm of head and there have been no mechanical failures. These tests also show this setup is capable of repeatedly dispensing 76 milliliters of chlorine solution which is sufficient to disinfect a five gallon water container. It is also capable of drawing a water sample through the optical engine without producing bubbles that would otherwise compromise an accurate reading.



4.6 Optical Engine

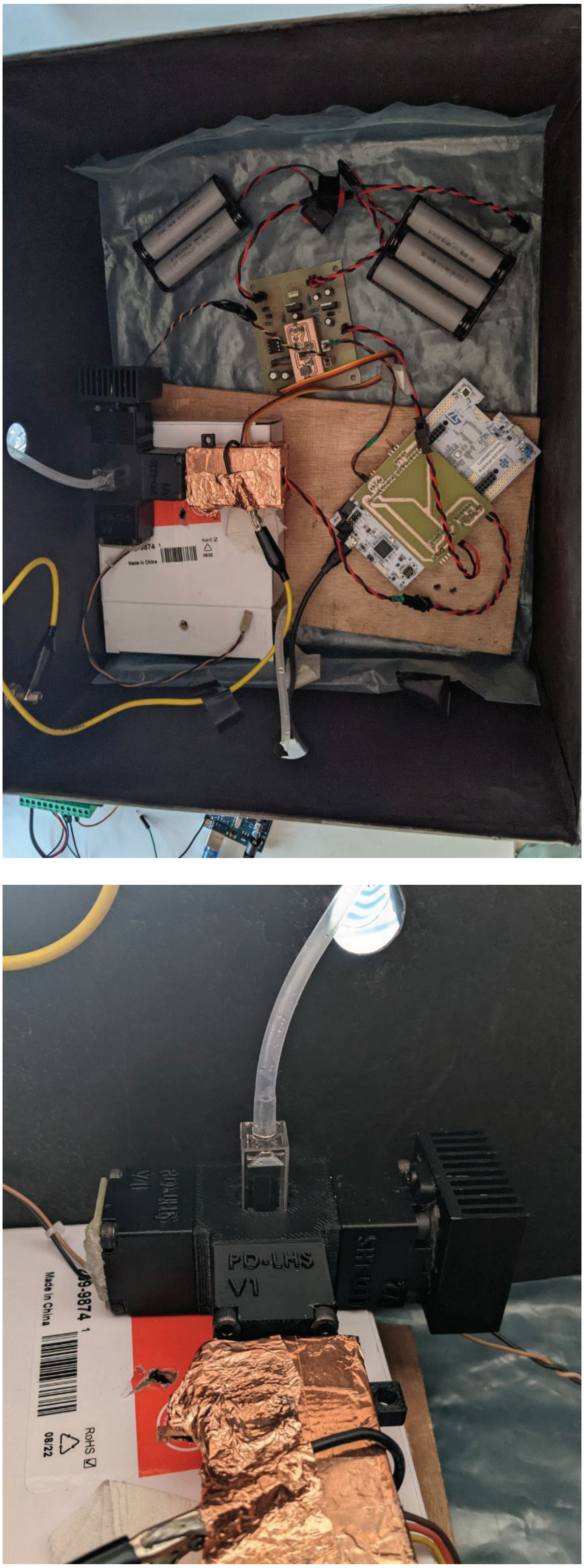
The optical engine is the sensor assembly responsible for detecting and quantifying bacteria in a sample. It works by shining a light of 365 nanometer wavelength into a quartz cuvette containing a water sample. Under these conditions, the proteins specific to fecal coliforms like E Coli fluoresce. This fluorescence is focused by a lens into a photodiode, which allows onboard amplifiers and processors to determine if the amount of bacteria in the sample is above a safe threshold. This setup is designed to work as a standalone device. As such it already has a casing designed for it by PRI. However, this casing is not conducive for use as an integrated sensor within this design. Therefore, it is necessary to analyze the optical engine and design a new casing that will allow it to integrate into the proposed design while still remaining effective with minimal changes to the electronic hardware.

4.6.1 Re-Design Criteria

While most of the optical engine hardware can be transferred to the new design, some design changes had to be made. An open cuvette is conducive for manual sample loading, but would present a leaking hazard within an automatic system. This component was changed to a closed flowcell and the housing was modified to fit this component. However, the flowcell presented the possibility of incorrect readings. For example, it was hypothesized the change in optical quality could affect the readings unpredictably. The hoses leading outside the system also had the potential to act as light guides. The optical engine requires complete darkness to operate effectively, therefore any additional light had the potential to compromise the system.

To determine effectiveness with the flowcell, an experimental setup was created with an optical engine inside a faraday cage. This is the standard setup used by PRI to test optical engines and has been proven to return accurate results. The only difference between the typical setup and this one was the use of a flowcell with water lines exiting the faraday cage. A water sample would then be pumped in using a peristaltic pump and a reading would be recorded with an attached computer. The test would then be repeated after replacing the flowcell with a cuvette and the data compared.

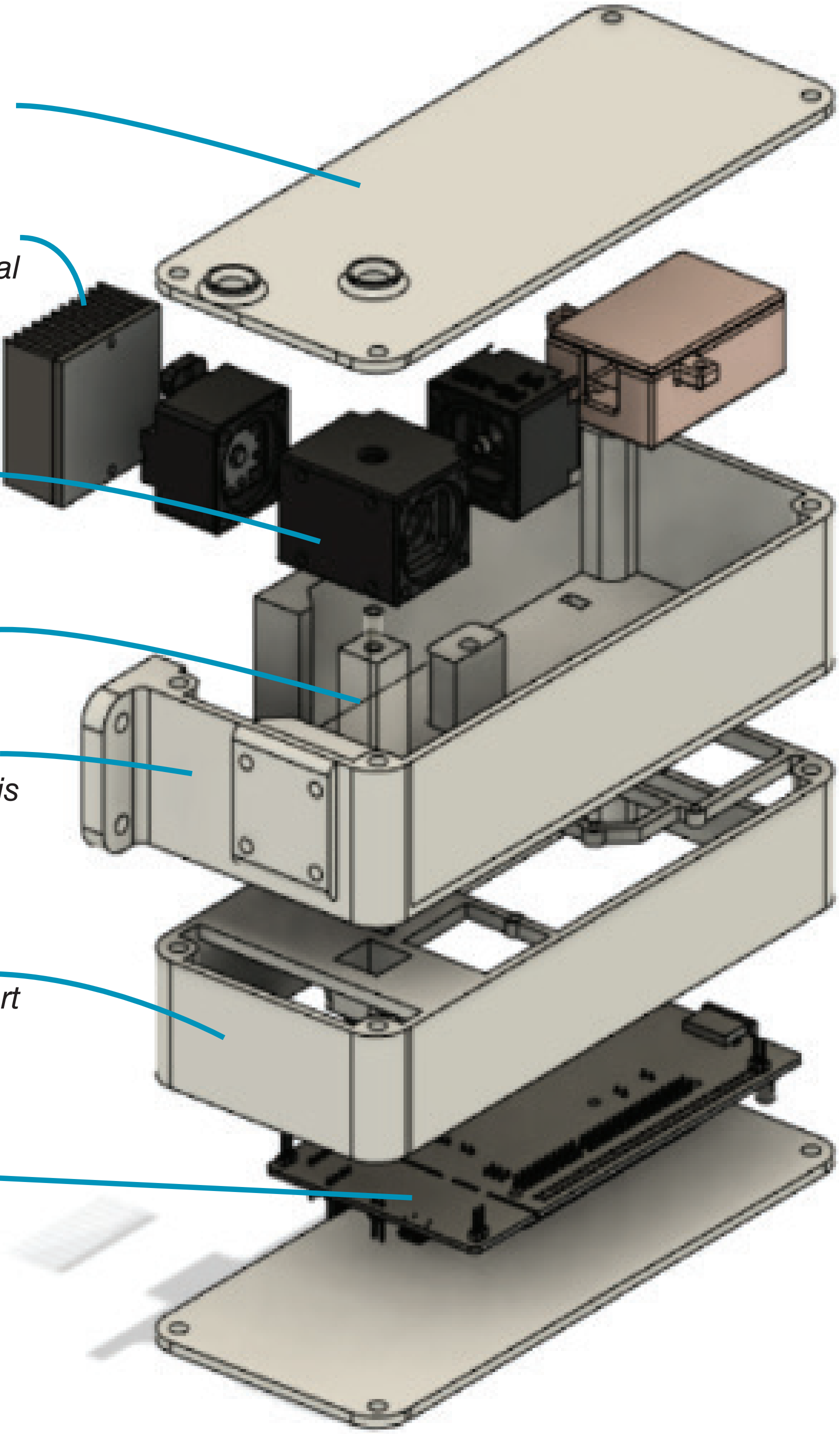
The test shows that the use of a flowcell does affect the optical engine readings in relation to readings from the cuvette. However, the readings are proportional to what is expected. This may be due to the different optical characteristics of the flowcell versus the cuvette. While this demonstrates the flowcell and the cuvette are not interchangeable, a flowcell system is still viable and would only require a different threshold to determine water safety. Mapping the flowcell values to the cuvette values would require extensive further testing, however PRI has deemed these results sufficient to continue developing a flowcell system, which will then be used for testing with PRI staff.



Testing the flowcell in PRI's optical engine testing setup to determine if it would effect its output.

4.6.2 Re-designed module

Now that the optical engine can be modified to fit the new design, the casing must also be modified. The design from PRI is a 3D printed three-layered box containing the electronics described in the previous section. This is sufficient for standalone use, but must be modified for use as an integrated sensor. The main differences between the two are the inclusion of a flowcell instead of a cuvette, the additional water lines connected to the pump, and the need for mounting points to secure the assembly to the main device housing.



Cover
To secure optical engine and water hose

Heat Sink
To maintain temperature in for the Optical Engine LED’s

Optical Engine
To detect bacteria in a water sample

Flowcell
To store water sample during detection

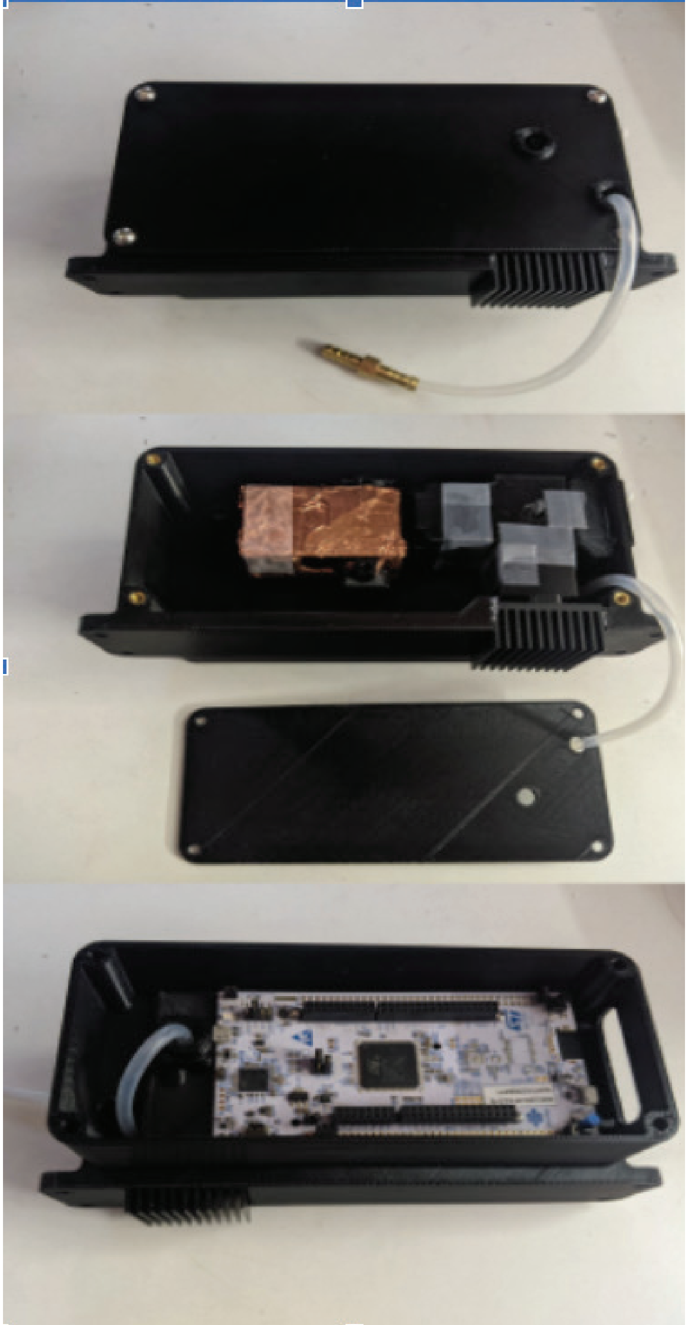
Shielded Casing
The main casing for the optical engine is shielded to prevent EM interference

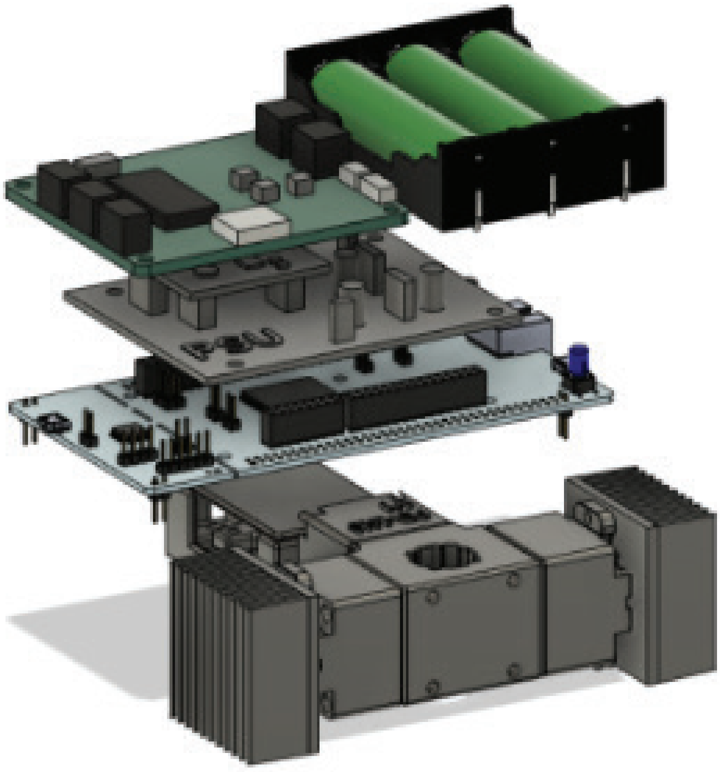
Processor Casing
To hold STM32 board and allow for short wires to optical engine

STM32
To interpret signals from Optical Engine

These considerations were addressed with a new casing design. This includes only the optical components, TIA and driver board as the other electronics could be stored elsewhere inside the case. The optical components were shielded from light in all directions by the case with the only openings being for the heat sink and water lines. The inlet and outlet water lines from the flowcell exit the casing in the same direction to allow easy connection to the pumps. It also uses the layered design of the PRI version, but with additional mounting points that bolt to the outer casing. The prototype casing was used only to hold the optical engine in place for pump testing and has not been tested with a working optical engine. This is because there are no working optical engines available beyond those used for testing at PRI, due to the lenses being very difficult and time consuming to produce in low quantities. However, PRI has verified that this casing is fit for purpose and would allow the optical engine to work correctly.

Despite these improvements, further iterations will still be necessary. For example, this casing was designed before a battery and BMS system were considered necessary. PRI is also developing a system that uses two LED's that will automatically detect turbidity. Therefore it is necessary to re-design the casing to reflect these new considerations, which will be implemented in the subsequent iteration.





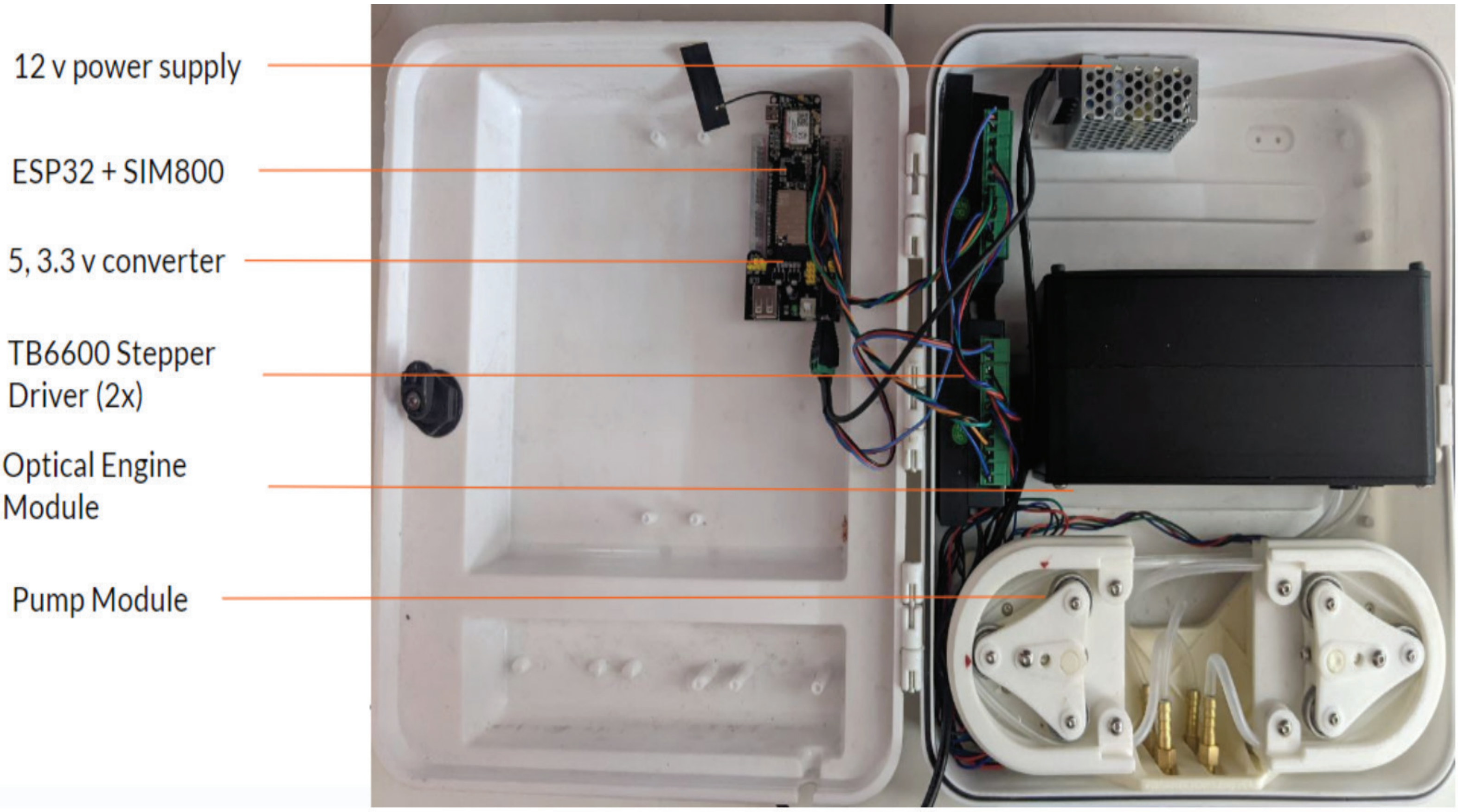
Top Right: The initial prototype optical engine housing
Bottom Right: The new optical engine design to be used in subsequent housing iterations

4.7 Other Considerations

Beyond the optical engine, there are other electronic components that complete the system. These components are not necessarily the optimal components for the final iteration. They were chosen for ease-of-use, robustness, and immediate availability. The reason for this is because developing the pump system and optical engine re-designs had higher priority. Therefore the components that were used to test these modules were used in this prototype due to their known functionality and compatibility.

With multiple heat-generating components (i.e. stepper motors, stepper drivers, transformers and LEDs) in an enclosed space, overheating presents a threat to system integrity. However, the intended application of this device presents a solution to this problem. Such a system does not need to run constantly. For example, the industrial treatment plants test each distribution point every other day and claim it takes 24 hours for bacteria to grow in their conditions. Therefore, the device can have a very low duty cycle(once per day to once per hour) while still re maining effective. This would allow thermal conditions to stabilize between tests and reduce the amount of heat produced by the device

The enclosure can also provide some degree of heat mitigation. By increasing the internal volume of the enclosure, air can circulate through the individual component heat sinks. Combine this with a low duty cycle and this consideration can also help return the internal temperature to ambient. The initial prototype uses a plastic off-the-shelf enclosure purchased in Nepal. Such an enclosure was chosen due to a water resistance gasket, locking feature, and low cost. However, future iteration will require a larger enclosure and the current one has insufficient internal volume. While also considering heat buildup mitigation, a larger container is necessary. However, plastic containers in a larger size are difficult to source in Nepal. Therefore, it is necessary to use a metal enclosure for this device. Sourcing issues like this one also demonstrate that mass-producing this device in Nepal will be difficult without understanding what can be sourced from where.



4.8 Resulting Prototype

Using the pump module, the revised optical engine enclosure, the electronics package, and chosen enclosure, the resulting prototype was constructed and demonstrated for PRI. This consisted of performing two key functions: drawing a sample that could be read by the optical engine and dispensing chlorine in a predetermined and precise quantity. The optical engine was not tested inside this prototype device as the optical components were not available at the time. However, the setup was inspected by experts in the technology and declared fit-for-purpose. Therefore injecting the sample into a mockup optical engine was a sufficient test.

Overall, the tests proved the device is satisfactory as an initial technology proof-of-concept. It performs the required functions such that the individual modules (with some modification) can be incorporated into a more holistically complete device. That said, there is still further improvement required before that happens. Nevertheless, it demonstrates that automatic water sampling and chlorine dispensing is technically feasible.

4.9 what else was learned

Another important aspect of the 'How' section, beyond how it works, is how it is made. A consistent issue when developing the prototype was sourcing components and materials. Nepal relies heavily on imports to build technical devices - especially for electronic components. Appliances are typically manufactured out of country by foreign companies and then imported to Nepal. This presents a barrier to an effective design for two reasons: first, the client has specified components should be sourced in Nepal whenever possible in order to stimulate the economy and produce jobs. Second, importing parts that are not already commercially imported has a very long lead time and a risk they might not make it into the country due to the relatively limited shipping infrastructure. Therefore, any outside components or manufacturing would be avoided whenever possible.

While this may limit the components used for the design, manufacturing in Nepal presents some unique opportunities for what can be created on a small scale. For instance, manually machined parts present a viable option compared to imported barts due to the low material and labor costs. PRI has demonstrated this already by electing to do an initial production run of their standalone WAS devices out of sheet metal instead of 3D printed plastic.

Prototype demonstration using PRI's rooftop water system

What?

Chapter 5

Introduction

Based on the findings from the Who, Why, How section, we have a general idea on what features should be included on the final design. These features/functions are divided based on the three main stages in the product life cycle: General use, Manufacturing, and Maintenance.

5.1 Required Functions and Features

5.1.1 Water Purification

The feature that separates this design from others from PRI is the ability to purify water. As stated in 4.3, this will be done through a liquid calcium hypochlorite solution injected by the pumps developed in the HOW section. To make this a viable product, however, additional features should include a container for the chlorine and a way to inject it into the water tank.

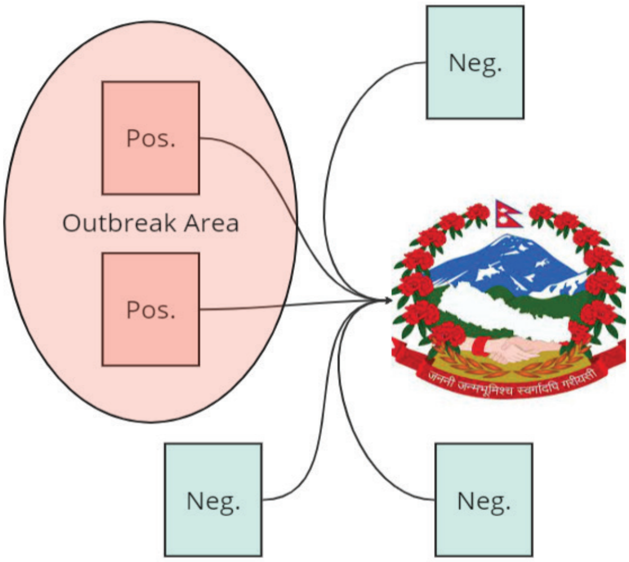
5.1.2 Water Testing

In order to aid the water purification process, the device should know if the water must be purified - more specifically, if the concentration of fecal coliforms is above an unsafe threshold. Given that this design also exists as a technology demonstrator for PRI’s optical engine, we know this will be the technical implementation of this function, along with the hardware developed in the HOW section. However, the overall design must use the existing optical engine as an integrated sensor, i.e. it must be operated repeatedly and automatically

5.1.3 Reduce User Intervention

The WHY section revealed several pain points with the current water tank setup - all of which come from the need for user intervention. By eliminating the need for user intervention, these pain points can also be solved. This design is in a unique position to do this because it is already integrated in the system they have and may be able to use what sensors it has to automate where the user would normally intervene. This implementation must still be explored in the next project phase, but incorporating it into the product will likely increase its desirability and the chances it will be adopted by the user.

5.1 Required Functions and Features (Continued)

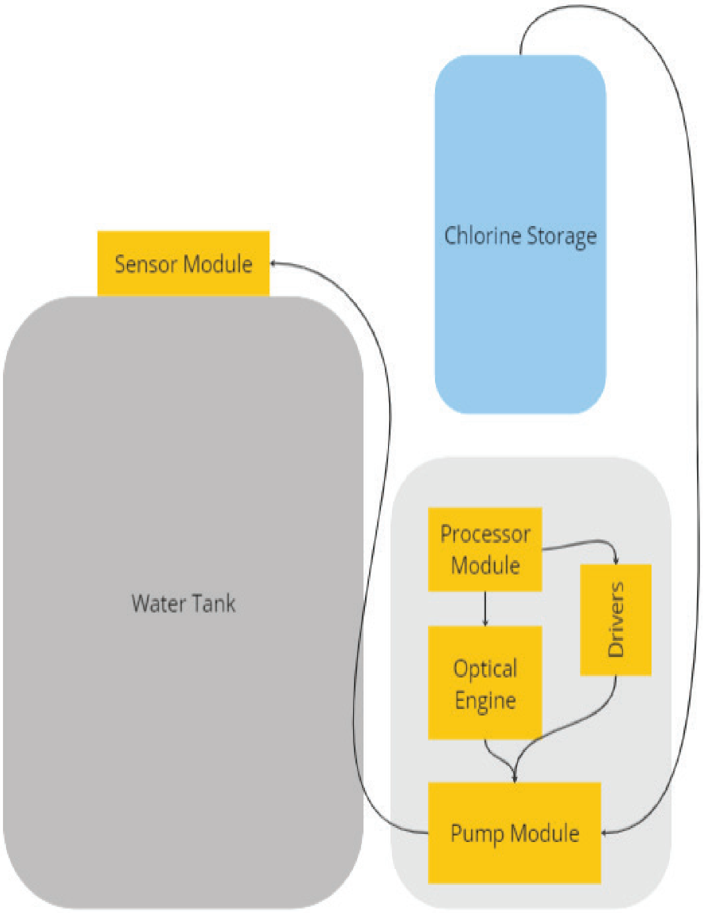


5.1.4 Telemetry

One of these functions is data telemetry. This feature was not examined earlier in the project due to its relative simplicity and relatively low impact on the final design. The purpose of telemetry is to transmit when bacteria detection happens such that the data can be collected and used to chart bacterial outbreaks. This feature is of interest to PRI as it can help determine if an early stage prototype is working in the field. Later on, the outbreak mapping can be used by health authorities to control the pathogen spread. However, this mapping is beyond the scope of the project. Instead, the device should be able to transmit data to a remote server and the additional functions can be added later.

5.1.5 Weatherproofing

This device is meant to operate outside on the roof of a building in order to be close to where the water tanks are positioned. This environment is subject to wind, rain, (relatively) extreme temperatures, and direct sunlight. For example, it must be able to operate in 40 degrees and direct sunlight without overheating, while remaining water resistant during Nepal's rainy season and operable at 0 degrees in the winter.



5.1.6 Modularity and Reconfigurability

This design should be modular and reconfigurable, i.e. sensitive or dangerous components should be inside self-contained 'modules' that can be removed and re-organized. This will allow for components to be swapped in the field (see 5.2.3.3.) and for the components to be reconfigured for certain use cases. This is relevant to this design because of the strict manufacturing and cost constraints associated with creating a product for the Nepali domestic market. Cost, logistics and manufacturing/material availability will present a barrier to many potential users acquiring this device regardless of how efficiently it is designed. For example, people in rural villages that might have a great need for such a device might not be able to afford it. Such villages might also be accessible only by trucks on dirt roads, making transportation or a large and heavy device difficult and expensive. However, having modules would allow for them to be transported independently of any enclosure and then attached to a locally produced enclosure. This would reduce costs, transportation difficulties, and potential barriers to some users.

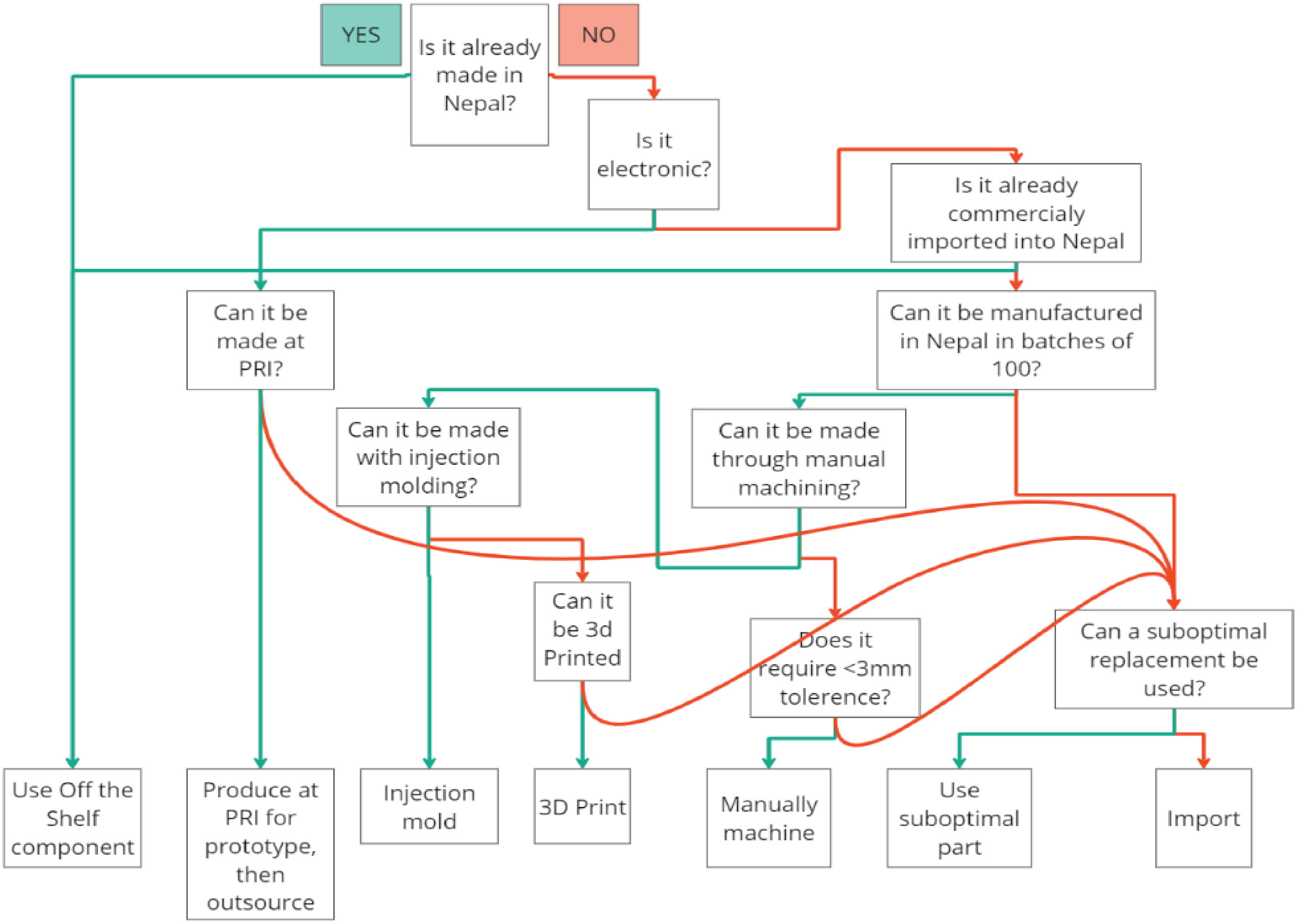
5.1.7 Domestic Manufacturing

According to PRI, the design should be manufactured in Nepal using Nepali resources wherever possible. This is a non-negotiable requirement and serves to protect and create jobs in Nepal while stimulating the local economy. However, not all components can be sourced locally. To determine how components should be sourced, the following decision flowchart was created.

By using this chart, the subsequent design decisions can be implemented in a way that is locally produced, thereby shortening the supply chains and creating a more economically sustainable business for PRI and Nepal.

5.1.8 Low-Volume Manufacturing

Part of working within the constraints of domestic Nepali manufacturing is low-volume hand machining. High output methods like injection molding and die stamping will likely not be available for the initial production runs of this product. For that reason, methods like 3D printing and manual machining can be used instead. In some aspects, this provides an opportunity instead of a disadvantage. The lack of tooling associated with 3D printing can allow for small design changes to occur during the production run in response to user feedback and testing data. Additionally, the low domestic raw materials and labor costs in comparison to import taxes make domestic manual machining a possible cost effective alternative.



5.1.9 On-site maintenance

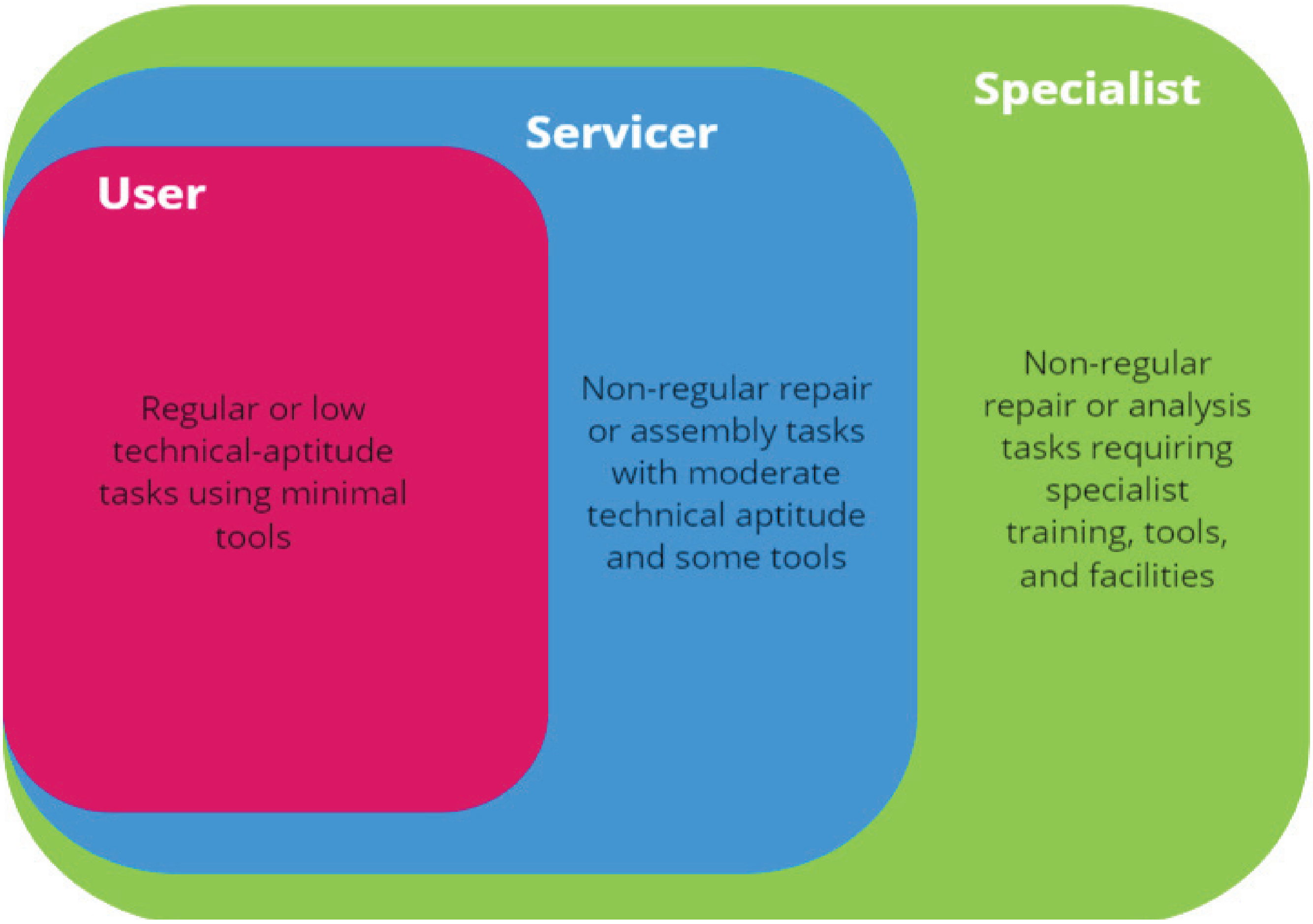
The device must be able to be serviced in the field, i.e. components must be repaired or replaced without moving the device from where it is installed. This is because the device will work as a critical piece of public health infrastructure and removing it may expose the user to pathogenic bacteria. Additionally, its large size and the limits of transportation infrastructure in Nepal mean returning the device to PRI for repairs would be costly and time-consuming. Therefore, it is more effective to repair the device where it is. This is especially important in the early stages of this product, where field testing might require the constant replacement and upgrades of components throughout the fleet of devices currently in the field

Modular Design

This hierarchy and division can be accomplished with a modular system. Instead of placing components within a large enclosure (like the technical prototype) they can be placed within their own smaller enclosures and connected to each other externally. This will ensure sensitive components are well protected while allowing the module to be replaced in the field by disconnecting the old one and connecting the new one. The old module can then be repaired offsite by a specialist. This approach will also allow for upgrades throughout the testing process and product lifecycle, so long as the modules maintain their compatibility. In this case, the modules can be divided into pumps, optical engine, electronics, and external sensors.

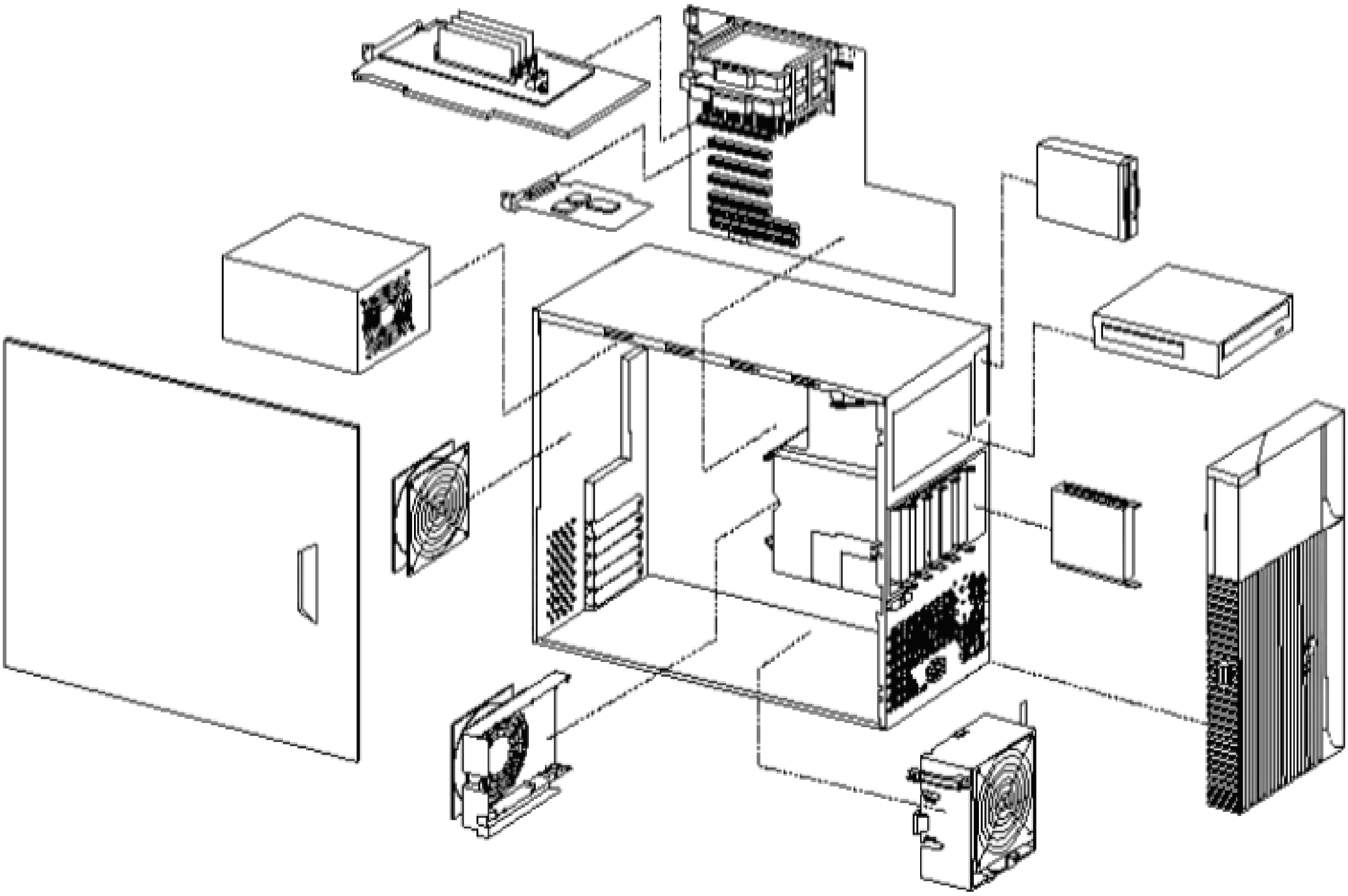
User vs. Servicer

Repairing the device on-site brings the possibility of user repair. This is preferable to traditional repair schemes where a specialist must come to the user to diagnose and correct issues as it would reduce cost and repair time. However, the device will contain sensitive electronics and dangerous voltages - certain components the user should not be expected to service. Additionally, the user should not be expected to have the technical knowledge required to diagnose/repair a system issue. Therefore, there is a hierarchy of system components that are part of regular use, user repair, and specialist repair.



5.2 Product Analogy

To quickly summarize the intended design and its features, an analogy can be used. In this case, the product should act like a computer server. For those who use them, they are a critical piece of infrastructure, but they are rarely seen, heard, or touched by the user. They are designed to run constantly with minimal maintenance, but when they do require maintenance, it is done quickly on-site, usually by the user or non-specialist. They are modular for this reason, and also to protect the sensitive components inside. The only difference (besides intended function) is that the design must be built within Nepal, but this constraint does not necessarily mean the design cannot operate like a server.



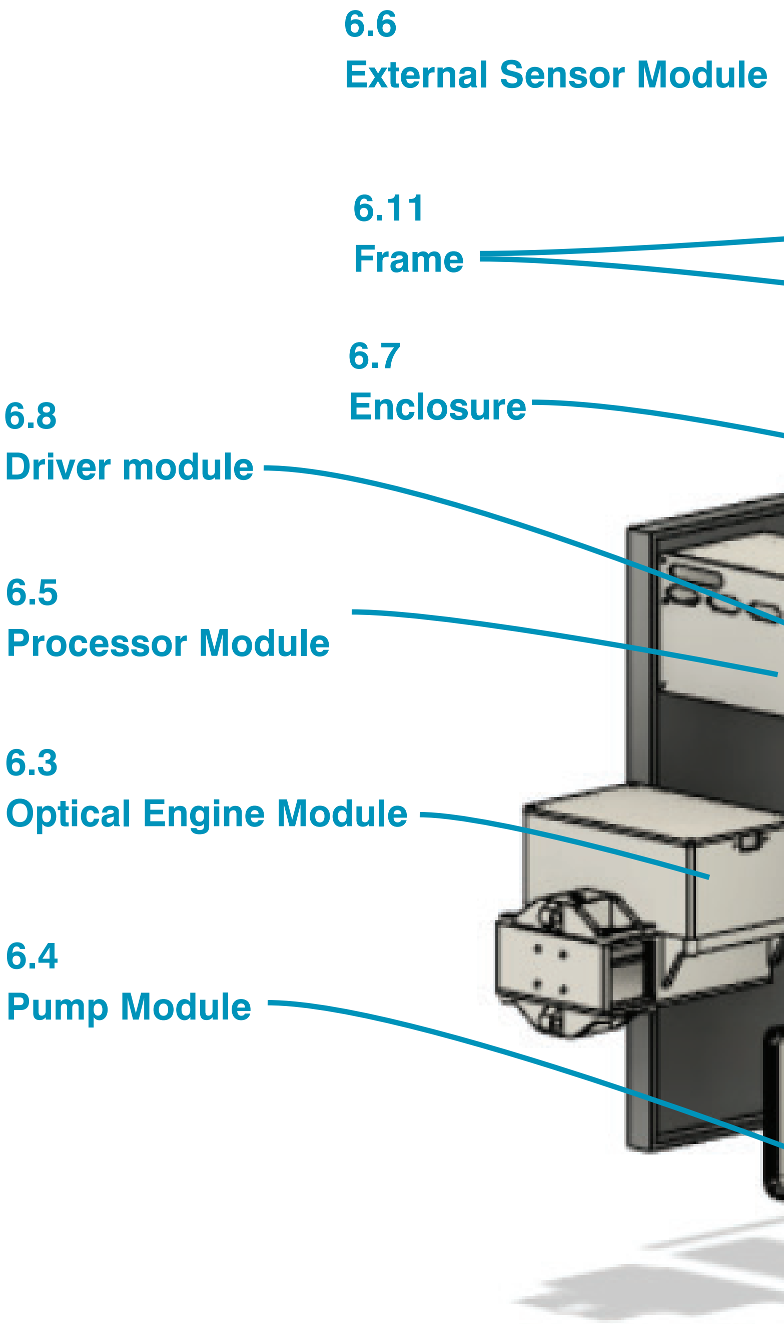
Resulting Design

Chapter 6

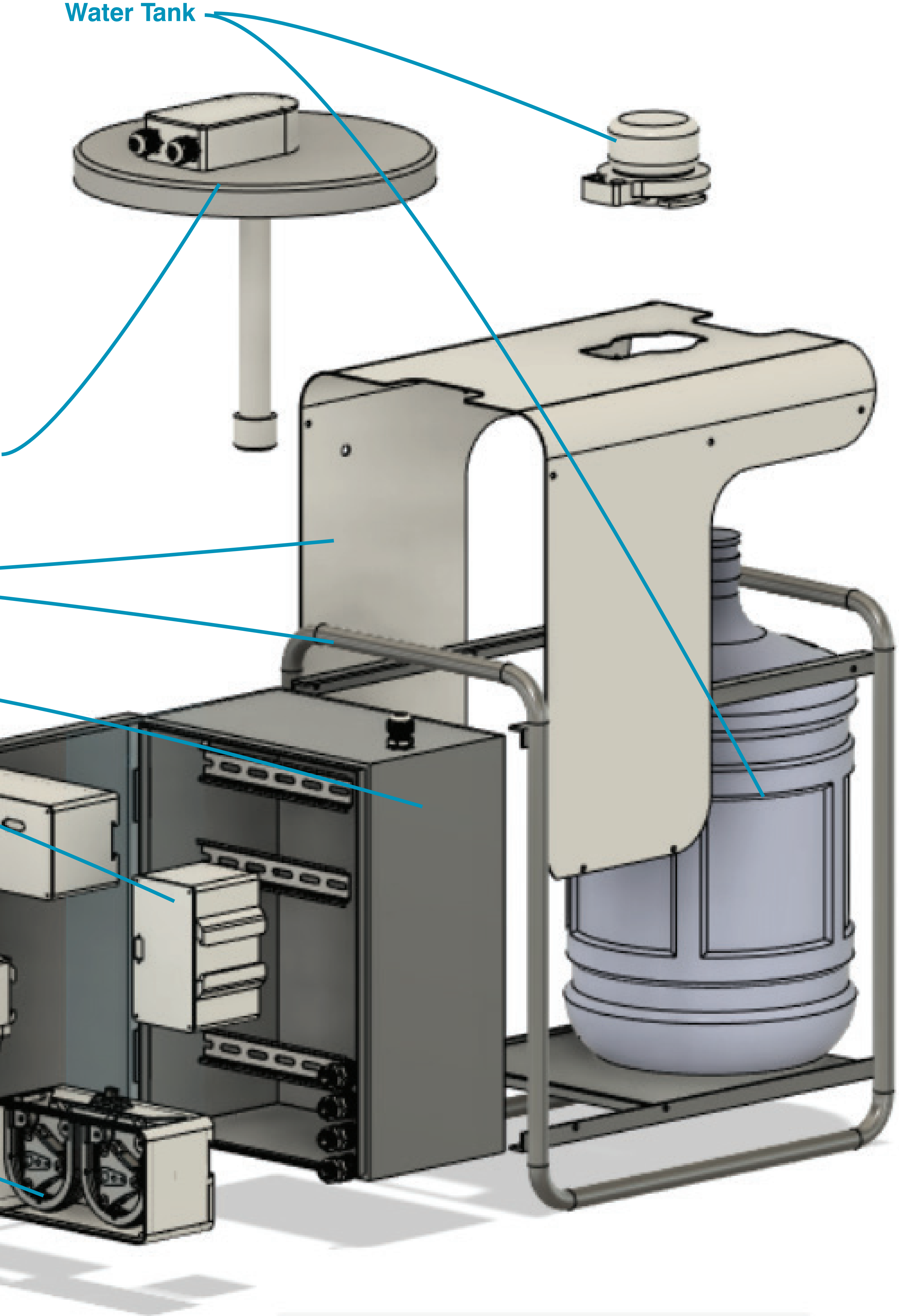
Introduction and Overview

Now that the design requirements and features have been laid out in the WHAT section, they must now be implemented in an actual design. This section details the major components and modules of the resulting design design, their rational, initial embodiment, and how they work together as a holistic system. A prototype was created for this purpos to both aid with illustrating the design and future testing, however it is not fully complete. Therefore, CAD models will be referenced occasionally for illustration purposes.

This page shows an exploded view of the device. Each component shown here has its own section detailing it, along with more descriptive photogrraphs of the prototype.



6.10
Water Tank



6.2 Flowchart

The device is intended to work on operational cycles. The frequency of each cycle depends on how frequently the tank is depleted and refilled. The progression of each cycle is as follows:

1 The water level sensor will detect when the water tank is depleted and send a signal to the control module, which closes a relay activating the home water pump and filling the water tank.

2 Once the tank is filled, the first peristaltic pump activates, transferring water from the water holding tank, through the pump, and into the optical engine module.

3 The control module powers on the optical engine module using the internal batteries inside the control module.

4 The optical engine module takes a reading of the bacteria concentration in the water sample and returns a positive signal or a negative signal depending if the bacteria concentration is above or below the safe threshold.

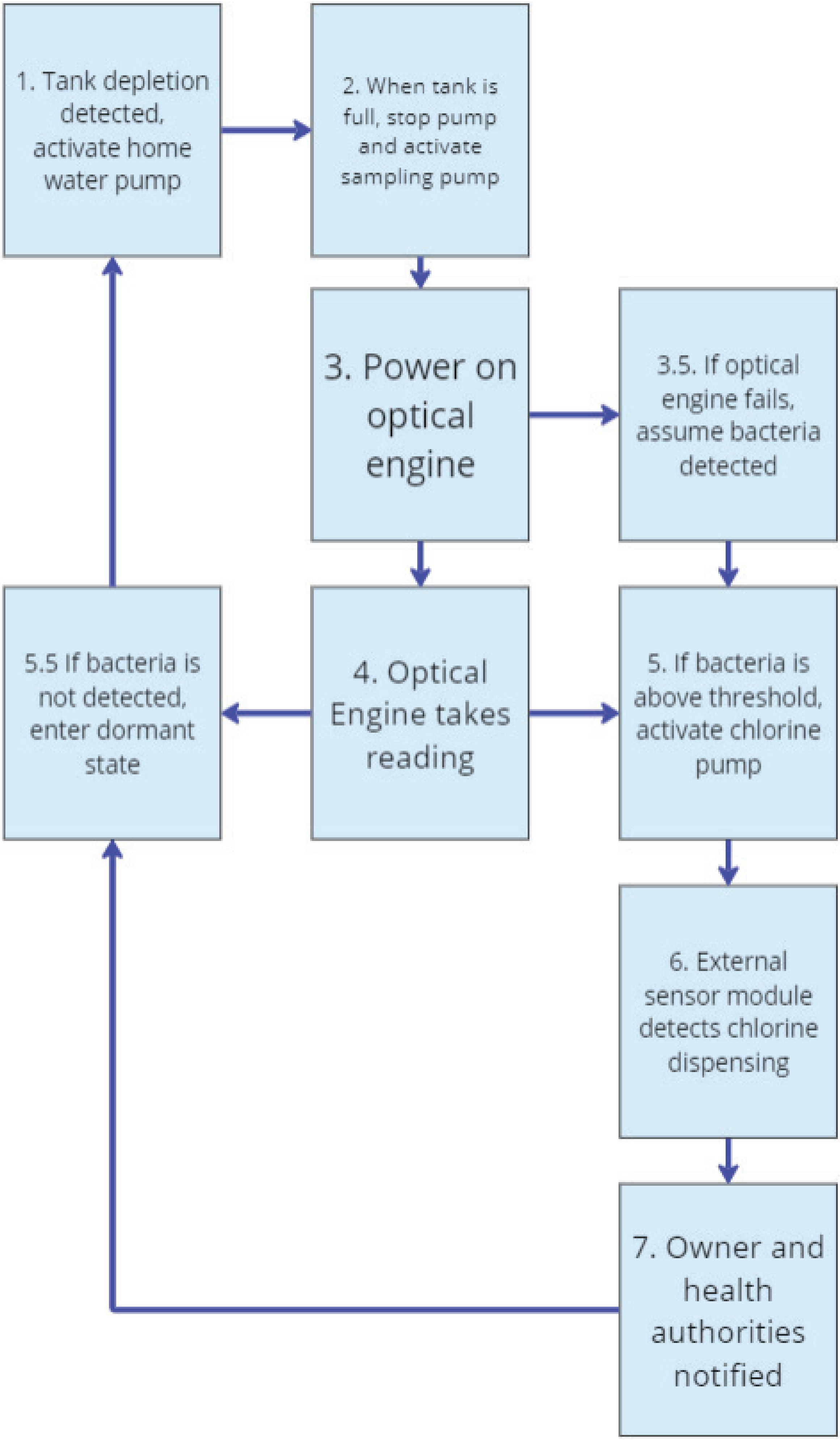
5 If the bacteria is above the safe threshold, the second peristaltic pump will activate, sending chlorine solution from the holding tank towards the sensor module above the water tank.

6 The sensor module will detect when the water reaches the tank and the control module will use this to determine how many more pump rotations must occur to dispense the correct amount of chlorine.

7 The telemetry module will inform the user and the potentially health authorities that bacteria was detected in this area and the device will enter a dormant state until the tank is empty or someone fills it manually.

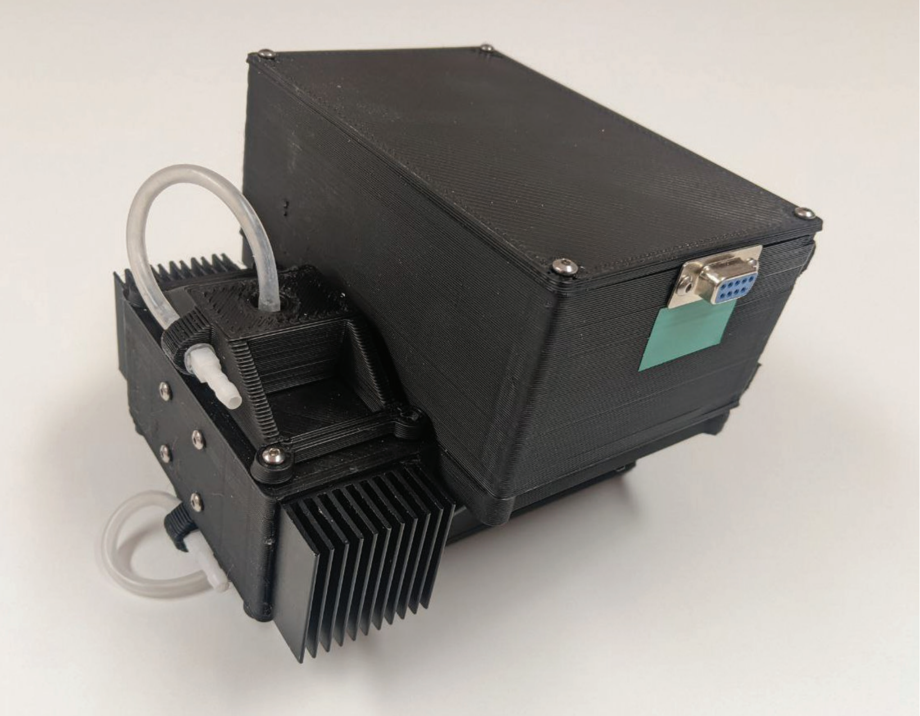
3.5 If there is a failure of the optical engine, the system can continue to operate under the assumption that the water is contaminated and will chlorinate on every operational cycle. In this case, the telemetry module will inform the user that the optical engine module needs to be serviced.

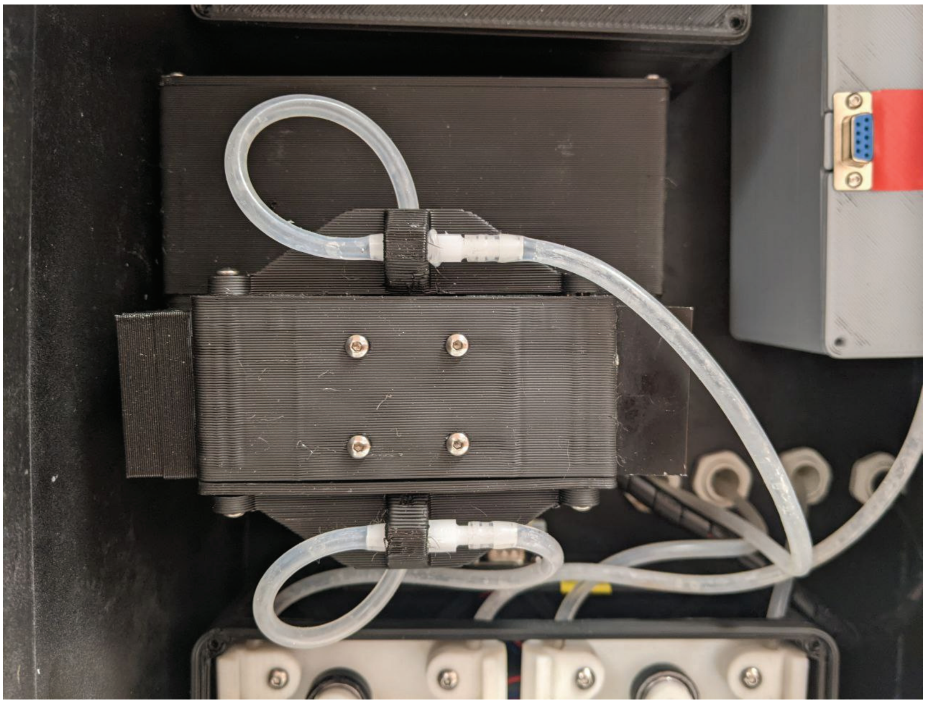
5.5 If bacteria is not above the safe threshold, the device enders a dormant state until step 1 occurs again.


1. Tank depletion detected, activate home water pump
2. When tank is full, stop pump and activate sampling pump
3. Power on optical engine
3.5. If optical engine fails, assume bacteria detected
4. Optical Engine takes reading
5. If bacteria is above threshold, activate chlorine pump
5.5 If bacteria is not detected, enter dormant state
6. External sensor module detects chlorine dispensing
7. Owner and health authorities notified

6.3 Optical Engine Module

The optical engine module contains the optical engine itself, an STM32 microcontroller, and a power converter circuit (see ‘Details of Optical Engine’ in appendix). It is divided into two sections: the optical section and the electronics section. This is done to prevent electromagnetic interference from the STM32 and power converter from affecting the optical engine. This is also done by coating the inside of the optical engine section with copper insulation tape. The water hoses that feed the water sample to the flowcell are retained by two shrouds that protect the connection from tampering, as this is the only point at which the water hoses can disconnect inside the enclosure and preventing leaks is of high priority. The entire assembly is held into the enclosure with a DIN style mounting bracket (see Assembly)





Cover

To secure PSU and STM32

PSU

To provide regulated power to the STM32, LED’s and TIA

STM32

To interpret signals from Optical Engine

Processor Casing

To hold STM32 board and allow for short wires to optical engine

Hosing Shield

To protect flowcell and connecting tubing from light, impact, and disconnection

Shielded Casing

The main casing for the optical engine is shielded to prevent EM interference

Flowcell

To store water sample during detection

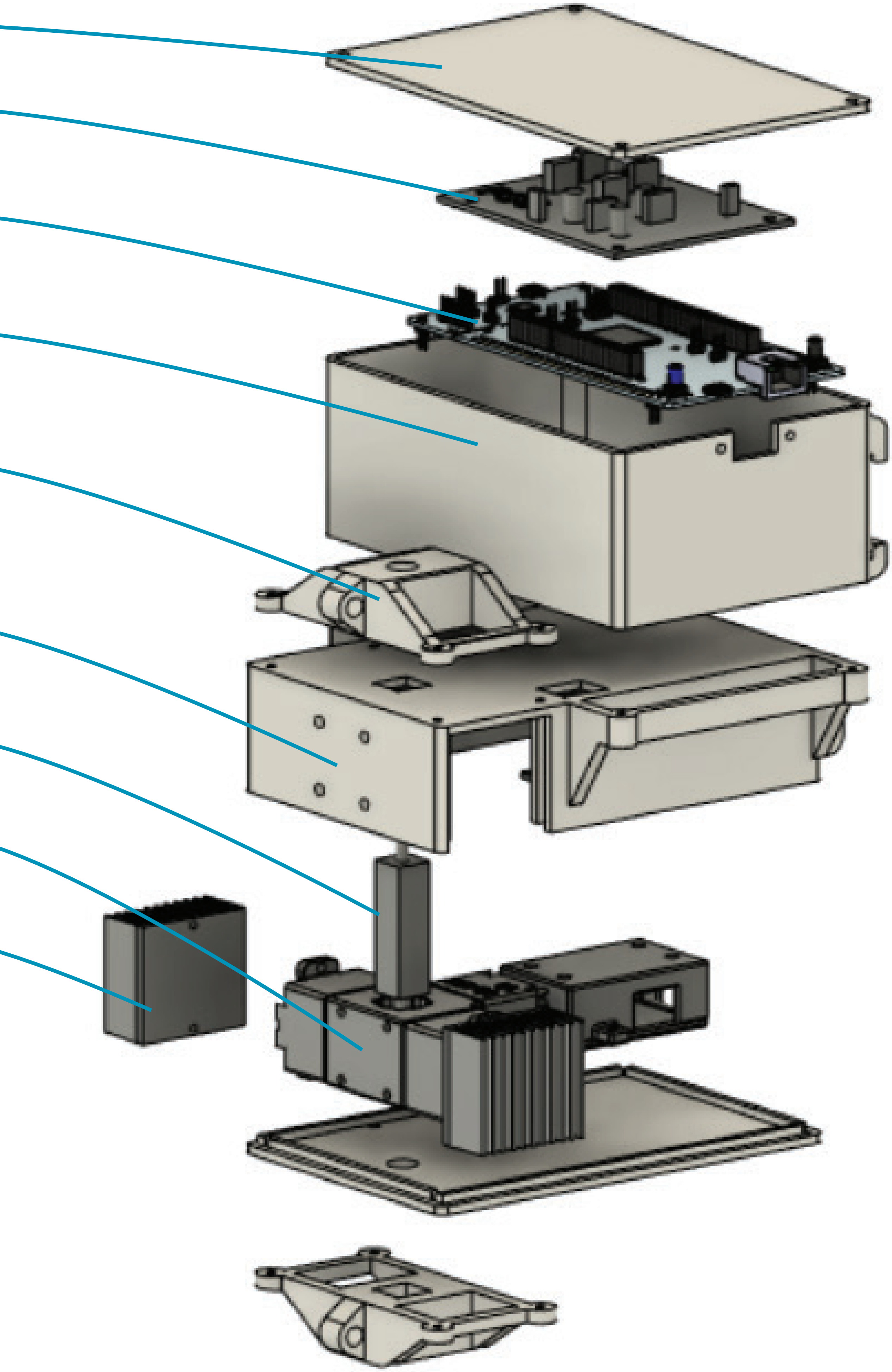
Optical Engine

To detect bacteria in a water sample

Heat Sink

To maintain temperature in for the Optical Engine LED’s

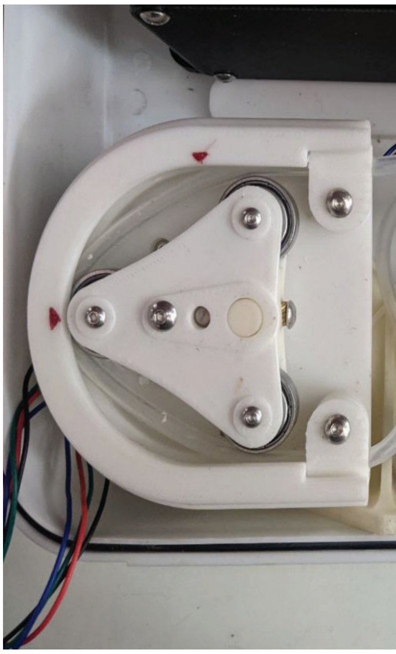
Left: The water hoses are connected to the hosing shield, allowing the user to connect them without touching the flowcell and potentially compromising its reliability. It also provides a strain relief to prevent disconnection and water leaks inside the casing



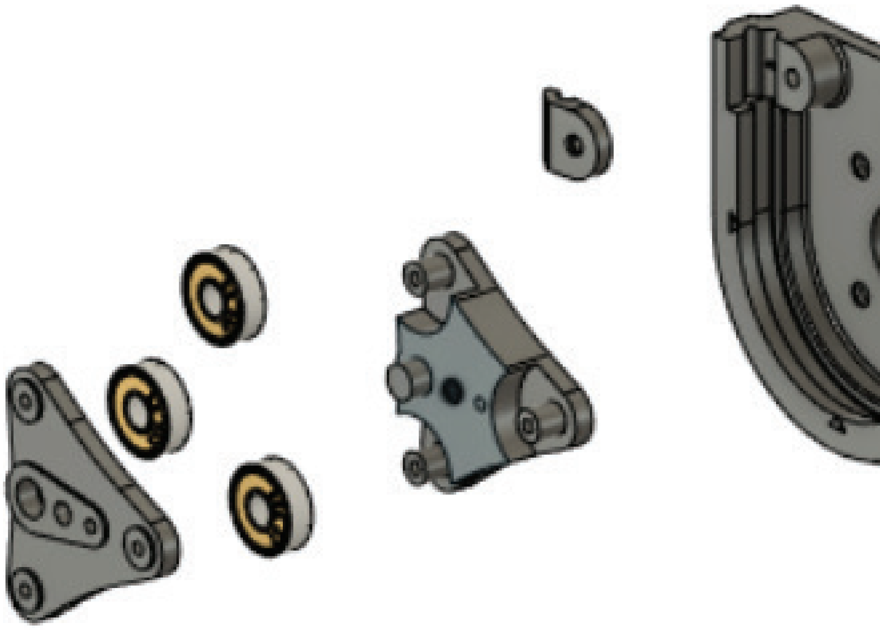
6.4 Pump Module

The pump module features the same pump design developed in the HOW section. The only difference is the protective casing around it. This is to prevent larger debris from falling into the pump and puncturing the hose. The casing also prevents users from placing fingers inside the pump rotors, which pose a pinching hazard. However, seeing the pumps operate proved useful for demonstration purposes as there are no other moving parts to indicate the device is operating. Therefore, the front of the module consists of a transparent lid. Like the other modules, the casing also allows for the module to be secured inside the enclosure with a DIN rail.

The pumps themselves are 3d prined with ABS plastic and are the only mechanical component in this device. Becaue of this, they were printed with this stronger material as opposed to PLA. The remaining components, such as the motor and bearings were chosen specifically because they can be easily sourced in Nepal, reducing the total components that must be imported.

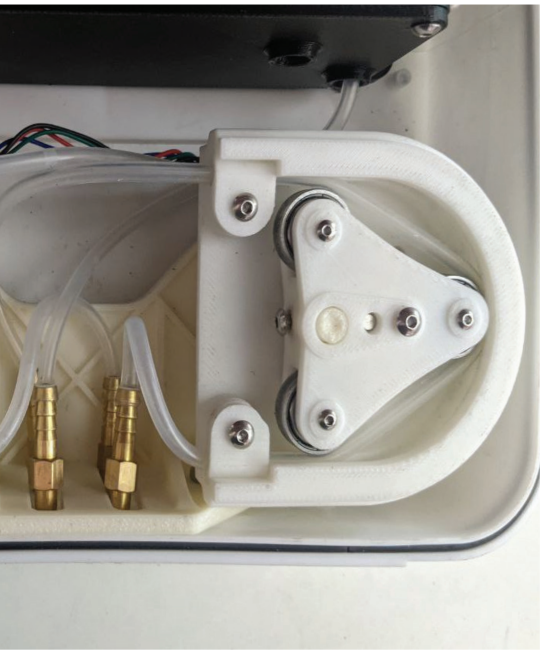


Top Right and Left: Comparison between the initial pump set-up seen in the HOW section vs the revised setup within its own module



Rotor
To turn bearins and drive the pump

Bearings
To compress tubing and push fluid through the pump

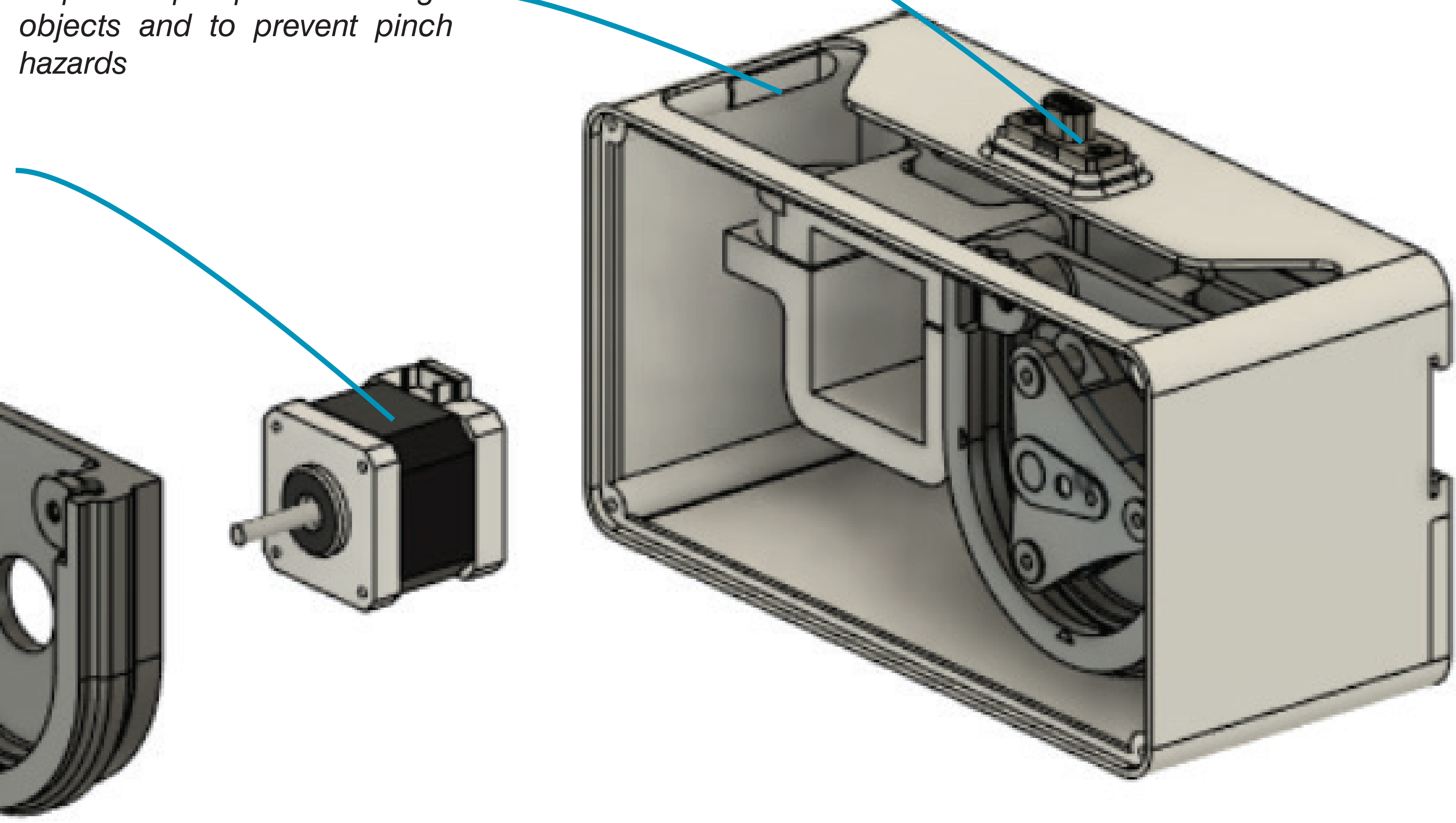


Connector

To provide power.

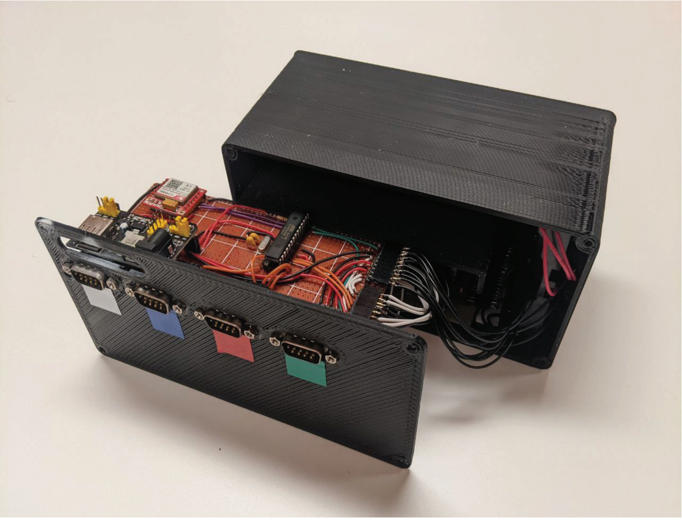
Casing

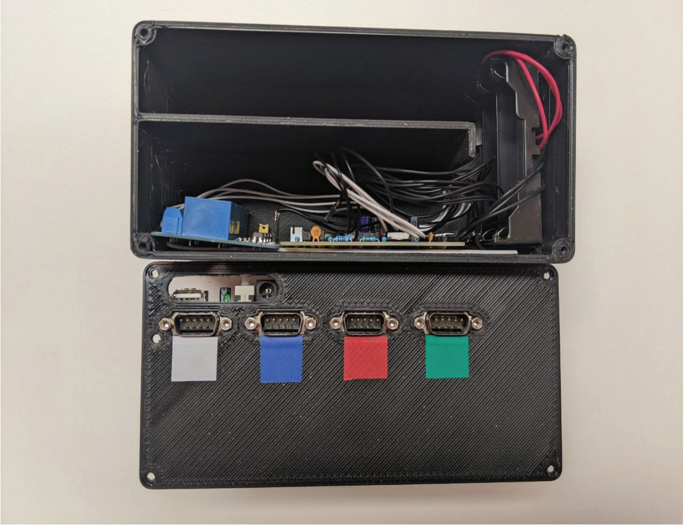
To protect pumps from foreign objects and to prevent pinch hazards



6.5 Processor Module

The processor module houses the microcontroller that drives the device. It also holds the optical engine batteries, battery management circuit, and relay board. The current circuitry will likely be consolidated into integrated PCB's by PRI, therefore the current iteration of this module is designed only to hold the volumetric equivalent of such a PCB. As such, no mounting hardware has been integrated yet, except for the electrical connections to other modules.

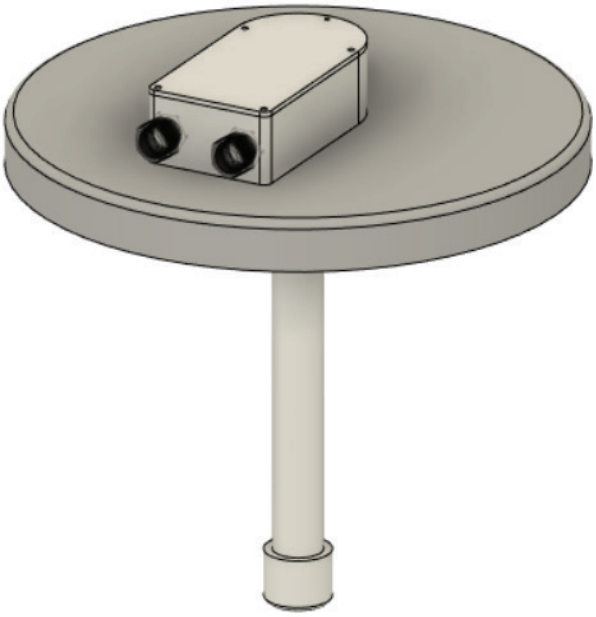




6.6 External Sensor Module

The sensor module is the only module outside the enclosure. It contains the chlorine ejection detector and the two limit switches that tell if the water tank is empty. Because it is outside, the weatherproofing requirements are much higher than the other modules. This requires the use of UV resistant ASA for casing instead of the usual PLA. Instead of a DB9 port, there is a weather proof cable that goes into the main enclosure to prevent corrosion at the connection point.

This module exists only as a CAD model as there is still technical development required to make a chlorine ejection detector that does not rely on easily corroded electrodes. This is further detailed in section 7.1.

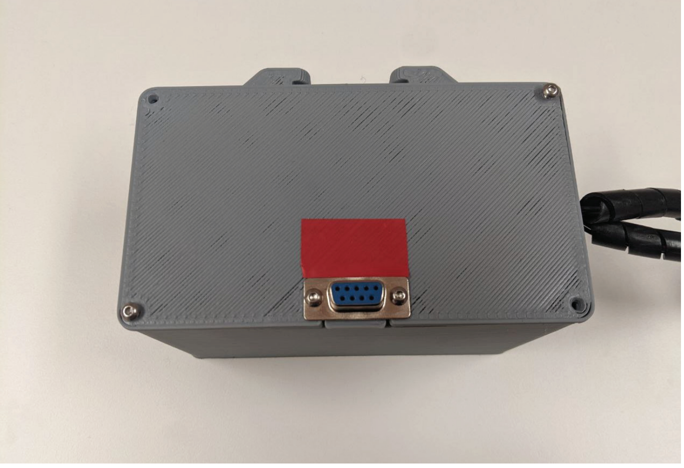


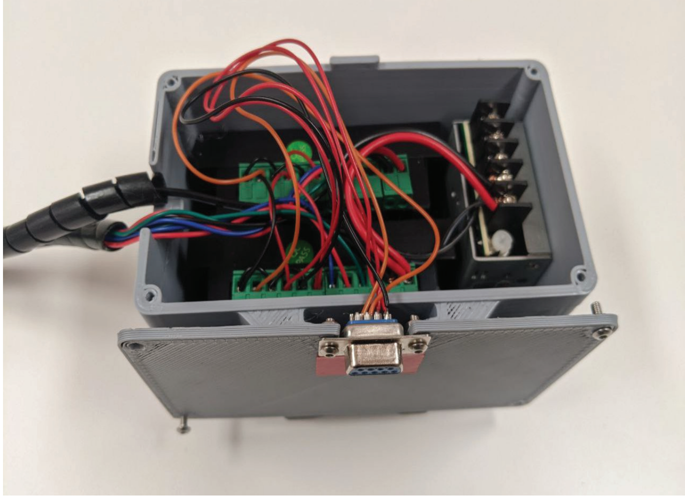
6.7 Enclosure

The enclosure that houses the modules is simply a box of welded sheet metal. While rudimentary, it has several advantages over a plastic or more specialized enclosure. First, it acts as a faraday cage. This is beneficial to the sensitive analog electronics inside, which might otherwise suffer from interference from outside sources. It is also more durable than plastic and less likely to degrade under UV light. For weatherproofing, the design specifies a rubber gasket around the edge of the lid and is held shut with a simple padlock to prevent tampering

6.8 Driver Module

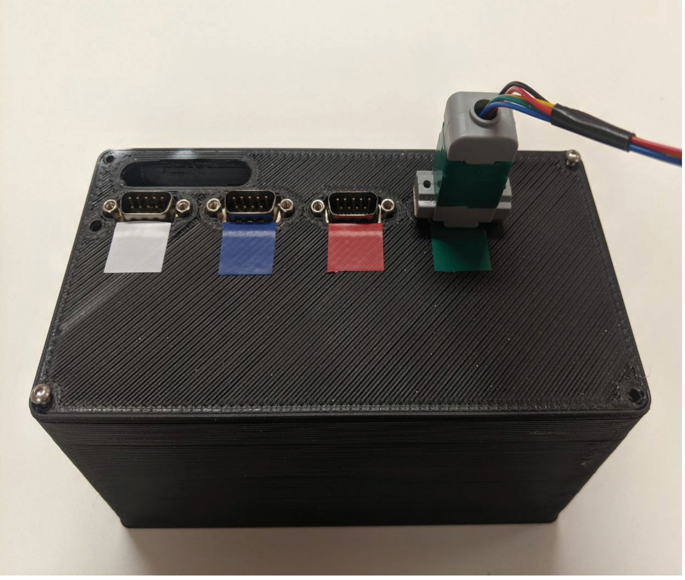
The driver module contains the 12v power supply and the two servo driver modules. While all three components are self-contained, they are placed in this module for two reasons. First, this eases the assembly of the device. Instead of 8 wires that go into the stepper drivers, there is only one DB9 cable that extends from this module. This allows for easier swapping of the module in the field. Second, this module contains dangerous voltage. According to the component accessibility hierarchy, this should not be accessible to the typical user (Section 6.13). Having this module also reduces the number of discrete components in the enclosure, making it less confusing to service.

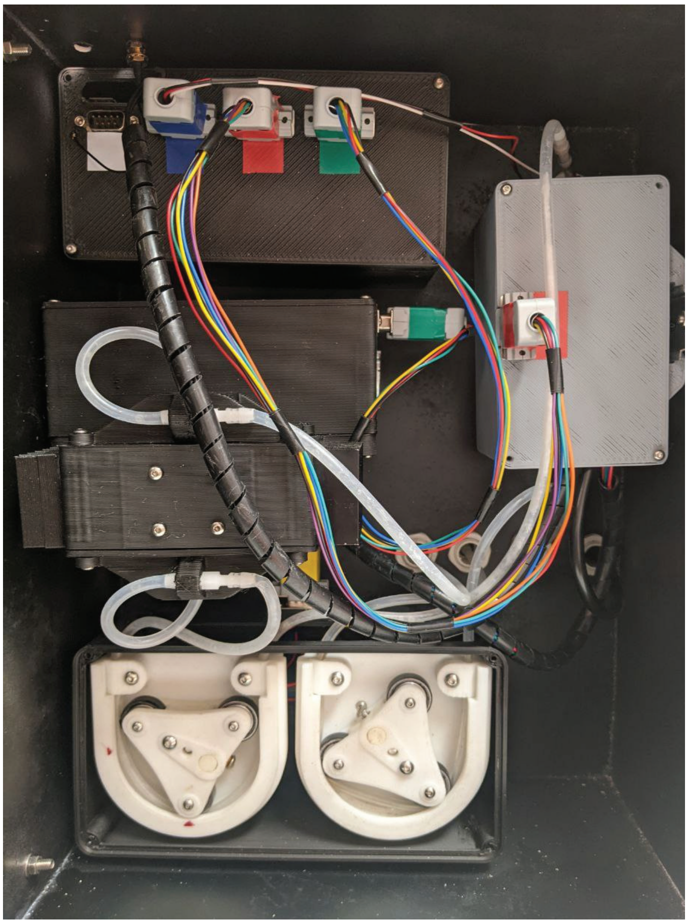


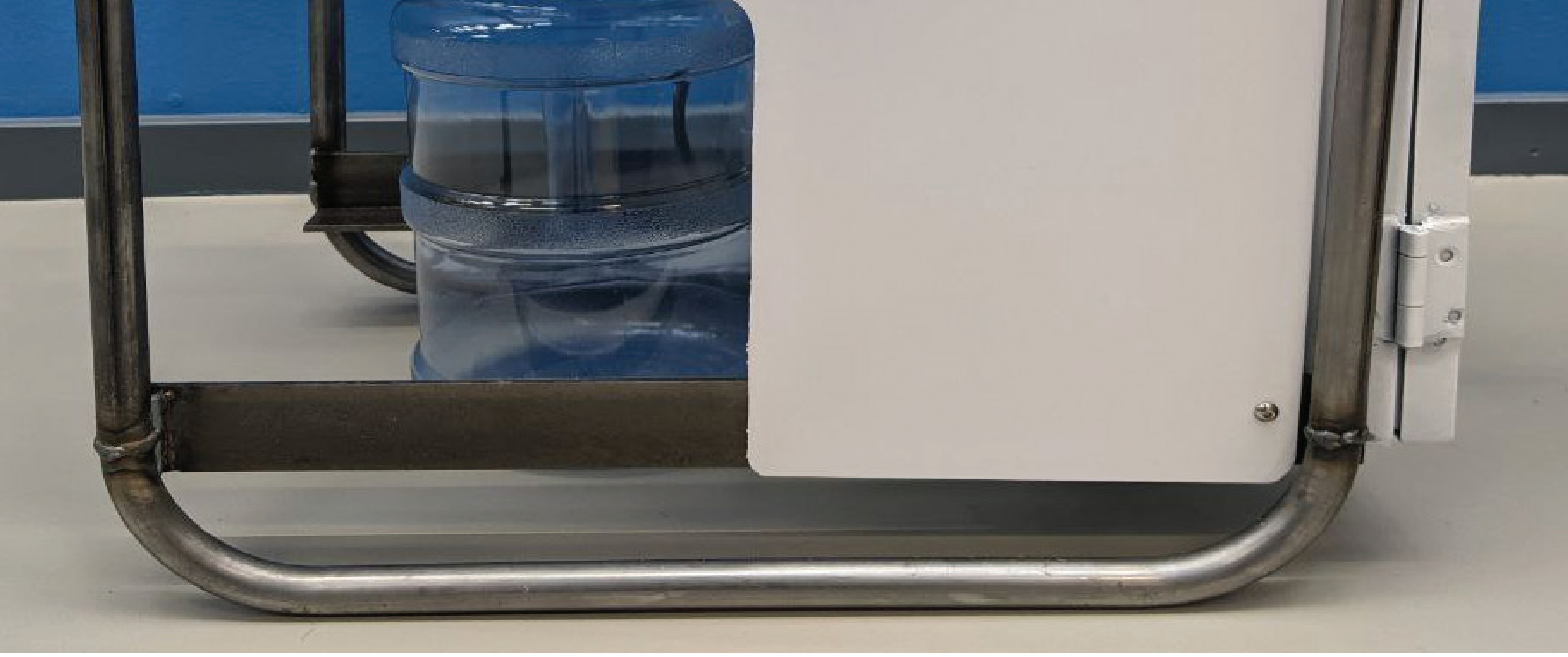


6.9 Connections

Each module is connected by a DB9 cable. The screw connections ensure a secure fit and enough individual conductors to transmit the necessary signals. Such connectors are already in use in PRI designs and the parts are readily available in Nepal. Additionally, each cable is color coded to ensure it goes to the correct module. This allows for easy assembly without having to localize the product based on written language or end user literacy.

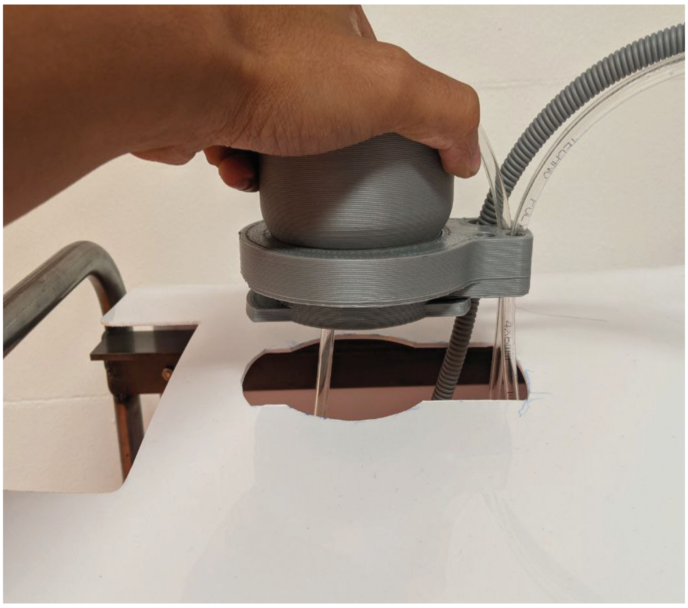






6.10 Water Tank Assembly

The water tank is not necessarily a module, but is still an integral part of the design. It consists of a repurposed 5 gallon water jug and a 3D printed cap. The jug is a common component in Nepal and is used in homes, offices, and restaurants. The cap is 3D printed as a single piece from ASA (for UV resistance) and locks onto the shroud of the device. This keeps the shroud in place while still keeping a non-airtight seal around the water container. This is important as the water container must be allowed to vent excess pressure (from temperature change) to prevent any back pressure on the pumps that might cause the incorrect amount of chlorine to be injected.



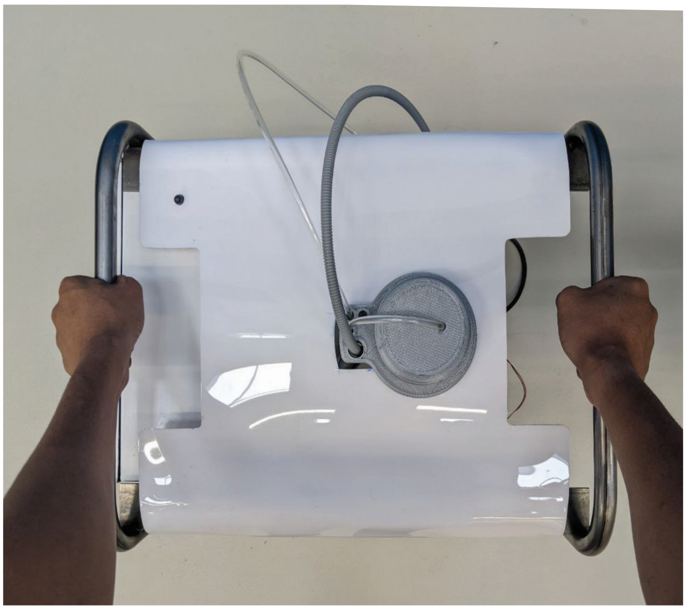
The cap can be removed from the shroud and chlorine jug with one hand and a twisting motion

6.11 Frame

The frame exists to protect the enclosure and water tank from impact, water, and direct sunlight. It consists of a tube steel frame, brackets for the enclosure and water tank, and cowling. The frame holds the entire structure together while keeping critical components off the ground (and potential water puddles). It also provides some protection should the device be tipped over.. It also provides the structure for the cowling, which prevents direct sunlight from heating the enclosure and water tank.

Form Factor

The visual similarities of this design to small generators are intended. This is intended to imply certain aspects about its use case. Like a generator, it is a utilitarian outdoor product, but not one that you directly have to interact with. The shielded areas of a generator are generally ones that shouldn't be touched, and the same holds true with this design.



Physical Ergonomics

This design is not intended for regular physical interaction, however there are some ergonomics considerations built into the frame. Two handholds allow the device to be moved around once assembled and the 100mm clearence allow space for the top 90% of Dutch adult's hands to fit (DINED, 2004). This space allowance should be more than sufficient for the average Nepali, who is approximately 16 centimeters shorter. Beyond this feature, most considerations for physical interaction are the cognitive ergonomics related to the assembly and disassembly process (see 6.2.5)`

6.11 Manufacturing

The most important aspect of this device is that it is domestically manufacturable. This is done to stimulate the local economy and shorten the supply chain. While there are certain necessary components that are not currently made in Nepal, such as most electronics and off-the-shelf plastic parts, such components are commercially imported to Nepal by Nepali companies. This product is designed around such components to assure that the money from its manufacture stays within Nepal. In short, everything required to make this design can be purchased in Nepal.

This is especially true for raw materials and labor. The frame and enclosure are to be built by hand, which is why the design geometry is simple and takes advantage of common stock materials such as 1mm steel sheet, tube steel, and angle stock. It also does not require tight tolerances to function properly, allowing the frame to be hand welded. This allows the metalwork to be contracted out to a workshop, which can build the frames in low batch numbers (<100). This reduces the startup costs of a production run and allows for improvements and modification throughout the production run.

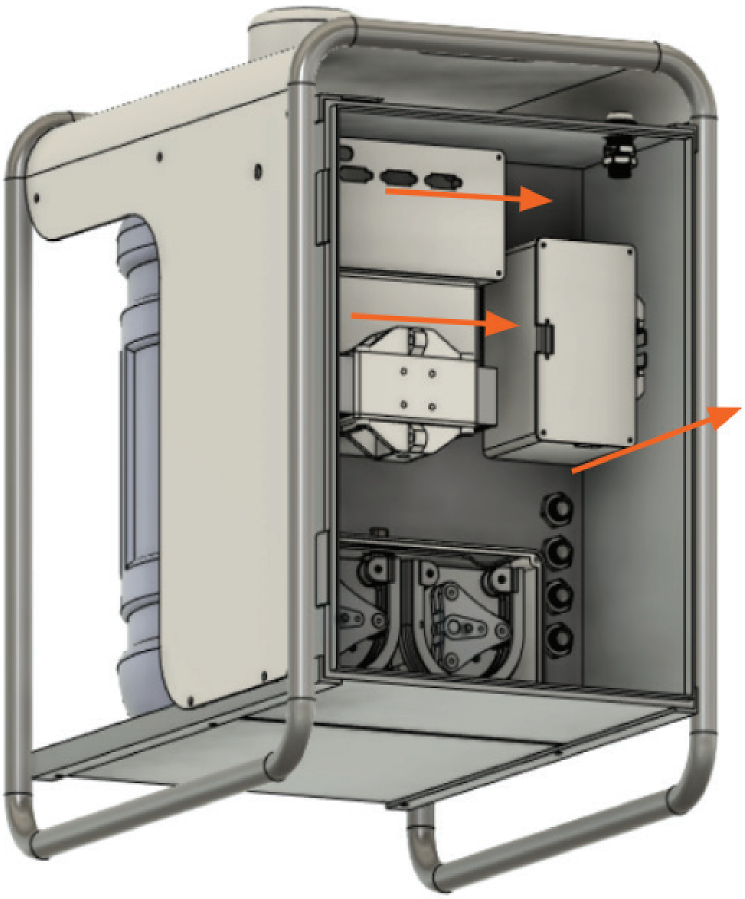
The modules themselves are not handmade, but can be 3D printed domestically. This too will reduce startup costs significantly as they require no tooling. However, this is a time consuming process and will eventually create a production bottleneck. Therefore it is recommended to explore the possibility of setting up an injection molding assembly line domestically.

Local workshop used to produce the metal enclosure box prototype

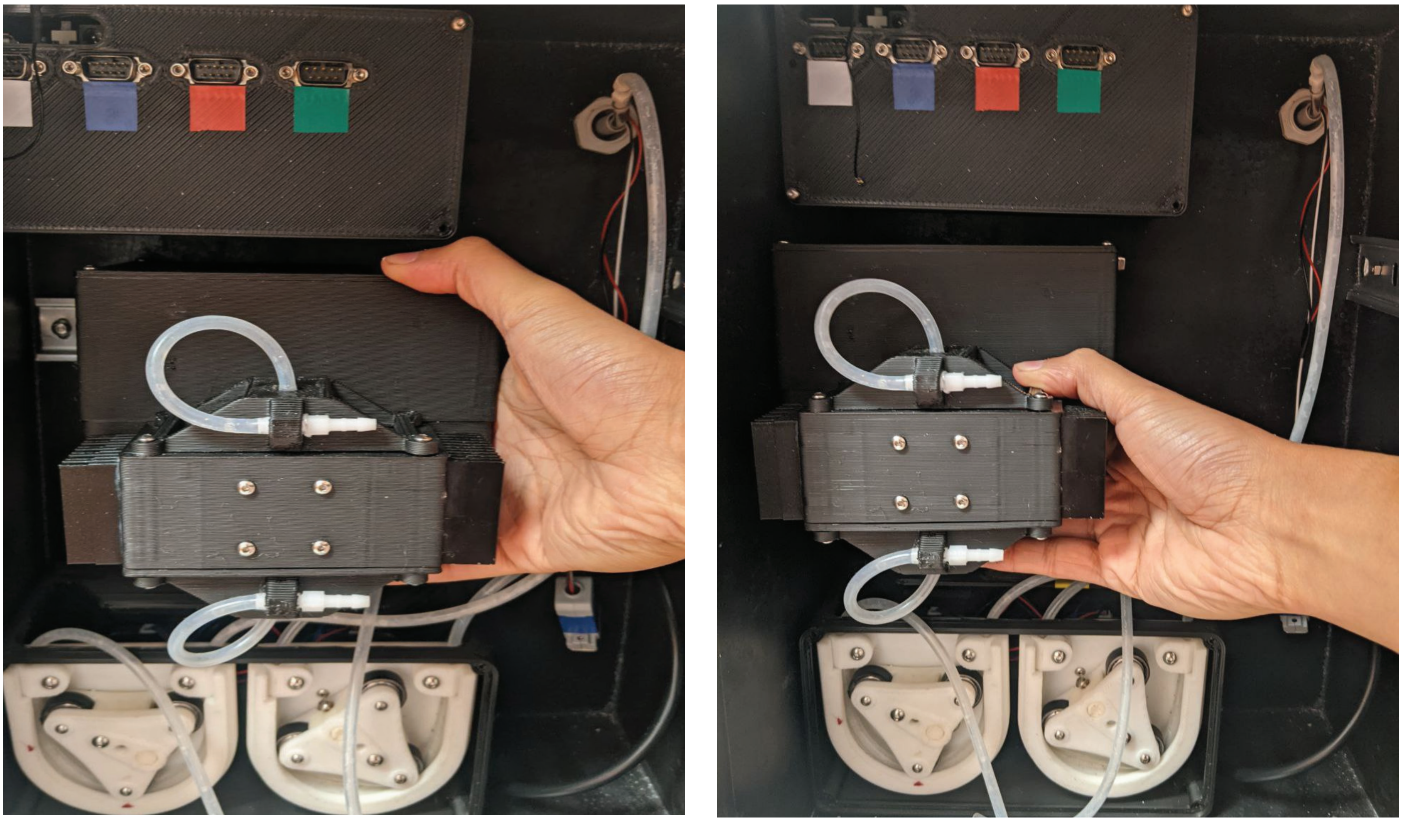
6.12 Assembly

The assembly process refers to how the modules are inserted into the enclosure and how they can be swapped in the field. This is done similarly to how industrial electrical cabinets are set up. However, this design takes into account that a non-specialist may perform the swap. Therefore, it is important to reduce the risk of personal electrocution and damage to the components from improper (dis)assembly as much as possible. This is done by configuring the modules in such a way that the driver module must be removed before all other modules. Removing the driver module first prevents the user from touching a component when it is still connected to power, which could cause injury or damage.

Another consideration is the cognitive ergonomics of module assembly. Each module has an identical mounting system and electrical connection. Because of this, there is a possibility of incorrect assembly or wiring, especially with an untrained or non-technical user. This design reduces this risk by colour coding the wires with the module they correspond to. The full layout of the box is also shown on the inside of the access door as a full color photograph, which eliminates any ambiguity as to how the modules should be set up.

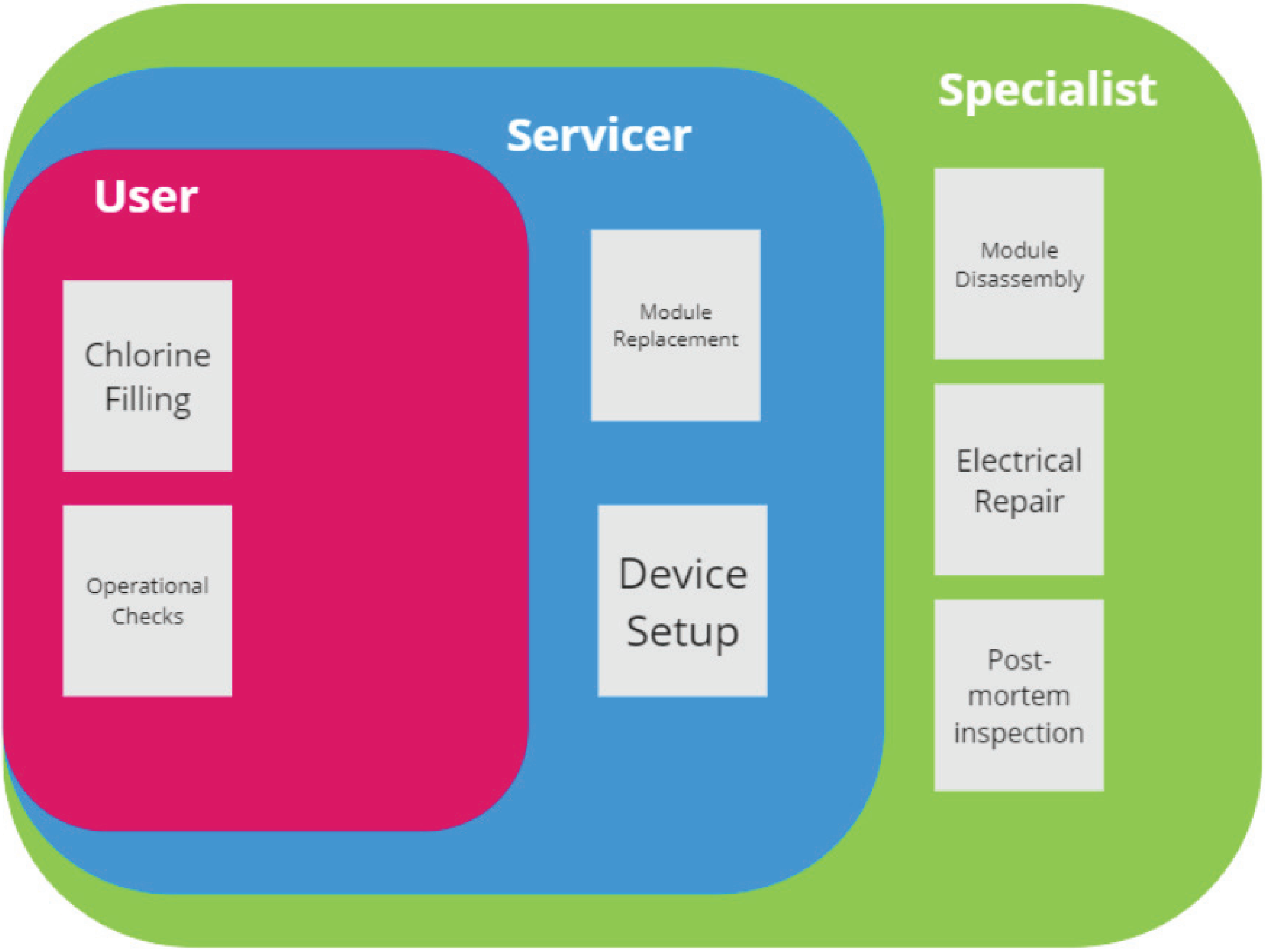


Top: The direction in which sensitive modules must be removed from the box
Bottom: Installing the optical engine module on the DIN rail system



6.13 Repair and Maintainence

This design will be field deployed throughout the entirety of its service life. Therefore it is expected to be maintained and repaire in the field to extend its deployment time. However, the end user cannot be expected to perform all tasks related to keeping the device operational - especially when it comes to sensitive electronics. The 'WHAT' section specifies that delineations must be made to separate end user tasks from servicer tasks and specialist tasks, i.e. operations that are a part of regular operation vs. hardware repair and diagnostics. Having a modular setup facilitates this boundry. Any component the end user (who is assumed to have no technical knowledge) has to interact with is not housed within a module and each module is closed with screw fasteners to prevent accidental tampering. The servicer (someone with rudimentary technical knowledge and instructions) can be instructed to install and replace modules in the field without having to open them as well. Having a modular setup also facilitates repair of the sensitive electronics. Instead of having to service them in the field, the sensitive compnents are removed with their module and can be sent to a specialist (likely PRI) without the user or servicer having to identify which specific components need repair. This also allows for constant failure analysis to occur as post-mortem inspections can also be conducted at a specialist site.

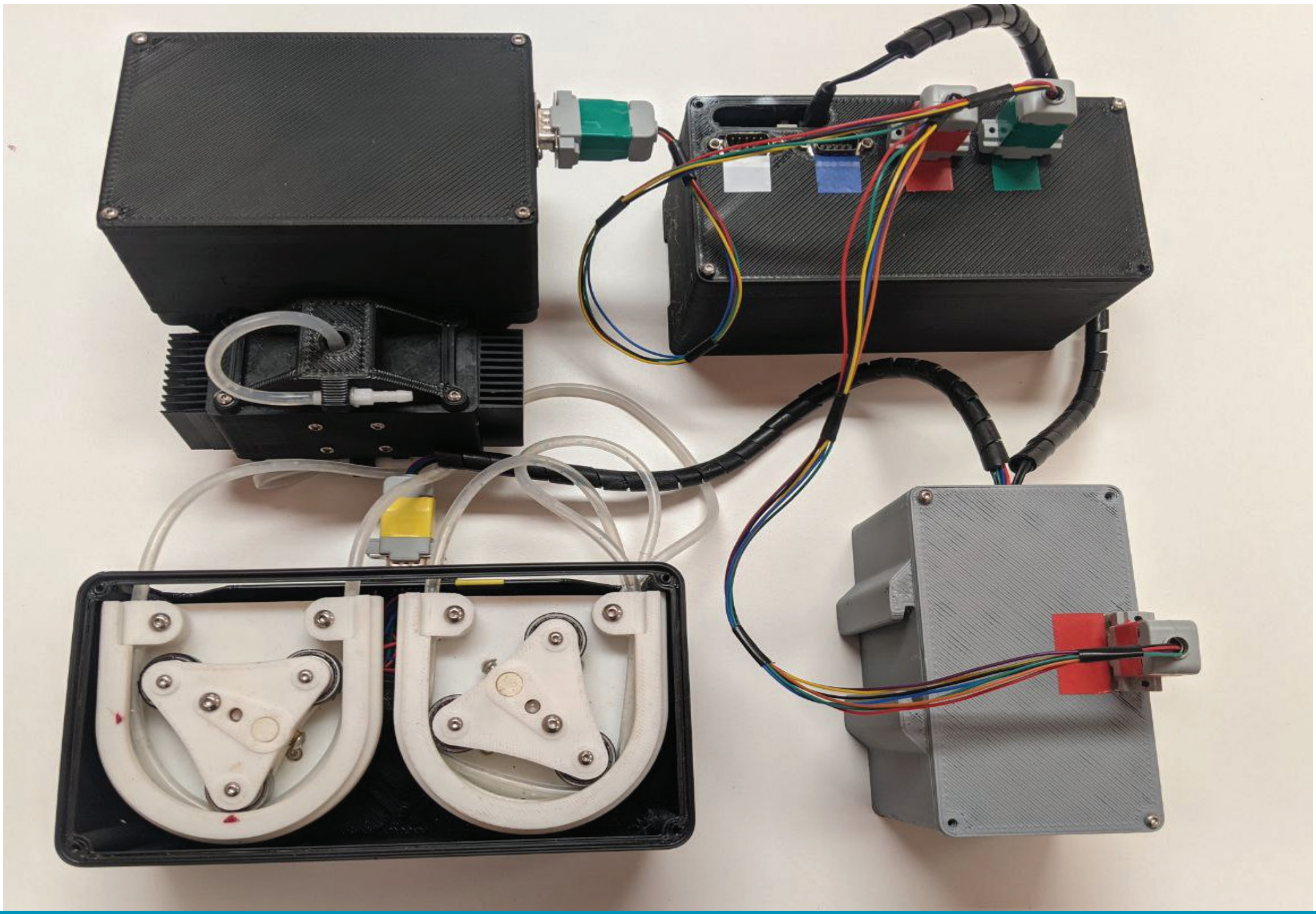


6.14 Reconfigurability

One advantage of using a modular assembly is that the modules can function independently of their surrounding structure. This is relevant to this design because of the strict manufacturing and cost constraints associated with creating a product for the Nepali domestic market. Cost, logistics and manufacturing/material availability will present a barrier to many potential users acquiring this device regardless of how efficiently it is designed. For example, people in rural villages that might have a great need for such a device might not be able to afford it. Such villages might also be accessible by trucks on dirt roads making shipping the entire device costly and time consuming. However, this barrier might be slightly reduced if PRI was to distribute the modules only, and have an enclosure built on-site. Such an enclosure would not have to be the same one specified in this design. It could be as simple as a plastic container with the appropriate holes cut in it, or even mounting the modules to a wall inside a building. This would shorten the supply chain even further, stimulate even more local economies, and reduce the distribution logistics.

That said, this implementation theory has not been tested and will not be the first course of action when producing and distributing these devices. There will likely be difficulties associated with this strategy as well, such as quality control over decentralized production. However, building this system out of modules is intended to not eliminate this possibility in the future, should it become necessary.

Even when connected outside the enclosure, the modules can still perform the base functions of the system



Next Steps

Chapter 7

Introduction

Even with this testing, this design is by no means ready for mass production. There are several components that need further development and testing such as the water tank sensor module, the optical engine, a general risk analysis of the design and field testing. This section details what still needs to happen to bring this design from its current form into a field-ready and fully operational public health device.

Technical Development

Capacitive Sensing

The water tank sensor module detects when chlorine is being ejected into the water. Therefore, it needs to detect the presence of water in the line. However, it cannot do this with any components touching the chlorine, as such components would inevitably corrode and destroy the sensor. Therefore, this sensor must work by detecting the change in capacitance as water flows through the module. However, there was not sufficient time to develop this module for the prototype, therefore it is necessary for PRI to develop this sensor based on literature. To account for this, a spacial allowance was made inside the module large enough for an arduino microcontroller, which should be capable of detecting such fluctuations in capacitance. A possible method of implementing such a subsystem is described by J. K. Roy and S. Das in “Low cost non contact capacitive gauge glass level transmitter suitable for remote measurement & control” (2015).

Integrating optical engine

The current prototype has a dummy unit - simply the plastic pieces that make up the optical engine. This is because the optical engine is still being developed and all prototypes are in use at PRI. However, the mechanical design is unlikely to change, so the optical engine module was built around the existing designs. Once returned to Nepal, the prototype of this design should be tested with a working optical engine against a proven WAS device to determine if the module is a viable containment structure for the optical engine.

Telemetry

Development of the telemetry portion of the design is limited to installing the SIM800c module for 2g transmissions. To implement it fully, there needs to be a server set up to receive the data. Such data should tell if bacteria was detected at the location. It can also be used as a diagnostic. If PRI can develop a diagnostic algorithm that determines which module requires servicing, this feature can also be integrated with telemetry to tell users directly to repair the device and what module requires replacing.

Risk Analysis

With the prototype fully functional, it is almost the point at which testing can begin. However, before this can happen, there must be a risk analysis in place to determine if the product is ready to field test. This includes risks to the device and risks to the user and their home. Such an analysis should include the consequences of failure, possible damage due to weather, and likelihood of incorrect use by the end user. All of these can be evaluated through a field testing regime.

7.4 System Testing

Pump Testing

The current pumps have been tested for precision and head pressure (0.1ml and 2 meters respectively). However, there are more factors that can affect pump performance, such as mechanical tolerence over time and the service life of the silicone tubing. Therefore it is necessary to do more long-term stress testing of these components.

Thermal Considerations

Thermal resilience is also something that should be tested for. Normally this would be done with simulation software, but as the duty cycle of the device is unknown and most of the heat inside the enclosure could come from indirect sunlight, it is likely more responsible to determine thermal resilience during the field testing stage.

Full Integration Testing

Containing all the components in this system in close proximity may result in complications not already discovered throughout this project, such as light or electromagnetic interference. Therefore, it is necessary to conduct full integration testing once completed to make sure the readings are accurate and all components work as intended. In the event that there is some sort of interference (likely within the optical engine as it is the most sensitive component), additional measures, such as more shielding should be implemented, or modifications to the software to interpred the different signals that occur as the result of the optical engine being integrated into a new device.

7.5 Field Testing

Following the completed design embodiment, it should be tested to determine if it has adequate functionality. The objectives of field testing are to determine if the device can successfully purify a 1000 liter water tank, whether it can do so repeatedly during an extended operational duration, and how extended use affects the components.

First at PRI

PRI has the necessary water tanks to install this design. Therefore, conducting the initial evaluations at PRI is a good first step to testing the device. This stage can be used to determine if the device works in context. PRI has the necessary equipment and expertise to determine if the water is successfully purified, so testing it there allows for quick and easy evaluation. This will also allow for additional features, such as telemetry, to be developed and integrated with the testing device in-house.

Potential initial testing site for the integrated device: the rooftop tanks at PRI

Determine more user-focused considerations

Once the technical functionality has been tested, the design should be tested with users. PRI has received interest from a local school that could be used as the first testing point. This will allow for further long-term testing and also user interaction testing. This can reveal if the telemetry system is useful, what is necessary to build user habits when replacing the chlorine in the tanks and whether or not it is ready for commercial distribution.

Conclusion

Chapter 8

8.1 Conclusion

At the end of the of the ‘WHY’ section, the findings of the project so far were used to generate a revised problem statement:

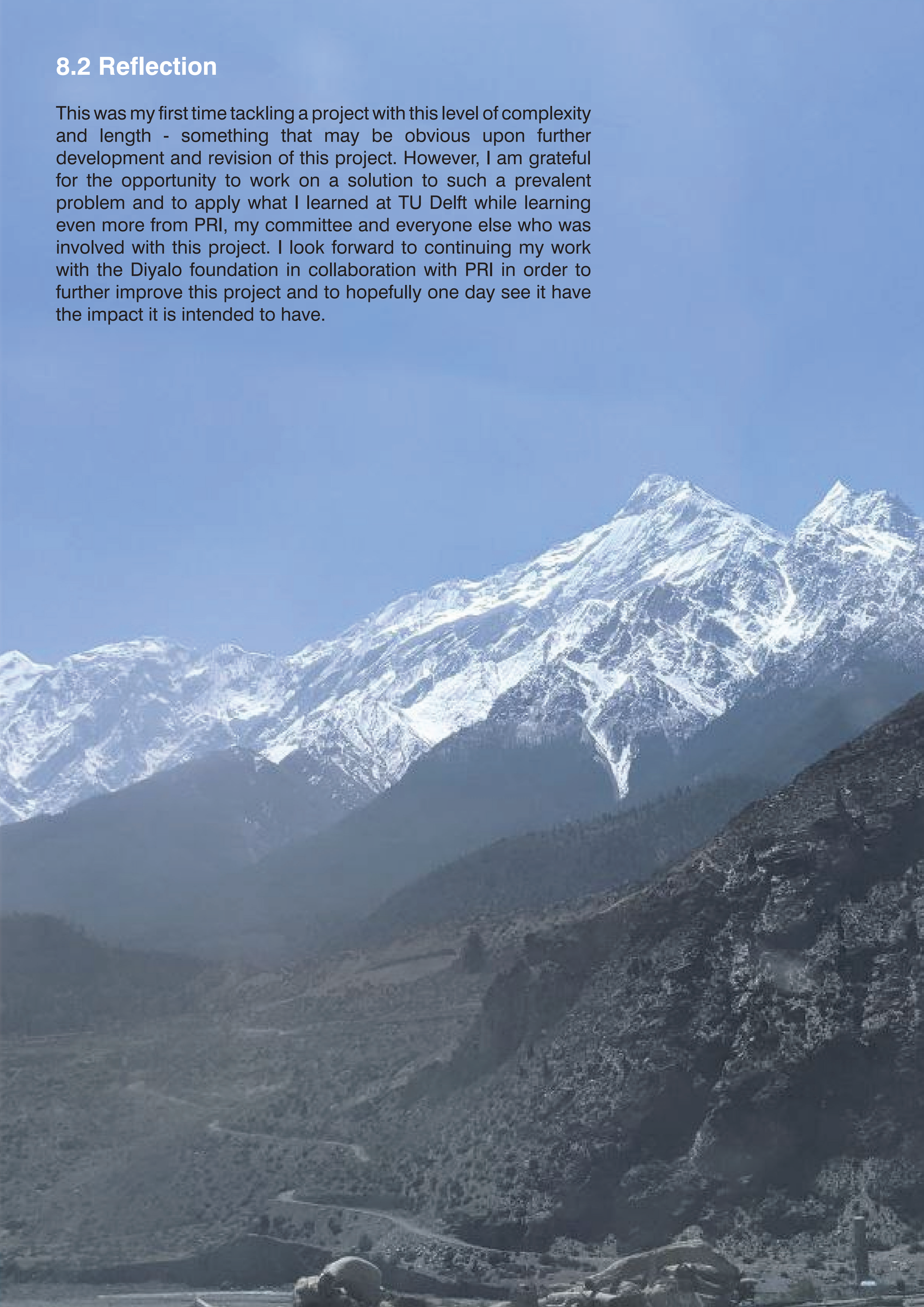
“How do we demonstrate a solution that brings the experience and safety of a water treatment plant to a single Nepali home using a 1000 liter water tank using PRI’s optical engine technology?”

I believe this project was successful in begining to answer this question and has generated the first steps in making a potential solution a reality to those who need it. This design is meant to serve as a holistic starting point for PRI and the Diyalo foundation to develop into something market ready and to demonstrate to other organisations (such as the Nepali government and the WHO) that their optical engine technology has applications beyond use as a standalone device. Eventually this may allow the PRI’s technology to have an impact beyond the intended users of this design and even the country of Nepal itself,

That is not to say, however, that the entire project was without fault - there is still a long way to go before any of this can occur. As seen in chapter 7, there is still much engineering and design work left to do before this device can be considered complete - work that is better left to specialists in their respective engineering fields. However, PRI has such engineers and should be more than capable of bringing this device from its design prototype stage to a highly impactful reality.

8.2 Reflection

This was my first time tackling a project with this level of complexity and length - something that may be obvious upon further development and revision of this project. However, I am grateful for the opportunity to work on a solution to such a prevalent problem and to apply what I learned at TU Delft while learning even more from PRI, my committee and everyone else who was involved with this project. I look forward to continuing my work with the Diyalo foundation in collaboration with PRI in order to further improve this project and to hopefully one day see it have the impact it is intended to have.



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Appendix

6594

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Maga
initials: P
given name: Anucha
student number: 5577160
street & no. [redacted]
zipcode & cit [redacted]
country [redacted]
phon [redacted]
em [redacted]

Your master programme (only select the options that apply to you):

IDE master(s): ● IPD ○ DfI ○ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ○ Honours Programme Master
specialisation / annotation: ○ Medisign
○ Tech. in Sustainable Design
○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Wolf Song
dept. / section: Mechatronics Design
** mentor: Martin Verwaal
dept. / section: DE Technical Support
2nd mentor: Ashim Dhakal
organisation: Phutung Research Institute
city: Kathmundu
country: Nepal

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Wolf Song date 23/2/2023 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 40 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

X YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name Robin den Braber date 13 - 06 - 2023 signature RdB

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: V APPROVED ○ NOT APPROVED

Procedure: V APPROVED ○ NOT APPROVED

comments

name Monique von Morgen date - KE 27/6/2023 signature MvM

Design of a water monitoring and disinfenction system for Nepal project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 13 - 02 - 2023

04 - 07 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The objective of this project is to prevent outbreaks of pathogenic bacteria in drinking water throughout Nepal. As natural resevoirs are not widespread in rural areas, it is necessary to store water in holding tanks. However, such tanks can become contaminated, hence the necessity of this project.

This project is in collaboration with and sponsored by the Diyalo foundation. This nonprofit organization collaborates with partners in Nepal to identify needs and technical knowledge gaps that can be addressed with technical solutions. They collaborate with outside technical experts to solve these problems and facilitate the transfer of knowledge to the local community to fill this knowledge gap such that the solutions remain effective and can be improved (fig. 1). Their role within this project is to facilitate discourse between other stakeholders, such as myself, the Phutung Research Institute, and other experts who may be consulted throughout the project.
Link for more information: https://diyalofoundation.org/model/

This project is also in collaboration with the Phutung Research Institute (PRI), non-profit research institute based in Kathmandu, Nepal. The institute's objective is to promote scientific and technological innovation to address the needs of developing countries through scientific, technological and social innovations. They have developed a low-cost optical sensor for bacteria detection and have begun pilot testing a handheld device that uses this sensor for water quality assesment (also in collaboration with the IDE Advanced Embodiment Design Course) (fig. 2). They also wish to use this technology to determine water quality within holding tanks, hence their involvement in this project. The role of the PRI within this project is as a source of technical and ethnographic knowledge.
Link for more information: https://pinstitute.org/

Ultimately, the primary stakeholder is the people in Nepal who depend on these holding tanks for drinking water. As this is a matter of public health, effectiveness and robustess of the system should be valued above all else, especially as we cannot assume there will be local technical expertise sufficient to repair a complicated electronic system.

This system itself also presents limitations to this project. PRI has specified that the device should be of low-cost and manufacturable (as much as possible) within Nepal. Therefore, this puts constraints on what manufacturing techniques can be used, in addition to the total cost of the system.

However, this also provides the opportunity to design the system from the ground-up. Apart from the holding tanks, this design does not need to fit into any existing infrastructure, therefore it can be designed with up-to-date wants and requirements in mind and not have to compromise in regards to previous solutions.

space available for images / figures on next page introduction (continued): space for images

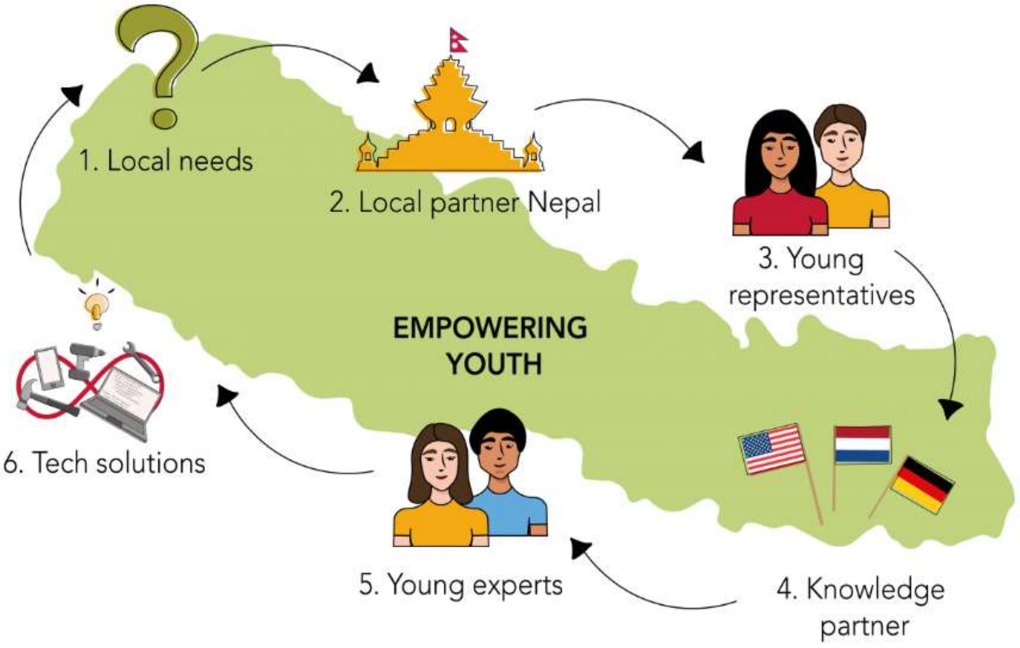


image / figure 1: Outline of the Diyalo Foundation need-to-solution model

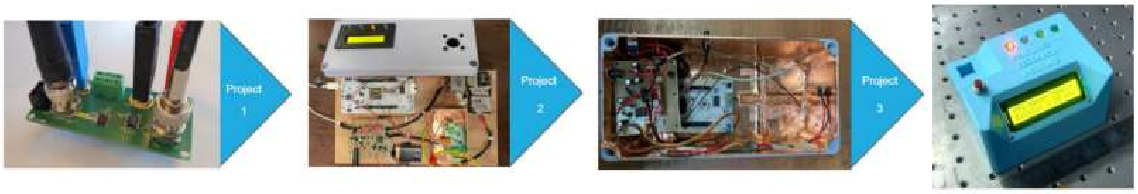


image / figure 2: Handheld water quality assessment device

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Problem: People in rural Nepal are at risk of pathogenic infection due to bacterial contamination within drinking water holding tanks. Local stakeholders require a means of detecting, preventing, and tracking contamination. However, existing solution are too complex, fragile, unable to fully the problem, and/or, cost prohibitive. Additionally, the end users - people in rural areas in Nepal - cannot be assumed to have the technological aptitude to operate and/or service existing solutions.

The scope of this project is to develop a prototype that can demonstrate the feasibility of a system that can address all parts of this problem. This includes multiple iterations of physical prototypes, the testing of such prototypes, and the generation of technical documentation to allow stakeholders to further develop the project.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will research methods of detecting and neutralizing bacteria, data transmission, and local manufacturing within the context of rural Nepal. Using this research, I will iteratively design and test of a system capeable of detecting pathogenic bacteria, releasing disinfectant, and transmitting related data to a central location where it can be accessed by concerned stakeholders, while generating documentation to aid further development of the system.

Objective/Deliverables: My objective is to understand the design drivers than determine a product/system's effectiveness in rural Nepal and deliver a functional prototype that can detect pathogenic bacteria, release disinfectant, and transmit relevant data from within this environment. This prototype will be tested to demonstrate feasibility and robustness. In addition, the development and construction of the prototypes and preceding prototypes will be documented such that the PRI can continue work on this project and achieve a TRL-8 prototype for field deployment.

This project involves 3 major requirements:

DETECTING: The solution must use PRI's optical bacteria sensor to detect bacterial contamination within a drinking water holding tank.
PREVENTING: The solution must also be able to prevent bacteria outbreaks by mechanically dispensing disinfectant. This introduces a mechatronic aspect to this project.
TRACKING: The solution must be able to report outbreaks of bacteria to a central location. This introduces a system/service aspect as this would facilitate remote diagnostics of local health and infrastructure by other stakeholders, i.e. government/health officials.

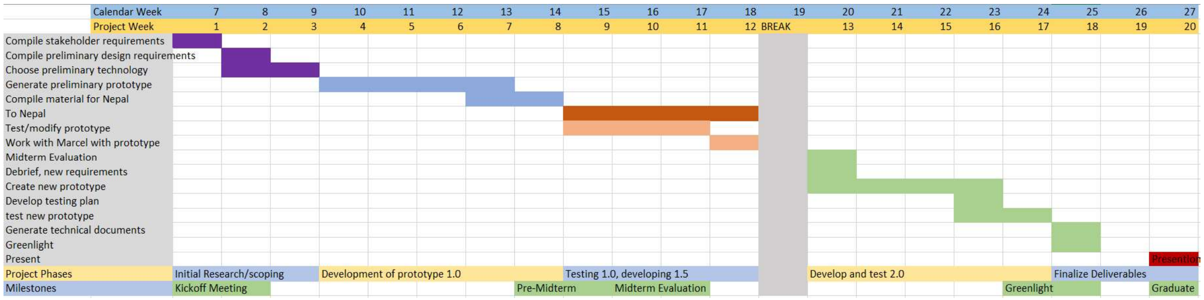
Additionally, the prototype must remain robust and simple so as not to impose the need for high technical literacy on the end user. It must also be of low-cost and easy to produce domestically.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 13 - 2 - 2023

4 - 7 - 2023 end date



Calendar Week	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Project Week	1	2	3	4	5	6	7	8	9	10	11	12	BREAK	13	14	15	16	17	18	19	20
Compile stakeholder requirements	■																				
Compile preliminary design requirements		■																			
Choose preliminary technology		■	■																		
Generate preliminary prototype				■	■	■	■														
Compile material for Nepal							■	■													
To Nepal									■	■	■	■									
Test/modify prototype									■	■	■										
Work with Marcel with prototype												■									
Midterm Evaluation														■							
Debrief, new requirements														■							
Create new prototype														■	■	■	■				
Develop testing plan																	■				
test new prototype																	■	■			
Generate technical documents																			■		
Greenlight																			■		
Present																					Presention
Project Phases	Initial Research/scoping			Development of prototype 1.0					Testing 1.0, developing 1.5					Develop and test 2.0					Finalize Deliverables		
Milestones	Kickoff Meeting							Pre-Midterm		Midterm Evaluation								Greenlight			Graduate

This is intended to be a very hands-on and practical project. As such, multiple iterations (and testing of such iterations) are necessary. For this reason, I propose a 'lean startup' approach that will allow for 3 iterations to be generated. I believe this approach is more appropriate for this project than a more linear 'double diamond' method because I have the opportunity to travel to Nepal to test and develop prototypes and conduct direct user tests/interviews. However, this would occur halfway through the project, therefore it is necessary to have a prototype ready for testing within the first half of the project. This would also allow for a 'version 1.5' to be developed in Nepal based on rapid feedback through on-site testing.

Research will still be an important part of this process, however it will be conducted simultaneously with prototype development. The one exception to this is at the begining of the project, which starts with problem scoping, technology research, and stakeholder analysis which will set the requirements for the first prototype.

Initials & Name P Maga Student number 5577160

Title of Project Design of a water monitoring and disinfenction system for Nepal

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I chose this project due to its potential social impact and the need for a practical solution. The most impactful course I have taken at TU Delft was Advanced Embodiment Design. I want to build upon competencies I just began to acquire during that project and use them for social good.

For example: we learned about design for manufacturing constraints, but in this project the constraints are much more severe. I wish to take that knowlege and apply it to a project that presents an even greater challenge than what we already faced in AED. Not only must the design withstand harsh weather, it must be locally made. This also presents the opportunity to use another acquired competence: additive manufacturing. I have frequently used 3d printing for prototyping (and in my everyday life), but the need for local manufacture presents the opportunity for 3d printed functional components which have a whole new series of requirements that I want to become familiar with.

I also want to demonstrate a specialization in electronic/mechatronic integration within design. I have no formal background with electronics, but have used microcontrollers and analog circuits in previous projects. I want to continue developing my competency with these systems in such a way that I can demonstrate it to future employers and work on electronics-related projects in the future despite having no formal training.

A practical deliverable is also a reason I chose this project. Throughout my education, I have found that I deliver better results and learn much more with practical projects. As this is my graduation project, I would like to maximize my chances of success as much as possible. More importantly, however, is the opportunity to apply theoretical knowledge. While I have worked on BOP design projects, all of the knowledge I gained and generated was through desk research. I want the opportunity to apply it in the field and further my knowledge, experience, and competency on the subject.

Lastly, and most importantly, is the social aspect of this project. Many of the practical projects I have worked on at TU Delft have been focused on 'first-world problems'. While I have learned a lot from such projects, I feel that is my obligation to use what I have learned to solve problems with serious consequences. A graduation thesis grants me the opportunity to work on whatever I choose without a profit motive and while there are many fascinating and futuristic graduation projects available, I will choose the one that does good by protecting and preserving human life.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

This project will likely involve travel to Nepal for a period of over 30 days. This number can be adjusted subject to the requirements of the university.

APPENDIX B

Disinfection Methods and Mechanisms

Poh Maga
WAS Graduation Thesis/Appendix Report

Purpose

The purpose of this report is to identify methods of disinfecting drinking water inside an enclosed holding tank. Of these methods, one should be chosen based on effectiveness, cost, and ease of implementation in an autonomous water assessment system. Based on that decision, a delivery mechanism will be chosen based on the same criteria

Considerations

This report assumes that the method/mechanism must be sufficient to purify a tank of at least 1000 liters. The water in this tank may contain particulate matter and dissolved solids. High turbidity can also be assumed. However, the target of purification is pathogenic bacteria as indicated by the PRI bacterial sensor. Additionally, power consumption is a factor in this assessment as access to ground power may be inconsistent. Consumable materials are also to be considered, however the logistics associated with them should be considered as well, such as cost, ease/safety of transport, and viable storage life.

Methods

Ultraviolet Light

Pathogenic bacteria can be neutralized from exposure to ultraviolet light. This does not require any consumable materials. There are two main methods to accomplish this: passive and active (1).

Passive

Solar energy filtered through a transparent material can transmit enough UV energy to neutralize bacteria. This is usually done on a small scale by filling a PET bottle with water and leaving it in the sun. However, this could possibly be scaled to a system capable of purifying a water tank should bacteria be detected.

Pros:
This would not require any additional power generation as this is a passive system.

Cons:
It is unlikely this system would be able to purify an entire tank at the same time as it takes time and light penetration for this method to be effective. This would require an additional

purification tank with a UV filter. Additionally, turbidity can reduce the effectiveness of this method. It also assumes solar energy will always be available, which might not be the case in the event of clouds or snow.

Active

UV radiation can also be generated by specialized light bulbs. Submerging such bulbs in a body of water can also neutralize bacteria similar to how the passive system works (2)

Pros:
An active system can operate regardless of weather condition by operating from ground power or batteries unlike a passive system. Multiple bulbs can be distributed throughout the tank to aid light penetration and eliminate the need for a separate purification tank.

Cons:
Effect of UV light is not residual, therefore the system must constantly run and consume energy to be effective. UV bulbs are also expensive and have a limited lifespan of around 6-12 months and require regular cleaning and special transport considerations. UV systems in general can be compromised by high turbidity.

Mechanical Filtration

There are many personal filtration devices intended for personal use. However, there are some that may be scaled to the required size. These consist of simple filters made from sand, gravel, and charcoal to more specialized filters with less common materials, i.e. colloidal silver ceramic filters (3)

Pros:
Very simple and inexpensive to build, no consumable materials, and does not require excessive purification time.

Cons:
Filters might not have sufficient throughput to supply a rural community - especially ceramic filters. Such filters can be clogged with excessive turbidity and will require regular cleaning. Some filters require a biofilm to operate, which takes time and specific environmental conditions to develop.

Chlorination

Adding chlorine to water, either directly or from a hypochlorite solution, neutralizes bacteria. This can also create residual chlorine, which continues to purify the water even after the original chlorine solution has been added. The chlorine solution can come in the form of a liquid (4)

Pros:
Chlorination is a simple and fast procedure. Residual chlorine can continue to neutralize bacteria so the operation does not have to be constant. Consumables are easy to acquire and are a very common method.

Cons:
Requires calculated dosage to be effective and requires at least 5 minutes before the water is safe to drink. Chlorine is a hazardous material and requires special dosage and storage considerations. Users may also detect difference in water taste that may result in poor perception of a new system.

Thermal

Raising water above 55 degrees celsius can neutralize most pathogenic bacteria. This can be accomplished with a pasteurization process, or simply boiling the water (5).

Pros:
Boiling gives an easy visual indication of when water is properly treated. This is a very common and effective method in neutralizing bacteria.

Cons:
This method requires very large amounts of energy to raise water to the critical temperature. Additionally, the boiled water can still become re-contaminated as the effects of pasteurization are not residual. Therefore, the tank will require insulation and constant heating to be effective.

Method Selection

Based on this assessment, Chlorination appears to be the right choice for this system. It is easily scalable to the 1000 liter volume required and does not require optimal weather conditions or consistent access to electricity. While it does require consumable materials, they are inexpensive and easily sourced throughout the world.

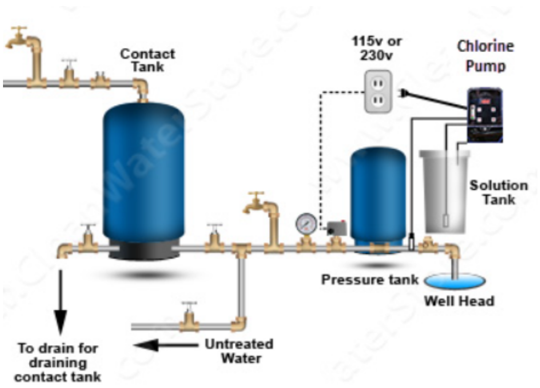
That is not to say this method is perfect. It involves the transport and storage of hazardous chemicals, which will impose additional considerations into the design of the WAS system. Additionally, the method of chlorination must still be defined. For example, a hypochlorite solution can come in the form of a liquid, a powder, or a tablet - each of which will also impose additional system considerations. For this reason, further research is required to define the delivery mechanism to introduce chlorine into the water supply. Additionally, the effectiveness of chlorine is determined by other factors such as temperature and turbidity. Therefore, more sensors will be required beyond the PRI bacteria sensor.

Mechanisms

Chlorine for water purification (in this case, a sodium hypochlorite solution) comes in three main forms: liquid, powder, and tablet. The gas form, used in industrial applications, is too dangerous to be used in this case. Mechanisms for delivering all three types will be identified and analyzed (6)(7).

Liquid

Direct Injection

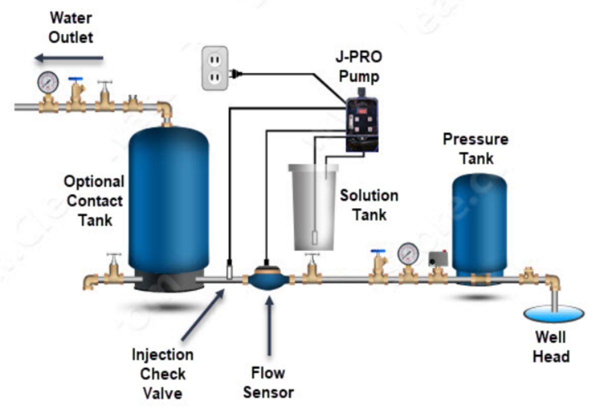


The simplest way to introduce chlorine into a tank of water is to inject it directly. This is a common method of ‘shock chlorination’ - a method of cleaning a water supply system to remove bacteria after contamination. This method requires the system to be fully flushed during chlorination. However, this may also be used to chlorinate an entire tank with a liquid hypochlorite solution. This is generally a point-of-use solution, but may be scaled to treat an entire water tank.

Pros: Liquid chlorine solution does not leave residue and can easily be pumped in precise amounts using a pumping system that can be turned on and off.

Cons: Direct injection takes time for the chlorine to take effect and mix with the treated water. Additionally, liquid hypochlorite solution has a limited shelf life (up to 6 months) (8) and does not last as long as hypochlorite tablets (based on pool chemical statistics.

Proportional Flow



A proportional flow system dispenses a calibrated amount of chlorine into running water, i.e. in an inlet or outlet from the holding tank. This requires a precise pump, which is activated and can be modulated by a flow measuring device placed in the inlet/outlet pipe. This application is generally used for homes that get their water from wells.

Pros: Proportional flow systems are efficient in chlorine distribution and reduce mixing time required for chlorine to take effect (if used with a static mixing device). This would also negate the need to measure stored water volume. Many off-the-shelf solutions exist for this already.

Cons: Requires a flow meter/sensor to work properly and must be finely calibrated to not over/under chlorinate the water. High chlorine levels or a short distance to point-of-use may also require a contact tank.

Contact tank

A contact tank can be used with any of the described methods. It is an addition to a system that allows chlorine to be mixed and stored before being distributed to the point-of-use. This is generally used for residential systems, but can be used to also provide water to a larger tank before use.

Pros: Allows for better mixing sufficient time for the chlorine to be effective. Some methods do not allow for enough time for the chlorine to mix, resulting in samples with too high/low chlorine concentrations.

Cons: Adds complexity and cost to the system as it would require a large tank and additional valves and level sensors. This addition may not be necessary depending on the distance from the holding tank to the point-of-use.

Powder

Chlorine can also be used in a dry powder form. This will require a different mechanism than the liquid systems described above. Such powders are common in point-of-use and personal applications, but may be scaled to work with the water tank specified in this application.

Pros: Powder has a longer shelf-life than liquid chlorine (over 12 months) and is easier to transport.

Cons: Powder can leave residue inside a tank and may result in additional maintenance. Additionally, powder has a tendency to clump upon exposure to moisture. This will likely result in additional complexity and maintenance in the distribution system. Additionally, mechanisms designed to work with powder are prone to jamming, which will result in more system failures and intervention.

Tablet/Pellet

Mechanical Applicator

Chlorine solutions also come in a tablet/pellet form and dissolve in the water to be disinfected. Such pellets are very common throughout the world and can be used at point-of-use for disinfecting a bottle or pot of water. For this application pellets can be inserted in quantities depending on the volume of the water in the tank by a mechanical applicator.

Pros: Pellets have a very long shelf-life and are not hazardous to transport. Their predictable size would not be as complex or error-prone as a powder mechanism.

Cons: Pellets are not as precise as liquid/powder application, therefore the size of the pellet must be in a denomination small enough not to exceed the chlorination threshold of the water tank. Additionally, pellets can also leave residue in the water supply. Broken pellets also have the potential to jam a mechanical applicator. Additionally, the tank would need some means of dissolving and mixing the pellets for faster results

Passive Applicator

A passive pellet applicator works by passing a calibrated quantity of water over a container of pellets. As the water passes over the pellets, they dissolve into the water, which is then mixed with the target water supply. This is an entirely passive system and requires only setting the water flow and replenishing the pellets once depleted. This is commonly used in residential applications for purifying well water, but may be used to disinfect a chlorine tank either from the inlet or outlet valve.

Pros: Very simple. No energy consumption and maintenance only consists of replenishing pellets. Several off-the-shelf solutions exist and could be replicated domestically in Nepal. Pellets do produce some residue, but this is constantly washed away by water flow and does not collect in a tank.

Cons: Pellets cannot be stored in water for long durations or they will dissolve completely. Water flow is required for the system to work. Small reservoir size may require frequent refills.

Conclusion

Of all the water purification methods that were researched and described, Chlorination seems to be the most viable. Despite requiring consumable materials, the results are consistent and require very little energy. However, this requires a method of introducing chlorine into the water tank, which depends on the form of chlorine that can be used. Previous system explorations assumed a liquid chlorine solution would work best, given the precise and robust nature of peristaltic pumps. However, passive pellet applicators seem to be the best option as they require no moving parts and can be pre-calibrated by design. Their drawbacks, such as low capacity and need for constantly running water can be addressed by a larger pellet storage tank and a bypass valve or u-bend. Such systems could potentially be 3d printed as their functionality comes from form, not moving parts. With that in mind, I believe a passive pellet applicator should be researched further to determine viability within a system deployed in Nepal.

Sources

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3. https://sswm.info/water-nutrient-cycle/water-purification/hardwares/point-use-water-treatment/biosand-filter

4. https://sswm.info/water-nutrient-cycle/water-purification/hardwares/point-use-water-treatment/chlorination

5. https://sswm.info/water-nutrient-cycle/water-purification/hardwares/point-use-water-treatment/boiling

6. https://extensionpublications.unl.edu/assets/html/g1496/build/g1496.htm

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8. https://www.myperfectpool.com.au/pool-chlorine-shelf-life.html

APPENDIX C

Lubu Water Treatment Plant Notes

General Overview and water sources

- Plant provides water to 1600 homes which is about 20,000 people at a rate of of around 1.5 million liters per day
- They source water from boring sites, shallow boring sites, and rivers
- The boring sites use 160, 180, and 240 meter wells

Process

- Combination of chlorination and filtration
- first filter is an aeration filter which removes iron and ammonia
- second filter is a tube-type particulate filter to remove turbidity
- third filter is a slow sand filter using 3m of water, sand and rock chips
- Final process is chlorination

Chlorination Process

- Water flows into holding tank and is dosed with chlorine
- Chlorine constantly flows from programmable dosing pump
- Chlorine comes from liquid chlorine solution mixed on-site
- Solution is made from calcium hypochlorite powder
- Site uses 5kg of calcium hypochlorite per day at 100 npr/kg
- Then it is stored and distributed to customers via pipelines

Testing

- Bacteria tests occur every other day
- Takes bacteria 24 hours to grow
- Source, holding tank, and customer homes are tested
- Wants to use PRI’s optical engine for these tests

Operation

- Lubu is a co-op and runs from money paid by customers
- customers can elect representatives to operate the plant
- Customers also gave start-up capital
- Some government funding but primarily customer operated

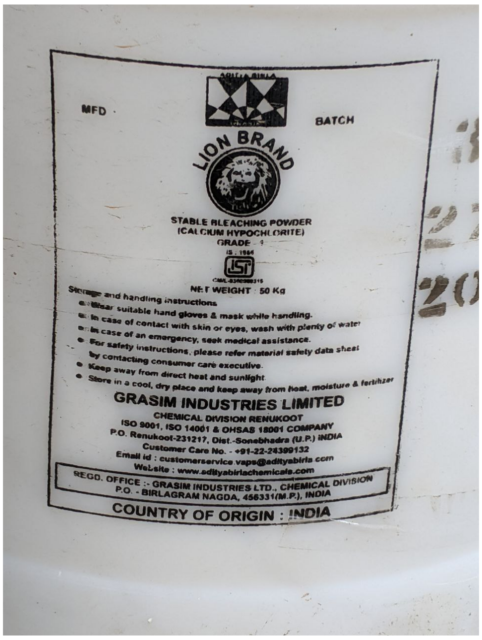
Images

Water flowing into the plant from a collection site

Aeration Filter

Chlorine storage and mixing site

Automated chlorine dosing pump



MFD

BATCH

LION BRAND

STABLE BLEACHING POWDER
(CALCIUM HYPOCHLORITE)
GRADE - 1
IS : 1065
CM/L-[illegible]
NET WEIGHT : 50 Kg

Storage and handling instructions

- Wear suitable hand gloves & mask while handling.
- In case of contact with skin or eyes, wash with plenty of water
- In case of an emergency, seek medical assistance.
- For safety instructions, please refer material safety data sheet by contacting consumer care executive.
- Keep away from direct heat and sunlight.
- Store in a cool, dry place and keep away from heat, moisture & fertilizer

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COUNTRY OF ORIGIN : INDIA

Industrial Calcium Hypochlorite used at Lubu

Sand and Gravel filter (before chlorine)

Main water containment tower

APPENDIX C

	Requirement	Metric	Testing Method	Stakeholder
General functionality				
1	Must determine if a water sample has contains unsafe bacteria concentration	Y/N	Defer to PRI threshold	End User, Health Authorities, PRI
2	Must dispence chlorine proportional to the amount of water to be chlorinated	Volume	Volumetric measurement of chlorine output	End User, Health Authorities
3	Must send data wirelessly to external server	Y/N	Send data to thingspeak server	End User, Health authorities
Chlorine/Water Dispensing				
4	Must dispense chlorine solution with precision of +/- 10 ml.	Volume	Volumetric measurement of chlorine output	End User, Health authorities
5	Water output must be stored greater than 30 min before point of use	Y/N		End User, Health Authorities (WHO)
6	Water output must not contain viable fecal coliforms	Bacteria PPM	PRI sensor or culture test	End User, Health Authorities
7	Must be able to pump at least 4 liters of chlorine solution per hour	Volume	Volumetric measurement of chlorine output	End User, PRI
8	Contact tank must be able to drain completely in 1 hour	Y/N		End User
9	Amount of chlorine should be variable depending on volume of contact tank	Y/N		End User, PRI
10	Pumps/intake should not introduce air bubbles into the system	Y/N		End User
11	Pumps must be able to withstand at least 1 meter of head pressure	Y/N		End User, PRI
12	Internal water lines should remain free of water/pressure during idle states	Y/N		End User
Detection/Optical Engine				
13	Flowcell must remain upright during operation	Y/N		End User
14	Optical engine must be powered by batteries	Y/N		PRI
15	Optical engine must share as many components as possible with standalone WAS device	Y/N		PRI
16	Optical engine casing must not allow light ingress	Y/N		PRI
17	Optical engine casing (specifically TIA) must not allow for EM interference	Y/N		PRI
System architecture/ assembly				
18	As many components as possible should be sourced from Nepal/Nepali importers	Qualitative		
19	Critical systems should be separated into modules	Y/N		
20	Modules should be replaceable in the field	Y/N		
21	Module housing should be 3d printed with possibility to injection mold with minimal adjustments to part geometry	Y/N		
22	Outer encloser should be water/dust resistant	Y/N	IP65	PRI
23	Outer enclosure should be OTS, and sourced in Nepal	Y/N		PRI
24	Modules should be able to fit within multiple available outer enclosures	Y/N		PRI

APPENDIX E

Technical Data Repository

The relevant technical data for this project comes in the form of a CAD model and photos of the resulting prototype. These have been uploaded to the following Google Drive folder accessible with the following link:

https://drive.google.com/drive/folders/1T984sUdwlYMp8t_z2MyUDOgq4jxC_Uy6?usp=sharing

In order to protect the intellectual property of PRI, the critical components of the optical engine have been omitted. However, the components created as the result of this project are all included. This repository may be subject to change subject to the requirements of PRI, TU Delft, or the author.

For questions or requests regarding this repository, Please contact

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