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A Culture-Centric & Sustainable Systems Engineering Approach: Water Filtration in Guatemala's Tzununa

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***Abstract*—The Partnership for University Research Abroad (PURA), a group of interdisciplinary students at the University of Virginia, has formed a partnership with Tzununa, a community on the shores of Guatemala's Lake Atitlan, to address its water quality needs. Faced with the need for a water filtration system, Tzununa has consented PURA's implementation of a point-of-use water filtration system. Utilizing a systems engineering design process, PURA designed a hygiene education program and selected an appropriate filtration technology to counteract the high incidence of waterborne illnesses in Tzununa. PURA emphasizes the sustainability of this project by laying the groundwork for a potential scale-up of the filtration system.**

I. Introduction

IN September 2009, an interdisciplinary group of University of Virginia (UVA) students in Engineering in Context (EIC) program formed the Partnership for University Research Abroad (PURA) to engage in an international development water sanitation project in Guatemala. PURA serves as a team under the auspices of the UVA-Guatemala Initiative (UVAGI), which is "an ongoing effort to develop sustainable partnerships with the peoples of Guatemala" [1]. UVAGI liaised with PURA to identify Tzununa, an indigenous Guatemalan community in dire need of a water purification system for its inhabitants.

In collaboration with non-profit medical services provider Mayan Medical Aid (MMA), PURA has launched a pilot project entailing a dual effort to counteract the high incidence of waterborne illnesses in Tzununa. First, PURA's establishment of an education program will serve to teach Tzununa's community members the importance of good hygiene habits in preventing the contraction of waterborne diseases. Second, PURA's implementation of a water filtration system will empower a subset of the community to self-sufficiently purify their own water.

Towards the end of 2009, PURA had taken a systems engineering approach towards designing the pilot project, which it seeks to implement in the summer of 2010. In January 2010, PURA assessed Tzununa's infrastructure, its community's demographic and medical situation, and ultimately received consent from the Tzununa's Emergency Committee to conduct the pilot project. In the spring of 2010, PURA conducted a cost/benefit analysis to designate the HydrAid® bio-sand water filter as the most appropriate technology to remedy Tzununa's water predicament. Additionally, PURA is testing the HydrAid® filter's effectiveness in counteracting waterborne viruses, bacteria, and parasites by simulating Tzununa's water environment in UVA's Civil Engineering laboratory. Simultaneously, PURA will be conducting the education program, through a locally hired Guatemalan liaison, to prepare the selected community members for their reception of the filters in the summer. Subsequent to the implementation of the twenty filters, PURA will evaluate the filtration and education systems' effectiveness at lowering the incidence of waterborne illnesses in Tzununa.

Moreover, PURA seeks to ensure the sustainability of the project through several mechanisms. First, the project places a heavy emphasis on educating the community about the assembly, operation, and maintenance procedures of the HydrAid® filter. Second, PURA has recruited and is training a future team of engineering students to pick up where PURA leaves off. Lastly, PURA seeks to create a "best practices approach" for future service-based projects on Lake Atitlan to replicate.

II. Background & Significance

A. Why Guatemala's Tzununa?

According to the World Health Organization (WHO), approximately 1.1 billion people lack adequate access to improved water [2]. Guatemala ranks highly amongst the the countries facing deficiencies in their provision and maintenance of water sanitation systems. Despite decades of collective action by aid agencies to provide water sanitation services in Guatemala, the country's population without access to sanitary water grows at a rate of 100,000 people per year [3].

PURA hypothesizes that Guatemala's water predicaments stem not from an unavailability of water treatment technologies, but from the incompatibility of these technologies with their host culture. The three main culprits of this incompatibility are:

1. Failure to involve the user community in the planning and installation processes,
2. The selection of unsuitable technology,
3. Lack of effective follow up by aid agencies [4].

The team selected Tzununa as its client due to the perilous water situation of its 4,000 community members [5].

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Tzununa is one of the only communities on Guatemala's Lake Atitlan without an adequate water filtration system. The World Water Forum dubbed Lake Atitlan "Threatened Lake of the Year 2009" due to its heavy concentrations of agricultural and household pollution [6]. As a result, Tzununa's inhabitants are highly susceptible to contracting waterborne illnesses. PURA's mission is to work with Tzununa to address its water quality concerns by implementing a sustainable point-of-use (POU) water filtration system.

B. Project Significance: A Scalable & Sustainable Model

PURA's mission is to combine the team's technical expertise and cultural understanding of Tzununa to successfully implement POU water treatment system that will lower the community's incidence of waterborne illnesses. The technical success of this project depends on the effectiveness of the HydrAid® bio-sand water filtration system. Yet to ensure that improved water quality yields a lower incidence of waterborne illnesses, the team seeks to use a systems engineering framework to manage the project, collaborate with Tzununa, and gauge the project's success.

The intended goal of this project is to create a long-term partnership with Tzununa based on mutual understanding. Instead of simply transferring HydrAid®'s turnkey filtration technology to the community, PURA seeks to ensure the project's sustainability by empowering community members to provide their own clean water. Furthermore, PURA is grooming a future team of UVA students to take over the project next year. PURA's vision is to create a scalable and sustainable model that will serve as a precedent for future UVAGI groups to replicate.

C. Significance of Bio-Sand Water Filtration (BSWF)

PURA's selection of the HydrAid® filter, which relies on BSWF, is manifold. First, BSWF is a technological adaptation of the centuries-old slow sand water filtration process. Generally, BSWF has proven to remove 95% to 99% of organic contaminants, i.e. bacteria, viruses, protozoa, and worms [7]. In support of BSWF's effectiveness, a 2007 study conducted by the School of Public Health at the University of North Carolina revealed that BSWF has the potential of reducing the incidence of diarrheal illness by up to 40% [8]. Hence, BSWF facilitates the achievement of PURA's goal of reducing the incidence of waterborne illnesses through the provision of clean water.

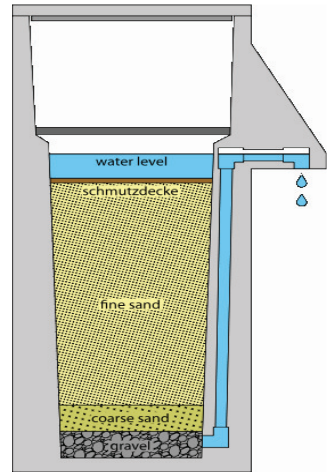

Fig.1. Schematic of generic BSWF [9].

III. A Systems Approach to the Pilot Project

A. Systems Engineering Methodology

By its very nature, a pilot project of this scale and complexity requires a systems engineering approach to effectively manage the project and evaluate its success. According to the IEEE, a system is "a set of elements that are related and whose behavior satisfies the operational needs and provides for lifecycle sustainment of the product" [10]. By this definition, the project qualifies as a system. The project's elements are a set of subsystems, namely the client assessment, BSWF technology, education program, and project evaluation. The systems engineering methodology allows us to synthesize these different elements to achieve the overarching goal of the system, i.e. cultivating a sustainable UVAGI-Tzununa partnership to alleviate Tzununa's water plight.

Throughout the project, PURA adhered to the standard six-step systems analysis process, which consisted of:

1. Define system problem and context,
2. Determine the system's goals and scope,
3. Establish criteria for evaluating alternatives,
4. Generate list of alternative solutions,
5. Rank solutions based on designated criteria,
6. Implement optimal solution.

This sequence of iterative steps provided a holistic framework within which PURA operated over the course of the project. PURA's intention to create a "best-practices approach" will be a Tzununa-specific rendition of this six-step process.

IV. Problem Definition, Goals, and Scope

A. Problem Definition

In order to tailor a suitable solution to Tzununa's water crisis, PURA had to first diagnose the problem. According to Dr. Craig Sinkinson, Director of MMA and prominent doctor in Tzununa, most of the medical cases he comes across are related to waterborne illnesses [11]. Additionally, Tzununa's members have drawn the conclusion that contaminated water is the culprit of their illnesses.

Tzununa's current sources of water are Lake Atitlan and a gravity-fed piping system that derives its water from a clean spring above the village. Holes in the piping system have resulted in ground-source contamination of the water during its transportation to the individual households. Replacing the current piping network is infeasible due to insufficient funding from the municipal government.

Another problem is the failed experience Tzununa had with POU ceramic filters. In the past, aid groups had sold some Tzununa members inexpensive ceramic filters. These filters were marketed as being purifiers (i.e. removing bacteria and viruses) instead of clarifiers (i.e. only removing turbidity), which they actually were [11]. Moreover, since these ceramic filters were mainly hand-made, they lacked quality control. This failed experience may lead to skepticism amongst Tzununa's members as whether to engage in PURA's pilot project.

B. *System Goals*

1. Work with Tzununa to address its water quality concerns by implementing a sustainable POU BSWF system.
2. Conduct an education program to teach community members:
    a. Hygiene habits to counteract waterborne illnesses.
    b. Use and maintenance of HydrAid® BSWF.
3. Engage community members in the design, planning, and execution of the system.
4. Ensure system's sustainability.

C. *Scope & System Boundaries*

PURA's pilot project will be on a small-scale. Only twenty families will undergo the education program and receive the HydrAid® filters. The project's intended goal will be twofold. On the humanitarian level, the project will provide the community with access to clean water, which will prevent community members from contracting waterborne illnesses in the future. On an experimental level, the project aims to serve as a precedent on which future UVAGI endeavors can be modeled.

V. Stakeholder Analysis

A. *Key Client & Affected Stakeholders*

The most immediate clients of PURA's pilot project will be a subset of Tzununa's population. Based on predefined criteria, PURA will select twenty families to participate in the hygiene education program and to receive twenty filters. To ensure the success of the pilot project, various other individuals and organizations are involved.

PURA has employed an on-ground liaison that is responsible for conducting the education program, creating a demographic census report of Tzununa, gathering water-testing data from the Guatemalan Ministry of Public Sanitation, and monitoring the sickness rate of participating families.

In addition to being under the auspices of the UVAGI, the project is of the utmost importance to the Tzununa Emergency Committee, which serves as the community's governing body. In addition to giving PURA the green light to go ahead with this project, the committee has a vested interest in ensuring the success of the filtration project to appease its constituents.

B. *The Client-Centric Approach*

A chief component of the systems analysis process is the involvement of the client in every stage of the system lifecycle. Thus, PURA has endeavored to engage the community by using the "participatory approach," a method of involving communities in development work [12]. PURA aims to employ this approach to avoid the first culprit of a project's incompatibility with its host community, as mentioned on the paper's first page.

The multifaceted stakeholder network PURA has at its disposal allows the group to gain insight on technical and cultural issues. This level of involvement "allows foreign engineering development workers to tap into the expert indigenous knowledge to determine information such as the location of water sources, key infrastructure, and the local history of the region" [13].

PURA made sure to hire its Guatemalan liaison from Tzununa so as to have an insider's perspective on board the team. Moreover, the client-centric approach intends to sustain the project's achievements by empowering the community members to perpetuate the education and filtration program in their municipal administration.

C. *Selection of Project Participants*

The community's participation in PURA's project was voluntary. Although UVAGI designated Tzununa to serve as PURA's client, the Emergency Committee's consent to go ahead with the project was the genesis of the project's implementation. In order to attract the interest of the community, PURA's Guatemalan liaison held an interest meeting in February of 2010 to brief interested community members about project. The interest meeting resulted in a total of forty family members expressing interest. The Guatemalan liaison subsequently selected twenty families based on a specific set of criteria.

The following is a list of sample criteria PURA used to select the families:

- incidence of waterborne illnesses,
- children under the age of five,
- elderly people,
- widows/widowers,
- no access to clean water.

PURA selected these criteria (amongst others) for three reasons. First, the group wanted to fulfill its humanitarian commitment to Tzununa. Second, the criteria served as a means to justify to the whole community why some community members were selected to participate in the program while others were not. Third, the selection of families with the highest incidence of waterborne illness will provide the best benchmark to gauge the success of PURA's project.

VI. ANALYSIS OF TECHNOLOGY ALTERNATIVES

A. Evaluation of Appropriate Technologies

The second culprit of a project's incompatibility with its host culture is the selection of an unsuitable technology. When selecting an appropriate filtration technology, PURA kept in mind that a suitable filtration technology was "any object, process, idea, or practice that enhances human fulfillment through satisfaction of human needs" [13]. PURA would accomplish this "satisfaction" by integrating a filtration system into Tzununa that was compatible with the community's environmental, cultural, and economic needs.

The specifications of the filtration technology were that it would need to be economical, POU, sustainable, quality controlled, durable, and efficient. In order to evaluate the existing POU filtration technologies, PURA created a matrix that compared the four most commonly used POU filtration technologies, as shown in Table 1.

Filter	**Cost**	**Cost/ Year**	**Rate (liters /hr)**	**Cost/Liter /Hour**
HydrAid	$32	$3.20	47	$0.68
Samaritan	$100	$20.0 0	60	$1.67
Ceramic Filters	$25	$6.25	1	$25.00
Aqua Clara	$15	$3.00	5	$3.00

Table 1. Evaluation and selection of technology.

B. Selection of Appropriate Technology

Subsequent to evaluating the different technologies by comparing the cost to filtration rate, i.e. the two metrics that were given the most weight, PURA selected the HydrAid® BSWF as the optimal technology in terms of compatibility with Tzununa. Figure 2 displays PURA's comparison chart of filtration technologies in terms of filtration rate and cost/year.

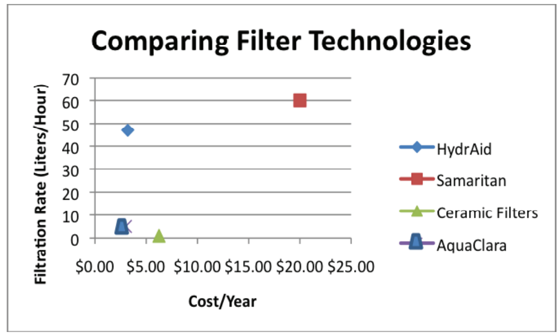

Fig. 2. Comparison of filtration technologies.

According to PURA's analysis, HydrAid® meets the needs of Tzununa since it is:

- POU,
- Sustainable: 10-year lifespan,
- Economical: Cost of $32,
- Durable & Portable: Triple Quest's plastic weighing 3.6kg (8 pounds),
- Effective: Removes 99% of waterborne contaminants.
- Flow Rate: 0.8 liters per minute.

In line with the participatory approach, PURA gauged the community's interest in the selected filtration technology. The group displayed a prototype of the HydrAid® filter to Tzununa's Emergency Committee which was pleased by the filter's simplistic design and reputed effectiveness [5].

HydrAid®'s compatibility with Tzununa is quite impressive considering that it could potentially rely on traditionally indigenous materials, such as special sand and gravel in lieu of HydrAid®'s proprietary components. During its visit to Guatemala, PURA ensured that local hardware stores are equipped with HydrAid®'s assembly materials.

VIII: RESULTS AND ANALYSIS

A. Monitoring & Data Collection

When assessing the overall success of the project, PURA intends to collect data and monitor the participants. PURA's monitoring process will replicate that of a longitudinal study in the sense that it will be collecting data about the families over a period of time. The data collected through the monitoring process serves as a way to determine whether PURA's project is achieving its intended goals and whether it has the potential to be scaled up to other Guatemalan communities.

PURA has tasked its liaison with collecting data through the use of questionnaires. There will be main monitoring phases:

- *Before Education:* Data collected on participants' water use habits and incidences of waterborne illnesses (baseline data),
- *During Education:* Data collected to track changes in hygiene habits and incidences of waterborne illnesses (comparative data),
- *Post-Filter Installation:* Data collected to track filter

use habits and incidences of sickness.

Hitherto, PURA has only completed the first phase of monitoring. The second and third phases are due to take places over the spring and summer, respectively. Moreover, PURA has used the first data collection phase to select the twenty families in most need of the filtration system.

B. Water Filtration Simulation

To verify it's research regarding the presence and type of contaminants in Tzununa's water, PURA tested a sample of the community's drinking water from the point of source. PURA's tests verified its research findings that the water was contaminated. Moreover, PURA visited Lake Atitlan's office for the Guatemalan Ministry of Public Sanitation, where it obtained valuable water test results confirming that the bacteria was mainly E. Coli and choliform. PURA's findings aid it in simulating Tzununa's water conditions.

Fig. 3. PURA water test verifying bacterial contamination

To simulate the water filtration system, PURA developed a filter component test plan and set up a prototype of the HydrAid® filter in a UVA's Civil Engineering laboratory. The HydrAid® filter consists of a gravel layer, two layers of sand in varying degrees of coarseness, and a biological layer, as shown in Figure 4. The filter's biological layer traps most of the microorganisms contained in the water. These microorganisms create a natural food chain that feeds on the contaminants in the water.

Fig. 4. HydrAid® BSWF schematic [7].

PURA successfully assembled and operated the filter during its simulation in order to achieve a flow rate of 0.8 liters/minute. Since the biological food chain takes two weeks to come into effect, PURA has yet to verify the HydrAid® filter actually filters up to 99% of waterborne contaminants. Overall, the filtration simulation will allow PURA to verify whether the HydrAid® BSWF is truly an appropriate technology for implementation in a Tzununa-like environment.

C. Evaluation: Metrics & Indices of Performance

The metrics PURA intends to use to determine the success of this project fall under three subheadings: hygiene, sanitation, and sustainability. These three subheadings fall under the overarching metric that will ultimately determine the success of the project, i.e. whether the project lowers participants' incidence of waterborne illnesses in the long run.

The hygiene metric will be used to assess the effectiveness of the education program. In order to measure the success of this program, PURA will collect data related to the participants' retention of newly acquired hygiene knowledge and the incorporation of this knowledge into daily hygiene habits. This will take place during the "During Education" monitoring phase.

The sanitation metric is the most crucial. This metric determines the success of the HydrAid®'s filter. The indices of performance to determine if the filter is accomplishing its intended function are: filtration rate, percentage of contamination removal, correct usage by user, and users' reduced incidence of waterborne illnesses.

Lastly, the sustainability metric will be based on three factors. First, the training of community members to assemble, operate, and maintain the filter will ensure that PURA has effectively transferred its technical knowledge to the community. Tzununa's provision of clean water by community members using HydrAid® filters would prove the success of this sustainability factor. Second, PURA aimed to achieve the filtration technology's success by selecting a product with a ten-year lifespan. Third, PURA can ensure the success of this project by recruiting, training, and handing over the project's responsibility to UVA students who will continue to foster UVAGI's relationship with Tzununa, follow up on PURA's project, and ensure that it is scaled up to meet most, if not all, of the community's water sanitation needs.

IX. Challenges Ahead

The next phase of PURA's project will be to order twenty HydrAid® filters for implementation in July. In the meantime, PURA is in the process of recruiting and training a new set of UVA students with the aptitude required to take over this project. By recruiting and educating these students, PURA aims to acquaint them with the project's technical and cultural expertise so that they won't need to "reinvent the wheel" when taking over the project next year.

Moreover, PURA intends to continue collecting data from its on-ground liaison so as to modify the project to reflect new developments.

X. Conclusion

This project synthesizes PURA's technical expertise with the cultural expertise of Tzununa's members and members of UVAGI and MMA to design, test, implement and sustain a community water filtration system. PURA intends to execute the participatory approach by incorporating the community members' recommendations into our project design. Furthermore, PURA endeavors to be flexible and versatile in its implementation of the project so as to reflect the client needs and environmental conditions.

In line with PURA's sustainability objectives, PURA has recruited a future leader of next year's EIC group. This student will serve as a member of PURA for the remainder of the year so as to gain relevant on-hands experience with the project. Although PURA will follow through until the implementation of the filters in the summer, the future EIC group will take charge of scaling up the project and meeting the future water sanitation needs of Tzununa.

XI. Broader Impacts

Using systems analysis and the participatory approach, this project has been conceived as a model for other water filtration development projects that will take place in the Lake Atitlan region. The project emphasizes the need for a holistic community assessment, training in personal hygiene and filter operation and maintenance, and the implementation of a POU BSWF system.

The system PURA designed is distinguished in the following ways (from development projects that have failed in the past):

1. Increased collaboration with the community and its leaders,
2. Integration of technical and cultural knowledge,
3. Flexible timeline adapting to the needs of the community,
4. Incentives for continued project management from individual stakeholders,
5. Scalability and sustainability ensured by continued UVAGI involvement.

PURA believes that such improvements will ensure the cultural acceptance and support of this project by the Tzununa community.

Acknowledgement

The success of this project hitherto would not have been possible if it were not for the dedicated efforts of many faculty and friends. The writers of this paper would like to thank the following people: PURA team member Alexander Beyard (UVA Economics & Foreign Affairs) and Jacob Letson (UVA McIntire School of Commerce); Professors Dana Elzey and Dr. David Burt for advising support; Dr. Craig Sinkinson, Jessica Gonzalez, and Paulina for cultural liaising between PURA and Tzununa; Systems technical advisor Garrick Louis; Mr. Ken Morino of the EIC program; Science, Technology, and Society professors Jack Brown and Benjamin Cohen; Professor Cahen & Lacey Fund, UVA Parents' Committee, and Engineering Student Without Borders for financial support. Lastly, we thank Tzununa's Emergency Committee and community members for their dedicated participation and cooperation to make this project a success.

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