Ecotourism in Alto da Esperança Reserve

Itacaré -Bahia, Brazil

Major Qualifying Project

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Structural and Energy System Design and Analysis in Bahia, Brazil

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Contents

Abstract

As development continues and the threat of climate change and the environmental crisis continue sustainability has become a major focus of governments and communities. Through different conservation efforts have looked to preserve the land and environment. The Alto da Esperança Reserve, a private nature reserve in Itacaré, Brazil shares their knowledge and experience living deeply connected to nature. Their efforts in ecotourism are compared to characteristics defined by Martha Honey in Ecotourism and Sustainable Development: Who Owns Paradise?.

Introduction

The influence of the environment and exposure to nature on people has become more prominent in society. Governments and communities alike have begun proposing sustainable solutions to otherwise conventional tasks and conservation strategies to preserve the world we live in. The influence of nature on people has not gone unnoticed as exposure to nature improves mental and physical health within humans and individuals. As development continues, many of these untouched diversity-rich ecosystems are being impacted by societal development. To solve this problem, adaptation and mitigation strategies such as conservation has become the main focus for scientists, government, and communities alike.

The challenge has been to determine what is truly sustainable and what strategies are the best to utilize. As development continues throughout the world, there needs to be a focus on preserving the values of each environment. This has led to government intervention to preserve the land and those in it. Many ecosystems and animals are going extinct or are the last of their kind. To preserve and protect the future allows us to live sustainably. Defining sustainability is difficult, leading to the ability to embody sustainability to its fullest extent.

The question remains, is the Alto da Esperança Reserve a truly sustainable ecotourism destination, or is it a branding technique to bring in those that want to feel as though they are doing good for the world. This proposal aims to look at the Alto da Esperança Reserve and see if ecotourism characteristics can define it.

Background

Nature and Knowledge

Humanity has realized that nature has an impact on human health and satisfaction. This has been evident in history as society has adjusted and integrated more exposure to nature into everyday living as exposure to nature as “direct physical and/or sensory contact with the natural environment (Wood, 2019)”. It is seen to “ improve mental wellbeing, attention, and mood, reduce stress, lower morbidity and reduce cardiovascular disease risk (Wood, 2019).” These benefits can also be seen through contact with spaces containing natural states of water. Exposure is also seen to increase physical activity by promoting participation. Nature Exposure improves health and wellbeing. It’s observed, “...that the enjoyment of scenery employs the mind without fatigue and yet exercises it, tranquilizes it and yet enlivens it; and thus, through the influence of the mind over the body, gives the effect of refreshing rest and reinvigoration to the whole system (Reddon & Durante, 2018).” The Nature Exposure Continuum, as demonstrated in Figure 1 is proposed by Reddon and Durante to better explain and categorize the influence and benefits mentally and physically on a spectrum rather than a divitive statement (Reddon & Durante, 2018). The Nature Exposure Sufficiency (NES) is described as the optimal amount of exposure to nature where the Nature Exposure Insufficiency (NEI) is described as the opposite. The continuum is used to better be able to categorize holistically.

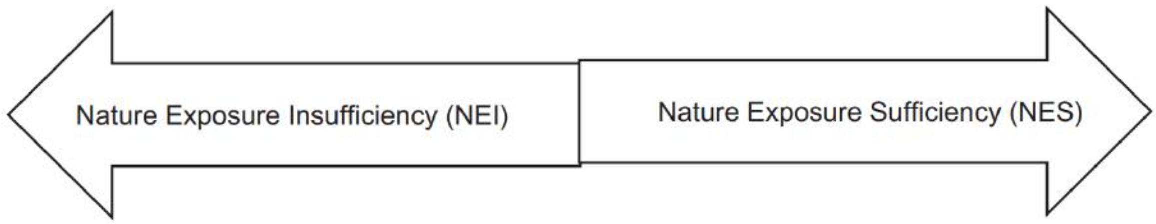


Figure 1. Nature Exposure (NE) Continuum (Reddon & Durante, 2018)

Many people understand and recognize nature as the beginning to sustain life and the therapeutic benefits as even the "fundamental affinity to living things (biophilia) as well as vegetation (phytophilia)" (Reddon & Durante, 2018). NE is what has been demonstrated in the past and acted upon. Houses were pushed back to allow for green space in everyday living exposing the suburban to more green space. This increases the natural exposure of the community. If people are able to commit more towards NES, then empirically the actual natural exposure contributes to "improved wellbeing but also improved connections with and transactions with our environment [4,5,39] (Reddon & Durante, 2018)." This is able to improve entire communities holistic lifestyles. The Alto da Esperança Reserve believes in holistic learning and promotes the connection with nature. Through increased NE, there is an automatic connection that is formed to the land which in turn improves lifestyle, land use, energy and water systems, and general sustainability because of this new formed connection.

Paulo Sanjines believes this more holistic view needs to be better understood and highlighted when looking at a person's knowledge and lifestyle. If one is to create a healthy life they need to look more holistically at themselves, their environment and how they interact. For one to understand where they are receiving information they need to understand how their environment influences information. Whereas nature exposure is explained to improve human life that constitutes that a person's environment has an impact on their health, priorities and lifestyle. Sanjines highlights the importance of distinguishing between the concept of organic knowledge and synthetic knowledge by their definition. Joao Claudio Goncalves speaks to his experience and the concept of synthetic versus organic knowledge.

In academia, there is a controlled experiment and research that allows for a better understanding of specific instances that is grounded in often linear thinking as to explain singular specific results. This then can be taken and compared and explained with other knowledge and synthetic results. Whereas organic knowledge is coming from a need of the community. This is created by understanding the world they are living in and those with whom they are living in parallel. The separation is in that synthetic knowledge does not often take into account the value of organic knowledge.

For example, an engineer, scientist, or researcher from another country or area comes into a smaller community to solve a problem in that community such as housing. This third party does not understand the way the community operates, but possesses solutions for them based on their academic research and professional expertise. A solution is proposed and then produced. However, as a result, a major body of water is damned and has destroyed a fishing space, irrigation service, and has disrupted the entire community. Whereas the community provided a solution to the placement and material use that was not acknowledged as developers looked to just what they were paid to do, ‘develop,’ instead of what the community needed. There is a need for more integration and preservation of organic knowledge into the professional world. Burying and bypassing the people of the communities in which professionals are entering and changing can often do more harm than good in the long term for the community and that environment.

Ecotourism

Ecotourism is a conservation strategy western colonia project that looks to promote cultural hegemony and the expropriation of nature (Reimer & Walter, 2013). There has been research into creating more specification between ecotourism and other types of tourism such as conservation tourism and wildlife tourism. As per the "The International Ecotourism Society offers the following—widely cited—definition: "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education (Stronza, Hunt, & Fitzgerald, 2019)." This definition by academia is different in its addition of a sustainable and non-invasive form of tourism. There is a clarification that not all tourism that is outdoors and involving nature is to be "ecotourism."

The variant of ecotourism is that of Community Based Ecotourism (CBET). This variant looks to focus on the community and culture preservation. This puts high regards and focus on sustainability of local communities and culture. This looks to be a mutually reinforcing concept in a mutualistic symbiotic relationship. Weave 2005 p 441 explained "the inclusion of a cultural component (in ecotourism) is a logical qualification to the 'nature- based' focus, given that few if any places are completely free from human influences(Reimer, Walter, 2013)." From a more conservational view this is seen to give legal rights to wildlife through the community (Fraser 2009 p 204). The businesses are able have a hold and develop around ecotourism and sustainable agriculture and agroforestry with purpose. They use local attitudes and knowledge to capitalize on resources while giving value that is worth protection and sustaining. Though different in the global south and global north "When local human populations are included in ecotourism projects, these projects often become a form of community development (Reimer, Walter, 2013)." Bjork 2007 3940 begins qualifying as it is responsible CBET through "development which considers social, environmental and economic goals (Reimer, Walter, 2013)." As it seems a paradox "Walter (2011, p. 160), then include: "(a) principles of local participation, control or ownership of ecotourism initiatives; (b) a focus on environmental conservation and local livelihood benefits; (c) the promotion of customary and indigenous cultures; and to some extent, (d) the promotion of local and indigenous human rights and sovereignty over traditional territories and resources.(Reimer, Walter, 2013)."

In a case study of a Thai-Malay fishing community "tourists stay as guests in local homes, and learn firsthand from family and community ecotourism guides (Walter, 2009)." There is a strong focus on using local knowledge. This is to promote a self determination and type of proprietary rights. These resources are creating values and becoming an economic resource. This model is not a mainstream form of development. Generally colonial and scientific epistemologies often devalue knowledge whereas this development is grown out of just that (Brigga and Sharp 2004, MacGregor 2004, Simpson 2004,Walter, 2009). By reaffirming local knowledge it does not further normaliz the colonization of the industry "destruction of this local knowledge—in this case, through the spread of commercial 'voyeur' tourism, mass media and environmental degradation—is thus also the destruction of local culture, language, and identity; that is, of a people, and as such is a violation of human right (Walter, 2009)" is understood in many articles. That part of ecotourism specifically is the highlighting and further preserving the value of local and indingeous concepts and ways. And part of this success is through education even before visiting the location.

Where many believe by providing resources on the location prior to the visit it will allow the visitor to be more educated and have a more encompassing experience. A great view of satisfaction has been seen empirically related to positive recommendations (Oviedo-García, 2016). There is said to be an effect of environmental knowledge on environmental responsibility. It is achieved "through environmental sensitiveness, both in a direct way and in an indirect way through place attachment (Oviedo-García, 2016)." The World Tourism Organization sees sustainable tourism as being able to be applied through three strategies as "optimal use of environmental resources that preserve ecological processes, natural heritage and biodiversity; respect for the sociocultural authenticity of host communities; while, providing fairly distributed socio-economic benefits to all.(Oviedo-García, 2016)." Informed participation is impactful and important to develop sustainable tourism. As it is one of the faster growing sectors of tourism (Das and Chatterjee, 2015) it is a need to be educated on the culture and environment the people are entering as to be respectful of the local concepts and culture. However there is to be found that just because a person has high ecotourism knowledge that did not always affect their actions (Oviedo-García, 2016)."

Honey describes a confusion in competing terms to define ecotourism. Many times, greenwashing and marketing the sustainability of tourism is just a facade to attract visitors. To move tourism beyond a new niche travel, Honey looked to incorporate the International Ecotourism Society (TIES) definition of "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education (TIES, 2015)." Honey described real ecotourism to consist of the following seven characteristics:

1. Involves travel to natural destinations

2. Minimizes impact
3. Builds environmental awareness
4. Provides direct financial benefits for conservation
5. Provides financial benefits and empowerment for local people
6. Respects local culture
7. Supports human rights and democratic movements.

Using these seven characteristics, one can understand and clarify if the Alto da Esperança Reserve currently qualifies for ecotourism, it is analyzed following these seven characteristics.

Ecotourism as a Western Construct

A discrepancy comes as ecotourism as predefined is a western conservationist concept that is now being proposed onto other cultures and communities. Ecotourism is inheritney nature based tourism with more defining qualities, but due to nature and the influence of the environment. A person is influenced by the environment and experiences of their life. TheTherefore the definition of nature is subject to be different based on different areas. The issue with ecotourism as a western construct is that not one size fits all. The ideas will actually if not properly acknowledged holistic reinforce inequalities in areas rather than reduce (Cater, 2006). There needs to be an acknowledgement and reflection of the concept of taken-for-grantedness of the natural world because of empowered social groups whereas the earth in other respects is actually the livelihood. For example, a tea farmer, Wang Shufang, from Longjing Village in Hangzhou, Zhejiang Province, China explained “if it doesn’t rain, the trees will die in the sun. Farmers eat from the sky (IQP).” Where her family has been relying on the farming and earth for her life. The connection between the land and livelihood is much stronger than a person of a more urban setting.

Brazil + Reserve

Brazil is able to acknowledge and understand the influence on climate change in the world. It is understood that there is to be a rise in the global average temperature with changes in rain period and droughts. There is also an increase in frequency and impact of storms due to this (Governo do Brasil, 2020). The Ministry of Environment acknowledges this phenomena as a consequence of the greenhouse gas effect and increase of Carbon Dioxide into the atmosphere. The ministry follows that these gases were emitted in more intensity after the industrial revolution and the future is mitigation and adaptation to the changes (Governo do Brasil, 2020). In 2019 the Federal Government established the Inter Ministerial Committee of Climate CHange (CIM) to address the concerns (Governo do Brasil, 2020). Where Brazil has seen the effects of climate change in their increase in temperatures and decrease in precipitation confirming a trend of global warming (Dubreuil,2018).

Where Brazil is being affected by climate change it also has a substantial impact on the climate due to the Amazon Rainforest and overall forest coverage. Brazil is home to 40 percent of the world's tropical forest and 13 percent of the biota (Pegas & Castley, 2014, p. 609). A tropical forest has a significant role in regulating the world's climate. Forests are able to store large amounts of carbon and regulate water and energy fluxes (Soares-Filho,2010). Deforestation, being the long term reduction of tree canopy, and forest degradation's combustion of biomass and decomposition has contributed to the greenhouse gas emissions [8].

Since 1972 and the meeting in Stockholm to understand the importance of taking care of the environment there has been greater focus and conversation of strategies to develop better efforts. Twenty Years ago there was an identification of hotspots where there was a high biodiversity that was threatened and land use was not sustainable. With the significant amount of endemic species that can not be found anywhere else in the world, there was great effort to preserve the water and forest in Brazil. As a result, the concept of biosphere reserve and mini biological corridors in the Atlantic Rainforest biome was developed. Brazil has created a top down approach to conservation including a well established private reserve system. Brazil conceived the strategy to develop seven ecological corridors: five in the Amazon and two in the Atlantic Forest. With the system these categories are used for sustainable use and integral for permanent protection, this all being a part of a larger legal framework.

The Alto da Esperança Reserve is located in the Cacao coast and the goal is to receive infrastructure that is able to be tailored to it's needs and promote business and tourism in general. In 1998 the area received a highway that was able to connect the region to the airport. This was a large step for the communities of the area as before Joao Claudio Goncalves found his family and himself biking.

With this highway system there was the realization there needed to be compensated for the large impact it was having in the area. So the government at the state level created more protected areas based on the biodiversity research done by the New York Botanical garden in 1991. This practice continued developing more protection sites as the infrastructure kept advancing.

The focus has been shifted to a larger strategic action to strengthen the Cacao Coast which holds the mosaic units. There has been a creation of long distance trails to connect the northeast trails and give access to the south of the country. The Alto da Esperança Reserve looks to be an access point and easy entry to this system to increase public use.

This area on the coast is where Joao Claudio Goncalves has grown up. Joao Claudio Goncalves explains that where he grew up is his identity "It is the place I was born, the culture and the environment that goes through me. That is my identity." Joao Claudio Goncalves describes how the word development is often only seen through tourism, but with tourism there is the creation of autonomy in citizens. He recognizes the values development has brought to the citizens. He explained how when they previously needed to go to the doctor they would need to ride a bicycle along the coast of the beach for 34-40 kilometers in one direction. With the addition of the highway they are able to have significantly better access. However, with conventional tourism he does not feel as though people always have this autonomy, as only the people that manage and own the hotels have this security. Instead many locals rely on 3 to 4 months of work in tourism. In the past, community and rural areas have found autonomy in using the land to provide for themselves.

Story of the Local Fisherman

Joao Claudio Goncalves described an experience in his life where he realized that organic knowledge and those practices of the local people are being overrun by western influence and economic need. He described a fisherman who has his Jangada traditional fishing boat, using the tides and moon to dictate his path. He spends his life saying goodbye to his family whenever he goes out to the water. He travels at least 25 km out into the water to provide for himself and his family.

This practice was common along the Atlantic but is now only alive on the coast on which the reserve neighbors. This practice was a part of the people—their connection to land, culture, identity, autonomy, and sustainability

However, with the new development, people are losing this connection to their surroundings and their legacies. The fisherman's children are now hotel staff workers in seasonal tourism. The autonomy their father had is gone and taken away by this new development strategy. The general population is not able to achieve the same financial prosperity and stability. As his children lose theses practices, they are also losing a connection to the land and environment they are so closely connected to and the ‘identity’ Joao Claudio Goncalves previously described.

The Alto da Esperança Reserve strives to “enable (a) human experience in harmony with nature.” Claudio Lôpo bought land to develop a space that will allow people to connect with nature. Their Interpretive Trail Activity works to teach people “ about the region and the management of the property as a whole, philosophy, and techniques adopted.” This allows people to better understand how to interact with nature and what they can gain as individuals from this interaction. Paulo Sanjines and Joao Caludia Goncalves both were able to live on the reserve for a nine month period to better understand nature and the world we live in. The Alto da Esperança Reserve believes there is a benefit in sharing the experience they have in nature with visitors and researchers. Those that experience this direct immersion into nature on the reserve gain immense knowledge of how aspects of the reserve work and how to help to maintain such a reserve truly benefits the entire world’s ecosystems.

The Alto da Esperança Reserve developed proposals for expansion by working with a Major Qualifying Project (MQP) at WPI to design possible expansion projects through infrastructure development. Through discussion and collaboration the students designed two structures: a dormitory and multifunctional center as pictures in Figure 2 and Figure 3

Figure 2: Dormitory design. A more detailed design and layout can be found in Structural and Energy System Design and Analysis in Bahia, Brazil supplement.

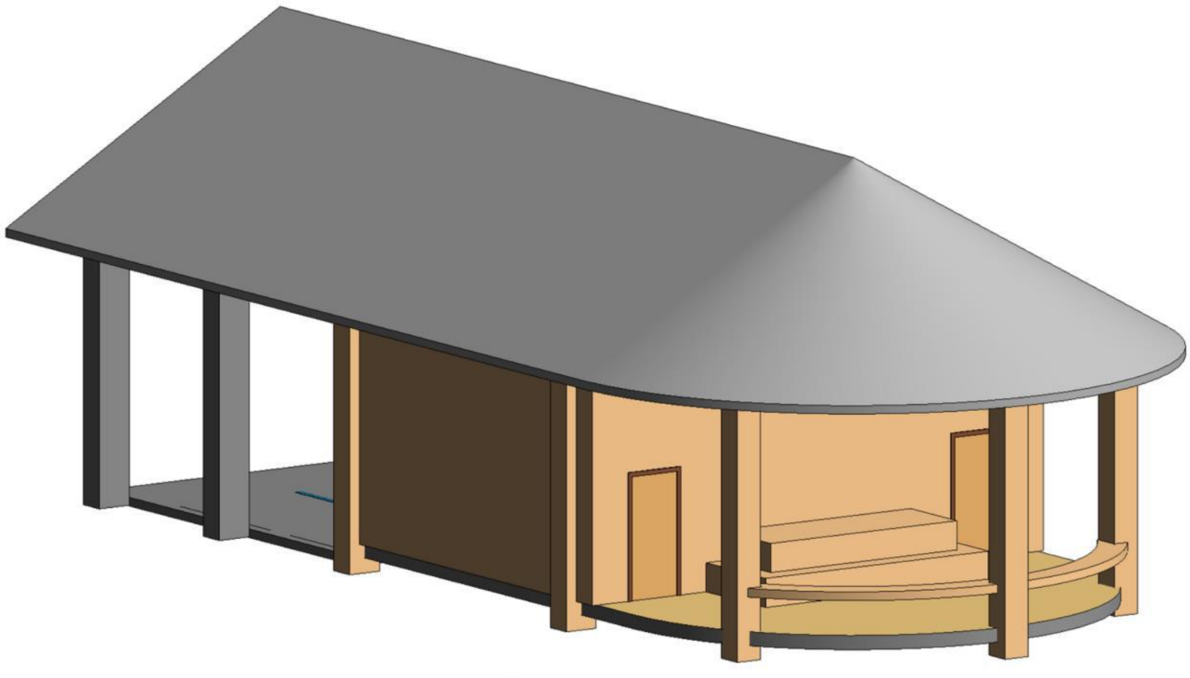


Figure 3: Multifunctional Center design. A more detailed design and layout can be found in Structural and Energy System Design and Analysis in Bahia, Brazil supplement.

The structures were required to be on 400 square meters of land as a requirement for conservation and sustainability on the reserve. The dormitory was designed to allow for visitors to stay for extended periods of time. There are eight bedrooms with four bathrooms, a space for laundry, kitchen and a multipurpose room that can be used for collaboration. The whole space contains a significant amount of windows, openings and decking to allow those who stay within to feel connected and close to the outdoors and environment. The multifunctional center was designed with two locker rooms to allow day visitors to change and shower and an attached stage area for presentations and performances.

The team proposed an energy system designed to capitalize on the resources available on the reserve as demonstrated in Figure 4. By using the available recourse and the sun the system harnesses steam power to generate energy as demonstrated in the appendix. An initial pump is needed to move the water through a pipe into a solar trough placed in sunlight. The water is then heated and continues through to a steam turbine. There the steam is harnessed to generate energy where the energy is then extracted. The steam is condensed into its original state and then piped back into the original source.

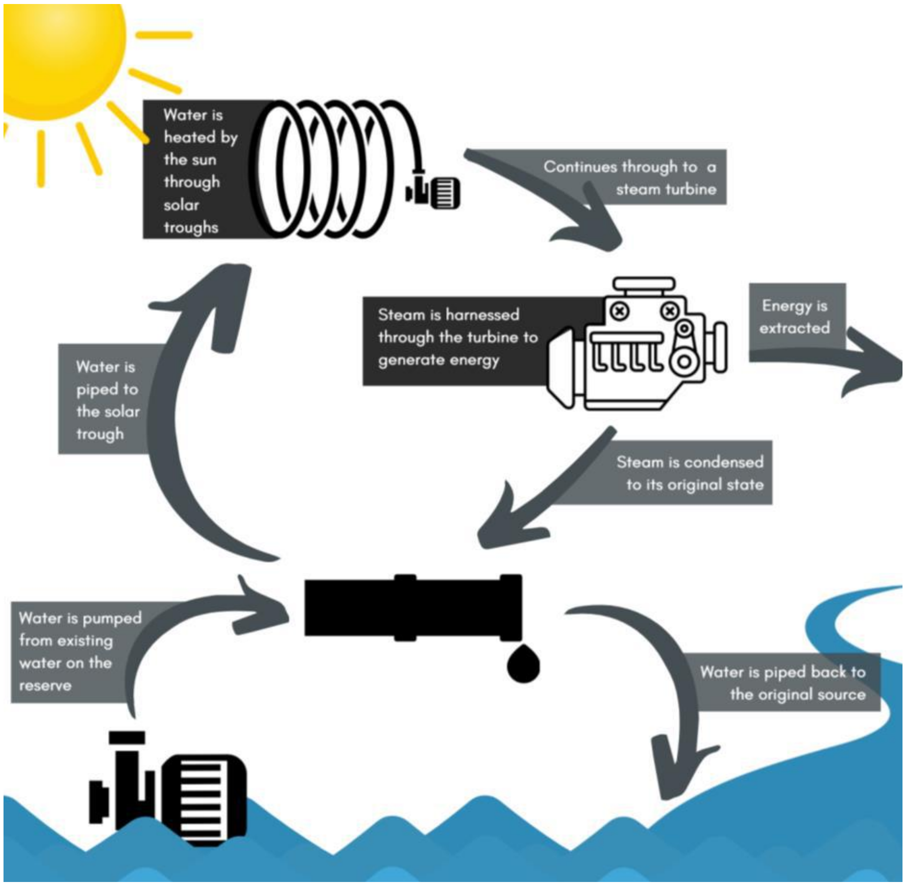


Figure 4: Energy System design. More detail can be found in Structural and Energy System Design and Analysis in Bahia, Brazil supplement.

A greywater system and proposition of constructed wetlands was designed to be able to harness the water from the rain as well as waste from the visitors. The greywater refers to water touched by humans. By reusing this water for other services, since it is not potable, the systems developed will be more sustainable. The water can be cleaned and used to water gardens and used in showers and sinks. The system is designed as explained in Figure 5 with a gutter to be connected to the structures, which are then placed in a position to allow gravity to bring the water down the pipe and into the filter tank. The tank then boils the water with a pit for a sustainable fire source to sterilize it. This process is more sustainable and accessible than harsh chemicals and does not disturb the surrounding area or the constructed wetlands. The water can then travel into the constructed wetlands to filter and collect runoff to allow a place for the water to collect as seen by the site layout in Figure 6.

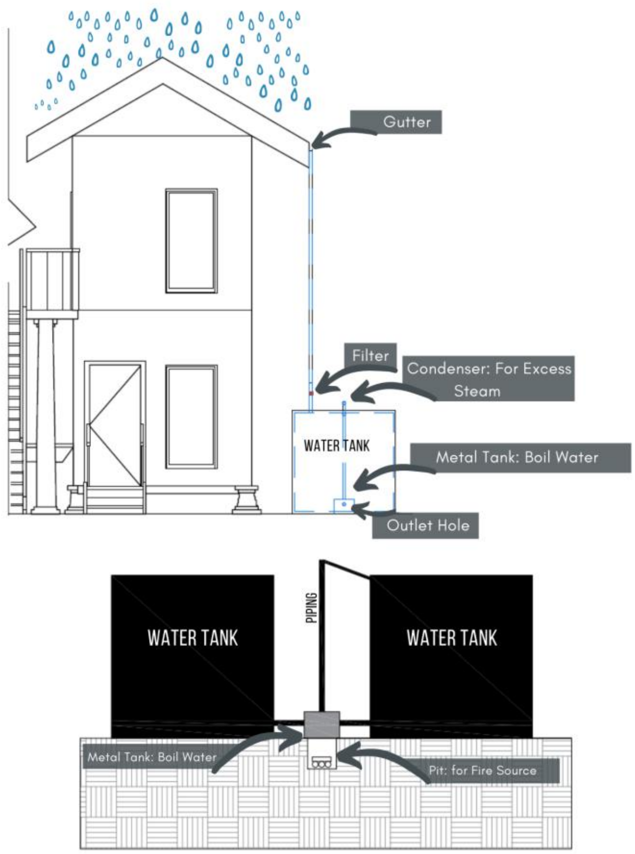


Figure 5: Multifunctional Center design. A more detailed design and layout can be found in Structural and Energy System Design and Analysis in Bahia, Brazil supplement.

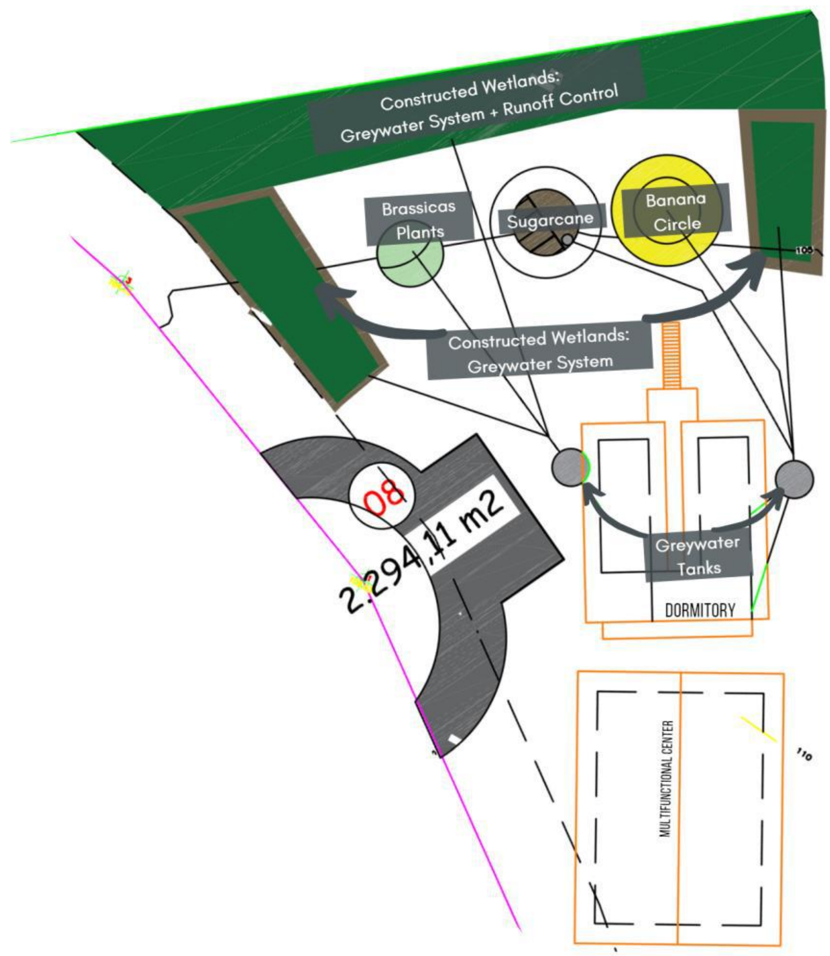


Figure 6: Site Layout design. More detail can be found in Structural and Energy System Design and Analysis in Bahia, Brazil supplement.

These design and graphics along with more were simplified into a smaller Sustainable Development report in the Appendix 1. The purpose was to have a simplified and less technician representation of the possibilities for the Alto da Esperança Reserve in the future.

Methodology

The overarching goal is to define ecotourism through a method of comparative analysis using the seven characteristics of ecotourism described by Honey in *Ecotourism and Sustainable Development*, *Who Owns Paradise?*. The main objective is to define whether the Alto da Esperança Reserve in Bahia, Brazil can be categorized as a place of ecotourism. If it does not fulfill the characteristics as described further a recommendation can be made to fulfill the gaps. The seven characteristics are described as followed:

1.Involves travel to natural destinations

Involving travel to natural destinations includes more remote areas. Whether they are inhabited or not, they would be under a type of environmental protection or conservation at any level whether federal, state, or private.

2. Minimizes impact

Ecotourism looks to have a low impact by doing little to no damage to its surroundings. This can be by reducing infrastructure effects by using recycled or locally sourced renewable resources in development. A more specific requirement is a minimization of transportation modes for tourists to travel to the site or attraction without damaging the surrounding ecosystems. Ecotourism is to be mostly non-extractive or nonconsumptive practice; however, sustainability based on renewable resources can be safe if done properly. Such an example is of hunting practices in ecotourism destinations such as Zimbabwe's Communal Area Management Programme For Indigenous Resources or CAMPFIRE program. It is built on the community integration of conservation to gain economic benefit while managing wildlife to create long-term sustainability. It gives the value of renewable natural resources to wildlife while giving ownership to indigenous and local people by allowing the people to use the wildlife as a resource on the private land. The program depends on hunting to benefit the local communities through contract safaris and tourism. The organization allows for support to manage hunting, poaching and empower the local community and value their land (Jonga & Pangeti, 2015).

3. Builds environmental awareness

Building environmental awareness in ecotourism is education for tourists and the community. Tour operators and other concessions such as hotels should provide materials to educate the visitors about the local culture, community, country, and societal norms to limit disruption prior to arrival. TIES guideline more specifically states "to learn about the places and people to be visited… to minimize their negative impacts while visiting sensitive environments and cultures (TIES, 2015)." This means the inclusion of knowledgeable, local, well-trained, bilingual naturalized guides. They should have a holistic understanding of the environment, including "natural and cultural history, environmental interpretation, ethical principles and effective communication (Honey, 2008, p. 44)." In education, the surrounding communities nationals and locals should also have reduced fees and conduct educational trips for students near the attraction.

4. Provides direct financial benefits for conservation

In providing direct financial benefits for conservation, the funds raised should go back to the protection agency, research, or an educational factor. Mechanisms of funding include "park entrance fees; tour company, hotel, airline, and airport taxed; and voluntary contributions (Honey, 2008, p, 45)."

5. Provides financial benefits and empowerment for local people

Ecotourism should provide financial benefit and empowerment for the local people. Honey described a Costa Rican based ecologist Daniel Janzen who explained that national parks and conservation areas only survive with “happy people” at the perimeters. The local community needs to have a stake and receive tangible benefits for the practice to be successful. Campsites, lodges, restaurants, and concessions should be run in partnership with protected attractions and tourist destinations. Businesses such as car rental, hotels, and airlines should be owned by host country nationals to allow better profits to stay within the local economy. The goal is to shift economic and political control to the local community.

6. Respects local culture

Respect for the culture is essential in ecotourism, and its goal is to be less culturally intrusive and exploitative. Conventional tourism finds by-products of prostitution, black markets, and drugs; ecotourism looks to be culturally respectful with minimal adverse effects on the host country. There is an unequal relationship power because of the “commodification of the relationship through an exchange of money (Honey, 2008, p. 46).” And to acknowledge and understand this relationship, ecotourists need to be responsible for understanding local customs and social norms and to learn not to be intrusive. To be sustainable when visiting and experiencing a culture is to allow it to remain pure for the next person who chooses to visit.

7. Supports human rights and democratic movements.

To support human rights and democratic movements as the World Tourism Organization explains, “international understanding, peace, prosperity and universal respect for and observance of human rights and fundamental freedoms for all(UN, 1945).” Tourism can build international understanding and a concept of world peace because of its use of exposure. However, tourism typically turns away from the attention from the political system of the host country and struggles unless it impacts tourists directly.

Results

As research has not been done with other locals related directly to the Alto da Esperança Reserve, it believes the benefit of tourism and ecotourism will only benefit the environment. Through empowering local people and providing new infrastructure, there can be more access to international tourism. . In the past, there was a lack of access to the area for visitors to come. Through the implementation of the highway and focus on the diversity of the area, it has allowed funding to be focused in this area. Brazil’s federal government also realized the importance of the area. Through the access provided by the highway, the local people have a significantly easier time accessing things such as the doctors, as Joao Claudio Goncalves explained.

The ability for tourists to come and focus on ecotourism may allow locals to feel a greater need to preserve their practices. Joao Claudio Goncalves described the old fisherman that practices his local ways but saw his family drifting away. If the community can be experienced and preserved through ecotourism it could bring them back closer to the land.

1.Involves travel to natural destinations

The Alto da Esperança Reserve is in a protected private reserve by the federal government. Therefore it involves travel to a natural destination.

2. Minimizes impact

The reserve instills the connection to nature and teaches others not to take away from the ecosystem, but teaches them the importance of preservation. A more specific requirement is the minimization of transportation which is a direct opposite of the experience in the Alto da Esperança Reserve. This is not the case in Brazil as they are still a developing nation. Joao Claudio describes how the highway was detrimental to the protection but integral to the area for development purposes. Since Brazil deemed the area under protection it required conservation and not be extractive.

3. Builds environmental awareness

The Alto da Esperança Reserve prides themselves in their knowledge of the area and their ability to share this knowledge with others..

4. Provides direct financial benefits for conservation

The privatized reserve of Alto da Esperança Reserve is run by the locals that believe investing and developing in the area is the path to true sustainability and conservation. The federal government in Brazil has been using the funding to develop the area to build the infrastructure to allow for increased ecotourism.

5. Provides financial benefits and empowerment for local people

Through empowering local people and providing new infrastructure, there can be more international tourism and access. In the past, there was a lack of access to the area for visitors to come. Through the implementation of the highway and focus on the diversity of the area, it has allowed funding to be focused in this area. Brazil's federal government realized the importance of maintaining those area. Through the access provided by the highway, the local people have a significantly easier time accessing things such as the doctors as Joao Claudio explained.

The ability for tourists to come and focus on ecotourism may allow locals to feel a greater need to preserve their practices. They automatically develop a sense of pride about their heritage and are able to pass this knowledge onto their offspring. Joao Claudio described the old fisherman who was no longer able to pass on basic communal values to his own children because in order to make money, they could not work in the fishing business. .

6. Respects local culture

The Alto da Esperança Reserve believes in preserving their own land, lifestyles, and culture in order to create a healthy sustainable life for the individuals who inhabit there.   There may not be specific restrictions or guidelines to preserve their local culture, but as an organization, it is their purpose to facilitate avenues for their reserve to continually expand and evolve. Their main purpose is to enable others to experience the love for their land and culture and to be able to transfer the information they learn to other places beyond the reserve.

7. Supports human rights and democratic movements.

The Alto da Esperança Reserve takes no specific political stance, but to share the world they live with others. They understand the value of local and outside knowledge and the need for their people to prosper within their own community. There is great respect for nature and those who inhabit it. They work in parallel with the concepts of peace, prosperity, and respect not just for all people, but for the environment and ecosystems within it.

Discussion

The Alto da Esperança Reserve doesn't fulfill all seven characteristics of ecotourism as described by Honey. This is not to say they may not be able to in the future, as they are always striving to develop ideas for the betterment of the reserve.

In the second characteristic to minimize impact, this is where the influence of the federal government and infrastructure has an effect on the Alto da Esperança Reserve. They want to be able to practice ecotourism as described in many western global north descriptions. Many of the descriptions of ecotourism and sustainability are dictated by the environment in which authors live and have grown. Therefore our ability to access remote areas is not the same as that in Brazil. The infrastructure is still being developed. The area just received a major highway that has greatly benefited the local community as described by Joao Claudio. The government realized the impact this would have on their new conservationist strategies; therefore they were able to have a lot more area to compensate or zero out the effects.

The Alto da Esperança Reserve also employed students of Worcester Polytechnic Institute for a project to allow them to take the first step in looking for donors. This demonstrated the interest in developing their property further. Expansion needs to occur in order for more people to understand and learn what the environment can do for themselves and others. There needs to be outside investment from others to allow for the organization to be able to conserve, protect and provide knowledge of the area. This is an effect of the society we have created where privatization is a major factor in conservation.

The predefined western conservationist concept, in this case, does not allow this organization and nature-based tourism to be a part of itself. The reserve is based on the owner and locals love and identity with nature and the environment they inhabit. . However, the lack of infrastructure by the federal and state government for outsiders or even locals to access this part of the country just reinforces the inequalities of countries. The recommendation lies that sustainable development to boost ecotourism is the best thing for the government to do; however, more research would need to be done on the local area and the exact reasons the government continues to allow these inequalities to perpetuate.

The third characteristic explains that there should be resources provided prior to a visit by tourists; however, due to the remote location, it is unknown if the hotels and tourist areas are experiencing this in practice. This is also a place of recommendation for the Alto da Esperança Reserve in the future. The Alto da Esperança Reserve prides itself on their knowledge of nature and their tourism so others can experience this environment that they hold so near to their hearts. As a result, they often believe a sense of immersion is what many visitors, tourists, or researchers need to experience Where providing materials may educate the tourists, the Alto da Esperança Reserve believes that a more holistic view is necessary for true immersion and understanding of their culture. By increasing nature exposure in holistic learning and lifestyle, it can improve the wellbeing of their body and mind. This is not something that can necessarily be taught to its full extent without direct experience within the environment. Traditional hotel tourist brochures with a list of facts and places to visit, will no longer be acceptable if the goal is true immersion. As the information, they are receiving can't be understood properly without direct exposure to the environment. This is also demonstrating the need for a concept of organic and synthetic knowledge. Where the synthetic knowledge is the pre arrival information the organic to be the engulfing experience of the reserve. When the outsiders are taught the organic methods of the land, they learn how the ecosystem works and by default they will learn how to appreciate the entire process.

Where the direct financial benefits for conservation and locals are not explicitly stated, there is the assumption that it will be reinvested as it is a protected area by the government. What is evident is that this impacts the local people. If the development that has come with investment into the area has been able to allow infrastructure to be built, this will only benefit the local economy. There is also a political influence that is not addressed in this paper but could be a place for future research. The Alto da Esperança Reserve is composed of locals who spend 9 months on the reserve and live in the area. This lets them create an identity with the land with the ultimate goal to share that identity with others. If done properly as it seems to be in the Alto da Esperança Reserve, it will empower the local culture. Even though there are no guidelines for education pre arrival and maintained local participation, the Alto da Esperança Reserve can share their identity through ecotourism.

The Alto da Esperança Reserve's message and identity follow the description of the World Tourism Organization in their principles. The Alto da Esperança Reserve wants to share their knowledge and respect for the environment with those not exposed to it. They want to see sustainable development efforts and conservation for the future. Whereas not explicitly stated they may not be capable of currently making a political stance on a system. They are not working against the ideology of peace, prosperity, and respect for all.

Conclusion

The Alto da Esperança Reserve believes there is a place in society to enable others to experience and connect with nature. The goal of the reserve is to enable outsiders to be able to sustainably connect with this community and to give them a better understanding of life away from their own homes. The Alto da Esperança Reserve looks to continue developing as an organization and its infrastructure to create true ecotourism and become a sustainable place for visitors to come. Through continued efforts and recommendations, the Alto da Esperança Reserve will be able to become a destination for ecotourism while continuing to preserve and empower themselves as a thriving local community. Through the help of Brazil's push to enhance conservationism and development, the concept of ecotourism is becoming a reality. The Alto da Esperança Reserve is a place to allow people to connect with nature, the environment, and gain an organic knowledge of how things truly work in this environment. Through continued efforts to understand and develop the definition of ecotourism out of the predefined western concept and the ability for the Alto da Esperança Reserve to develop, the Alto da Esperança Reserve will be able to be properly recognized and described as an ecotourism destination.

Appendix

1. Sustainable Development


SUSTAINABLE DEVELOPEMENT

Alto da Esperança Reserve

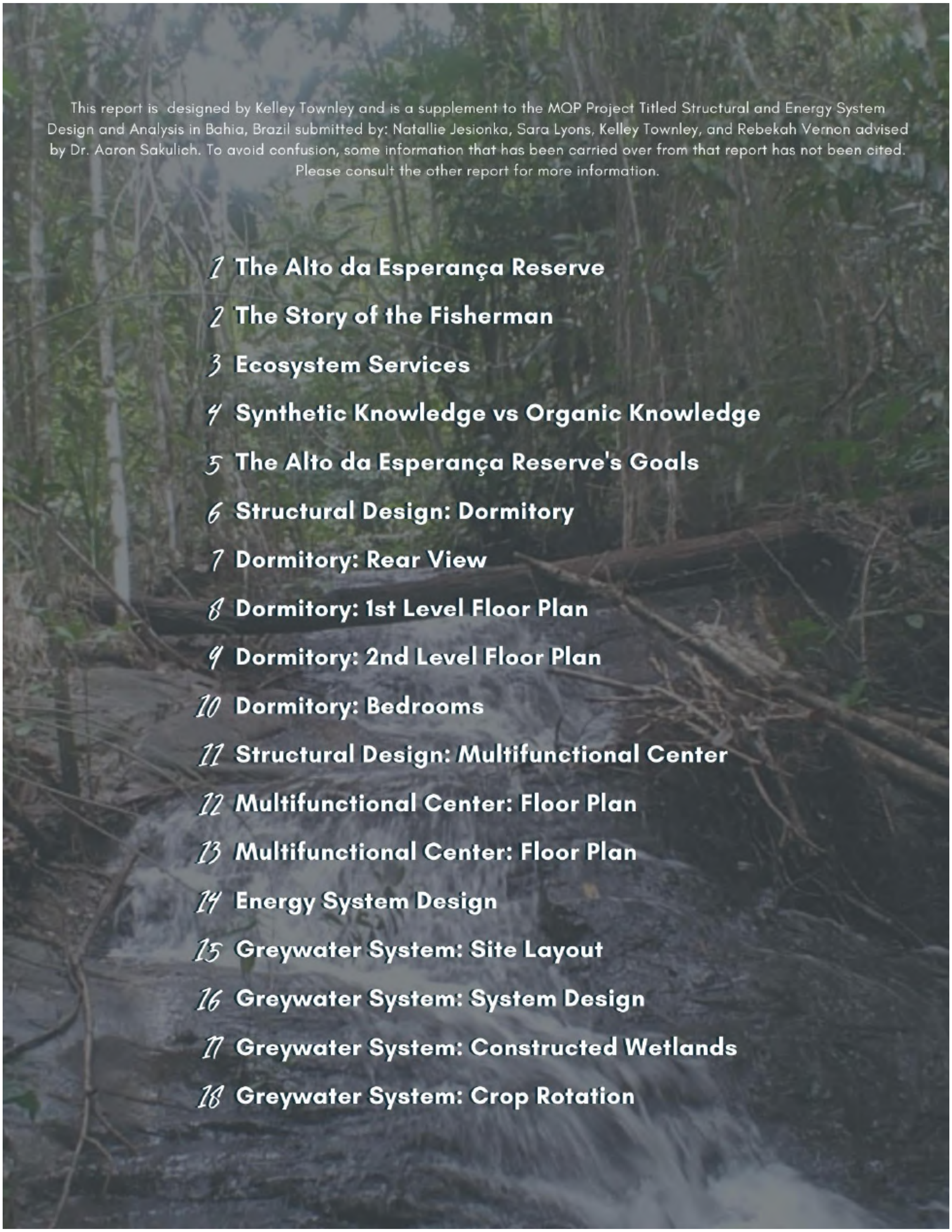
ITACARÉ - BAHIA - BRAZIL

A supplemental report from

STRUCTURAL AND ENERGY SYSTEM DESIGN AND ANALYSIS IN BAHIA, BRAZIL

Major Qualifying Project - Worcester Polytechnic Institute

Designed by Kelley Townley



This report is designed by Kelley Townley and is a supplement to the MQP Project Titled Structural and Energy System Design and Analysis in Bahia, Brazil submitted by: Natallie Jesionka, Sara Lyons, Kelley Townley, and Rebekah Vernon advised by Dr. Aaron Sakulich. To avoid confusion, some information that has been carried over from that report has not been cited. Please consult the other report for more information.

The Alto da Esperança Reserve wants to

"enable (a) human experience in harmony with nature."

Claudio Lôpo bought this land to develop a space that allowed people to connect with nature. Their Interpretive Trail Activity works to teach people

" about the region and the management of the property as a whole, philosophy and techniques adopted."

With this people are better able to understand how to interact with nature and what they can gain as individuals from this interaction.

The story of the local fisherman

explained by João Cláudio

A fisherman has his Jangada traditional fishing boat, using the tides and moon to dictate his path. He spends his life saying goodbye to his family whenever he goes out to the water. He travels at least 25 km out into the water to provide for himself and his family.

This practice was common along the Atlantic but is now only alive on the coast on which the reserve neighbors. This practice was a part of the people—their connection to land, culture, identity, and autonomy. Many people describe themselves by the land they were born and raised in and their relationship to it.

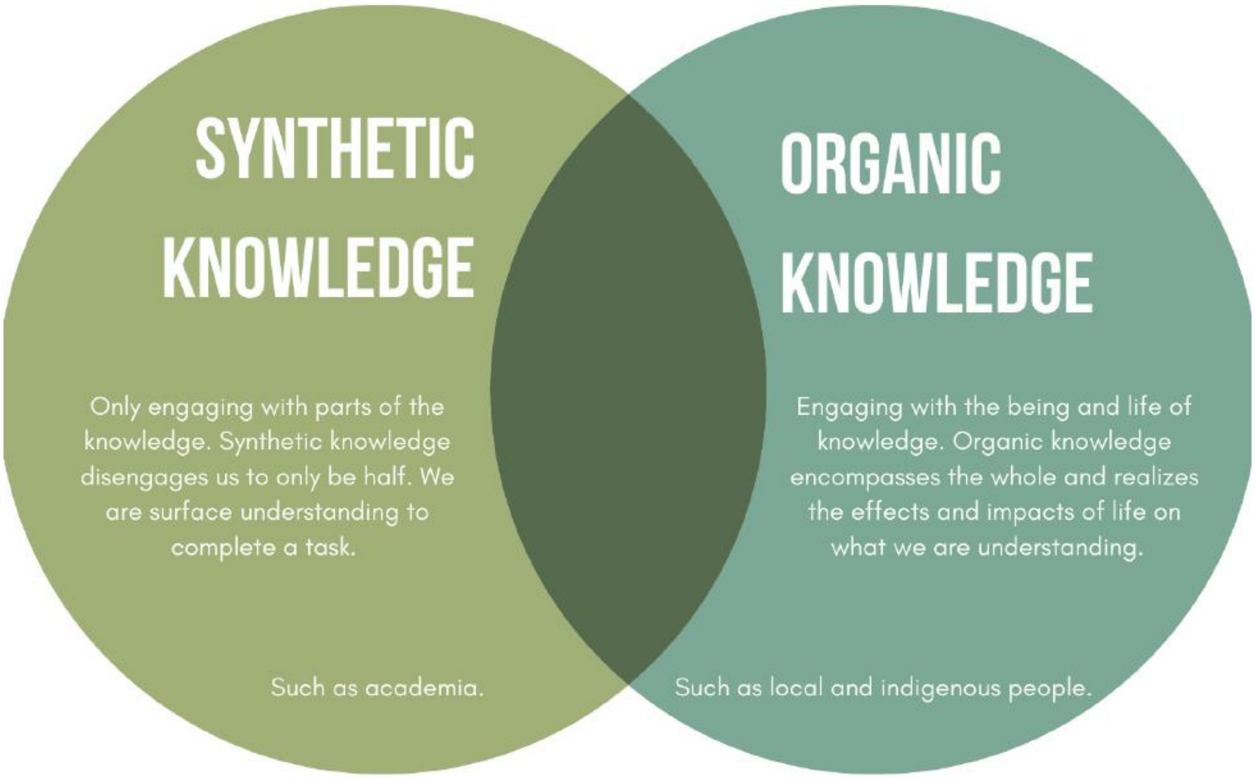
However, with the new development, people are losing this connection. The fisherman's children are now hotel staff workers in seasonal tourism. The autonomy their father has is gone taken away by this new development strategy. The general population is not able to achieve the same financial prosperity and stability. As his children lose this practice they are also losing a connection to the land and environment they are so closely connected to.

The Alto da Esperança Reserve wants to bring visitors in so they can experience a true connection to nature. In Brazil they have been able to create 3 strategic lines of landscape management going from the most broad to most specific.

With each level those in the area are able to do their part to protect all that nature provides. To better understand the land in which the Alto da Esperança Reserve is on one needs to understands what it does. The reserve provides different ecosystem services which are benefits that nature and the ecosystems provide to people and the developed world. They can be better organized into 3 categories.


ECOSYSTEM SERVICES
PROVISION SERVICES
are benefits extracted from nature
Raw Fibers
Materials for Artisans
Pasture Area for Cattle
Contains Cacao, Acai, Coconut, Hearts of Palm, and other Medicinal plants
SUPPORT SERVICES
are benefits of basic services that allow for human life to be possible
Highest biodiversity for amphibians in the world
High number of endangered species for big animals
New spider and ant species
High number of endemic birds and amphibians
Rich biodiversity of fish reptiles and bats
REGULATORY SERVICES
are benefits of basic services that allow for human life to be possible
Hydrological Regulations
Climate Regulation
Carbon Sequestration
Ecosystem Services
3

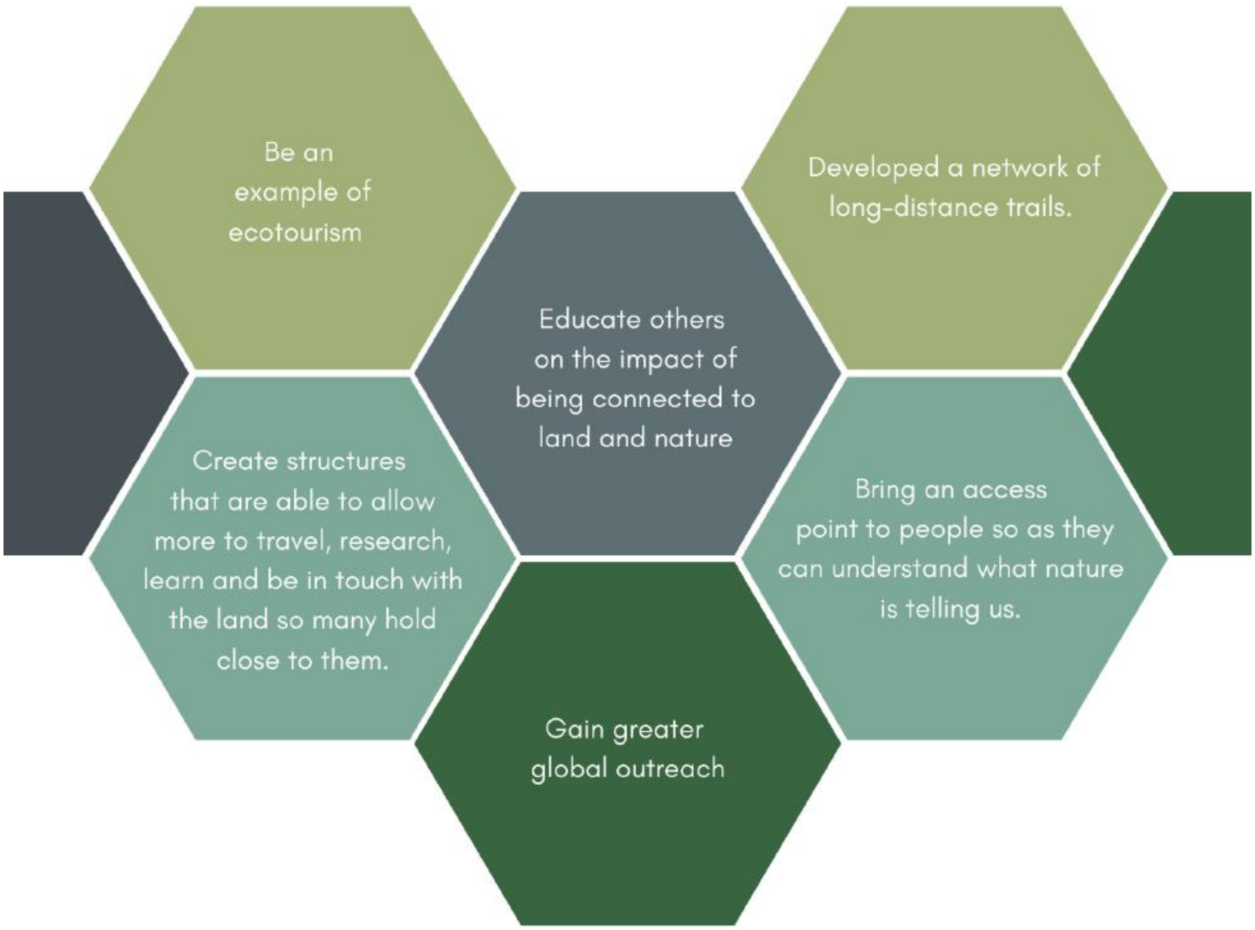
The Alto da Esperança Reserve wants to teach people how being immersed in nature can bring knowledge that may not be found otherwise. The best way to categorize these is by understanding synthetic versus organic knowledge.



Organic knowledge is important as they care about the ecosystem and the interactions. Synthetic knowledge can be out of touch with the area and may not be practical. Organic knowledge brings the people who are connected to the land and inhabit this area to the forefront of knowledge such as the the story of the local fisherman. By understanding the two and where they can come together people can better solve problems and grow.

We have brought new propositions for sustainable development for Alto da Esperança Reserve. With a concentration of the environment in which this development is happening there is new opportunity for structural development, a new energy system and a greywater system. With these new development the Alto da Esperança Reserve can grow and share their knowledge.

Alto da Esperança Reserve looks to ...



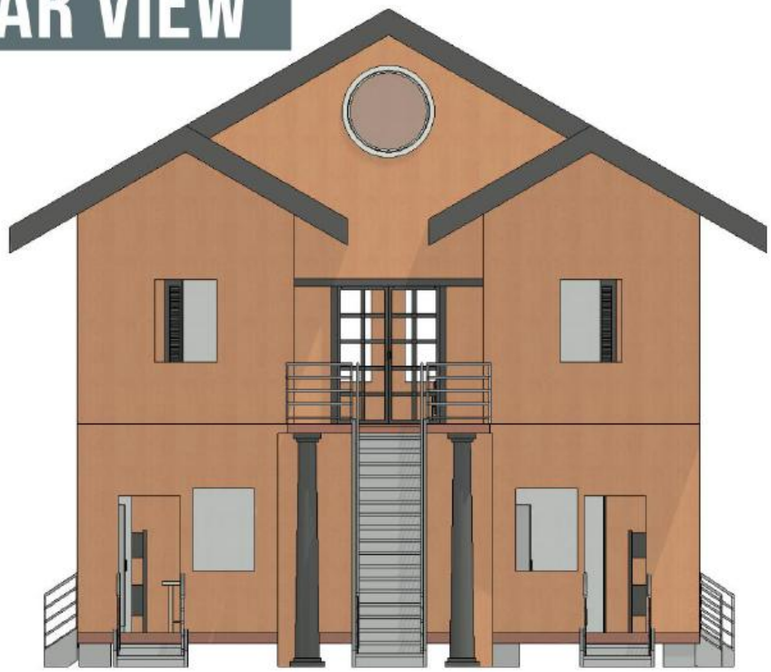
STRUCTURAL DESIGN

DORMITORY

As the reserve is expanding there is need to house a greater amount of people for different needs. The dormitory space includes rooming to stay, a workspace or multifunctional room, a kitchen with an opening to the patio outside, a patio for outdoor eating, a laundry space and a small closet for storage. The whole space has a significant amount of windows, openings and decking to allow those using the space to feel as close to the outside environment as possible.

This housing would allow greater amount of visitors, researchers and tourists to understand the benefits and impacts of the wildlife in which Alto da Esperança Reserve is located.

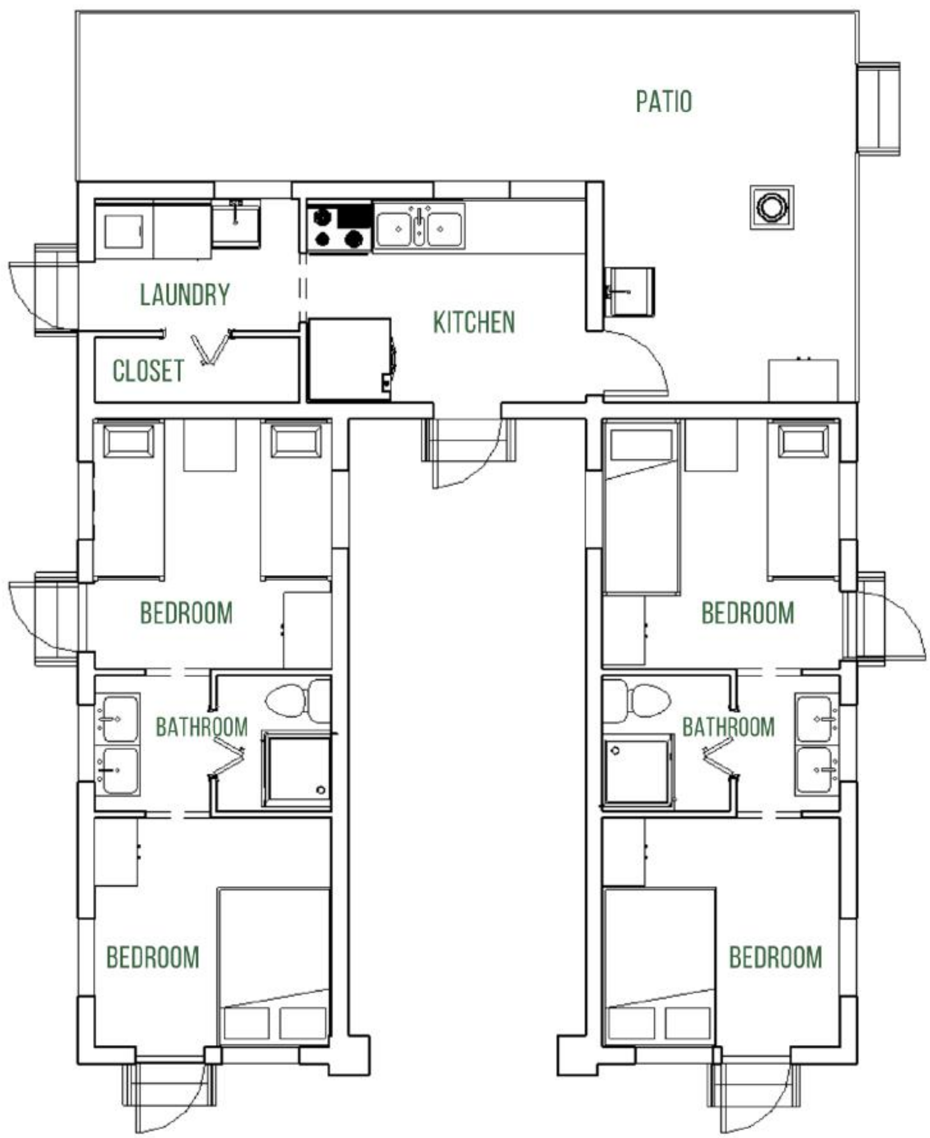
REAR VIEW



Dormitory: Rear View 7

DORMITORY

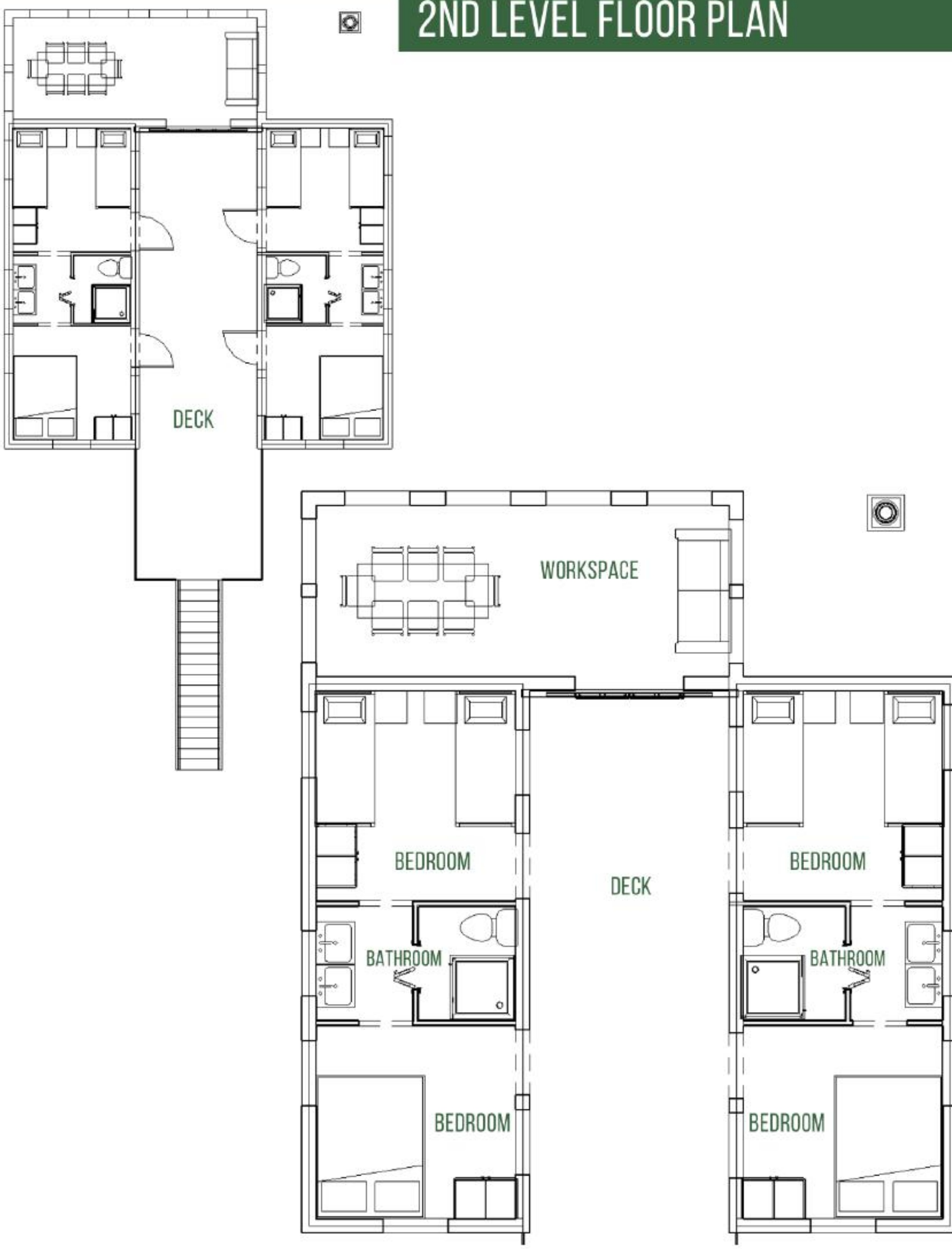
1ST LEVEL FLOOR PLAN



Dormitory: 1st Level Floor Plan 8

DORMITORY

2ND LEVEL FLOOR PLAN



Dormitory: 2nd Level Floor Plan 9

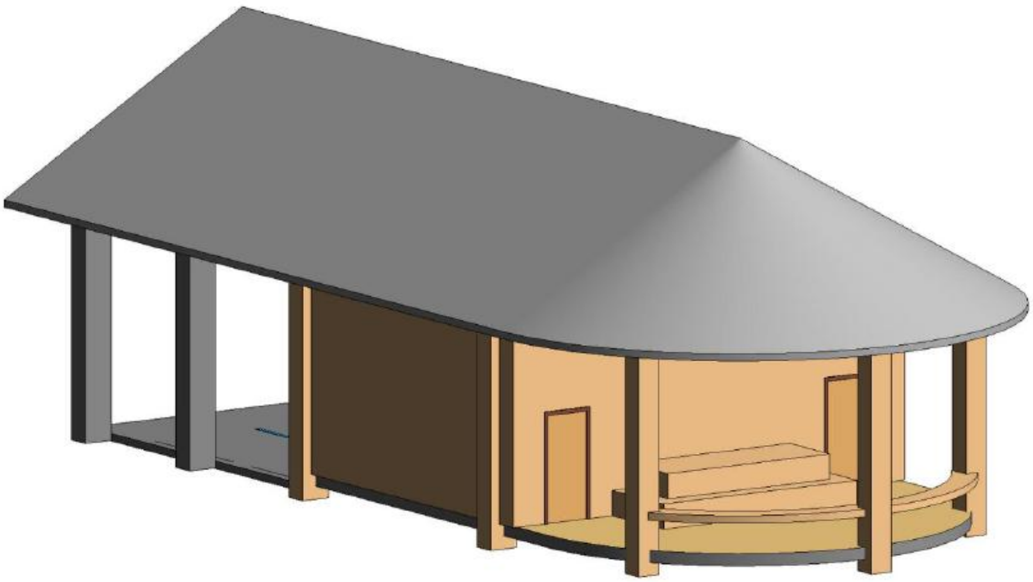
DORMITORY

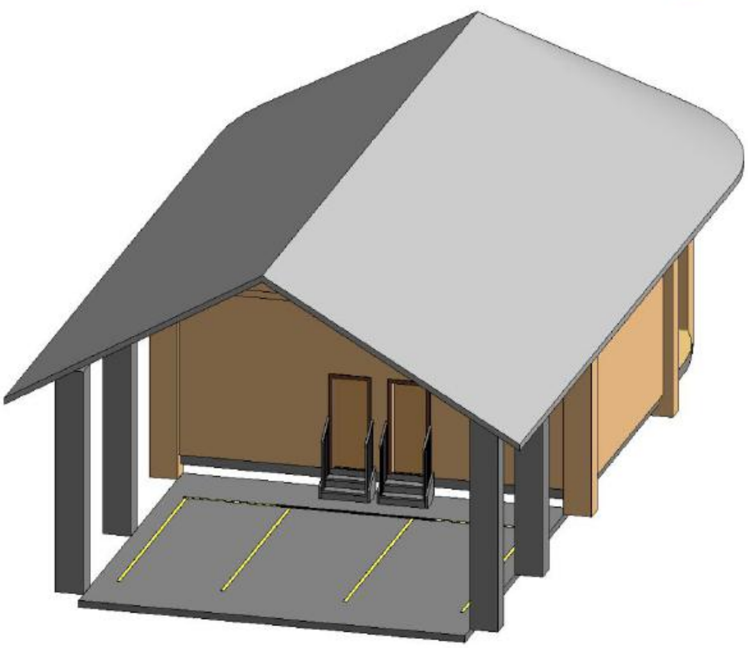
A LOOK INTO THE BEDROOMS

Each bedroom is able to fit a queen size bed, two twin size beds or a set of bunk beds. Each room also has space for a wardrobe or another type of storage. The bathrooms are adjoining between 2 rooms with the sink open in between. The shower and water closet is separated by a folding door way. The bedroom floor plan is identical on the first and second floor. The only difference is on the first level the doors are placed on the perimeter where as on the second level the doors are inward opening to the deck.

STRUCTURAL DESIGN

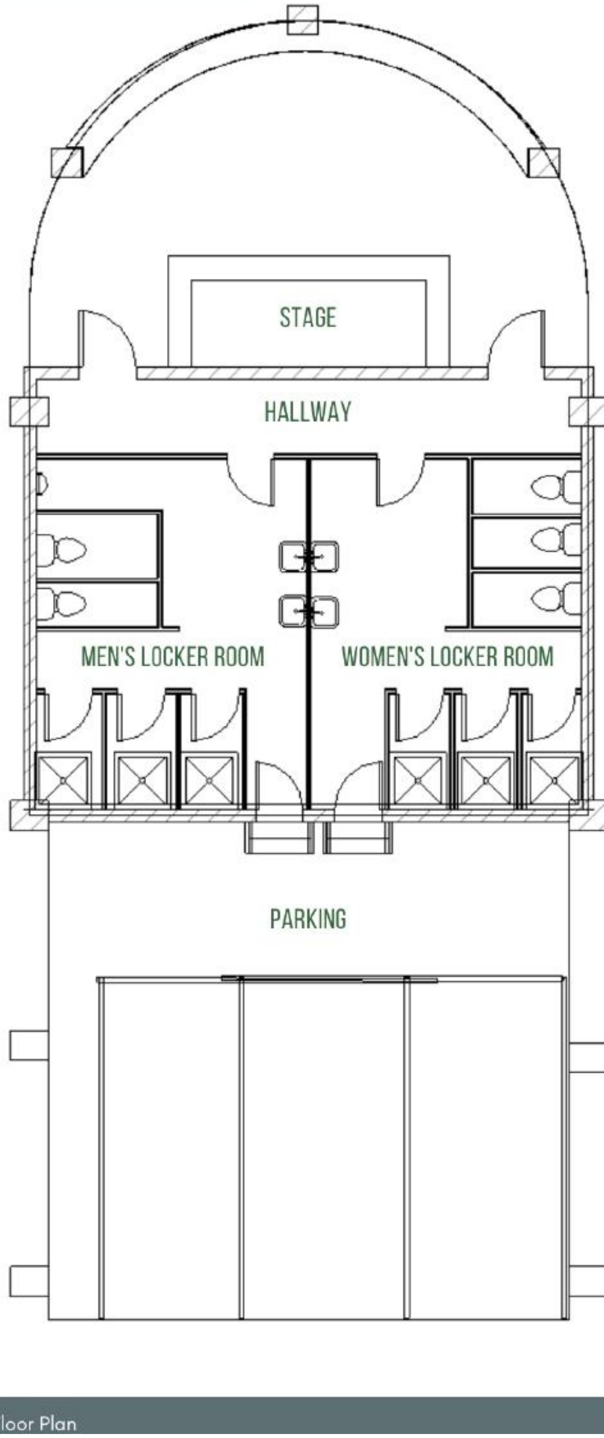
MULTIFUNCTIONAL CENTER



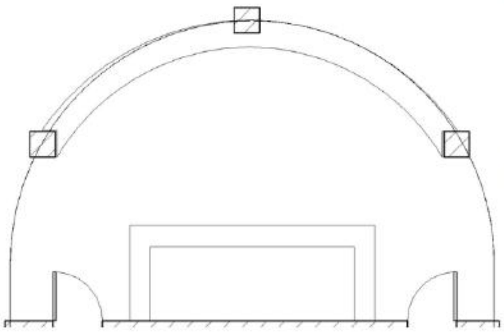


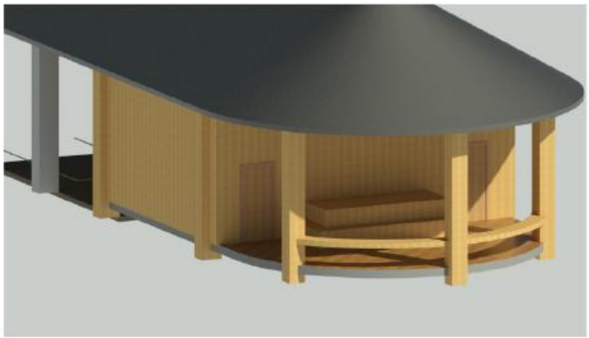
The multifunctional center is a space for the larger groups to gather. This includes a stage for presentations and performances that is covered yet open to allow for maximum amount of people to view. The indoors consist of locker rooms for men and women visitors that may not be staying overnight. There is also covered parking in the rear.

FLOOR PLAN

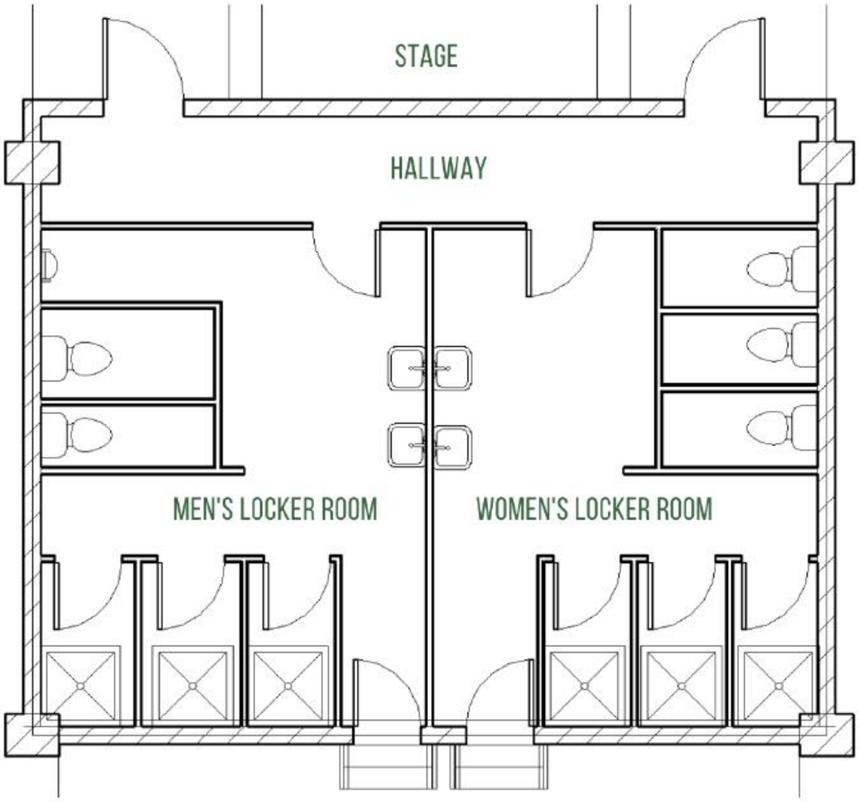


MULTIFUNCTIONAL CENTER





The stage is meant to be centered and viewed from most angles. It gives opportunity for flexibility for musical performances to research presentations bringing in a podium and projector.

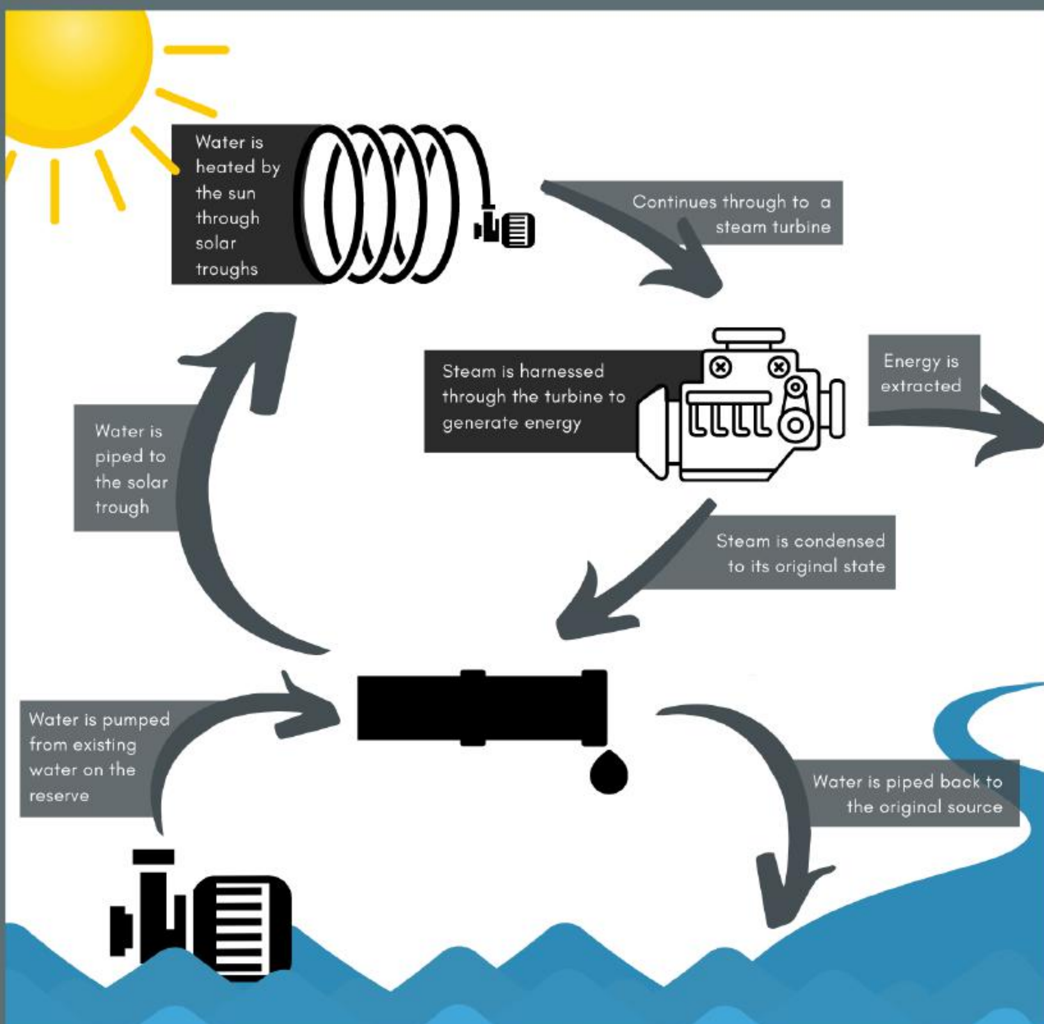


The locker rooms are able to be used by short term visitors that may not be staying long enough to use a dormitory room. There is restrooms and individual showers that allows multiple users at once.

ENERGY SYSTEM

DESIGN OF SYSTEM

The energy system is designed to use the resources available in the Alto da Esperança Reserve to generate a sustainable energy source for the remote area. By capitalizing on the available water resources and the sun the system is able to harness the steam power to generate energy to be used on the reserve.



Energy System Design

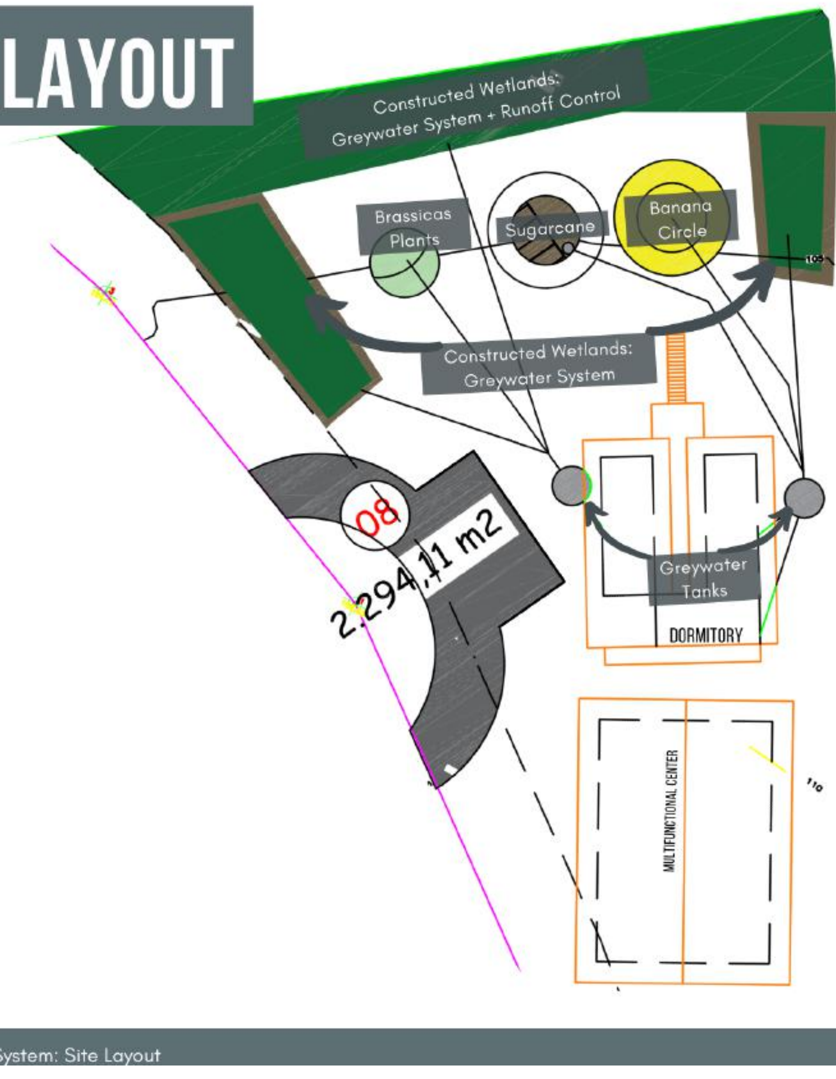
14

GREYWATER SYSTEM

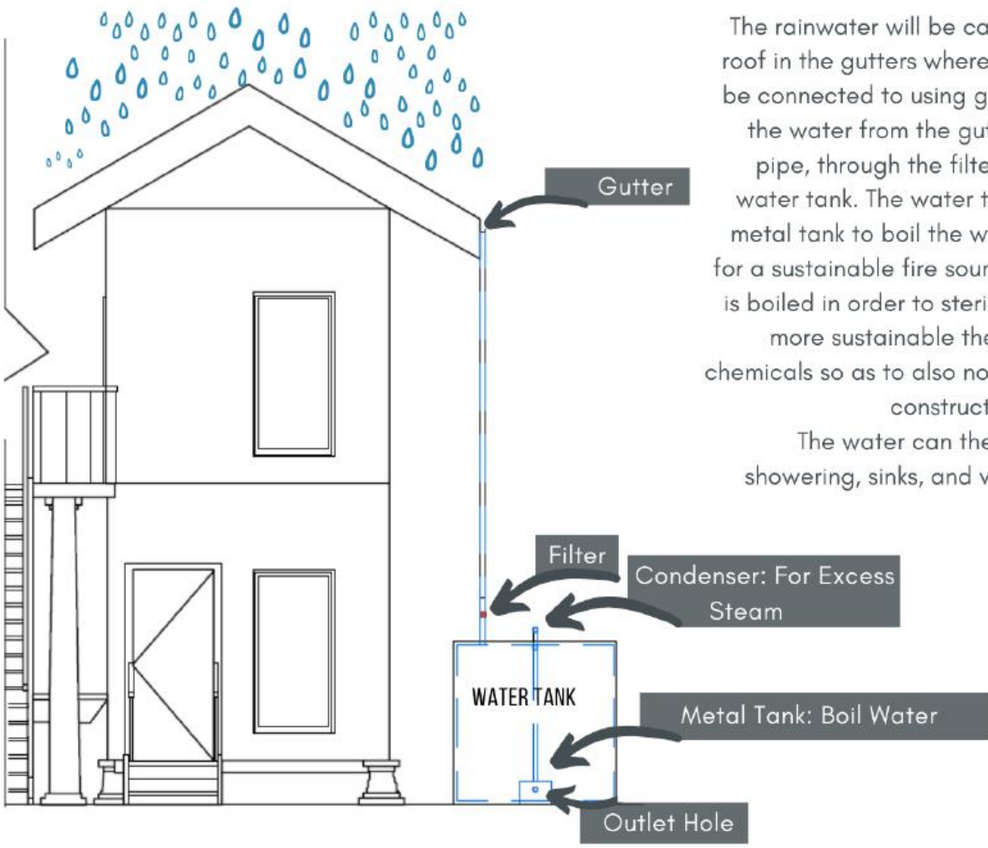
THE PURPOSE OF THE GREYWATER SYSTEM IS TO REUSE WATER WHICH LOWERS DAILY USAGE

Greywater is the water that has been touched by humans, but not fecal matter. By including a greywater system on the Alto da Esperança Reserve there is the ability to reuse water for other services on the reserve. This water is not potable, but can harness the contaminants to use as nutrients. This will allow for a more sustainable structure and will have a lessened impact on the environment around it. Having a greywater garden is an easy way to teach others how to live in a way that is sustainable, the true value of the gifts that nature gives them, about a deeper connection and understanding of nature, and an understanding of the impacts of everyday decisions on the nature around them.

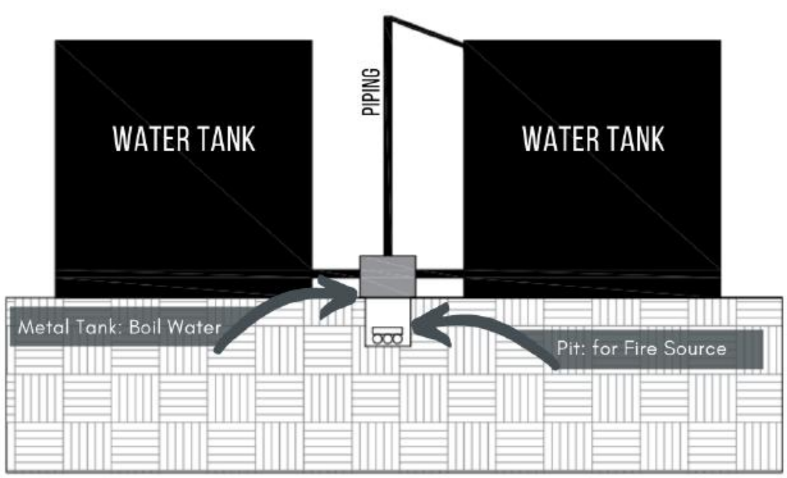
SITE LAYOUT



SYSTEM DESIGN



The rainwater will be caught from the roof in the gutters where the tanks will be connected to using gravity to bring the water from the gutter, down the pipe, through the filter and into the water tank. The water tanks will have metal tank to boil the water and a pit for a sustainable fire source. The water is boiled in order to sterilize it which is more sustainable then using harsh chemicals so as to also not damage the constructed wetlands.
The water can then be used for showering, sinks, and water closets.

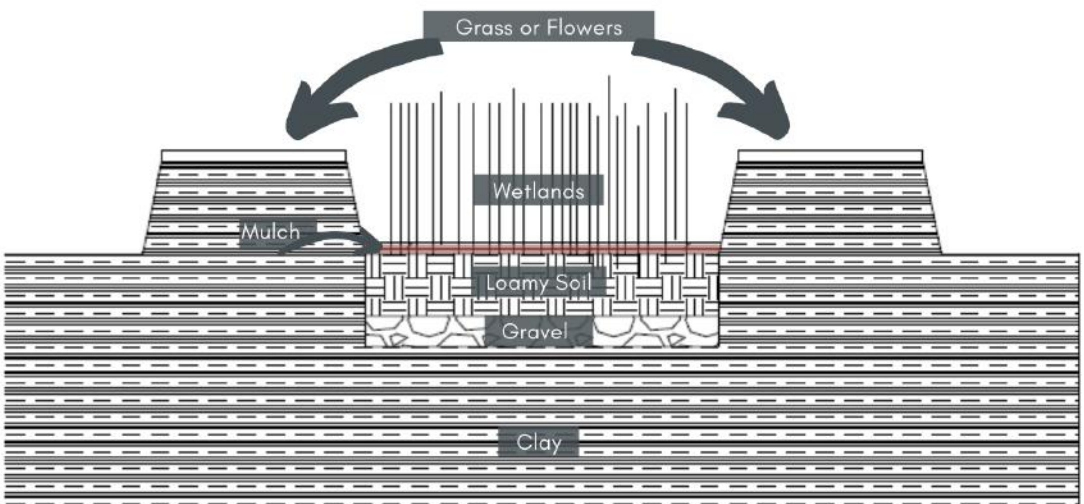


CONSTRUCTED WETLANDS

Constructed wetlands can store and process a large amount of water due to their nature of needing very saturated soil. Some advantages of constructed wetlands are that they are less expensive and do not require continuous maintenance, they are able to tolerate flow fluctuations while also being able to fit "harmoniously into the landscape", and they are "an environmentally-sensitive approach" to treating wastewater and runoff (Handbook).

The Environmental Protection Agency recommends that while designing a constructed wetland it should be "conveniently located to the source of the wastewater, is gently sloping, so that water can flow through the system by gravity, contains soils that can be sufficiently compacted to minimize seepage to groundwater, is above the water table, and is not in a floodplain." Constructed wetlands can help eliminate runoff due to wetlands being able to "slow water velocities, allowing suspended material to settle." This will help eliminate runoff, which in the use of a greywater garden, is important to have these plants filter out the nutrients that will end up polluting the local waterways (Handbook). There are three wetlands on the reserve, two located on the sides that will process greywater consistently, and a third wetland that is located between the greywater garden and the stream to ensure there is no runoff into the local waterway.

A SECTION VIEW OF THE CONSTRUCTED WETLANDS



CROP ROTATION

Crop rotation is when one plants different crops in certain areas at different times to replenish nutrients and help improve soils. By rotating crops the soil is not deprived of the same nutrients constantly while also benefiting crop yield. For the Alto da Esperança Reserve the banana tree is a focal point of the greywater system; however, having a good crop rotation will allow for a more sustainable system.

SUGARCANE

is a crop that can be planted prior to the banana tree. Sugarcane is able to protect banana trees even though the banana tree does nothing for the sugarcane. A study demonstrated that "sugarcane tends to limit infestation by the banana weevil to the first year of banana cropping, whereas banana does not help protect the sugarcane crop (Evidence, 2011)". Sugarcane is also able to provide nutrients to the soil while not utilizing a significant amount of water.

BRASSICAS

are a type plants that are known for their rapid fall growth and ability to absorb nutrients as they have deep roots. They are able to absorb nitrogen from soil for their own growth. They are also able to help control bacteria, insects, nematodes and other pests and diseases. By having a variety of crops in rotation they are able to coexist and have a mutualistic relationship. Rapeseed and Broccoli are both examples of brassicas that would be beneficial in the reserves ecosystem.

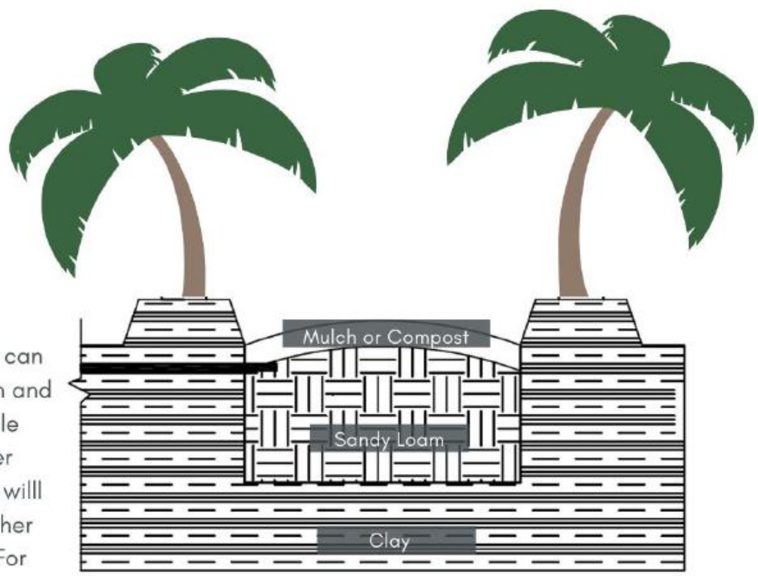
This is a change for Alto da Esperança Reserve to create sustainable farming and environment for themselves and their visitor.

BANANA CIRCLE

A METHOD TO SUSTAINABLY TREAT GREYWATER WHILE AIDING IN BIODIVERSITY AND FOOD SOURCE.

A banana circle consists of a central basin where the greywater and composted material can be stored while providing a dike for runoff control. The banana trees are then planted in the dike to allow for the trees to process the runoff of greywater.

The roots from the banana tree can then grow into the central basin and providing structural support while minimizing erosion. Adding other plants along with banana trees willl also aid in reducing erosion. Other plants have different benefits. For example marigolds can reduce chanced of pests.



A DIAGRAM OF THE BANANA CIRCLE

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Structural and Energy System Design and Analysis in Bahia, Brazil
Major Qualifying Project

Submitted by:
Natallie Jesionka, Sara Lyons, Kelley Townley, and Rebekah Vernon.

Advised by:
Dr. Aaron Sakulich

A Major Qualifying Project Report Submitted to the faculty of the Civil & Environmental Engineering Department and the Mechanical Engineering Department at Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science in cooperation with the Reserva Alto Da Esperança. Submitted 10.15.2020

Abstract

This project encompassed a site layout design using structural analysis methods for the Reserva Alto Esperanca in Bahia, Brazil. Collaboration with the project sponsors and research allowed the team to produce architectural designs, structural calculations, and a cost estimate for the reserve. The generated building designs, influenced heavily by sustainable building techniques, are powered by a renewable onsite energy system. The Revit and RISA-3D deliverables will aid in fundraising for the proposed facilities.

Acknowledgments

The team would like to extend gratitude to those who assisted with the successful completion of this project.

Cláudio N. Lôpo, *Project Sponsor*

Paulo Sanjines Barreiro, *Project Sponsor*

João Cláudio Gonçalves Lôpo, *Project Sponsor*

Aaron Sakulich, *Project Advisor*

Leonard Albano, *Interviewee*

Authorship

The team collaborated on all aspects of the project, with each member contributing to the final report. Each person wrote and edited the introduction, background, methodology, and results sections. For all of the structural calculations and software designs, one group member led a section of the project, but all group members contributed to revisions and validation. Primary roles were assigned to each team member and were as follows:

Natallie Jesionka - Natallie served as the primary designer of the energy system. This work included research into energy system design and calculations to find the correct sizing of the parts. For the report, Natallie served as a primary author in several sections, including the Background, Methodology, Results, and Final Draft, with editing also being a big focus.

Sara Lyons - Sara served as the primary architectural designer of the buildings on Revit. She designed the buildings to accommodate the sponsors' wishes by drafting and revising the multifunctional center and the dormitory designs. For the report, Sara served as a primary author of several sections, including the Abstract, Executive Summary, Design Statement, Professional Licensure Statement, and Recommendations and Conclusion, with editing being her secondary focus.

Kelley Townley - Kelley served as the primary structural building designer on RISA-3D. This work included using software to design a structural system and produce member calculations based on its features. For the report, Kelley served as a primary editor of the paper, focusing on writing in certain sections such as Introduction, Background, Methodology regarding RISA-3D, and Results.

Rebekah Vernon - Rebekah served as the primary designer of the structural buildings. She worked through hand calculations of loading, beam and column layout, and truss design. For the report, Rebekah was primarily focused on editing numerous sections, with some focus on writing in certain sections such as Background, Abstract, Design Statement, Professional Licensure Statement, and a portion of the Methodology and Results sections.

Table of Contents

List of Figures

List of Tables

1.0 Executive Summary

In the Reserva Alto da Esperança, researchers and travelers visit to enjoy the rainforest and disconnect from modern life. Currently, some buildings on the reserve are outdated and need replacement so that visitors can have a more enjoyable experience. The sponsors have the goal of using the reserve as a tool to teach others about sustainability. They plan to have gatherings where they can speak to large groups about the importance of protecting the rainforest and the resources within it. As one of the most biodiverse places globally, Itacaré is a region that has been heavily affected by carbon emissions and deforestation. Current building projects in the region threaten the rainforest and could have detrimental effects on the viability of the Brazilian rainforest.

With sustainability in mind, the sponsor requested the group design structures to replace pre-existing buildings and implement a renewable energy system. Designing these buildings included architectural work, structural work, and a cost analysis of the design. Most importantly, the sponsor asked that the design be sustainable, so the group made several decisions regarding this. Passive cooling, sourcing materials locally, and renewable energy were all considered factors to improve the design's sustainability.

Passive cooling was considered when designing the overhangs and the orientation of the buildings; this allowed for the building to naturally be cooled. Locally sourced materials meant designing the structure with pine, instead of more common building materials like concrete or steel. Using a locally sourced wood, such as pine, cuts down on emissions from the material's transportation. The renewable energy system designed for the reserve was created to harness the natural power from the reservoir. Using a steam turbine allows for power to be generated by the water in the reservoir heating up, phasing into steam that turns the turbines, and cooling to return to the liquid phase again. Solar energy was also considered for this area.

The first objective was to devise a site layout and architectural floor plan inspired by the project sponsor's wants and needs for the reserve. This objective was focused on learning what the project sponsor was interested in having on the reserve. It included several calls via Zoom, where the group asked questions to understand more about the sponsor's wishes and readjust the design. The goal was to draft a design aligned to the sponsor's goals, and research was performed to ensure this.

Pine was selected as the material to build the two structures on the reserve. The sponsor requested that it be locally sourced lumber and pine was the best option of a Brazilian wood in abundance. Piassava fiber was also utilized in the design, as was concrete to make the structure more structurally sound at a lower cost. The sponsor initially requested three buildings: a kitchen, dormitory, and an amphitheater. After deliberation, the sponsors concluded they preferred a multifunctional center and a dormitory.

The dormitory building was upgraded to include the kitchen and eight bedrooms, a bathroom between each room, a laundry room, storage space, a stargazing balcony, an office, and a deck with outdoor seating. The multifunctional center was redesigned to include an area for vendors to sell products or educate visitors on the reserve. Also, locker rooms were added for visitors that are not residing on the reserve yet might still need to use the restrooms or freshen up and a small covered parking area was attached to the building as well.

Using a Google Maps image of the reserve, the group worked with the project sponsor to determine the energy system's best location with respect to the proposed buildings. Together, it was decided that the energy system's ideal placement would be at the southern end of the reservoir.

The second objective was to design a building along with an energy system. From the previously devised architectural layout, the team worked to determine a site layout consisting of the two buildings and an energy system. To further the structural analysis of the buildings, the architectural rendering was transformed into a structural layout. This was done by using the software Revit to design a sound structural system.

Upon finalizing the architectural drawings, a structural layout of the building was derived from the floor plan. A one-way, post and beam design was decided upon for ease of construction and alignment with the sponsor's goals. Columns were placed at the corners of each room, and the beams and joists were placed 3.28 ft (1 m) apart. This system was uploaded into RISA-3D, where boundary conditions were chosen, load combinations were applied onto the system, and the members could be analyzed.

The energy system was designed to incorporate both solar energy and waterpower. Parabolic solar troughs were incorporated into the design along with a steam turbine. Several factors were calculated for the turbine to find the velocity, pipe size, head loss, pressure, and system inefficiencies. These values were then used to calculate the work of the turbine. The average solar irradiance was used to calculate the amount of energy produced per day from the sun.

The energy system utilized solar troughs that heat water as the working fluid in a 1 in (2.54 cm) pipe. This pipe ran to the steam turbine, where the water exited, and the pipe will run through a counter-flow condenser to be restored to the original pressure and temperature. The decision was made that 44 kWh accommodated the building's basic needs within reason. To cut down on the installation space required, the team chose to incorporate solar panels with the largest surface area, where each unit is 12 m (39.3 ft) long. The sponsor would need to purchase two units to satisfy the assumed energy needs of 44 kWh. Several factors were calculated to determine the efficiency of the steam turbine system. The pumping power needed to move the fluid from the condenser to the solar troughs is 4.85 kW and to bring the water up to the condenser is 4.6 kW.

The third objective was to perform a complete analysis of the building and energy designs. Calculations were carried out for the analysis of the structures and the analysis of the energy system. The structural analysis was completed with the assistance of Revit, Excel, and RISA-3D. The Revit structural design was first completed to show structural members' placement, beams, joists, and columns. Calculations were completed to find each beam's tributary area, the dead load, the occupancy live load, the wind load, and the seismic load. The load combination was then found using these factors, and it was applied to the structure. Using the RISA-3D software, calculated loading was placed on the drawings. The model was then used to produce the member sizes and confirm the building's structural soundness. The appropriate codes and information based on the chosen materials are all factored into the RISA-3D design calculations. This process was completed for both the roof and the flooring. The layout was uploaded into RISA-3D using southern pine with 2 ply and a 2 x 6 member size and using the calculated basic loading.

The final objective was to conduct a cost estimate of the proposed design. This was completed for the structural design using an Excel document and the *RS Means Building Construction Costs* textbook. This allowed the team to break the building into segmented costs. The cost of demolition, foundations, wood structural supports, and other design elements were broken down and calculated for the structure. The building's total cost was calculated to be around $75,456, which converts to 420,331 Brazilian real. The total costs of the energy system were found using websites to find the value of the different aspects of the energy system. The total energy system cost was calculated to be about $40,848, which converts to 225,910 Brazilian real. This analysis included the costs of supplies, safety equipment, condensers, piping, pumps, parabolic solar troughs, and a generator.

The team recommends that the sponsor uses the proposed designs and ideas as a baseline. Additional analyses of these structures could prove to be useful, as the analysis provided did not include accurate information for the region in Brazil that the facilities would be constructed. Once the sponsor has further knowledge of the site itself including the specifics for the structure, the group would recommend performing an in-depth analysis to get a more accurate cost estimation. Prior to construction, a complete site analysis combined with the help from architects and professional engineers is recommended for the project sponsor in order to produce a safe and cost efficient addition to the reserve.

Considerations of both the structures and energy systems are interconnected and essential to the development of the project site. Sustainability and efficiency were a top priority during the design and analysis of this project work. Both the energy system and structural system design were created so that the sponsor could quickly adapt them and expand the uses later, if necessary.

2.0 Introduction

Reserva Alto da Esperança, owned and operated by sponsors of this project, Cláudio Lôpo and Paulo Sanjines, is an environmental reserve located in Itacaré, Bahia, Brazil. The reserve allows visitors to experience the beautiful rainforests of the region for research or leisurely purposes. The Interpretive Trail activity has been open to visitors for ten years; however, the reserve itself is not yet developed for visitors to stay and enjoy the reserve for extended periods. To tackle this dilemma, a team of WPI students collaborated with the project sponsors to provide them with a site design containing two new buildings and a renewable energy system.

The goal of this Major Qualifying Project (MQP) was to design and perform a structural analysis of the sustainable facilities for Reserva Alto da Esperança. The proposed dormitory building is equipped with eight rooms, a kitchen and eating space, an office space, a lounge, a laundry room, and a storage space. Another separate building, the multifunctional center, was designed to include a stage and entertainment area, locker rooms, and a small covered parking area. Sustainability was an influential component in the design process for these structures to truly emphasize the theme of nature and green living at the reserve. The structural plans were designed to be sustainable and for the energy system to be as self-reliant and renewable as possible. They are implementing this clean energy system, local resources, and a viable design allowed for a successful project resulting in two functional and sustainable reserve structures.

3.0 Background

The team aimed to provide two new functional spaces for the up and coming Reserva Alto Da Esperança, located in the Serra Grande Environmental Protection Area in Itacaré, Bahia, Brazil. The Reserva Alto Da Esperança has been a leader in the Interpretive Trail activity for over ten years (*Reserva Alto Da Esperança 2020*). This activity "includes information about the region and the management of the property as a whole, philosophy, and techniques adopted." Cláudio Lôpo, the project sponsor, bought this land to create a reserve, allowing visitors and scientists to experience the rainforest. Those who visit the Reserva Alto da Esperança also have the ability to stay in the forest for an extended time. Some of those who have taken part in such excursions are Paulo Sanjines and João Cláudio, partners of Cláudio Lôpo. These three share a bright and sustainable vision for the Reserva Alto Da Esperança, hoping to one day share the natural landscape with others to enjoy as they have.

The focus of the Reserva Alto Da Esperança is to work sustainably in ecotourism and agroecology. The group wants to "enable (a) human experience in harmony with Nature." (*Reserva Alto Da Esperança, 2020).* Reserva Alto Da Esperança is intended to be a nature reserve for guests ranging from conservation groups and scientists to individuals interested in experiencing the Brazilian Rainforest for personal reasons. In these long-term experiences on the reserve, it is understood that the goal is to connect with nature. The reserve sponsor strives to welcome guests to become more in touch and understanding of their surroundings.

The sponsor currently has some structures on the property. The visitor center is described as "rustic" and a typical structure for the area *(Reserva Alto Da Esperanç*a, 2020). These areas are meant to be safe and accessible for visitors and researchers to use in their time on the reserve. The sponsor is interested in teaching people to live with nature and be more aware of their carbon footprint and energy consumption. With this interest, they want to make these practices of more remote living more accessible. Expanding and creating large buildings and more gathering spaces would create a sanctuary for visitors and researchers. The sponsor expressed that they wanted to draw inspiration from the region by bringing the regional knowledge and experience into this modern movement.

Itacaré, located in the southern region of Bahia, Brazil, has complex ecosystems, tall trees, unique waterfalls, and exotic beaches *(Serra Grande, 2020).* Described as an "Atlantic forest ecosystem," the small town of Itacaré lies about 150 mi (241.4 km) south of Salvador in Bahia, Brazil, as shown in Figure 1.

Figure 1: The State of Bahia, Brazil, with Itacaré indicated by a red square, and the coastline of Itacaré. (Serra Grande, 2020).

Year round, the temperature in the area remains stable between 75° and 85°F (23.9° and 29.4°C). Bahia also has an annual humidity average of 81 percent, with May generally being the most humid month *(Weather & Climate, 2020*). Significant rainfall variations occur in the area year round, with the wet season spanning from November to July. There have been flash floods and landslides during this time because of the heavier rains *(The Guardian, 2020*). Rain, along with natural disasters, have a drastic effect on structural supports, the different capacities needed for utility systems, and can be dangerous to citizens' lives. Brazil has seen severe rainfall and floods in recent years due to the increase in global temperature.

As a result of climate change, the world has found itself in unprecedented times. The world's global average temperature has increased by 1.5 °C *(IPCC, 2020)*. This influx in temperature has caused arid climates to be more extreme, changing weather patterns, rising sea levels, and more extreme natural disasters *(IPCC, 2020)*. In Brazil, they have experienced extreme rainfall and flooding. These weather patterns can change drastically as global warming evolves.

One of the main contributors to climate change is the amount of greenhouse gases released into the atmosphere. Carbon dioxide (CO_2) is a greenhouse gas that absorbs and radiates heat *(Rebecca Lindsey, 2020*). The local forests help combat CO_2 emissions in the area, as trees can absorb CO_2 emissions. Brazil is home to about 13 percent of the total forest area on the planet. Deforestation partnered with the extreme emission of greenhouse gases can and will affect everyone in the coming years. Protecting natural land, forests, carbon sinks, and the reserve can aid in mitigating climate change. When designing for sustainability, looking to mimic the surroundings can be helpful.

Sustainable design within new building construction is important to preserve the environment. When looking to design sustainably, there is a large focus on energy use, materials, and carbon emissions. Sustainable designs include passive cooling, sourcing materials locally, renewable energy, and health and wellness. Passive cooling is the act in which a structure can remain at cooler temperatures based on architectural design, by having overhangs or positioning a structure in a specific direction based on the sun's orientation. Sourcing local materials are generally more beneficial to local economies. This also can lower the number of materials transported, which reduces the total emissions of the project. Lastly, by relying on local materials, there is significantly less risk of disrupting local ecosystems by suddenly integrating foreign plants or debris.

One of the regional materials identified was the attalea funifera or piassava fiber. The fiber originated in the north and middle-east coastal regions of South America. This fiber is an extraction from palm tree leaves local to Brazil by the native people as “pia’sawa” *(Monteiro, 2009*). Piassava fibers are generally used for brooms, ropes, and baskets, and it has made its way into more structural practices in Brazil’s roofs. This stiff thin fiber is harvested once a year and can grow up to 13.1 ft long (4 m) *(Woodford, 2019)*. These palm trees can yield 17.6 - 20 lbs (8 - 10 kg) of fibers *(Woodford, 2019)*. Piassava fibers are found to have “lower stress at rupture and lower Young's modulus" than more common fibers. The team looked to incorporate local materials, such as the piassava fiber, to bring the outdoors to the built environment.

Health and wellness are also staples in sustainable design. A design team should always be conscious of the owner's goals, those who will be utilizing the facility, and the ecosystem the facility will be placed in. Exposure to nature has proven to effect persons health such as being able to reduce blood pressure, reduce stress and anxiety, and boost mood *(Russell et al., 2013).* By designing systems and structures with sustainable intent, there is the ability to bridge the gap between the built environment and the natural world for the visitors. By creating spaces that push visitors to interact and be exposed to nature, there is a positive effect on their health. Incorporating a more holistic approach to design allows them to be more connected to their surroundings and the local region.

Wood is also a material that allows the feeling of being more connected to nature. This is because of its abundance in the wild, and the aesthetic coating generally used that leaves it in a more natural state. Wood is a common material used in construction as the raw material itself can be used for load bearing support while still bringing an aesthetic appeal to the space. Wood is a popular material in its cost, ease of production, ease of use, energy efficiency, and eco-friendliness *(Aaron Sakulich, 2020)*. Wood can offer a lower carbon alternative to steel and other forms of structural supports as it can be a sustainable option in its lifetime.

Mass timber is a framing style, consisting of large solid wood members, often used in construction to encompass support and visual appeal into a space (*Mass Timber, 2020*). When designing with timber, the distribution of loads may present boundaries; therefore, it is necessary to consider the limits within a material's properties. Tension refers to the force of an object being pulled outward, stretching a material. Compression works oppositely when referring to a force generally pushing inward shortening or shrinking a material. This is important when looking at wood as a material. Wood's properties correlate to the direction a force is being applied to the grain, the orientation of wood-cell fibers that present themselves visually in different line patterns *(Aaron Sakulich, 2020; Wood Magazine, 2020)*. This force orientation changes the wood's mechanical properties, such as when various forces are applied, like the Modulus of Elasticity, tensile strength, and elongation. Other loading includes shear loading.

Capitalizing on renewable energy can create a more sustainable future by mitigating the use of mainstream energy sources with large greenhouse gas emission tendencies. This practice also proves to be better in the long term as it is capitalizing on generally renewable resources allowing the source of energy to be more stable. By using their natural environment of heat, sun, humidity, and lush forest, the sponsors have a vision of powering their building complex using renewable and local sustainable sources. More than half of Brazil's energy production comes from hydroelectricity *(EIA, 2020)*, which inspired the team to tap into the water source's potential near the nature reserve. One example is utilizing hydroelectric dams. When working with hydroelectric dams, the falling water turns turbine blades *(EIA, 2020).* Water falling from gravity turns the turbine. Apart from dams, another method of utilizing water is through its heated form of steam, such as in a steam turbine. Fossil fuels have conventionally powered this method of using a steam turbine. However, recently the process has turned to renewable resources, such as having the water be heated by photovoltaic (PV) panels *(Chris Woodford, 2020*). When water is heated, the molecules expand apart from each other. As the steam cools, the molecules condense back to their original volume, temperature, and pressure. Steam turbines operate using this principle.

This ‘movement’ of the steam inside the turbine allows the blades to spin. Similarly, in a steam engine, this movement and force push the piston to move up and down. However, in a bladed turbine setting, this movement allows for the blades to spin without any breaks continuously. Steam turbines are also more compact than other turbine arrangements, which is important in the constrained area the project is located *(Chris Woodford, 2020*). Like other types of turbines such as those powered by wind or water, steam at incredibly high pressures and temperatures turn generators at much faster speeds. The heating process can take advantage of the sun by placing PV panels or solar troughs when placed in the trees' clearing or above the tree line. The output of energy in light radiance from the sun per unit area is irradiation *(NASA, 2008).* The average direct, normal solar irradiation near Itacaré is 148.69 kWhr/ft^2 (1,600 kWhr/m^2) *(NREL, 2018*). This value of the sun's strength can be a great indicator of how well solar energy will work in the researched area.

4.0 Methodology

During this project, the team produced a design to complement the functional space for Reserva Alto Da Esperança, consisting of two uniquely designed structures and a sustainably sourced energy system. After the site design was configured, the goal expanded to include a full structural analysis of the project's buildings. To achieve this goal, the team worked through a set of four objectives.

Objective 1 - Devise a site layout and architectural floor plan inspired by the project sponsor's wants and needs for the reserve.
Objective 2 - Design a building with the architectural floor plan and site layout, along with an energy system.
Objective 3 - Perform a complete analysis of the dormitory building and energy designs.
Objective 4 - Conduct an approximate cost estimate of the energy system and provide recommendations for cost analysis of the structure.

To begin, a design was devised from the specific wishes of the project sponsor. The design needed to adhere to their feedback as this project was intended to be later utilized to develop the new Reserva Alto Da Esperança in Bahia, Brazil. The team was tasked with designing and implementing two building designs as well as a sustainable energy system into the site layout. The following section highlights the specific actions the team performed achieve the previously defined objectives in order to reach the final goal.

4.1 Objective 1 - Devise a site layout and architectural floor plan inspired by the project sponsors' wants and needs for the reserve.

The first objective was to determine the scope of work by drafting the design of the site layout. The team needed to understand what the project sponsor wanted and needed this space to include. It was essential to consult with the sponsor when designing the buildings and energy system because it was intended to develop the reserve. The team was very invested in giving the sponsor design and analysis that would help them make progress. Meetings were held via Zoom with the project sponsor, project advisor, and team to discuss the sponsor's vision for the land available.

The group worked to streamline the sponsor's information by asking in-depth questions, working through conversations, and taking notes to streamline answers and readjust designs based on the responses. If a response was not sufficient, the team rephrased and continued asking until the group received the necessary information.

The team followed up the new design criteria by researching to assure that the work being done would fit seamlessly into the local architectural design and energy system. Research was conducted through the internet to learn more about the local building designs and utility systems and Brazilian structures. The group also did research through WPI's library database, Google Scholar, and the internet on the local building codes for the structures and utilities while accenting the surrounding environment. As mentioned, the group valued the sponsor's desires for this project. Thus, the goal was to develop a building and energy system that complied with their wants and needs, including their attraction and connection to nature and sourcing local materials to ensure a sustainable design. For this reason, the group decided the buildings should have an open concept. The energy system was also designed to consist of a combination of renewable resources that would fit the reserve's needs and work appropriately with the surrounding environment.

After the research was complete, the team could design an architectural floor plan and site layout adhering to the project sponsors' goals for the reserve. Using Revit, the team was able to draft a visual that would then be shown to the sponsor and adjusted as requested.

To make the energy systems work, the group needed the solar energy equipment to be in direct sunlight, avoiding tree coverage from the rainforest canopy. To ensure the parabolic solar troughs were exposed to sunlight, the group looked at a Google Maps satellite view to ensure the placement of the parabolic solar troughs would not require extra site preparation, such as making an additional clearing to make room for natural sunlight.

In the final design stage, the group looked to receive the sponsor's approval to ensure that all their requirements would be met. Receiving final approval allowed the team to begin structural design, analysis, and calculations.

4.2 Objective 2 - Design a building with the architectural floor plan and site layout, along with an energy system.

From the previously devised architectural layout, the team worked to construct a site layout consisting of the two buildings and an energy system. To further the structural analysis of the buildings, the architectural floorplan was transformed into a structural layout. This section has been divided into the two components of the site layout - the design of the structures and the design of the energy system.

To devise a structural design, the group began with research through WPI's library databases and online resources. Another research tactic utilized by the team was to consult with Associate Professor Leonard Albano to better understand the process of transforming architectural floorplans into a structural design layout. Paired with the team's research, previous work experience, and course knowledge allowed the team to efficiently design the buildings' structural layout to fulfill the sponsor's wishes and match the goal and vision of life at the nature reserve. Several varied materials were researched as viable options to be applied to the determined design. This research included the influence that structural supports would have on the designed space.

The research was then taken and incorporated into a combination of hand-drawn and software-designed plans. This was done through a calculation process and the use of Revit. The group chose Revit because of the ease of use and availability to use it. This was also done as an iterative design process. The group worked through the process, inputting the information and designs, until a solution was found. If the process failed, the group went back to the research and design stage to begin again until the structure was approved.

Methods were brainstormed after research about renewable energy systems. The team researched essential factors such as the sponsors' desires, efficiency, cost, and feasibility with the water source. The differences in possible layouts determined the amount of energy needed for the pumps. The property's topography was accessible in a provided AutoCAD file, and a Google Map pinned with information about the property in Bahia State.

Some initial challenges found while researching energy choice were the high initial investment, regulatory uncertainties, supply and demand, mismatch of power, and obsolete technologies. The article *Off-Grid or Stand-Alone Renewable Energy Systems (Energy Saver, 2020)* emphasizes the importance of needing the main elements such as solar panels and additional equipment to transmit the electricity, including batteries, safety equipment, and meters. The group knew to locate the batteries in a safe area and find a system not to overload the battery. An inverter is recommended as photovoltaic (PV) panels produce direct current (DC), where alternating current (AC) electricity runs on most appliances. Additional safety equipment was researched, such as disconnection pieces for safe maintenance, grounding equipment, and surge protection to protect from accidents.

The sponsor saw placements of the energy system using visual tools of AutoCAD and PowerPoint slides with labels of structures and possible design layouts. The differences in a layout determined the amount of energy needed for the pumps.

4.3 Objective 3 - Perform a complete analysis of the dormitory building and energy designs.

For organizational purposes, the team divided this section again into two sections – the analysis of the structures and the analysis of energy system. This was how the calculations were carried out. This division of work made sense to the team as each system operated individually from the other.

Structural analysis of the building design was conducted to prove the structural soundness and safety of the building. This was carried out by researching information regarding variables and material properties, using a variety and combination of formulas, consulting experts, and utilizing software programs. The formulas and information came from research, past class experience, and textbooks. The group also consulted with experts, such as Associate Professors Leonard Albano and Aaron Sakulich, to ask specific questions regarding the structural analysis calculations. Multiple software programs were used, including Revit, Excel, and RISA-3D, chosen based on the group's experience, the ease of use, and accessibility.

The analysis began with converting the architectural design to a structural design on Revit. Columns, girders, and joists were added based on the recommended spacing for wood structures outlined in textbooks and other research sources. Restraints and the final design for the designated buildings were provided by the sponsor using the metric system. The team first converted all metric units to imperial units. This was done to aid in ease of calculations as the imperial system's use made it easier to check if the structure complied with building codes.

To find the tributary area for the first and second floors, each beam's centerline was determined to isolate the columns. Calculating the tributary area allowed the team to apply the dead and live loads to determine each column's point loads. The tributary area was then calculated for each of the columns. The tributary area was determined by assigning each column a zone, determined by the spacing between columns, that the loading for that member would be responsible for.

Once the tributary area was determined, the team used the information gathered from the textbook *Design of Wood Structures ASD* to determine the floors' dead load. The dead loading was then applied to the tributary area to determine a point load for each column and thus determine how much force each column will be responsible for reciprocating. The live loading for each floor was determined similarly by researching online sources and through the *Design of Wood Structures ASD* textbook. A dead load was calculated to determine the weight of structural components, and the live load was calculated from the structural code that was researched. Multiple resources were used when determining the live loading for the structure to ensure accuracy within the calculations. For the live loading, the team used values researched from a loading article produced by *Building Construction Technology (BCT Umass Amherst, 2003)* and the *Design of Wood Structures ASD.* Both of these were used to confirm and calculate the live load applied to the floor. While the flooring system had a live load to account for people and objects being present, the remaining structure, including the building skeleton and truss system, had to account for wind and seismic loads. Wind and seismic loading were calculated because this project is based in Bahia, Brazil and these conditions are applicable to the location. The dead load and live loads are necessary to conduct further analysis of the members in the structure. This process was also performed on a truss system that contributed to the roof structure.

The equation for point dead load for columns:

$$PD_L = D_L * A_T$$

PD_L = Point dead load
D_L = Distributed dead load
A_T = Tributary Area

The equation for point dead load for beams:

$$PD_L = D_L * L$$

L = Length of the member

The equation for point live load is the same as the dead load. The calculated values for live load are plugged into the same equations where the dead load values were listed. These calculations were all performed using an Excel spreadsheet to increase the efficiency of the calculations. Following, the lateral live loads were calculated. Values were determined through research, and the seismic live load was determined using the following formula:

$$EQ = \frac{m * PGA}{3217.41}$$

$$m = \frac{D_L}{g}$$

PGA = value obtained by research.
g = acceleration due to gravity

Similarly, the wind load was obtained by use of the following formula:

$$W = .00256 * K_z * K_{zt} * K_d * v^2$$

K_z = velocity pressure coefficient
K_{zt} = topographic factor
K_d = wind directionality factor
v = basic wind speed

The building's wind load was calculated by using researched information to find accurate values for the equation. The wind load was then was multiplied by the area of the building. This process was repeated for the surface area of the roof to find the roof wind loading. The load combination was then calculated using the dead, live, wind, and seismic loading previously calculated. The loading factors were multiplied with the calculated loads to produce a load combination using the following formula:

$$\text{Load Combination} = 1.2D_L + 1.6\ W + 1.0\ E + L_L$$

W = Wind load
E = Seismic load
L_L = Live load

Following the loading calculations, these values were used with a structural drawing in RISA-3D. This software is designed to run structural calculations, using the loading of the building. First a structural drawing is derived from a Revit Design or through RISA-3D by developing a grid system and then manually placing members and joints. There is also the option in RISA-3D to generate common structures such as trusses. Once the system is designed the material is selected based on need and the loads are applied. These loads are applied on the members through joint loads, point loads and distributed loads. Once this is complete, a set of load combinations is generated through the software based on the codes chosen.

As determined by the design, loading values and dimensions were used with the formulas found in the *Design of Wood Structures ASD* textbook and calculated by hand. These formulas were also placed in Excel using its formula capacity to change values and quickly check calculated work. Software such as RISA-3D was also used to check the design's calculations and load capacity by inputting the design and changing the load placement and values. Once finalized with the roof truss calculations, the flooring system was designed. RISA-3D was used to check the design values and output the necessary information like member size and structural loading. The software also was used to check for structural stability. This process was repeated for both the flooring and the roofing system. All the calculations were performed and then checked using RISA-3D. If a result seemed obscure or out of place the material was adjusted, and the calculations were run again. This was done until the loads and beams were sufficient, giving the group the proper beam size.

The energy system design incorporated both the solar energy and use of the water in the rainforest; the team made this design based on some preliminary checkpoints they wanted to hit regarding the sponsor's needs. The design was then developed in a visual to better explain and show to the sponsor. Once the system was finalized and accepted, the team was able to begin calculations.

After researching solar panels, the group discovered panels are not necessarily the most common energy generation method used in Brazil. There is a lot of tree coverage blocking the sun's rays. Nonetheless, the group still wanted to incorporate renewable resources and decided to research a parabolic solar trough. The parabolic solar trough will either be mounted above the trees or in a clearing to reach sunlight. Heated water will go through a small industrial sized steam turbine. The team wanted this system to also utilize the water from the reservoir and discovered that the reservoir water could be brought through a condenser to cool the looped water after exiting the turbine. The group also knew to account for any unexpected pressure drops using pumps throughout the subsystems themselves.

The research was done to begin calculations to find the density (ρ), viscosity (ν), and dynamic viscosity (μ) of the working fluid in the loop. The flow rate (Q) of water affecting the amount of energy produced by the steam turbine is needed. The material of galvanized steel was picked to protect the pipe from water damage.

The sponsors provided images and videos of the water source, where an assumption was made about water flow velocity. Using the equation $V = Q/A$ where V is water velocity in m/s, and A is an inner pipe cross-sectional area in m^2, the solution for A of the pipe is then matched to the closest manufactured pipe size. Now that a real pipe size was known, the group calculated backward to solve the actual cross-sectional area where the water would be flowing.

Friction factor, f, is a value associated with energy lost due to fluid friction resistance along the material. The group utilized the Moody diagram in Figure 2. The Reynold's number of water at the desired characteristics aided in foreseeing the fluid flow pattern throughout this subsystem.

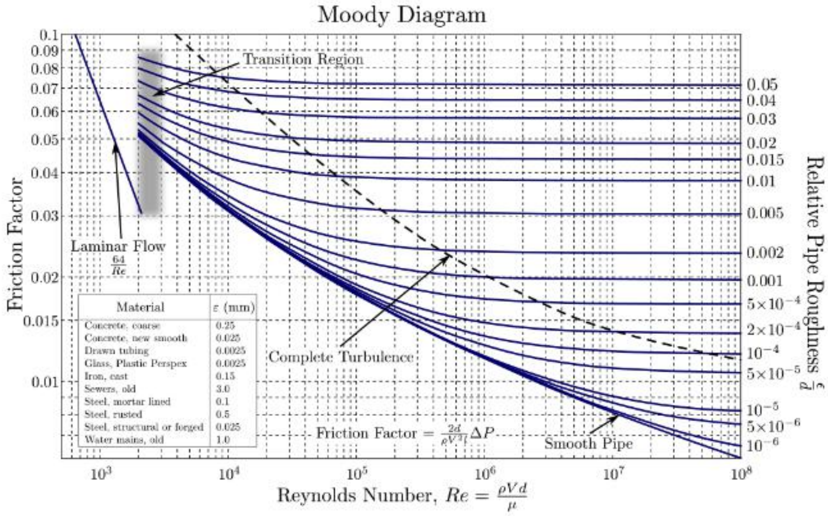


Figure 2: Moody Diagram *(Engineers Edge, 2020)*

Head loss is the loss of pressure due to friction in a pipe and is unavoidable. The equation for head loss:

$$H_L = f(\frac{L}{D})\frac{V_2}{2g}$$

H_L is the pressure loss
f is the friction factor
L is the pipe length
D is the hydraulic diameter
V is the fluid flow average velocity

The pressure change across the pipe equation is found to be:

$$\Delta P=\rho g H_L$$

ΔP is the change in pressure in pascals
ρ is the density of water at the desired characteristic in $\frac{g}{cm^3}$
g is the acceleration due to gravity in $\frac{m^2}{s}$
H_L is the head loss in m

Inefficiencies are accounted for in the system if unknown variables impact the results. For this reason, it is good practice not to assume 100% efficiency for subsystems. With η representing efficiency, which is a unitless value, the group assumed η_{pump}=.5. The pumping power is calculated using the change in pressure multiplied by the flow rate and can be adjusted with expected inefficiencies by dividing by this value. This power produced and needed to operate the separate subsystems was calculated throughout the design process.

$$\text{Pumping Power} = \frac{\Delta PQ}{\eta}$$

P is the differential pressure
Q is the flow rate of the pump
η is the pump efficiency

The turbine's work, W_T, would be calculated by multiplying the mass flow rate, ṁ, by the change in specific energy between the inlet, h_{in}, and outlet, h_{out}, expressed in equation form by $W_T = \dot{m}(h_{out}-h_{in})$. Specific energy and other thermodynamic values were found in the backreference pages of a thermodynamic textbook. An assumption was made about the turbine's inlet conditions, so as the pressure and the steam temperature are not to cause material failure. The steam turbine's quality is estimated by approximating actual specific energies from the isentropic process and the real process. This is explained in Figure 3, a simplified version of the Mollier Diagram. The quality of the fluid is thought of as the percentage of steam saturating a material. When there is a quality of 100%, or x = 1, the material is thought to be 100% steam. As seen below, this is a simple fraction equation of the amount of vapor in a mixture.

$$X = \frac{m_{vapor}}{m_{vapor}+m_{liquid}}$$

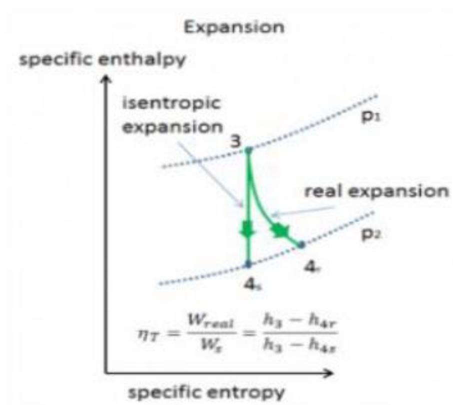


Figure 3: Simplified Mollier Diagram *(Nick Connor, 2018)*

The values along the Y axis can be thought of as increasing heat, and the values along the X axis can be thought of as the level of disorder in the fluid of the system. When doing engineering calculations and there is a decrease in temperature, what the actual system does is different from theoretical values. In this case, one can estimate calculations with the entropy value of the previous state for the next state. However, this "next state" value is not the true value, but rather along the pressure curve that can be followed up to the true temperature, and then followed down the graph to the true entropy *(Nick Connor, 2018).*

Accepted quality for a turbine must be above about .9, to ensure enough percent of the working fluid is a steam mixture. When thinking about another subsystem of the total design, a condenser was previously mentioned to utilize water from the reservoir to cool the water in the loop. The enthalpy coming out of the condenser is needed to calculate the total efficiency. To find the enthalpy, a series of equations that build off each other is applied with the thermodynamic and fluid characteristics of the working fluid.

$$\mathrm{Re} = \frac{\mathrm{VD}}{v}$$

Re is the Reynold's number
V is the velocity
D is the diameter
v is the kinematic viscosity

$$\mathrm{Nu} = .023Re^{.8}Pr^{.4} = \frac{\mathrm{hiD}}{k}$$

Nu is the Nusselt number
Pr is the Prandtl number
h is the heat transfer coefficient
k is the thermal conductivity of the fluid

$$\mathrm{h\pi DL\Delta Tlm} = \dot{m}\mathrm{C\Delta T}$$

L is the length
T is the change in temperature
ṁ is the mass flow rate
C is the specific heat

$$Q = \dot{m}_{total}\Delta h - \dot{m}_{riverusage}C_p\Delta T$$

Q is the heat transferred to the system
Δh is the change in enthalpy

The total volumetric flow rate for the entire system Q is known. The change in enthalpy across the condenser is known, C_p is constant, and the change in temperature across the condenser is estimated. The team needed to account for pressure drops at any point in the system.

Regarding the solar troughs, as seen in Figure 4, the group researched average solar irradiance in the area in kWh/m^2 /day over the year and the average number of sunlight hours per day. These values were divided to get the amount of energy produced on a panel in W/m^2. An assumption is made regarding the hours that the system would be running, so the group accounted for this ratio into the total amount of power produced per day. The group assumed a photovoltaic panel's efficiency to be 20% *(Catherine Lane, 2020).* By dividing the estimated kWh per day by the irradiance multiplied by the panel's efficiency, the group found the surface area of the PV panels needed. This calculated value is to be adjusted based on the land area. The curved aperture area of a parabolic collector can be calculated with an approximate ratio of 3.5 to 4 times of surface area difference. This allowed the group to choose a particular trough; the group figured out how many units are needed to satisfy the heating conditions by dividing a single trough value by the total energy needed.

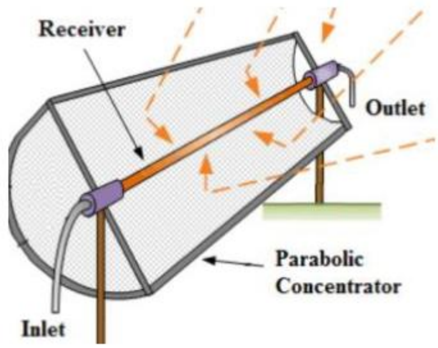


Figure 4: Parabolic water heating solar trough *(Chloe Melnick, 2018)*

4.4 Objective 4- Conduct an approximate cost estimate of the energy system and supply recommendations for cost analysis of the structure.

Cost is an integral part of any project, as finances are commonly a limiting factor in construction. To estimate the total cost for this site's construction, the team divided the analysis into two parts: demolition and new construction. While the majority of the project's cost has come from constructing the new design, the site must first be cleared prior to the start of construction; therefore, site demolition is also an essential part of cost analysis. Demolition costs have been determined using *RSMeans Building Construction Costs* based on the square meters of the site footprint. The team used this information for comparative cost estimates. An approximate cost of the energy systems was determined by researching parts online, using the most common price found, or doing calculations based on the material quantity needed. These price quotes include American hardware stores for materials or international online shops for more specific subsystems such as the turbine and solar troughs. The team found which solar-powered system and water pump device met the energy requirements and included the respective costs in the total analysis through research. The complete analysis consisted of the demolition cost estimates, structural building cost estimates, and estimated costs associated with the energy system.

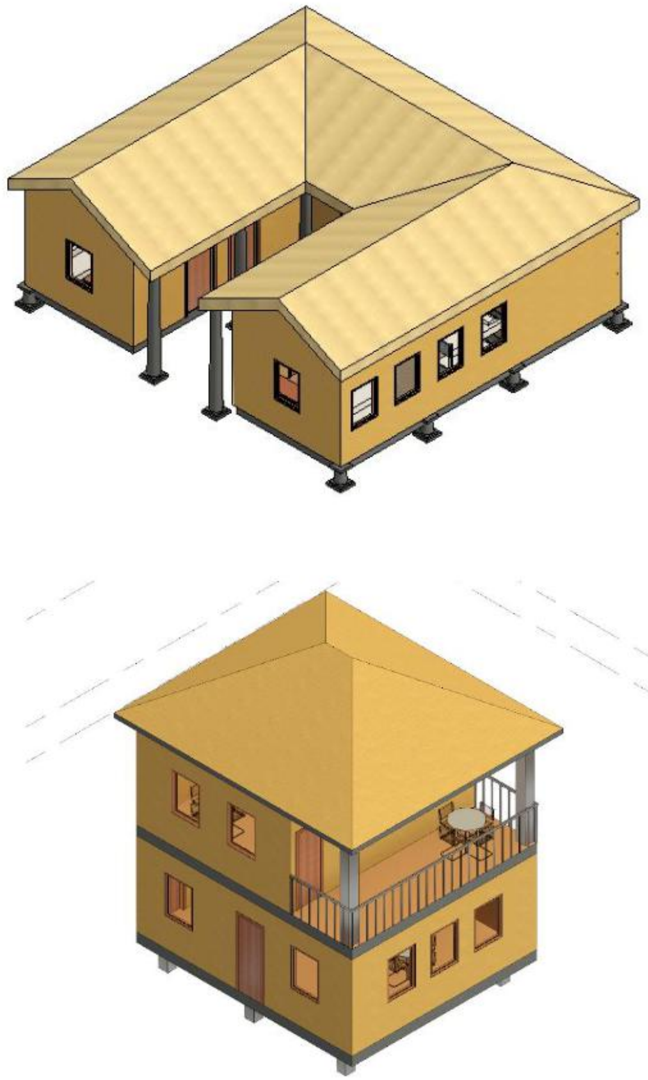
5.0 Results

Two structures were proposed to the project sponsors for an addition to the Reserva Alto Da Esperança. Architectural floor plans were drafted for both the dormitory building and the multifunctional building. Designs were generated with the plan to create two spacious structures, all while prioritizing sustainable building techniques. A complete structural analysis was conducted to prove the integrity of the dormitory building and an analysis of the renewable energy system. In addition, a complete cost analysis helped give the project sponsor a concept of the expected project expenses.

5.1 Objective 1 - Devise a site layout and architectural floor plan inspired by the project sponsors' wants and needs for the reserve.

Conversations with the project sponsor lead the team to design two structures, a dormitory, and a multifunctional space, with a total footprint of 1,507 ft^2 (140 m^2). With the sponsor's goals in mind, the team decided to build the structures out of wood, which is a more sustainable option than that of concrete (*IWBCC, 2018).* Brazil has an abundance of this softwood. Other local materials, such as piassava fiber, were used to make the buildings blend with the local architectural design. While the concrete was not implemented in the structural design it was necessary for the foundation to ensure structural soundness. While the team could have designed the entire structure out of wood and other locally sourced materials, a small amount of concrete decreased the overall cost significantly.

The sponsors provided the team with a list of features they desired within the building designs. Using the software Revit, the team began drafting designs suitable for the project sponsor's wants and needs. However, multiple redesigns were conducted to adhere to their exact vision for the reserve. Respectively, Figures 5a and 5b show the original designs generated for the dormitory and kitchen space. The sponsors formerly instructed the kitchen to be a two-story building separate from the dormitory. The dormitory building's initial requirements were relatively simple; the space was to include four bedrooms, a laundry room, and two bathrooms.



Figures 5a & 5b: First design draft of the dormitory space and the kitchen space.

Through further discussion, the sponsor and the group finally landed on a design that included the kitchen in the two-story dormitory, as shown in Figure 6. The dormitory building was upgraded to include the kitchen and eight bedrooms, a bathroom between each room, a laundry room, storage space, a stargazing balcony, an office, and a deck with outdoor seating. The group designed the dormitory structure to optimize the reserve's land space, attempting to keep the overall footprint as conservative as possible. The bedrooms mirror each other, with bathrooms in between allowing for shared access. While this project did not focus intently on the mechanical, plumbing, or electrical systems within the building, the team still valued supplying a realistic approach to the dormitory design. Therefore, the bathrooms were purposely designed to be stacked above one another to simplify the structure's plumbing system. They are designed so that reserve visitors can use the sinks while another visitor is utilizing the shower or toilet. Each bedroom has enough space to have a maximum occupancy of four people, whether that be two sets of twin sized bunk beds or 2 queen sized beds per the sponsors request. The kitchen was incorporated into this design along the backside of the building. The sponsor requested that the kitchen be accessible by the deck, where there would be a seating area allowing visitors to eat without physically entering the kitchen. A small opening in the wall with a platform encourages visitors to rinse their dishes in the outdoor sink and stack them on the windowsill.

Figure 6: Final design draft of the dormitory space, inclusive of a kitchen, balcony, and deck.

The team also drafted designs for a multifunctional space as the sponsor initially mentioned the need for an amphitheater within the reserve. This space's original idea would be an open concept structure with a stage or sizeable entertaining zone with a plethora of seating. The sponsors urged the open concept and asked that the space contain minimal interior supports to avoid disrupting the usable entertainment zone. They requested this space be designed to have a stage that would be in open air. A straightforward design responding to all of their wishes was generated through Revit and shown in Figure 7.

Figure 7: First design draft of the multifunctional space.

Upon further deliberation, the sponsors decided that they genuinely wanted a space adhering to various functions, rather than just an amphitheater. The new and improved space concept would contain a portion of the original amphitheater idea, including a staging area for lectures or concerts and seating with additional features. The multifunctional center was redesigned to include an area for vendors to sell products or educate visitors on the reserve. Also, locker rooms were added for visitors that are not residing on the reserve yet might still need to use the restrooms or freshen up and a small covered parking area was attached to the building as well. While the design of the building has evolved, as seen in Figure 8, the team still made sure to incorporate the original features that the sponsors stressed; therefore, the stage area remains open, allowing visitors to continually feel the connection to nature on the reserve as they listen to presentations. The openness of the space also allows for the opportunity to have more people listening, as they can sit on the lawn. The multifunctional space inside the building is designed to be used for various functions, allowing the project sponsor to decide what they specifically want to do with space at a later time. The locker rooms within the multifunctional center include bathrooms and showers for both genders and doors accessible from the exterior of the building to avoid unnecessary foot-traffic inside.

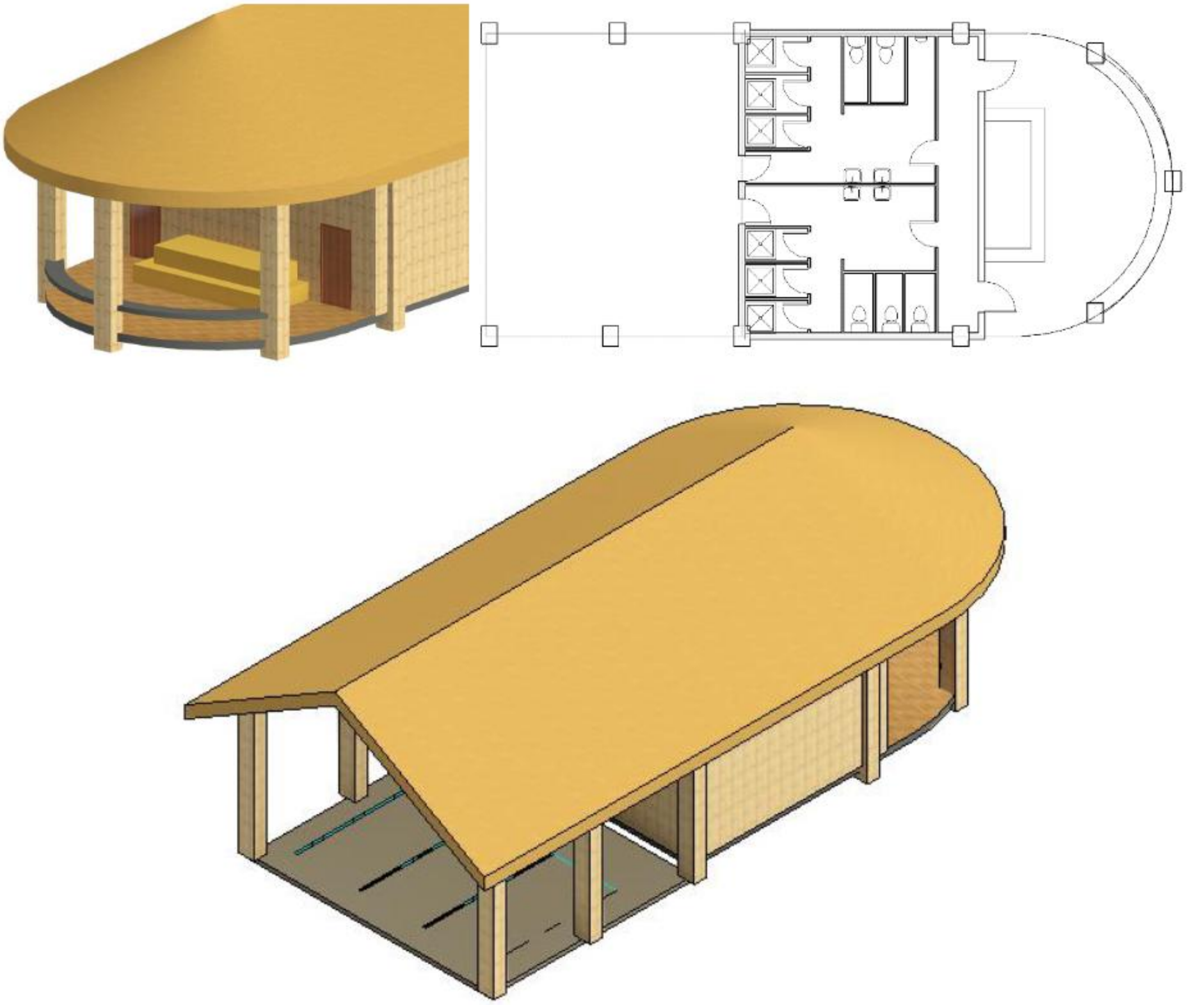


Figure 8: Final design draft of the multifunctional space with a presentation area, a multipurpose room, and a parking area.

Using a Google map image of the reserve, the group worked with the project sponsors to determine the energy system's best location with respect to the proposed buildings. Together, the ideal placement of the energy system would be at the southern end of the reservoir. The piping from the energy system would fall along follow the reserve's property line. The bird's eye view of the site obtained from Google Maps also allowed the team to decide where to place the solar troughs to have an optimal amount of sunlight.

5.2 Objective 2- Design a building with the architectural floor plan and site layout, along with an energy system.

Upon finalizing the architectural drawings, a structural layout of the building was derived from the floor plans. Transforming the architectural drawings into structural drawings allowed the team to analyze each member of the building. A one-way slab system was then decided on, as this design is satisfactory when applied to wood structures and would be the simplest layout for the team to work with. The one-way structural system is defined as a structural system where the loading is carried in one direction by the supports (*Breyer, 1999*). This system differs from a two-way system. A one-way system is only supported on two opposite sides and experiences deflection in one direction, as opposed to the two-way system, which is supported on all four sides, bends in two directions. For the simple two-story buildings being proposed, a one-way system will satisfy the building's needs and was implemented in the structural design.

Aligning with the project sponsor's goals, the team decided to use a post and beam design for the wood structure as this allows for an open concept with an aesthetically pleasing finish (*Breyer, 1999*). Upon recommendation, columns were positioned at the corners of each room to avoid columns interfering with the space, allowing for the largest open area possible in each room. Placing beams and joists less than 4 ft (1.22 m) was recommended for safety; therefore, the design includes beams each spaced 3.28 ft (1 m) apart (*Breyer, 1999*). Shown below in Figure 9 is the structural design of the dormitory. A grid system was used to navigate the drawing, and thus, each column has been labeled with both a number and letter.

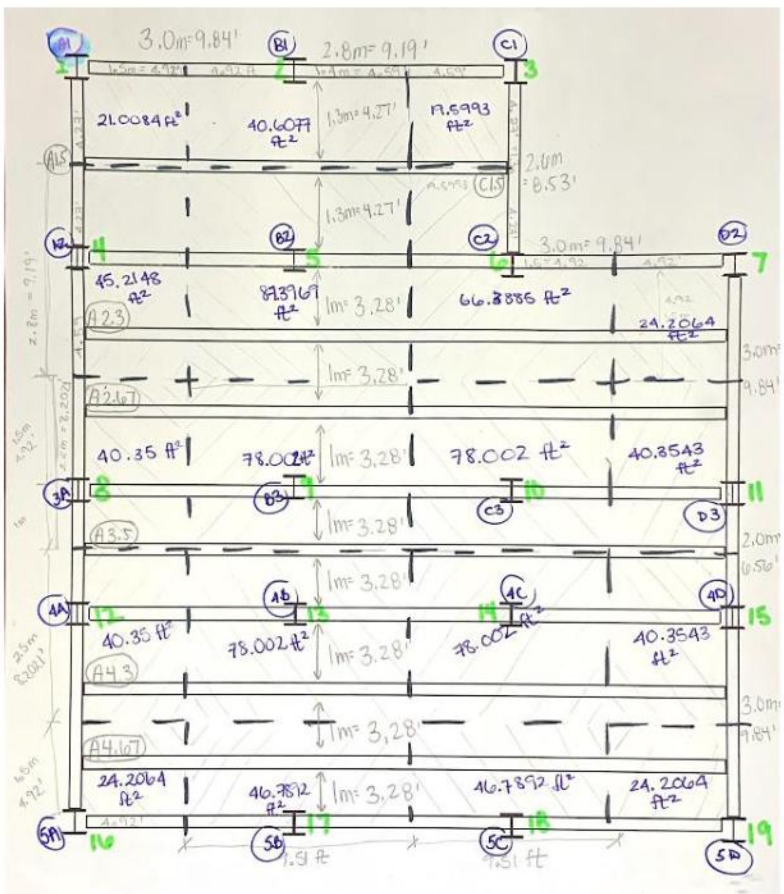


Figure 9: Structural layout of the dormitory illustrating the placement of columns and beams.

When working in RISA-3D, the template structure was uploaded. There were two methods in which this can be done. One method was by importing an AutoCAD file or a Revit file. Alternatively, a layout grid can be uploaded from Revit or created on RISA-3D as in Figure 10. When a structural system was uploaded, the member and joints are generated. When the layout grid was uploaded or created, the members and joints need to be inserted manually.

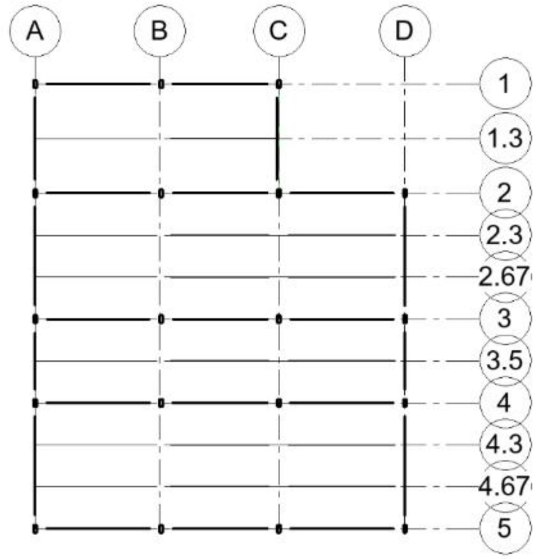


Figure 10: Revit grid layout to be imported into RISA-3D.

When all the members and joints are loaded and labeled per liking, the loading begun. The boundary conditions were then decided. The boundary conditions included the X, Y, Z reactions and translation on members and joint restrictions. This was then applied to each joint or member that is necessary. The load combinations were placed in the basic load cases spreadsheet shown in Figure 11. This was a list of the loads in the file. They were labeled and categorized to be added to the system. The system was loaded by inserting point loads, joint loads, and distributed loads determined by prior research and knowledge. This was done by insert loads and clicking on the members or joints on the system. The load combinations were then generated by opening the load combinations spreadsheet, and RISA-3D then generated the load combinations based on different codes that are already loaded into the software. The system generated an analysis of the member deflection, member loading, and moment and shear diagrams.

BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area(Member)	Surface(Plate/Wall)
Beam Distributed	DL								
Beam Point	DL								
Beam Distributed	LL								
Beam Point	LL								
Earthquake	EL								
Wind	WL								

Figure 11: Basic Load Case spreadsheet to be populated with predetermined loads.

If a system resulted in non-plausible results, the team went back and adjusted member size. More research was done on the proper loading of multiple members and checked boundary conditions. The influence of the restrictions of reactions and translations have a significant impact on the system. The next step was to add more members or reshape the system until the results fell into a position that were feasible.

5.3 Objective 3 - Perform a complete analysis of the dormitory building and energy designs.

The structural analysis of the dormitory was conducted using a top-to-bottom approach. To do this, the team broke the structure into sections: the roof, second floor, and first floor. Since the lower levels would need to uphold the upper levels, the roof design was conducted first, followed by the second floor, and finally the first floor. For each section (level), an analysis of the two loading conditions – dead loads and live loads – were conducted.

The team's first step towards making advances through the structural calculations was to calculate the tributary area generated from the structural drawings for the floor space. Since the second floor mimicked the first floor, only one set of data was generated as the data would remain true for both the first and second floor of the dormitory structure. The tributary area is needed to calculate each column's point loads and determine how much of the floor load each column is responsible for. As shown in the methodology (pg 31), the team used a grid system to identify each column, illustrated in Figure 9. Table 1 lists the tributary area values obtained respective to the appropriate column. The structural design was recreated in Revit to produce a model that could be placed into Risa-3D, shown below in Figure 12. This model included design constraints and was made up of the beams, joists, columns, and truss design; it also excludes the extended second floor porch. During this process, it was determined that the roof was to be changed to one extensive truss system instead of three smaller sectioned truss systems seen in Figure 13. This was done to aid in the ease of calculations. Due to the limitations in the program, the group also changed the truss design. The original truss design was to have a 1 meter overhang of the roof. This was changed so the walls would align at the end of the truss per Figure 14. A second model was developed on Revit of just the first-floor structural beam and column layout as per Figure 15.

Figure 12: Structural design of the dormitory.

Figure 13: Comparison of one extensive truss system and three smaller sectioned truss systems.

Figure 14: Simplified structure no roof system or extended porch.

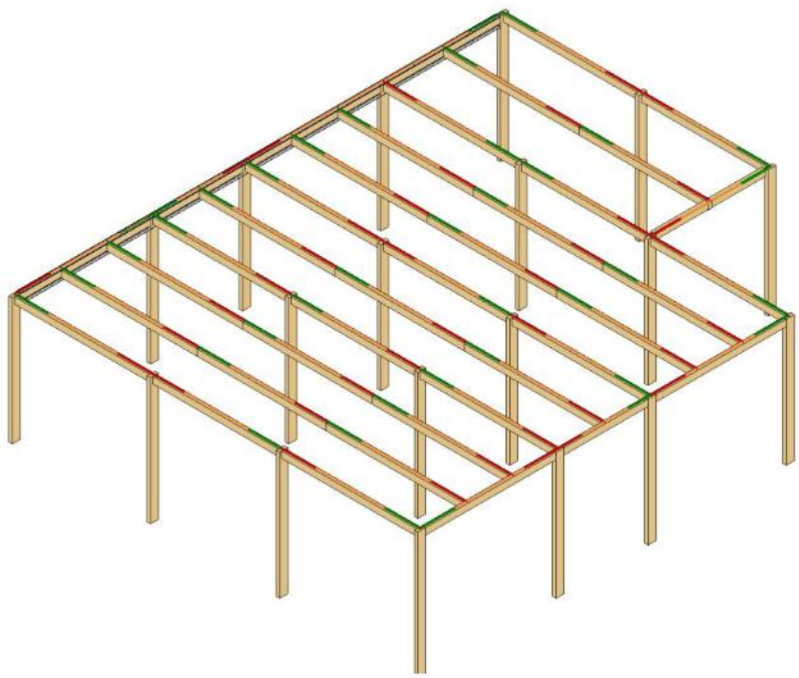


Figure 15: The first-floor structural beam and column layout.

The tributary area for each of the columns was calculated and is listed in the table below. The tributary area is important for the loading of the structure.

Column Name	Tributary Area (ft^2)
A1	21.0084
B1	40.6077
C1	19.5993
A2	45.2148
B2	87.3969
C2	66.3885
D2	24.2064
A3	40.3543
B3	78.002
C3	78.002
D3	40.3543
A4	40.3543
B4	78.002
C4	78.002
D4	40.3543
A5	24.2064
B5	46.7892
C5	46.7892
D5	24.2064

Table 1: Tributary area for each column.

The first floor dead loading was calculated using the weight of each component of the floor. Due to this project's time constraint, calculations began amidst consultations with the project sponsors and material research. Thus, the team did not have specific information on what type of wood would be implemented in the construction process. The team decided to use values from the *Design of Wood Structures ASD* textbook to over design the structure since the material data was not predetermined. The dead load for the first floor was determined using the following information:

Lightweight concrete = 12.5 psf
1 1/8" plywood = 3.4 psf
Framing members = 2.5 psf
Ceiling supports = 0.7 psf
Ceiling = 2.5 psf

Before totaling these values, a suggested partition load of 20 psf was added to the dead load calculations as instructed by the *Design of Wood Structures ASD* textbook. The resulting dead load of the floor was discovered to be equal to 38.4 psf. While the first and second floors' layout and materials remain constant, the additional loading on the first floor must be taken into consideration. Since the first floor will also be supporting the second floor above, the textbook recommended factoring another 10-15 psf for the additional load of the second floor. To overdesign the structure, the team opted to add an extra 15 psf to the first floor dead load. The resulting floor dead loads for the second and first floor are as follows, 38.4 psf and 53.4 psf. The corresponding tributary area and dead load for each floor were multiplied together to determine the amount of weight that each column was required to carry. These calculations were conducted with the plan to later upload the structural skeleton to RISA-3D. The point dead loads were then added with the distributed live loads to each beam to determine deflection and adjust the column strength accordingly.

Research and meeting consultations lead the team to decide on a scissor truss as this design provided structural strength while allowing for high ceilings. Upon deciding on a scissor truss, the truss was sketched and sized to span the 35.515 ft (10.82 m) of the dormitory building, including the 3.281 ft (1 m) overhang on each side. Due to time constraints, it was discussed that the dynamic roof with multiple smaller truss systems would be replaced by one large truss spanning the entirety of the dormitory building, as seen in Figure 16. A series of trigonometric calculations were then conducted to determine the specific layout of the truss. Figure 17 illustrates the truss layout and labeling system for the organization of calculations. Trigonometric functions allowed the team to calculate the member lengths and angle specifics within the truss system, as shown in Table 2. The truss's final layout included a top chord pitch of 7/12 in. and a bottom chord pitch of 3/12 in.

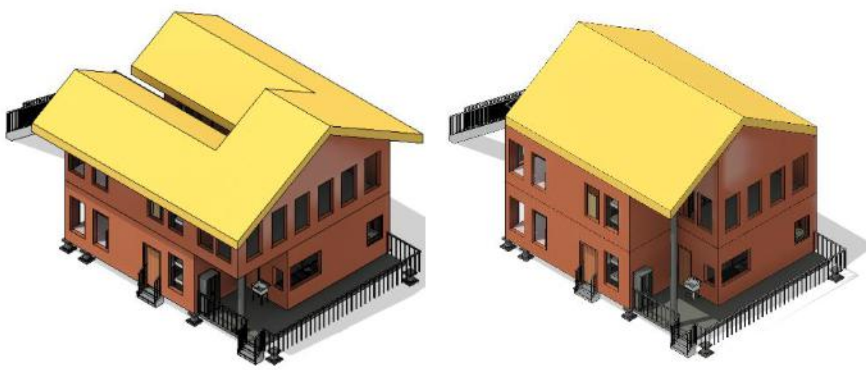


Figure 16: Roof of one large truss spanning the entirety of the dorm building with the walls connecting to the edge of the truss system.

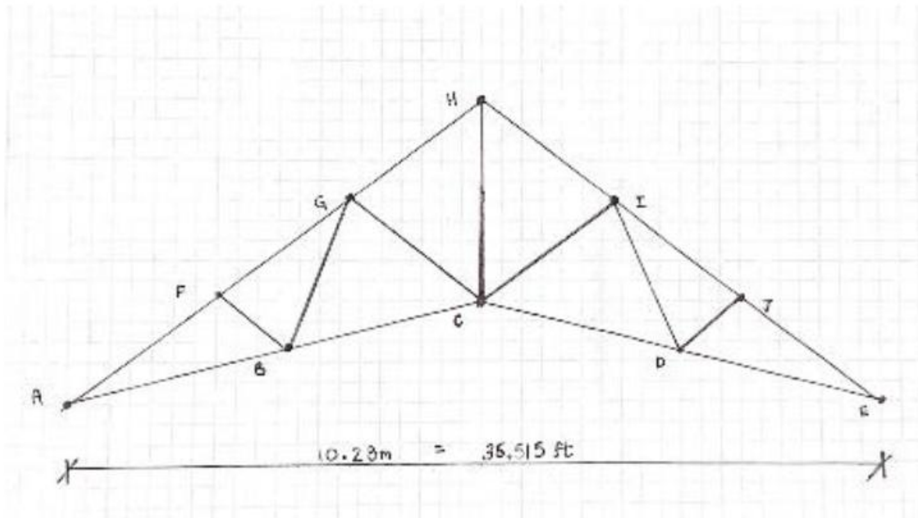


Figure 17: Truss layout calculation organization.

Member	Length (ft)	Angle	Measure (degrees)
AF = JE	6.86	FAB = JED	16.22
AB = DE	9.15	AFB = EJD	110.79
FB = JD	3.20	ABF = EDJ	52.99
FG = JI	6.86	BFG = DJI	69.21
BC = DC	9.15	FGB = JID	27.60
BG = DI	6.46	GBF = IDJ	83.19
GH = HI	6.86	GBC = IDC	43.82
GC = CI	6.34	BGC = DIC	88.55
HC	6.99	BCG = DCI	47.63
-	-	CGH = CIH	63.85
-	-	HCG = HCI	61.70
-	-	GHC = IHC	54.45

Table 2: Member length and angle specifics.

The team then proceeded to calculate the dead load of the truss system designed for the roof. Similar to the floor dead loading, the roof dead load was determined by summing the weight (per square foot) of the material data found in the *Design of Wood Structures ASD* textbook. The roof dead loading was calculated to be:

Roofing (5-ply with gravel) = 6.5 psf. This value was used in place of the local piassava palm that is planned to cover the roofing. Data regarding piassava palm weight could not be obtained; therefore, the team assumed the 5-ply gravel would weigh about the same.

Reroofing = 2.5 psf. This is applied to loads that are applying shingles over old shingles that have already been in existence. While this usually would not apply to this structure due to its lack of previously weathered shingles, the team decided to keep this load to over design uncertainty regarding the piassava palm. The piassava palm would need to be layered. The team was uncertain of its loading; thus, to err on the side of caution, valuing safety and reassurance within the calculations, the team chose to overdesign.

½" plywood =1.5 psf

Framing = 3.2 psf

Furthermore, the total dead for the roof was determined to be 13.7 psf. This value was saved for later use in calculations and RISA-3D modeling.

The next step was to calculate the live load of the structure. Like the previous calculations, the team treated the truss as a different system from the rest of the building because this is how the obtained values and drawings must be uploaded into the RISA-3D software. To determine the floor live loading, standards from the Massachusetts codebook were used (*Understanding Loads, 2017*). Per the Massachusetts codebook, both the second and first floor experience live loads of 40 psf. While the roof may not experience vertical live loading from foot-traffic, it, along with the remainder of the structure, will experience a lateral wind load. In addition to the wind loading, this structure's location in Bahia, Brazil, requires attention to the potential seismic loading that the dormitory could experience.

For the Peak Ground Acceleration (PGA) Figure 18 demonstrates a value closer to 0.01-0.02 for the project's location in Itacaré. However, the group chose to overdesign the structure and therefore used a PGA value of .03.

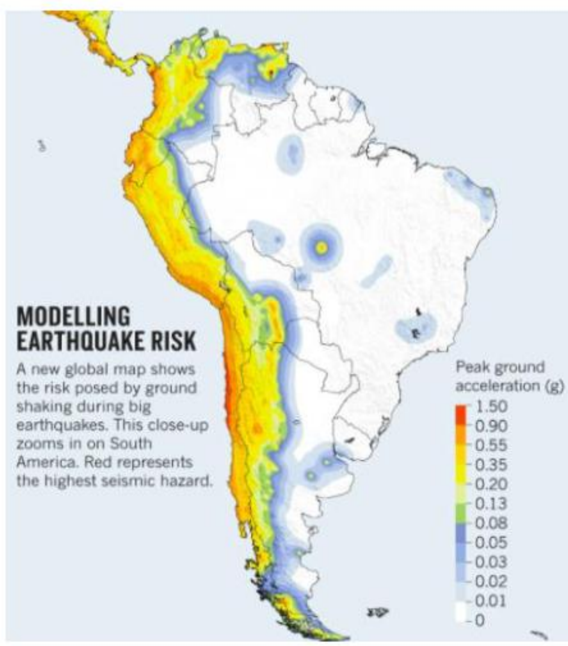


Figure 18: Map of South America illustrating the Peak Ground Acceleration (PGA) associated with the risk earthquakes pose on communities through the movement of the Earth's crust *(M Pagani, 2018)*.

Using the seismic loading equation, denoted by EQ, the earthquake load for this structure was determined to be 3.2 kips and was assumed to be applied to the entire structure. Following the seismic calculations were the wind loading calculations. By *CADDTools* this structure was classified as risk category II and exposure B; therefore, the wind directionality was determined to remain constant with the standard value of 0.85. The exposure velocity reflected a value of 1.00 *(Design. medeek, 2020).* The topographical feature value was shown to be 0.99 per the ASCE 7-10 wind loading map *(ASCE, 2020).* The velocity for Bahia, Brazil was determined to be 50 $\frac{m}{s}$ as shown in Figure 19. The implementation of these variables determined the wind load on the structure to be equal to 27.02 psf. The wind loading value was applied to the entire structure and the roof truss.

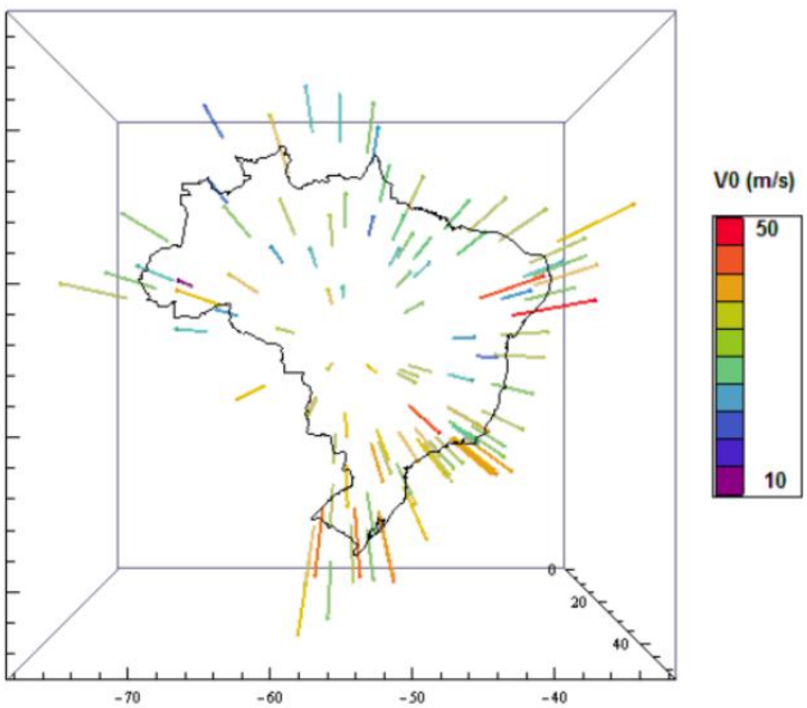


Figure 19: Risk categories to wind exposure (Andre Beck, Marcio Correa, 2013)

Using the previously determined dead loads, wind load, live loads, and seismic loading, the team used the appropriate square footage to calculate a combination load of 415.4 kips.

Hand calculations were performed to determine the truss system's member forces to aid in simplifying the RISA-3D analysis. Since the roof is constructed of multiple trusses, as shown in Figure 20, each truss would be responsible for loading 2 ft (0.61 m) or 1 ft (0.30 m) on each side of the truss.

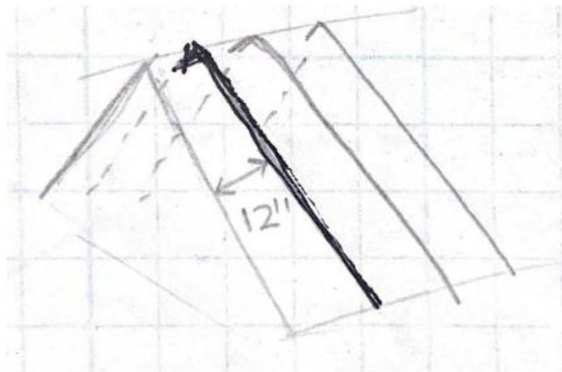


Figure 20: Sketch of the truss system within the roofing structure.

To determine the loading on one singular truss in this trusses system, the roof dead load was added to the roof live loads totaling 45 psf. As previously stated, each truss is responsible for 2 ft (0.61 m) of loading; therefore, the load equal to 45 psf was multiplied by the two feet span by 20.58 ft (6.27 m) roof length as this was the area that the loading would affect for the truss. This truss was calculated to need to support 4,436 lbs in total. Therefore, the walls at point A and E on the labeled truss shown in Figure 17 would each need to support 2,218 lbs. The loading for the truss's top and bottom chord was determined by multiplying the applicable loading by the span equal to two feet and the chord length. Figure 21 demonstrates the initial point loads calculated for the top and bottom cords. Figure 22 illustrates the actual loading once the loads were combined, and the upward force from walls at A and E were factored in.

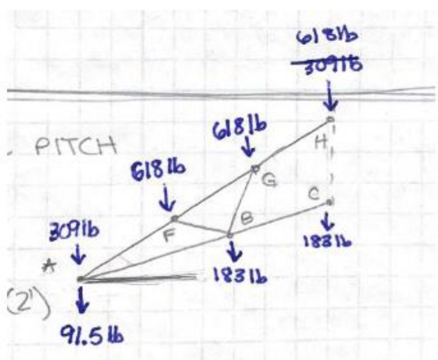


Figure 21: Initial point loads calculated for the top and bottom chord of the truss.

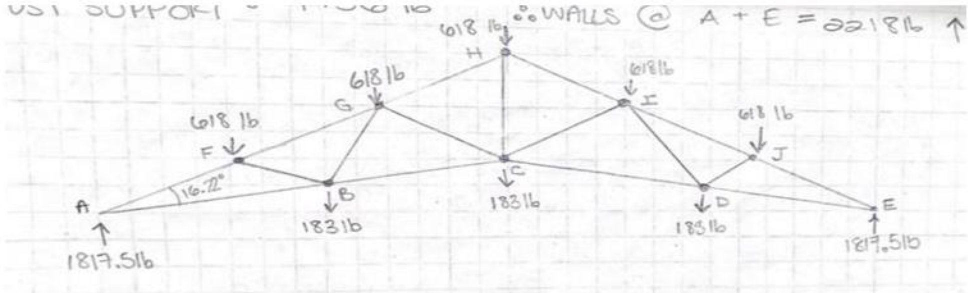


Figure 22: Actual loading on the truss used to calculate the member forces.

The loading demonstrated in Figures 21 and 22 helped the team to determine the member forces. Member forces were calculated using the members' angles and lengths previously determined and displayed in Table 2 (pg 37). Trigonometric functions were again used to determine the forces in the truss members, and whether they are in compression or tension as shown in Table 3.

Member	**Forces (lbs)**	**Compression or Tension**
AF = JE	6,343	Compression
AB = DE	5,644	Tension
FB = JD	627	Compression
FG = JI	4,320	Compression
BC = CD	2,952	Tension
BG = DI	2,448	Tension
GC = CI	549	Compression
HG = HI	1,364	Compression
HC	758	Tension

Table 3: Member forces determined their compressive state within the truss.

These values were calculated with the intention that the truss would be uploaded into the software RISA-3D. This software will help determine the members' deflection and member sizing, along with other critical structural components. While these calculations were performed with great attention to detail, when the team went to double check the static system, the resulting force was not zero pounds. The team tried to recalculate to prove a static system but the errors within the calculations could not be determined. One solution was to use a member force of 2,274 lbs for member HC, approximately three times the original force calculated. This would work for the structure as member HC is the center of the web, which would not affect anything else in the truss and would also get the system to prove to be relatively static. The other problem the team discovered was that the truss used to perform the series of hand calculations could not be used in RISA-3D. To overcome this complication, the team picked a similar truss available on RISA-3D and applied the dimensions and angles previously calculated from the original truss system, shown in Figure 17, to the new truss. This unfortunately meant that the team would not be able to put as many predetermined values into the software. The new truss design generated by RISA-3D will be discussed in the coming section.

The structural design was recreated in Revit to produce a model that could be placed into RISA-3D. This first model generated is shown in Figure 23, this included the change to the roof truss design. However, this begins the previous discussed changes, but in the RISA-3D work.

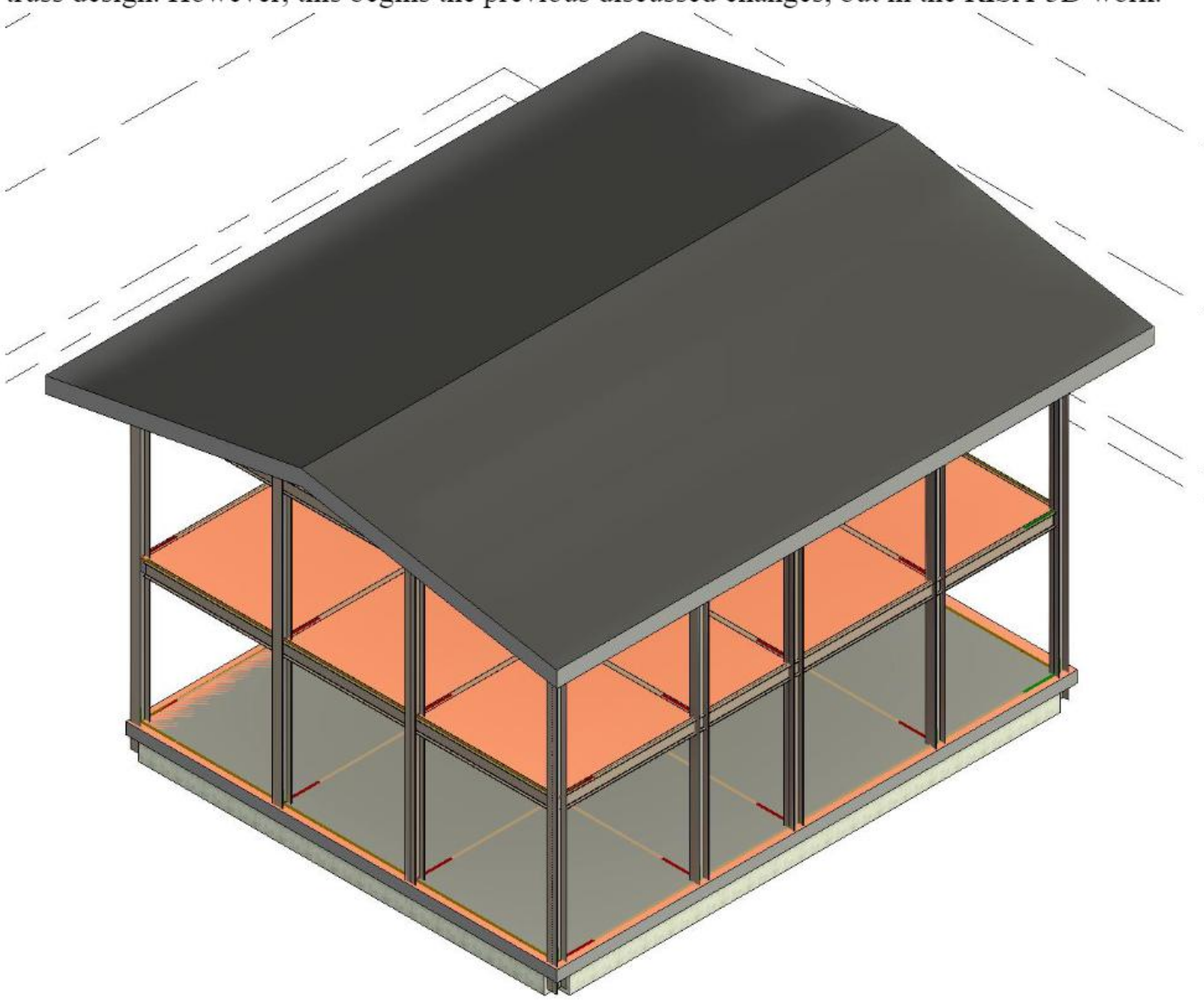


Figure 23: Structural Design Version 1.0, complete with .5 m raise from the ground. This version has an adjusted roof and no extended balcony.

The layout from Figure 23 was then uploaded to RISA-3D, which generated members and joints to produce the model depicted in Figure 24. The material chosen was southern pine with 2 ply and a 2 x 6 member size. Basic loading was added, dictated by the information calculated in Table 4 and Table 5. For the columns of the structure, the distributed dead load was calculated as 53.4 psf, and the distributed live load was assumed at 40 psf. Similarly, for the beams of the structure, a distributed dead load of 5.83 psf was calculated along with the point load of an assumed 40 psf live load. The load combinations generator calculated the table as followed in Table 6 based on the LC Code of the 2018 IBC Strengths. When set to get results, the system was determined unstable and did not output any results as it had inadequate restraints. This is due to the beams and columns of the structure being identified incorrectly. The complexity of the system is too large for the team to understand the proper boundary conditions and loads needed. The complexity of the system challenged the team to understand the proper boundary conditions and loads needed.

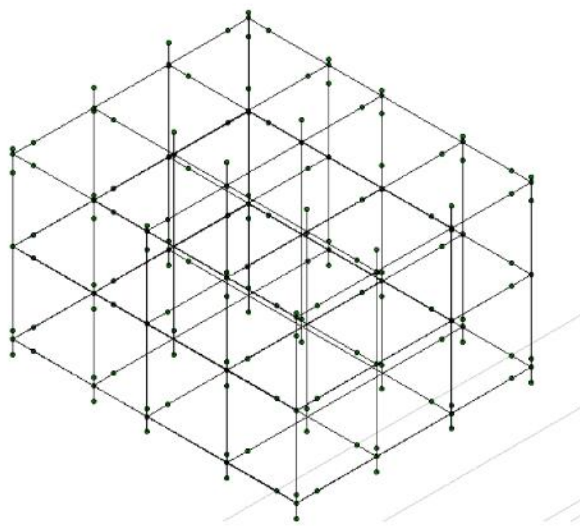


Figure 24: RISA-3D output from the Revit structural design version 1.0.

Name	Tributary Area (ft^2)	Point Dead Load	Point Live Load
A1	21.0084	1121.84856	840.336
B1	40.6077	2168.45118	1624.308
C1	19.5993	1046.60262	783.972
A2	45.2148	2414.47032	1808.592
B2	87.3969	4666.99446	3495.876
C2	66.3885	3545.1459	2655.54
D2	24.2064	1292.62176	968.256
A3	40.3543	2154.91962	1614.172
B3	78.002	4165.3068	3120.08
C3	78.002	4165.3068	3120.08
D3	40.3543	2154.91962	1614.172
A4	40.3543	2154.91962	1614.172
B4	78.002	4165.3068	3120.08
C4	78.002	4165.3068	3120.08
D4	40.3543	2154.91962	1614.172
A5	24.2064	1292.62176	968.256
B5	46.7892	2498.54328	1871.568
C5	46.7892	2498.54328	1871.568
D5	24.2064	1292.62176	968.256

Table 4: Column analysis.

Name	Span Length (ft)	Tributary Width	Point Dead Load	Point Live Load
A1 - C1	19.03	2.135	110.9449	1625.162
A1.5 - C1.5	19.03	4.27	110.9449	3250.324
A2 - D2	28.87	3.775	168.3121	4359.37
A2.3 - D2.3	28.87	3.28	168.3121	3787.744
A2.67 - D2.67	28.87	3.28	168.3121	3787.744
A3 - D3	28.87	3.28	168.3121	3787.744
A3.5 - D3.5	28.87	3.28	168.3121	3787.744
A4 - D4	28.87	3.28	168.3121	3787.744
A4.3 - D4.3	28.87	3.28	168.3121	3787.744
A4.67- D4.67	28.87	3.28	168.3121	3787.744
A5 - D5	28.87	3.28	168.3121	3787.744
A1 - A5	34.77	-	202.7091	
C1 - C2	8.53	-	49.7299	
D2 - D5	26.24	-	152.9792	

Table 5: Beam Analysis

Description	Sol...	PDelta	SRSS	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
Deflection 1	☑	Y		DL	1						
Deflection 2	☑	Y		LL	1						
Deflection 3	☑	Y		DL	1	LL	1				
IBC 16-1	☑	Y		DL	1.4						
IBC 16-2 (a)	☑	Y		DL	1.2	LL	1.6	LLS	1.6	RLL	.5
IBC 16-2 (b)	☑	Y		DL	1.2	LL	1.6	LLS	1.6		
IBC 16-3 (a)	☑	Y		DL	1.2	RLL	1.6	LL	.5	LLS	1

Table 6: Load combinations generated based on the LC Code of the 2018 IBC Strengths for the Structural Design Version 1.0. Where BLC is the Basic Load Combination and factor is the factor in which previous BLC would be multiplied by.

The structure was changed in the next rendition to be a one-way system. The beams in this revision do not follow the system designed. The Revit Structural Design Version 2.0 was then revised to produce the system in Figure 25. This model included more design constraints and excluded the extended second floor porch and the roof truss system. This was due to a compartmentalized approach to calculations. Due to the limitations in the program, the group also changed the truss design. The original truss design was to have a 1 m overhang of the roof. This was changed so as the walls would end at the end of the truss per Figure 26.

Figure 25: Revit structural design version 2.0.

Figure 26: Example of roof with no overhang and one meter overhang on the design.

The structural analysis was then compartmentalized to just look at the first floor. This was modeled in Revit, as shown in Figure 27. This file was not directly imported into the RISA-3D software; instead, the grid system was imported. The grid system was then used to place members in joints in line with calculations and design done by hand and labeled, as shown in Figure 28.

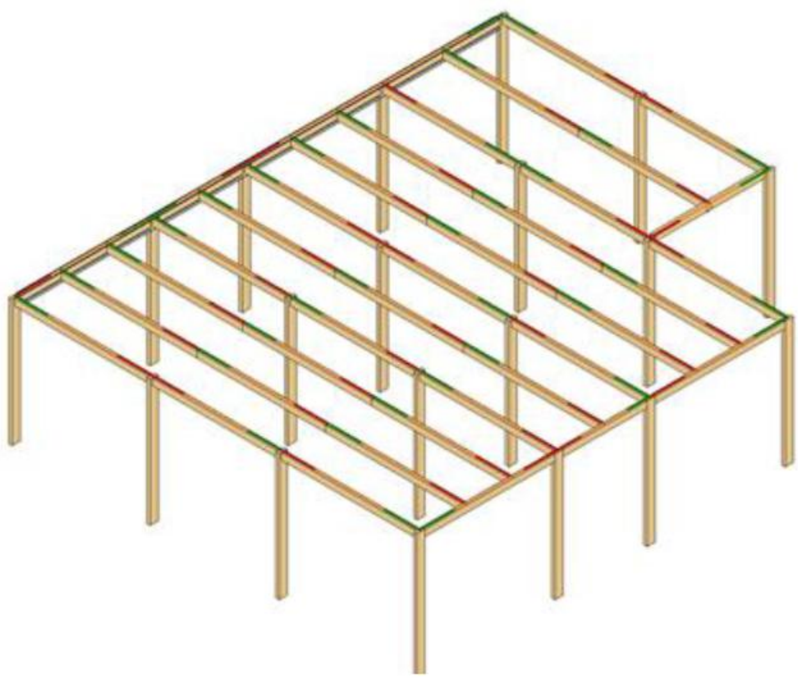


Figure 27: Revit structural design of first floor.

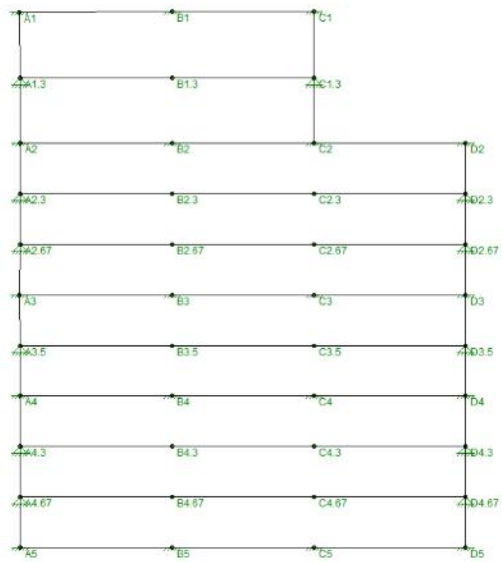


Figure 28: RISA-3D layout including labels, pins, and fixed members.

Boundary conditions were then added based on the discretion of the team. A fixed restraint was added to the columns' locations, and pins added to where beams converge. The load combinations generator calculated the table as followed in Table 9 based on the LC Code of the 2018 IBC Strengths. The loads were placed on the members based on Tables 6 and 7 and the team's discretion. When the loads were applied individually, and results were calculated, they were not plausible. The next step was for the team to adjust and get joint deflections, forces, and stresses to be in a realm where they would be plausible. However, due to a lack of certainty when creating the system and using RISA-3D, the team was unsure of the next steps. The team changed beam sizes and readjusted the loading, but none of these solutions made the system more plausible due to complexity of the complexity of the structural system. The only results that were outputted were the joint deflections. This is an indicator that there is something wrong with the system as there should be results for just joint deflection and reactions, which are shown in Tables 7, 8, and 9. Other changes were made to readjust the placement of loads, strength, and overall capacity of the members. This, however, still lead to results that would not be successful.

Description	Sol...	PDelta	SRSS	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
Beam	☑			DL	1	DL					
	☑			DL	1						
Deflection 1	☑	Y		DL	1						
Deflection 2	☑	Y		LL	1						
Deflection 3	☑	Y		DL	1	LL	1				
IBC 16-1	☑	Y		DL	1.4						
IBC 16-2 (a)	☑	Y		DL	1.2	LL	1.6	LLS	1.6	RLL	.5
IBC 16-2 (b)	☑	Y		DL	1.2	LL	1.6	LLS	1.6		
IBC 16-3 (a)	☑	Y		DL	1.2	RLL	1.6	LL	.5	LLS	1

Table 7: Load combinations generated based on the LC Code of the 2018 IBC Strengths for the Structural Design of First Floor.

L...	Joint Label	X [in]	Y [in]	Z [in]	X Rotat...	Y Rotat...	Z Rotat...
6	A1	0	0	0	0	0	0
6	B1	0	0	0	0	0	0
6	C1	0	0	0	0	0	0
6	A1.3	0	0	0	0	0	0
6	B1.3	0	0	0	0	0	0
6	C1.3	0	0	0	0	0	0
6	A2	0	0	0	0	0	0
6	B2	0	0	0	0	0	0
6	C2	0	0	0	0	0	0
6	D2	0	0	-35.038	-1.184e+	-4.174e-0	0
6	A2.3	0	0	0	0	0	0
6	B2.3	0	0	0	0	0	0
6	C2.3	0	0	0	0	0	0
6	D2.3	0	0	0	0	0	0
6	A2.67	0	0	0	0	0	0
6	B2.67	0	0	-7837.97	0	6.409e+01	0
6	C2.67	0	0	-7837.97	0	-6.409e+0	0
6	D2.67	0	0	0	0	0	0
6	A3	0	0	0	0	0	0
6	B3	0	0	0	0	0	0
6	C3	0	0	0	0	0	0
6	D3	0	0	0	0	0	0
6	A3.5	0	0	-18.883	0	6.572e+	0
6	B3.5	0	0	-8368.413	0	6.619e+01	0
6	C3.5	0	0	-8368.413	0	-6.619e+0	0
6	D3.5	0	0	-18.883	0	-6.572e+	0
6	A4	0	0	0	0	0	0
6	B4	0	0	0	0	0	0
6	C4	0	0	0	0	0	0
6	D4	0	0	0	0	0	0
6	A4.3	0	0	-74.874	1.886e+	1.295e+01	0
6	B4.3	0	0	-8921.174	1.886e+	6.822e+01	0
6	C4.3	0	0	-8921.174	1.886e+	-6.822e+0	0
6	D4.3	0	0	-74.874	1.886e+	-1.295e+0	0
6	A4.67	0	0	-74.874	-1.886e+	1.295e+01	0
6	B4.67	0	0	-8921.174	-1.886e+	6.822e+01	0
6	C4.67	0	0	-8921.174	-1.886e+	-6.822e+0	0
6	D4.67	0	0	-74.874	-1.886e+	-1.295e+0	0
6	A5	0	0	0	0	0	0
6	B5	0	0	0	0	0	0
6	C5	0	0	0	0	0	0
6	D5	0	0	0	0	0	0

Table 8: Joint Deflection results for Structural Design of First Floor for the Beam Distributed Live Load. Deflection in the given direction X, Y, Z.

Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
A1	0	-40.157	57.583	-12.401	-65.858	-65.858
B1	0	-40.157	77.661	0	8.413	65.858
C1	0	0	54.93	-12.401	57.444	0
A1.3	0	0	75.009	0	-65.858	0
B1.3	0	0	77.661	0	8.413	0
C1.3	0	0	72.356	0	57.444	0
A2	0	0	70.969	5.084	-65.858	0
B2	0	0	77.661	0	8.413	0
C2	0	0	103.683	29.17	-44.872	0
A2.3	0	0	66.928	0	-65.858	0
B2.3	0	0	77.661	0	8.413	0
C2.3	0	0	77.661	0	-8.413	0
D2.3	0	0	111.876	123.34	83.593	0
A2.67	0	0	144.59	0	-566.903	0
D2.67	0	0	144.59	0	566.903	0
A3	0	0	139.223	-118.564	-345.152	0
B3	0	0	77.661	0	8.413	0
C3	0	0	77.661	0	-8.413	0
D3	0	0	139.223	-118.564	345.152	0
A4	0	0	276.813	-197.606	-895.666	0
B4	0	0	70.661	0	8.413	0
C4	0	0	70.661	0	-8.413	0
D4	0	0	283.813	-197.606	895.666	0
A5	0	0	198.133	323.487	-616.371	0
B5	0	0	77.661	0	8.413	0
C5	0	0	77.661	0	-8.413	0
D5	0	0	198.133	323.487	616.371	0
Totals:	0	-80.314	2978.127			
COG (ft):	X: -17.173	Y: 46.223	Z: 0			

Table 9: Joint Reaction results for the First Floor for the Beam Distributed Live Load.

With the information from the structural analysis of hand calculations, the information was placed in the general truss generator on RISA-3D. When this was done, a scissor truss with webbing was initially designed in Figure 17. However, it was not able to be designed in RISA-3D due to constraints due to time and ability. A similar truss had generated as shown in Figure 29. It was designed with the constraints in the truss builder. The load combinations were generated from RISA-3D, as in Table 10. The basic load combinations are shown in Figure 30.

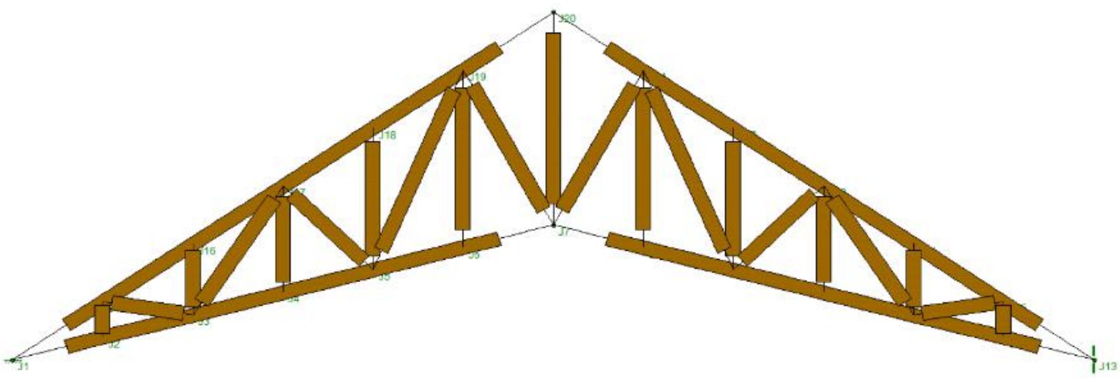


Figure 29: Roof Truss Version 1.

	Description	Sol...	PDelta	SRSS	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	Deflection 1	☑	Y		DL	1								
2	Deflection 2	☑	Y		LL	1								
3	Deflection 3	☑	Y		DL	1	LL	1						
4	IBC 16-1	☑	Y		DL	1.4								
5	IBC 16-2 (a)	☑	Y		DL	1.2	LL	1.6	LLS	1.6	RLL	.5		
6	IBC 16-2 (b)	☑	Y		DL	1.2	LL	1.6	LLS	1.6				
7	IBC 16-3 (a)	☑	Y		DL	1.2	RLL	1.6	LL	.5	LLS	1		
8	IBC 16-3 (b)	☑	Y		DL	1.2	RLL	1.6	WL	.5				
9	IBC 16-3 (d)	☑	Y		DL	1.2	WL	.5						
10	IBC 16-4 (a)	☑	Y		DL	1.2	WL	1	LL	.5	LLS	1	RLL	.5
11	IBC 16-4 (b)	☑	Y		DL	1.2	WL	1	LL	.5	LLS	1		
12	IBC 16-6	☑	Y		DL	.9	WL	1						
13	IBC 16-5	☑	Y		DL	1.2	EL	1	LL	.5	LLS	1		
14	IBC 16-7	☑	Y		DL	.9	EL	1						

Table 10: Roof Truss Version Load Combinations.

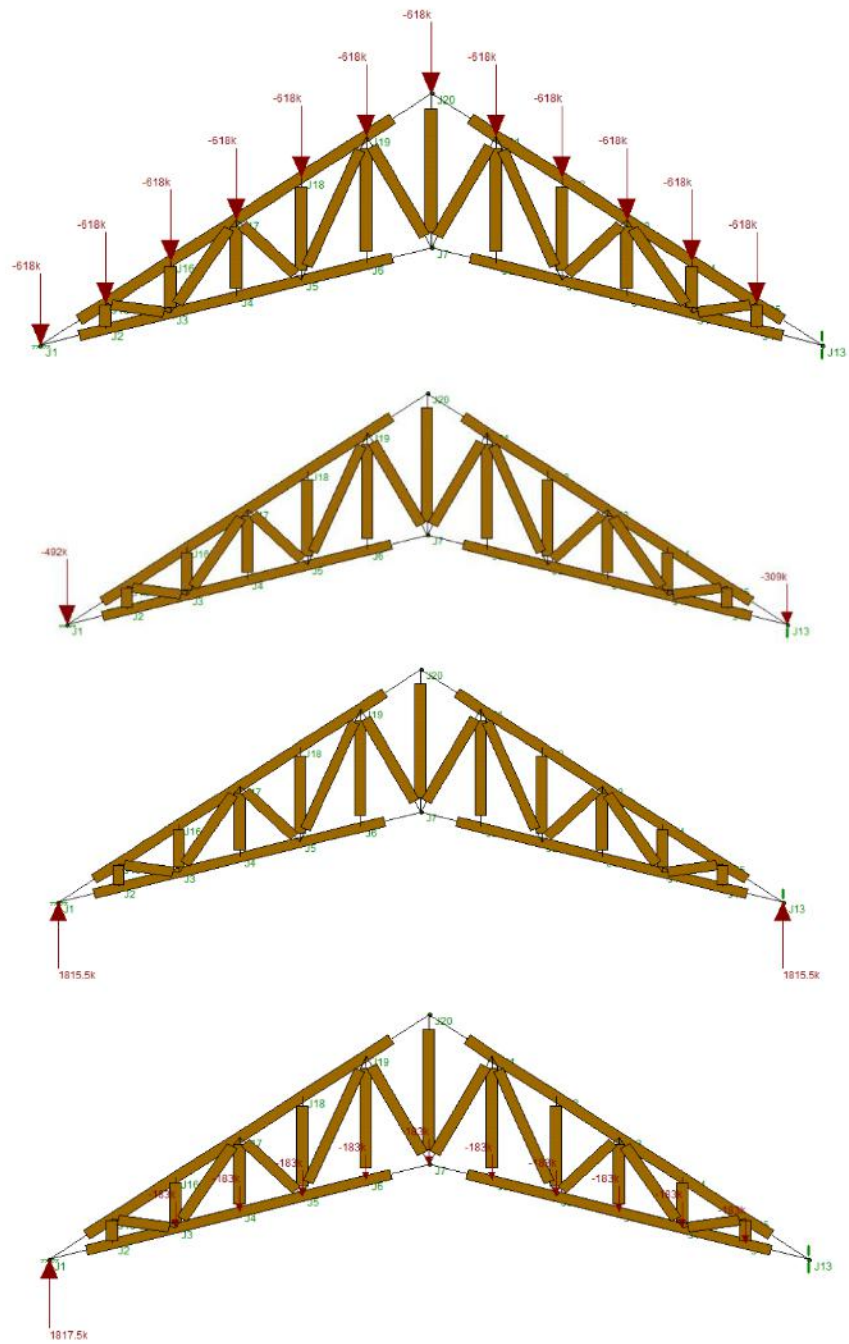


Figure 30: Loading of Roof Truss Version 1.

The analysis came back incomplete as the same trouble came as it was determined unstable due to mislabeled members. When trouble shootings and relabeling the members, the software did not output anything different from this change, this is a result of the experience of the team on RISA-3D.

The team then reevaluated the truss design and created a design that follows the truss generator. The truss generator was filled out as follows in Figure 31, generating the model in

Figure 32. Load combinations were added similarly to those of Figure 22 on the joints. The output released the same trouble as previously deemed the system unstable.

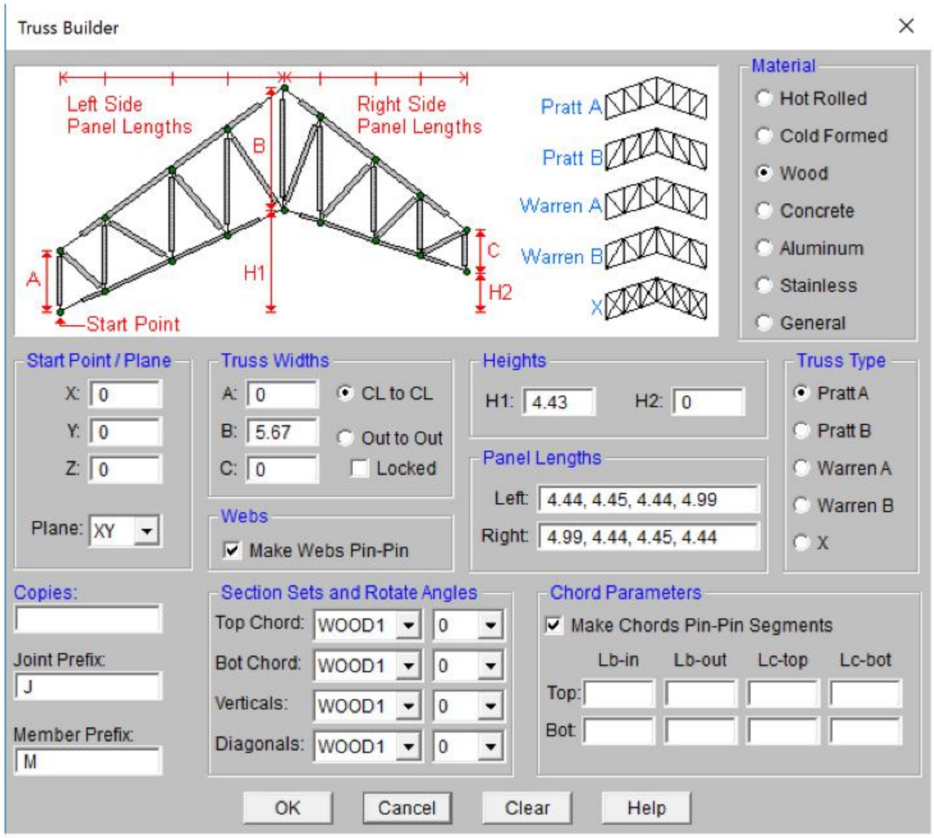


Figure 31: Roof Truss Version 2 Truss Builder.

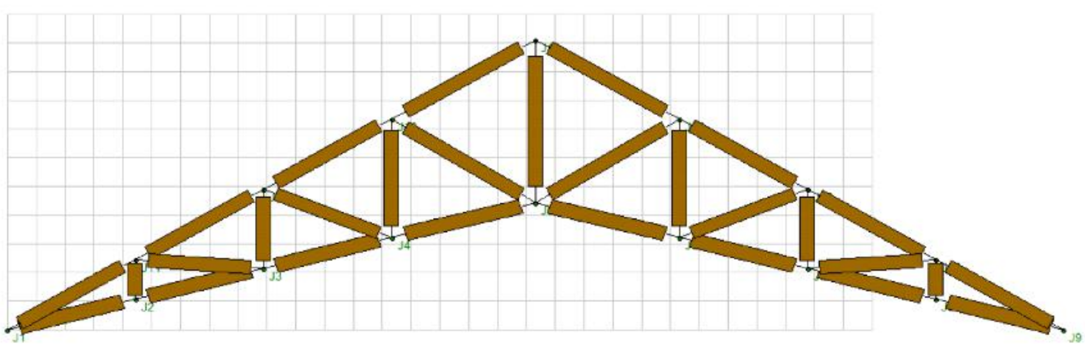


Figure 32: Roof Truss Version 2 RISA-3D Generated.

5.4 Objective 4 - Conduct an approximate cost estimate of the energy system and provide recommendations for cost analysis of the structure.

A cost analysis of the dormitory structure was determined using Excel, and the information provided in the *RSMeans Building Construction Costs* textbook. Using the structural design, the building was broken down into the components that will significantly increase the cost of the building. Demolition is the first cost that was examined. A small, wood building exists on the reserve, which was estimated that it would cost around $5,875 to demolish. The foundation was the first part of the building structure that was looked at. In the foundation, the concrete slab's cost for the floor and the concrete footings were calculated. Looking closer at the building's wood aspects, the cost of beams, columns, and joists were calculated using a typical beam size of straight, glulam wood, 5 1/8 in by 19 ½ in. The total number of members was counted to be used for the cost of the lumber. The cost of wood stairs was factored in, along with the doors, windows, floors, and furnishing. The building's cost of material was calculated to be around $75,456, which converts to 420,331 Brazilian real. This does not include labor costs.

For the energy system, there will need to be at least 380.6 ft of 1" pipe (116 m of 2.54 cm pipe). For 10 ft, this galvanized steel piping is $20.17 at *Home Depot*. For the total distance, this would be about $787. The length of the condenser was estimated to be .35 m, where both four 5" pipes and one 16" pipe were calculated. Using pricing from *MSC Direct*, this would amount to a total of $61. The pumps using about 5 kW of power each can have costs that vary greatly, as seen in *Pump Catalog*. An estimate is that an additional $800 can be set aside for this. As for the parabolic solar troughs, when using the same troughs that gave the estimation of an area of 72 m^2, the estimated two units needed would cost around $13,200 *(Gaia Solar, 2020).* An example found of an industrial-sized 50 kW turbine from *ACME Tools WINCO Generac*, and a generator to hold the energy produced, costs about $15,000 (*WINCO, 2020*). Safety equipment and extra supplies such as power inverters, batteries, and grounding equipment, as well as extra piping in-between all of the subsystems, can add $6,000. Before construction and site preparation costs, and based on this research, the energy system's cost estimation is $40,848, which is 225,910 Brazilian real.

The team drafted an energy system designed to utilize both the sun's power and the rainforest water located on the property. Solar troughs heat water as the working fluid in a 1 inch (2.54 cm) pipe. This 1 inch pipe then runs to a steam turbine, where the turbine's work will be the energy producing subsystem. Once exiting the turbine, the pipe will run through a counter-flow condenser to restore the original pressure and temperature. The counterflow fluid will be pumped from the water source. When the process is complete, the water will go back through the solar troughs to ensure continuity in the calculations and characteristics. This process is illustrated in Figure 33. Table 11 represents a summary of essential variables during the process, of which are defined in Table 12.

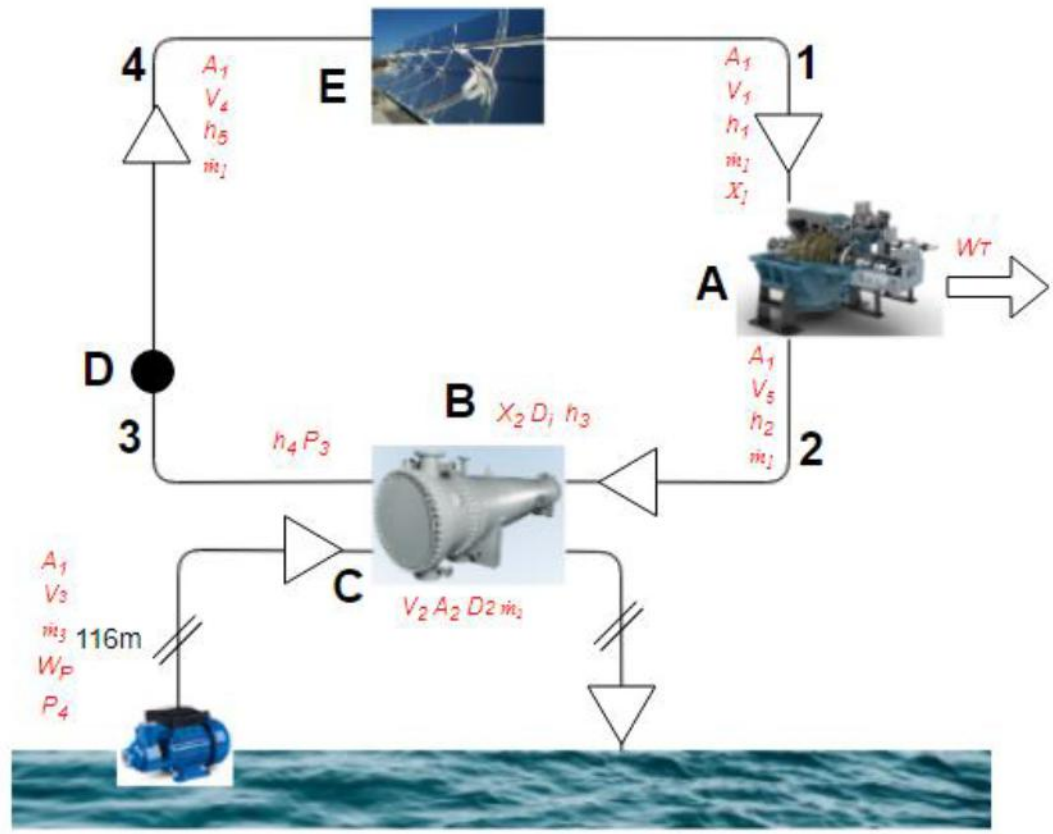


Figure 33: Overview energy system; Water piped and heated through solar troughs (E), continues through a steam turbine (A) to extract thermal energy, is condensed back to original conditions (B), with the help of water from the property (C) and repeated in a looped process across pipes 1-4 *(Natura EcoEnergy, 2020, Siemens 2020, DHT, 2020)*. Figure 11: Overview energy system; Water piped and heated through solar troughs (E), continues through a steam turbine (A) to extract thermal energy, is condensed back to original conditions (B), with the help of water from the property (C) and repeated in a looped process across pipes 1-4 *(Natura EcoEnergy, 2020, Siemens 2020, DHT, 2020)*. Important variables are shown in red.

1: Piping H_2O @350^{oC}, 30 bar $\dot{m}_1 = .058\frac{kG}{s}$ $\rho = 15\frac{kG}{m^3}$ $V_1 = 8.54\frac{m}{s}$ A_1 = 1" pipe = $4.5*10^{-4}$ m $D_o = .033$m $D_i = .024$m	**2: Piping** H_2O @40^{oC} $\dot{m}_1 = .058\frac{kG}{s}$	**3: Piping** A_1 = 1" pipe = $4.5*10^{-4}$m $D_o = .033$m $D_i = .024$m $\dot{m}_1 = .058\frac{kG}{s}$
4: Piping A_1= 1" pipe = $4.5*10^{-4}$m $D_o = .033$m $D_i = .024$m	**A: Steam Turbine** $h_1 = 3116.1\ \frac{kJ}{kG}$ $h_2 = 2361.45\ \frac{kJ}{kG}$ $X_1 = .911$ $s_1 = 6.5412\frac{kJ}{kGK}$ W_T = 44KW	**B: Condenser** $h_3 = 2361.45\ \frac{kJ}{kG}$ $h_4 = 167.53\ \frac{kJ}{kG}$ $V_5 = 9.43\frac{m}{s}$ 1 pipe; 16" $D_{o1} = .4064$m $D_{i1} = .373$m
C: Water Pump $V_3 = .13\frac{m}{s}$ H_2O @ 20^{oC} $\dot{m}_3 = 1.522\frac{kG}{s}$ 4 pipes; 5" $D_{O2} = .141$m $D_{i2} = .122$m $\dot{m}_2 = .0145\frac{kG}{s}$ $V_2 = .0012\frac{m}{s}$ ΔP_4 = 1.55MPa Pumping Power from Water Pump = 4.6KW $\Delta P_3 = 8.5*10^{-5}$Pa $L_B = .35$m	**D: Possible Cooling Device** Cooling device to bring down the fluid temperature from 40^{oC} → 20^{oC} to ensure continuity in the loop.	**E: Solar Trough Assembly** Aperture area needed: 145m^2 Using collectors with $A_{ap} = 72m^2$ Two panels $L_E = 24$m $h_5 = 83.92\frac{kJ}{kG}$

Table 11: Overview of variables; Each title of the table cell corresponds to a location in the system, with numbers being piping and connections, and letters being subsystems. Nomenclature is defined in Table 14 below.

	Units	Terminology
W_x	Kilowatts	Work of the subsystem X where X can be a turbine or pump
$\dot{m}$	Kilograms/ second	Mass-flowrate of: The looped cycle, the condenser fluid
h	Kilojoules/ Kilogram	Specific enthalpy of the working fluid; where h_f is at a quality of 0 and h_g is at a quality of 1.
S	(Kilojoules/kgram) per K°	Entropy of the working fluid, where s_f is at a quality of 0 and s_g is at a quality of 1.
ρ	Kilograms/ $meter^2$	Density of the fluid
n	unitless	Efficiency of the referenced subsystem
X	% vapor	Quality: Mass fraction of vapor in a fluid
A	$meters^2$	Cross-sectional area of the inner pipe
V	meters/ second	Velocity of the working fluid
$\dot{Q}$	$meters^3$/ second	Volumetric flow-rate
C_p	(Joule/ gram) per C°	Specific heat of the working fluid
D_x	meters	Diameter where x refers to nominal or inner (i) and outer (o)
Re	unitless	Reynolds number of the working fluid
ν	$meter^2$/ second	Kinematic viscosity of the working fluid
Pr	unitless	Prandtl number of the working fluid
μ	Pascal- second	Dynamic viscosity of the working fluid
k	Watts/ meter K°	Thermal conductivity of the working fluid
Nu	unitless	Nusselt number of the working fluid
P	Pascals	Pressure
L	meters	Length
ε	meters	Absolute roughness
~		The following value is the result of an assumption

Table 12: Nomenclature of energy system calculations.

To begin calculations on the system, the team assumed the dormitory and multifunctional space would use the same amount of energy as three average American homes *(Electric Choice, 2017).* This assumption was derived from the idea that the amount of energy required should satisfy all basic needs. In contrast, over-consumption of energy would reduce the reserve's sustainability. The team aimed to encourage people to live naturally, instead of being consumed by electronics and overuse of energy. To accommodate these boundaries, about 11 kWh per year for a house was determined to be an adequate amount of energy *(Electric Choice, 2017).* Other contributing factors, such as the subsystems and solar panels' inefficiencies, were considered and added in the average energy that the pumps themselves would consume. Taking all of this into account, the team finalized a decision, settling on 44 kWh to accommodate basic needs within reason.

Average sunlight hours and average shortwave solar energy per square meter were researched and calculated for Itacaré (*Weather Spark, 2017).* The median value of sunlight hours was determined to be twelve hours of sunlight. The average monthly solar irradiance is shown in Table 13 (*Weather Spark, 2017).* From this, it was possible to calculate the yearly average solar energy 6.05$\frac{kW\,hr}{m^2}$/ day by dividing the daily average by the number of hours of sunlight per day 12 $\frac{hrs\ sunlight}{day}$. This was used to calculate the area of PV panels needed.

Monthly Average Daily Incident Shortwave Solar Energy per m^2 *(Weather Spark, 2017*)	
Month	Incident Shortwave Solar Energy in ($\frac{kW\,hr}{m^2}$ $\frac{kW\,hr}{m^2}$) /day
January	6.9
February	6.8
March	6.35
April	5.75
May	5.1
June	4.7
July	4.9
August	5.6
September	6.3
October	6.7

Table 13: Monthly Average Daily Solar Energy

Assuming operation during daylight hours and using this measurement to figure out what the area of the panels needed is : (44kW)(12 hr) = .528$\frac{kW\,hr}{day}$. To get the area of PV needed, the energy needed is divided by the energy made.

Area of PV needed is

$$\frac{amount\ of\ energy\ needed}{(efficiency)(amount\ of\ energy\ made\ per\ day)} = \frac{528\,\frac{kW\,hr}{day}}{(.15)\ 6.05\,\frac{kW\,hr}{m^2}} / \text{ day} = 581\ m^2 \text{ of PV}$$

This area is to be divided by 4 to account for the curved aperture area of parabolic panels: $\frac{581\ m^2}{4}$ = 145 m^2 A_{ap}

Various solar collecting troughs are manufactured and available to purchase, with fluctuating areas and lengths to choose from. Some examples of these include 69.12 m^2 (742 ft^2), 72 m^2 (775 ft^2), and 15.3 m^2 (164 ft^2) *(Gaia Solar, 2020).* To cut down on the installation space required, the team chose to incorporate solar panels with the largest surface area with an assumption of 72 m^2 (775 ft^2) per unit, where each unit is 12 m (39.3 ft) long. The sponsors would need to purchase two units to satisfy the assumed energy needs of 44 kWh.

When considering the system's thermodynamic principles, an assumption of the steam's inlet characteristics into the turbine was made. While typical turbines powered by coal operate with inlet temperatures of up to 800°C (1472°F), steam turbines powered by renewable sources operate at temperatures of even under 400°C (752°F). The team assumed an inlet temperature of 350°C (662°F) and a pressure of 30 bar. Turbines follow isentropic processes, which help find the percent vapor and flowrate of the working fluid needed. In steam turbines, there needs to be a certain percent of vapor in the incoming mixture. To find this, the team used thermodynamic values of the assumed input value of both the saturated liquid and saturated vapor states and found the fractions of vapor for real enthalpy and state 2S enthalpy, which accounts for inefficiencies. In addition, the efficiency of the turbine can be taken into account with these calculations to have the efficiency equal to the difference of input enthalpy with real enthalpy to input enthalpy and state 2S enthalpy with inefficiencies.

Quality of the turbine:

$X_1 = \frac{S - S_f}{S_g - S_f}$

$\sim n = .7 = \frac{h_1 - h_2}{h_1 - h_{1-2S}}$; h_1 = 350°C, 30 bar

$X_{1\text{-}2S} = \frac{S\ @\ 350\,°C, 30\ bar - S_f\ @40\,°C}{S_g @\ 40\,°C - S_f @\ 40\,°C} = \frac{6.5412\,\frac{kJ}{kG}K - .5724\,\frac{kJ}{kG}K}{8.25\,\frac{kJ}{kG}K - .5724\,\frac{kJ}{kG}K} = .777$

$X_{1\text{-}2S} = \frac{h_{2S} - h_f @ 40\,°C}{h_{fg} @ 40\,°C} = .777 = \frac{h_{1-2S} - 167.53\frac{kJ}{kG}}{2406\,\frac{kJ}{kG}}$

$h_{1\text{-}2S} = 2038.03\,\frac{kJ}{kG}$

$n = .7 = \frac{3116.1\,\frac{kJ}{kG} - h_2}{3116.\frac{kJ}{kG} - 2038.03\,\frac{kJ}{kG}}$

$h_2 = 2361.45\,\frac{kJ}{kG}$

$X_1 = \frac{2361.45\,\frac{kJ}{kG} - h_f @ 40\,°C}{h_{fg} @ 40\,°C} = \frac{2361.45\,\frac{kJ}{kG} - 167.53\frac{kJ}{kG}}{2406\,\frac{kJ}{kG}} = .911$

With the result of the steam turbine having a quality of 91% vapor, this is a high enough value for the operation. With the temperature and pressure characteristics, there should be no material failure, either.

In terms of the piping into the turbine, when dividing the expected turbine work by the enthalpy change across the subsystem, the needed flowrate to meet these conditions is found. $W_T = \dot{m}_1(h_2 - h_1)$, $44\text{ KW} = \dot{m}_1(2361.45\,\frac{kJ}{kG} - 3116.1\,\frac{kJ}{kG})$. Where $\dot{m}_1 = .058\,\frac{Kg}{S}$. The velocity of this input is found with $\dot{m}_1 = \rho v A_1$; with ρ @350 °C, 30 bar (*ThermExcel, 2003),* inside 1 in pipe: $A_1 = \pi\frac{.024m^2}{2}$; $V_1 = 8.54\,\frac{m}{s}$.

The output enthalpy, flow rate, and working fluid velocity helped the team design a condenser, as seen in Figure 34 (pg. 30). The distance from the water where the energy system will be placed was found using Google Maps to be about 116 m (380.6 ft). Upon speaking with the sponsors, the team was informed that the water temperature fluctuates between 12°C (53.6°F) and 25°C (77°F). As for the looped water in the cycle, when exiting the turbine as saturated liquid at $40^{°C}$, the equation $\dot{Q} = \dot{m}_3\Delta h_{f3} = \dot{m}_3 C_p \Delta T$ was applied to get a mass flow rate of pumped water. The water pump flowrate ($\dot{m}_3$) in the opposite flow of cycle in the condenser was calculated as follows:

$.058\,\frac{kG}{S}\,(h_3 - h_f @ 40^{°C}) = \dot{m}_3(4.18\frac{J}{gram\ °C})(40^{°C}\text{-}20^{°C})$; where h_3=h_2; h_2= $2361.45\frac{kJ}{kG}$

$X_2 = \frac{h_2 - h_f @ 40\,°C}{h_{fg} @ 40\,°C} = \frac{2361.45\,\frac{kJ}{kG} - 167.53\frac{kJ}{kG}}{2406\,\frac{kJ}{kG}} = .911$

$.058\frac{kG}{S}(2361.45\frac{kJ}{kG}\text{-}167.53\frac{kJ}{kG}) = \dot{m}_3(4.18\frac{J}{gram\ °C})(40^{°C}\text{-}20^{°C})$

$\dot{m}_3 = 1.522\,\frac{kG}{S}$

A temperature of 20°C (68°F) was assumed for water being pumped to cool the cycle water, and the team also kept the baseline temperature of water in the cycle as 20°C. Another critical assumption was to presume little to no flow in the water source; the water is relatively stagnant. In quantitative terms, a small assumed flow that worked turned out to be about .13 $\frac{m}{s}$ (.43 ft/s). The original assumption calculation for this value included pugging in .1$\frac{m}{s}$ into $\dot{m}_3=\rho V_2 A_2$, and calculating backward for a real pipe size to be used and accommodate the results.

Calculate backward for pipe size: $\dot{m}_3=\rho V_2 A_2$

$1.522\frac{kG}{S}= (997\frac{kG}{m^3})(.1\frac{m}{S})(\frac{\pi}{4}*D_i^2)$

D_{i2}=.1394m → 5.48in → 5" pipe. (*USA Industries, 2020)*

D_{i2}= 4.813in → .122m

D_{o2}=5.563in → .141m

Once these pipe sizes were known, the backward calculation was continued to get the actual velocity that would work, and not an assumed one, using the same equation as before. To get the actual V_2 with the real pipe of A_2, the team performed the same calculation again.

$1.522\frac{kG}{S}=(997\frac{kG}{m^3})V_2(\frac{\pi}{4}*.122m^2)$; $V_2=.13\frac{m}{S}$.

This velocity will be flowing counter the post-steam in the condenser. The post steam will need to be in a big enough pipe on the outside for the flow-rate and pressure to fit within the process's thermodynamic constraints and hold a certain amount of the 5 inch pipes inside of it. For this reason, the following calculations were performed where the inner area multiplied by an unknown variable to be solved for was subtracted from the outer area, and this should equal the flow-rate of the post-steam in that outside area.

The number of pipes (N) of D_1 to fit in D_2 is calculated by:

$\pi\frac{D_{i1}2}{2}$- $\pi\frac{D_{O2}2}{2}$ (X) =$\dot{m}_1$

D_1 = 16" where: (*USA Industries, 2020)*

D_{o1}=16" → .4064m

D_{i1}=15.688" → .373m

$\pi\frac{.373m_2}{2}$-$\pi\frac{.141m_2}{2}$ (X) =.058$\frac{kG}{S}$; X=3.28 → 4 pipes.

.058$\frac{kG}{S}$ ÷ 4 = .0145$\frac{kG}{S}$ per pipe.

$\dot{m}_2=\rho V_2 A_2$

.0145$\frac{kG}{S}$=997$\frac{kG}{m^3}$ $\pi\frac{.122m_2}{2}$(V_2)

V_2=.0012$\frac{m}{S}$

Now, the velocity for each of the 5" pipes is known. Figure 34 (pg. 61) shows a schematic. In the condenser, a 16 inch pipe (0.4 m) will hold the post-turbine steam, with four 5 inch (0.127m) pipes of cooling water inside this pipe running in the opposite direction. The calculations were done to make the cooled cycle water come out of the condenser at about 40°C (104°F). The velocity of this steam can also be found, applying the same equation set and incorporating the quality of the turbine to get the output specific volume.

$$.911 = \frac{v - .001008\frac{m^3}{kG}}{19.515\frac{m^3}{kG} - .001008\frac{m^3}{kG}};\ v = 17.77\frac{m^3}{kG}$$

$$.058\,\frac{kG}{s} = \frac{V_5(\pi)\frac{D_{11}}{2}^2}{v} = \frac{V_5(\pi)\frac{.373}{2}^2}{17.77\frac{m^3}{kG}}$$

$$V_5 = 9.43\,\frac{m}{s}$$

Location D in Figure 33 (pg 33) is a placeholder for how the sponsors would like to cool this water further back to 20°C, whether that be an air-cooling device or a cooler powered by a generator. Pressure drops were considered across the system and can be seen at different locations in the system.

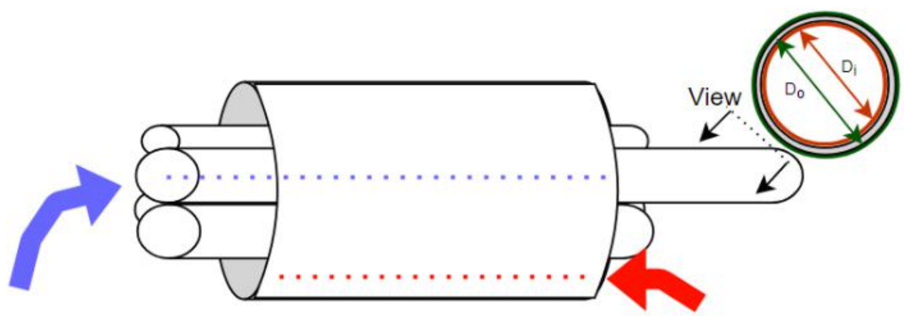


Figure 34: Schematic of the condenser design where water from the rainforest reserve, symbolized in blue, is a valuable component of the energy system. The red arrow and line symbolize the hotter working fluid that came out of the turbine and needs to be cooled before being cycled back again. The D_i/D_o cross sectional diagram shows how piping diameters were referenced.

A fluid flow analysis process was followed by finding the Reynolds, Prandtl, Nusselt, and heat transfer coefficient values to get the length and pressure drop across the condenser. These unitless values have standard equations:

$$Re = \frac{VD}{v};\ v\ H_2O\ @20^{\circ C} = \frac{(.0012\frac{m}{s})(.122m)}{1.004 * 10^{-6}\frac{m^2}{s}} = 14.58$$ *(Engineers Edge, 2020)*

$$Pr = \frac{\mu C_p}{k}\ \text{for}\ H_2O\ @20^{\circ C} = \frac{1.002 * 10^{-3}\frac{Ns}{m^2}(4.182\frac{J}{gram\ {}^{\circ}C})}{.6\frac{W}{mK}} = 6.98$$

Nu # *laminar flow* $= .332(Re)^{.5}(Pr)^{.33}$; $.332(14.58)^{.5}(6.98)^{.33} = 2.407$

$Nu = \frac{hD}{k};\ 2.407 = \frac{h(.122m)}{.6\frac{W}{mK}}$; $h = 11.83\ \frac{W}{m^2\ {}^{\circ}C}$ *heat transfer coefficient*

The next step was to find the only unknown value of length.

$\dot{Q} = \dot{m}_2 \Delta h_{43} = h\pi D_{i2} L_B \Delta TN$; where h_4 is h_f@40°C

$.0145\frac{kG}{S}(2361.45\frac{kG}{S}-167.53\frac{kG}{S})=(11.83\frac{W}{m^2\ \circ C})\pi(.122m)L_B(4)(5^{\circ C})$

$L_B=.35m$

These calculations further concluded that the condenser would only need to be about .35 m (1.15 ft) long, but with testing and further analysis, perhaps adding length to this condenser will replace the need for an extra cooling device at location D.

To find this process's work, the change in pressure across the condenser is needed because this will lead to the adjusted output enthalpy value.

$\Delta P_B=f\frac{L_B}{D_{i2}}\frac{\dot{m}}{A_2}V_2$

f: $\frac{\varepsilon}{D}=\frac{.15*10^{-3}}{.122m}=.001$, with Re of 14.58. Reference Moody Diagram; f=.02

$\Delta P_B=.02\frac{.35m}{.122m}\frac{.0145\frac{kG}{s}}{\pi\frac{.122m^2}{2}}.0012\frac{m}{s}$

$\Delta P_B=8.5*10^{-5}$ Pa, which is negligible.

P_3:

P_{SAT}@20°C → 2.34kPa → 2340Pa

2340Pa-$8.5*10^{-5}$ Pa = .02 bar @20°C

$W_P=\dot{m}_1(h_4-h_5)$

$h_4=h_f$@40°C$=167.53\frac{kJ}{kG}$

$h_5=H_2O$@20C°C$= 83.92\frac{kJ}{kG}$

$W_P= .058\frac{kG}{s}(167.53\frac{kJ}{kG}-83.92\frac{kJ}{kG})$

W_P= 4.85 KW. Overestimation of power needed accounts for this value.

The pumping power energy needed to move the working fluid from the condenser to the solar troughs is 4.85 kW. Now, the pumping power for the water being pumped up is found.

Pumping water up to the condenser:

~ $V_2=.13\frac{m}{s}$

$\dot{m}_3=1.522\frac{kG}{s}$

$\dot{m}_3=\rho V_2 A_1$ ~ where A_1 is a one-inch pipe

$1.522\frac{kG}{s}=997\frac{kG}{m^3}(V_2)(\pi\frac{.024m}{s}{}_2)$

D_{03}=1.315 in → .033 m

D_{i3}=.957 in → .024 m

$V_2=3.37\frac{m}{s}$

A$_1$=$\frac{Q}{V_2}$; $\pi\frac{.024m}{2}_2 = \frac{Q}{3.37\frac{m}{s}}$

Q=.0015$\frac{m^3}{s}$

Re= $\frac{4Q}{\pi D_{i3} v} = \frac{(4).0015\frac{m^3}{s}}{\pi(.024m)(.9*10^{-6}\frac{m^3}{kG})}$ = 88419 turbulent

f: $\frac{\varepsilon}{D} = \frac{.15*10^{-3}}{.024m}$ =.00625, with Re of 88419. Reference Moody Diagram; f=.055

h$_L$= f$\frac{L_{Distance}}{D_{13}}\frac{V^2}{2g}$= .055 $\frac{116m}{.024m}\frac{3.37\frac{m^2}{s}}{19.62}$=153.8 m

$\Delta P_4 = \rho g h_L$ =(997$\frac{kG}{m^3}$)(9.81$\frac{m}{s^2}$)(158.8m)

ΔP_4= 1553895Pa = 1.55MPa

Pumping power = $\frac{\Delta P_4 Q}{n_p} = \frac{(1.55*10^6 Pa).0015}{.5}$= 4661W = 4.6 KW.

The pumping power needed to bring the water up to the condenser is 4.6 kW. The sum of these values fits the team's initial estimation of needing to account for additional power that will be taken up by subsystems to operate themselves. This energy cycle's efficiency can be found by applying the equation for the Rankine cycle efficiency seen below. The efficiency of this designed system is .27, which is satisfactory.

$$n = \frac{(h_{into\ the\ turbine} - h_{into\ the\ condenser}) - (h_{into\ the\ collector} - h_{out\ of\ the\ condenser})}{(h_{into\ the\ turbine} - h_{into\ the\ collector})};$$

$$n = \frac{(h_1 - h_2) - (h_5 - h_4)}{(h_1 - h_5)}$$

6.0 Recommendations and Conclusions

Considerations of both the structures and energy systems are interconnected and essential to the development of the project site as a whole. Sustainability and efficiency were a top priority during the analysis of this project work. The group acknowledged the location's economic, social, and environmental needs to create a long-lasting and sustainable design. On the reserve, the project impacted the sponsor's ability to accommodate visitors and sustainably produce power. The designs created are easily adaptable for the sponsor to expand the reserve's residential area in the future if they feel necessary.

6.1 Objective 1- Devise a site layout and architectural floor plan inspired by the project sponsors' wants and needs for the reserve.

The multifunctional center was designed to allow visitors to learn more about the reserve and have a space to congregate or participate in events planned. On one end of the multifunctional center, an area with a stage was designed for the sponsor to use for lectures, gatherings, or educational programs based on their interior decoration. The surrounding natural beauty of the reserve inspired the open concept incorporated within the multifunctional center. Inside, men's and women's locker rooms exist to allow guests not residing in the dormitories to have access to bathroom amenities. The project sponsor requested this area be versatile; as space where visitors could learn more about the sponsor's mission on the reserve, as a gift shop, as a library, and as a possible meeting area.

The dormitory incorporates many spaces including bedrooms, a kitchen, an eating area, an office space, a storage space, and a laundry room. Eight bedrooms were designed with adjoining bathrooms between each pair of rooms. A communal kitchen provides an area where food can be served and eaten outside on an outdoor deck, encouraging people to enjoy and embrace the outdoors. Upstairs, a study was placed where meetings and research could be done, with one wall being extremely open, to help people who are utilizing that space to stay connected to the natural essence of the reserve. Open air spaces such as the upstairs balcony allow visitors to enjoy the view and observe the surrounding ecosystem. This space was designed so that if the project sponsors wanted to expand later, additions could easily be applied.

The placement of the energy system was determined through discussions with the sponsor. Information regarding the dam on the reserve and the reservoir's flow and size were essential factors in the energy design.

6.2 Objective 2 - Design a building with the architectural floor plan and site layout, along with an energy system.

Transforming the architectural design to a structural design was achieved through formatting via Revit. The architectural design's dimensions were used to place columns and beams into a structural Revit drawing. The structural plan was designed to optimize the open space using a post and beam design for the sponsor, and primarily contained wood. This was achievable by placing columns at the corners and positioning joists and beams around those columns.

The energy system included a way to supply power to the building. Water heated to a high temperature with solar panels will pass through a small, industrial-sized steam turbine to produce electricity for the community through a generator. When the heated steam leaves the turbine, it will cool and cycle back through the heating system.

6.3 Objective 3 – Perform a complete analysis of the dormitory building and energy designs.

Design calculations were conducted for both buildings using the structural and architectural Revit models. Dead and live loading values were calculated along with the design, were uploaded into RISA-3D, therefore the size of the beams, columns, and joists could be calculated. All calculations pertaining to the structure were conducted in a top-down approach. The group began the structural analysis with the roof followed by the second floor and finally finished with the first floor. The design calculations were unable to be complete due to the experience within the group regarding the software RISA-3D. Various errors appeared throughout the analysis and while the team attempted to resolve these issues, many could not be solved due to the vast range in options on RISA-3D along with the overall complexity of the software.

The calculations were run and the team did receive results from the system, however, the results produced exponentially large values. The team had then attempted to adjust member sizes and load cases but nevertheless, errors were still produced. This led to the group not being able to determine sufficient member sizing, however, if more time was available, member sizing and could have been analyzed in more detail.

The calculations computed for the energy system were determined by considering important characteristics and assumptions for the area and using these values in equations to satisfy thermodynamic and fluid equation statements. The analysis of the overall system has a reasonable efficiency of 0.27, which is expected. The efficiencies of the subsystems would need more consideration when constructing this design as the team relied on assumptions where specifics were not provided. The calculations benefit the design most when the values used represent the exact attributes of the land and surroundings of the proposed system. One example of this is the distance the system is placed away from the water source. A more precise measurement of the actual terrain would be beneficial to construction. Suppose the fluctuation of water temperature or water flow is extreme. In that case, parallel calculations can be carried out with low and high values. Two systems are being constructed and operating when environmental conditions best match what the individual systems are suited for. Another aspect of the energy system is the solar panels, where the design is essentially the minimum energy that is likely to be used by the reserve. In practice, more panels should be placed to account for heat energy that may be lost, cloudy days, obstructions to direct sunlight such as trees, and more. Many constants used in heat and pressure calculations rely on minimal changes to water characteristics across pipe distances. The use of a more advanced analysis software, one that considers the fluctuations across subsystems, might be necessary before physical construction. Overall the calculations and assumptions are technically viable but not reliable.

6.4 Objective 4- Conduct an approximate cost estimate of the energy system and provide recommendations for cost analysis of the structure.

The cost estimate was produced for the sponsor for both the building design and energy system design. The building cost estimate accounted for the demolition of the current buildings and the new dormitory's construction. This cost was a rough estimate to give the sponsor an idea of what to expect. A similar cost analysis could be produced for the multifunctional center, and it would be useful for the sponsors to have an idea of the costs. The most important factors of the cost analysis are the materials used and labor. The energy system cost analysis was determined based on size and output. The energy requirements of the buildings were factored into the size of the system. The system's total cost depended on the overall size, length, and capacity of each subsystem. Additional cost analysts, such as safety equipment, is essential and was added to the estimate.

6.5 Recommendations

Due to the broad scope of this project, the team performed structural calculations solely for the dormitory facility as time would not allow for a complete and well done analysis of both structures designed for the reserve. The group recommends using the work that has been produced to create a similar analysis of the multifunctional center. Additional analyses of these structures could prove to be useful, as the analysis provided did not include accurate information for the region in Brazil that the facilities would be constructed. Once the sponsor has further knowledge of the site itself including the specifics for the structure, the group would recommend performing an in-depth analysis to get a more accurate cost estimation. A cost analysis is foreseen to be extremely useful for the project sponsors when attempting to solicit funding from different organizations for construction expenses. More comprehensive studies of the region surrounding the energy system, including a more precise estimate of the natural resources available, will be beneficial for pre-construction preparation. Prior to construction, a complete site analysis combined with the help from architects and professional engineers is recommended for the project sponsor in order to produce a safe and cost efficient addition to the reserve.

7.0 Design Statement

According to the Accreditation Board for Engineering and Technology (ABET), engineering design is a necessary component of the engineering curriculum for students to be thoroughly equipped for engineering practice. The design at hand was required to appeal to the sponsor's desired needs while also satisfying the different aspects of engineering standards and constraints. The design constraints this project addressed are economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

This Major Qualifying Project (MQP) focused on providing designs for two buildings, equipped with an energy system, for the nature reserve in Bahia, Brazil proposed by the project sponsors. Using the software Revit, multiple building designs were modeled to proceed with the structural design and analytical calculations for the dormitory. The reserves' energy system was designed and calculated to provide the sponsor with the project site's specifications. The location of the reserve, local resources, and the project's sustainability were all constraints of the design that needed to be addressed.

7.1 Environmental

Environmentalism is on the rise in modern-day infrastructure for the essential purpose of preserving the planet's longevity. Sustainability was a fundamental concern contributing to designing the buildings and energy system for the reserve in Brazil. To mitigate this project's environmental impact, the design incorporated locally sourced materials, limiting hazardous emissions associated with shipping. A renewable energy system was designed to harness power from the dam on the reservoir. This was designed to pump water from the dam to the water tank found closer to the buildings, where the sponsors could use the water, as necessary. The environmentally conscious aspects of the project design meet LEED standards.

7.2 Social

The design was generated to focus on bringing people together on the reserve. The multifunctional space specifically inhibits the social goals of the project. The multifunctional center incorporates an amphitheater where reserve visitors can attend lectures or other social events such as concerts. A dormitory building was also designed to house guests of the reserve with a kitchen and eating space for the culinary congregation. Both building designs are heavily influenced by the sponsors' wishes to emphasize intermingling between guests.

7.3 Political

Since the buildings and energy systems are being placed onto a reserve, certain precautions must be taken. A particular area is to be used for buildings, as the sponsor could not clear more land due to the need to preserve the area to its most natural state. Wood from the reserve could be seen as a controversial topic if used for the buildings because of the reserve's ideals of preserving the environment. The restrictions of building on a reserve were taken into account by the group.

7.4 Ethical

International standards were followed to follow ethical obligations centered around producing a safe and quality design. The groups' moral commitment was to satisfy the project sponsors' desires, and thus the team prioritized conservation of the environment by limiting the building footprint on the reserve. The building's goal was to maintain a cost-efficient design while over-designing the structures as the team struggled to find specific Brazilian building codes. The safety of the reserve visitors and sponsors was the top priority when designing the structure.

7.5 Health and safety

Various health and safety restrictions were met throughout the project design. The team followed the International Building Codes (IBC) to ensure the structural integrity of the buildings. As the structural calculations were conducted, the team over-designed in any instance where there was a lack of critical design standards local to the project. The energy system was also ensured to supply clean water free of contaminants.

7.6 Manufacturability

Since the project was designed to adhere to the project sponsors' specific wants and needs, this MQP encompasses a strong sense of constructability. A simplistic design, coupled with locally available resources, has made the teams' design a realistic project sponsor option. The dormitory and multifunctional center can easily be implemented into the reserve as it features Brazilian-style architecture made from cost-efficient local materials.

7.7 Sustainability

Sustainability focuses on implementing environmental adjustments for longevity. Sustainable practices often reap social and economic benefits in a community as well. This project encompasses a lot of sustainable influences in the energy system design and site layout. The renewable energy source focuses on delivering water from the reserve to the designed facilities. The footprint of the buildings was restricted to limit the clearing of trees for the proposed buildings. The goal to benefit both the reserve as well as the environment was achieved with these concepts.

7.8 Economic

A cost analysis of the two-story dormitory building was conducted to provide the sponsors with an estimate of the project expenses. The cost estimate focused primarily on the cost of materials needed to build the structures. This review of expenses enhanced the team members' ability to comprehend realistic construction project expenses.

8.0 Professional Licensure Statement

While this project was developed to deliver a suitable design for Reserva Alto da Esperança, the implementation of the proposed plans would require the aid of Professional Engineers. To obtain status as a Professional Engineer, one must prove their high level of competence through years of rigorous work. Responsible for the safety and reliability of structures in their domain, only engineers with professional licensure may prepare, sign, seal, and submit drawings and other engineering work to the public authorities for approval. Obtaining accredited licensing has become a standard in today's' practice as official licensure regulates the profession through state authorities. Proper licensure ensures that said engineer will produce work backed by credible ethics and an authentic skillset. Those who aspire to work in upper management within the field of civil engineering should be prepared to seek appropriate licensure.

Qualification as a Professional Engineer is considered a significant milestone for any engineer as the process requires countless hours of dedication to a career in civil engineering. There are several steps that several steps must be taken in order to obtain licensure as a Professional Engineer. Aspiring candidates must first graduate with an engineering degree from a four-year university accredited by the Engineering Accreditation (EAC) and the Accreditation Board for Engineering and Technology (ABET). Following graduation, individuals must pass the industrious Fundamentals of Engineering (FE) exam, consisting of 110 questions spanned over 6 hours. The FE exam is offered for a range of engineering careers but consists of an assortment of topics including but not limited to statics, structural analysis, geotechnical engineering, fluid mechanics, and materials, to name a few. The FE exam also includes questions on ethics and professional practice, reinforcing these topics' importance.

After passing the FE exam, the individual is recognized as an Engineer in Training (EIT). EITs are expected to apprentice under one or more Professional Engineers for four added years to gain relevant experience in their desired discipline of civil engineering. Upon completing four years of apprenticeship, the EIT may register to take the Principles and Practice of Engineering (PE) exam. This is the final step in obtaining recognition as a Professional Engineer. The PE exam consists of 80 questions over 8 hours. Like the FE exam, the PE exam is offered for various engineering disciplines; however, those pursuing achievement in civil engineering will choose to complete the exam in one of the following categories: construction, water resources and environmental, geotechnical, structural, or transportation. Receiving a passing score on this exam will officially certify the candidate as a Professional Engineer in their respective state. Many states require PEs to continuously enhance their skills and knowledge through professional development programs, thus encouraging continual education.

Obtaining and maintaining professional licensure is no easy feat. The rigorous process tests an engineer's skill set and dedication to quality engineering over an extensive timeline. PEs must prove their ability to practice ethical and safe engineering as this title embodies a plethora of responsibilities and influential decisions. A PE license's credibility ensures that engineers are developing a quality product with public safety in mind. This MQP imitates the work completed by licensed professionals through designing and analyzing drawings, structural and mechanical calculations, and cost estimates. The team supplied a complete design and analysis suitable for Reserva Alto da Esperança; however, implementing the proposed design, review, and approval from a Professional Engineer is required before construction.

Receiving a professional license as a civil engineer is extremely important for a person's career. Licensed engineers are the only engineers allowed to prepare and submit engineering plans for approval *(NSPE, 2020).* Working with clients and the public means that professional engineers are responsible for those lives and must use intelligent and moral business practices. All personnel in charge of work legally must have professional licensure. Professional licensure's importance is continuing to increase, as more job positions are requiring professional licensure.

After receiving a professional license, professional engineers are required to maintain their status. These people must continue to improve their skills through professional development opportunities like web seminars, independent study, events, and educational courses. Continuing education is an important part of the engineers' process to stay updated with the latest practices and improve their skills.

Licensure is extremely important to the profession, to the individual, and the public. Becoming a professional engineer qualifies that an individual is held to a certain standard of dedication, quality, and skill. The Professional Engineering Exam licensure ensures that an individual has skills critical to the profession, commitment to the standards of engineering practices, and can offer engineering services. Professional engineers are held in high regard, and the title is important for professional development. Receiving a professional license proves to all groups that an individual has a quality understanding of civil engineering concepts.

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Design of a greywater garden and a pedestrian bridge for the Reserva Alto de Esperanca

A Major Qualifying Project Report

Submitted to the faculty of the Department of Civil Engineering at

Worcester Polytechnic Institute

in partial fulfillment for the requirements for the

Degree of Bachelor of Science

with Reserva Alto de Esperanca in Bahia, Brazil

Submitted October 16, 2020

Submitted By:

Spencer J. Hoagland

Project Advisors:

Dr. Aaron Sakulich

Abstract

For this project, a WPI student partnered with a sponsor in Bahia, Brazil to design a greywater system and pedestrian bridge for their reserve. The sponsor was an ecotourist group whose goal was to have the student design a greywater garden and bridge which would be used to gain funding to create these designs on the reserve. The designs followed the *International Building Code* and minimized the impact on the natural vegetation and be sustainable by requiring as little electricity as possible.

Acknowledgments

This report was completed with the help, guidance, and cooperation of numerous people throughout the seven weeks of this project with Reserva Alto de Esperanca (Reservation High of Hope). Each person provided critical information or feedback throughout the project which helped the student grow as a person, as well as helping the student along the journey of becoming a professional engineer. The group would like to thank our advisor, Dr. Aaron Sakulich, for all your time spent on this project answering questions, providing feedback, and editing the student's writing throughout the term.

To our sponsors, Cláudio Lôpo, Paulo Sanjines, and João Cláudio, the group wanted to thank you for all the time you spent providing insight on your dreams for the reserve, for bringing the group into the culture of the forest, and in the feedback the about the design as this was critically important in creating a design that would work at the reserve. The group also wanted to thank both for the opportunity to be part of this project. The group would also like to thank a few people for their support and help throughout the term with creating and revising this project and report. These people are:

- Zan Hoagland
- James Hoagland
- Michael Laks

Thank you all of you for the support, information, and experience of this project as it was an incredible opportunity and learning experience the group was thankful to have been a part of.

Table of Contents

List of Figures

List of Tables

Introduction

For this project, a student from Worcester Polytechnic Institute worked with the Reserva Alto de Esperance, an ecotourism group in Bahia, Brazil, to be able to help their reserve grow and provide a source of income that other groups around the world could use as inspiration. Ecotourism is defined as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education" (Ecotourism, 2019). Ecotourism is a great way to be able to bring wealth to areas through tourism that are more isolated and not developed. Ecotourism thrives in places where the natural land has preserved and basically untouched by humans for its exotic nature. The sponsor has a beautiful location of the reserve in the Atlantic Rainforest that is well preserved due to the acts of the sponsors and others in the area.

According to "the United Nations Food and Agriculture Organization estimated in 2005 that just 36% of the world's forests remain relatively untouched by humans" (Second, 2008). This is what the reserve is trying to fight and educate people about along with how to live in the rainforest, alongside with this biodiversity, in a sustainable manner. The rainforest has been having its natural resources stripped and depleted in a manner that is not sustainable since the before the 1970's.

There used to be a plentiful amount of natural vegetation, which "originally covered 1.5 million square kilometers (579.153.24 square miles) along the South American Atlantic coast ... [however, this land] is now reduced to around 12% of its original extent" (Brazilian, 2011). This means there is only 180,000 square kilometers (69,498 square miles) left of this rainforest. This deforestation impacts countless numbers of plant species and wildlife native to the area and threatens the rainforest's biodiversity. In the Atlantic Rainforest over "6,000 plant species, 263 amphibians and 160 mammals, including 22 primate species, are endemic" (Second, WWF). Endemic means that a plant, animal, or virus is native to a certain place. With the deforestation that continues to go on, there is possible extinctions of over 6,000 plants species and hundreds of species of animals. This biodiversity is important in the function and survival of the rainforest.

The sponsor's reserve is used as an interactive trail walk in order to teach people the importance of biodiversity and agroecology to teach how important the idea of being sustainable truly is. The sponsor's reserve, as it was, had their guests bring their own sleeping set up to the reserve and did not have formal housing. This, as much as it allowed the guest to feel connected with nature, can be off putting to some people. Since, the sponsors were looking to grow and had plans for a dormitory for their site to provide shelter, freshwater, and restrooms to their guest, this project was focused on creating sustainable structures for the sponsors to be able safely treat the wastewater that comes from these buildings. The sponsors wanted to make sure this was done in an environmentally sustainable manner, meaning they wanted to minimize the impact on the land and vegetation that is present on the reserve, and for them be able to use this a system as part of their educational experience.

The sponsors had this design of a dormitory for the reserve but wanted to create a way handle and process the wastewater from this dormitory without the implementation of a septic system or public water. The sponsors were interested in being able to reuse or repurpose this wastewater on site to lower the water need of the reserve which in return would make the design more sustainable. The sponsors were interested in creating a greywater garden and would like the garden to have banana trees, so the sponsors get a delicious treat from this sustainable system.

The sponsors themselves were not educated in creating a greywater garden or system and did not know where to start and wanted the WPI student to research and design a functioning greywater system for the reserve.

This design would be used by the sponsors to entice investors to give the reserve funding in order to create these designs on site as the sponsors do not have enough money to do this now. This design should be well explained and educational in order to fall in line with the goals of the sponsors of creating an educational experience at the reserve. The design and deliverables for this project should allow the sponsors to talk to investors and sell them on their vision of creating an ecotourist reserve that is sustainable, but also this design would help them create a source of income for the reserve and for southern Bahia as this would be a great tourist attraction. This will hopefully bring back the culture of the forest by allowing young adults to have jobs in the forest instead of having to move to cities as the sponsors mentioned this in a zoom meeting. The sponsors hope to inspire people with this project and be able to be at the start of creating a positive change that allows the growth of humanity and the natural world harmoniously.

The group also designed a pedestrian bridge for the site to be able to connect the where the dormitories are to the rest of the reserve. The group wanted to make sure the design minimizes the impact on natural vegetation and minimize the use of concrete and steel in the design as this was direct mentioned to the group by the sponsors. The group wanted to make the bridge aesthetically pleasing so it adds to the beauty of the forest rather than taking away from it.

Background

Reserva Alto de Esperanca is in southern Bahia, Brazil, inside of the Serra Grande Environmental Protection area in the Cacao Coast. This reserve was purchased by Cláudio Lôpo and made into an interactive trail walk in 1997 to teach people about biodiversity and how to sustainably live in the rainforest (Forest, 2020). Throughout the years he has complied a team of people that are working towards growing the reserve and trying to bring light to the beauty of the forest. Two of these people on Cláudio's team who the team directly worked with was Paulo Sanjines and João Cláudio, who both had dreams of the reserve and its future as well as the passion for the earth that Cláudio has.

The goal of the sponsor's reserve is to find teach people about "environment sustainability through ecotourism and agroecology" (Forest, 2020). Environment sustainability is the practice of acting in a way that is in harmony with the natural world and work to improve the life of humans as well as the nature around them for future generations (Environmental, 2020). Agroecology is one way to become more environmentally sustainable due to agroecology being defined by the Merriam-Webster Dictionary as "an ecological approach to agriculture that views agricultural areas as ecosystems and is concerned with the ecological impact of agricultural practices." The reserve is flourishing and "rich with biodiversity" which will also be a selling point the reserve's managers use to promote their interactive walking trail, so the sponsors wanted to make sure the design is sustainable and will not cause damage to the land (Forest, 2020). The reserve's managers have made sure that they have worked to preserve this land to the best of their ability.

The sponsor has also bought other property near the reserve to be able to preserve the natural springs and much of the forest that are close to the reserve. These springs supply the reservation with potable water which is particularly important in preserving for this reason. This decision to buy this property has allowed the sponsors to be able to keep the natural beauty of the land and waterways basically untouched by humans.

The sponsors are interested in providing an educational experience that can teach people about how to live sustainably within nature and the importance of biodiversity while acting as a benchmark or guide for other places around the world to be able follow in their footsteps in creating an ecotourism group. The sponsor also wanted to ensure that this educational experience would be thorough and to have people leave the reservation having the knowledge about how to live in the nature more sustainably and allow them to feel connected to the forest and to nature.

The sponsors wanted their reserve to be able to be a guide or inspiration to others around the world and groups in southern Bahia of how to be able to create an ecotourism group or reserve by using the beauty of the local nature and biodiversity, as well as educating their guests about sustainable practices to be able to bring in a consistent source of revenue. While talking to the sponsor, the sponsors made note that lots of young adults are leaving their hometown in the forest to go to cities to find jobs. This is because there are more jobs in cities. With the young adults leaving for cities, more cities are being created which is taking away from the natural biodiversity and the identity and the way of life of the people that have lived in the area for generations. The sponsors wanted to be able to show people how they can work to be able to keep their way of life and personal identity while also being able to have a consistent income. The sponsors believe that ecotourism is an area that needs to be developed in Bahia to be able to find and sustain jobs in their hometown and hope to inspire others.

For the reserve to become an inspiration to others, the sponsors needed a way to be able to educate and reach more people. So, the sponsors wanted the group to create a way to be able to house a 12-40 people in a way that minimizes the impact the environment and is sustainable. There was a design for a dormitory that had eight bedrooms that could be fitted with two bunkbeds or a queen sized bed comfortably. The design was made from as much wood as possible as this was a sponsor's request so they can remain as natural as possible. For this same reason, the sponsor did not want to implement a septic system due to having to excavate the land and destroying the natural beauty of the land. Mr. Lôpo wanted to use this project to design a greywater garden for the reserve that could handle the amount of water created by the dormitory with their recommended 12-40 people limit.

This greywater garden would a very natural and useful way to deal with greywater and would make for an excellent teaching point on the reserve. He made it clear that the reason for this plan was to be able to use this plan to advertise and find investors, who care just as much about the rainforest as them to raise funding that will allow him and his team to construct these plans at the reserve.

The main purpose of a greywater system is to reuse water that has not been contaminated with fecal matter which reduces the daily water usage of a structure by reusing the greywater for beneficial reasons, such as a garden. The reason greywater systems have been developed is to counteract issues with limited access to freshwater in the world while also learning to live in a way where everyone values the gifts that nature gives them and works to be sustainable with their use.

Water is a particularly important resource and is responsible for making life on Earth possible. The world's oceans are responsible for moderating the Earth's climate while supporting between 50%-80% of life on Earth and covers 71% of the Earth's surface (Water, USGS). However, this is not the only resource of water that is present in this world. There are resources of water that are contained in the atmosphere, such as water vapor, and on land, such as aquifers, rivers, and lakes, as well as in polar ice sheets and glaciers. There is also a resource of water that makes up the water content in the soil and in every living organism. The total amount of water that was present on Earth in 1993 (Table 1.1). These number have only preceded to get smaller a smaller as the human population has risen and the amount of freshwater needed for agriculture has risen too.

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	321,000,000	1,338,000,000	--	96.54
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	--	1.69
Fresh	*2,526,000*	*10,530,000*	*30.1*	*0.76*
Saline	*3,088,000*	*12,870,000*	--	*0.93*
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	--	0.013
Fresh	*21,830*	*91,000*	*0.26*	*0.007*
Saline	*20,490*	*85,400*	--	*0.006*
Atmosphere	3,095	12,900	0.04	0.001
Swamp Water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological Water	269	1,120	0.003	0.0001

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York).

Table 1.1: Breakdown of the water distribution on Earth from United States Geological Survey (Water, USGS)

The total amount of freshwater is only about 2.5% of the total amount of water on the planet; of this 2.5%, almost two thirds of the Earth's freshwater supply are frozen in ice caps, glaciers, and permanent snow. This value is slowly declining with the warming of Earth's atmosphere. The other third is distributed between ground water, soil moisture, swamps, rivers, ground ice, lakes, the atmosphere, and biological water. A minimal amount of freshwater present on Earth makes up the total amount of freshwater that is available for human beings to use. The National Ground Water Association quantifies this number to be only 0.3% of the entire water supply of this world (Information, 2020).

Freshwater is a resource that human beings need in order to survive due to using it to drink, for cleaning, and for personal hygiene and is a resource that has been becoming more and more scarce every day. In developing areas, access to potable freshwater may be a challenge due to not having the infrastructure in place or access to the water sources that are safe for humans to use. According to World's Health Organization reports in 2017, "Only 71% of the global population (5.3 billion people) used a safely managed drinking-water service – that is, one located on premises, available when needed, and free from contamination" (Drinking, 2019). This means there are over 2.1 billion people living on Earth that did not have access to safely managed drinking water where they were living. Not having access to safely managed drinking water can transmit diseases and cause health issues for human beings. Some of the diseases that come along with not having clean drinking water is "cholera, (diarrhea), dysentery, hepatitis A, typhoid, and polio" (Drinking, 2019). One way to extend freshwater supplies is to reuse the wastewater, particularly the greywater due to it not having contacted human feces.

The group did, however, know that there was going to be a freshwater supply to the reservation for the restrooms, showers, laundry stations, and sinks in the buildings they were designing for their sponsor. The sponsor was looking for the group to design a greywater garden to reuse some of the wastewater as this means the buildings will require less water and therefore energy required to pump freshwater to the reserve.

Greywater is water that has not been touched by human fecal matter. Some sources of greywater in a home are “bathroom sinks, showers, tubs, and washing machines” (About). This adds contaminants to the water such as grease, hair, and detergents. There are certain plants that can use these contaminants as nutrients and absorb and process the greywater naturally. For this reason, a greywater system does not need to go through extensive treatment before the water can be reused. The only exception is if the greywater can enter the local waterways, as the contaminates in the water can nutrients for the plants but is pollution for any waterway.

There are types of plants that can handle greywater with the grease, hair, and detergents that are present in the water, and types of plants that cannot. If the plant is not able to process the greywater, the greywater would end up sitting in the position it was irrigated to because it will not be absorbed. This allows for rainwater to cause the greywater to run off into local bodies of water, polluting them. A constructed wetland is a “treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality” (Constructed, 2017). Constructed wetlands can be used to absorb greywater that is irrigated close to a body of water to stop the pollutants from entering the body of water. Constructed wetlands can be part of a bigger system in order to treat blackwater, water that contains fecal matter, as well (Constructed, 2017).

Fruit trees are commonly used for greywater gardens. There are certain species of fruit trees that can function with having salt due to detergents commonly using salt or boron for washing clothes. However, there are also soaps for sinks, body, and laundry that are designed without salt and/or boron for greywater use such as Oasis soaps and ECOS (Greywater). The sponsor was interested in using banana trees as the fruit tree for the reserve's greywater garden. One promising aspect of banana trees is that "boron's primary role in banana is to act as a key component in a number vital process such as structure integrity of cell walls, cell division, root development, and membrane permeability of potassium . . . which allows proper growth and development, pulp consistency, and sucker development," proved that boron is useful in a banana plant's growth (Boron, 2020).

Banana trees are a valuable resource that can use greywater as nutrients to help the growth of the plant, while also reusing water that would otherwise have to be treated by a water treatment plant. Banana trees can also "filter out the soaps and detergents that are used" for cleaning and personal hygiene (Banana, 2015). This will be useful to be able to process the greywater that comes from showers, sinks, and even water from doing laundry with guest sometimes bringing their own shampoo and soaps which may contain chemicals or salts that could harm plants. Banana trees need a plentiful amount of nutrients in order to grow and fruit properly, as well as a lot of water (Banana, 2014). For this reason, banana trees are a great resource for treating greywater, as greywater is plentiful due to human beings' consumption of water and the plant also gets the benefit of the nutrients that are in the water.

Banana plants can be used to create a banana circle in order to be able to efficiently store and treat greywater. This system can be a great design "in creating abundant, regenerative system to solve some of the problems of soil degradation, waste disposal, and water management" (Banana, 2017). A banana circle is a design in which the user creates a circle that is excavated to a specific depth in order to place the proper soil for the tree to get its nutrients from and act as a central basin for the greywater to be stored. This central circle will be used to place natural material in order to create a compost pile that can reuse the natural material and nutrients in them such as grass, fallen trees, and even organic material that come from human consumption. This compost pile will supply the banana circle with sufficient nutrients as the natural material will breakdown into organic material for the tree to use. This compost pile provides a place to "recycle the abundant organic material" around the reserve (Banana). With banana trees needing a plentiful amount of nutrients, the placement of organic material in the center of the circle will allow the trees to thrive. Another benefit of the natural material on top of this pile is that this natural material on top of the banana circle will create a barrier so that mosquitos are not be able to access the water that is stored within it.

The next element of a banana circle is to form a mound where the banana trees will be planted and grow from that goes around the central circle in order to create a barrier above the ground level to minimize the run-off from the circle while also providing a base for the banana trees.

Crop rotation is where the farmer rotates which crops, they plant in certain areas as certain crops will use more of a few nutrients and replace others which helps improve the soils (Importance). The group discovered that planting the same crops also make the plants susceptible to the same pests or diseases can cause long term issues (Importance). Banana trees are susceptible to nematodes, which are worms that live in the soil and "destroys the roots of bananas and plantains so that the plants are starved of water" (Burrowing, 2017). Starving the plants of water will kill the plant and impact the fruit yield, as well as leave large amounts of greywater in the basin to not be absorbed at the calculated rate. This is important in having banana trees used to absorb and process greywater and wanting to mitigate the runoff that comes from the garden.

Direct benefits from rapeseed include pest control, such as nematodes, as well as suppressing weeds if used as a green manure (Plants). A green manure is defined by the Merriam-Webster dictionary as "an herbaceous crop (such as clover) plowed under while green to enrich the soil." "Brassicas can grow roots to depths of six feet, or more, scavenging nutrients from below the rooting depths of most crops this reason" (Brassicas). These plants will be used as part of the compost pile that will be in the center of the banana circle. This will ensure the banana circle to have plenty of nutrients readily available to absorb by the trees. These plants will be planted in the year after the banana trees to be able to replace the nutrients the banana trees used in the year prior, while also protecting the banana trees and sugarcane from nematodes.

Broccoli grows above ground, so the edible parts of the plants never encounter the greywater. This is important in not transmitting diseases to anyone who eats the plants because of the greywater having been used by humans. The broccoli will be planted in years after the banana tree was in that specific location in order to be able to get rid of any nematodes present in that specific location and still provide a delicious treat as a result of the greywater garden. Having the garden produce food was valued by the sponsors and a reason they were so interested in banana trees, so the group wanted to design the garden to also be able to produce other food. The broccoli will be planted on half of the circle where rapeseed is to create biodiversity within the garden.

Sugarcane is also an acceptable option while looking into plants to rotate the banana trees with, however, the sponsor must keep an eye on the health status of these plants as sugarcane is susceptible to nematodes. These plants can be used even though they are susceptible to these pests because these plants being able to help lower the number of predatory ants, banana weevil, and even control nematodes if done properly. There was a study that looked at the different combination or crop rotation using banana and sugarcane crops that found “sugarcane tends to limit infestation by the banana weevil to the first year of banana cropping, whereas banana does not help protect the sugarcane crop” (Evidence, 2011). This means that when the team is implementing crop rotation, the sugarcane will be planted the year prior to the banana trees planting in the designated spot as it will reduce the chances of pests and diseases infesting the banana crops.

The designs of the greywater systems and bridge should not impact this biodiversity or the stream that is in the reservation due to it providing fresh, potable water. The reserve has different plots of land throughout southern Bahia, all located in close proximity of each other, so the group wanted to create a way to cross the waterway by the reserve to bring them into the forest without having to walk on the road to get over the stream dry.

The bridge will be constructed in the woods as a trail structure for pedestrians. Trail structures refer to “almost all structures… passing through or across wet areas or open water such as bridges, puncheon, or boardwalks” (Continued, 2016). These structures are to connect and purpose the land over these areas of hard to travel land. The National Park Service recommends that these structures “should be built of quality, long-lasting material and designed to harmonize with the surrounding environment.” These structures should not damage the surrounding environment in order to minimize the effects of human beings on the land and water and be able to safely cross over the area, while also being durable.

Puncheons are recognized by the United States Forest Service as “a wooden walkway used to cross bogs or deep muskeg, to bridge boulder fields, or to cross small streams” (Trails). These structures are typically constructed using sills laid horizontally on the ground with planks laid across them (Figure 1). They typically are extremely low to the ground, usually one foot, because of this style of construction. A puncheon is like a boardwalk which can also be low to the ground, typically two to four feet off the ground, but a boardwalk is supported by vertical columns. This method of construction causes puncheons to have a bigger footprint on the ground, which creates a stronger base. However, at the same time causes more impact to the land where it is placed by impacting the water flow on the surface for the length of the puncheon.

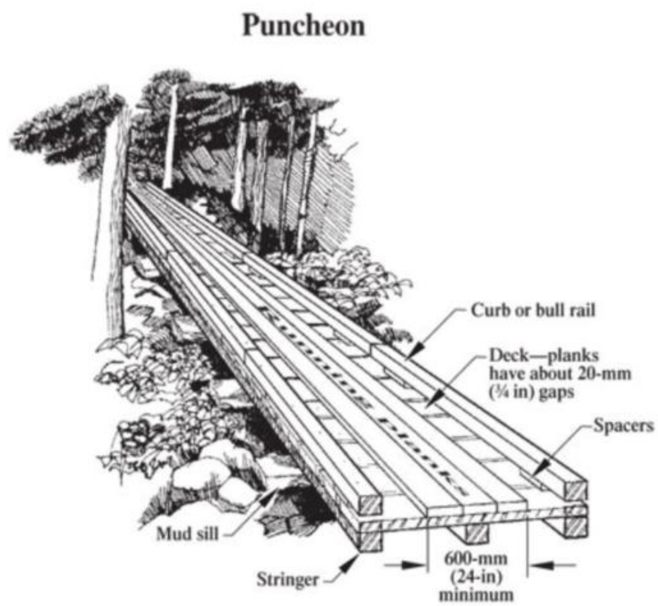

Figure 1: Example of a Puncheon (Trails)

Puncheons are usually constructed with wood. Wood can rot in the presence of air and water; however, if either of these are not present, the wood will not be able to rot. According to the United States Forest Service, "a good rule for reducing rot is to keep the structure continually dry or continually wet. Totally saturated wood will not rot because no air is present. Cover the surface between the curb logs with a layer of gravel, wood chips, or soil to help keep everything wet" (Trails). With the reserve being in the Rainforest, the group pursued a bridge option instead to elevate the walkway off the ground and minimize the impact on the structure and nature.

Bridges are defined by the Merriam-Webster dictionary "a structure carrying a pathway or roadway over a depression or obstacle (such as a river)." For this reason, bridges can be used in nature trails to cross streams and connecting hiking trails. There are many aspects that go into the design of the bridge such as the location, size, environmental impact, materials, feasibility of construction, and cost. It is important to understand these aspects the different styles of bridges to create a design that will be structurally sound, aesthetically pleasing, and minimize the impact on the earth. The group kept these in mind along with the sponsors request to minimize the steel and concrete needed to construct this to keep the reserve as natural as possible. There a six major bridge types that the group investigated to ensure the proper style was chosen for its application in the reserve. They are:

1. Beam bridge
2. Arch bridge
3. Truss bridge
4. Cantilever bridge
5. Suspension bridge
6. Cable-stayed bridge

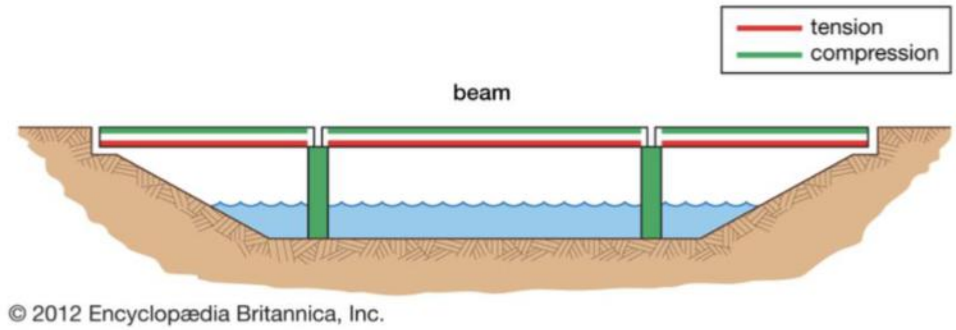

Figure 2: Example of a beam bridge (Beam, 2018)

Beam bridges are simply designed bridges that typically span short distances. These bridges use girders to support a deck and the weight of the bridge itself. Beam bridges do require at least two abutments on either side of the bridge and can have piers to shorten then span (Figure 2). For this reason, beam bridges have multiple different variations and a relatively low aesthetic appeal. Beam bridges are easily constructed and can be constructed out multiple different materials for a relatively low cost.

These kinds of bridges require frequent work to maintain the structural integrity (Beam, 2018). The work of these bridge is to ensure the structures safety, the piers located in the water will have to be inspected and replaced due to water eroding concrete or rotting wood. Due to its relative low standing nature, the abutments on each side of the bridge will have to be inspected after storms to ensure material has not been swept away which would jeopardize the loading of the bridge.

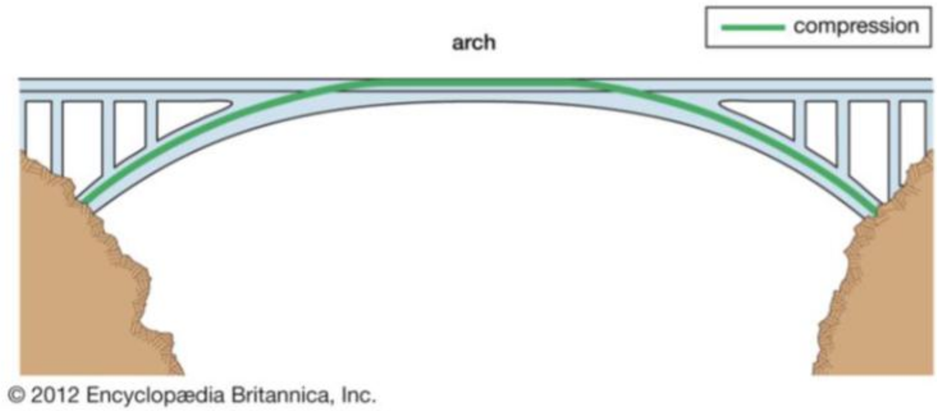

Figure 3: Example of an arch bridge (Primary, 2015)

Arch bridges are bridges that use the natural strength of an arch to transfer all the weight to the two piers on each side. Arch bridges are common throughout history because these bridges can be made of virtually any material that can handle compressive forces (Primary, 2015). This is due to gravity being the main force the is acting on the structure allowing it to only have compression forces throughout the structure that transfer directly into the ground (Figure 3). However, due to the high levels of compressive forces transferring into the ground the impact on the ground and the soil under the abutments is high (Primary, 2015). But if the soil can withstand the weight on the bridge, the structure will lock in place.

These bridges are relatively cheap and efficient to build if spanning small distances; however, the building process is more involved when constructing the bridge itself. The bridge, just like beam bridges, are typically meant for small spans or have multiple piers. However, unlike beam bridges, the arch brings an aesthetic appeal to the design. This is due to large arch structures are subjected to larger bending forces caused by wind forces that the bridge would not be able to counteract; however, under small distances these bridges can counteract withstand these forces.

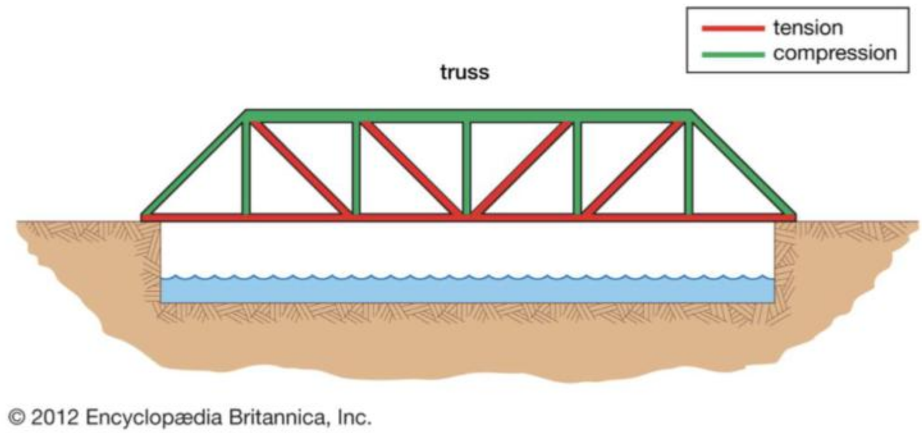

Figure 4: Example of a truss bridge (Truss, 2018)

Truss bridges are bridges that use a truss in order to carry the forces to the abutments. Truss bridges for this reason can span short and long distances safely, and can be built out of virtually any material, even wood. However, due to the nature of trusses, these bridges create large structures that are not very aesthetically pleasing (Figure 4). This also requires good soil under the abutments in order to stabilize the structure due to the weight of the truss the abutment would support. These structures can be light depending on the size, but also with large scale trusses the weight can end up being significant (Truss, 2018).

Truss bridges are very efficient and cheap due to them being able to be fabricated off site or on-site. This, of course, also comes down to the size of the truss that is being constructed as cranes and other heavy machinery could be needed for larger constructions. One downside of these bridges is that they require frequent work to inspect and replace and rusted or rotted members and make sure the joints of the truss are secure in order to keep the structure sound (Truss, 2018). This inspection is required because if a member or joint were to fail, the whole structure has a potential of collapsing while redistributing the forces the broken member was withstanding.

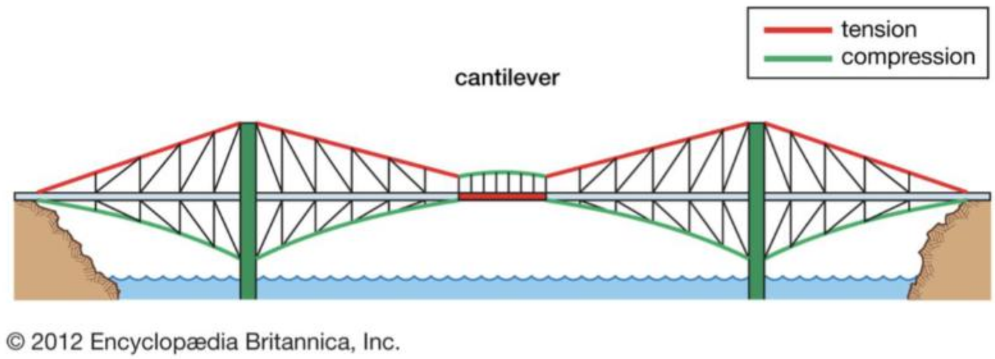

Figure 5: Example of a cantilever bridge (Cantilever, 2017)

Cantilever bridges are bridges that utilize uniformity to allow for a quicker and easier construction of the bridge while also providing a slightly more aesthetic appeal than a truss bridge, but not by much. The designs of these bridges utilize two central columns and are built outwards in order to balance the weight on either side (Figure 5). This allows the bridge to be built in sections which is one reason the construction process of these bridges is easy (Cantilever, 2017).

These bridges require large structures in order to balance the bridge itself and allow for stability as people or cars are to enter on either side. This means that the footings have a tremendous amount of weight and good, firm soil is needed in order to minimize the settling of the bridge (Cantilever, 2017). These bridges have columns that located close to the center of the bridge to allow for construction resulting in the need to inspect the piers as water will erode them as well as having to insect the trusses of the bridge, the same as the truss bridge, in order to make sure the structure is sound.

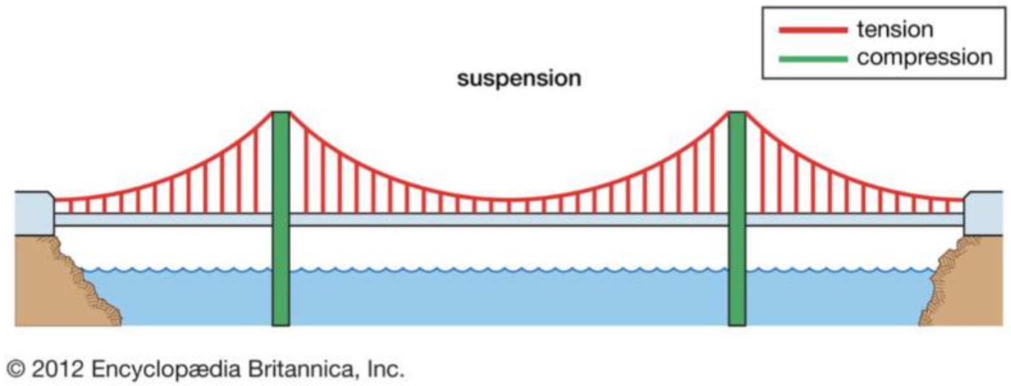

Figure 6: Example of a suspension bridge (Main, 2015)

Suspensions bridges utilize anchorages, cables, and a roadway that are all tied together. These bridges can span thousands of feet and is the type of bridge that can span the longest distance. These bridges are very aesthetically pleasing and can be built using wood and rope, as well as concrete and metal. With the deck being supported by cables, the roadway is vulnerable to wind loads and has limited load capacity that the structure can handle. These cables can be place as close together as the engineer would like which can lower the size of the deck or truss that is needed to support the deck.

However, these cables require large structures, typically made of concrete, to provide the proper tension of the cables as well as the distribution of the force on a greater surface area to ensure stability. These structures have piers close to the middle of the span to allow for even distribution and the natural arch shape of the cables that can be seen above (Figure 6). This means typically these bridges usually have piers that are in the water which requires frequent work on the pier in order to fix spalls and keep the structure sound (Main, 2015).

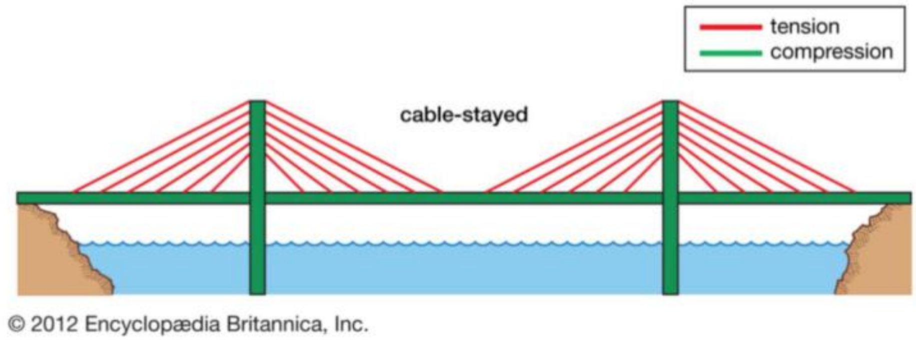

Figure 7: Example of a cable-stayed bridge (Foremost, 2018)

Cable-stayed bridges are bridges that are similar in nature to a suspension bridge, however, offer more strength and rigidity. This is due to the cables directly being connected to the piers. This means this design can offer more resistance and handle heavier live and dead loads. Cable-stayed bridges also take less time to build due to being able to use fewer piers and cables than a suspensions bridge. The lower construction time and lesser materials make for a cheaper design than most bridges while providing great versatility due to these structures being able to add multiple spans that connect with each other relatively easily(Figure 7).

However, these bridges can be unstable in certain environments and have limited length capacity. These bridges are also extremely hard to inspect and are susceptible to corrosion which means there are inspections and fixes will have to be done consistently in order to ensure the stability of the structure (Foremost, 2018). In Brazil, there five cable stayed bridges that are major constructions. The Octavio Frias de Oliveira bridge is an example of the Brazilian bridges that is in São Paulo, Brazil (Figure 8).

Figure 8: Picture of Octavio Frias de Oliveira bridge (Octavio)

This style of architecture is unique to Brazil as each bridge is unique and brings an aesthetic appeal to the land surrounding it (Figure 8). The design of the bridge allows for the piers to be supported on land which mitigates the risk to the bridge piers as well as the local waterway and the pollution that arises. The deck is suspended high above the water way to ensure the water activities below were not interrupted as well as providing a tolerance to if the waterway were to rise. This structure uses an amazingly simple, but elegant, design in order to add to the beauty of the land and create a unique design that can be appreciated. This bridge style is extremely large and would not be fitting if placed in the middle of a rainforest.

The team wanted to create a design that would be fitting for the reserve and follow the sponsors wishes of using minimal concrete and steel. The team was looking a low profile and open concept of the deck to allow the person using the bridge to feel like they still are in nature while still providing the necessary clearance of the waterway. The teams was also looking designs that had relatively the same length span to visualize what their design would look like while also being able to withstand the designed forced of dead load, live load, and other loads such as wind loads. The team looked on Google for examples of wooden pedestrian bridges that are in nature reserve for inspiration in their design (Figures 9 and 10). The group used these structures as inspiration for their own design to look at how others have approached the task and come up with a logical plan of action.

Figure 9: Wooden pedestrian bridge at Lafayette Heritage Park (Pedestrian, 2015)

Figure 10: Montmorency forest bridge in Quebec (Montmorency, 2020)

The bridge in Figure 10 is constructed using glulam wood beams. Glulam, or glue laminated timber, beams are wooden beams that are relatively new and are engineered. The Engineered Wood Association states that “pound for pound, glulam is stronger than steel and has greater strength and stiffness than comparably size lumber.” With these beams being stronger than steel pound per pound and the sponsors wish to use mainly wood in the design, the team selected to incorporate these beams into the design of their pedestrian bridge is order to allow for a longer center span over the river and minimize the number of footing that are needed. Glulam beams can be exposed to weather if the wood has been treated for this just like any other wood due to woods nature of rotting when exposed to water and air. Treating the wood ensures the material properties will be consistent longer throughout the beams life by mitigating the chance of rotting occurring.

These beams are also very cost competitive to other materials due to the properties of the glulam wood will require less material for the same strength (Glulam, 2020). This is important when thinking about the cost aspect of the design. Glulam come in standard sizes as well as custom sizes due to the wood being engineered and can even come in different shapes and sizes such as “pitched and curved beams, radial arches, and tudor arches” (Glulam, 2020). One manufacturer of glulam beams, Boise Glulam, specifies that these beams can be manufactured “with lengths up to 66 feet with our without camber.” These two facts will allow the group to provide an adequate setback from the stream without needing a large truss structure that would take away from the walker’s experience of being in nature. However, due to glulam being relatively new, the group wanted to minimize the amount of this timber needed in the construction due to our sponsors location in Brazil and may be not having access to plentiful amount of this material.

Rainwater collection is another method the sponsors were interested in looking into due to the heavy rains during the wet seasons due to the reservation being in a rainforest. The sponsors were interested in a rainwater system because it would require less water to have to pumped from their freshwater source which will require energy to pump to the reserve. The sponsors got this idea based on their neighbor's implementation of rainwater collecting and thought it was a great idea especially with having a building where the rain from the roof will already be captured and transport with the gutters.

Minimizing the amount of electricity needed was important due to the reserve having to create its own electricity using solar panels and a parabolic solar trough. These methods were chosen by the sponsor due to the sustainability of these systems as well as their ability to create enough energy for the reserve. These methods do not generate a tremendous amount of energy so being able to conserve the energy for the building or pumps will allow them to be more sustainable.

Rainwater is a great source of water that can be used for any application in a house; however, the Center for Disease Control (CDC) specifies that "rainwater can carry bacteria, parasites, viruses, and chemicals that could make you sick, and it has been linked to disease outbreaks." This is because the rain has contacted the roof and gutters which could have particles of bird feces or other organic material that is not safe to drink or use. There are methods such as adding chlorine and iodine or boiling the rainwater that are used in order to purify the rainwater, however these methods do not meet the CDC's guidelines for drinking water due to bacteria and chemicals still being able to be present (Rainwater, 2013).

This water can be used for cleaning and for toilet use though which is helpful due to not require as much fresh drinking water that will be used for purposes that will turn the water into wastewater to be process by the greywater garden. Having this rainwater be purposed for cleaning and toilet use will be useful as rainwater can be directly used for water plants as the soil and plants will be able to tolerate these contaminants and having the greywater of the reserve already being processed by a greywater garden (Rainwater, 2013).

The sponsor also mentioned later in the term that they would be interested in having the group design a blackwater garden. Blackwater is the water comes from the toilet due and is called blackwater due to the "high level of contamination" that is present in the water and should never be used in gardens (Difference, 2015). The group, because of time and scope of the project, was not able to investigate this issue of a blackwater treatment system. This was something the team knew was important to the sponsor, but just did not have the time with the project only being seven weeks long.

The group decided that in order to be successful, the group would like to have made sure they complete a finalized design and analysis of the greywater garden that looks at the sites layout and creates a sustainable system that will require as little electricity for pumps as possible, as well as completing a design and structural analysis of the pedestrian bridge. Both designs should follow the *International Building Code* of 2018 to ensure these designs can be used by the sponsor to generate funding and require little work to be done by the engineer who is signing off the plans. This is important in the field of civil engineering and working with structures and design that will affect both the earth and people.

Methodology

The goal of the project was to design a greywater system and a pedestrian bridge for the Reserva Alto de Esperanca. The greywater system will allow the reserve to be able reuse their greywater from the buildings in a sustainable way. The bridge will allow for the plot of land where the dormitory will be to be connected with the rest of the reserve without polluting the water itself while providing a safe crossing by the dormitory designed Cota 8 to the other side of the stream. To make sure the project accomplished the goal, four objectives were created:

Objective 1 – Literature Review of greywater systems and bridges

Objective 2 – Design of greywater system and bridge

Objective 3 – Analysis of the greywater system and bridge

Objective 4 – Deliverables for the sponsor

Objective 1 – Literature Review of greywater systems and bridges

The first object was to accomplish a literature review of greywater systems and bridges in order to design the project to work well at the reserve and better understand the project. The first step was to understand what greywater is and what a greywater system does. The group conducted research using WPI's Library database alongside of Google Scholar in order to understand what greywater is. Once the team understood the idea of what greywater is, the team was able conduct research into different greywater systems. While doing the research, the team found multiple options of different greywater systems, but through a Zoom call with the sponsor, the team learned the sponsor were interested in a greywater garden for the reserve in order to provide a delicious and sustainable method of living the in forest.

Research was conducted on Brazilian architecture and Brazilian bridges in order to understand the style of bridge that is commonly used in Brazil. The team wanted to design a bridge that would work well with the architecture that is common in Brazil as well as the architecture of the reserve. The team used Google Scholar and the internet to complete this research. The team had the sponsor send them over pictures and posters of the reserve in order to familiarize them with the sponsors dreams for the reserve and in order to have a visual idea of what the reserve looks like. Research was also done on the pros and cons of the different bridge styles based on their design. The students looked at the materials used in each design, the lengths the design can span, the sustainability of the structure, and other factors in order to have an informed decision of the bridge type that would be best fitting.

Objective 2 – Design of greywater systems and bridge

The group began designing the bridge by deciding the best locations for it on the reserve. To do this the team met with the sponsors through Zoom calls to better understand what the sponsors criteria and dreams were for this project and their Ecotourist group. The group also needed a site plan that had a topographical map layer to better understand the plot of land involved. This was done by asking the sponsors to send the team over a topographical map of the site in an AutoCAD file and looking at Google Maps satellite view. Once the team understood the sponsors mission and land, the team was able to start selecting possible locations.

The group used the knowledge gained through their research and created three preliminary designs of the site’s water supply and greywater reservoir that included the freshwater pump, water lines to the reserve, placement of the potable water storage tank, the greywater reservoir, and back up greywater reservoir. The group then sent the sponsors these three options through an email using AutoCAD and the topographical map file, the sponsors had sent earlier, to let the sponsor, familiarize themselves with the layout before the next meeting. The team then met with the sponsors through a Zoom call to present these three options. The sponsor gave them feedback about the designs and proposed a fourth option, with which the group proceeded.

The team moved forward with the preliminary design based on estimates of the amount of greywater the completed building would produce. To correctly calculate the volume of greywater the building and people would produce, the group first looked at the World Health Organization. The group found out the World Health Organization quantified the amount of water an individual uses in a day to meet the basic hygiene needs and food hygiene needs per day. The group then researched and found the amount of water used on average for showering and cleaning laundry to get a more precise number.

The group found that the World Health Organization also had a report on the individual needs considering showering or bathing, toilets, and the amount of water for around the house such as kitchen and bathroom sinks. The group then multiplied it by the maximum number of people that the sponsor wanted to be at the reserve, 40. This resulted in the quantity of water of that the group knows will be used on the reserve in one day. The group decided that it would be smart to add in a factor of safety of 1.5 on this quantity to ensure that the reserve never runs out of fresh clean water and that the gardens can handle a day if the sponsors have 60 people on site. This allowed the group to start designing the size of the water tanks that will be on site. The team used this same logic in determining just the water that is required for toilets and subtracted this value from the total amount of freshwater the reserve would use in a day.

Once the team got the requests back from the sponsor about the plants and site plan, the team was able to start a final design of the of the greywater garden. The group was able to move forward in deciding the final variety of plants to use as well as a location for each plant to be able to draw the piping that will be required in order to transport the water to each plant. The group knew the sponsors wanted to implement bananas into the greywater garden to create a delicious treat from the greywater garden. The group researched how bananas can be used to treat greywater and efficient ways that have been created to treat greywater to help them design a functioning system.

The group knew that continuing planting the same plant over and over cause issues for the soil and depletes the nutrients needed in that plant's growth. So, the group investigated crop rotation to mitigate this effect and follow the sponsors goal of educating people on agroecology as this will be implemented in the garden itself. This allowed the group to choose plants that will work well with the banana plant for a variety of reasons .This allowed the group to start designing true size of the garden.

The group wanted to use gravity as the source of energy of the system to transport the greywater from the water so the garden must be located downhill from the dormitory. The group designated three locations designated to hold the banana trees and be able to change the location of the banana tree every year while providing adequate time, 2 years, in between planting of this crop in the same location. The designated those locations based on the size of the banana tree roots but was later changed to be the size of the banana circle the group was implementing due to researching this topic and finding it to be extremely useful if implemented into the reserve' garden.

The group wanted to mitigate the risk of greywater running off into the local water due to it being the reserve's source of freshwater along with the impacts that happen to the environment. The group decided to outline the garden with constructed wetland to avoid greywater runoff on three sides of the banana locations that is even or lower in elevation that the rest of the garden. The three sides were chosen to mitigate the risk of run off flowing downhill and polluting the water waterways. The group also decided that a backup constructed wetland 30 meters (322.92 feet) away from the water source would be used in order to assure any greywater that ran through the other two sides of the constructed wetlands, would be caught by these wetlands and have no chance of polluting the river.

The wetlands that are on the sides of the banana locations, are located uphill from the backup wetland and will be used to mainly store and treat greywater on a regular basis. The backup wetland will be used for when there are events at the reserve and excess greywater was created. This will also serve as a filter for any runoff that come from the rest of the garden. The group designed this plan of the greywater garden using AutoCAD and the topographical map that the sponsors sent us to be able to get proper dimensions and location on site.

The team came up with a list of design specifications that was also useful in determining which type of bridge should be used based on the sponsors wishes along with the pros and cons of each bridge style. The group created the pros and cons of the different bridge style in order be able to compare the environmental impacts of each design, the materials used in each design, the span length, the aesthetic aspect of each design, the ease of construction, as well as the repairs that will be needed to maintain the structure. The group also kept in mind the sponsor's goal of the reserve to allow people to feel connected with nature so the selected bridge style should not obstruct the view of nature as much as possible, but still following the *International Building*

Code. The group also made sure to try and follow the sponsor's wishes of not building within 30 meters (98.4 feet) away from the water and minimizing the amount of concrete and steel that will be used in the design as much as possible while creating a design that will be fitting in the reserve. The group used these criteria to look at the different potential site locations on Google Maps and the topographical map the sponsors sent us in the site plan. This helped the group decided to be able to figure out where the bridge would be placed which in turn gave the group a definite length of bridge that is need.

The team wanted to make sure they did not end up polluting the local waterways per the sponsors' request. For this reason, the group tried to use a minimal steel and concrete in the design. The group also did not want to impact the natural vegetation where the bridge footings would be, so the group tried to also minimize the number of footings used in the design.

With the length of the bridge determined, the group decided on which bridge style would work best for the reserve. The group looked at the key points of each bridge style in order create a bridge design that will be the most fitting for the reserve while focusing on the sustainability and that would follow the sponsors guidelines as well as be able to fit with the architecture of Brazil and the reserve. The team tried to create a design of the bridge that would be able to bring the user closer to nature while also bringing an aesthetic bridge to the reserve in order to follow the sponsors mission with the reserve of being sustainable. The group used AutoCAD in order to draft up three orthographic views of the design they had in mind to submit to the advisor for feedback.

With the advisor's feedback, the group was able to start the final design of the bridge. The group realized that following the sponsors request of having a 30-meter (98.43 feet) setback from the water source would scale this project to be over 63 meters (206.69 feet) for the smallest design. The group knew this would be a lot larger of a project that could be completed in seven weeks, so the group did asking the sponsor how high the water level rises the wet season and in flooding to ensure the soil under the footings would not get eroded. The group set these bounds to follow the goal and mission of the sponsors reserve, while also mitigating the risk to the local water source, to the best of their ability. With these new constraints, the group created another preliminary design in order to have a project that had a reasonable scope while also keeping the sponsors request and goal high in their mind. The group then creating another three orthographic view drawing using AutoCAD in order to get the final go ahead in the starting the modeling and doing the calculations.

Once the advisor gave the team the go ahead, the team started by detailing the three orthographic views with more of the actual hardware of the bridge and started to brainstorm more ideas of exactly how to design the bridge. The group did the more in-depth draft using AutoCAD. Once the group felt like they were at a good point of the design, the group started to model the bridge using RISA-3D.

The group created a structural model of the using RISA-3D. This software was chosen because of the ability it must be able to model actual beams and columns that can be bought and already have associated properties such as modulus of elasticity and moment of inertia which that will be useful in the structural analysis that the group completed next. As well as the program allowing the user to apply loads directly to the model and analyze using different load combinations.

Objective 3 – Analysis of greywater system and bridge

The next objective is the analysis of the greywater system and bridge which entails a full analysis of the amount of greywater that can be process by greywater garden, a full structural analysis of the bridge, and a cost analysis for each one if the team has time. The team started by researching the codes and regulations that are in place for each bridge using the WPI's library database in order to find the proper building codes.

The group then needed to figure out how much of this water would become greywater, and make sure that the system and the garden would be able to handle the amount of greywater that is created. The greywater comes from the showers, the bathroom sinks, and laundry. The greywater system does not include the toilet water or water from the kitchen sinks due to the amount of grease and food particles that are in the water, as well fecal matter, which can clog these systems, and be a breeding ground for bacteria. The group used the World Health Organization's standard for water needed for a single human being to determine the amount of greywater the reserve would produce. This allowed the group to determine the size of tanks to hold the greywater.

Now, the group could start looking at the size of the garden and the different plants within it to ensure all the greywater can be properly processed. To do this the group looked at the amount of water that every plant needs in order to come up with an efficient design of the greywater garden. The team found that fruit trees are particularly useful in greywater gardens as well as providing delicious fresh fruit to the user. The sponsor also had mentioned having banana trees in the garden which worked perfectly from what the group has learned from their research. Through the group also researched other options, like berries bushes, constructed wetlands, sugarcane, and other plants that can absorb the greywater and it be beneficial to the plant as well as crop rotation to ensure the greywater was properly processed and this system keeps in mind the nutrients from the soil and follows the sponsors goal of agroecology.

Then, the team looked at the average rainfall close to the reserve to be able calculate the amount rainwater the system will have to process. It is important to subtract this value from the total amount of water that the garden is designed to handle to ensure the system can properly absorb the nutrients in the greywater without polluting the local area or waterways. This was done to make sure the greywater garden could hold all the greywater without damaging the plants or producing runoff. Runoff was another concern for the group as having too much greywater in a basin during a storm could cause a tremendous amount of runoff from these crops and end up polluting the reserves freshwater source. With having this information, the group could use this and the information about the amount of water required by each plant in order to determine the size and location of the garden more accurately.

To assist the greywater system, the greywater reservoir was placed up hill in order to let gravity control the flow without the need for pumps. This allowed the group to be able to ensure the system will flow because gravity will provide the energy need to transport the water to the garden. This limited the area the team could design the garden for as the dormitory would still have to be placed on site and the group did not want to require pumps in the system to mitigate the need of electricity while still allowing the sponsor to use this idea. The group just needed a way to properly quantify the amount of water that has gone through a pipe to ensure the sponsors do not over fill a plant which could lead to lesser fruits or runoff. The group investigated using a flowmeter at the start of each pipe going to a different location in the garden to provide the sponsor with an accurate volume of water that has been distributed to each plant.

The group researched about the different soils that can be used in gardens for specific plants due to their needs of nutrients and soil types. This allowed the group to understand the amount of water the soil could be able to retain that the plants will use. This allowed the group to get a value of greywater and rainwater that each volume of soil can hold, and plants can process to ensure that the greywater will be processed. The group used the British Columbia Ministry of Agriculture's water conservation factsheet to determine this value. This allowed the group to calculate how much water the soil in the garden could retain to ensure that the design of the garden would minimize the runoff that comes from the design. This is important as greywater should not be able to be able to come in contact with humans as this water carries bacteria and diseases that is harmful to humans. For this reason, the group needed to make sure the piping will be underground, as well as the designing an inlet that is below the surface to the garden.

To do this the group looked at the Environmental Protection Agency's *Handbook to constructed wetlands* which specifies specifications for the entrance to the wetland as well as other key aspects when designing greywater system using constructed wetlands but this same system can be used for the other greywater garden entrances.

The team was able to find a code called *The International Bridge Design Standards and Approaches* as a starting point in their design. While doing more research on codes, the group remembered codes they were familiar with such AASHTO LRFD and decided to do some research in these regulations too. The group also looked at past Major Qualifying Projects (MQPs) in order to familiarize themselves with all the different codes that are used in bridge design. This allowed the team to find journals and codes that will be useful in understanding the regulations around building a bridge. The group decided to use *LRFD Guide Specification for the Design of Pedestrian Bridges* and *AASHTO LRFD Bridge Design Specification* to calculate the dead loads and live loads and *AASHTO Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (AASHTO Signs)* for the wind loads that the structure will be design for.

The team then created a structural model that was created in RISA-3D and will apply these loads to the structure to perform a structural analysis of the bridge. This will allow the group to properly size the members of the bridge to ensure the stability. The team also was able to analyze the bridge using the different load combinations that are required by code to prove the structure is safe. Once the team had all the members and connections sized to the point it passed all the code requirements, the design was determined to be structurally sound. The group then planned to size down members that passed and size up members that failed to create the most efficient design.

Objective 4 – Create deliverables for sponsors

The team used a combination of Piktochart.com, an online digital design resource, and PowerPoint in order to the sponsors posters for the sponsors to be able to use in the location of the that they could use on the reserve to demonstrate the environmental impacts that the greywater garden has to make the reserve more sustainable. This allows the sponsor to be able to demonstrate information about the greywater garden in a remarkably simple easy to read and understand way rather than having their guest read this report. The group used Piktochart.com in order to design these posters originally. This allowed for the group to select a color way and easily add graphics and text.

In order to allow the sponsors and advisor to create revisions and make modifications, the group copied this information into a PowerPoint presentation to send via email. This allowed the sponsor and advisor to be able to easily edit and send feedback on these posters to ensure the grammar and proper information is included in these posters. This is important to ensure the reader can learn and understand this system on a deep basis. This is important as the sponsors are looking to educate people on topics of environmental sustainability and as well as making sure the sponsors are happy with the information portrayed.

The group friend review and revise the different sections of the paper and the poster to ensure that people who had no idea about these topics would be able to understand the information as well as have a third person besides the advisor and I revising the writing. These revisions also helped understand which sections needed a little more work or which parts needed more explaining. This was extremely helpful as having an outside source be able to read and understand the information is important in having deliverables that will be useful to the sponsor for teaching their guests.

Results

In order to design the greywater system, the team needed to know how much water was greywater that will be used for the greywater garden. The group found out the World Health Organization says the amount of water an individual uses in a day to meet the basic hygiene needs and food hygiene needs is 60 L (15.83 gallons). The sponsors were interested in being able to house 12-40 people, so the team multiplied the 60 L (15.83 gallons) by 40. This resulted in the quantity of water of 2,400 L (634.01 gallons) that needs to be stored for just one day.

The group used a factor of safety of 1.5 to make sure the greywater system can handle that amount of water easily. This made the amount of water 3,600 L (951.01 gallons). The group the calculated the amount of water that would not be greywater, which would be water from the toilets. The group subtracted this value from the total of 3,600 L (951.01 gallons). The group knew that only 10 L (2.64 gallons) per person was used for waste disposal (World). This volume was multiplied by 40 and 1.5 to make the amount of blackwater 600 L (158.5 gallons). This means there is a total of 3,000 L (792.60 gallons) of greywater that the garden would have to be able to hold.

In order to be able to effectively manage this greywater, a storage tank was needed to store the water before using it to water the garden. The team used a factor of safety of 1.25 for this tank since the tank can have a valve to the garden could be left open to continuously drain and would not have to hold the full amount of water and the *International Building Code* also specifies that greywater should not be store for more than 24 hours due to the nutrients in the water breaking down (International, 2018). This brought the size of the storage tank to need to hold 3,750 L (990.75 gallons) of greywater. The team selected two 1,892.5 L (500 gallon) tanks to be used to store the greywater to reduce the size of the tanks needed. Also, this will be useful due to the dormitory having two different sides where bathrooms are located. This will also help distribute the greywater evenly to the garden because of the location of the greywater garden and plants within in it.

These tanks will be placed right near the buildings, uphill from the greywater garden to allow gravity to be able to bring the water to the garden without the need for pumps. This allows the system to not require any electricity and be as sustainable as possible. Each tank will have a single outlet of two-inch of PVC pipe. This PVC pipe will branch out to have three different tubes using a two-inch PVC Double Y connection. Each tube will lead to a different plant or different location within the constructed wetlands in order to evenly distribute the greywater across the system. Each of these tubes will have a flowmeter six inches past the three-way split.

A flowmeter is a device that can quantify the amount of water that has passed through a pipe. This will allow for the sponsor to open a valve and easily be able to know the volume of water that has flowed through the pipe. This will be critically important due to the different plants needing different amounts of water to grow, different amounts of greywater the plants can handle due to the nutrients needed, as well as the absorption factor of the soil that each plant requires. This will also allow for an easily way to quantify the volume of water that has enter the garden to properly distribute.

The group then had to design a greywater garden that could handle that amount of greywater using banana trees per the sponsors' request. Banana plants can be used to create a banana circle in order to be able to efficiently store and treat greywater. The group then had to decide a proper size of the circle for the reserve. The size of the circle can vary in each design which will result in a different number of trees that will be able to grow. Through research, the team found a two-meter (6.6 feet) wide depression will allow for "ample water storage and composting area but not big enough where the constant flow of materials will not keep the depression without material" (Banana). The group was planning on this banana circle being able to process greywater and store it so the group selected the two-meter sized hole in order to make sure there if there is no natural material to be placed within the circle that the center of the circle will not fall in height. The group now needed to choose the depth of this circle, so the group decided to use a depth of one meter instead of the TreeYo's recommendation of 66 cm (two feet) to allow for more greywater storage without having to increase the diameter of the circle.

The next element of a banana circle is to form a mound where the banana trees will be planted and grow from that goes around the central circle. The TreeYo Permaculture's guide to a banana circle calls out for a mound that is 66 cm (two feet) wide and 33 cm (one feet) high that goes around the two meter (6.6 feet) central circle (Figure 11).

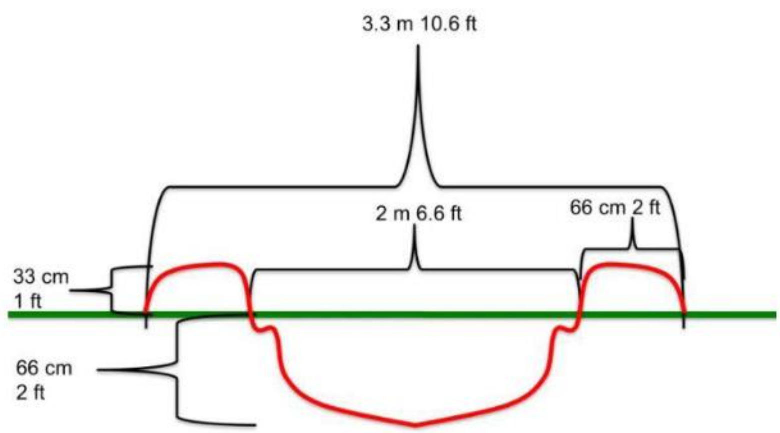

Figure 11: Banana circle section from TreeYo Permaculture

In order to create the most efficient banana circle, the trees should be placed equally distant from each other and should have a gap for the user to walk to the central circle to be able to place organic material without having to damage the outer ring and the vegetation that is growing on it (Banana, 2017). The group decided the gap should be 66 cm (two feet) in order to allow for easy access. With the total size of the of the banana circle being 3.3 meters (10.6 feet), this system will be able to "support five banana trees" that should be equidistantly planted around the edge on the top of the mound (Banana, 2017). This will make sure there are not too many trees to close together to impair growing and allow for enough room to bring natural material through unobstructed. The soil that is present at the sponsor sites is a clay-like material that has a low natural fertility for plants to grow. This is one reason why a compost pile will be created in the center of the banana circles in order to make sure there are adequate nutrients for the trees to grow.

With banana circles having a ring that is built up around the central basin, one concern is this material washing away with rainwater. For this reason, banana circles should have other plants, such as cassava, manioc, or tropical grasses around the outer ring in order to provide stability for this mound. Having these plants in the design not only allows for stability, but it also is useful in "providing a root crop yield while the system is still young . . . (that can be) chopped and dropped to make mulch for the emerging system" (Banana). These crops, if chosen properly, can also be a source of pest control. Strongly scented grasses provide a natural pest control and provide a windbreak to minimize the amount of natural material that can be blown off the center compost pile and mound (Banana). This is extremely important in Brazil, as the sponsors had made it clear that there are strong rains and winds that come from the south throughout the year.

With the sponsor being in tropics, winters are mild which results in no frost, no snow, and no ice. This results in "the crops (having) to compete with a high population of insects, weeds, and pest" (Economics, 2016). This could cause issues to the plants due to insects and pests carrying diseases that could wipe out the plant. "Unless suitable agronomic practices are adopted, monocultures in the tropics are prone to devastation by plant diseases, pest, and natural competition with highly biodiverse ecosystems" (Economics, 2016). Monocultures are "the cultivation or growth of a single crop or organism especially on agricultural or forest land" (Monoculture, n.d.). The group also knew from prior knowledge that planting the same plant in the same location will deplete certain nutrients in the area while building up excess of other nutrients. For this reason, the team investigated crop rotation in order to minimize this as well as specifically crop rotations that are beneficial to banana trees.

The group selected to use marigolds around the edge of the outer rim of the banana circle, as marigolds are natural nematicide and replace the nitrogen in the soil, as well as the use of rapeseed and broccoli, two different species brassicas, for crop rotation (Burrowing, 2003). Brassicas are defined by Dictionary.com as a species of plants that are part of the mustard family which include broccoli, cauliflower, rapeseed, as well as others. The team choose to use broccoli and rapeseed as the brassicas that they would use in their garden. The team chose these plants based on them being native to Brazil, being able to tolerate salty soils and greywater, as well as the plants growing above the soil to eliminate greywater touching the edible parts of the crop. For this reason, the team selected rapeseed and broccoli as the plants that will be used in the banana crop rotation.

Banana trees need about 2.5 centimeters (one inch) to 3.75 centimeters (1.5 inches) of water a week in order to survive (Banana, Ruben). Banana tree roots can extend anywhere from 1.83 meters (6 feet) to 3.05 meter (10 feet) outward, which results in a water need of 785.39 L (207.5 gallons) to 1,193.81 L (315.41 gallons) (Banana, 2019). The team knew that there would be five banana trees to a circle so the 785.39 L (207.5 gallons) to 1,193.81 L (315.41 gallons) must be multiplied by five to get the amount of water the banana circle can process in a week.

This results in the five banana trees being able to process 3,926.95 L (1,037.50 gallons) to 5,969.05 L (1,577.03 gallons) a week. However, only a portion of the banana trees' roots will be inside of the basin to absorb the greywater. The group calculated this value to be 6.95 square meters, which is only 23.79 % of the total area the root system takes up. This means the values for the banana circles should be multiplied by 0.2379 to get an accurate quantity of water the banana circle can process from inside of the basin. This results in a banana circle being able process 934.22 L (246.82 gallons) to 1,420.04 L (375.17 gallons) of greywater inside the banana circle's central basin in one week.

The area that the rainwater was first calculated was the area of the banana circle that is in the central circle. This was to find the amount of water that would have to be processed by the central basin that is not greywater. The average monthly rainfall in Bahia, Brazil close to Itabuna varies from 73 mm (2.9 inches) to 171 mm (6.7 inches) (Itabuna). This value was divided by 31 to get average rainfall per day. This value was multiplied by seven to get the total rainfall in a single week. The area is 12.57 square meter of the central basin which makes the amount of rain from 207.20 L (54.74 gallons) in a week in the dry season to 485.36 L (128.23 gallons) in a week in the wet season. During the drier months, the banana circle will be able to process more greywater than during the dry season due to the plants not getting as much water from rain as during the wet season.

The soil that is in the central circle is sandy loam in order to help the plants have well irrigated soil while also providing adequate nutrients to the plants and storage of water. Sandy loam can store 125 mm of water/m of soil (1.5 in. water/ ft of soil) (Soil, 2015). The area is 12.57 square meters (135.30 square feet). This means that the amount of water the soil can store is 1,571.25 L (415.13 gallons). The depth of the banana circles the team chose was one meter (three and about one third feet) which will multiply the value by one meter which would not change the volume. During the dry season, this means the circle has 207.20 L (54.74 gallons) of rainwater and 1,364.05 L (360.38 gallons) of greywater a week. During the wet season, the value of rain is higher, so the value of greywater is lowered. These values are 485.36 L (128.23 gallons) of rainwater and 1,085.89 L (286.89 gallons) of greywater in a week in order to supply the inner circle with the proper amount of water the soil can hold. This way the trees have access to this water from the basin to be able to process every week which will keep the system being able to process the greywater.

The group knew there could be up to 3,000 L (792.60 gallons) of greywater produced a day by the reservation. This means the weekly value of greywater is 21,000 L (5,548.22 gallons). This amount of greywater would not be able to be processed by this single banana circle. There was enough space at the reserve to have three different locations where the banana trees could be planted. However, the group wanted to use crop rotation to limit the disease and pests while also providing good biodiversity. The crop rotation will be with the implementation of banana trees, sugarcane, and rapeseed and broccoli. Now, the group needed to look at the water quantities that the other two plants would need. These plants would just be planted in the inner circle of 2 meters (6.6 feet) where there will be sandy loam is in order to provide adequate soil for the sugarcane, broccoli, and rapeseed.

The water that can be processed by these locations includes both the amount of water the plants can process, the amount of rainfall, and the amount of water the soil can hold just like the banana circle. The location was determined by placing them lower in elevation from the buildings, as well as not too far away from the buildings in order to not require pumps as talked about earlier (Figure 12).

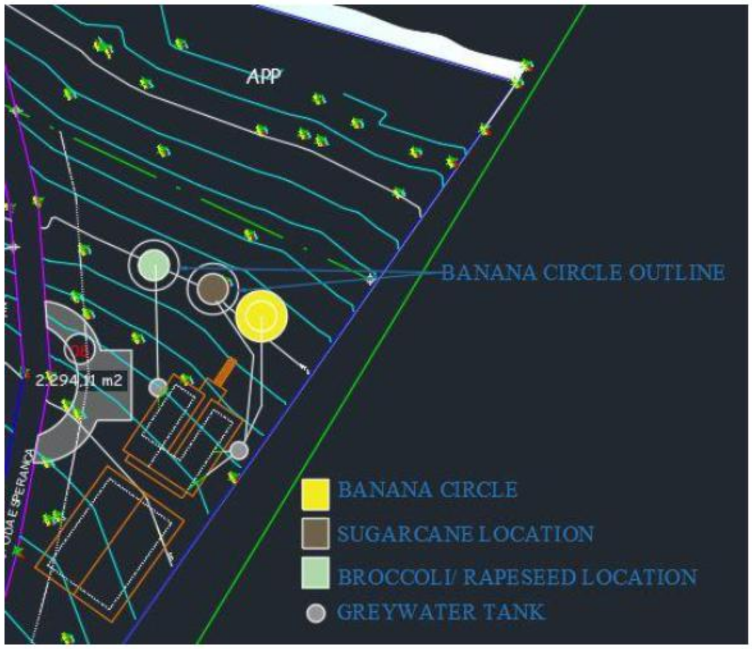

Figure 12: Location of the three banana circles for crop rotation

In all three locations, an area of the banana circle is outlined even though in the sugarcane and broccoli circles the area of planting is only in the center two-meter circle. The area was chosen to be above the 30-meter setback that the sponsor wanted so that the team can provide constructed wetlands behind these circles to ensure that if any greywater was to runoff, it will be filtered by the constructed wetlands before entering this protected land.

The amount of water the sugarcane plants can process is 2.5 to 5 centimeters (one to two inches) a week to have these plants properly grow (Sugarcane). The area the sugarcane will be planted is inside the inner circle which has an area of 12.57 square meters (135.30 square feet). This brings the value of water the plants need to be 314.25 (83.03 gallons) to 628.50 L (166.05 gallons). However, the group knew the inner circle can hold 1,571.25 L (415.13 gallons) of water in the soil. Even though the plants will not be able to process all the water quickly, the group knew that these plants would absorb 314.25 (83.03 gallons) to 628.50 L (166.05 gallons) a week.

So, depending on the amount of rain fall during the week, these plants will be able to process 44.2 L (11.6 gallons) to 143.14 L (37.81 gallons) of greywater.

It is important to not over water these plants with greywater due to them not being able to process all the water that is in the central basin in a timely manner. If greywater were to be used to fill the basin frequently to the top of the 1,571.25 L (415.13 gallons) limit, the amount of runoff that would arise that is greywater would be tremendous. This is due to the plants not being able to process a tremendous amount of this water. The group knew this plant did not require as much water as the banana circle, but the group knew the benefits of the sugarcane crop to the soil, so this process was still chosen to be implemented for the benefits. This brings the amount of greywater processed by the banana circle and sugarcane plants to 1,130.09 L (298.57 gallons) to 1,507.19 L (398.20 gallons). The group recommends watering these plants daily with 1/7th of the weekly value to ensure proper soil moisture without overfilling the central basin.

Broccoli needs about 2.5 to 3.8 centimeters (1-1.5 inches) of water per week in order to properly grow but can handle a little more (Growing). Broccoli should be planted 45.72 cm (18 in) apart, and if there are multiple rows, they should be planted 91.44 cm (36 in) apart (Finding, 2020). This means there should be five rows inside the two-meter inner circle, and with the spacing of 18" there should be a total of 14 broccoli plants on one half of the circle. Taking the water needs of a single plant this value should be multiplied by 14. This means the broccoli can process 35 to 53.34 cm (13.78 to 21 inches) of water. The area the broccoli will be plants is half of the banana circle which is 6.29 square meters (67.70 square feet) due to rapeseed being planted on the other half. This makes the water needs of the broccoli 220.15 L (58.16 gallons) to 335.51 L (88.64 gallons) per week. So, depending on the amount of rainfall that occurred the broccoli will be able to process 0L (0 gallons) to 128.31 L (33.90 gallons). This brings the value of the greywater to 1,130.09 L (298.57 gallons) to 1,635.50 L (432.10 gallons) a week. Again, it is important to not overfill this basin with greywater, similarly to the sugarcane to mitigate the risk of runoff. However, the broccoli will be planted with the rapeseed so the water demand for those plants will have to consider.

Rapeseed matures 74 days after seeding and requires 40.64 to 45.72 cm (16 to 18 in) during throughout its life (Canola). This means that in one year, there can be five planting and harvesting periods. The harvested plants can be used on the compost pile of the banana circle or used to make cooking oil. The rapeseed will be planted on the other half of the broccoli resulting in an area of 6.29 square meters (67.70 square feet). This brings the value of water needed for the rapeseed is 2,556 L (675.36 gallons) to 2,875.79 L (759.79 gallons) per cycle and a yearly total of 12,780 L (3,376.49 gallons) to 14,378.95 L (3,798.93 gallons). This valued divided by 52, the number of weeks in a year, makes the weekly value 245.77 L (64.93 gallons) to 276.52 L (73.06 gallons) of water the plants can process. Accounting for rainwater, the group knew the plants will only need at most 69.32 L (18.31 gallons) of greywater to fulfill the water needs of these plants. This brings the total amount of greywater that can be processed by the three circles to 1,199.41 L (316.89 gallons) to 1,704.82 L (450.41 gallons) a week. The group recommends watering these plants daily with $1/7^{th}$ of the weekly value to ensure proper soil moisture without overfilling the central basin and eliminating the amount of runoff that will occur.

This means there is at least 19,295.18 L (5,097.80 gallons) that is still needing to be treated. So, the group designed constructed wetlands to be able to put this excess water while also controlling the runoff from these three circles. Constructed wetlands can store and process a large amount of water due to its nature of needing very saturated soil. Some advantages of constructed wetlands are that they are less expensive and do not require continuous maintenance making the maintenance expense low, they are able to tolerate flow fluctuations while also being able to fit "harmoniously into the landscape", and they are "an environmentally-sensitive approach" to treating wastewater and runoff (Handbook).

The Environmental Protection Agency recommends that while designing a constructed wetland it should be "conveniently located to the source of the wastewater, is gently sloping, so that water can flow through the system by gravity, contains soils that can be sufficiently compacted to minimize seepage to groundwater, is above the water table, and is not in a floodplain." The group also knew that constructed wetlands can help eliminate runoff due to wetlands being able to "slow water velocities, allowing suspended material to settle." This will help eliminate runoff, which in the use of a greywater garden, is important to have these plants filter out the nutrients that will end up polluting the local water ways (Handbook). The location of the constructed wetlands was drafted on the AutoCAD file the sponsors sent us in the beginning of the term (Figure 13).

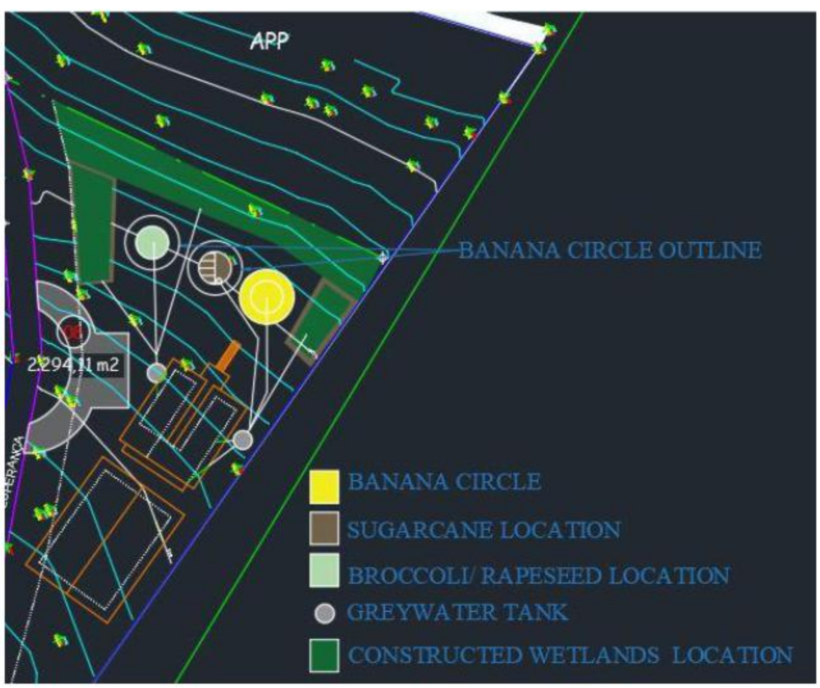

Figure 13: Location of greywater garden on site

In order to design the constructed wetlands, the wetlands should be made by removing material where they will be placed, as well as building up dikes. Dikes are like the outer circle of the banana circle that is raised to minimize runoff. The dikes are represented in the drawing as the brown outline around the two wetlands, the dark green, located around on the sides of the three banana circles. The Environmental Protection Agency's handbook specifies "to ensure long-term stability, dikes should be sloped no steeper than 2H:lV and riprapped or protected by erosion control fabric on the slopes. This means that if the dikes are one foot wide, they must be two feet tall. The decided to use the same dimensions of 66 cm (two feet) in width and 33 cm (one foot) in depth. The implementation of marigolds and other flower crops along the dike will allow for the roots to provide stability and erosion control of the dike while also adding to the biodiversity that is present in the greywater garden. The group drafted a section of the constructed wetlands showing the different layers of soil as well as the dimension for the dike (Figure 14).

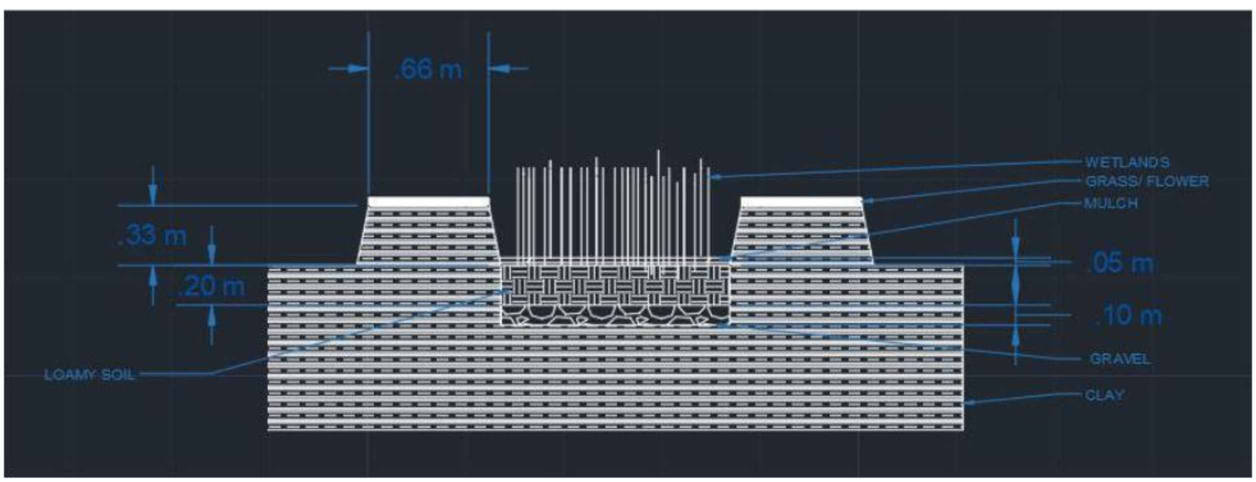

Figure 14: Section of constructed wetland

The group knew the greywater would damage local waterways so they were looking into potential liners to prevent this greywater from infiltrating the ground water; however, if the soils that are in the design area are clay it is acceptable. "Clay provide(s) an adequate seal (as long as the) compaction of these materials (is) sufficient to line the wetland" (Handbook). The team knew that the sponsors soils was clay from zoom meetings so to keep the design as natural as possible, the group decided to not uses a plastic liner. In order to not use a plastic liner, the soil must be compacted to a permeability of less than 10 ft/sec (Handbook).

The group had to now design the inlets of the constructed wetlands. There were multiple options in the Environmental Protection Agency's *Handbook for constructed wetlands* of how to have the water enter the constructed wetlands. The team design to use the "Inlet with Buried Distributed Pipe" in order to minimize the exposure to humans and other wildlife to the greywater (Figure 15).

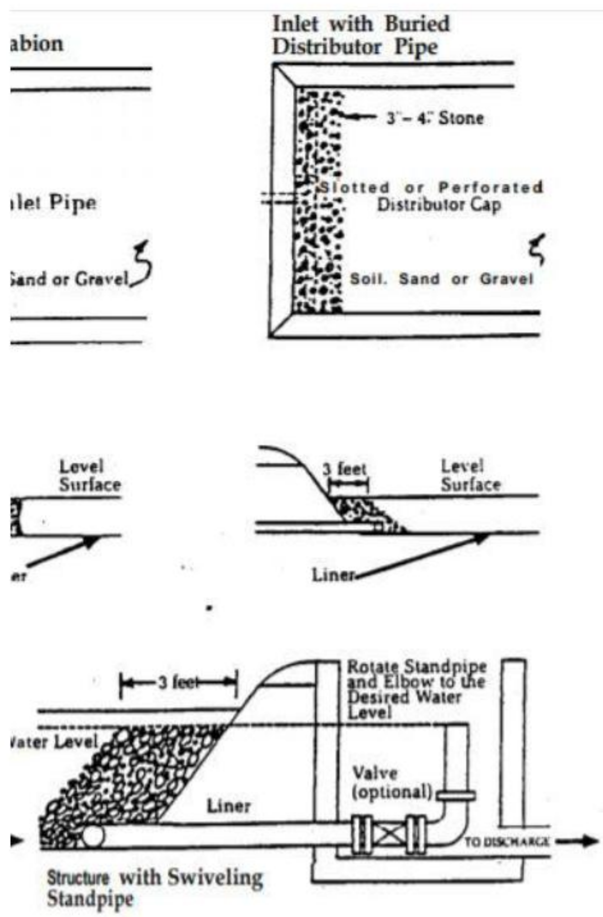

Figure 15: Inlet to constructed wetland using a buried distributed pipe (Handbook)

Next, the group had to look at the soil that will be used in order to construct this wetland. The group knew the soil would have to be able to store and process a lot of water and pollutants due to it being used to treat greywater. The EPA's Handbook specifies that "sandy, coarse-textured soils have low potential for pollutant retention . . . (while) medium textured or loamy soils are a good choice, as these soils have high retention of pollutants and little restriction on plant growth." For this reason, the group chose to use a loamy soil that below this layer, a layer of gravel will be used as "sands and gravels dry out quickly" (Handbook) as well as gravel being able to adequately transport water which is why it is used for the entrance of the buried distribution pipe. The soil water retention rate of loamy soil is 0.13 cm^3 / cm^3 which is 0.013 L / cm^3 (5.62 x 10^{-4} gallons/ in^3) (Soil, 2015). To understand how much water the soil can retain, the group used the soil retention value of 0.013 L/ cm^3 (0.056 gal/in^3) can be multiplied by 1,000,000 in order to convert cm^3 to m^3 to make 13,000 L/ m^3 (97.45 gal/ft^3)

The group designed three wetlands, two located on the sides that will process greywater consistently, and a third wetland that is located between the greywater garden and the stream to ensure there is no runoff into the local waterway. The two wetlands on the sides of the garden have an area of 87.58 square meters (942.70 square feet) and will be made to a depth of 33 cm (1 foot) in order be able to use a variety of wetland types to create the biodiversity that exist in the Atlantic Rainforest. This means these two wetlands have a volume of soil of 26.70 m^3 (942.90 ft^3). This means the soil will be able to retain 347,100 L (91,704.10 gallons) of water, which is well over the value of 19,295.18 L (5,097.80 gallons) that is left to process from the banana circle, sugarcane, and rapeseed and broccoli circles in a week.

The plant species the team recommends is any species that requires a depth of one foot (33cm) due to the two wetlands being design for one foot (33 cm) in depth as there was a wider variety of plant selection that could be used for this depth. The bottom four inches of the constructed wetlands will have gravel as this will provide adequate storage as well as reducing the amount of soil that will be needed to be bought or excavated. The other eight inches will be loamy soil in order to provide adequate nutrients and retention of water and nutrients from greywater. The top of the soil will be cover with two and a half to five centimeters (one to two inches) of mulch in order to eliminate the ability for humans and wildlife to come in direct contact with the greywater by providing a layer of protection. The exact species the team would recommend using was impossible to find as there is not central list of constructed wetlands that are native to Brazil that is easily accessible.

The backup wetland has a volume of 209.72 m^3 (7,406.19 ft^3) which will be used for collecting any runoff that comes from the rest of the greywater garden. This garden will be made from the same soil in order to have a high retention rate as well being able to absorb and retain the pollutants in the water. This garden will utilize common three-square bulrush wetlands due to their nature of being a "fast colonizer. Can tolerate periods of dryness. High metal removal. High waterfowl and songbird value" (Handbook). These are all aspects that will be beneficial to using these plants as the runoff as this species can go time without needing water, which will be great for these wetlands not being used for greywater all the time. This means the rainfall will be able to adequately water this garden while also providing a habitat for birds creating biodiversity local to the reserve.

This species is also able to colonize fast which is important to be able to grow quickly and will be able to catch the runoff as the other two wetlands as they are beginning to grow. This species is also native to South America and will be able to easily implement this species in their garden. The group stumbled upon this species due to this species ranging across the Americas, North, Central, and South America and was included in the EPA's handbook.

The group wanted to make sure the sponsor had educational material for the greywater system so the group decided to make posters that could be placed in front of the different plants in the greywater garden for guest to be able to understand what they are looking at and how it was designed. This was to support the sponsors goal of educating their guest with their ecotourism reserve while also allow the sponsor to have a very simplified version of the design in order to understand the system on a basic level. The group design the four posters below (Figures 16-19)

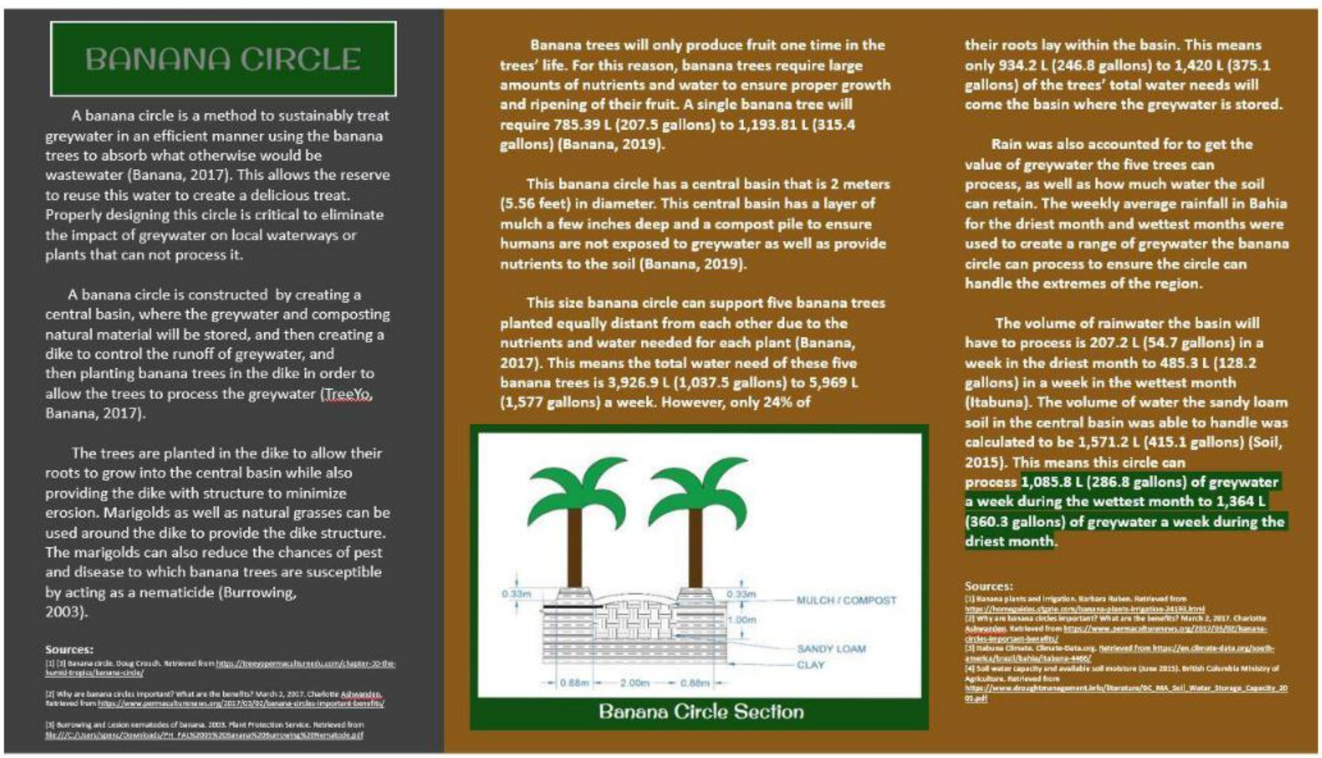

Figure 16: Banana circle informative poster

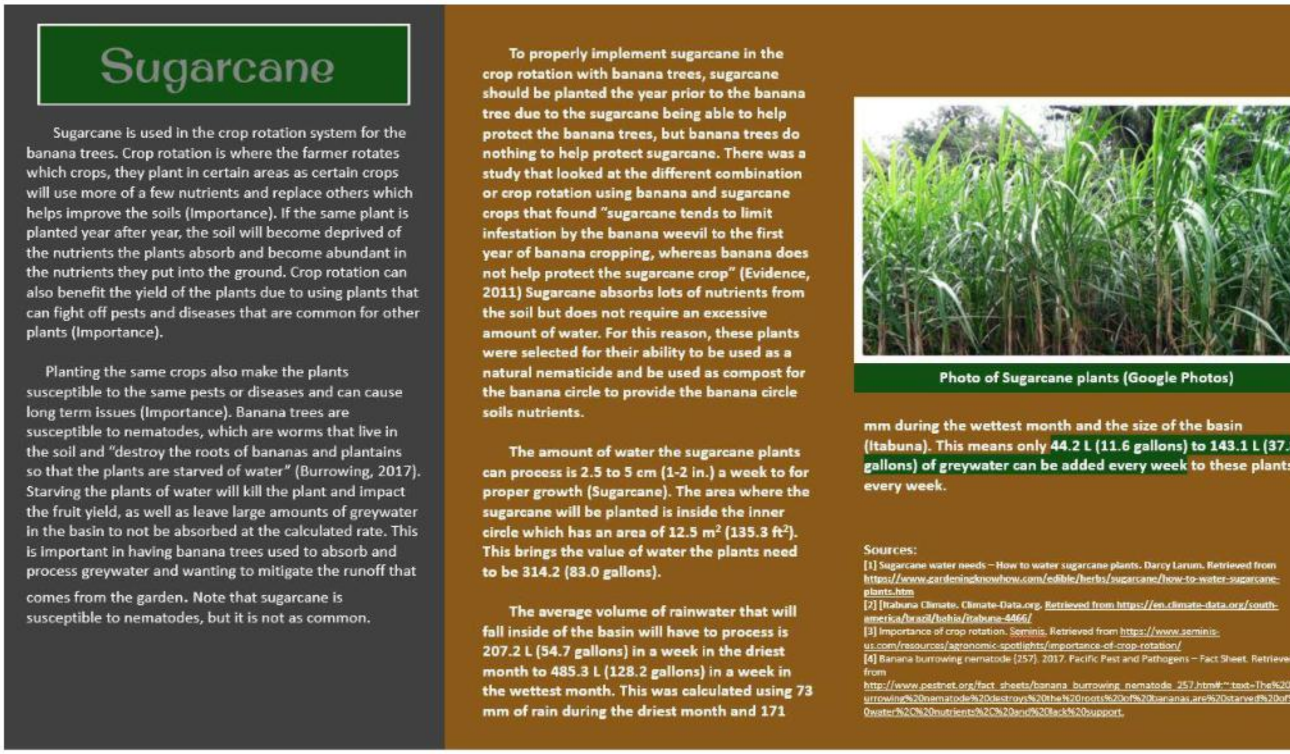

Figure 17: Sugarcane informative poster

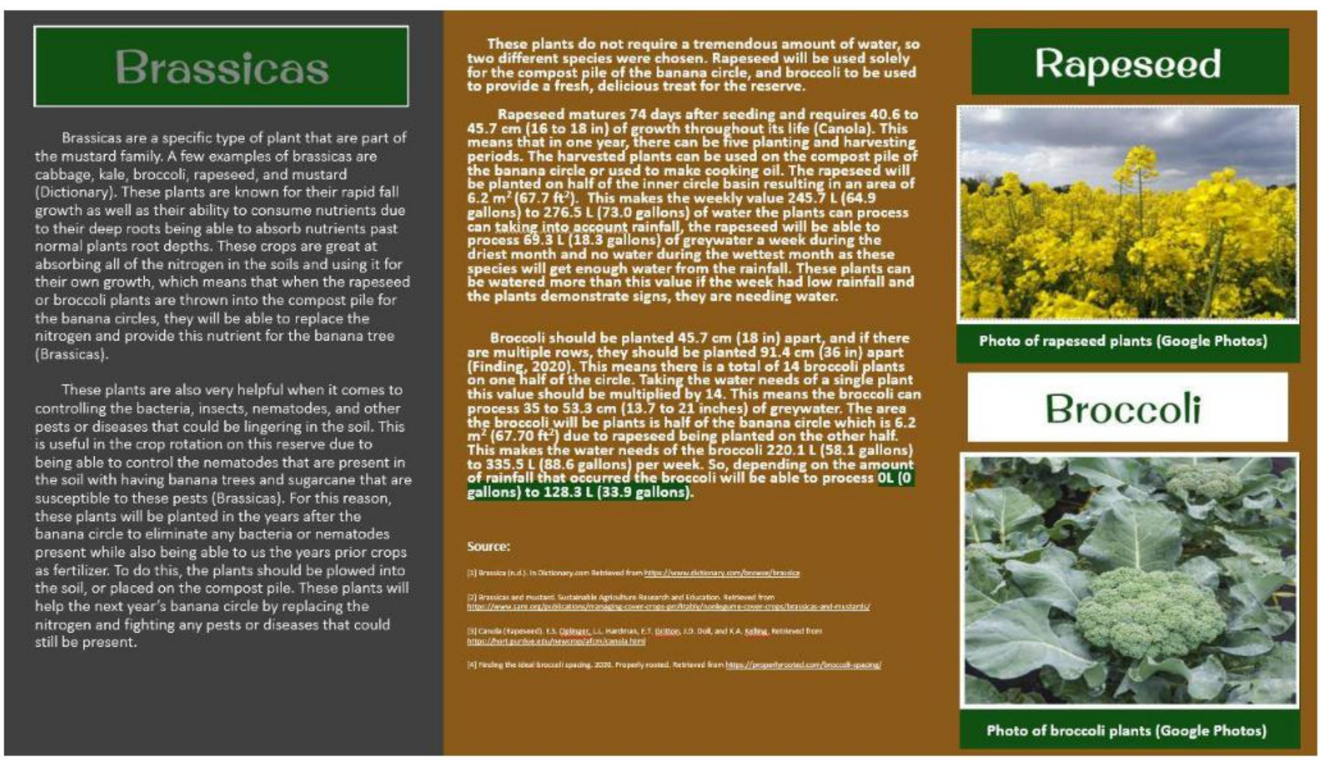

Figure 18: Brassicas informative poster

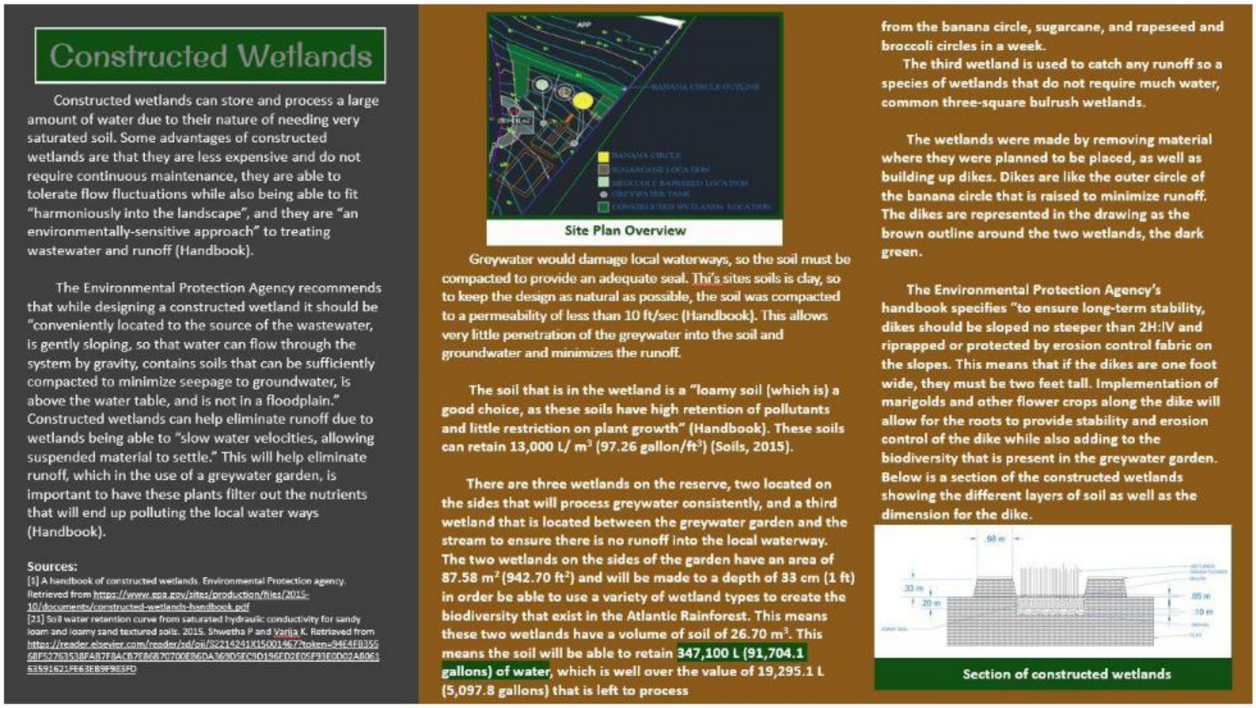

Figure 19: Constructed wetlands informative poster

To start designing the pedestrian bridge for the reserve, the team used the AutoCAD file of the sponsors site to find a place where the bridge could be useful and allow access to the rest of the reserve. Their research about the different bridge styles to make sure the design would be sustainable and not be harmful to the land. The team knew from Zoom meetings with the sponsor that they were trying to not build within 30 meters (98.4 feet) of their local stream, as it is their supply from fresh water. This was one of the sponsors main goal of the reserve, and the group wanted to follow to it but this would have made the bridge have to be at least 63 meters (206.6 feet) and required a huge structure that is not fitting for the reserve or its goals.

So, the team asked the sponsor how much the river rises during the wet season compared to the map. The sponsors told the group the water rises above five meters (16.4 feet), so the group knew the central span should not have footings within those first five meters (16.4 feet) from the water way on the site plan. The team was also told the sponsors would like as minimal concrete as possible, and to keep the reserve as it was. The team investigated small pedestrian bridge that are in nature parks using Google. The team used this as inspiration for their bridge. The group then design a preliminary design on the bridge using AutoCAD (Figure 20).

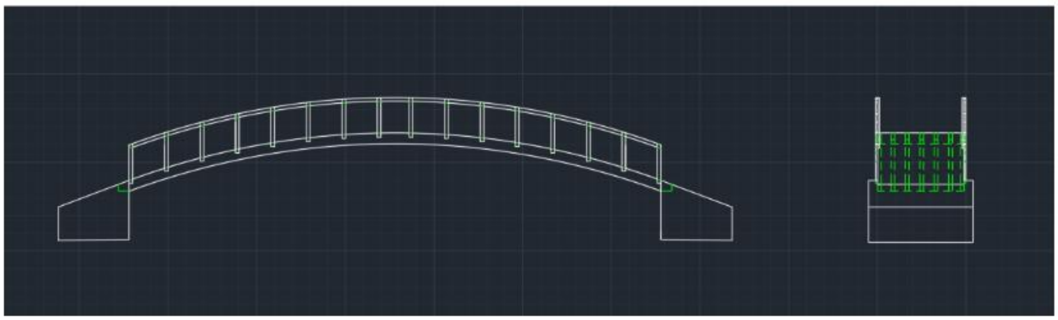

Figure 20: Preliminary Design of pedestrian bridge

The group sent this design to the advisor to get his opinion on the design and see if the student could improve it. The advisor mentioned to the student, that the footing that the bridge rest on are a little large, as these would be made of concrete. The student agreed and went back to try to minimize the amount of concrete needed. The sponsors also told the team about their love of hammocking and being close to nature. This inspired the team to design something that would allow them to hammock near their local stream if they wanted to. With both factors in mind, the group selected to use columns to support the structure and minimize the size of the footings, as it would only be required under a column. The group then designed a new preliminary draft of the bridge using AutoCAD (Figures 21 and 22).

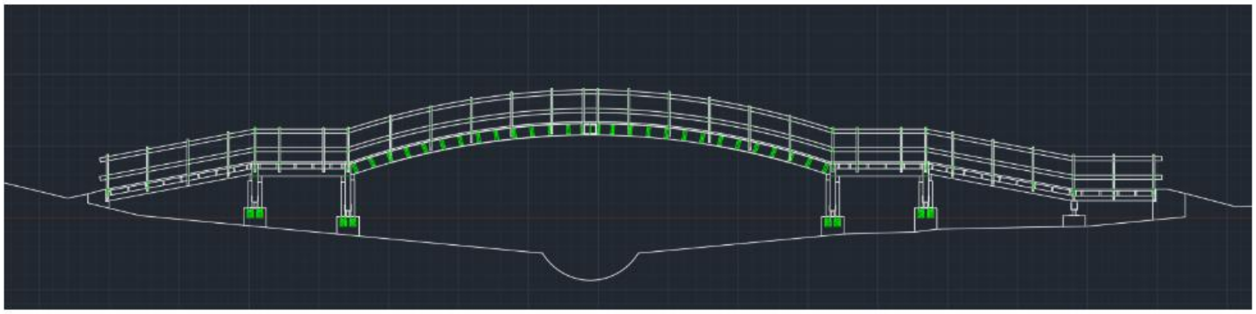

Figure 21: Second preliminary design of bridge

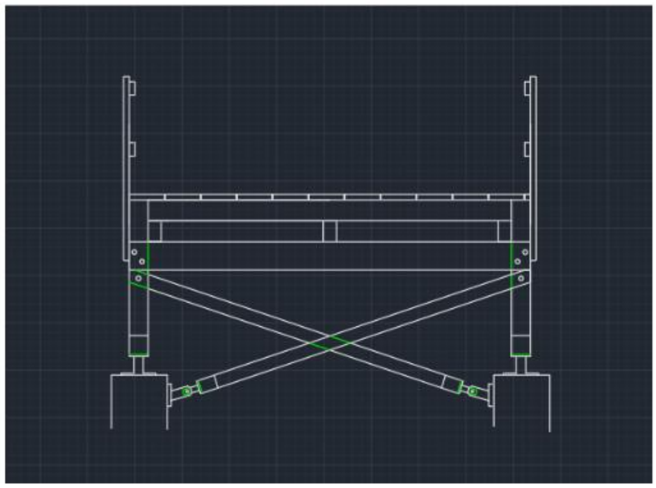

Figure 22: Cross Section of second preliminary design

The group once again turned this design into the advisor to receive feedback. The professor thought the design was adequate and fitting, so the group proceeded to model this bridge. To model the bridge, the group used a computer software call RISA-3D (Figures 23 - 26).

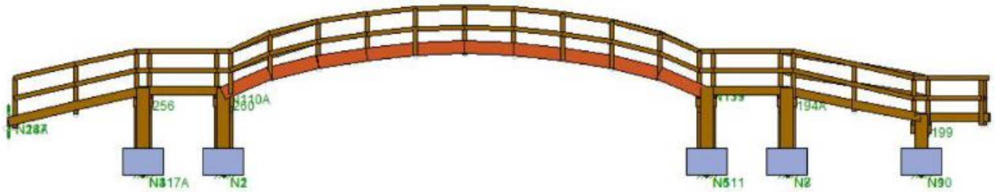

Figure 23: Front Side view of RISA-3D structural model

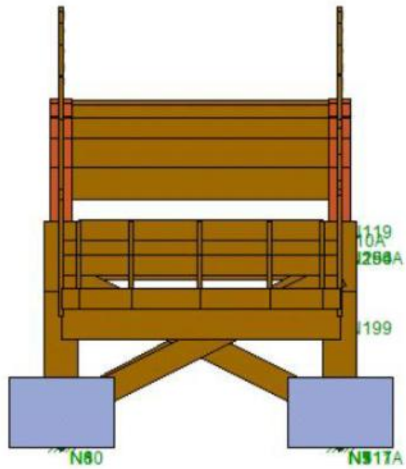

Figure 24: Front side view of RISA-3D structural model

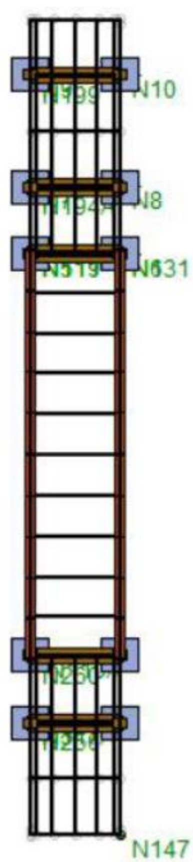

Figure 25: Top side view of RISA-3D structural model

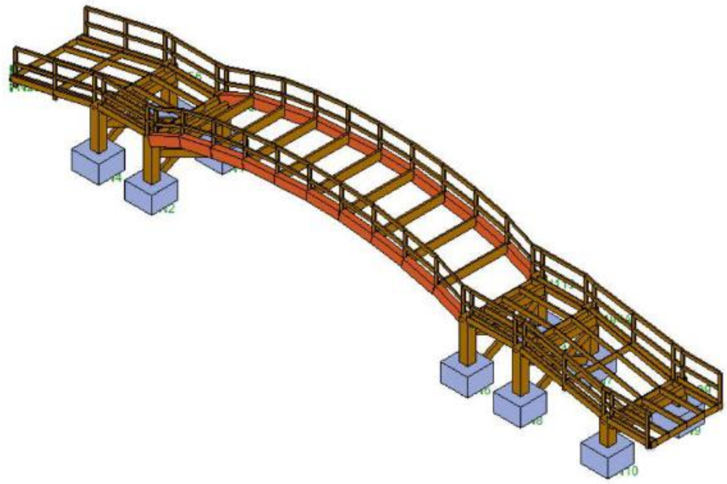

Figure 26: Isometric view of RISA-3D structural model without deck

The group then had to look at the codes and regulations around pedestrian bridge to design the loads for the bridge. The dead load (DL) is specified to be the weight of the structure in *AASTO LRFD Bridge Design Specifications* in section 3.5.1. The group calculated the total weight of the bridge by using the unit of the materials used as well as the total volume of materials used. *AASTO LRFD Bridge Design Specifications* includes a table that specifies these values, Table 3.5.1-1. The unit weight for soft wood, as much of the bridge is softwood is 0.05 kips per cubic foot (kcf) (800.92 kilogram per cubic meter (kg/m^3)). The value for glulam wood is specified by the American Institute of Lumber as the unit weight of the woods with 12% moisture content (American, 1996). However, the group could only find the weight of the timber with 20% moisture content, which the group decided to use as this value is higher due than the 12% due to the weight of the water in the wood. The density of southern pine wood at 20% moisture content was 36 to 41 lb/ft^3 (576.66 to 656.76 kg/m^3) (Wood, 2005). The decided to use the higher value of 41 lb/ft^3 (656.76 kg/m^3) to ensure the members' capacity.

The group knew that to follow the *International Building Code* a railing would have to be installed on the bridge that could withstand a point load of 200 lb (90.72 kg). Due to the project length, did not get to running the calculations on this part. So, the group assumed the use of 2" x 4" (5.08 cm x 10.16 cm) columns spaced evenly for each section of the bridge but never any farther six feet (1.83 meters) apart, center to center, that stand 36" (91.44 cm) higher than the deck, as required by the *International Building Code*, with two 2" x 4" (5.08 cm x 10.16 cm) spaced 18" (45.42 cm) apart, center to center, that are perpendicular to the columns and run the length between the columns would satisfy the code. The group planned to attach the railing to the side stringer with two ½" (1.27 cm) diameter galvanized bolts to have a longer life. The group planned to attach the two 2" x 4" (5.08 cm x 10.16 cm) that are perpendicular with two construction screws at every column.

The group then calculated the weight of the bridge using the unit weight values and the amount of lumber used in the design. In order to do this, group made a timber list of the material to calculate the total volume of wood being used (Tables 2.1 and 2.2). This list was compiled based on the model shown above. The group calculated the volume using equation Volume = (width/12) *(depth/12) *(length/12) because these measurements were in inches and the group wanted to calculate cubic feet. The group multiplied the volume and the density, or unit weight, of the wood that was specified in the codes above, to calculate the weight of the bridge members.

	Timber list w/ weight calculation						
	Quantity	Width (in)	Depth (in)	Length (in)	Volume (ft^3)	Density (lb/ft^3)	Weight (lb)
Columns	8	12	12	54.00	36.00	50	1800
	2	12	12	30.00	5.00	50	250
Deck Stringers	7	2	8	60.00	3.89	50	194.44
	7	2	8	122.50	7.94	50	396.99
	7	2	8	72.00	4.67	50	233.33
	2	8	10	216	20.00	41	820.00
Lateral Bracing	18	2	8	22.25	3.71	50	185.42
	18	2	8	16.25	2.71	50	135.42
	9	2	12	88.00	11.00	50	550.00
	8	2	8	4.20	0.31	50	15.56
Floor Beams	10	8	10	96.00	44.44	50	2222.22
Cross Bracing	8	4	10	107.33	19.88	50	993.80
Decking	240	4	2	48.00	53.33	50	2666.67
	111	4	2	96.00	49.33	50	2466.67
Railing	32	2	4	45.00	6.67	50	333.33
	1	2	4	60.00	0.28	50	13.89
	2	2	4	120.00	1.11	50	55.56
	14	2	4	72.00	4.67	50	233.33
						Total weight =	13566.62
						Total area of bridge (ft^2) =	584
						Dead Load (lb/ft^2) =	23.23

Table 2.1: Timber list w/ weight and dead load calculations with imperial measurements

	Timber list w/ weight calculation						
	Quantity	Width (cm)	Depth (cm)	Length (cm)	Volume (m^3)	Density (kg/m^3)	Weight (kg)
Columns	8	30.48	30.48	137.16	1.02	800.92	816.46
	2	30.48	30.48	76.20	0.14	800.92	113.40
Deck Stringers	7	5.08	20.32	152.40	0.11	800.92	88.20
	7	5.08	20.32	311.15	0.22	800.92	180.07
	7	5.08	20.32	182.88	0.13	800.92	105.84
	2	20.32	25.40	548.64	0.57	656.76	371.95
Lateral Bracing	18	5.08	20.32	56.52	0.11	800.92	84.10
	18	5.08	20.32	41.28	0.08	800.92	61.42
	9	5.08	30.48	223.52	0.31	800.92	249.47
	8	5.08	20.32	10.67	0.01	800.92	7.06
Floor Beams	10	20.32	25.40	243.84	1.26	800.92	1007.98
Cross Bracing	8	10.16	25.40	272.62	0.56	800.92	450.78
Decking	240	10.16	5.08	121.92	1.51	800.92	1209.57
	111	10.16	5.08	243.84	1.40	800.92	1118.86
Railing	32	5.08	10.16	114.30	0.19	800.92	151.20
	1	5.08	10.16	152.40	0.01	800.92	6.30
	2	5.08	10.16	304.80	0.03	800.92	25.20
	14	5.08	10.16	182.88	0.13	800.92	105.84
						Total weight (kg) =	6153.69
						Total area of bridge (m^2) =	54.3144
						Dead Load (kg/m^2) =	113.30

Table 2.2: Timber list w/ weight and dead load calculations with SI measurements

The group then used *AASTO LRFD Specifications for the Design of Pedestrian Bridges* in order to understand the other loads that are necessary to apply to the structure. This first was a pedestrian load (PL). According to this code, "pedestrian bridges shall be design for a uniform pedestrian loading of 90 psf" (439.42 kg/m^2) (AASHTO, 2009).

The next loading to look at is the vehicle load, which is a live load (LL), due to the bridge not having permanent structures blocking the access of cars to the bridge, as specified in 3.2 of *AASHTO LRFD Specifications for the Design of Pedestrian Bridges.* Due to the bridge having a width of eight feet, the vehicle selection of design is a H5 (AASHTO, 2009). This vehicle has a front axle load of two kips (907.18 kg) and the back axle has a load of eight kips (3628.74 kg).

These loads are spaced 14 feet (4.27 meters) apart and the wheels of the axles are six feet (1.83 meters apart) (AASHTO, 2009).

The bridge would not be purposed to transporting horses, so the equestrian load can be nullified. The next load to look at was the wind load (WS). The *AASHTO LRFD Specifications for the Design of Pedestrian Bridges* calls for the *AASHTO LRFD Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals (AASHTO Signs)* to be used for this calculation, however the group was unable to access this book. Instead, the group used *AASHTO LRFD Bridge Design Specifications* calculations for the wind forces.

In the *AASHTO LRFD Bridge Design Specifications* section about wind loads, it specifies if the velocity of the wind is absent at the specific site locations, 100 mph (160.93 kmph) should be the design value (V_{DZ}). Using equation 3.8.1.2.1-1 of the code, $P_d = P_b(V_{DZ}/V_B)^2$, where P_d will be the calculated wind pressure, P_b is the base wind pressure specified in Table 3.8.1.2.1-1 of the code, and V_B is the base velocity of 100 mph (160.93 kmph) (AASHTO, 2004). The value for P_B changes based on the type of structure it hits. For arches, beams, and columns on the windward side of the beam, the value is 0.05 ksf (244.12 kg/m^2). Only arches and columns require a leeward calculation, so the value of the base wind pressure is 0.025 ksf (122.06 kg/m^2). Because the two velocities are the same value for the equation above so the $(V_{DZ}/V_B)^2$ would come out to be one, the force that is applied to any member on the windward side is 0.05 ksf (244.12 kg/m^2) and for the arches and columns on the leeward side the value is 0.025 ksf (122.06 kg/m^2).

The code also specified the need to calculate the velocity of wind create by the vehicle passing; however, in the *AASHTO LRFD Bridge Design Specifications* it specifies that this force would be applied six feet (1.83 meters) above the surface. With the bridge only having handrails for the superstructure, the height is only three feet (0.91 meters) above the surface so this force can be nullified. However, wind also creates an uplift force on the structure which will have to be considered as well. The code specifies that the vertical uplift force cause by wind is calculated using 0.02 ksf (97.65 kg/m^2) (AASHTO, 2004). The deck of the bridge is eight feet (2.44 meters) which makes this value 0.160 klf (238.27 kg/m) across the entire deck.

The group was not able to consider seismic loads due to the time constraint of only seven weeks as well as the footing size calculations. This is partly due to not having adequate information about the soil type that is present in the location the bridge would be place. The group did know that the sponsor said the soil majority clay in a Zoom meeting. But the group knew how much soil's property can change based on the locations in proximity of water as the soils water content will change the soils properties from the group's prior coursework in their foundations class taken at WPI. The group was also aware that depending there could be different layers of material such as sand, gravel, and silt which could change the footing required. This means the codes the group designed for were the dead load, pedestrian load, vehicle load, wind load, and uplift (Table 3.1)

	Value	Imperial Unit	Value	SI Units
Dead Load (DL)	23.23	lb/ft^2	113.3	kg/m^2
Pedestrian Load (PL)	90	lb/ft^2	439.42	kg/m^2
Vechile Load (LL):				
Point load for front axle	2000	lbs	907.18	kgs
Point load for back axle	8000	lbs	3628.74	kgs
Wind Load (WS)				
Column / Arches / Beam Windward	50	lb/ft^2	244.12	kg/m^2
Columns / Arches Leeward	25	lb/ft^2	122.06	kg/m^2
Uplift	20	lb/ft^2	97.65	kg/m^2

Table 3.1: Design loads table for pedestrian bridge (AASHTO, 2009; AASHTO, 2012).

The group knew these values would be used in load combinations as multiple loads present at a single point in time. The group was using RISA-3D for the analysis of the structure and one aspect of this software is that this software has built in load combinations based on the selected design code in the software. The group planned on applying these loads to the structure in RISA-3D. For this reason, the group planned to use the load combinations would be based on the 2018 *International Building Code* (Table 4.1).

	Description	Solve	PDelta	SRSS	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	IBC 16-1	☑	Y		DL	1.4								
2	IBC 16-2 (a)	☑	Y		DL	1.2	LL	1.6	LLS	1.6	RLL	.5		
3	IBC 16-2 (b)	☑	Y		DL	1.2	LL	1.6	LLS	1.6				
4	IBC 16-2 (c)	☑	Y		DL	1.2	LL	1.6	LLS	1.6	RL	.5		
5	IBC 16-3 (a)	☑	Y		DL	1.2	RLL	1.6	LL	.5	LLS	1		
6	IBC 16-3 (e)	☑	Y		DL	1.2	RL	1.6	LL	.5	LLS	1		
7	IBC 16-3 (b)	☑	Y		DL	1.2	RLL	1.6	WL	.5				
8	IBC 16-3 (d)	☑	Y		DL	1.2	WL	.5						
9	IBC 16-3 (f)	☑	Y		DL	1.2	RL	1.6	WL	.5				
10	IBC 16-4 (a)	☑	Y		DL	1.2	WL	1	LL	.5	LLS	1	RLL	.5
11	IBC 16-4 (b)	☑	Y		DL	1.2	WL	1	LL	.5	LLS	1		
12	IBC 16-4 (c)	☑	Y		DL	1.2	WL	1	LL	.5	LLS	1	RL	.5
13	IBC 16-6	☑	Y		DL	.9	WL	1						

Table 4.1: Load Combinations in RISA-3D based on *International Building Code* with load factors

The group would have used the design loads they calculated for the bridge and to fill in these values and model the loads on to the bridge. This would allow the students to run the analysis of the different load combinations on the structure. The software would run the analysis of the shear, moment, and other structural analysis of each member based on the design loads as well as the deflections the loads cause.

These results would be analyzed by the group to ensure no beam has more load than it could handle. The group would also be able to easily check that no deflection of a member passes 1/360 times the span length under an unfactored pedestrian load (AASHTO, 2009). This would allow the group to look at members that passed and be able to size down these members, while also looking at members that failed for these members to be sized up or even a new design of that section to be reconsidered. However, the group did not get to the section of the project as the time constraint of seven weeks made it difficult to finish all the necessary work and calculations.

In order to design a rainwater collecting system that worked, the group needed to properly size the gutters and the rainwater collecting tank. The group first looked at the gutters to be able to transport the water to the rainwater collecting tank. The group investigated the 2018 *International Plumbing Code* to have their design met regulations. The code specified that "the size of the vertical conductors and leaders, building storm drains, building storm sewers and any horizontal branches of such drains or sewers shall be based on the 100-year hourly rainfall rate." With this information the group looked to find the 100-year storm information in Bahia, Brazil. There is no codes or regulations that the team could find specifying the exact rainfall in a 100-year storm in this area, so the group started researching hurricane rainfall and record storm rainfall in the area. The group found an article that specified that "a list compiled by meteorologist Jérôme Reynaud includes several 24-hour totals exceeding 400 mm from the Petropolis area on March 17-18, 2013, including 474.7 mm" (Southeastern, 2020). The group used this number as their storm data due to the lack of information that could.

The group went back to the *International Plumbing Code* in order to now be able to size the gutters and leaders that would transport the water to the rainwater tank. Based on Table 1106.2 in this code and the average hourly rainfall, the group decided to use 2" leaders which would have a capacity of 30 gallons per minute (gpm). The group calculated this size would work due to the average hourly rainfall was 474.7mm/day which translates to 19.75 mm/hr (.778

in/hr). This translates to .329 mm/min. The group then calculated the volume of rain by multiplying .329 mm/min by the area of the roof, 123 m^2 to get a volume of 40.4875 L (10.69 gallons). The group then multiplied this value by a factor of safety of 1.5 to make sure the volume of water is accurate due to not finding the exact value that is used in this area. This made the volume come out to 16.05 gallons (60.75 L). The 2" (5.08 cm) leader had a capacity in the code of 30 gpm (113.55 Lpm) so the group was confident the pipe could handle the volume of rainwater that was calculated.

The horizontal gutters had its own table that is used to determine the size and slope. The group knew the gutters had to be able to process 16.05 gallons (60.75 L) and the table specified that a 1 ½" x 2 ½" (3.81 cm x 6.35 cm) gutter with a ¼" slope per foot (2.08 cm/m) could handle 26 gpm (98.41 Lpm). So, the group selected this size of gutters and was able to move onto the size of the tank. The group decide the gutters will directly drain into the top of the storage tanks to eliminate the need for a pump to transport the water to the tank by allowing gravity to do the work (Figure 27).

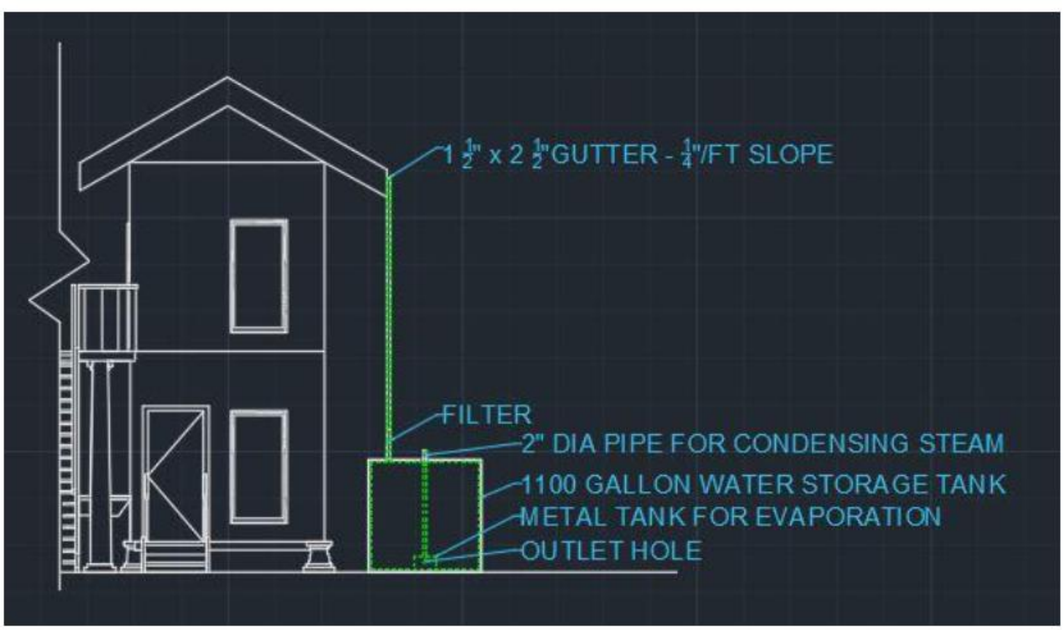

Figure 27: Side elevation of rainwater collecting system

The group determined if the rainfall for a storm in one day was used, the size of the tank would have to be 58,302 L (15,403 gallons). This would require an extremely large tank to hold the rainwater, so the group looked for the average rainfall in Bahia to design a tank that would be fitting for the reservation. The group used the value of rain needed to be stored enough rainwater for average rainfall during the wet season. In Bahia, more specifically Itabuna, which is close to the reservation, the highest average rainfall is 171 mm (6.73 in) in the month March (Itabuna). March has 31 days so the average rainfall for a single day in March is 5.5 mm (0.22 in). The group used the same method of finding the volume produced by this amount of rain by multiplying by 123 m^2 (1,324.18 ft^2) to get a volume of 676.5 L (178.73 gallons).

The group then used another article that specified that in Bahia there is on average 223 days of the year it rains (Average, 2020). The group divided 223 by 364 days to find out it rains 61% of the time. This means it rains 4 days a week on average, by multiplying .61 by 7 to get the number of days a week it rains. The group multiplied the 676.5 L (178.73 gallons) by 4 to figure the tank should be able to hold 2,706 L (714.92 gallons) so it can handle an average week of rainfall without overflowing. Due to not having a code regulate how much rain occurs in Bahia, the group used a factor of safety again of 1.5 to ensure the tanks will be able hold the amount of water needed. This brought the volume up to 4,059 L (1,072.38 gallons) of water.

The group choose to use a 1,100-gallon plastic storage tank to make sure the design is cheap and efficient. Since the rainwater was coming from the gutters of the buildings, the group needed to add filters in order to filter out all the debris that gets picked up in the gutters. This filter will have to be checked frequently in order to minimize the ensure the flow is not interrupted which will back up the system. The group selected to use a plastic storage tank and piping in order to have easy removal of the filter and have a cheap and accessible replacement parts in case a part of the system breaks. Through research the group found that plastic #1, #2, or #4 plastic must be used because these plastics are BPA-free (Long, 2020).

With using plastic, the group had to be mindful of the amount of sunlight that enters the tank in order to minimize the algae growth. One way to minimize the amount of sunlight that enters the tank is to paint the storage tank black. The paint would absorb all the sunlight and mitigate the risk for algae to grow inside the tank.

Through research the group found that standing water is grounds for mosquitoes to lay their eggs. This is another factor that had to be thought of when selecting and design the tank. The group found that in order to mitigate the risk of mosquitoes laying their eggs, the group could one put a teaspoon of oil in the tank, which will separate from the water and stay on the top of the water, and will make mosquitoes will not lay their eggs due to this protective layer (Long, 2020). The group also found out that the system had to be sealed in order to minimize the exposure that mosquitoes will have to the standing water. To do this the group found that collecting rainwater and storing it, the system must make sure the system in water tight and has not leaks for mosquitoes to get in, as well as adding filters that are "no coarser than 1mm" (Keep, 2018). This will eliminate mosquito larvae that could be picked up in the gutters or on the roof.

The tanks will be located directly underneath the leader of the gutters and will have a PVC Y piece with a valve in order to be able to control which tank receives the rainwater. The water that is collected by this system will be solely used for showering, sinks, and toilet use due to the rainwater having to encounter the roof and gutters. This would require as chemicals would have to be added to make the water safe to drink or a be boiled to get rid of any toxins. The sponsor showed interest in using this water for potable use.

The team decided that between the two tanks, the water will be boiled in order to sterilize the water instead of having to add specific amount of chemicals as the sponsors goal is to be as sustainable as possible and adding these chemical could cause harm to their greywater garden. In order to this, another tank must be added to the design in order to allow for the water to be boiled inside of it. The top of tank that is responsible for boiling the water should be higher than the top of the other water tanks and slanted towards the tank that is empty. This will allow for the water that has been evaporated to condense at the top on the tank and flow towards the tank that is empty.

There are two methods the sponsor could use to evaporate this water. One being using the sun’s rays and a clear top of the tank to allow for the sun’s ray to heat up the water. Doing this however will allow for algae to grow as we talked about earlier, so the team decided to use an open flame below the tank to apply the necessary heat to the system to evaporate the water. This, however, would have to make this part of the system that is open to the flame to be made from metal and not made of plastic as plastic will leach into the water at higher temperatures. For this the group design this system that would require a small metal tank, a tube to transport the steam up to the top, and at the top there will be a tube that will be attached to the tank that slopes towards it (Figure 28).

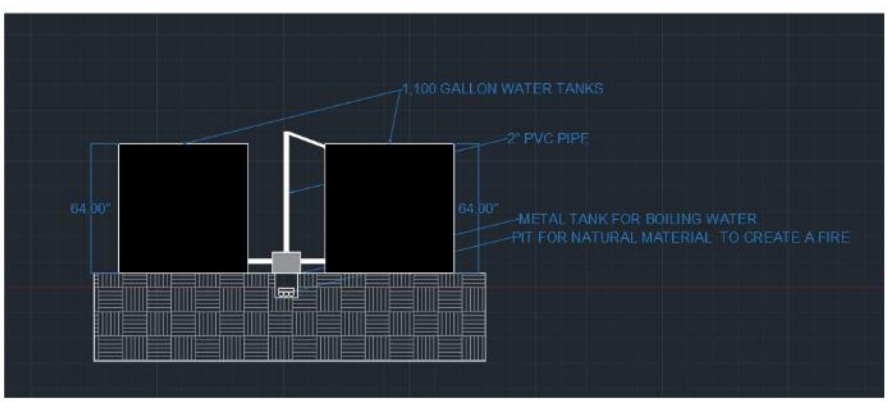

Figure 28: Rainwater collection tank with evaporating system

Conclusion

Throughout this term, the group learned a tremendous amount about the process of designing a greywater system and pedestrian bridge. The group started this project and had never even heard of greywater and had not designed a bridge of this size before. The group gained an understanding surrounding the codes and regulations around both systems as well as the design and analysis process. The group used the *AASHTO LRFD Specifications for the Design of Pedestrian Bridges*, *AASHTO LRFD Bridge Design Specifications*, *International Building Code*, and the *International Plumbing Code* as the codes for regulations surrounding this system and structure. Through designing this system and structure, the group was able to develop an understanding of the way the code is wrote and how to use it to design these structures. The group also learned a lot about the different topics that these codes encompass even the topics the group was not able to complete. The group learned a lot about the different design loads and load combinations that are required in designing a bridge, which will be directly useful in their future careers.

The group learned a lot about what greywater is and the proper way to handle and process this water that is up to health codes and regulations. The group wants to make sure the sponsors uses the greywater garden correct and recommends that the sponsors empty the greywater tank every 24 hours due to health codes and due to the nutrients start breaking down after this time. The group also recommends that the banana circle be filled first, then the sugarcane and brassicas circle next, and if any is left over to distribute it amongst the constructed wetlands on the sides of the garden. This is due to the banana circle requiring a significant volume of greywater and being an interest of the sponsors. The group recommends watering the constructed wetlands last as the volume of greywater this system can process is significantly large, whereas the other the sugarcane and brassicas circles cannot process a tremendous volume of greywater. This ensures all the plants are getting their water requirements and is a beneficial part of the greywater garden

The group recommends using 1/7 of the weekly requirement of greywater for each plant circle each day. This is to ensure the proper absorption of the greywater into the soil and plants to mitigate the risk of runoff. Another method to minimize the risk of run off is to make sure the clay around the garden in compacted to a degree where the permeability of less than 10 ft/sec (Handbook). This minimizes the absorption rate of the water into the soil and ground water that is surrounding the greywater garden.

The group did not get around to being able to apply the different design loads and load combinations as the timeframe of seven weeks created a challenge to the group; however, the group did learn a lot about the factors that go into designing a pedestrian bridge as well as the analysis of it even though the group was not able to complete the analysis in the seven weeks. The reason for this was the sponsor need for a greywater garden that would be used to process the greywater on the reserve. The group wanted to add a design of pedestrian bridge because of their interest in marine structural engineering, more specifically being a professional engineer who designs bridge, in the future. For this reason, the group prioritized the greywater garden first to ensure the sponsors have a design of a greywater garden that is up to code and functioning.

Another factor that played into the group unable to completely designing the pedestrian bridge requires a vast knowledge of the soils in the limits of construction of the bridge as well as the seismic design values that should be used in the Bahia, Brazil, and the group could not find any information on the soil or design values. The group recommends if the sponsors are interested in having this bridge on their site, to bring this design to an engineer that can obtain these values and design criteria to ensure the design is up to code.

For the rainwater collection system, the group recommends the sponsors clean the gutters regularly to minimize the amount of debris in the rainwater as the filter getting clogged will reduce the flowrate. This would cause the system to build up rainwater and not be able to process the water completely. The group also recommends using this water only after it has been evaporated, or filtered by another method, before being used for the house as this water can contain contaminants for debris on the roof and in the gutters. The group also recommends the sponsor to move the water between storage tanks as this will help keep the water from developing algae and mitigate risk for mosquitos to lay eggs in the tank.

Design Statement

This project included the design and use of a greywater garden and building a pedestrian bridge, both of which were performed using the ACP and ABET process. These projects follow specific requirements set forth by Worcester Polytechnic Institute (WPI) and ABET to complete a design capstone. WPI calls this design capstone the MQP and according to ABET, an engineering design capstone must be open ended, use an iterative design process in which the student should use basic science, mathematics, and engineering sciences. The design component of these projects must show the development of student's creativity while using modern design theory in order for the student to consider alternative solution that take into account the safety, reliability, and aesthetics to design the most efficient and effective design.

The student had two projects to design, the first project was designing a greywater garden which required the group to use knowledge gained from researching greywater, greywater systems, more specifically a greywater garden as the sponsors showed interest in implementing this system, crop rotation, the weather in Bahia, Brazil, and different soils properties of water retention to gain an understanding of the project at hand. The student created four objectives that would allow the student to break the project into manageable sections. The group then followed these objectives to ensure the project would be able to be completed.

The group designed the greywater garden based on the requests of the sponsor in using a banana tree in the garden as well the use of crop rotation to make sure this design is sustainable. The group used the average rainfall for the wettest and driest months to design the systems for the extremes to ensure the system will be able to work year around. The group looked at the soil retention rate of water as well as the amount of water the different plants could process to make sure the system minimizes the runoff, as this will end up polluting the local waterway. This was an important aspect of the design as the waterway is the reserves freshwater supply.

The group then investigated different crops that work well in crop rotation with banana trees and selected to use sugarcane, rapeseed, and broccoli for this reason. The group selected these plants based on their natural ability to limit pests and diseases, as well as replacing the important nutrients into the soil. The group selected to implement a constructed wetland around the lower elevations of the garden to mitigate the risk of the runoff entering the waterway.

The group ran the calculations of the amount of water each plant can process then subtracted the amount of rainfall that would fall in that area. The group then resized the garden to be able to properly handle the amount of greywater created from the reserve and rainwater that the system would have to handle until the garden was large enough to be able process all of this water. To do this the group increased the size of the constructed wetlands to ensure there was adequate water storage. To ensure the students design this system to code, the group made sure the system followed the *International Building Code*.

The second project was a pedestrian bridge for the reservation. The student designed this bridge by using the knowledge the student has learning throughout his undergraduate courses, the student's internships at engineering companies in the summer, as well as the knowledge the group has gained through literature review throughout the project. This was to ensure the safety of the structure and its users. To be able to create a design of a pedestrian bridge that is structurally sound and up to the code, the group used the code *AASHTO LRFD Specifications for the Design of Pedestrian Bridges* and *AASHTO LRFD Bridge Design Specifications* for their design loads.

To design the bridge, the student created four objective which would allow the student to break the project into manageable sections. The group then followed these objectives to ensure the project would be able to be completed. The group used the site plan that the sponsors had sent over in an AutoCAD file in order to get proper dimensions and elevations to design the bridge with. The group created the design based on the materials the sponsors wanted to use, the number of footings, the location of the footings, as well as the site the bridge would be constructed at and took into account the water source the bridge was passing to ensure the sustainability of the structure.

The group created a preliminary design of the bridge that was then sent to the advisor to make sure the feasibility and construction of the bridge was fitting to the reserve and the scope of this project with it only being in seven weeks. The group made sure to include lateral support as well as uplift resistance as these are points of interest is designing structure. The group then used the feedback in order to create a more fitting design for the nature reserve and continued to revise the design until the student was satisfied with the aesthetic appeal.

The group then used their knowledge from prior classes and internships to model the bridge in RISA-3D in order to apply the loads based on the code to the model and properly size the members. The group used the software RISA-3D to perform the structural analysis due to the student having used the software in a summer internship prior to the project and the software's ability to analyze structures. The group planned to resized the beams by increasing the size of beams that failed while also trying to minimize the size of the beams that passed in order to create the most efficient design but due to time this part of the project was unable to be completed.

Licensure Statement

It is important for civil engineers to get their professional license because having a professional license certifies a person to be able to create, sign, and seal an engineering design that can be brought to public authority for approval. This license ensures that the engineer can perform their engineering responsibilities to a “high standard of ethics and quality assurance” as their work has the potential to affect numerous people (PE, 2020). In order to become a licensed engineer, the person must complete several steps:

- “Four year degree in engineering from an accredited program
- Pass the Fundamentals of Engineering (FE) exam
- Complete four years of progressive engineering experience under a Professional Engineer (PE)
- Pass the Principle and Practice of Engineering (PE) exam” (PE, 2020).

These steps have been put into place to ensure the health and safety of the public and having the license gains respect among other PE’s and their trust in the work produced. This license also always for better career development as “employers are impressed with engineers who have their PE license. Licensure not only enhances (the engineers) stature, it shows commitment to the profession and demonstrates heightened leadership and management skills” (Why, 2020). This is important in the engineer’s professional life as this is a major step in becoming a respected engineer in the eye of the public and employer.

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