

# *Construir Una Casa es Como Construir Una Vida*



## Assessing Sustainable Bio-construction Alternatives Locally Appropriate for the Parish of San Rafael, Ecuador

### **Report Completed by:**

Abigail King  
Caitlin Lopez  
Kara Martin  
Kathy Suqui

# **Assessing Sustainable Bio-construction Alternatives Locally Appropriate to the Parish of San Rafael of the Azuay Province, Ecuador**

---

An Interactive Qualifying Project Report Submitted to the Faculty of the WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science.

**Date: 03/03/2017**

Abigail King  
Caitlin Lopez  
Kara Martin  
Kathy Suqui

**Report Submitted to:**

Dr. Laureen Elgert  
Dr. David DiBiasio

---

This report represents the work of four WPI undergraduate students submitted to the faculty in partial completion of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review. For more information about the projects program at WPI, please see

<http://www.wpi.edu/Academics/Projects>



## **ABSTRACT**

This project involved the collaborative effort of local people and volunteers to promote sustainable community construction. Sustainability incorporates three pillars: society, environment, and economy. These considerations together encapsulated the present needs of a community and plans for the future. These sustainability pillars were applied to a bio-construction initiative in the Andean community of San Rafael, Ecuador. Our goal was to cooperate with the Azuay Prefecture, San Rafael administration, and community members to contribute to sustainable bio-construction designs that are locally appropriate to the parish of San Rafael. Project objectives included assessing construction needs from the community, interpreting the preferences of the people, and creating a design catalogue conducive to future construction projects San Rafael. We incorporated a human-centered design approach to this project to ensure desirability, feasibility, and viability of our materials assessment. Our methodology included organizing a community forum and semi-structured interviews, and implementing a decision matrix. In this way, we assessed materials with regards to societal importance and presented simple sustainable bio-construction designs in the form of a customized design catalogue.

## **ABSTRACTO**

Este proyecto involucra al esfuerzo colaborativa de la gente local y de los voluntarios para apoyar a construcción sostenible de la comunidad. Sostenibilidad incorpora tres pilares: la sociedad, el ambiente, y la economía. Estas consideraciones juntas encapsulan a las necesidades del presente con las planificaciones del futuro. Estos pilares de sostenibilidad fueron aplicados a la iniciativa de bio-construcción en la comunidad Andina de San Rafael, Ecuador. Nuestra meta fue a cooperar con la Prefectura de Azuay, la administración gubernamental de San Rafael, y los miembros de la comunidad para contribuir diseños cuales son apropiados localmente a la parroquia de San Rafael. Incorporamos al concepto de diseño centrado en el humano a este proyecto para asegurar la deseabilidad, factibilidad, y viabilidad de nuestra evaluación de materiales. Nuestra metodología incluyó organizar una charla comunitaria y entrevistas sema-estructuradas e implementando un matriz de decisiones. De esta manera, evaluamos a los materiales con respeto a la importancia social y presentamos diseños de bio-construcción simples en forma de un catálogo de diseños.

## EXECUTIVE SUMMARY

### INTRODUCTION

Sustainable bio-construction is defined by three pillars of sustainability: society, environment, and economy. These pillars can be actualized through human-centered design: a concept revolving around the desirable, viable, and feasible aspects of a product to a user. Social sustainability ensures a **desirable**, long-standing project that is reflective of community culture. The environmental pillar represents the **viable** use of natural resources and accommodation to the environment. Economic sustainability refers to **feasible** budgeting of high quality work and resources. All three pillars must be actualized through human-centered design to implement a sustainable approach in community bio-construction. Bio-construction depends on readily available resources within a specific environment. This practice incorporates locally available materials and workforces to improve the infrastructure of a community. Sustainability addresses the needs of the present while planning for the future. Together these concepts compose sustainable bio-construction, which preserves local resources while developing structurally enduring buildings.

The parish of San Rafael, located in the mountains of the Azuay province in Ecuador, is spearheading the development of their community through a sustainable bio-construction initiative (Azuay, 2011). One example of bio-construction showcasing sustainable design is the ongoing restoration of a government building sponsored by President Luis Yanez of the Decentralized Autonomous Government (GAD) of the parish of San Rafael, the Azuay Prefecture, and the community members. The restoration intends to preserve historical architecture while improving infrastructure and maintaining community member involvement.

The goal of this project was to work with the sponsors and the community members to contribute to sustainable bio-construction designs that are locally appropriate to the parish of San Rafael. Our three objectives collectively incorporate all three pillars of sustainability. The first objective was to **assess** community needs, building designs representative of San Rafael architecture, environmental conditions, and economic factors through observation and data collection. The second objective was to **interpret** collected data and determine the ranked importance of materials with respect to community cultural preference, environmental appropriateness, and economic feasibility. Third, we followed the determined preferences in order to **create** a design catalogue of buildings, walls, and concrete connections. This final deliverable was presented to the community for future construction.

### BACKGROUND



*Figure 1. A vernacular building restored by Badillo*

We performed background research on the three pillars of sustainability as they apply to Ecuador to understand our project. Through this literature review, we were able to apply what we learned to the sustainable bio-construction project in San Rafael.

The social pillar of sustainable bio-construction depends on preservation of cultures and traditions when designing buildings (Republic of Ecuador, 2008). According to vernacular architect Juan Diego Badillo, "Traditional buildings [are] perfectly designed to deal with the Andean landscape and climate" ("Saving Ecuador's Vernacular Architecture," 2014). Vernacular architecture is the process of constructing and restoring these traditional

structures while maintaining the culture and beauty of the original buildings (Edwards, 2011). In this way, traditional aesthetic and structural integrity can co-exist. **Desirable** bio-construction in San Rafael can be modeled after vernacular architecture.

The environmental pillar ensures regionally appropriate construction while preserving natural surroundings (Goodland, 1995). A community must consider this when planning sustainable development to prevent depletion of natural resources. Conditions such as geography, natural disasters, and climate must be factored into structural design to reduce negative impact and improve longevity of the structure. Environmental sustainability requires the controlled use of accessible resources and the understanding of ambient conditions. San Rafael's environment must be taken into consideration when planning **viable** bio-construction projects.

The economic pillar of sustainability ensures a positive impact on the local economy through appropriate construction budgets. Case studies in Bangladesh have proven the financial impact that construction can have on local economies (Alam, G.M. 2009). Completion of sustainable bio-construction projects depends on affordability and managing a budget. When the funds are depleted from a project, work cannot continue until more funding is available, according to officials from the community. Therefore, materials must be affordable to build homes and structures that last. A long term goal of resiliency and replicability is vital to sustain construction projects. Determining local resource costs and demands for a project promotes **feasible** construction.

## OBJECTIVES

Through working with the Azuay Prefecture, the administration of San Rafael, and the community members, we were able to contribute to sustainable bio-construction designs that are locally appropriate to the village of San Rafael. Our project was accomplished through the completion of three objectives:

1. **Assess** community needs, building designs representative of San Rafael architecture (or sustainable construction designs), environmental conditions, and economic factors through observation and data collection.
2. **Interpret** community preferences based on sustainability factors and determine the ranked importance of materials.
3. **Create** a design catalogue of the separate components of a building specific to the community for future construction.

## METHODOLOGY

For the first objective, we traveled to different communities in San Rafael to assess community needs, representative building designs, environmental conditions, and economic factors. We conducted semi-structured interviews throughout four communities within San Rafael: Dagnia, Tullosiri, Chaguar, and Sharug. We asked the residents about their homes and what materials they used and preferred. We also collected dates of season changes, information on location of materials, and cost estimates for materials and construction labor in San Rafael. To speak with a larger audience, we held a community forum and conducted surveys. The information gathered was useful for assessment of the community and culture, while also building relationships. In addition to interviews, we assessed the buildings in the different communities. From there, we generated profiles of 41 different buildings throughout San Rafael recording details such as material, roofing, connections, and stories. This data collection helped us understand architecture in San Rafael within the three pillars of sustainability.

We gathered this information and moved to the second objective: interpreting the data from interviews and observations. We determined which criteria of construction were important to the community members including material types, ability to resource locally, aesthetic, cost, and structural integrity through compressive strength. This information was implemented into a decision matrix that allowed us to first rank importance of criteria, then deduce which materials were most preferred by the community.

After determining the preferred materials, we completed our last objective. This was to create a construction design catalogue of separate building components that combines effective structural stability with community culture, traditions, and preferences. The designs in this catalogue preserve San Rafael architecture while augmenting stability and structure of buildings.

Our group split up into two teams in order to effectively complete these objectives. The Linguistics Team consisted of teammates with the most advanced Spanish speaking skills. They conducted the interviews, communicated with the people and GAD project leaders, led and advertised the community forum, and translated verbally and on paper. The Design Team consisted of the teammates with more technical experience in computer programs for civil design. They created the building profiles, performed research on structure supports for adobe and cement, networked with civil engineers based in Cuenca, and created the designs for the catalogue.

## **RESULTS**

Each finding reflects different combinations of the pillars of sustainability. Oftentimes, the pillars can overlap, thus bringing **desirable**, **viable**, and **feasible** solutions into light.

### **Finding 1: Adobe, cinderblock, and wood are the most common building materials in the parish**

- A. *Adobe is repairable and naturally available to the community, but it is more time-consuming to build with and less popular.*
- B. *Cinderblock is quicker to build with and cheaper, but is not as strong or durable as adobe.*
- C. *Aesthetic is important to the people of San Rafael*
- D. *Wood is commonly used as support framework and flooring in buildings.*

These findings reflect the societal, environmental, and economic pillars of sustainable bio-construction. A quicker building time is **desirable** to contractors and homeowners alike. Local availability of materials is critical for a construction design to be **viable**. Quicker building times and use of common materials, such as wood, can lower the required budget for a project, thus increasing **feasibility**.

### **Finding 2: Certain materials are not useful for San Rafael**

- A. *Ceramic tiles are not used due to high cost and lack of practicality.*
- B. *Bamboo is not used, because it must be outsourced from the coast.*

This finding is reflective of the environmental and economic pillars of sustainable bio-construction. It is important for the community members to have locally sourced materials to use in construction to make it **viable**. In addition, using locally available materials is more economically **feasible** for construction to avoid outsourcing.

### **Finding 3: Cost influences the materials and size of a construction.**

- A. *Interviews reveal adobe is more expensive to build with than concrete.*
- B. *Approximately 35% of community members received assistance from MIDUVI, an Ecuadorian government agency that provides construction assistance services*

The economic pillar is directly related to this finding as it is important that the construction is financially **feasible** for the members of the community.

### **Finding 4: Implementing a design catalogue that is inclusive of community preferences could be a beneficial construction tool**

- A. *Structural design in San Rafael could benefit from several engineering concepts, such as minimal beam sizing, minimal rebar calculations, and symmetrical design*
- B. *Compiling the beginnings of a construction catalogue could be beneficial for builders in the community*

These findings reflect the economic and social pillars of sustainable bio-construction. Publishing minimal requirements for materials, such as rebar, can reduce the cost of a project and make it more **feasible** for a builder. Creating designs based on assessments and interpretations of community preferences could make our project **desirable** for the people of San Rafael. Local contractors can use the designs as a point of reference and a source of inspiration for when they build the structures. Symmetry also adds to aesthetic and structural longevity.

## **CONCLUSIONS AND RECOMMENDATIONS**

Bio-construction in San Rafael involves several key materials and common building practices that are reflective of its culture, applicable to its environment, and supportive of its economy. Adobe, cinderblock, and wood are the most common construction materials in the parish. Although wood is currently used primarily for paneling and framework, it can be used for different purposes and should be taken into consideration for future projects. The problem with wood, as pointed out by a representative from FEPP (Fondo Ecuatoriano Populorum Progressio, 2015), is that harvesting wood is a process that takes down forests. This can be addressed by choosing more renewable resources, such as bamboo. Although bamboo and other materials are not traditionally grown in San Rafael, future projects could tackle the challenge of growing bamboo locally and away from its natural habitat on the coast. If future groups could learn how to grow bamboo locally, eco-friendly designs could be implemented into the catalogue to further satisfy the environmental **viability** of the project.

Cost is important to the community members when planning for construction. Future endeavors may include approaching material fabricators, conducting surveys with local material fabricators, and compiling gathered data in order to make full cost estimates for the construction of our designs. By ensuring a **feasible** cost to community members and outlining a budget, local contractors are more likely to make use of our catalogue.

Implementing a design catalogue that is inclusive of community preferences could be a beneficial construction tool for the community members and builders. Cultural features were combined with effective construction techniques to encapsulate the character of San Rafael as well as the structural integrity and longevity of the buildings. A next step for this project could be collaborating with University of Cuenca professor, Dr. Francisco Flores, to involve more students in creating house and building designs. It is also possible to recommend collaboration with the University in terms of commencing construction of the aforementioned designs.



## Table of Contents

1. INTRODUCTION.....	1
2. BACKGROUND .....	3
1. The Three Pillars in Sustainable Bio-Construction.....	3
2. Socia Pillar: Incorporating the Traditions and Needs of the People.....	3
3. Environmental Pillar: Accounting for the Environment as a Stakeholder .....	4
4. Economic Pillar: Maintaining Economic Viability .....	5
3. METHODOLOGY .....	6
1. Assessing Community and Volunteer Preferences.....	6
2. Interpreting Preference Data and Building Profiles.....	7
3. Creating a Design Catalogue.....	8
4. RESULTS AND ANALYSIS.....	9
1. Finding 1.....	9
2. Finding 2.....	11
3. Finding 3.....	12
4. Finding 4.....	13
5. CONCLUSIONS AND RECOMMENDATIONS.....	17
6. REFERENCES.....	19
7. APPENDICES .....	21
Appendix A1. Badillo Vernacular Architecture.....	21
Appendix A2. Earthquakes in Ecuador .....	22
Appendix A3. Using Mardin Stone in Turkey for Construction .....	23
Appendix A4. Case Study on Adobe.....	24
Appendix A5. Local Fabrication through MASS Design Group.....	25
Appendix A6. Sustainable Construction for Earthquakes and Seismic Activity .....	26
Appendix B1. Ethical Considerations .....	27
Appendix B2. Community Questions: Interviews.....	28
Appendix B3. Community Forum Survey .....	29
Appendix B4. The Environment as a Stakeholder.....	30
Appendix B5. Pugh Matrix .....	31
Appendix C1. Data from Analyzed Buildings in San Rafael and Other Communities .....	33
Appendix C2. Calcuations to Find Minimum Steel Requirements for Reinforcing Concrete ...	34
Appendix C3. Cumulative Interview Data.....	35

## TABLE OF FIGURES

Figure 1. A vernacular building restored by Badillo.....	iii
Figure 2. An auditorium being built in San Rafael. ....	1
Figure 3. The pillars of sustainability. ....	3
Figure 4. The old government building in Sharug .....	7
Figure 5. The Pugh Matrix as applied to materials and community preferences in San Rafael .....	8
Figure 6. Construction materials in San Rafael .....	9
Figures 7 & 8. Adobe with concrete façade vs. bare adobe.....	11
Figure 9. Wooden beams used for support .....	11
Figure 10. Different ways buildings were constructed. ....	12
Figure 11. Results from the community forum survey about what is most important to community members.....	13
Figure 12. Adobe Wall Design. ....	15
Figure 13. Minimum Steel Requirements for Reinforcing Concrete.....	15
Figures 14 & 15. Full designs of the government building, the first with adobe, the second with cinderblocks.....	16
Figure 16. A collapsed building.....	22

# 1. INTRODUCTION

## Defining a Project in Sustainable Bio-Construction

"Building a home is like building a life."<sup>1</sup> Sustainable bio-construction in rural Ecuador is not only about creating shelter; it is about encapsulating lifestyle and culture. Bio-construction depends on the resources readily available within a specific environment. This practice incorporates locally available materials and workforces to improve the infrastructure of a community. Sustainability addresses the needs of the present while planning for the future. At the 2005 World Summit, the United Nations established the three main pillars of sustainability as the society, the environment, and the economy (United Nation, 2005). These pillars are the foundation of a sustainable system; if any pillar is weakly represented, sustainability collapses. The social pillar ensures the longevity of community interest in a project that is reflective of their culture. The environmental pillar represents the appropriate use of natural resources and accommodation to the environment. The economic pillar refers to budgeting for quality of work and resources.

These pillars can be actualized through human-centered design: a concept revolving around the **desirable**, **viable**, and **feasible** aspects of a product to a user. In the context of sustainable bio-construction, a project must be **desirable**, **viable**, and **feasible**. Social sustainability ensures a **desirable**, long-standing project that is reflective of community culture. The environmental pillar represents the **viable** use of natural resources and accommodation to the environment. Economic sustainability refers to **feasible** budgeting of high quality work and resources. A building provides a sustainable place in the community when structural and social needs are met simultaneously. Sustainable bio-construction in rural Ecuador is accomplished by engineers and community members using customized preferences.

The Ecuadorian government has actualized the ideals of sustainability through societal, environmental, and economic perspectives. In 2013, the National Plan for Good Living was implemented nationwide by the Ecuadorian government to promote community solidarity, co-responsibility, replicability, and harmony with nature (Correa, 2013). This nationwide plan calls towards incremental development through community-driven works such as bio-construction. Further Ecuadorian legislation in the newest national Constitution succeeded in recognizing the environment as a stakeholder in arenas such as land development (Republic of Ecuador, 2008). These precedents are apparent in the individual initiatives that provinces are taking to increase sustainable development. Sustainable bio-construction, defined by the three pillars, is preceded by ideas of sustainable architecture that correspond with the same three categories: society, environment, and economy.

An example of these initiatives is the sustainable bio-construction of community buildings in the parish of San Rafael, a community located in the mountains of the Azuay province. San Rafael acknowledges the societal, environmental, and economic requirements of sustainability for inciting positive and efficient change. One way this is evident is in the community's continuous living laboratory construction. The living laboratory is a sustainable bio-construction project in San Rafael that includes the construction of dormitories, a cafeteria, and an auditorium. In Figure 2, there is a photograph of the bamboo, which is native to the coast. This was built by *minga*, or community



*Figure 2. An auditorium being built in San Rafael*

---

<sup>1</sup> David. (2017, Jan). Personal interview with FEPP Representative.

volunteers. However, funds are currently depleted for this particular project and progress is on hold but other projects remain in progress.

San Rafael is in the process of restoring a government building sponsored by President Luis Yanez of the Decentralized Autonomous Government (GAD) of the Parish of San Rafael, the Azuay Prefecture, and the community members. A representative from the Prefecture, Enrique Loaiza, was our sponsor in this project and helped us understand the background of the community and the projects. The GAD included Presidente Luis Yanez and Gustavo Narvaez, who aided us in the community and provided us with information and hospitality. For the project, the retrofitting of the government building intends to preserve historical architecture while improving stability and community involvement. This new construction serves as a model for future sustainability endeavors. By documenting different materials and building techniques, the people of San Rafael and parish advocates are developing sustainable construction alternatives.

The goal of this project was to cooperate with the Azuay Prefecture, San Rafael administration, and community members to contribute to sustainable bio-construction designs that are locally appropriate to the parish of San Rafael. These objectives will be seen through the three pillars of sustainability: society, environment, and economy. The first objective was to **assess** community needs, building designs representative of San Rafael architecture, environmental conditions, and economic factors through observation and data collection. The second objective was to interpret collected data and determine the ranked importance of construction materials. Third, we followed the determined preferences in order to create a design catalogue of buildings, walls, and concrete connections. As explained above, a project must be **desirable, viable, and feasible** in the context of the pillars of sustainability. By accomplishing these objectives, we determined locally-appropriate sustainable bio-construction designs of separate parts of buildings in San Rafael that are **desirable, viable, and feasible**.

## 2. BACKGROUND

### 1. The Three Pillars in Sustainable Bio-Construction



*Figure 3. The pillars of sustainability*

In this section, we will revisit the three pillars of sustainability. The key aspect to sustainability is the collaboration of the three aforementioned pillars: society, environment, and economy (Figure 3). These pillars can be actualized through human-centered design; a concept revolving around the **desirable**, **viable**, and **feasible** aspects of a product to a user. In the context of the pillars of sustainable bio-construction, a project must be **desirable**, **viable**, and **feasible**. Desirability is the fulfilment of community needs and preferences within a work, in this case, a bio-construction. Feasibility is the technical ability of designing a long-standing building to endure environmental factors. Viability is the assurance that the sustainable construction occurs at an appropriate cost for the community.

We will be using the three pillars of sustainability as a guide in the implementation of our project. Ideally, the three pillars overlap and work harmoniously within a community to achieve sustainable development. We will look at construction as a technology with human-centered design as our social approach. In this way, we will create a project that is desirable, feasible, and viable for the people of San Rafael.

### 2. Social Pillar: Incorporating the Traditions and Needs of the People into Desirable Construction

To achieve a socially sustainable bio-construction, we observed the social dynamic of San Rafael and involved the community in the design process. Co-responsibility and **desirability** for this project is possible by incorporating community preferences and culture into construction. Community participation allows people to develop interest in town development on their own. Social sustainability requires a combination of understanding cultural identity and assistance through volunteers.

Cultural identity is reflected in the materials used for buildings and the workforce in charge of construction. MASS Design Group (MASS), an architecture group based in Boston, embraces cultural identity in architecture that heals communities across the globe (MASS Design Group, n.d.). The group incorporated local materials and local workforce into the construction of a hospital in Rwanda (MASS Design Group, Butaro, 2011). When a Rwandan community of avid farmers leveled their land to plant crops, large rocks were dug out and classified as useless. MASS delegated local masons to mold the unwanted rocks into stones for constructing a new, open-design hospital that prevented the spread of airborne diseases. By doing this they incorporated the materials of the community, kept local masons involved, and improved the society with a safer hospital. The ideas behind this type of sustainable bio-construction show that local fabrication is essential for encapsulating all three pillars.

Ecuador emphasizes the preservation of cultures and traditions while promoting active community improvement (Republic of Ecuador, 2008). Architect Juan Diego Badillo instills cultural pride in the Ecuadorian people by utilizing traditional vernacular architecture in Andean villages ("Saving Ecuador's Vernacular Architecture," 2014). Vernacular architecture is a building style tailored to people's preferences while using local materials and incorporating local culture (Edwards, 2011). An example of vernacular architecture is the collection of stone homes built alongside the Andes mountains ("Saving

Ecuador's Vernacular Architecture," 2014). Traditional building skills in some mountainous communities have been replaced by modern construction techniques due to the "misunderstanding of the economic potential [and cultural value] there is in saving the architecture" ("Saving Ecuador's Vernacular Village Architecture," 2014). Badillo's mission is to revitalize the traditional construction techniques of the Andean communities to preserve the culture in architecture (Appendix A1). In this way, traditional aesthetic and technique should be incorporated into updated and safer building techniques. Modern designs offer design evolutions and creativity; however, traditional techniques can be better suited for locations (Appendix A2).

Construction projects can benefit from external volunteers contributing innovative perspectives. Volunteers must consider traditional techniques and true needs of the local communities. One instance of the consequences of neglecting culture in construction is the rebuilding of Haitian communities after the 2011 earthquakes. While volunteers quickly provided emergency resources and temporary shelter, the Haitian communities remained in shambles after the initial aid ceased. The misunderstanding of the long-term crisis needs inhibited Haitian communities from recovering years later (Jobe, 2011). This phenomenon is a well-intended act of assistance that proves to be unsustainable. Our team strives to assess these discrepancies and highlight the positive motivations that unify external volunteers with local community members.

### **3. Environmental Pillar: Accounting for the Environment as a Stakeholder to Ensure Viability**

A community must consider the environment when planning sustainable bio-construction. This second pillar of sustainability originates from social concerns of humans, and it seeks to improve the welfare of human beings by protecting the sources of raw materials (Goodland, 1995). Environmental sustainability in bio-construction is the protection and preservation of the surrounding ecosystem and the use of construction in favor of sustainable development (Goodland, 1995). Conditions such as geography, natural disasters, and climate must be factored into design and construction. Alongside this, the environment must be protected from damage, pollution, and resource depletion. Environmental sustainability requires the controlled use of accessible resources and the understanding of ambient conditions in order to ensure the **viability** of construction.

In Ecuador, disasters such as deforestation, landslides, and earthquakes influence bio-construction. When these environmental challenges are not considered, construction grounds face imminent risks (Torre, 2008). Agrarian Andean settlements experience great amounts of deforestation due to land-clearing for growing crops (Torre, 2008). Deforestation has caused soil erosion, a common human-created disaster that occurs from uprooting large areas of flora while decreasing land quality and stability (Gillaspay, 2003). The western coast of Ecuador itself has soil erosion within 95% of the natural area (The Biodiversity Group, 2016). Prioritizing the environment in construction protects the resiliency and promotes the sustainability of a building over time. Structures must be built with the capability to withstand common geographical conditions of the area including any natural disasters. Constructing buildings that are too vulnerable to the elements can result in extensive damage and even human casualty.

Climate of a site affects the design of bio-constructions. The Hungarian architect Victor Olgyay's book highlights that the climate must be accommodated for before constructing sustainable buildings. A case study was performed on modern and traditional houses in the city of Mardin, Turkey to determine which material had better thermal properties to keep out the intense heat (Yılmaz, 2006). Mardin is located in a hot-dry desert climate; the summers are very hot, and the temperature difference between day and night is quite large (Yılmaz, 2006). Structures that are built in such a climate with extreme temperatures must have the capability to insulate properly for regulating indoor temperatures; hence, the houses must be constructed with a material that has the appropriate properties. This case study shows how appropriate

allocation and choice in material based on an understanding of the environment and geography of a region is the key to environmental sustainability in bio-construction (Appendix A3). To construct safely, reliably, and economically, the construction materials and designs must be tailored to the climate of the target site.

#### **4. Economic Pillar: Maintaining Economic Feasibility**

Completion of a construction work depends on affordability of sustainable bio-construction projects. Construction budgets are limited; when the funds are depleted from a project, work cannot continue until more funding is available. Therefore, materials and buildings must be affordable for the people of the community to construct well-built and enduring homes.

Construction creates a local job market for existing workforces. A study conducted in Bangladesh connected sustainable development to an improvement in the local job market (Alam, G.M. 2009). Bangladesh reached a plateau in their growing economy where they could no longer develop without training their workforce to fill new markets (Alam, G.M. 2009). By educating the community members on sustainable development trades, the workforce could apply skills in sustainable construction within a new construction market. By encouraging the community members to participate in construction as a profession, Bangladesh greatly increased their local job markets and benefited the economy, allowing for further sustainable construction in the future.

The main concept that Bangladesh used in strengthening the community from within also applies in Ecuador. Bangladeshi leaders involved community members in education and projects, thus enriching their own skills and abilities. In doing so, the people are more equipped to be hired for local works, rather than calling upon outside experts to work. Local training and hiring improves the local job market and supports economic sustainability.

A long-term goal of resiliency and replicability is vital to sustainable projects. Both materials and construction techniques must be resilient and accessible within their specific locations. A case study on adobe in the Andean mountains displays the resistance of this material in its local environment (Appendix A4). Determining local resource costs and demands for a project promotes the **feasibility** of a construction. Several projects have capitalized on this concept and created sustainable developments that have empowered communities (Appendix A5). The most successful sustainable projects result from the synergy of social, environmental, and economic sustainability.

### 3. METHODOLOGY

The objectives set for accomplishing our project goal were:

1. **Assess** community needs, building designs representative of San Rafael architecture (or sustainable construction designs), environmental conditions, and economic factors through observation and data collection.
1. **Interpret** community preferences based on sustainability factors and determine the ranked importance of materials.
2. **Create** a design catalogue of the separate components of a building specific to the community for future construction.

This section describes the methodology we used to achieve our three objectives following the human-centered designs. By assessing the community needs and preferences, we determined the **desirability** of certain materials for construction. Evaluating those preferences allowed us to determine **viable** methods of construction with the preferred materials based on availability and ease of use. Finally, we made designs for construction based on those interpreted preferences and created **feasible** alternatives for constructing the buildings in the community.

#### 1. Assessing Community and Volunteer Preferences

Assessing the perspectives of the community, the GAD project leaders, and the environment allowed us to identify the key factors of the construction that are of importance to the people living in San Rafael. Desirability of the team's work is necessary for successful implementation of our design catalogue in future construction. To counteract the potential negative effect of interacting with community members, we established a policy of optionality and confidentiality (Appendix B1). We assessed the different stakeholders in different ways, outlined below.

1. To assess the community we conducted semi-structured interviews, a community forum, and structured surveys. The interviews identified the needs of the people in construction and allowed us to learn more about where the person lived, what his or her house was made of, and how they constructed their houses (Appendix B2). The community forum in Sharug explained the motives of our project and interpreted the material preferences of the people on a scale of importance and accessibility. The surveys collected at the forum quantified portions of the qualitative data being gathered during interviews (Appendix B3).
2. To assess the leaders we worked closely with them on site. The GAD leaders include President Luis Yanez and his city council, whom make large decisions in community development and direction of workforce. We maintained constant communication with these project leaders. The GAD was consulted for an unstructured interview before project began and asked for opinions throughout the project.
3. Lastly, sustainable bio-construction took the environment into consideration, establishing it as a stakeholder (Appendix B4). To assess the environment we observed San Rafael in four different locations: outside towns (Dagnia, Tullosiri, Chaguar) and the center of San Rafael (Sharug). We also discovered which materials were able to be resourced locally and which required



outsourcing. The climate of the area was important to assess, including seasons, weather, and humidity.

## **2. Interpreting Preference Data and Building Profiles**

The team created two specialty groups to fulfill both social and technical components of the project. The Linguistics Team consisted of teammates with the most advanced Spanish speaking skills. They conducted the interviews, communicated with the people and GAD project leaders, led and advertised the community forum, and translated verbally and on paper. The Design Team consisted of the teammates with more technical experience in computer programs for civil design. They created profiles of 41 structures in the San Rafael parish, performed research on structure supports for adobe and cement, networked with civil engineers based in Cuenca, and created the designs for the catalogue.

We conducted semi-structured interviews with community members to discuss construction, housing, and material availability in San Rafael. We recorded materials and verbal quotes with permission from community members. The community members were informed that all identifying information would be kept confidential. The team organized the collected qualitative data points by prevalence and importance to the community. The quantifiable data points were then analyzed via decision matrix for ranking of the materials (Appendix B5).



*Figure 4. The old government building in Sharug*

The team set a baseline for sustainable building by assessing the current materials and methods of construction. As per the GAD, we considered the old government building in the town center as a baseline for construction. The old government building is considered the baseline due to its status as a historical building and its traditional design (Figure 4). The bio-construction initiative of San Rafael focuses on preserving cultural preferences of buildings while complementing structure and stability. We expanded upon our baseline by analyzing information on buildings in four total communities in San Rafael. These data were analyzed through a decision matrix, also known as a Pugh matrix.

The Pugh matrix is a comparative chart that quantifies the characteristics of different materials (Figure 5 below). The materials are listed in the column headings while row headings list out different criteria. The four criteria used were aesthetic, cost, ability to resource locally, and compressive strength. The raw data was added into the Pugh matrix and ranked for relevance based on the preferences of the community. In order to determine the ranked importance of each of the materials in the matrix, weights were assigned to the criteria on a scale of 1 to 4 with 4 representing the most important criterion. Then, rankings on a scale of -1 to +1 were assigned to each material for each criterion. Positive numbers signify that the alternative material is better than the baseline. Negative numbers signify that the alternative material is worse than the baseline. The numbers are then multiplied by the weight of each respective criterion. The products are added together to form a final score, and the higher the score, the more preference the material has. For more detail on the calculations we performed, see Appendix B5. The Pugh matrix shows the appropriateness and accessibility of materials through engineering as practiced in the rural mountains of San Rafael. This insight allowed us to create a concise design catalogue that combined our knowledge in engineering with the culture of the community.

Criteria	Weight of Criterion	Materials				
		Adobe (Base)	Bamboo	Cinderblock	Adobe + Cement Facade	Brick
Ability to Resource Locally	On a scale of 1 to 4.	Rankings for each criterion on a scale of -1 to +1	Rankings for each criterion on a scale of -1 to +1	Rankings for each criterion on a scale of -1 to +1	Rankings for each criterion on a scale of -1 to +1	Rankings for each criterion on a scale of -1 to +1
Aesthetic						
Compressive Strength						
Cost						
<b>Total Points:</b>						

Figure 5. The Pugh Matrix as applied to materials and community preferences in San Rafael

3. Creating a Design Catalogue

The analyzed data in the Pugh matrix ranked the materials used in community construction. These preferred materials were used to create designs and instructions in a catalogue for building components. For example, the catalogue contained a Revit® image of a stable concrete beam; instructions were written on how to build it to engineering standards while conserving materials. Information for design was retrieved from adobe construction research and through working with Dr. Francisco Flores, PhD, University of Cuenca. Our goal was to present the catalogue as a tool for local contractors to refer to when building new constructions.

We determined our assertions through a human-centered approach. Summarization of findings is reflective of the opinions of the stakeholders. Cumulatively, our objectives had one common goal: to improve sustainable bio-construction for the community of San Rafael. By categorizing our findings into assertions, we were able to interpret community preferences to create a final deliverable.

## 4. RESULTS AND ANALYSIS

Below are the assertions and corresponding findings we found from interviews, surveys, and building profiles. Each finding reflects different combinations of the pillars of sustainability. Oftentimes, the pillars can overlap, thus bringing **desirable**, **viable**, and **feasible** solutions into light. The complete building profiles can be found in Appendix C1.

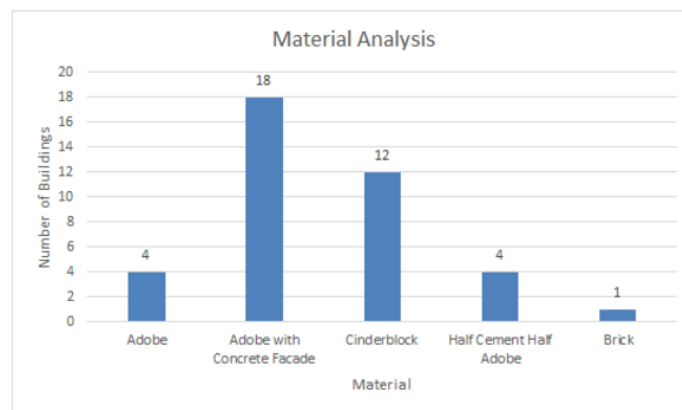
### Finding 1: Adobe and cinderblocks are the most common building materials in the parish

More people are favoring quick-building with cinderblocks as opposed to using adobe. The traditional adobe houses are reminiscent of an agrarian culture, where the people of San Rafael depended solely upon the land to live. One person commented to the team that, "Cinderblock buildings are like Coca-Cola. They're readily available, but not good for you." While cinderblock does not carry the cultural significance of adobe, it is now much easier to access and preferable for less expensive and shorter schedule constructions. Generally, younger generations have shown a clear preference towards cinderblock whereas older generations have a preference to adobe, while acknowledging cinderblock as the new, most popular material.

The next most commonly used material is cinderblock with cast-in-place concrete beams and columns, reinforced by steel. This material was introduced to the area within the last 10 years and is being used more frequently in new construction. Cinderblock is also being used for additions on adobe houses. These additions can be for reinforcement as well as more room. Although cinderblocks are easier to build with, there are structural faults with the way these houses are being built. When analyzing cinderblock houses we discovered that the beams and columns are the same width. This creates instability within the structure. According to the American Concrete Institute, to be more structurally sound, the columns must be 25% larger in width than the beams. These suggested proportions can be found in the catalogue in the "concrete reinforcement suggestions" section.

A. *Adobe is repairable and naturally available, but more time-consuming to build with and less popular.*

Through the interviews, survey responses, and building profiling, we determined adobe is one of the most available materials for construction. Figure 6 shows what materials we observed. The majority of the buildings were constructed with adobe and cinderblock as seen in Figure 6.



*Figure 6. Construction materials used in San Rafael*

Adobe is locally available in San Rafael so it does not need to be outsourced. Community members found that adobe has high thermal resistivity, thereby maintaining a warmer temperature within when the weather is cold and vice versa. The adobe is also more impact resistant than other materials because of its weight and density, which offers more protection than thinner walls of cinderblock. Adobe is made from dried earth and reinforced with straw and sand, which makes it biodegradable. The mixture can be made in smaller batches for wall patchwork and construction repairs.

After determining that both adobe and cinderblock were mainly used for construction in San Rafael, we made a list of advantages and disadvantages of each material. The results were garnered from community interviews as seen below in Table 1.

*Table 1. Advantages and Disadvantages for adobe blocks and cinderblocks*

ADOBE		CINDERBLOCK	
<u>Pros</u>	<u>Cons</u>	<u>Pros</u>	<u>Cons</u>
Insulates well	Heavy	Space-saving	Outsourced
Environmentally Friendly	Selective Availability	Faster to build with	Doesn't insulate
Naturally sourced	Less popularity	Clean/aesthetically Pleasing	Expensive
Impact Resistant	Prone to crumbling with age/needs more repairs	Humidity Resistant	More difficult to repair
Locally available	Not humidity resistant	Lighter (weight)	

While adobe is a naturally sourced material, the bricks can only be made in the summer when the earth and climate are dry. During the winter, there is a lot of rain which does not allow the clay mixture to dry. People typically hire a contractor to create the bricks and construct with them. In addition, some of the people we interviewed said that adobe is not as popular to construct with, because the material is heavier than cinderblock and it takes more time to build with. Adobe bricks are also not resistant to humidity and become weaker when exposed to water for prolonged periods of time.

*B. Cinderblock is quicker to build with and cheaper, but not as strong or durable.*

Building with cinderblock has become increasingly popular in the communities of San Rafael according to the people we interviewed. There are several advantages to using cinderblock. In comparison to adobe, the cinderblocks are lighter and take less time to build with. People don't need to hire a specialist to construct with cinderblocks since they come to the community premade and ready to use.

The disadvantages to using cinderblock include being weaker than adobe and more difficult to repair. Cinderblocks are created with two empty spaces in the center, making them lighter but also weaker than adobe. According to the homeowners we spoke with, the cinderblock houses are said to not last as

long as adobe houses. Improvements to this can be made using reinforced cast-in-place concrete column/beam structures, which are outlined in the catalogue for community use.

Cinderblock is also not damaged by rain or wind to the same magnitude as adobe. Cinderblock can be used to build during both rainy and dry seasons, unlike adobe. Although cinderblock has a lower thermal resistivity, community members that we interviewed assured our team that the cold does not take away from the appeal of cinderblocks. In accordance with the interview data, we included designs for both adobe and cinderblock walls in our catalogue.

### *C. Aesthetic is important to the people of San Rafael*



*Figure 7. Adobe with concrete façade*



*Figure 8. Bare adobe*

As stated above, adobe is one of the most commonly used materials in San Rafael. However, most of these adobe buildings have a concrete facade. Having this layer of concrete provides weather protection, as water and humidity deteriorates adobe walls. These cement coverings keep houses intact for longer periods of time saving money on repairs. Figures 7 and 8 contain examples of an adobe house without a cement facade, and an adobe house with a cement facade. The deterioration of the adobe house without the facade is evident. There are visible holes in the building

allowing cold air to pass through while simultaneously weakening the structure. Another benefit of the cement facade is the ability to add color and design to make the house more visually appealing and reflective of cultural preferences. Aesthetic is very important to the people of San Rafael and should be taken into consideration when designing buildings.

### *D. Wood is typically used as support framework and floors*

As a renewable resource, wood is often used to support adobe building structures, some cinderblock structures, roofing beams, and floors. Figure 9 is picture of one of the buildings in San Rafael showing the visible wood beams that are used as support for the roofing. Wood is not best suited for construction with cinderblocks, but is often used when building with adobe.



*Figure 9. Wooden beams used for support*

## **Finding 2: Certain materials are not useful for San Rafael**

### *A. Ceramic tiles are not used due to high cost and lack of practicality.*

Observing the buildings and conversing with the people revealed that ceramic tile roofing, or "teja," is not popular in San Rafael communities. When asked about ceramic used for roofing, the general consensus of the community members was that it is rarely used for several reasons. The ceramic tiling costs more than other roof materials such as tin, composite or "ternil", and concrete. Since it must be outsourced and involves a longer process to make and install, it is not an economic material for construction within the

communities. They are also not functional enough for the local weather, because they leak easily in rain and are not resistant to winds.

Ceramic tiling is typically used as a decorative touch to a home, but the people of San Rafael have expressed more interest in the practicality and effectiveness of the roof material. Since ceramic tiles are not effective with keeping the elements out, cost more, and are difficult to repair and/or replace, people prefer not to use them when constructing their homes in San Rafael.

Most people use tin, composite, or cement roofs because they have much more practicality and are more available to the community. Quality tin roofs called DuraTech are found in El Paisaje, Pucará, and Santa Isabel, nearby San Rafael. These materials for roofing last about five years before they need repairs, depending on the quality of the material sheets.

*B. Bamboo is not used, because it must be outsourced from the coast.*

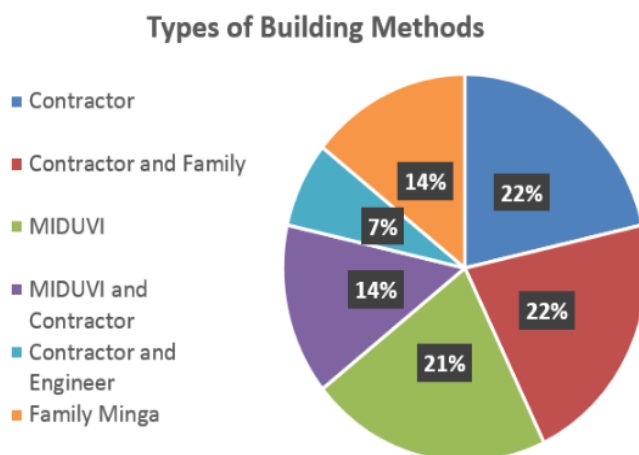
Through interviews, it was determined that bamboo is not a common building material in San Rafael. Bamboo comes from the Ecuadorian coast, therefore it must be transported into the communities, thus making bamboo a less economic building material for larger projects. Bamboo is being used as support for the newer auditorium structure being constructed by the Azuay Prefecture as of 2016. However, it is not commonly used as a structural component, because it is naturally hydrophilic and must be treated to be used in humid or rainy climates, such as San Rafael.

**Finding 3: Cost influences the materials and size of a construction.**

*A. Interviews reveal adobe is more expensive to build with than concrete.*

One important aspect of material research is cost. Personal accounts reveal that older buildings were often built among families and neighbors, however, some of these same buildings begin to deteriorate and are either rebuilt or reinforced with new material (adobe and/or cinderblock). Recent buildings are constructed by either contractors or engineers, depending on the type of project. One local contractor revealed his labor costs an average of \$20 per day of work with a project taking anywhere between 15 to 30 days. Another interviewed community member revealed adobe blocks to cost at about \$1/block while cinderblocks cost about \$0.45/block. All interview data can be found in Appendix C3.

*B. Approximately 35% of community members received assistance from MIDUVI, an Ecuadorian government agency that provides construction assistance services*



From the survey responses, we deduced that most people did not build their houses within family or community *mingas*, or volunteers. The majority of people rely on the services of a contractor or government organization to assist with the construction as seen below in Figure 10.

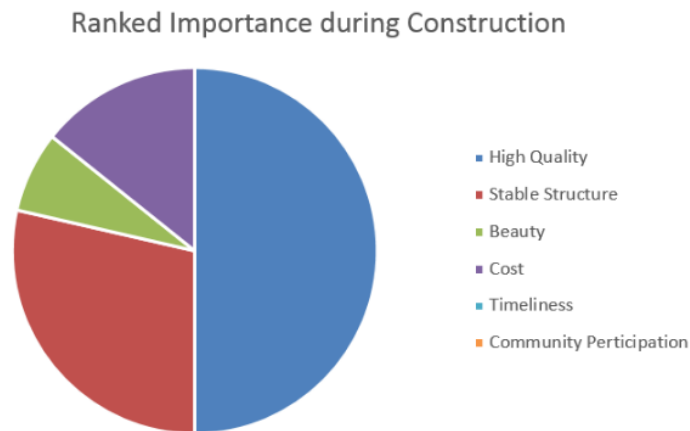
Thirty-five percent of the people interviewed said that they received assistance from MIDUVI. Only fourteen percent of the participants said they constructed or repaired their homes exclusively through family. This information is critical to understanding how

*Figure 10. Pie chart of material types*

the community members typically build their homes. The workforce in San Rafael is shifting from younger local people to external organizations and contractors.

C. *Material quality and integrity are most important to the community members.*

The surveys also revealed that the majority of people do not rank community participation (through *mingas*) very highly as compared to other factors in private home building. Below in Figure 11 are the survey results of what mattered most to the community members when constructing a home. On a scale of importance from one to six, with one being the least important and six being the most important, the people within a community forum voted high quality of materials to be the most important when building their homes and community participation to be the least important.



*Figure 11. Results from the community forum survey about which construction aspects are most important to community members*

According to these results, the quality of the materials and the structural integrity of the buildings are the two most important factors of construction to the community members. We took this into account when creating the design catalogue to ensure the structural integrity of the walls.

**Finding 4: Implementing a design catalogue that is inclusive of community preferences could be a beneficial design tool.**

Overall, the interviewed and surveyed community members approve of construction efforts by volunteers and the GAD of San Rafael. However, one account reported dismay over the previous failed adobe auditorium project on Loma de Ileen in 2015. Loma de Ileen is an area of the community where sustainable bio-construction projects are in different stages of completion and construction. One of the larger projects is an auditorium made of wood. It was originally made of non-reinforced adobe, but deformations in the walls caused the auditorium construction to collapse. Despite the failure of the first auditorium, the people are still willing to experiment with new construction methods. This is one reason sufficient structural designs would benefit the community.

A. *Structural design in San Rafael could be beneficial using engineering concepts such as: minimal beam sizing, minimal rebar calculations, and symmetrical design*

The people want to be assured that new structures will have structural integrity and longevity. Our team has researched, designed, and produced a catalogue of partial construction designs. The purpose of this catalogue is to provide basic engineered design concepts. We calculated minimal beam sizes to determine

the appropriate dimensions for concrete beams used in construction. Minimal rebar calculations were performed to determine where steel reinforcements should be placed within concrete beams and columns in order to provide the most effective support. Symmetrical design was another important design concept to ensure symmetry of the buildings. This maintains pleasing aesthetic as well as structural integrity by making the structure well balanced.

We gave the catalogue to the GAD to make available for contractors and community members for guidance in building adobe walls, concrete walls, and concrete beam structures. A full building design included in the catalogue offers alternative design options for the former government building in the center of the community. One is designed as a structure of adobe, and another of cinderblocks, since those are the two most common construction materials used in San Rafael. We worked with Dr. Francisco Flores, a civil engineering professor at the University of Cuenca, to formulate, research, execute, and check the catalogue before presenting it to the GAD.

*B. Compiling the beginnings of a construction catalogue could be beneficial for builders in the community.*

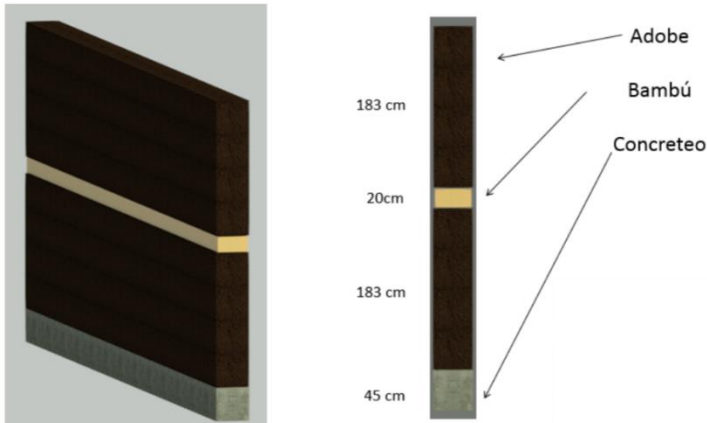
There are several benefits that the construction catalogue can provide for the community builders. The designs in the construction catalogue serve as a source of inspiration for the local contractors when they are building the structures in San Rafael. We provided two sample designs of a government building to which the builders could refer to while creating structures. These designs purposefully conserve symmetry within the support columns, beams, and rebar placements, which is critical for structural longevity. In addition, the catalogue demonstrates that extra structural integrity can still save material. The minimal rebar calculations give the minimum amount of steel bars needed for the most effective support in concrete beams, thereby minimizing the budget for concrete reinforcements. Finally, there is potential to update the catalogue to include additional housing styles desired by the community. This is something that Dr. Francisco Flores suggested for future additions to the catalogue through collaboration with the University of Cuenca.

Analysis of our qualitative data have determined that a design catalogue for sustainable construction would cover three main areas of need within the communities: need for preserving cultural architecture, need for protection from natural elements without damaging the environment, and need for maintaining appropriate cost. Next, it is important to understand the preferences of the people to understand what materials and designs are included in the catalogue.

The catalogue is comprised of four simple sections; walls, concrete reinforcements, a retrofitted adobe government building as a completed example, as well as an additional concrete building example. These sections are then further broken up into numbered subsections and categories. The first section is a renovated example design of an existing government building located in the center of Sharug. The second section is an example of concrete home with correct beam and column connections that can be built throughout the communities within San Rafael de Sharug. The third section, walls, contains two subcategories for two different materials. These materials are adobe and concrete. Each material is analyzed and the results are divided further into different categories. These include a description of the material, designs built using computer aided design, an estimated cost to build with this material, and a suggestions section for more advice. The fourth section explains how to improve the stability of concrete column and beam connections. As previously mentioned, this is a common problem throughout San Rafael that can be addressed with these reinforcement suggestions.

With this guide, builders will be able to browse through the catalogue and choose the material and wall design that suits their needs and preferences. Once they have selected a material and design, they will be



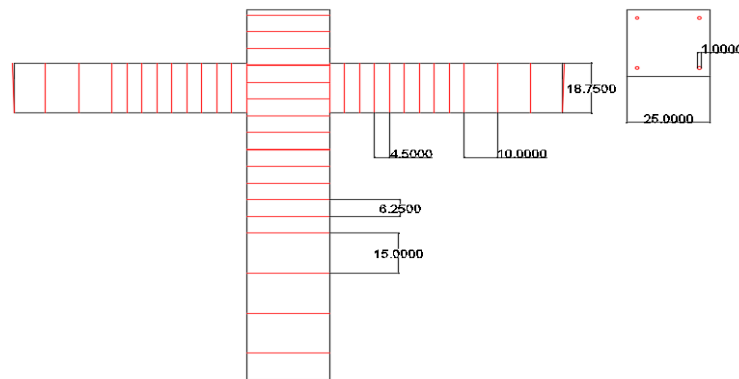


*Figure 12. Adobe Wall Design catalogue page*

able to build walls and connections that are sturdy following the simple design instructions. This will ensure that these structures are safe. This also adds consistency of how buildings are made throughout the town making repairs and training in this area easier. Although there is an addition of structure and consistency, the builder is still allowed the freedom of designing the building to their taste. The purpose of this piece-by-piece catalogue is to give the people of San Rafael freedom to decide the material and design of the home while

promoting structurally sound structures.

Above is an example of a design page in the adobe section of the catalogue, including the section numbers and names, materials, and dimensions. As seen in Figure 12, this design contains dimensions to help the contractors in the building process. To complete this catalogue, information gathered from interviews and analysis were compiled and the important patterns were extracted. From here, collaboration with Dr. Francisco Flores allowed further suggestions to be made. These include the bamboo reinforcement seen above as well as proper concrete reinforcement placement as seen below in Figure 13. This figure represents rebar (steel) placement and spacing dimensions based on calculations outlined in Appendix C2. These calculations followed rules stated in the code book by the American Concrete Institute (ACI 318). Through these calculations, we were able to determine the best placement for steel reinforcement within the concrete beams and columns.

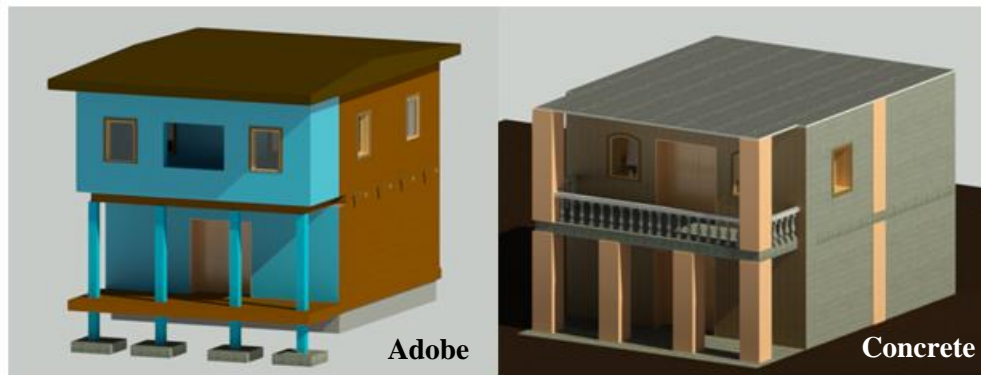


*Figure 13. Minimum Steel Requirements for Reinforcing Concrete*

Preceding pages in the catalogue outline further instructions on building, description of the material, an estimated cost to build with this material, and a suggestions section for more advice.

The buildings below in Figures 14 and 15 are the retrofitted government building in Sharug and a San Rafael-inspired design. The original building in Sharug was used by the local government, but was

abandoned when a newer, larger building was constructed. President Yanez and the GAD asked the team to update a design for the collapsing building so it can be used again in the future. To do this, we incorporated all of the data we collected during our time in San Rafael.



*Figures 14 & 15. Full designs of the government building, the first with adobe, the second with cinderblocks*

At the request of the GAD, the reconstructed government building was designed with adobe and wood. The historical beauty of the building was maintained in the design by using bright colors, wooden façade, and wooden beams. Then, we used cinderblock and concrete to design a second structure as it was a popular material choice. We also implemented local San Rafael architecture by including the intricate wooden railings and the colored wood paneling overlaying the concrete. Through this design we can show how it is possible to make a structurally sound building while still including all the aspects that make the San Rafael buildings unique.

## 5. CONCLUSIONS AND RECOMMENDATIONS

In this section, we assert the final conclusions from our gathered data and results. The goal of this project was to contribute to sustainable bio-construction designs that are locally appropriate to San Rafael. After assessing the community preferences, interpreting the data to determine the ranked importance of materials, and creating the design catalogue based off of those preferences and ranked materials, the following conclusions and recommendations were made.

### *Conclusion 1: Adobe, cinderblock, and wood are the most common construction materials in the parish*

Bio-construction in San Rafael involves several key materials and common building practices that are reflective of its culture, applicable to its environment, and supportive of its economy. Adobe, cinderblock, and wood are the most common construction materials in the parish. Since the people and local contractors already know how to make the adobe bricks, we found that it would not be conducive to the goal of our project give instructions or recommendations for how to create them. Similarly, we did not offer instructions or recommendations for creating cinderblocks since the people receive them already made and ready for immediate use.

We also found that wood is currently used primarily for paneling and framework. However, it can be used for different purposes and should be taken into consideration for future projects. The problem with wood, as pointed out by a representative from FEPP (Fondo Ecuatoriano Populorum Progreso, 2015), is that harvesting wood is a process that takes down forests.

Recommendations: To prevent deforestation, we recommend that future groups choose more renewable resources to use in place of wood for construction. Although bamboo and other materials are not traditionally grown in San Rafael, future projects could tackle the challenge of growing bamboo locally. If future groups could learn how to grow bamboo locally, eco-friendly designs could be implemented into the catalogue to further satisfy the environmental **viability** of the project.

### *Conclusion 2: Designs must exclude luxurious materials and include most commonly used and practical materials*

Cost is important to the community members when planning for construction. We found that it would be impractical to include uncommon materials such as ceramic tiling in the designs. This would require excessive budgeting, where the goal of this project included maintaining economic sustainability as well as social and environment sustainability. For a building to be replicable, it must be low cost. Extraneous materials could accumulate extraneous cost since the transportation required to bring those materials to the community could be expensive. If the people lack experience in constructing with the outsourced materials, it would make building with them more difficult due to the unfamiliarity. The use of local materials would support economic sustainability since the budget would not be as excessive as it would be with outsourcing.

Recommendations: Future endeavors may include approaching material fabricators, conducting surveys with local material fabricators, and compiling gathered data in order to make full cost estimates for the construction of our designs. For example, it is possible to expand upon the option of using bamboo in future additions to the catalogue. Our team included bamboo as a suggestion for strengthening adobe walls. If the use of bamboo in construction becomes more popular to local contractors, they could approach material fabricators and create cost estimates to obtain and use bamboo. By ensuring a **feasible**

cost to community members and outlining a budget, local contractors are more likely to make use of our catalogue.

***Conclusion 3: Creating a living design catalogue promotes stability in new constructions and project longevity***

Implementing a design catalogue that is inclusive of community preferences could be a beneficial construction tool for the community members and builders. Cultural features were combined with effective construction techniques to encapsulate the character of San Rafael as well as the structural integrity and longevity of the buildings. By displaying that extra structure does not have to come at high cost using minimal rebar and cement, builders can buy minimal materials. Another contribution of the catalogue is introducing the importance of symmetry through designs of buildings and beam/column sketches.

***Recommendations:*** A next step for this project could be collaborating with the University of Cuenca professor, Dr. Francisco Flores, to involve more students in creating house and building designs. These novel blueprints can be presented to the community of San Rafael and even expanded to other rural Ecuadorian communities. Through these designs, it is possible to further minimize the amount of naturally resourced materials used, such as wood and adobe. It is also possible to recommend collaboration with the University in terms of commencing construction of the aforementioned designs. This ensures **desirability** by continuing the catalogue and keeping the people interested in continuing with the project.

## 6. REFERENCES

1. Alam, G. M. (2009). The role of science and technology education at network age population for sustainable development of bangladesh through human resource advancement. *Scientific Research and Essays*, 4(11), 1260-1270.
2. Azuay. (2011). History of San Rafael parish. Retrieved from <http://sanrafaeldezharug.gob.ec/azuay/?p=100>
3. Correa, R. (2008). *Plan nacional buen vivir 2013 2017*
4. Edwards, S. (2011). Vernacular Architecture and the 21st Century. Retrieved December 14, 2016, from <http://www.archdaily.com/155224/vernacular-architecture-and-the-21st-century>
5. Egred, Jose. (1987). *Ecuador earthquakes: Mass wasting and socioeconomic effects*. Washington, DC 20418: National Research Council.
6. Fondo Ecuatoriano Populorum Progressional (FEPP) et. al. (2015). Plan de Desarrollo y Ordenamiento Territorial de la Parroquia San Rafael de Sharug.
7. Gillaspay, R. (2003). What is Soil Erosion? - Definition and Causes. Retrieved February 15, 2017, from <http://study.com/academy/lesson/what-is-soil-erosion-definition-causes-effects-prevention.html>
8. Goodland, Robert. (1995). *The concept of environmental sustainability Annual Reviews*
9. Gupta, I., R. Shankar, & Amita Sinvhil. (2007). Earthquake vulnerability assessment of house constructions in Himalayas. *Journal of Design & Built Environment*, 3(1), 1-14.
10. Jobe, K. (2011). Disaster relief in post-earthquake haiti: Unintended consequences of humanitarian volunteerism. *Travel Medicine and Infectious Disease*, 9(1), 1-5. doi: 10.1016/j.tmaid.2010.10.006
11. MASS Design Group. (2011). The butaro district hospital. Retrieved from <https://massdesigngroup.org/work/design/butaro-district-hospital>
12. MASS Design Group. Retrieved from <https://massdesigngroup.org>
13. MASS Design Group. (2011). The umubano primary school | MASS design group. Retrieved from <https://massdesigngroup.org/work/design/umubano-primary-school>
14. Max Planck Institute, & Rainer Grote. Constitution of the republic of Ecuador: September 28, 2008 (as amended to May 7, 2011) (ecuador [ec]). Retrieved from <http://oxcon.ouplaw.com/view/10.1093/law:ocw/law-ocw-cd733.regGroup.1/lawocwcd733>
15. Michael Pearson, Catherine E Shoichet, & Rafael Romo. (2016, Apr 20.). Ecuador earthquake: 654 dead, emergency tax measures introduced. *CNN Wire Service* Retrieved from <http://search.proquest.com/docview/1782196560>
16. Razani, R. (1978), Seismic Protection of Unreinforced Masonry and Adobe Low-cost Housing in Less Developed Countries: Policy Issues and Design Criteria\*. *Disasters*, 2: 137–147. doi:10.1111/j.1467-7717.1978.tb00082.x
17. Saving Ecuador's Vernacular Architecture. (2014). Retrieved December 05, 2016, from <http://adventuresinpreservation.org/upcoming-adventures/saving-ecuador-vernacular-architecture-2014/>
18. Taylor, P., & Luther, M. B. (2004). Evaluating rammed earth walls: a case study. *Solar Energy*, 76(1), 79-84.

19. Torre, C. d. I., & Striffler, S. (2008). *The ecuador reader: History, culture, politics*. Durham: Duke University Press.
20. Yilmaz, Z. (2007). Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate. *Energy & Buildings*, 39(3), 306-316. doi: 10.1016/j.enbuild.2006.08.004

## 7. APPENDICES

### *Appendix A1. Badillo Vernacular Architecture*

Badillo noted that "when talking to residents of many of Ecuador's villages, it becomes apparent that community members no longer have the skills needed to repair and maintain their traditional stone buildings, perfectly designed to deal with the Andean landscape and climate" ("Saving Ecuador's Vernacular Village Architecture," 2014). Since these people didn't have the ability to repair and upkeep their own architecture, they were losing the ability to sustain a part of their culture. Badillo and volunteers build sustainable communities through heritage tourism. They focus on traditional stone construction native to the area. "Cultural heritage conservation in Ecuador has grown since 2007 but the focus has been on monumental architecture, leaving almost 80% of the country's beautiful vernacular architecture at risk" ("Saving Ecuador's Vernacular Village Architecture," 2015). This is why the focus of this effort is incorporating the culture in regular construction of Andean communities.

Diversity in architectural style arises from incorporating the resiliency of tradition with the progressiveness of modernization. Badillo's project aims to renew an appreciation for the value of historic buildings ("Saving Ecuador's Vernacular Village Architecture," 2014). His work also demonstrates the inclusion of traditional construction techniques in modern architectural design to better suit the community's original traditions and dynamic preferences. Modern design preferences evolve with the changing dispositions of community members while traditional building techniques are a staple of past generations on the local landscape (Gupta, 2007). Plans for sustainable development should incorporate the culture and address the need for functionality. These diverse criteria strengthen the sustainability of the bio-construction.

## ***Appendix A2. Earthquakes in Ecuador***



*Figure 16. A collapsed building*

Earthquakes are common in Ecuador and must be accounted for in sustainable construction (Appendix A6). Over the 20th century, over 104,000 people died from seismic damage in the Andean region (Razani, 1978). Of these, many more adobe buildings were damaged or destroyed by the seismic activity. While Earthquakes are not a major problem in San Rafael specifically it is still important to take structure and stability into consideration when building to prevent damage due to a rare earthquake or other natural disaster. Adobe and concrete are used similarly throughout the Andean region; therefore, information can be gathered from seismic reports.

On March 5<sup>th</sup> 1987, powerful earthquakes struck Ecuador and the entire country suffered the aftermath. As seen in Figure 16, the two major tremors that occurred in the eastern Napo Province mountains had inflicted serious damage onto thousands of buildings and houses and worsened the threat of additional landslides (Egred, 1987). There were direct effects to the infrastructure, such as the Trans-Ecuadorian pipeline, that came from the landslides, debris flows, and some flooding (Egred, 1987). The most extensive damage occurred to houses constructed of "tapia", or adobe bricks, especially the buildings that were constructed in the 19<sup>th</sup> century or built by improper construction practices (Egred, 1987). As a result, many people were left homeless and had to sleep in tents, shelters, and community buildings (Egred, 1987). This serves as an example as to why it is necessary to follow proper construction techniques and use reinforced materials that are more suitable to withstand extreme conditions such as the force of an earthquake.

The impact of earthquakes in Ecuador are likely to be similar to other mountainous, rural regions. One example of an earthquake and its consequences on construction has been seen recently in the Himalayan Mountains. Previous to a string of landslides in 2005, a magnitude 7.3 earthquake hit the region. The destruction that resulted was assessed by a team of researchers based on vulnerability of settlements, general damage of settlements, effects from ground fissures and landslides, and human casualty due to the earthquake (Gupta, 2007). It was found that while agricultural houses were built relatively low in height and on top of level ground, constructions were built close enough to impact each other in the event of an earthquake. Additionally, modern construction practices yielded structures that were less stable for the Himalayan fault region. Cumulatively, these points express the impact that the vulnerable constructions had on the people of Tehri Garwal, Uttaranchal, where the study was conducted. Ecuador experiences similar problems with earthquakes and the resulting damage to vulnerable structures that aren't able to withstand the force of the tremors. It is necessary to recognize geographical risk factors to plan and design accordingly so as to build structures that will be able to withstand such extreme conditions and experience as little damage as possible.



### ***Appendix A3. Using Mardin Stone in Turkey for Construction***

The traditional houses were constructed with Mardin stone from calcareous rock found in volcanic regions, while the modern houses were built with brick and reinforced concrete (Yılmaz, 2006). After conducting tests on several samples of traditional and modern houses, it was concluded the traditional houses made from the calcareous rock had cooler indoor temperatures (Yılmaz, 2006). The calcareous rock had a better capability to keep the heat outside than the bricks and reinforced concrete had. With this knowledge, builders and homeowners in Mardin are able to conserve heating and cooling energy by using a material that can insulate more effectively against the intense temperatures of the region (Yılmaz, 2006). This is prevalent in Ecuador as well, because the infrastructure must harmonize with the Andean landscape, climate, and ecosystem.

#### ***Appendix A4. Case Study on Adobe***

A case study performed on adobe proved that it is not only effective against climate extremes, but it also has replicable and resilient factors needed to ensure economic sustainability. Adobe is readily available at low cost and the process of building is not long or expensive. The quality of adobe is not compromised by the affordability, as it can withstand typical conditions seen in environments similar to la Sierra.

Unfortunately, they have a low R-value (the capacity for a material to prevent heat flow), therefore it is expected that they would not be able to insulate sufficiently (Taylor 2004). Through testing and experimenting on an adobe building however, it was found that despite the low R-value, they still had a large thermal capacity allowing them to have more resistance to heat flow (Taylor 2004). This thermal property makes adobe an cost-efficient and energy-efficient material. Because it regulates heat naturally, money is saved on both heat and air conditioning. It is also a good example of a material that has resiliency as well as replicability; hence, rural communities similar to those in la Sierra have something they can use to ensure the low cost, longevity, and ease of production of their structures.

### ***Appendix A5. Local Fabrication through MASS Design Group***

The company MASS Design Group is one of the companies that have successfully represented all three pillars of sustainability in their projects. In their designs, architecture is not only beautiful and true to the culture, but also functional. Through their success they have introduced the idea of local fabrication, also known as lo-fab (MASS Design Group, n.d.). This method of design and construction involves the local community throughout the project. For example, MASS Design designed and constructed a school in Rwanda that incorporated all aspects of the community (MASS Design Group, Umubano, 2011). To begin, the school was designed to match the hills of the local landscape. To do this, local tradesmen were used for their understanding of the available materials. By doing this, MASS Design cut import costs while also improving the local economy as they hired the tradesmen to do the work. This concept was carried throughout the project thus providing jobs for the locals. Other projects around the globe can use this idea to improve both sustainability and their local economy and job market.

### ***Appendix A6. Sustainable Construction for Earthquakes and Seismic Activity***

The impact of earthquakes in Ecuador is likely to be similar to other mountainous, rural regions. One example of an earthquake and its consequences on construction has been seen recently in the Himalayan Mountains. Previous to a string of landslides in 2005, a magnitude 7.3 earthquake hit the region. The destruction that resulted was assessed by a team of researchers based on vulnerability of settlements, general damage of settlements, effects from ground fissures and landslides, and human casualty due to the earthquake (Gupta, 2007). It was found that while agricultural houses were built relatively low in height and on top of level ground, constructions were built close enough to impact each other in the event of an earthquake. Additionally, modern construction practices yielded structures that were less stable for the Himalayan fault region. Cumulatively, these points express the impact that the vulnerable constructions had on the people of Tehri Garwal, Uttaranchal, where the study was conducted. Ecuador experiences similar problems with earthquakes and the resulting damage to vulnerable structures that aren't able to withstand the force of the tremors. It is necessary to recognize geographical risk factors to plan and design accordingly to build structures that will be able to withstand such extreme conditions and experience as little damage as possible. Earthquakes are still a problem today as recently seen in the Himalayan earthquake that sparked landslides in 2005 and the 7.8 magnitude quake that struck Ecuador in April 2016 (Pearson, Shoichet, & Romo, 2016).

## ***Appendix B1. Ethical Considerations***

To pursue these methodologies, the team will implement certain protections to abide by the Institutional Review Board regulations. We assessed the possible risks of collecting interview data and created protections against these risks. In addition, we outlined safety specifications for the on-site work occurring in the community of San Rafael.

The possible risks from the implementation of our methodologies revolve around the concept of research participant identifying information. Interview testimonies, survey responses, and personal preferences or experiences can all be traced back to a research participant if not kept confidential and free of key individualistic phrases, connotations, or ideas. Identifying information, especially name, address, contact information, etc., publishing traceable information or data poses a risk to the participant. When an individual's preferences or information are published, their personal information and preferences can easily be accessed by family, potential employers, and unknown parties.

No participant will be forced to answer survey questions or to speak about any certain topic during an interview. No participant will have his/her picture, video, or audio documented without consent. Participants will also need to provide approval for demographic information, material and cultural preferences, and any other self-produced statement to be incorporated in the final report.

Construction in Ecuador is maintained safely through regulation, as in the United States. "The law states an *Inter-institutional OSH Committee* that must coordinate the enforcement of actions of all public-sector bodies with responsibilities in labor risk prevention to comply with the law and the OSH regulations" (ILO 2016). Therefore, all safety regulations will be maintained by governmental officials and the construction project management itself.

## ***Appendix B2. Community Questions: Interviews***

### *Community Interview Guide*

#### **Greeting:**

Buenos/as \_\_\_\_\_. Me llamo \_\_\_\_\_. (Y yo me llamo \_\_\_\_\_). Somos estudiantes de ingeniería trabajando por el Presidente Yanez y la Prefectura de Azuay. Tiene un ratito para hablar con usted?

#### **If NO:**

Bueno, esta bien. Será que nos encontramos otro día?

#### **If YES:**

##### **"Getting to Know Them":**

Gracias. Como se llama usted? Esta bien si lo anoto? Solamente para nuestros archivos, no mas.

#### **If NO:**

Do not proceed to take a note. Ask again later if you can write down important information or suggestions in your notebook and then annotate location of interview.

#### **If YES:**

Make a short profile for the interview as follows:

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Location: \_\_\_\_\_

Age: \_\_\_\_\_

#### **Fill in Profile:**

(Note date and community name)

Ask: Cuantos años tiene usted?

De que comunidad eres?

#### **Introduce Why You're Here:**

Estamos aquí en un proyecto del bio-construcción. Estamos tratando de aprender acerca de la construcción de casas seguras, económicas, y lindas. Pero, necesitamos la voz de la gente en orden para entender cuales preferencias tienen acerca del construcción de las casas y áreas comunitarias. Necesitamos su opinión para entender cuales materiales son mejor para usar.

#### **Interview Questions:**

- Cuales cosas de la arquitectura son característicos de [insert community name]?
- De que materiales esta hecha su hogar?
- Apoye a la construcción hecha en Loma de Ileen?
  - Que le emociona de la construcción nueva?

## ***Appendix B3. Community Forum Survey***

### **Sustainable Bioconstruction in San Rafael, Ecuador**

The goal of this project was to cooperate with the Azuay Prefecture, San Rafael administration, and community members to contribute to sustainable bio-construction designs that are locally appropriate to the parish of San Rafael. To achieve this goal, we have established three core objectives. The first objective is to assess community needs and sustainable construction designs with regards to available resources. Secondly, we will interpret community preferences based on sustainability factors and determine the weighted importance of materials and processes. Third, we will create a design catalogue of the separate components of a building to present to the community and the government for them to use for future construction.

As you may see, surveyed contributions from community members are crucial to the collection of data for this project. Your input to this survey will be used to assess the values, needs, and general sentiments of the community of San Rafael. All responses on this survey will be recorded and maintained anonymously. We would also like to emphasize that all responses are completely voluntary and in no way required.

If you have a question about your participation in this survey, you may contact the Sustainable Bio-Construction team at [bsb@wpi.edu](mailto:bsb@wpi.edu). Once you have completed the survey, please submit it anonymously to a team member. Thank you very much for your time.

Por favor, circular o escribir la respuesta. Este encuesta es opcional. Ninguna pregunta es obligado. Gracias!

1. Which community are you from?  
\_\_\_\_\_
2. What is your house made of?  
\_\_\_\_\_
3. What material is easiest to access if you want to build on to your house?
  - a. Concrete
  - b. Adobe
  - c. Wood
4. What is the most important aspect of a project to you?
  - d. Building materials
  - e. Beauty
  - f. Structure
  - g. Cost
  - h. Community participation (*Mingas*)
  - i. Use of building (house, government, community)
5. Who built your house?  
\_\_\_\_\_
6. Have you made any repairs or additions to your house?  
Yes    No
7. Do you like our project?  
Yes    No
8. Do you have any comments or suggestions?

#### ***Appendix B4. The Environment as a Stakeholder***

As previously mentioned, the Ecuadorian government has taken national initiative to protect the diverse environments (Correa, 2008). Community development must consider the geographical location of San Rafael before implementing specific materials and structural designs. The climate of San Rafael influences construction practices. Additionally, we must note which natural occurrences are prevalent in this area. We will perform research and geographic mapping to collect background data as well as on-site data concerning geography, climate, and natural occurrences. Researching climate data archives and recent natural disaster reports will improve our knowledge of the environment. Firsthand observation, notation of landmarks, and area mapping provides a tangible awareness of the aforementioned factors. We have GIS mapping data from the Azuay Prefecture to consult detailed maps.



## Appendix B5. Pugh Matrix

### New Pugh Matrix

The Pugh Matrix is a decision making model that we used to compare different building materials. The aspects that we use to judge each material with were found in the survey and interview questions. The weights of each aspect of construction were based upon the summation of the people's rankings.

#### Key

- 1 = **Worse** quality than Baseline
- 0.5 = **Slightly worse** quality than Baseline
- 0 = **Same** quality as Baseline
- +0.5 = **Slightly higher** quality than Baseline
- +1 = **Higher** quality than Baseline

Calculations:

$$\text{Material Ranking} \times \text{Criterion Weight} = \text{Points for specific criterion}$$

$$\sum \text{Points for all criteria} = \text{Total points for respective material}$$

Criteria	Weight of Criterion	Materials				
		Adobe (Base)	Bamboo	Cinderblock	Adobe + Cement Facade	Brick
Ability to Resource Locally	1	$0 \times 1 = 0$	$-1 \times 1 = -1$	$-0.5 \times 1 = -0.5$	$0.5 \times 1 = 0.5$	$-1 \times 1 = -1$
Aesthetic	3	$0 \times 3 = 0$	$-1 \times 3 = -3$	$1 \times 3 = 3$	$1 \times 3 = 3$	$1 \times 3 = 3$
Compressive Strength	4	$0 \times 4 = 0$	$1 \times 4 = 4$	$0 \times 4 = 0$	$1 \times 4 = 4$	$-1 \times 4 = -4$
Cost	2	$0 \times 2 = 0$	N/A	$1 \times 2 = 0$	N/A	N/A
<b>Sum of Points</b>		$\sum 0 + 0 + 0 + 0 + 0$	$\sum -1 - 3 + 4$	$\sum -0.5 + 3 + 0 + 2$	$\sum 0.5 + 3 + 4$	$\sum -1 + 3 + -4$
<b>Total Points:</b>		<b>= 0</b>	<b>= 0</b>	<b>= 4.5</b>	<b>= 7.5</b>	<b>= -2</b>

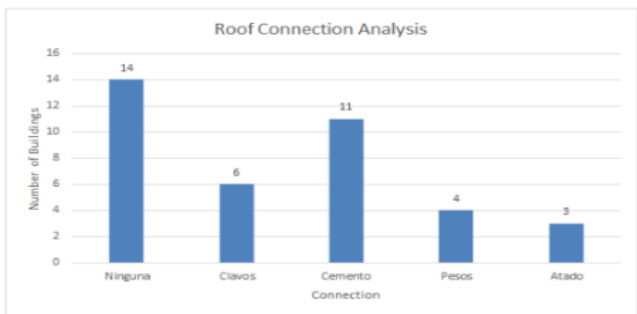
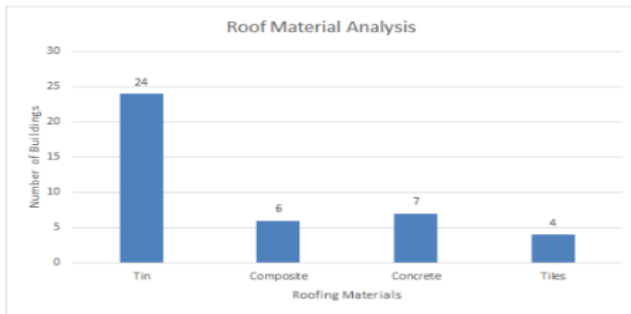
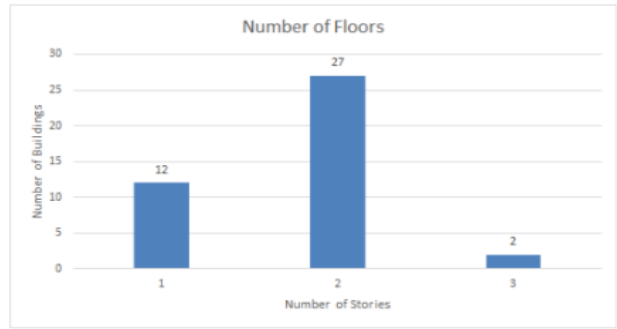
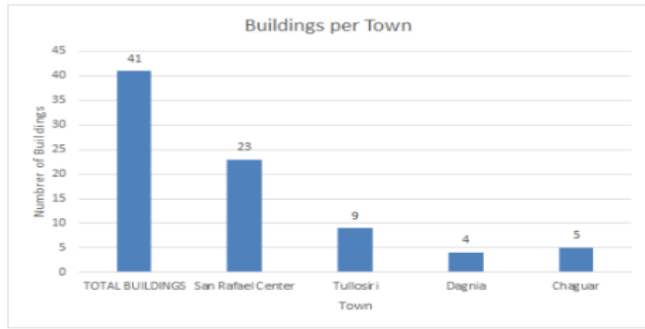
For weights of criteria, 4 is ranked the most important, whereas 1 is ranked the least important. Adobe is considered a baseline material, because the original government building was made of adobe and the GAD asked the team to consider adobe as a baseline material. After the baseline material, four alternative materials are listed. Each row ranks the materials with respect to a specific criterion. A ranking of "0" means that the material is similar to the baseline material in the respective criterion. Positive numbers

signify that the alternative material is better than the baseline. Negative numbers signify that the alternative material is worse than the baseline. The numbers are then multiplied by the weight of each respective criterion. The products are added together to form a final score. Higher scores are better.

*Data for Compressive Strength*

	Bamboo	Cinderblock (including structural concrete and iron)	Adobe	Adobe + Concrete Facade	Brick
<b>Comp. Strength</b>	8674 PSI	>1000 PSI	312 PSI	No change in structure - better resistance to weather	1000 PSI
<b>Source</b>	Gong, Y., Zhang, C., Zhao, R., Xing, X., & Ren, H. (2016). Experimental Study on Tensile and Compressive Strength of Bamboo Strasher. <i>BioResources</i> , 11(3), 7334-7344. doi:10.15376/biores.11.3.7334-7344	Superlite   an Oldcastle Company. (n.d.). Retrieved February 15, 2017, from <a href="http://superliteblock.com/technical_strength">http://superliteblock.com/technical_strength</a>	Clifton, J. R., & Davis, F. L. (n.d.). Mechanical Properties of Adobe. National Bureau of Standards. US Dep. of Commerce. doi: <a href="http://nvlpubs.nist.gov/nistpubs/Legacy/TNsubstechnicalnote996.pdf">http://nvlpubs.nist.gov/nistpubs/Legacy/TNsubstechnicalnote996.pdf</a>	None	Clay bricks, pavers, veneers manufacturer   Claybricks & Tiles Sdn. Bhd., Malaysia. (n.d.). Retrieved February 15, 2017, from <a href="http://claybricks.com/more_info/basic-of-bricks.html">http://claybricks.com/more_info/basic-of-bricks.html</a>

**Appendix C1. Data from Analyzed Buildings in San Rafael Communities**



These graphs represent the rest of the data collected when the buildings in San Rafael and the surrounding communities were analyzed. These are factors to consider when adding to the catalogue in the future but will not be completed this term.

## ***Appendix C2. Calculations to Find Minimum Steel Requirements for Reinforcing Concrete***

### Calculations: 30 x 30cm Column (ACI 318, 2014)

1. Beam rule of thumb

Minimum beam requirements:

0.75 times the overall dimension of supporting member C1

Minimum Beam =  $0.75 \times 25 = 18.75$  cm width and depth

2. Vertical Rebar (min)

Excel: diameter = 10 cm    # of rebar = 3

3. Hook angle

$45^\circ \Rightarrow$  rebar

4. Transverse Rebar (Beam)

Blast total =  $2h$      $h = 18.75$  cm     $2h = 37.5$  cm

Spacing:  $d/4 \Rightarrow d = 18.75 \Rightarrow 18.75 / 4 = 4.68$  cm apart

Normal:

Spacing:  $d/2 \Rightarrow d = 18.75 \Rightarrow d / 2 = 9.375$  cm apart

5. Transverse Rebar (column)

Blast total = 45 cm

Spacing:  $\frac{1}{4} C \Rightarrow C = 25 \Rightarrow 0.25 \times 25 = 6.25$  cm apart

Normal:

Spacing: 15 cm

**Appendix C3. Cumulative Interview Data**

Below are cumulative transcripts of data collected through semi-structured and unstructured interviews.

Person	Community/ Affiliation	Age Range	Quotes	Personal Profile Notes
1	Loja, Ecuador/ FEPP	50+	"Cement buildings are like coca-cola. They're readily available, but not good for you"	Strongly believes in culture conservation
			"Building a home is like building a life"	People are becoming materialistic/ want things fast
			"For every bamboo plant cut down, you can grow three in its place quickly. For every tree, you tear down an entire ecosystem that took years to build up"	He likes permaculture
				Most architects don't want to wait to use adobe. Want to be paid fast.
				Sleeps in adobe house for warmth
2	San Rafael de Zharug	40+	"People are getting bored of adobe"	Prefers cement to adobe
				Believes old volunteers were lazy - blames fallen auditorium on this
				Believes that the new auditorium and playground constructions on Loma de Ileen are nice escapes for relaxing
				New generation has its preferences – doesn't know how to feel about it
				Grew up in poverty. Worked in the camps until the workers from Azuay Prefectura created a need for a food business

<b>Person</b>	<b>Community/ Affiliation</b>	<b>Age Range</b>	<b>Quotes</b>	<b>Personal Profile Notes</b>
3	Tullosiri	40+	Made own house with neighbors	
4	Dagnia	30+		Likes the construction in Loma de Ileen, a family area that is beautiful in the summer; people don't go out much in the winter
				First started building house in 2003
				Hired a maestro to build
5	Chaguar	50+	"Cement is easier"	ASKED FOR HELP REPLACING ROOF AND SINK - Apologized and explained that we may not be able to without the training - She is fine and understands
				Hired maestro for adobe and engineer for cement
6	Chaguar/ Maestro (Contractor)	25+	"Cement is cleaner"	Lives with Doña Maria
				Ran out of material for Adobe 1: between walls and roofing
				Recognize Adobe 1 as not well-built
7	Dagnia	70+	"Dagnia is an agricultural community."	Has a store on first floor of house