Utilizing Waste to Provide an Economically Viable Alternative to Roofing in Ghana.

A Major Qualifying Project
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Table of Contents

List of Figures

List of Tables

Abstract

This MQP was a part of the C-Term 2023 Ghana Project Center: Development Design Lab. Our team's main objective was to develop an affordable and sustainable alternative to corrugated sheet metal roofing using plastic and coconut fiber waste with the Ghanaian community. Following axiomatic design principles, our team designed a compression molding process. Our team tested this process by producing a recycled LDPE beam and conducted material testing. Additionally, we created a value stream map, cost sheet, and ran an in-depth interview. Overall, it was concluded that this process was not viable for producing composites of this nature but demonstrated significant potential for future work to be explored.

Acknowledgements

We would like to thank Professor Robert Krueger for allowing us this opportunity and Professor Mahamadou Lamine Sagna for overseeing us in Ghana. We would also like to thank Chief Osabarima Owusu Baafi Aboagye III of Akyem Dwenase and Statesman Barfuor Adjei-Barwuah for teaching us about Ghana's history and culture in preparation for this experience. We would also like to thank Dean Debra Jackson and Professor Walter Towner for advising Jackson Baker on the management engineering elements of this project and for providing additional guidance on project management. We would also like to thank Professor Mustafa Fofana for advising Michael Morin on the mechanical engineering elements of this project. We would also like to thank Academic City University College, President Fred McBagonluri, Pinnock Casely-Hayford, Benjamin Boamah Odame, and Abu Karim for graciously allowing us to use their workshop, equipment, and materials, in addition to providing invaluable guidance and lessons while in Ghana. Last and most importantly, we would like to thank the people of Ghana for welcoming us into their country and the beautiful experience.

Figure 1: (from left to right) Benjamin Boamah Odame, Jackson Baker, Pinnock Casely-Hayford, Michael Morin, and Abu Karim

Authorship

Jackson Baker was responsible for the anthropogenic perspectives of our project. Mr. Baker was responsible for formatting, writing, and editing the report, as well as performing extensive research on Ghanaian infrastructure, financial constraints, and the ideals and practices of generative justice. Jackson Baker additionally created an in-depth value stream map and costing analysis. Mr. Baker worked with Mr. Morin on the structural aspects of the project by practicing welding and further constructing the material through methods of melting and pressing. Lastly, Mr. Baker had worked closely with members of the Ghanaian community to build a working relationship as well as collecting statements (through interviews) to help provide a contextual perspective, unique to Ghana.

Michael Morin was responsible for the design and material elements of our project. Mr. Morin was responsible for writing and editing the report, documenting the experience through photographs, as well as performing extensive research on Ghana’s housing, climate, and waste conditions, in addition to plastic and composite materials. Mr. Morin created a SOLIDWORKS model and drawing of the mold design and worked with Mr. Baker to construct the mold and manufacture the sample material. Lastly, Mr. Morin conducted material testing on the sample material to assess its value for applications in Ghana.

CHAPTER 1: Preparation

1.1 Foundation of Project

This project was an abroad single term (7-week) MQP located in Ghana, Africa as a part of WPI's Development Design Lab. Before entering the country, our team, alongside several other IQP and MQP groups, was briefed in a preparatory class on Ghana's rich history, culture, and development to contextualize ourselves and our work. The messages held throughout both the class and our projects were to embrace co-creation and reject the ideals of colonialism. To help promote these teachings, the teams were fortunate enough to be guided by Professor Robert Kruger, Professor Mahamadou Lamine Sagna, former Ghana-U.S. ambassador Barfuor Adjei-Barwuah, and Chief Osabarima Owusu Baafi Aboagye III of Akyem Dwenase (located in the Eastern Region in Ghana). With their insight, our team entered Ghana with an enhanced perspective and an intentionally flexible project plan and aims to develop a naturally incited multicultural solution.

While most of the students in this group stayed in the town of Akyem Dwenase, our team was stationed in the capital city of Accra due to the nature of our objectives. Our team was tasked with developing and analyzing a sustainable alternative to corrugated sheet metal roofing using plastic and coconut fiber waste. To achieve this, we collaborated with Academic City University College to develop and actualize ideas. We were granted access to the engineering department's facilities and tools and received invaluable guidance from faculty members Pinnock Casely-Hayford, Benjamin Boamah Odame, and Abu Karim - with whom we co-created this project with.

Our team's initial design was aimed to be built from both plastic and coconut waste to provide a sustainable and affordable alternative to roofing. Two different perspectives were considered throughout the project to help determine a practical solution that accounts for external factors that may influence the project. The differentiation in perspectives was set in place to ensure that there was both structural and economic viability throughout. To prove structural viability, it was essential to run several tests to determine whether our product could withstand the conditions that Ghana would bring to roofing. Additionally, through communicating with residents of Ghana, we demonstrated the value of our proposed alternative to the public, which ultimately determined overall interest and economic viability.

Since our team was composed of two members, it was important to delegate tasks with clear intentions. This delegation was intended to keep the team on track and to ensure coverage of the several tasks to construct a composite mold. To prove structural viability, it was essential to run material testing to determine whether our product could withstand the conditions that Ghana would bring to roofing. To further decompose these tasks in an organized and simplistic manner, we created an axiomatic design to maintain a concrete goal.

1.2 Axiomatic Design

Before beginning research and construction of a mold that would form a composite material, it was necessary to compare the functional requirements with the design parameters, by decomposing our process with an axiomatic design. This method allowed our team to properly view the different components of our project from each stage of our project. To appropriately recognize the key concerns in roofing, our team sat down with engineer and project sponsor, Pinnock Casely-Hayford for further insight. After noting the recommended considerations from Mr. Casely-Hayford (see Appendix C.2), our team was then able to gain a strong foundation to build concrete goals. Considerations including UV protection, energy consumption, tariff limitations, strength degradation, fault lines, sorting, diseased coconuts, and many other factors had not been considered when our team had entered Ghana. With the help of Mr. Casely-Hayford, our team had been given insight to then form a well-informed design.

Our team adjusted the axiomatic design as further changes were made to the project to ensure that our project did not deviate from our objective. Keeping this updated prevented further setbacks and allowed us to consider any possible barriers with our proposed design. Creating an adequate axiomatic design allowed for optimal time management and efficiency throughout our process. In doing so, we began by dividing our approach into functional requirements and design parameters to determine what areas of research were necessary to examine. This allowed us to accomplish the different steps needed to create a cohesive alternative. This design was then referenced again once material testing was completed, so that we would be able to determine whether this was a suitable framework to meet the necessary criterion. Listed below is the axiomatic design, consisting of both the functional requirements and design parameters for our initial approach:

1.2.1 Functional Requirements

- FR0: Produce affordable roofing in Ghana using waste.
    - FR1: Configure design to withstand Ghanaian weather.
        - FR1.1: Optimize Weight.
        - FR1.2: Maximize Longevity.
        - FR1.3: Increase Strength.
    - FR2: Produce an affordable product.
        - FR2.1: Minimize energy consumption.
        - FR2.2: Utilize waste.
    - FR3: Demonstrate value to the public.
        - FR3.1: Determine cost.
        - FR3.2: Communicate with the Public.
        - FR3.3: Compare Pre-Existing Methods.

1.2.2 Design Parameters

- DP0: System to produce affordable and sustainable roofing.
    - DP1: Materials for roofing.
        - DP1.1: Plastic waste that is low in density.
        - DP1.2: UV Resistant.
        - DP1.3: System to press into a mold.
    - DP2: Methods to prove affordability.
        - DP2.1: System using energy efficient equipment.
        - DP2.2: Composite material from plastic and natural waste.
    - DP3: Value stream map
        - DP3.1: Cash Flow Analysis.
        - DP3.2: Statements/Survey.
        - DP3.3: Product Comparison Chart.

CHAPTER 2: Project Rationale

2.1 Introduction

This chapter acts as a preface to our experimental work and provides context to the project objective. To better understand the objective and develop the goals of our axiomatic design, extensive background research regarding the nuances of roofing in Ghana was necessary. This research included topics of Ghana's housing and waste conditions, plastic and composite materials, Ghana's infrastructure and financial conditions, and generative justice. Through this research we were able to explore the most practical and sustainable approaches for our objective and approach this work in good faith with an enhanced adaptation of the ideas of generative justice and co-creation.

Roofing provides several critical functions for a building, all rooted in providing protection from external conditions. In Ghana, around 80% of all roofing in both the urban and rural settings are made from metal sheets. These sheets come at a premium cost which creates a significant financial barrier for much of the population. In addressing roofing concerns, our team explored the most sustainable approaches, given the abundance of plastic waste in Ghana. Exploring the overall availability and distinctive properties in the plastics that make up Ghanaian waste allowed us to determine what the most appropriate type of plastic to utilize. Our team additionally researched sustainable methods that were/are being incorporated into Ghana's infrastructure. With sustainability in mind, it was crucial for our team to consider the overall affordability of our product. Further understanding any potential financial constraints specific to Ghana, was essential in determining overall economic viability in our proposed solution. Additionally, regarding structural and economic viability, we ensured that through the practices of generative justice, our team would be encouraging co-creation and discouraging [un]intentionally incorporating colonialist ideals and practices into our proposed solution.

2.2 Population and Housing in Ghana

Ghana is in the Sub-Saharan region of Western Africa. It borders Burkina Faso to the North, the Atlantic Ocean through the Gulf of Guinea to the South, Togo to the East, and Côte d'Ivoire to the West. Ghana is home to a population of just over thirty million people, spread across sixteen different administrative regions (Ghana Statistical Service, 2021).

Figure 2: Administrative map of Ghana's sixteen regions (Ghana Statistical Service, 2021)

Over half of this population lives in just four regions: Greater Accra (17.7%), Ashanti (17.6%), Eastern (9.5%), and Central (9.3%) (Ghana Statistical Service, 2021). While overall population growth during the last decade in Ghana has hit an all-time low since independence, urban populations have seen greater growth rising from 12,545,229 (50.9%) in 2010 to 17,472,530 (56.7%) in 2021, with just under half of this increase (47.8%) coming from the Greater Accra and Ashanti regions alone (Ghana Statistical Service, 2021).

To house this population, as of 2021 there were almost six million residential structures with ten million actual dwelling units (Ghana Statistical Service, 2021). Due to a lack of affordable housing and maintenance, this infrastructure is currently severely strained. Only 31.4% of residents in urban settings own their dwelling, with 67.8% renting or living under rent-free conditions because of the high housing costs, causing crowding (Ghana Statistical Service, 2019). The mean housing size of these urban dwellings is 3.5 persons, with 52.5% of one room dwellings occupied by two to five people, conditions known for causing health problems (UN-Habitat, 2011 & Ghana Statistical Service, 2019). Additionally, the conditions of the structures of the urban poor are said to be in a "deplorable state" with declining infrastructure stemming from Ghana's harsh environmental conditions, crowding, and the costs of maintenance (Danso-Wiredu, 2020 & see Appendix D).

Figure 3: Residential units in Kyebi. Photo Credit: Michael Morin

The unaffordable housing prices in Ghana are a consequence of "high land construction costs, high labour costs, persistent land litigation, poor land tenure system, high borrowing costs, difficulty in obtaining funds and a shortage of building materials" (Zakaria, 2020). It also comes as a factor of a low per capita income, with the mean in urban settings being 16373 GHC (~1300 USD) and rural settings being 5880 (~470 USD) (Ghana Statistical Service, 2019). As of 2011 only the top 20-25% of urban households could afford rental housing available on the market, even with housing payments set at just a third of the person's income (UN-Habitat, 2011). Furthermore, the bottom 35% of urban households would need a monthly rental payment of GHC10 to be considered affordable, even with housing payments set at just a tenth of the person's income (UN-Habitat, 2011).

Almost all housing structures in Ghana are made from concrete bricks or mud bricks due to resource availability and Ghana's environment. In urban areas, over 80% of housing structures are made from concrete while in rural areas mud bricks are more prevalent with only 40% of structures being made from concrete (Ghana Statistical Service, 2021). While concrete ultimately performs better than mud, it comes at a much more expensive cost. Despite this, the biggest building material expense comes from roofing. In Ghana, around 80% of all the roofs in both the urban and rural settings are made from metal sheets (Ghana Statistical Service, 2021).

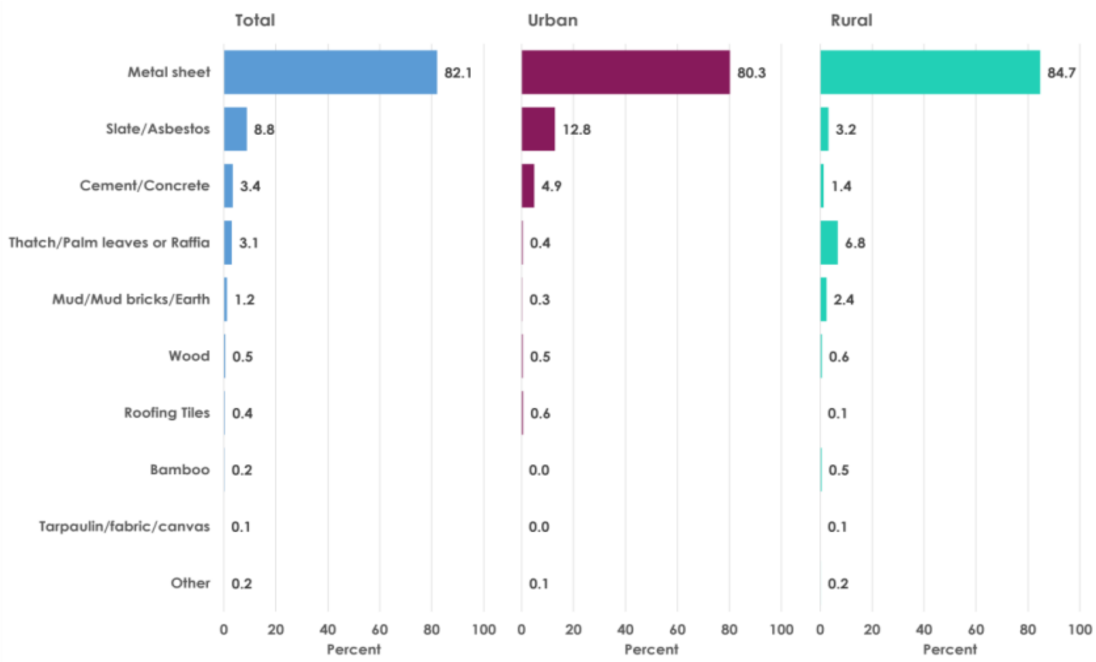

Figure 4: Percentages of roofing materials for living units in Ghana (Ghana Statistical Service, 2021)

These metal sheets are typically made from a form of galvanized aluminum for its desirable strength and corrosive properties in relation to Ghana's harsh environmental conditions (see Appendix D & Appendix E). Because of these properties, metal sheets have lengthy cycle lives which reduce costs over time and the need for maintenance, increasing the appeal for property owners who have limited desire and resources to maintain their properties (Konadu-Agyemang, 2001). Almost all the metal roofing sheets in Ghana however are either imported or manufactured locally from imported materials, which severely increases their cost (Agyei, 2022 & Konadu-Agyemang, 2001). Consequently, roofing is said to make up around a third of the construction costs of a house and thereby factors into home ownership being unattainable for significant portions of the population (Arku, 2009).

As a result of the housing conditions, there is a market in Ghana for affordable, attainable, and sustainable building materials. A few companies have already capitalized on this market, one example being *Nelplast Eco, Ghana Ltd*. who uses plastic waste and sand to produce pavers and bricks.

Figure 5: Nelplast Eco's prototype home built entirely from Eco Blocks (excluding the roof). Photo Credit: Michael Morin

By using local and waste materials, *Nelplast Eco, Ghana Ltd* produces building materials at a fraction of the cost of concrete, providing an alternative and more sustainable path forward for Ghana's housing problems. The market however has yet to find a solution for roofing.

2.3 Waste in Ghana

In Ghana, waste generation is experiencing significant growth because of population growth and urbanization, following global trends (see Appendix F-1). Such growth has outpaced growth in waste management infrastructure, with collection rates falling only between 50-80% (Lissah, 2021, Kaza, 2018, & Kusi, 2016). As a result, around 90% of all waste ends up at locations outside of designated dumping sites, making it commonplace to see open dump piles and loose waste littering the streets, waterways, and overall environment (Lissah, 2021, Kaza, 2018, & Kusi, 2016).

Figure 6: Pile of assorted waste located near the beach in the town of Elmina in the Central Region. Photo Credit: Michael Morin

Waste that does not end up scattered across the environment is either subject to incineration, a widely practiced waste disposal method in Ghana, or landfilling, both infamous for generating severe negative effects on public health and the environment (see Appendix F-2).

Waste reuse and recycling however are a fundamental and growing part of Ghana's economy and culture. Due to limited manufacturing infrastructure, many engineering materials and parts that are readily available in more developed parts of the world are not in Ghana. As a result, creative solutions lie at the core of Ghanaian engineering and engineering resources are commonly sourced through waste products. Landfills and dump sites are regularly populated with scavengers looking to recover this value for the Ghanaian economy. Overall, this culture reduces the amount of waste in the hazardous disposal stream and enables significant reduction in material costs for projects, making it a highly valuable practice in Ghana. One waste resource with a lot of reuse and recycling potential in this system are plastics, due to their material properties and abundance in Ghana's economy (see Appendix F-3).

2.4 Polymers & Plastics

Plastics, or scientifically, thermoplastics, are a category of polymers, synthetically made materials commonly made up of long molecule chains built from covalently bonded repeating units of atoms known as mers, that are defined by their ability to be melted down and reformed without causing permanent damage to the material (Chen 2021, Chamas, 2020). Their abundance in the modern global economy comes because of their enhanced material properties, manufacturability, and cost (see Appendix H).

In 2018 alone, globally around 400 million metric tons of plastic products were produced (Chen, 2021 & World Wildlife Fund, 2019). This number is expected to grow by 40% or an additional 150 million metric tons by the year 2030 (World Wildlife Fund, 2019). One area of industry that is driving this growth is the packaging industry and the rising use of single use plastics or SUPs. It is estimated that half of all plastic produced is for single use plastics, making plastic a big part of global waste streams (Chen, 2021). This causes several issues, as the enhanced properties of plastics make their disposal challenging, with degradation times under natural conditions taking multiple decades or centuries (Chamas, 2020). With a third of all plastics ending up as pollution, this poses devastating effects on environments and ecologies across the globe (Chen, 2021).

Outside of SUPs, plastics have found significant use in the automotive, aerospace, and nautical industries for their strength and low density (Mills, 2020). Many of these applications however require strength properties not naturally achievable by plastic alone, causing the need for some level of reinforcement. Such reinforced materials are known as composites.

2.5 Composites

Composite materials can be defined as the resultant combination of two or more constituent materials which usually results in a final highly tailored product with enhanced material properties. They typically consist of two main constituents, a harder elongated set of fiber-like materials, and a softer surrounding material known as a matrix (Clyne, 2019). The fibers are said to provide significant reinforcing effects on the matrix, making the final composite material durable and strong while staying lightweight.

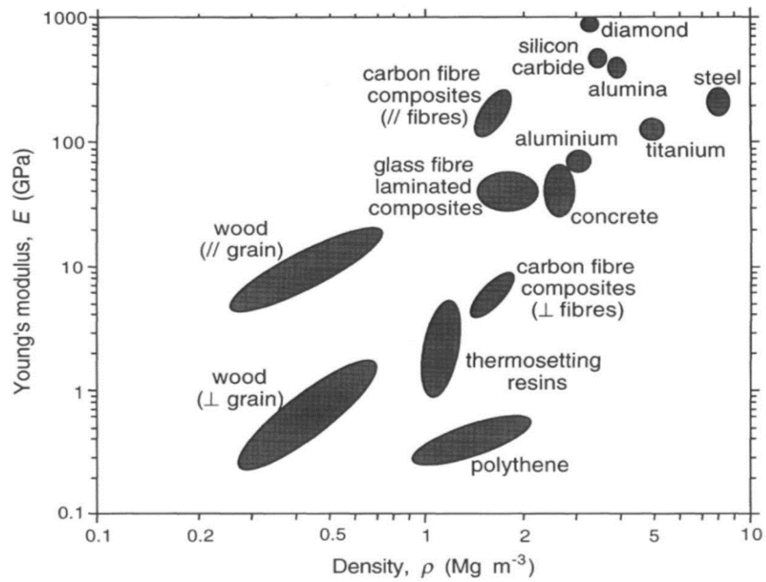

Figure 7: "Data for some engineering materials in the form of areas on a map of Young's modulus E against density ρ" (Clyne, 2019). It is shown that composites can have comparable mechanical strength to various alloys while being less dense.

Because of the load transfer onto the fibers, these composite materials usually display anisotropy, meaning their strength and overall properties are dictated by the direction and plane of the load (Clyne, 2019). This presents additional design considerations for engineers as in general most engineering materials are isotropic but allows for enhanced and more optimized control over the material for specific components and applications (Clyne, 2019).

In industry, most composites consist of a polymer matrix with ceramic fibers. Composites of this nature can be found in most vehicles including cars, boats, and airplanes and are used in many various sport and civilian infrastructure applications because of their benefits (Clyne, 2019). Because of their widespread use and critical role in modern engineering, composites are at the center of many modern product and research ventures.

One area of modern composite research is in natural fiber reinforced polymer composites (NFRCs), which are defined as composites that use reinforcing fibers from natural sources. Natural fibers provide several advantages over their synthetic fiber counterparts: they are widely available and more environmentally friendly in the long term, require less energy to process and thereby come at a lower cost, and can still provide good mechanical properties while at lighter densities than alternatives (Balla, 2019 & Mohammed, 2015). These fibers however can be difficult to work with as properties are highly dependent on the hydrophilicity of fiber and the composite manufacturing process used (Balla, 2019). Despite this, with proper manufacturing and utilization NFRCs provide a highly sustainable and practical alternative engineering material. These benefits can be even further extended through the use of waste plastic recycling to construct the matrix, a process that has large potential for value reclamation and is perfect for developing nations, like Ghana.

2.6 Ghanaian Infrastructure, Economic and Social Impacts on Development

2.6.1 Ghanaian Infrastructure

Due to the lack of sustainable infrastructure, Ghanaian urban development is currently in dire need of reconstruction. In the capital of Ghana, Accra, the significant lack of infrastructure has left the city divided by socio-environmental inequality and unequal access to formal networked services that continuously reinforce unequal social relations (Silver, 2014). This division further causes Ghana’s economy to suffer - making the attention of financial stability a main priority. From this, sustainability and environmental care becomes a secondary concern. With the Ghanaian economy on the decline, further development of housing and roofing has not progressed as needed. Ghana’s residential industry cannot financially afford their current approaches due to the unstable nature of their economy. The lack of accessibility of construction equipment, as well as costing from imports and energy consumption, have been additional factors that are worsening Ghana’s financial position. In turn, roofing construction and further maintenance on housing then creates another financial burden on the Ghanaian community. If Ghana were to pose sustainable approaches to infrastructure, greater opportunities for further economic and environmental development could allow for affordable housing maintenance, including roofing. Given the overabundance of waste in Ghana, sustainable infrastructure will be a valuable resource.

Existing efforts such as urban green infrastructure offers relevant and viable alternatives that could potentially benefit Ghanaian infrastructure. These approaches intend to promote initiatives that present sustainable solutions to communities that are struggling with economic and environmental development. Urban green infrastructure (UGI) can be defined as “a fundamental fragment of sustainable urban development that has the potential to provide stability and connection between the opposing ideals and outcomes of environmental protection, economic growth, and socio-cultural development in growing cities" (Cobbinah & Darkwah, 2016; UN-Habitat, 2014; Zakka et al., 2017). Incorporating these sustainable methods (see Appendix A.1), not only benefits the environment but also creates stronger unity, further motivating to help strengthen their community (see Appendix A.2). Making the UGI efforts appealing to the public is an important factor that increases engagement as well as investment in sustainable initiatives. Without the proper funding and support from the [Ghanaian] government, UGI’s will not be able to succeed in improving the infrastructural development.

2.6.2 Financial Constraints

Ghana’s economy has prospered tremendously in comparison to many African countries since they gained their independence in 1957 (see Appendix A.3). While achieving the classification of a low-middle class country, there has been minimal growth in industrialization while services have increased tremendously (Diao, 2019). Without the prosperity of industrialization, Ghana continues to face challenges within the development of construction both industrially and residentially. Even with an increase in GDP and services, the overall value and productivity from workers is not aligning with the economic growth in Ghana (Diao, 2019). This is ultimately due to the lack of automation/industrialization in the country, motivating workers to pursue short-term careers to ensure a consistent flow of income. Considering workers are struggling to manage their own financial stability, naturally, the wellbeing of the environment is not as much of a concern to the Ghanaian community.

Sustainability may not be a priority for the public, although policymakers in Ghana expressed a deep level of concern for the environment and intended to achieve 10% of its energy needs through renewable sources by 2020 (Energy Commission of Ghana [ECG], 2018). Given the lack of investments in UGI's, minimal [local] public concern, and high tariff rates, Ghana is faced with an ambitious challenge to address sustainability. While access to electricity is at a high of 83% in Ghana (USAID, 2018), there is an inherent need to prioritize renewable energy, as most energy sources being utilized are not sustainably viable (see Appendix B.2). With continuous interruptions to the power supply and minimal interest from investors, Ghana has only been able to achieve 0.2% of their renewable energy goal (Energy Commission of Ghana [ECG], 2018). Ghana still intends to reach this goal, as over two-thirds of Africa's population is without electricity; attributed to lack of development and affordability (IEA (International Energy Agency), 2014). Without a lack of consistent financial support, Ghana will be unable to develop residential and industrial areas efficiently and affordably. In this instance, the premium it costs to manufacture/import steel, account for labor, and supply consistent access to [affordable] energy for workers is significantly hindering the development of housing and roofing in general.

In addition to the significant expenses within energy consumption, import costs for resources are also preventing further development. The current method for specifically roofing in Ghana, has primarily been to import corrugated sheet metal. Given that metal is in scarce supply [in Ghana], importing corrugated sheet metal globally has been a costly avenue for roofing. According to Trading Economics, the total expenses of iron and steel imports has gone from over $100 million USD in 2006 to $359.24 million USD in 2019 - accounting for approximately 3.4% of Ghana's total imports (COMTRADE, 2023). The increase in spending is due to the ECOWAS Common External Tariffs, set into place by the GRA (2022), who established five tax rates (see Appendix B.3). Given the substantial taxation applied to imports alone in Ghana, it is not an affordable solution to continue outsourcing material for roofing at the current rate. Rather than importing goods, it will be crucial to focus on materials that are readily available. Shifting the mindset away from outsourcing can ultimately create opportunities for further development in Ghana.

2.6.3 Generative Justice

Before posing any solutions to an issue in a foreign country, it is crucial to prioritize co-creation within the Ghanaian community - rather than unintentionally (or intentionally) supporting problematic colonialist ideologies that have damaged foreign communities in the past. It is paramount to ensure that when entering a new country such as Ghana, the pre-existing ideologies and cultural norms are taken into strong consideration. The Colonialist ideologies and approaches in Western African countries, such as Ghana, historically have negatively impacted the country's development and discouraged further co-creation. Before leaving the United States, our team studied the significance and impact that generative justice can have on a developing country. Generative justice can be defined as, generating value through bottom-up efforts that address forms of inequality through shifting the fundamental approaches of economics, politics, technology, ethics and more (Eglash, 2016). This project is intended to practice the ideals of generative justice by encouraging co-creation between different cultures that can offer insight from unique perspectives that are unique to the site being studied. Not only is this creating a well-informed process, but it is also promoting global unity, equality and economic and environmental stability through encouraging sustainable practices that require a communal effort.

Over the years, the Ghanaian mindset has begun encouraging the younger generation to pursue engineering as a viable career path. For instance, the city of Agbogbloshie, has begun incorporating different methods of generative justice into practice to further address sustainability issues in Ghana (see Appendix C.1). As a result, the Ghanaian community has seen benefits both culturally and environmentally. Through institutions such as the nationally accredited university of Academic City in Accra, Ghana, students can pursue further pursuits in engineering with the appropriate equipment and guidance necessary.

To incorporate these practices of generative justice, our team worked closely with the engineering workshop, who offered tremendous insight from the design stage to construction. We were able to learn many useful skills at the university and gain insight that otherwise was not available without the local perspective. Working closely with engineer Pinnock Casely-Hayford and his assistant, we have been able to work together on designing a mold that is capable of pressing a mixture of plastic waste and natural components into one composite material. Before we began, we sat down with engineer Casely-Hayford and asked a series of questions to help further understand our design parameters (see Results section for full interview). Though our approaches may have differed, we were able to identify key barriers and the best way to address them through exchanging ideas and engaging in productive discourse that informed all parties respectively. Our team entered Ghana with an indistinct approach to the project and issue. While we knew what our prompt and initial objective was, we had no contextual foundation. Talking with the local Ghanaian community allowed for further insight on our project that otherwise could not have been acquired in the United States. Initiating our project with the practices of generative justice allowed us to properly structure and form a timeline with corresponding goals and objectives that are well representative of the roofing concerns in Ghana.

CHAPTER 3: Methods and Process Design

3.1 Process Design and Construction

One key aspect of our project was to ensure that our proposed material alternative is both appealing and practical to construct. To assess this, our team designed and tested the capabilities of a compression molding process. This type of process was chosen for its energy efficiency and simplicity, as parts could be molded without the use of electricity through mechanical means such as hand clamps.

The design for the mold and thereby the shape of the sample was based on material testing requirements and the commonly available scrap material and tools in Ghana. The team ultimately pursued beam samples because of their geometric simplicity and fundamental role in building applications. These design ideas were initially substantiated through rough sketches and were later refined in SOLIDWORKS through a model and drawing (see Appendix I).

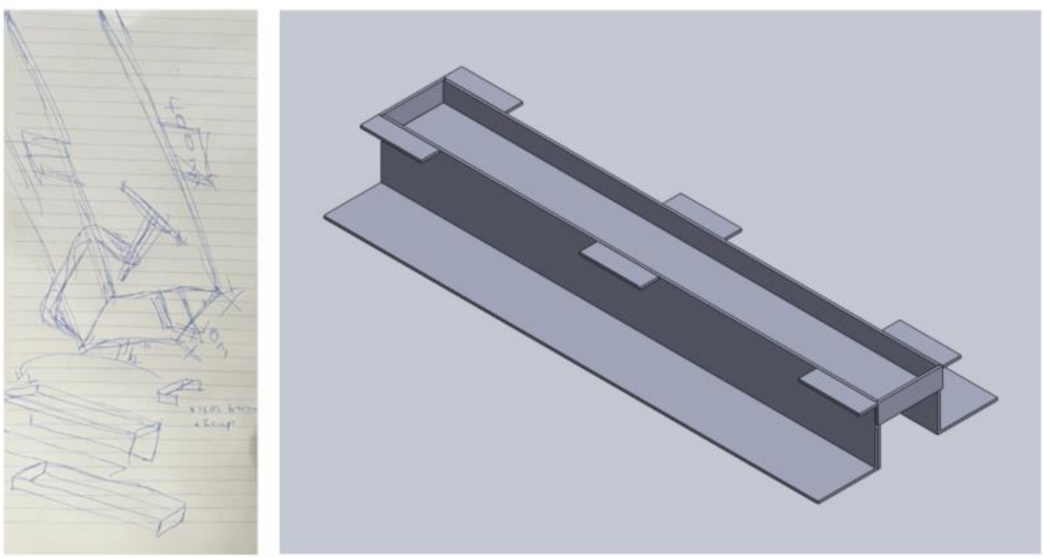

Figure 8: Left: Photo of initial design sketches from Pinnock. Right: Modeled design in SOLIDWORKS

Following this design, three 49mm x 49mm x 2mm mild steel angle iron pieces were cut to a length of ~405mm. One of these pieces was then further cut down to 33mm x 47mm x 2mm to form the bottom of the cavity. Additional pieces were cut from scrap mild steel sheets, including six rectangular 50mm x 15mm x 2mm pieces for the compression points, two rectangular 53mm x 16mm x 2mm pieces to seal the ends of the mold, and an additional 416mm x 75mm x 3mm piece for a lid.

Figure 9: Photo of local scrap yard owner cutting the lid piece from a large sheet of mild steel. Photo Credit: Michael Morin

After acquiring the individual pieces, faces that would be internal to the mold cavity were polished by hand using sandpaper to produce cleaner samples and enable easier sample removal from the mold. These pieces were then welded together at edges outside of the cavity to keep the internal geometry intact.

Figure 10: Photo of Mike welding the clamp pads onto the mold with assistance from Abu. Photo Credit: Jackson Baker

Welds were then tapped with a hammer to remove bad material and were grinded, sanded, or filed down as needed to allow for quality compressing. After such, the final mold was completed.

Figure 11: Photo of the final welded and polished mold assembly. Photo Credit: Michael Morin

To create the melts, hundreds of wastewater sachets were collected and sourced through scavengers at local waste dumps. These sachets were cut open using scissors, unfolded into flat sheets, skewered onto a metal rod, and left out in the sun for two hours so that they could be effectively dried.

Figure 12: Photo of the sachet drying set-up. Photo Credit: Michael Morin

After drying, ten sachets were individually weighed using a digital scale and averaged to find the weight of a typical waste sachet. Using this value, the dimensions of the mold, and the known density of LDPE, the weight and count of sachets needed to fill the mold volume was calculated and used in preparation for the melts. For the coconut fibers, fresh coconut husks were purchased from a coconut seller near the university and the fibers were pulled out by hand. Fibers would be added to the melt at 2g intervals to produce the various composite samples.

To melt down the sachets, an aluminum pot and propane burner were acquired by Ben and Abu through local sources. As a means of temperature control, an IR thermometer would be used to monitor the pot and melt. If temperatures were to approach the burn temperature of LDPE, the gas flow would be adjusted as needed. The coconut fibers for each composite would be added after the sachets were fully melted down so they could be uniformly mixed in. Once the final melted material was created, it would be transferred into the mold and compressed by the lid using six of the workshop's hand clamps.

3.2 Material Testing

To assess the reinforcing properties of the coconut fiber and the resultant composites, a three-point bending test would be conducted on samples using even surfaces around the workshop and standard weights.

Figure 13: Photo of the 1kg, 2kg, 4kg, and 10kg standard weights for deflection testing. Photo Credit: Michael Morin

A level would be used to ensure the bar laid flat and a tape measure would be used to measure deflection at 1kg intervals.

As an additional means of testing, there was an AIT-300-N Impact Testing Machine from Daksh available in the workshop.

Figure 14: Photo of the AIT-300-N Impact Testing Machine.
Photo Credit: Michael Morin

Smaller samples would be cut to the appropriate size from the sample bar and would be tested according to unnotched izod impact testing methods, meaning samples would be held vertically using a vice at one end.

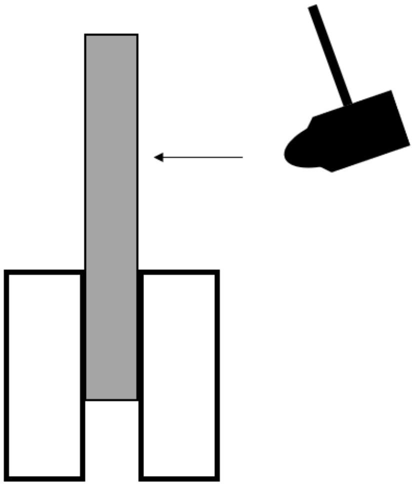

Figure 15: Diagram of an unnotched izod impact test.

3.4 Value Stream Map

A value stream map communicates added value through calculated process times and determined wait times regarding the customer and supplier. In our case, we examined where the materials would be sourced and how they would be utilized in each process. Between each process, we determined the amount of wait time to analyze how efficiently the system was being run. Along with wait time, we also calculated the process time to ensure that we achieved minimal work in progress time. Once this data was collected, our team created a visual that intuitively displayed this information. This visual is crucial to help communicate to the Ghanaian community how our proposed solution can add value.

3.5 Cost Sheet Analysis

After communicating the value of our solution to the public, our team created a cash flow analysis. A cash flow analysis demonstrates the changes in net cash flow by itemizing expenditures and any inflow. In our team's case, we mainly recorded expenditures to calculate the overall cost to produce this composite material. Once the costs were collected, we then organized a cost sheet in an intuitive fashion to clearly display the range of pricing in material and energy consumption. Our team then intended to compare this cost sheet to an estimated cost sheet for corrugated sheet metal to show how the different approaches financially compare. This visual was intended to be used as a tool to help communicate the costs of each individual component used to create this product.

CHAPTER 4: Results and Discussion

4.1 Process

The average weight of an individual waste sachet was found to be 1.43g, with variations resulting from how the sachet was opened and manufactured.

Sachet #	Weight (g)
1	1.36
2	1.38
3	1.45
4	1.42
5	1.45
6	1.45
7	1.48
8	1.43
9	1.31
10	1.59
Average	1.43

Table 1: Table of the weights of the ten different sachets

As a result, to make a pure LDPE beam it was found a minimum of 187 sachets would be needed. To better fill the mold, 200 sachets were used.

Sachets were melted down a handful at a time to better control the melting process. The first few sachets melted quickly and stuck to the pot, but a small ball of molten plastic began to form. This ball kept getting bigger as more sachets were added every few minutes. Once all of the sachets were melted down into the ball, the melt was moved from the pot to the mold. The melt however was not spreading effectively due to rapid cooling. To deal with this, the whole mold was put onto the propane burner to keep the melt hot and malleable.

Figure 16: Photo of Jack spreading the LDPE melt into the heated mold. Photo Credit: Michael Morin

The position of the mold on the burner had to be shifted around to provide a more uniform temperature distribution to achieve the desired result. After the melt was sufficiently spread, the lid was placed on top of the mold and compressed shut using only four hand clamps, one at each corner. An additional weight was added to the center of the lid to allow for better compression. This set-up was then left overnight to cool back down to room temperature naturally.

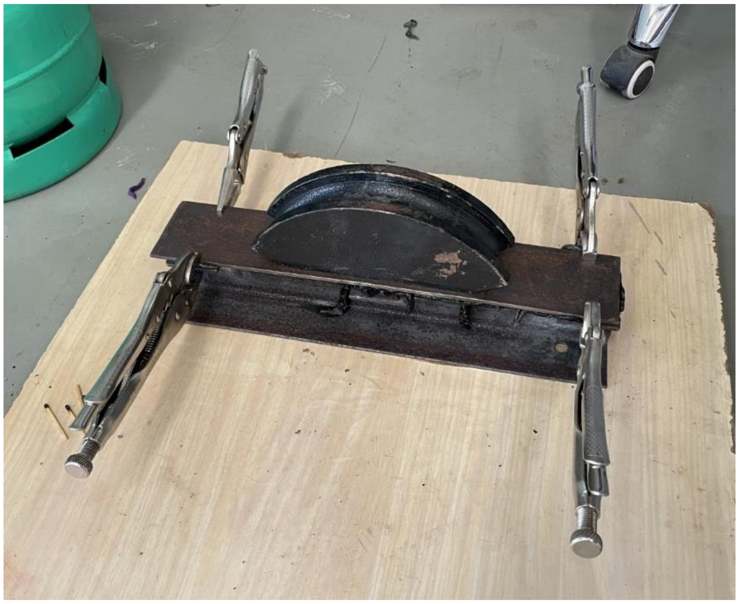

Figure 17: Photo of the melt being compressed into the mold via four hand clamps and a weight. Photo Credit: Michael Morin

After being sufficiently cooled, the clamps and lid were removed from the mold:

Figure 18: Photo of the resultant LDPE bar in the cooled mold. Photo Credit: Jackson Baker

Removing the bar from the mold however proved to be a much more difficult process. Initially a chisel was used to try and pry the bar out from its spewed edges, however this was unsuccessful. Next, four holes were then drilled into the bottom of the cavity such that a hammer and tap could be used to push the bar out.

Figure 19: Photo of Ben using a mallet and tap in attempt to remove the bar with assistance from Abu. Photo Credit: Jackson Baker

This attempt however was also unsuccessful, and the drill damaged the bar in the process. Next the side of the mold was cut off using a grinder and a chisel was used to pry the bar from the bottom of the mold, successfully releasing the bar.

Figure 20: Photo of Abu using a chisel to pry the bar from the mold with assistance from Ben. Photo Credit: Jackson Baker

Once the bar was removed, excess material was trimmed using a hacksaw and edges were cleaned with sandpaper.

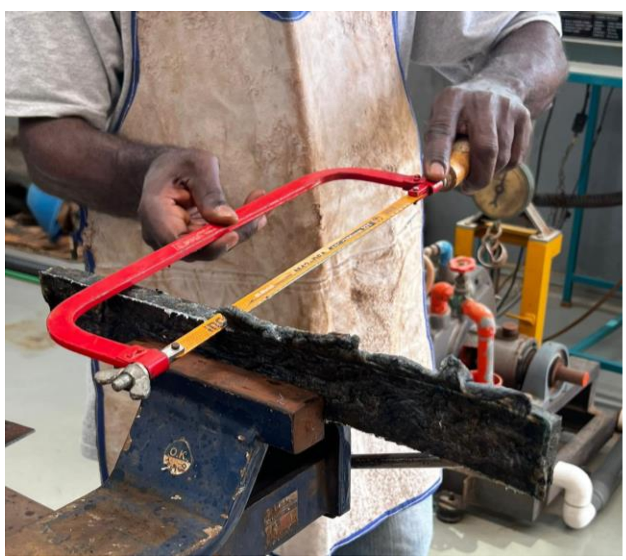

Figure 21: Photo of Ben trimming the excess material from the top edges of the bar. Photo Credit: Jackson Baker

The resultant bar turned out as follows:

Figure 22: Photos of the top of the bar (top) and the bottom of the bar (bottom). The top is notably rough and wavy, and the bottom is smooth with demolding damage. Photo Credit: Michael Morin

After this process, it was determined no other melts would be pursued due to the state of the mold and the limited available time in Ghana. As a result, material testing was conducted just on the pure LDPE sample.

4.2 Material Testing

Figure 23: Photo of the three-point deflection test set-up for 2kgs. Photo Credit: Michael Morin

The final three-point deflection set-up used two large pipe benders to hold the bar. With this set-up, nine data points were acquired from 1-10kgs (9kgs was excluded for the weight was not achievable with the available equipment).

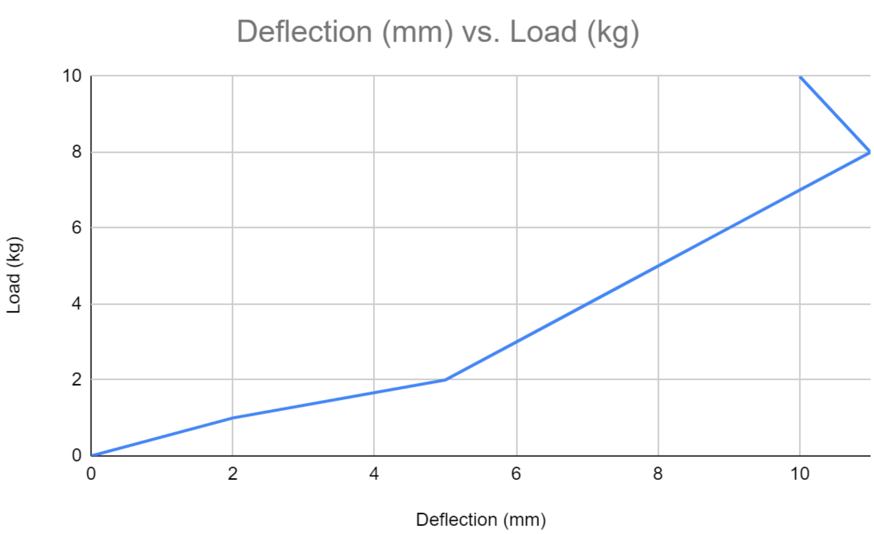

Figure 24: Plot of the deflection data in mm vs the load in kg. The material did not hit its yield point under these loading conditions. 10kgs demonstrated less deflection than 8kgs, likely a result from the size and position of the load.

For the impact testing, four 9mm x 9mm x 78mm samples were cut from one end of the bar. One sample had the bonus of damage from the mold removal process, providing enhanced insight into the behavior of the material.

Figure 25: Photo of the four test samples cut from the bar for the charpy impact test. Photo Credit: Michael Morin

Samples were set vertically approximately 30mm deep into the vice, exposing 48mm to the hammer.

Figure 26: Photo of Mike performing the impact test. Photo Credit: Abu Karim

The data from these tests is shown in Table 2:

Sample #	Energy Absorbed (J)
1	7
2	10
3	4
4	11

Table 2: Table of the samples and resultant energy absorption from the charpy impact test. Normal samples absorbed an average of 9.33J. The damaged sample (Sample #3) absorbed significantly less at only 4J.

4.3 Comparing Proposed Alternative to Existing Methods

4.3.1 Value Stream Map

Throughout production, our team recorded the process to account for the total time it would take to make each truss. To find this total time, we approximated the total time it would take to complete each step in the process, as well as the wait time between those steps. We then put this information in an intuitive visual that applied this process to a smaller scale production scenario. It is important to note that our team was not able to create multiple samples (due to time constraints and unexpected alterations towards the mold when removing the material), so the overall total time is approximated from one trial run. Below is the visual representation of our value stream map that shows each step of the process. Next to each key step is a number that corresponds to a detailed description of that step in the process - listed below.

1. Facility initially receives an order from the customer (10), requesting a certain quantity of roofing trusses made from recycled plastic waste.
2. From this order, production then communicates the necessary materials needed from the sachet and coconut fiber suppliers. These suppliers are local scavengers who collect the waste and are then paid by the production facility for their labor.
3. After the material that is necessary to fulfill the order is collected, it is then added to inventory prior to production.

4. Considering the nature of the water sachets, it is necessary to dry them in the sun for approximately one hour to properly eliminate as much water as possible (to prevent air bubbles in the melting/mixing process).
5. Once the sachets have dried, production will begin by organizing approximately 200 sachets in batches of 50. With each batch, a worker will incrementally add sachets individually to the melting pot at a controlled temperature. The worker will continuously mix these sachets together to form a viscous and gum-like material. The powdered coconut fibers would then (ideally) be added continuously throughout the mixture process (although our team was unable to test this step) to form the composite material.
6. Once the material has mixed, a worker will then manually (with proper heat proof gloves) stretch out the material and form it appropriately so that it will fit into the mold. It is important to do this step quickly to prevent the material from hardening - due to the significant drop in temperature.
7. As soon as the material is transferred, a worker then manually clamps the welded tabs to the steel cover to properly press and seal the material into the mold.
8. Given that the steel from the mold will be extremely hot from the melting process, it will take approximately 5 hours (without a quench) to cool the material naturally. To speed this process up, it would behoove the worker to submerge the mold into water. Once cooled, the material is then removed from the mold by prying out the material with a chisel.
9. After the material has been removed, it is then packaged and shipped to the customer.
10. The customer then communicates to the production facility that their order has been received.

4.3.2 Total Cost Sheet

The purpose of providing this specific cost sheet is to further inform the public of what would be required to execute our team's proposed method. In this case, we itemized the total costs of the equipment, labor and materials used throughout our entire process. While a majority of the equipment used through the process was at our disposal (through the generosity of Academic City University), we decided to include all possible expenses to communicate the maximum cost that it would take to apply this specific method for someone who may not have access to these components.

It is worth noting that these prices are subject to vary significantly given the unique nuances and unpredictability of Ghana's economy. During our time in Ghana, there were daily fluctuations regarding the value of the Ghanaian cedi. The instability within the currency in turn ultimately affects material costs, energy consumption costs, and tariffs (that accompanies each expense) as a whole. In addition, since our materials foundation is built upon waste from plastic sachets and coconuts, the total material expenses will be on behalf of labor costs rather than paying specifically for the waste directly. Considering that the material being used is essentially free to acquire as waste, our method was to hire waste collectors and pay them for their labor (see Appendix G.1) to provide a systematic approach that offered additional pay for people in search of work. If this were to be put into a production scenario, it would be necessary to calculate the labor for cutting open the sachets so that they can be dried out in the sun. Additionally, it is important to reiterate that this cost does not represent a large-scale production cost. Due to the limited time frame of our project, we were unable to upscale the production. If this were to be expanded upon, it is important to consider the costs for packaging, shipping, warehousing, floorspace, energy consumption, and additional labor costs of manufacturing.

With these considerations in mind, the cost sheet below is an itemized estimate of the total expenses that would be necessary to attempt our proposed method:

Expense	Description	Quantity	Cost (GHS)	Cost (USD)
	Materials			
Labor to Acquire Used Sachets *	Collected Low density plastic	(1) 40hr Work Week	GHS 150.00	$11.66
Labor to Acquire Coconut Fibers *	Collected Coconut Waste	(1) 40hr Work Week	GHS 150.00	$11.66
Mild Steel	Mold construction	41.6 X 7.5 cm	GHS 30.00	$2.35
Angle Iron 2 X 2	Mold Construction	40.5 X 7.5 cm	GHS 65.00	$5.10
	Equipment			
Cooking Pot	Area in which the plastic will be mixed	1	GHS 50.00	$3.89
300A Portable Inverter Welding Machine	Spot Welding Machine	1	GHS 1,800.00	$139.56
Liquid Propane Gas (6kg)	Gas supply for stove top	1	GHS 90.00	$7.06
Bosch Angle Grinder- GWS 710 (PROMO + Concrete Disc)	Polish welds	1	GHS 585.00	$45.48
TOTAL Steel Measuring Tape 8M	Measurements for mold construction	1	GHS 35.00	$2.72
Sanding Belt 120 Grit	Remove rust and smoothen edges	1 roll	GHS 115.63	$8.99
Kerro BL P3B/6002	600g Max Electronic Scale	1	GHS 125.00	$9.80
Benetech Infrared Industrial Hot Surface Thermometer	For monitoring heat control	1	GHS 300.00	$23.32
Deltaplus Respiratory Nose Mask/Ffp2 N95	Protection from fumes	1 per person	GHS 190.00	$14.77
Ingco Leather Gloves - HGVC01	Handle plastic when hot	1 per person	GHS 45.00	$3.50
		TOTAL COST	**GHS 3,730.63**	**$289.86**

Table 3: Cost Sheet of project expenses in both American currency (USD) and Ghanaian currency (GHS)

4.3.3 Feasibility of Product Implementation

Once the analysis of the product was complete, our team sat down with the sponsor and on-site advisor, Pinnock Casely-Hayford and conducted an in-depth interview on the feasibility of product implementation. This informal interview progressed into a natural and informative conversation between Mr. Baker and Mr. Casely-Hayford. The invaluable perspective from a local Ghanaian resident such as Mr. Casely-Hayford, provided insight on how to appropriately implement and develop our project (and the possible future approaches that it may hold) further, so that the value of our team's project remains relevant to the Ghanaian community.

Figure 27: (from left to right) Jackson Baker and Pinnock Casely-Hayford, post interview.

4.3.3.1 Interview with Pinnock Casely Hayford

March 1st, 2023

<Start of Audio>

Jackson Baker: “Starting now. My first question for you specifically would be, what do you believe to be the number one issue regarding roofing in Ghana?”

Pinnock Casely-Hayford: "I think it's the cost. It's the cost. Um, in Ghana, down to village level, everybody's exposed to what should be. They also know what they don't have. And with the cost of living, you can imagine if you lose your roof, you are looking for a very cheap alternative to put back on top. And that's not a time to worry about what's up there. It's the question of worrying about whether the water gets in or not. That's the level that you know, they're at right now. And as you see, a lot of people have moved from thatch roofing to galvanized sheets. Galvanized sheets rust, many haven't even turned to aluminum sheets yet. And what more galvanized aluminum sheets that, you know, the Americans use so much. Which is the thing in Accra right now where you have sheets that can go maybe 40, 50 years. This is part of what is happening. So, I would pin the primary problem on money."

JB: "Are there any other alternatives being used or experimented with currently other than what we're trying to do right now?"

PCH: "There are a few. If you cost any systems or products coming out that are being or have been used, they are very expensive. I remember the clay tiles that were used. They were very heavy. They needed to have an asphalt sheet under them that also needed plywood under it to lie on the rafters. And the rafters of course lay on trusses. And these were expensive timber members of the roofing structure - substructures. So, all these alternatives have not been cheap, and many have been discontinued. So, market for them. And one of the other reasons is the warping of the trusses, the wooden trusses. There is much wood that is used in this industry that ends up with the carpenters. And in this case, well, let's call them construction carpenters. We got trim and we've got, uh, construction. So, these reconstruction guys, they buy it and it is wet. It is not seasoned. So they nail it all together. Lovely for them because the timber is soft. And the nails just go through <laughter> nicely. Finish your work and get your money and you are gone. Right. Any other problems they call for, they pay for, right?

So, there's your wood now; drying out, gradually seasoning maybe over a year. Dry spells, no water, getting into it to rehydrate it, it dries up, begins to split and warp.

JB: “It's not reliable.”

PCH: “That's right. Now if you have tiled the roofs, whether they're clay tiles or they're other members, long sheets, you won't feel it so much. Because the roof structure begins to warp - twists and turns here and there. The shorter the roofing tile, the more it's going to feel and get gaps under there.

And then when a storm hits, remember in the storm the wind is traveling around and changing direction very quickly, and the water is coming at you from all angles, so from the engineering point of view, you've gotta look at whether it is to leak or not leak.

And they went to heavier tiles, I remember casting heavier tiles, and the materials didn't get any cheaper. Processes didn't get cheaper. And you have a clay kiln where you are gonna dry off the clay and then fire it up. And then you find that the cost of the electricity is too high. So, you move to firewood, you move to gas. Look at the cost of gas right now, it's not cheap in production.

So, you end up, maybe your best option, economically, is just sheets, going down to aluminum. But in the village, how many can afford that? And of course, with each of the different materials comes the need for specialized fasteners. The fasteners on top of each type of roofing sheet is very important. Whether you screw it down into wood or it's screwing into [whatever], eventually the fastener lifts off or it rusts or it goes through, and you get gaping holes developing. The wind then lashes at the sheets, and it rips it off. It rips big holes in it. And you can't expect a village construction guy to use maybe top class, um, let's say a self-tapping roofing screw that you'd put on a DeWalt <laughter>. And hold it.in there and it may just go, you know, go with the right silicone washers or something. Ah-ha.These are some of the issues.”

JB: “So approximately, how expensive is it [for roofing currently]? I've had some estimated numbers before, but I know that [pricing] changes very often as you know, the material pricing changes [frequently]. How expensive do you think, approximately, it would cost to provide roofing for a standard home?”

PCH: "Standard living in a village?"

JB: "Yes"

PCH: "In a village, you're just talking about very little space. Okay. They're not out of land. Land is not a problem for them. Structures are only limited in terms of size. They're limited by their pockets again. Okay. Whether you're using, using mud or clay or whatever. And of course the techniques - they don't build very large [buildings], you know, people's needs are pretty, pretty small. Just get a bed in there and just stick all your stuff in the corners. They don't live like maybe we do in the west or something like that. No. They don't live that way. So they're inclined to design to suit their way of living. And out in, in American imperial terms, we would talk about maybe 8, 8 feet by 12, you know, we find four people in that kind of floor space. Now roofing that would be thatch, thatch is the old choice. Okay. And it's usually bamboo up with clay filled walls. And in East Africa it'll be dung, animal dung. And in the north of Ghana it would be animal dung. People are now going to cement. You're just cementing all that. And you've got that up. Okay. Now you want to lock in, and they're not even using bamboo enough. Bamboo rots very quickly here compared to southeast Asia, where it's extensively used. But over here, what I find is that the easiest way to use bamboo is to treat it. If you treat it, you get a good termite, uh, what do you call it? Insecticide. And it's good if you put a few holes between the nodes of the bamboo and just soak it up. If you are doing a lot with bamboo, it would be advisable to have a long tank. If it's a ten, twelve foot tank cemented up for your mixture in there - and it's just so many cups per maybe gallon of [insecticides]. If you can afford it, then you soak there. You put each piece in there for a day or two, take it out, drain it off, and almost for life, plug up your hose, they would never go back in there. That's the best way to use it. So if you've got bamboo like that, you can use that for not even just trusses.

The technology they know in construction just to put straight pieces across everywhere. Bamboo is pretty resilient. You start with any straight piece. We all know in structures and in engineering, you put a straight piece there, you have weight in the center, it's gonna pull down your sides. Right? Unless you bow it a bit from the middle. You pull down on a bow, it rather pushes your sides up.

But if you start from straight, it'll cave in. I mean this is just straightforward structures, frameworks and bridges for example. So this is the way they would go. Now, if any roofing is gonna be put on substructures like that, it just means you've got to be able to tolerate the flexibility of your substructures. Remember the wind is gonna play tricks with you also. It's going to oscillate your structure and everything. So no tight tolerances. It's got to be flexible. The best people for flexible structures - well outside appropriate technology - maybe the Japanese, if we are looking at them, they're dealing with earthquakes, they've gotta absorb tremors. In Ghana, it's a different story. And they'll go the way they know.

So this is why for a project like this, I would always recommend starting with a truss. I think from the beginning [of this project] I mentioned PVC. PVC is extremely durable. In this case it's a forever material. Especially since it's gonna be under your roof. As a truss, we take care of that with filets and you've got your trusses. So you produce a cheap truss that'll span let's say sixteen feet with eight feet into the interleaving wall, supporting it. That's all you need. And if it's cheap enough and you go across your rafters can then be bamboo. And then on top of that, off you go. That I think will be one of the cheapest types of roofing."

JB: "So if this [project] were to be progressed into the future, that could be a viable alternative?"

PCH: "It would be. And you've been here now, you've seen the installed capacity, well a little of it for, there's still more coming, which they're trying to encourage from outside loans of extrusion of trash plastic. The beams can be pretty heavy, but they can be dense. But as a substructure, this is what I would recommend under, let's say PVC. Now if the extrusion is done and we can get long enough pieces, there's nothing like maybe the ultraviolet playing tricks on our material under sheets or under a thatched roof. And that's where it's gonna be even cheaper and just as long lasting as PVC. PVCs are an excellent material. In Ghana it's coming in [a] round [cross-section]. Right? Cross section is round because it's made for pipe work. It's not too cheap, but when you look at what it saves you in terms of longevity, I would put my finger on PVC. Now I'm saying this also because even in our workshop, all our sheets are fastened with PVC."

JB: "Is that right?"

PCH: "Yeah. We made special hooks from PVC, and threaded them about ten millimeters. And that's what holds all our sheets down. Now we were forced to do that because we had an area that is on a hill and it faces southwest, looking at the moisture laden breeze that comes across right from the sea. There are salt flats right down near the coast, barely two miles down. And that's all we get. You should see what it's done to our machines out there. The rust is just incredible. You're fighting rust all the time. So PVC was the best alternative.

That's the third time, lemme say the third type of fastener that we arrived at. The first one was straight metal because we were in a hurry to roof and get the machines out of somebody's premises there. So it was straight metal, 6 millimeter, fasteners. We hooked them up. Oh, within about eight months it was all gone, from rust.

Then we did insert molding. Insert molding is where you put another piece in a mold and inject, let's say plastic around it. So we did that. We said, "oh, aluminum should love blah, blah, blah, blah" -we forgot that there's cathartic action. Wherever you have salt in the air and its moisture, there is cathartic action. So that chewed all the aluminum away.

And we eventually ended up with the PVC. We had lots of scrap PVC. We are always collecting scrap pieces and preferably the thick gauge and any road construction that goes on, you find PVC, because the earth moving equipment is constantly ripping up old pipes and stuff, you know, and we pick that up, wash it, stick it in the workshop when we need it. Get the circular saw on there, cut it all up, and then heat it in an oven, flatten it, and then square off with your bench cutter. Create your fasteners and off you go. Off you go. So that holds the aluminum down very well.

The only thing I would say wasn't a mistake - it was the question of money and cash at the time- was that we went down to 0.6 and that was too light. It's the lightest gauge we could afford, and because we needed to roof. We are a hundred feet just on the shed here. And 25, 25 wide, a 100 long just for, for that shape. I wish we had stronger sheets. But for now we take it like that. But it's been up there - the PVCs have been up for 20 something years. No, no visible effect at all. I would look at that.

Jack, it's all about costing. It's all about costing. So a good spreadsheet for costing is so essential in whatever you plan. Some things may seem more expensive, but there are other factors in costing which one has to look at longevity, and what it's gonna cost you, you know, in the end. So let's say it's projected for 10 years, at the end of 10 years, there will be serious inflation in the country, and it should not have been viable for this material to have survived maybe between 10 years onwards. But because you try the material and it's proven itself, it's now saving you so much. So much. And that's the way to go. There is a future in scrap plastic, no matter how many units are out there. And it's all about the shape of it. And what I was suggesting for your project- and it's a pity you guys just had two months to go. If you had enough time and we had a sense with this backing here [from] the university. And with the consent of those industries handling the scrap, we could have made the nozzles to any profile that we choose. And they would have consented to putting it on their machines. It's the last exit for your form to come out, so it's not injurious to their machines, and they would consent to that and we get a special profile coming out and we [would] know exactly which of the PVC pipes it's gonna handle.

And later at a certain stage, we would go onto longer pieces. Any material can be fileted into a truss. Remember that. And that's where I think the future lies for this project. So it still has a big future. What you guys were into has a big future. Whether it's [your product] that you made or not, it's still got a future. And you see, then we take it a step further and look at the fasteners. You want to fasten [your product], PVC on maybe another straight piece. You gotta have cheap fasteners. Right? And that's where injection molding can come in. And it's not expensive to make a quick mold and make these fasteners here. And remember they won't degrade because they're under a roof. They're under a roof and we can add composites - we've done that in the past.

I think we've mentioned that we've mixed all sorts of composites before; sawdust into low density polyethylene. We measure them all under injection molding conditions. And the negative for it, first of all, at about 30% mix. (I remember telling the <inaudible> of my friend, the engineer what do you call, is it Dupont? And I met, what do you call also at <inaudible> when I was in the States and we discussed this thing. He was fascinated that we'd gone that far.) What happens is that you get an ingression of kerosine into your plastic and it dilates. It rather expands. So, in a pump, like a spray pump, it'll seize in the barrel. That's the cylinder that your piston is working in. But then there are other uses of that, and it's all a question of brainstorming, sitting down and getting the ideas to know what you can do and what you can't do with each material.

But strength wise, it's amazing where it gets to. Now at that time, they had just finished with their glass. Actually, I had put a few bottles aside and it had struck me as far back as 1985, that we could mix glass powder into plastic. When I arrived there, they were working secretly on that <laughter>. And that is the Rynite that you find in most of the phones - all your black plastics on these kinds of appliances are all Rynite. That's where Rynite came on. It gives it the non scratch effect and it's resilient enough. I think this morning we talked about toughness and hardness, so when it falls, it won't crack.

And it's an excellent use of glass. You know, glass is fully recyclable as well, but if you powder it up and put it in there, I think the results are fantastic. So with every mixture and recycling, it's all about what you want your final material product to do. It's all about what you want it to do. And that's where you mix and you shoot forward."

JB: "That's very helpful to consider in the future because there's so many other ways that this could go. I think one of the things I wanted to know was, this [project] something that, no matter which direction [or approach] this project could go in the future - is this [still] something that could be implemented in Ghana?"

PCH: "Yes."

JB: "Yes. How so?"

PCH: "I say yes. Yes. And yes. Not only in roofing, because the possibilities are endless. The end products that you can get and the uses of mixtures are endless today. It may all be lined there. Scrap creating disease and turmoil in the cities, collecting it and just tossing it in landfills, which are not properly, maybe isolated and drained and leached. You know, it just leeches into the soil and that's it.

But properly used - now I'm looking for something that you can dry, irrespective of what's in the trash. We can dry it, pulverize it, and mix it. Remix. Now there's so many open drains and manholes in town. It's senseless that they haven't been, you know. We look at the states, we are looking at manhole covers; they're round, they're tapered. You know, one worker can open up a big manhole. right? Take it off and because it's round, you can wheel it and just park it somewhere. Get what you're doing finished and just wheel it back and let it sit. And it sits perfectly because it's just tapered and it finds its own hole. What do we have in Ghana? First of all, you start with square, square is a no no when it comes to holes, you know? And if you think square, you are square <laughter>. So this engineering square, you know? Yeah. Something like that. You know, you gotta think it's all pros and cons. Pros and cons. Is this better than that? When is it better to use this? Is it appropriate or inappropriate? And then is it intermediate? You know what you need, but you're not there yet. So you use something in between - that's in intermediate technology. Is it okay now or not? Is it good for what it's doing and it's cheap enough? Then it's appropriate. Somewhere where you have a lot of uranium and nothing else - maybe nucleus, you know, appropriate. That's the way, you know, technology's going. But covering the manholes, it's all the same technology. It's all the same. We just gotta get it in the right form such that it can be bought and it's gonna be cheap enough.

PVC didn't start overnight. Talk to the Japanese. They'll tell you. I was, uh, just out of secondary school. We call it secondary school here. High school, when they opened the factory in town, the Japanese opened the first PVC factory in town. Daddy took me because he knew and he loved projects. So come on, let's go, you know, and to see the stuff coming out. What's the composite, what is it? Of course they palletized it before they brought it in, but the way they kept to the temperatures and all that. Yeah. You don't go beyond charing point, because eventually it's a product that should handle a certain pressure of water. Right? That's the way they came in. We have used PVC endlessly for so many things. And it makes you know the material and what you can use it for.

I think as trusses, people haven't been daring enough to really. You know, when somebody came to our shop, I said, "well, our fasteners are all PVC." "So what will it all blow off?" I said, "oh, it's been up there for 20 years." And then he goes and he does the same thing in his place. You know, so these are some of the things.

But let's look at the combinations of what is appropriate now, what is available now, and then begin to add the trash.

Long ago I did say, look, for the chemistry of stuff, leaching and poisons leaching out into water, we should dry all our trash and mix it in concrete. And then go and put it out on the, let's say the erosive beaches. The beaches of erosion along the coast. You know? Hitler used metal to stop the allied forces. Right? On the beaches of Omaha in the Normandy campaign. Right? That was what, June 6th? June 6th, 44, if my memory serves me?"

JB: "Yes, the invasion on Normandy was June 6th, 1944."

PCH: "I wasn't in it, but I mean the war fascinates me because of the innovative engineering that came of it."

JB: "So much engineering. It was a war of engineering essentially."

PCH: "People want to kill each other and they go to great lengths, huh. To design stuff for killing. And out of one tank; can you imagine the bushings and the ball bearings and you know."

JB: "It's remarkable."

PCH: "Yeah, ball bearings also came out of the war, you know, during the same war by the Germans. So much that was done. And, uh, synthetic rubber too. So these things were all there. Now, this is like a war. Trash is a war. So why, shouldn't we be sitting and discussing and coming out with stuff that can pull out of this war condition? Which is what we are in."

JB: "Do you think that the Ghanaian community would be interested in [an alternative like ours]?"

PCH: "If it's right, it means the price is right, number one. Does it work? It works, number two. And the rest is history. Really.

Look, Ghanaians, they love society. Nigerians, worse, ostentation. Nigeria will tell you, you got the money, flout it. Show it cause you got it. That's the way they go. Expensive, their dressing and everything. But if something is good, they want it. If it's a benz - today, if it's a Toyota four wheel drive, they want it. You know, that's the way this society is.

When it comes to village level, does it work? And is it gonna last? That's what they're gonna look at if it's good. So cars came along, everybody wanted a benz. Right? All the high ups in society, everybody wanted a benz. Then they realized the Japanese came in and Americans had the biggest cars, the longest cars, the biggest engines. 12 to a gallon, eight to a gallon. I remember Lincoln Continentals and stuff like that. Ooh. And then they went onto the pickups, the big Chevy pickups, Ford, and Jeep. 12 to a gallon was about the best you're going to get. Then 15, then they crept and kept going up. And then what happened? The Japanese realized that Uhuh, the future is [this], you know. 73 came along with the oil crisis, and they started designing very small [cars]. Japan is a small place, all these island places, so they designed small cars because of parking space. And then they realized long ago, what's the big deal? You know, you're just going shopping, you're alone, you're in one car, you know 50 cc can pull you on a small bike. Then what's the big deal? Just get in their pocket. Do what you gotta do. So they began to design small cars. Americans said, "oh, we don't sit in these things, we don't ride in these things." Africa took it up! Now let me speak for Ghana. One of the cars that was really taken up very quickly because of the fuel prices at the time, was the Datsun 120Y. 47 to a gallon. Straight, simple to look after straight in line four. Easy. Really easy. And a lot of Americans began to buy it as a third car. For their kids who were in college. That's the way it took off over here. It was big business for Japan motors, because that was the standard taxi. Like today, it's the Toyota Vitz. And your question, we are still on your question because it says, will they take it up? I tell you, they will suck it up. They gave the little cars. The earliest Honda was a cube. Like a cube. And they gave it a name in Akan. In Akan it translates as, "the child of a car". That's how it translates in Akan. You know? And it was like they laugh at you as you pass and stuff like that. "Oh, look at him riding in this little car today". What's happening on the streets here. But they crept on, and they got on the market. America was left far out. At the time, they couldn't design little Chevys. They couldn't do anything. And they were against that. Today, they're fighting trying to claw their way back in, into these markets. And these cars are all serving a good purpose. The only thing that sets them back a bit are the potholes. And if all the road roads were well, um, paved and asphalted, it would be a dream to ride this thing. But they're here to stay and they have stayed. If it's roofing and it trusses, what works for his neighbor, he's going to get the same thing. This thing is gonna work whether you like it or not. We've had a situation where we've done certain things with PVC that have blown people's minds. You know, and even in road work, if somebody says, “ah, you use plastic for this”, and then later they start to realize that man, this thing is still standing and it's still doing this. It's like you do a cover for, look at the number of open drains that you came to see right in this country. You know, there's still so much that should be and can be done. And if you start from a domestic level and stuff, like even if it's something that a private guy will buy to seal a hole in his house, word gets around and it takes off like wildfire. So it's for us to look at the equipment, the production equipment that's gonna produce these plastic components, these composite things we're talking about - all from trash and see what's best. If you buy a standard injection molding machine or an extruder, for example, let's look at some of the world's most expensive extruders, not from India, but maybe Austria like Engel. We're talking about Engel. Or maybe in the states some of the best machines produced. And you look at what's coming out. You drop a nail or some hard metal chips in there and you finish that screw. It will cost you quite a few hundred thousand to replace and to change. So you're dealing with scrap and trash. You need a machine that will take scrap and with as little sorting as possible and turn it into something viable. And that's the secret to what we're talking about. If we can achieve that, you got a market, wow. No matter how ugly, it is to be used and it'll just fly. It'll fly.”

JB: “So there is production viability? [These approaches] could be [scaled] into a [larger] production facility?”

PCH: <Nods in agreement> "I keep telling you, if it's your wish to be back in this country, there's a reason why I said that. Cause there's so much, you're gonna go back, you're going to think of all these little things and you're going to see, hit your Excel sheets and you are gonna see green lights blinking at you telling you things that you know should be right. And you shouldn't be scared of, you know, the trash. You're gonna see everything in that trash. Something we call take away in the trash. It's just poo. It's just poo tied in the bag and thrown out, you know. How long does poo stay? You know, open it up within three days - it's all dry and powderized. What's the big deal? You know? So it's all about auto sorting, sorting to what you want. You don't need to really go to great lengths and then mix it up. I've often looked at pelletizing all the types - well that we normally would find from, PETs, PPPs and all that, and just mix 'em all up and see what kind of products you think come out with. So another thing will be covering all the drains and making sure it can handle the weight of a car. The average car, maybe a ton and a half. Put two tires on that, and they don't sink in. Because you can't tell drivers, "don't park here", they will do anything. This is not America. You know, this is not America. So the engineering has to, you know, handle the weight…the design is bold and it sits in, you know, specific."

JB: "I mean you pretty much all of my [initial] questions. I guess my last question would be: with energy consumption being a large issue (with the [substantial] tariffs and taxation [costs in Ghana]), how would you get around [that]? Because while you may have the equipment and you may have the materials and the solutions [to solve] this issue, making it energy efficient is really important. That is probably the biggest part of the costing [as well]. So do you have any recommendations [on how to minimize] energy consumption from the equipment?"

PCH: "Yes. You know, most equipment you're gonna find in standard places that they're recycling today are overpowered."
JB: "Really?"
PCH: "Yes. They're overpowered. If you look at horsepower input into a process, you can bring that horsepower right down. Now, if you were making $50,000 a day net, and you had to come down to $25,000 a day, would you grumble? If you had it all in place and you had your own input here, you wouldn't be dependent on government, electricity and

government tariffs as much. This is what I'm talking about. So we tailor it to suit the costing. What the costing tells us is where we gotta move. Now we had a similar problem. You'll see, I think I've provided you enough documentation, in which you're going to carry back with you. The injection molding process we did. We did go from a hydraulic little machine - it was a lab, what do you call it? But it had I think a 3 horsepower motor running the hydraulic pump and with an 18 millimeter barrel. So it was for small work and stuff like that. What we ended up with doing the same thing, producing what we needed to be produced and bigger components. We used an old washing machine motor. And there's lots out there. Plus rewinders who can rewind an old motor that's burnt. You know, this is where it's a question of appropriate technology. When you talk about appropriate, pick something that is readily available now, here you are. The washer market is changing. Right? Where is it right now? It's on inverter motors. That's where it's at. All the old American motors were on induction. GE’s and all that, you know, they were induction motors and they had a changeover gearbox and they needed to reciprocate - or let's call it oscillation. They would oscillate. That's how the American top load machine works. It would, you know, oscillate. But it was all done from beautiful gear boxes, half sector, sector gears and you know, beautiful mythology inside there, if you ever worked on any of them. The consumption came in water, [they] consume a lot of water. Because they would fill up and the technology wasn't for sensing. You know, today we have sensors, electronics has taken us tighter in costing, hasn't it? Very, very tight. Before we put 60 gallons of water to rinse maybe two t-shirts. So you can work on all that and bring it down. So this was our thinking. Find out what is the most available motor on the market.

If one type of technology is going out, what can we use the parts for?

Do you know that companies that had big shares in the technology of flat screens; the cathode ray tube shareholders paid for that to wait. If not they felt safe, we lose. Same thing with certain parts on cars and stuff like that. There are many things in industry that come out like that. When one is about to sweep the market, they will pay to hold it at bay. Many companies are bought out because of technology that [is] coming out. Competitors don't want that kind of competition at the time. So they buy you out, and hold you back or absorb you. And that's the nature of industry. And capitalism is not, is not really for the world. But that's what we got in front of us. Unfortunately, capitalism comes with a little more freedom, human rights and stuff like that than whatever we do, maybe in the east.

That's the nature of it. So look at what is available or most available. If you're looking at appropriate technology and use the component parts of what is there to bring your cost right down, you will be competitive.

And again, it brings us back. It's all about costing. The socioeconomic side, if it works, it'll sweep the market. If it's good, it lasts long, it'll sweep the market. There's nothing to worry about.

Africa is at a point where it's all about money and people's, you know, daily existence. So, step out, be bold in the design world, and be daring. Very, very daring.

So in our machines, geez, if I tell you the parts we have, the barrel has to be absolutely completely smooth for injection molding. Absolutely smooth. And it was a question of machining each one.

When I met dad, he was having machinists do that. So when I came outta school and I knew some parts, I looked at a truck, 33 millimeter, 25 millimeters, the most popular for the man, diesel trucks and stuff like that. And a steering connecting bar rod right across Lincoln, the steering. And it's a beautiful ball. Absolute. I mean like, like it's ready for a gun. Yeah! And it's long. So you just cross cut and you got your barrels, no machining, nothing. You know, you just crosscut and if you're got a machine, you just face it off and that's it. That's how we solved that problem.

Now we found also, we've had everything in the trash plastic that we've been injection molding, scrap metal and everything. But our nozzles are very quickly, what do you call removed? And we haven't had any crisis of any barrel being changed…since 85. So I would look at solutions like that. So, against maybe $450,000 for an Engel from Austria, this is the way one should go.

I have some gear boxes waiting over there, which we bought long ago. We didn't need them then, but we thought, okay, if the future turns out that we will use them. We paid peanuts for them in the scrapyard. And they're from Turrets! From breakdown trucks. Just to turn the whole, you know. One of them is I think 150 ton capacity and the others grade down. They grade down accordingly. That's how big they are. 40 to one ratio, 30 to one ratio. And they're waiting for projects like this. That is the sort of thing where, you know, so in recycling you need to have that muscle to go in. And if it doesn't cost you much to get stuff like that and you have the space for it, why are you going for $450,000?

So set it up with this and it's cost effective and then introduce other machines as you go along. That's the way I would go to make it competitive. And I know how, I mean the spray pumps we were making where the Chinese couldn't compete with us. We were far cheaper, we had a full guarantee and everything and that's the way we went. So it was a combination of recycled polyethylene and PVC. That's where we went. And our problem was the politicians at the time."

JB: "Thank you so much. I appreciate this very much, and thank you so much for your time."

PCH: "I hope this was helpful for you"

<End of Audio>

Over anything else, costing remains to be the focal point of this project. If this project remains cost efficient, through the means of the utilization of appropriate technologies (which encapsulates the ideals and practices of generative justice), and creates a solution with substantial longevity, there will be immense interest from the Ghanaian Community. Future considerations recognizing these aspects, could possibly include PVC as a viable approach. While it is momentarily expensive, the longevity of the material proves to be a smart long-term investment. This process can additionally be applied to not only just roofing trusses. It is key to note that once this process is fine-tuned, this sustainable material can be used for many other purposes (including fasteners). Maintaining these ideals and approaches, further proves that this project is an economically viable solution, which can be implemented on a production level in Ghana.

CHAPTER 5: Conclusions and Final Remarks

Our team successfully developed a physical deliverable with Academic City University College by fully immersing ourselves in the practices and perspectives of Ghana. At the beginning of our experience our team had a loose understanding of the final deliverable. While this was intentional to support the ideals of generative justice, our team had a healthy and necessary level of pressure for progress. From this we began furthering our research based on the suggested path from our advisors at WPI and co-workers in Ghana. As a result of this continuous adaptation, the trajectory of our project was a suitable representation of our growth.

From our original axiomatic design, we were able to achieve a majority of the functional requirements and design parameters that were to be addressed in our project. After our team completed the project, we revisited the axiomatic design to compare our initial planning with our results. Below is a copy of the axiomatic design that is highlighted to communicate the success rate of our initial approach.

Green: represents a successfully addressed and fulfilled component in the final product.

Yellow: successfully addressed component in design, but not fully incorporated into the final product.

Red: addressed component in design, but not incorporated in the final product.

Functional Requirements

- FR0: Produce affordable roofing in Ghana using waste.
  - FR1: Configure design to withstand Ghanaian weather.
    - FR1.1: Optimize Weight.
    - FR1.2: Maximize Longevity.
    - FR1.3: Increase Strength.
  - FR2: Produce an affordable product.
    - FR2.1: Minimize energy consumption.
    - FR2.2: Utilize waste.
  - FR3: Demonstrate value to the public.
    - FR3.1: Determine cost.
    - FR3.2: Communicate with the Public.
    - FR3.3: Compare Pre-Existing Methods.

Design Parameters

- DP0: System to produce affordable and sustainable roofing.
  - DP1: Materials for roofing.
    - DP1.1: Plastic waste that is low in density.
    - DP1.2: UV Resistant.
    - DP1.3: System to press into a mold.
  - DP2: Methods to prove affordability.
    - DP2.1: System using energy efficient equipment.
    - DP2.2: Composite material from plastic and natural waste.
  - DP3: Value stream map
    - DP3.1: Cash Flow Analysis.
    - DP3.2: Statements/Survey.
    - DP3.3: Product Comparison Chart.

Several shifts in trajectory from our team made it difficult to address all initial components and parameters - given the short time frame and minimal personnel. If this project were to be a long-term solution, it would be paramount to consider incorporating other plastics like PVC and forming a composite material from (coconut waste or other) to properly address UV resistance and affordability, respectively.

Figure 28: Photo of wooden roofing trusses at a church in Akyem Dwenase. Photo Credit: Michael Morin

One notable shift made through this adaptation was the shift in focus from roofing sheets to roofing trusses. While this was not the initial intent of this work, the available resources and manufacturing process demonstrated better value in this area.

The compression molding process we pursued had value in its simplicity and costs but demonstrated several drawbacks: the plastic melt experienced damage because of poor temperature control, the melt was hard to work with as a result of rapid cooling and its viscosity, sample removal was inefficient, and the addition of coconut fibers was impractical. Despite this, the resultant LDPE bar sample demonstrated promising material properties even in its damaged state. As such, our team believes there is clear value in these concepts for Ghana and future work should be pursued.

If this project were to be continued, the following list contains several points of improvement and alternate approaches regarding processing these composite materials that we identified throughout our work:

- Coconut fibers need to be introduced into the process, which was not achieved by the team and is likely impractical with the current methods.
- Improvements should be made to the temperature control system. The final sample displayed evidence of thermal damage and temperatures were widely inconsistent during melting.
- Improvements should be made to the sample removal process. A coating could be used on the inside of the mold prior to molding and a pin system should be implemented into the mold design.
- LDPE sachets can be turned into polymer powder using a thermochemical dissolution process following the work of Ahmed, Akintola, Afolabi, and Adebisi, which enables the use of several other manufacturing techniques which may be more appropriate for the nature of these composites.
- Coconut fibers can be sandwiched between sheets of LDPE, in this instance sachets, and hot pressed following the work of Brahmakumar, Pavithran and Pillai, which enables enhanced control over fiber orientation and appears more appropriate for manufacturing roofing.
- Additional material tests should be done regarding moisture and UV degradation, as these are important aspects of Ghana’s environmental conditions.

In considering these ideas, future teams may be able to better accomplish what we sought to do with this work.

In working closely with the Ghanaian community for close to two months, our team was exposed to a completely unique approach to engineering and project management. One quality that has been impressed upon our team greatly, was persistence. The continuous devotion and commitment to the project that the workers (Benjamin Boamah Odame and Abu Karim) at Academic City University College showed throughout each workday helped to ultimately progress our project further. The creative persistence to generate solutions both inside and outside of this project from Mr. Casely-Hayford - given the limited resources in Ghana - truly showed the team the beauty of engineering and multicultural co-creation. Through these qualities and lessons, our team was able to overcome the challenges of having limited familiarity/resources and complete each objective in a meaningful way for Ghana.

While MQP's are usually under the conditions of a 21-week initiative with (usually) 3 or more team members, our team was subject to a 7 week timeframe, with only 2 team members. Additionally, we had to navigate around fulfilling the requirements of two different majors - resulting in a split advisership, which interfered with united progress. These conditions generated additional stress and a lack of organization between our team which could have been avoided prior, with better planning, briefing and overall communication. Our team learned how to appropriately pivot the direction of our project by enhancing our communication and organization. These sporadic changes and adjustments that were made, were valuable lessons to take into our prospects with our individual careers.

Returning from Ghana was an unexpectedly challenging aspect of this journey. Team member Baker experienced what could be called "reverse culture-shock". While settling into Ghana was an adjustment that took time to acclimate to, returning home was an even more difficult transition to embrace. American culture is commonly known to offer success and areas of "great opportunity" for anyone who may reside; causing some members of developing countries (including Ghana) to aspire to one day travel to America. This notion made Mr. Baker particularly uncomfortable upon his return. While the climate of the mid of winter was already a physical shock, the pure overabundance/availability of food, water, supplies, electricity, technology, accessible medical care, advanced infrastructure/transportation, (along with several other elements in American culture that are taken for granted each day) was purely overwhelming. For instance, the availability of tap water was something that gave Mr. Baker a particular sadness. A significant sense of guilt in a way that clean water is unavailable to such a large population was unsettling to become accustomed to for him. Along with clean water, the overabundance of necessities and rampant materialism in America seemed almost heartless. Creating opportunities for members in developing countries that allow for prosperity into a comfortable life should be of utmost importance to countries who already have that opportunity. This importance stems from the immensely driven, persistent, versatile, adaptable, intelligent, and welcoming attitude/mindset that cultures, specifically Ghanaian, can help create unity in our divided world. Mr. Baker continued to ruminate significantly over the hypotheticals that equal opportunity and true co-creation could potentially bring together not only one community, but several. Returning made Mr. Baker almost feel that he had been abandoning this community in a way that made him question the team's approach of generative justice. While the team embraced the practices of generative justice through the project itself, Mr. Baker considered that even the act of leaving a country after offering support does not align fully with a post-colonialist approach. However, given the time frame that was allotted, our teams' attempt to respect generative justice ideals and discourage colonialist approaches was successfully completed mindfully and with full consideration of the community. Returning home may have been a difficult adjustment for Mr. Baker, however it has created a profound sense of gratitude for the opportunities in his life and for the power of human connection that can be achieved through traveling, co-creating, and most importantly, listening.

Despite the difficulties, our team believes this journey was both a beautiful and rewarding experience. Our team highly promotes exposing oneself to an immersive experience in a foreign country such as Ghana. Expanding one's knowledge through experiential learning in a developing country offers invaluable insight to not only a specific field of study, but by building one's character. This character development leads to understanding and awareness, and if change is to be truly made in this world, it can only be done from diverse synergy. This project is proof that postcolonialism, through the practices of generative justice and co-creation, can truly develop a multicultural project that can offer a versatile perspective to a local community.

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Appendix A: UGI’s (Urban Green Infrastructure)

Appendix A.1 - Benefits of UGI Implementation

UGI emphasizes the implementation of urban parks and reserves, wetlands and stream corridors, street trees and roadside verges, gardens and vegetable patches, bikeways and pedestrian trails, wall and rooftop gardens, orchards and farms, cemeteries and derelict land (Cobbinah, 2022). It is proven that increasing the UGI of a densely populated city by 10%, can maintain that city's summer temperature for 70 years - with climate change being a major factor (Heinze, 2011).

Appendix A.2 - Residential Impact from UGI’s

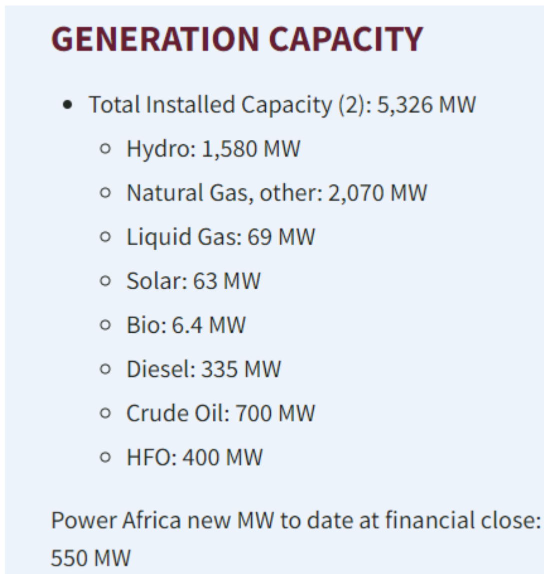
Residents with access to UGI’s are also 83% more likely to be engaged in social activities than communities without UGI’s (Sullivan et al., 2004). In the case of the city of Kumasi, Ghana, there has been an exponential decline of over 80% reduction in UGI’s, with over 70% of household residents expressing deep concerns for their communities (Cobbinah, 2022).

Appendix B: Ghanaian Economy

Appendix B.1 - GDP History

In fact, from the years 1984 to 2017, Ghana saw a steady rate of growth in their GDP per capita each year - despite the annual rise of 2.5% - 2.8% in population and sporadic rainfall fluctuations that interfered with agricultural growth (Diao, 2019).

Appendix B.2 - Generation Capacity


GENERATION CAPACITY

- Total Installed Capacity (2): 5,326 MW
  - Hydro: 1,580 MW
  - Natural Gas, other: 2,070 MW
  - Liquid Gas: 69 MW
  - Solar: 63 MW
  - Bio: 6.4 MW
  - Diesel: 335 MW
  - Crude Oil: 700 MW
  - HFO: 400 MW

Power Africa new MW to date at financial close: 550 MW

Figure 29: Generation capacity and Ghanaian energy consumption.

Appendix B.3 - Tariffs and Taxation in Ghana

ECOWAS Common External Tariffs:

- Zero (0) Rated - Essential Social Goods
- 5% - Basic necessities, basic raw materials, Capital Goods, Specific Inputs
- 10% - Inputs and Intermediary Products (Semi-Finished Goods)
- 20% - Finished Goods (final Consumer goods)
- 35% - Specific goods for Economic Development

Along with the Five-Band Tax Rates listed above, there are additional taxes and charges applied to imports, including VAT's (Value Added Tax), ODC's (Other Duties and Charges) and other additional fees, as designated by the ITA (2022):

- VAT's are calculated by multiplying the VAT rate by the sum of the CIF (Cost Insurance Freight) value of the goods and the regular duty.
- ODC's include excise, environmental tax (2013), ECOWAS levy, African Union levy (2017), National Health Insurance Levy (2021), Covid recovery levy (2021), Education Fund (2018), Sanitation and Pollution Levy (2021), energy sector recovery levy (2021), energy debt recovery levy (2021), energy fund levy (2021), special petroleum tax (2021).
- Fees and charges include Processing Fees (2002), Destination Inspection Fee and ICUMS charge (2020); approximately 12% of the cost insurance freight value of imported goods.

Appendix C: Generative Justice

Appendix C.1 - Agbogbloshie Makerspace

In the article titled, "Crafting Spaces Between Design and Futures: The Case of the Agbogbloshie Makerspace Platform", author Cher Potter, focuses on a study called Causal layered analysis (CLA), that is intended to create transformative spaced to help create an alternative future (Potter, 2019). In this article, there is a specific focus on the region of Agbogbloshie and their critical issues regarding e-waste. E-waste briefly can be described as any disposal of electronic devices, including computers, cables, cellphones and more. The common method citizens turn a profit is to incinerate the waste by burning the electronics and harvesting the copper from the cables. This is an extremely harmful method that releases copious amounts of heavy metals and toxins into the air. The approach to CLA involves four main levels that are intended to essentially promote distributive justice: litany, system, worldview, and myth/metaphor.

Through litany analysis, one is able to access or discover information because of the topics popularity and overall reporting from the media. As the media has continued to report on the issue of e-waste burning in Agbogbloshie, there has been somewhat of a forced change in narrative due to the increased exaggeration throughout the media's reporting (Potter, 2019). The media has primarily focused on the negative events and portraying Agbogbloshie as nothing but a "dumpsite". However, after UN-sponsored research, there have been discoveries of action being taken by Agbogbloshie and other external factors that may be worsening the current issues of e-waste. The Agbogbloshie Makerspace Platform (AMP), has taken a generative justice initiative to promote engagement from the community around recycling, repairing, reconstituting and inventing products from the electronic waste in Agbogbloshie (Potter, 2019).

With litany analysis, the findings of exaggerating media coverage have led to even further discoveries with additional analysis. The next method of systems analysis is focused around mainly educating the community in systems design and engineering and incorporating further safety to help promote sustainability (Potter, 2019). This method allows for a possible increase in infrastructure and a streamlined approach to developing the community.

The third approach mentioned in the article, regarding worldview analysis focuses primarily on the concept of Afrofuturism. Intended to liberate African Americans from the monopolized power of the Euro-American control of space and time (Potter, 2019). The AMP has taken the priority of opposing the top-down model and promoting generative justice. To accomplish this feat, AMP is focusing on a large, centralized factory that is intended to monetize e waste and ultimately turn a large-scale profit and improve the health and working conditions for the production in Agbogbloshie (Potter, 2019). This act promotes generative justice immensely because it is motivating the community to see the value in prioritizing sustainability and indirectly promotes the maker-space approach.

The final approach mentioned in the article regarding myth/metaphor, ultimately summarized the total approaches previously mentioned. Applied to Agbogbloshie, the article states, "Agbogbloshie is both misrepresented and misunderstood as a dysfunctional and uninhabitable site outside of its local community and as such (b) makers that operate within Agbogbloshie are marginalized and lack the support to further develop their skills, tools and trades so as to amplify their reputation as makers" (Potter, 2019). To help communicate this information to the public, the designers behind AMP use scientific metaphors and space exploration to help describe the project:

> *"AMP spacecraft is an alternative architecture 'for making'.*
> *Small-scale, mobile, incremental, low-cost and open-source, spacecraft operate as a set of tools and equipment to 'craft space' in different ways, enabling makers with limited means to jointly navigate and terraform their environment (qamp.net)."* (Potter, 2019)

Using this metaphor allows for further education and a more informed perspective for the local community. This metaphor also can be applied to many different local issues as well that the African American people may be facing as well. Ultimately, these approaches utilized are reshaping and reframing the perspective of the uninformed by encouraging generative justice that will rebuild their local community in an effective manner.

Appendix C.2 - Notes from Initial Meeting (January 11th, 2023) with Pinnock Casely-Hayford

- Needs to consider:
    - UV lighting and how it will affect the properties of the roofing material.
    - Methods to melt/press the material.
    - Fault lines and the viscosity in the type of plastic being used.

- Overall cost and availability of materials, equipment, and energy consumption
- Sustainability of alternative
  - Emissions
- Contemporary Issues
- Cost Sheet
  - Tariffs
    - Water
    - Electricity
- Making product attractive and appealing to the local community
  - Solution could be seen as appealing because it is termite and rust resistant.
- Possible diseases that the coconuts carry.
- Shaping of roof
  - Different roofing styles
- Composite Plastics
  - Charred plastics
- <u>Sorting the plastic in an efficient manner</u>
- Ventilation for the fumes if we were to melt the plastic.
- Feeds and speeds of cutting tools when working with plastic.
- Cold pressing plastic vs. hot pressing plastic
- Possibly scoring or creating grooves to connect roofing tiles together.
- Cost efficient.
- Continuously reused plastic waste and how that may affect the material properties.

Appendix D: Ghana's Environment and Climate

Because of Ghana's position relative to the equator, Ghana's climate is categorized as tropical, and its mean temperatures range from 25.65℃ (78.17°F) at the lowest during the month of August to 30.18℃ (86.32°F) at the highest during the month of March (World Bank Group). Additionally, this causes the daily UV index during midday in Ghana to fall almost always in the 'extreme' category of 11+.

Ghana has two main seasons, the dry season, and the rainy season. The dry season usually falls around December through February and the rainy season falls roughly around March through November (World Bank Group). During the rainy season Ghana experiences roughly 150mm or 6in of rain a month, with significant rainstorms said to occur weekly (World Bank Group). Outside of the rainy season these values drop to around an inch or below per month (World Bank Group).

Appendix E: Corrugated Metal Roofing

Metal roofing provides excellent corrosion resistance to UV and moisture degradation through the galvanized zinc coating while providing sufficient mechanical strength for making them a strong long term roofing option relative to other available materials, lasting potentially for several decades depending on the environment (Agyei, 2022 & Elewa, 2019).

Metal roofing however fares quite poorly in coastal conditions. In such an environment, the salt from the ocean causes quicker and severer corrosion and rusting, making metal sheets less appealing than alternatives (Agyei, 2022 & Konadu-Agyemang, 2001). As a result, in the 1990s and 2000s, corrugated asbestos made-up most of the roofs in coastal urban settings and still remains a common sight in Accra and the coastal regions today (Konadu-Agyemang, 2001 & Ghana Statistical Service, 2021).

Appendix F: Waste Picture

Appendix F.1 - Waste in Africa

Globally the generation of waste comes as a byproduct of population growth, urbanization, and growing consumer culture (Kaza, 2018). As of 2016, annual waste production around the world was estimated to have surpassed over two billion tons and is currently predicted to reach over three billion by 2050 (Kaza, 2018). The total amount of waste produced in the Sub-Saharan Africa region alone is expected to triple by the year 2050 following urbanization in this region (Kaza, 2018).

Due to limited waste data, growth in waste production in Ghana is difficult to quantitatively track. A 2015 study however estimated that the average daily waste generation fell around 0.47kg/person totalling to 12710 tons of waste produced daily (Miezah, 2015). These rates were even higher in the more populous metropolitan areas, with an average of 0.72 kg/person across the cities of Accra, Kumasi, Takoradi, and Cape Coast (Miezah, 2015). Of this waste, 50-70% consisted of organic matter followed by plastic making up around 14% (Miezah, 2015).

Appendix F.2 - Environmental Effects

Most waste in Ghana ends up getting landfilled or burned. Landfill sites are generally poorly managed, especially those outside of urban areas, providing little to no waste segregation, litter or dust control, water or gas drains, and environmental monitoring (Kusi, 2016). Many of these sites are located close to critical infrastructure such as waterways, roads, and schools, and are subject to rampant scavenging further increasing their impact on public health and the environment (Kusi, 2016, Lissah, 2021, & Miezah, 2015). Waste that gets incinerated has the potential to release toxic fumes into the atmosphere and generates additional environmental pollutants (Kaza, 2018 & World Wildlife Fund, 2019).

Appendix F.3 - Plastic in the Drinking Water Sector

Between 1990 and 2017, Ghana was reported to have imported over three million tons of plastic, ranking eighth out of thirty-three African nations (Abrokwah, 2022). Much of this plastic gets used for packaging in the drinking water sector (Abrokwah, 2022). In both rural and urban areas, Ghana’s water sanitation infrastructure fails to consistently deliver sanitized water and keep up with the increasing demand from population growth (Abrokwah, 2022). Additionally, many areas do not have water infrastructure at all, requiring water to be delivered from other locations. Consequently, there is a major dependence on distilled packaged water which is typically found in the form of plastic bottles or sachets (Abrokwah, 2022). There are over 800 sachet water producers in Ghana, with each producing anywhere from 45000-15000 sachets a day, adding tens of thousands of kilograms of plastic daily to the waste stream (Abrokwah, 2022).

Appendix G: Cost Sheet Estimates

Appendix G.1 - Labor Estimates

Given:

Labor for (sachet/coconut) collectors = GHS 600/month

Therefore:

[(600 cedi) / (1 work month)] X [(1 work month) / (160 hours)] X [(40 hours) / (1 work week)] =

GHS 150.00 per worker/work week

Appendix H: Polymers & Composites

Polymers are synthetically made materials commonly made up of long molecule chains built from covalently bonded repeating units of atoms known as mers (Chamas, 2020 & Mills, 2020). They are produced using petrochemicals, or natural oils, as a base and a catalyst to initiate the polymerization reaction (Chamas, 2020). These molecule chains can assemble into two categories of structures: amorphous and semi-crystalline, each influencing the resultant material's properties (Mills, 2020). Amorphous structures have molecule chains of varying lengths in no arrangement while semi-crystalline structures have more consistent molecule chains arranged in a structured array (Mills, 2020). There are numerous types of polymers, some of the most common being polyethylene(s) (low-density, high-density), polypropylene, and polyvinyl chloride, each being defined by the type of repeating mer and the resultant chain structures.

Based on these properties and their resulting effects, polymers are categorized into two different types: thermoplastics and thermosets. Thermoplastics, or more commonly known as just plastics, are malleable and can be melted down and formed without permanent damage while thermosets are more rigid and cannot be fully melted down without permanent damage to the material (Chamas, 2020 & Mills, 2020). The malleability of plastics gives them the ability to be "molded into virtually any desired shape through rotation, injection, extrusion, compression, blowing, or thermoforming", making them a highly practical manufacturing material (Chamas, 2020). Additionally, because of the nature of the polymerization reaction there is enhanced control over the material properties of the resultant product, furthering their appeal. Combining these factors with the availability of natural petrochemicals results in a cheap yet highly effective product, explaining their widespread and growing use in industry.

Appendix I: SOLIDWORKS Drawing

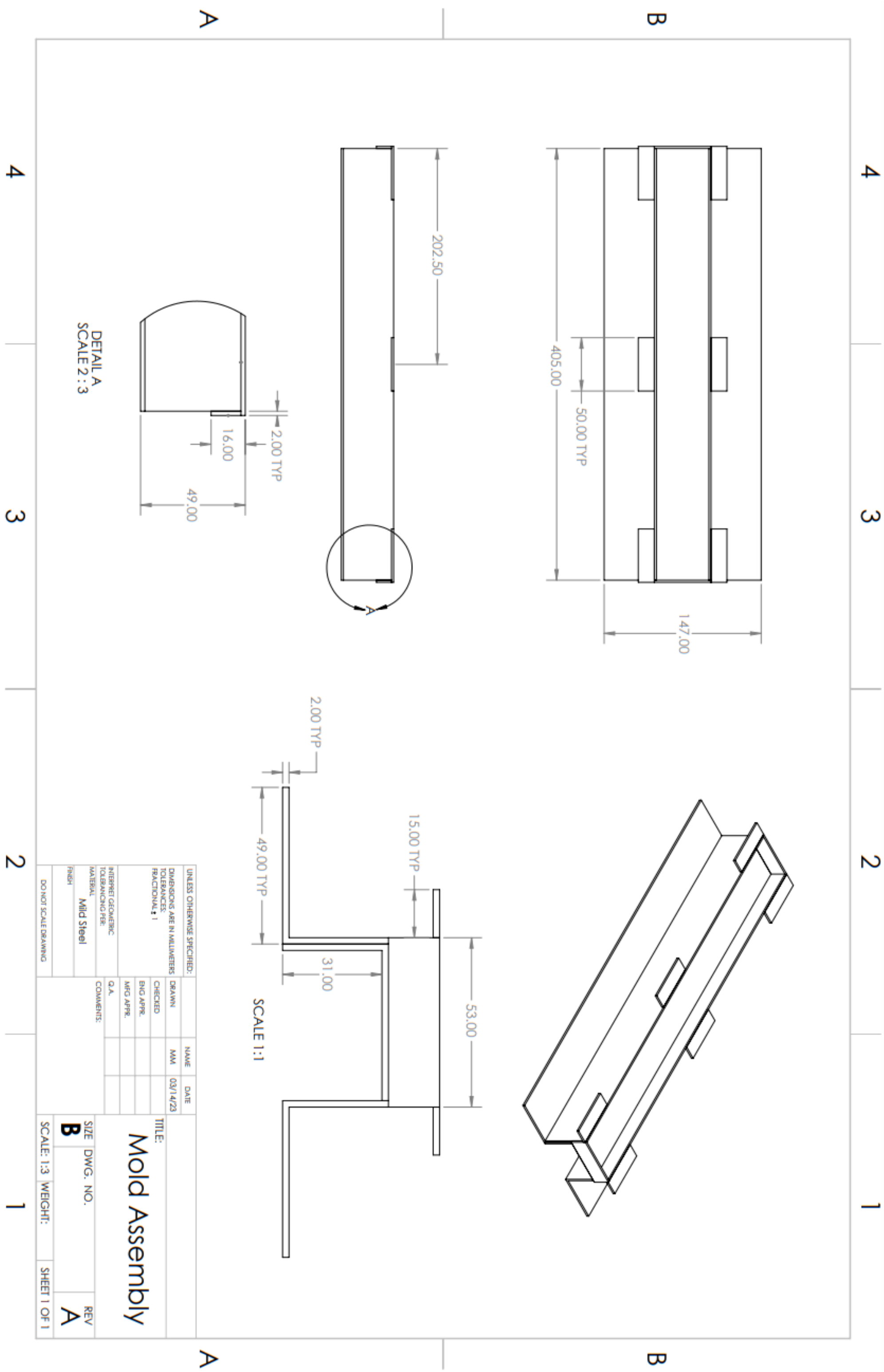


Figure 30: CAD drawing of mold design.