Rural Food Processing

Preliminary Proposal

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1 BACKGROUND

1.1 Introduction

The project titled "Rural Food Processing" will be designed and created by Team 16 as part of NAU's senior capstone program. The project design includes a simple raw cocoyam dispenser and roller that are both reliable and safe for daily use in the creation of Ekwang and Kwacoco Bible meals. The project aims to be a continuation of the manual grinder of cocoyam completed by a different senior capstone team from Georgia Tech last year.

Figure 1: Raw Cocoyam [1]

Raw cocoyam, as shown in its un-grated form in Figure 1, is the base ingredient for Ekwang and Kwacoco Bible. The grating of the cocoyam is done prior to the introduction of the processing system. The purpose of this project/design is to provide a new alternative method to substitute the current hand-rolling technique used for rolling processed raw Cocoyam in banana leaves and aluminum foil by members of rural West and Central African communities. The current hand-rolling method is time consuming and requires effort as it is a process done entirely by hand. The cocoyam dispenser and roller will provide a better alternative that is both quicker and less demanding overall. This will benefit both residents of the rural areas of Africa as well as those living in cities in central Africa. It will benefit rural residents by allowing for more time to pursue different activities due to less time required for preparing meals. Similarly, it will also benefit those in cities by providing a more efficient method that can reduce electrical costs since this design will require no electricity. This project will also aid in the transfer of this technology to the younger generation in African rural areas, which will help in the creation, sale and spreading of the technology among the members of the community. This will aid the Central African communities by providing a simpler solution in the long-term than the current highly inefficient and demanding method of hand-rolling the Cocoyam in leaves or aluminum foil.

1.2 Project Description

The following is the original project description provided by the sponsor.

"Grated raw cocoyam, called Ekwang and Kwacoco Bible are staple meals in much of West and Central Africa. Traditionally, this food is prepared by manually grating cocoyam and wrapped in vegetable or banana leave. The process is labor intensive and time consuming. It can take up to 2 hours to grate cocoyam's for a family of five. A few rich people in the cities in Africa and the diaspora have found creative ways to still eat the food by using blenders or juicers to process the food. However, mothers in rural areas still use the traditional manual method of grating the cocoyam's and wrapping it in leaves. Preparing the food takes enormous amounts of time from women in performing other productive activities. There is a need to improve upon the process of preparing the food by designing a simple and affordable system to use to process the food. Such a system will not only help those in the villages with no electricity, but also people in the cities that have roadside restaurant that sell the food. Even the rich people in the cities will still like to use it, since it reduce their electricity consumption from using the blender to make the food. Africans in the diaspora have figured out a way to use aluminum foil to wrap the paste since it is difficult to have leaves here."

1.3 Original System

1.3.1 Original System Structure

The original system in use was hand rolling technique to roll the raw Cocoyam into either leaves or aluminum foil. Apart from a couple kitchen-based utensils, the process is mostly hand labor intensive. The kitchen equipment used includes: A large metal spoon, a tablespoon, and a large bowl. The process also requires cooking ingredients. These include ghee, smoked fish, tilapia sardines, chicken flavored bouillon, salt, as well as leaves. All ingredients except for the leaves and cocoyam are not required for the processes of the original system, but are optional to taste. The process requires at least one person.

1.3.2 Original System Operation

The team traveled to Phoenix, AZ, to observe how the hand-rolling process of cocoyam is conducted. The team met with Jacky Nwana who performed the demonstration. The operation begins by preparing the cocoyam by grating it very finely into a bowl. It is then seasoned and other ingredients are mixed in as desired; this includes ingredients such as ghee, smoked fish, tilapia sardines as well as seasoning such as salt, and chicken flavored bouillon.

Figure 2: Banana Leaf

This mixture will then become the "stuffing" that is rolled into the leaves. Prior to that the leaves are rolled out, washed, and patted dry to ensure cleanliness as depicted in Figure 2. The stuffing mixture is then adding onto the leaves, by scooping it using the large metal spoon. The leaves are then rolled delicately by hand and then placed into a large empty cooking pot. Once a whole cooking pot is filled with the rolled cocoyam, smoked fish is then added on top and the dish is cooked for approximately two hours.

Figure 3:Completed Ekwang Dish

Therefore, the main aspect of this operation is the hand-rolling technique that is performed by the individual preparing the dish. This technique involved laying the banana leaf flat on the surface, and placing the grated and seasoned cocoyam into the center of the leaf. The top and bottom edges of the banana leaf are pinched together and rolled into a cylindrical shape with open ends. The open ends are folded inwards as to close those open circular ends. The above steps must be completed for every rolled cocoyam to be made prior to placement in the cooking pot.

1.3.3 Original System Performance

Upon meeting with Jacky, the team noted down the measurements of randomly chosen leaves (weight, length, width, and area), the volume of cocoyam used, as well as the approximate time taken to roll each roll of Ekwang and Kwacoco Bible respectively. The total time taken to grate the cocoyam, the total time taken to process the ingredients as well as the total time taken to finish rolling the cocoyam rolls was recorded for an understanding of the complete process. The total time for preparation is not of consideration in regards to the scope of the system being designed.

For the smaller Ekwang rolls, the leaves were smaller in size. An average weight of 15.7g was calculated. The average dimensions of the leaves were 4.49cm in length and 5.08cm in width. This equated to an average area of 23.093cm2. An average of 1 tbs of grated Cocoyam was added to every rolled leaf. The time taken to roll the Ekwang rolls ranged from 20.04 seconds to 11.28 seconds, with the average time taken to roll an Ekwang roll being at 14.123sec. The end width of these randomly tested leaves was recorded as well, with the average end width (diameter) of 0.92cm. In total, 42 Ekwang rolls were prepared.

In terms of the Kwacoco Bible rolls, however, the time taken is shorter (per roll) as the rolling process was less demanding. Similarly, to the Ekwang rolls, random banana leaves were picked, and dimensions were measured (weight, length, width, area). The average weight of the banana leaves was around 176.5g. The average length of the banana leaves used was 10.15cm. The average width of the banana leaves used was 11.775 cm, and the average area was 119.05cm2. The banana leaves were then stuffed with an average of 10 tbs of Cocoyam. The average time taken to roll a Kwacoco roll was around 23.03sec. The average end length of a Kwacoco roll was around 5.725cm and the average end width was 2.525cm.

1.3.4 Original System Deficiencies

To begin, the current conventional hand-rolling method is time consuming and physically demanding. It requires attention in which the person performing it could save a lot of time and effort that could be spent being productive elsewhere. From our measurements we can notice that the time to roll is the longest time taken out of the three essential steps to making this meal. The motion required to roll each individual Kwacoco bible took around 4 different steps (grabbing the edges, pinching, folding and crossing edges), which consumes a lot of energy and time. The customer aims to reduce the average time taken to roll the Ekwang and Kwacoco Bible, allowing the same amount of work done to be completed within a reduced timeframe.

2 REQUIREMENTS

The project goal is to create a dispenser and roller for Ekwang and Kwacoco Bible to help West and Central African communities. Preparing these meals is labor intensive work. Therefore, our goal is to reduce the time for preparing the food to make sure they can spend time in other areas of life outside of food preparation. This chapter will discuss the requirements of the project.

2.1 Customer Requirements (CRs)

Table 1: Customer Requirements and Ranking

Customer Requirement/importance	Importance Ranking
1. reliability	3
2. durability	2
3. lightweight	1
4. safe to use	3
5. simplicity	3
6. low cost	2
7. adjustable dispensing	2
8. mobility	1
9. faster than hand rolling	3

The customer requirement ranking was based on what the customer wants. The scale of the customer requirement is 1-3, where 3 is the most important requirement. The importance rankings can be seen in Table 1 above. The top customer requirement requirements are reliability, simplicity, faster than hand rolling, and safe to use. The device needs to have high reliability in order to ensure that the workers will be able to produce a roll with every pass through the system. Moreover, the device needs to be simple to use because people in a rural village will be the main operators. Additionally, the device will be manufactured in these communities which have limited resources and tools. Therefore, simplifying the device is the only way to ensure its public utility. The device must also be safe to use for everyone in the community since both children and adults will use the system.

Requirements based on what the customer stated as important but not of the highest consideration have a lower weight in the requirements in Table 1. These include durability, low cost, and adjustable dispensing. The device durability and cost were not as important to the customer as the device will be manufactured with different materials in Africa than what the final design may be created with. Consequently, the durability and low cost will be ultimately determined by the workers in Africa. However, if our design was able to account for the materials and costs of manufacturing in Africa, it would be better for the customer. The adjustable dispensing is important as there are two different meals that people consume: Ekwang and Kwacoco Bible. Adjusting the dispenser would allow for people to prepare the different dishes easily. The lowest requirements were based on what the customer deemed as features he would like incorporated. The client would like the device to be lightweight or mobile. The customer explained that the device will be used in almost stationary places such as homes, street. However, the customer says that it would be better if it can be mobile to ensure that it does not get stolen, especially if the device was being used in the street.

2.2 Engineering Requirements (ERs)

Table 2: Engineering Requirements and Target Values

Customer Requirement/importance	Importance Ranking	Engineering Requirement	low weight	base footprint	volume of material to create device	minimize number of parts	smooth edges	low price	minimize time to produce one roll	material strength	material density	number of dispenser settings	capacity
Target ER values			7 kg	0.125 m^2	0.02 m^3	20	r=5 mm	$35.00	30 sec	44 MPa	1040 kg/m^3	4	7 L
Tolerances of Ers			>10 kg	>0.25 m^2	>0.1 m^3	>30	<5mm	>$45.00	>60 sec	<44 MPa	<1040 kg/m^3	<4	>7 L

Minimizing number of parts targets simplicity. Quantifying simplicity is important to determine whether our design will be simple enough to manufacture in Africa. The target goal is to have 20 parts and tolerance of up to 30 parts as seen in Table 2. 30 parts was selected because the design was considering off the shelf items such as nuts, screws and rollers. Moreover, the 20 parts goal considers the number of unique parts that will be manufactured.

Number of dispenser settings targets to quantify the types of the different types dispensing settings that the user will have for the different dishes. The target goal is having four settings between the two dishes, two settings per dish. These four settings are set in order to give the user the opportunity to choose the type of dish and the amount. These two different settings were set in case users wanted to use a different amount of cocoyam (more or less) in the prepared dish. The tolerance of two more than four dispensing settings was selected because the more options allows for a user's personal preference in preparation.

Low price targets how the price is affected by other customer requirements. The price is mostly affected by simplicity because the simpler the design will lower the manufacturing cost.

The price goal is $35 and the tolerance is to be less than $45. The goal is set to $35 because the lower the price the better. The price goal is lower than our customer price goal because the lower price, the more people will be able to afford the device.

Low weight targets to quantify the mobility of the device. As the weight decreases, the mobility of the device will increase. The goal is to create a design of approximately 7 kg. This weight was determined based on assuming that this device will be carried by kids and adults. Therefore, 7 kg was based on the average weight the team determined would be easy enough for a ten-year-old to carry. The tolerance is set to be less than 10 kg as the upper weight limit.

Minimize time to produce one roll targets to quantify the time it will take to create one roll when compared to the hand rolling process. The goal determined prior to a real-life demonstration was 30 seconds. Material strength's target is to quantify how durable the material is. The goal is to have a strength of 44 MPa. The 44 MPa will ensure that our design is capable of handling high forces. The tolerance is set greater than 44 MPa because the higher the material strength the better volume of material to create device target is to quantify how mobile our device is. Since the materials to be used have not been determined, this may shift.

Volume of material targets the mobility of the device. The goal is 0.02 m^3 of material. The tolerance is set to no greater than 0.1 m^3. Material density targets to quantify how heavy the weight would be and what materials to choose. The goal is 1040kg/m^3 because the material has to be dense enough to withstand the processes. The tolerance is set to greater than 1040 kg/m^3 because the team is unsure what material will be used.

Smooth edges targets to quantify the safety of the device. The goal radius of the design is to have a radius of 5 mm. The team predicts this radius on sharp corners will provide a smoot finish to minimize the danger of cuts on the device. The tolerance is set to greater than 5 mm because as the radius increases, the curvature becomes smoother. Base footprint targets to quantify how much space will the device will occupy. The goal 0.125 m^2. The team deemed this reasonable considering it is a two stage system but anticipates a vertical orientation for the device rather than horizontal. The tolerance is set to more than 0.25 m^2 because the larger the design, the less mobile the device becomes.

2.3 House of Quality (HoQ)

Customer Requirement/importance	Importance Ranking	Engineering Requirement	low weight	base footprint	volume of material to create device	minimize number of parts	smooth edges	low price	minimize time to produce one roll	material strength	material density	number of dispenser settings	capacity
1. realibilty	3		1	0	0	9	0	3	9	9	0	1	0
2. durability	2		3	0	0	9	3	3	1	9	3	0	0
3. lightweight	1		9	1	9	9	0	3	0	3	9	1	3
4. safe to use	3		0	0	0	3	9	0	0	3	3	3	0
5. simplicity	3		1	1	1	9	0	9	0	0	0	9	0
6. low cost	2		9	3	9	9	0	9	0	0	3	3	3
7. adjustable dispensing	2		1	0	0	9	0	3	1	0	0	9	1
8. mobility	1		9	9	9	3	1	0	0	0	3	1	3
9. faster than hand rolling	3		0	0	0	3	0	0	9	0	0	3	0
Absolute Technical Importance (ATI)			50	19	39	138	34	69	58	57	33	74	14
Relative Technical Importance (RTI)			11.8	3.2	6.7	23.6	5.8	11.8	9.9	9.7	5.6	12.6	2.4
Target ER values			7 kg	0.125 m^2	0.02 m^3	20	r=5 mm	$35.00	30 sec	44 MPa	1040 kg/m^3	4	7 L
Tolerances of Ers			>10 kg	>0.25 m^2	>0.1 m^3	>30	<5mm	>$45.00	>60 sec	<44 MPa	<1040 kg/m^3	<4	>7 L
Testing Procedure (TP#)													

Figure 4: House of Quality

The highest engineering requirements are minimizing number of parts, numbers of dispenser settings, low price and low weight as seen in Figure 4. Minimizing the number of parts was the highest engineering requirement because this device needs to be able to be manufactured in Africa. Moreover, minimizing the number of parts reduces the cost and makes using the device simpler. Therefore, minimizing the number of parts has the highest value because it correlates with other engineering requirement.

Number of dispensing has the second highest importance because the number of settings will appeal to individuals' personal preparation preferences and encourage widespread usage. Therefore, the labor time involved with preparing the dishes will reduce within the entire community. Low price is the third most important engineering requirement. Lowering the price is important because it will determine whether people in Africa will be able to recreate the design. However, the price is dependent on other factors such as minimizing the number of parts.

Light weight is the fourth ranking in importance. The moderate engineering requirements are minimizing time to produce one roll, material strength, volume of material to create device and smooth edges. Minimizing the time to produce one roll is the core of the project. However, if the price or number of parts were high, the design will fail to meet main correlated requirements. Material strength is important to ensure the device will meet the customer requirements of reliability and low weight. However, the device strength will not be exposed a lot of traveling; the main goal for this device is to be used at home. Volume of material is important to ensure that the device is mobile to be moved in villages and directly relates to the mobility customer requirement. Smooth edges are important this device will be used by a variety of ages and will be picked up and moved around. The lowest engineering requirements determined were material density, base footprint and capacity. Ultimately, the main customer requirement of the new device being faster than the current hand rolling technique only related to minimizing the number of parts, minimizing the time to produce one roll, and number of dispenser settings engineering requirements. The correlation between customer requirements and engineering requirements were on a 0-1-3-9 scale, where zero is no correlation, one is a weak relationship, three is a moderate relationship, and nine is a strong relationship (Figure 4).

3 DESIGN SPACE RESEARCH

This section includes literature review from team research regarding different aspects of the project, benchmarking based on the original system and other devices that are similar to the goal of the system, and a black box model and functional decomposition to describe the goal of the new system.

3.1 Literature Review

Each member of the team researched a particular aspect of the project. Findings from this research are outlined in this section.

3.1.1 Student 1 (Humoud Alanjari)

An important part of the project is to transfer the technology and knowledge for the people to create the design with the materials that they have. Central Africa has the second Largest tropical forest which makes wood a great resource [2].

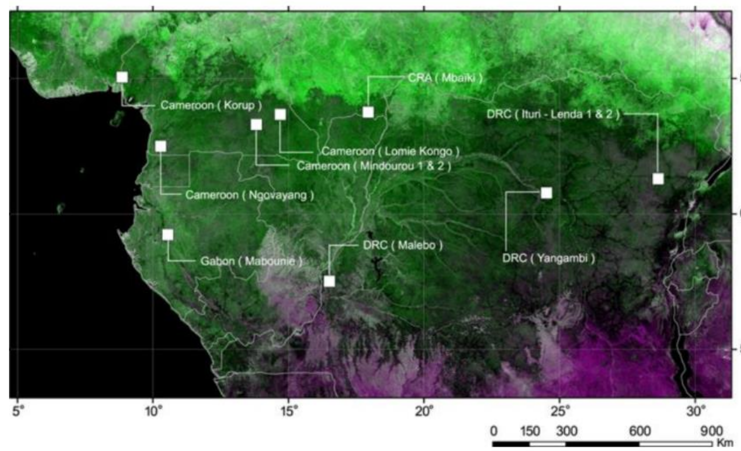

Figure 5: Image of Forest in Central Africa [3]

Figure 5 illustrates a picture of the forests in central Africa [3]. Moreover, the research indicates that Large trees play an important part in indicating the above ground biomass from the large tress. Therefore, the plant life should not include large tress just because of their size. In addition, the forest maintains high densities of large mammals. Therefore, whatever material the team should take impacts into account.

The forest is not the only resource. Africa is rich in minerals such as gold, diamond and iron. However, iron prices are increasing with high demand of iron coming from China [4]. Therefore, the team has to look for alternative to ensure that the design price would not double in the future [4]. If the team decides to go with a metal part, they have to account to the rusting factor. Even though, our client indicated that they use palm oil to prevent iron rusting. The team has to account for bacteria as they can be a source for rusting [5]. Additionally, painting can prevent the iron from rusting which will reduce the maintenance cost for the device [5]. On the other hand, wood has different types that can be used differently in our project. For example, some Umbila wood is durable, resistance to insects and can work easily with both hands and machine tools [6]. On the other hand, Pau Ferro wood dries slowly is resistant to nails. Therefore, Pau Ferro could used as the rolling plane because the rolling plane needs to be smooth and wet.

3.1.2 Student 2 (Musab Albalool)

First literature review: - Rolling Machine

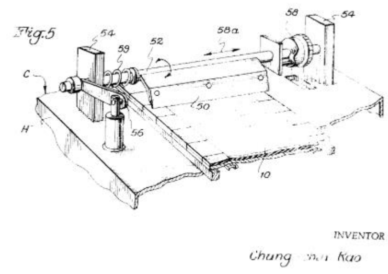

Figure 6: Rolling Machine [7]

In this literature review it discusses the rolling process of the machine. In which the machine is mounted to a horizontal stainless-steel plate and three different pads connected vertically. The pads and the plates are being connected to a large belt to ease the rolling motion of the machine [7].

Firstly, this literature review helped us to come up first with the idea of including a rolling belt on our device, and that's because regardless of any type of material we think we will be using the belt on our device would help us increase the speed of the rolling process.

Second Literature review: A Dehydration Avoidance Mechanism: Leaf Rolling

In this literature review it discusses how plants fold their leaves when their exposed to high temperatures. Plant can benefit from rolling their leaves in two different ways. Firstly, damage caused by the increased leaf temperature resulting from high levels of solar radiation and secondly transpiration rates can be reduced through the creation of a microclimate having both higher humidity and boundary layer resistance near the leaf surfaces [8].

Our project includes different types of leaves for the cooking process, such as banana leaves, cocoyam leaves and collard green leaves. This article helps in knowing more about how plant leaves change during different seasons across the year, by knowing how and when the leaves roll up during the season. Knowing that the leaves roll up due to different temperature change and due to certain damages that the weather caused them to do this we could then assume that we are most certain that the leaf is not good for peeling and using for cooking. We could see if the leaves are not rolled up this could be the perfect season and time to peel off the leaves and use them for the Ekwang and the Kwacoco Bible.

Third Literature review: The influence of roll speed on the rolling of metal plates

In this literature review it discusses how the speed of the rolling can be affected by the type of metal that is being rolled upon. This articles also discusses that the rolling process is divided into different categories based on the metal flow induced and the geometry of the rolled product, as well as it discusses on how the temperature of the plate were using if its hot or cold plate and how will it affect the rolling process and how will the friction play its part in that process [9].

The speed of rolling is one of our main customer requirements is that to build a process that is faster than the hand rolling process that's currently being used. Looking up articles that explains the different speed of roll caused by different metal plates will definitely hit our main target in choosing the type of metal plate for our rolling device, cause as we know different types of metal can cause different friction caused on the banana leave and can cause to slower or faster rolling process.

Fourth literature review: Effects of surface roughness on rolling friction

In this literature review it discusses how that rolling on a horizontal surface will come to rest due to the result of the rolling friction. The rolling friction will eventually depend on two different factors, firstly, the deformation of the object and secondly the deformation of the surface if the surface is soft or thick. In this literature review also discusses the loss of energy due to the elastic deformation. Elastic deformation will depend of the surface of the metal if the surface was real and inelastic then the deformation will result in no loss of energy [10].

The effect of surface roughness on the rolling will help us as a team to come up with different idea on how to look for smooth material surfaces so that we can have energy in our system, and that's because smooth surfaces will result in less deformation of the system as well as we could decrease the loss of energy in our system and by that we have maximum efficiency of our product.

Fifth Literature review: Rolling Process

In this literature review it discusses different type of rolling process. Rolling processes could be preformed under different circumstances such as hot temperature or cold temperature. In the article it discusses how hot temperature will affects the surface of the metal in which it will cause the surface of the metal will deform easily and faster than rolling in cold temperature [11].

The effect of temperature is huge factor in our project since it is based in center African countries. These countries are usually known for very high temperature in which it will affect the surface material and it will cause the materials to deform easily.

3.1.3 Student 3 (Nygel des Vignes)

The technical aspects focused on were ways or nozzles to dispense the cocoyam paste. Cocoyam is very viscus so it will not flow through a typical fitting like water does, to mitigate flow issues I researched different types of fittings and flow characteristics. The first fitting utilized different volumetric areas and shapes to manage the flow rate of the substance [12].

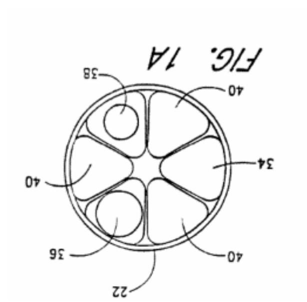

Figure 7: Volumetric Dispenser [12]

This fitting would be easy to purchase and implement into the design. But doesn't not allow for the team to choose the amount being dispensed. Another option that was researched was a nozzle that could change dimension [13]. This nozzle uses the pressure of the surrounding fluid to restrict the flow. So as the tank lowers in volume the nozzle will expand to compensate for the reduced weight of the fluid. The issue of viscous flow was also talked about with the team's capstone advisor Chuck. Chuck mentioned how it would be hard to accurately represent the flow in a simulation or calculation since there were so many unknowns. He stated that the team could make assumptions and hope they would be correct but making the wrong assumption would drastically change the results [14]. Another way to deal with this was to add a plunger or to be able to increase the forces on the substance forcing it through the nozzle. With this in mind the team then need see if it was possible to evaluate the flow at the nozzle and what characteristic the flow would have. To evaluate this research was done on compressible flows. The Journal of Applied Mechanics talked about this and how compressible flow theory would be the most applicable to evaluate the flow at the nozzle exit [15]. Considering a nozzle and compressible flow a system that could handle both seemed to be the best for this product. A pump nozzle was then found which would meet both criteria. The nozzle uses a squeeze bag to propel the material inside the bag out of the nozzle [16]. This is very similar to the plunger idea our advisor suggested. Being able to secure for the design would help to quickly dispense the cocoyam paste.

3.1.4 Student 4 (Samantha Morrison)

In using various materials, the consideration of a material's contact with food is a major concern to maintain food safety within a system. If a metal were to be selected, stainless steel is one of the main materials for consideration by the team. Stainless steel, and many other materials, have inherent surface roughness. In consideration with stainless steel contact with food particles, this roughness creates cavities that allow for the "attachment and confinement of pathogens" [17]. These pathogens lead to food-borne illnesses due to the repetitive contact with the contaminated surface. In order to avoid this, a use of a foodsafe oil-based slippery coating (FOSC) can be used to block microbial growth, enhance surface cleanability [17]. This article emphasizes how sanitation methods and cleaning habits of equipment plays a large role in preventing the buildup of bacteria. The article mentions how even chemical disinfectants can even be ineffective due to the microstructured grooves [17].

Biofilm formation in particular describes what is trying to be avoided by using FOSCs. A biofilm is of particular concern of increasing post-processing contamination [18]. Depending on the food type that is in contact with the surface, various pathogenic microorganisms can grow on those surfaces [18]. In this project, safety is a requirement, which extends to the safety of the food being prepared. With the knowledge of this article, the team has background knowledge that can drive conversations with the client to determine steps that will be necessary to maintain food safety if metal is the selected material.

Another material of consideration is plastics. Although the cocoyam will not be stored in the system for a prolonged period of time, "Safe Food Packaging and Storage for Better Health and Environment" provides insight into what aspects of the use of plastic are concerning when in contact with food. It is not all plastics that are potentially dangerous; plastics can contain small molecules that, when in contact with food, can transfer to the food in contact with it [19]. The most common compound in question in plastics are xenoestrogens (or endocrine disruptors) which can cause low fertility, insulin resistance, and thyroid dysfunction among other side effects [19]. The transfer of endocrine disruptors is accelerated by the warming of plastic causing a softening in the plastic, as well as the food being a liquid rather than a solid or being acidic [19]. Luckily for this project, the likelihood of endocrine disruptors is lowered because the system will not experience any heating processes when in use, other than heat caused by friction within the system. Although not likely a large concern, the team knows to investigate plastics before use to ensure that it is food-grade in order to avoid the health problems outlined within this article.

With the use of plastics, another potential option to reduce costs is the use of recycled material. This would help to minimize adverse environmental impacts of plastic waste. Monomers are the driving force behind the composition and chemical nature of plastics, but there are hundreds of plastic structures that can be created using various polymers [20]. As described previously, there is an allowance for transfer through plastics – although this article focuses on the permeation of gas and vapors – and that barriers are necessary when dealing with thin plastics such as wrappers [20]. The use of recycled material increases the chance of additional chemicals present in the material than "virgin material" because remnants of a container's previous contents can be within the chemical structure of the recovered plastic [20]. Although recycled plastic is an opportunity for West and Central African communities to reuse materials, the team will have to consider the possible effects these materials can have when used in the system. The team will have to evaluate the best ways to maintain food safety so, if materials like these are used, the community is aware of potential dangers and how to potentially eliminate these risks.

Another concern for food safety is the handling of the equipment and the food being prepared. The client mentioned that the system is intended to be used by both families as well as street vendors. When observing vendors at random in New York, many vendors do not follow proper health codes which can lead to contamination of products [21]. Although New York has different standards than West and Central Africa, a consideration of the handling of the food prior to being inserted and after it has exited should be mentioned within the operation instructions of the system.

3.2 Benchmarking

The rural food processing project is based entirely on improving upon the pre-existing system for dispensing and rolling cocoyam in order to create traditional West and Central African dishes. The team had the opportunity to meet with Jacky Nwana who was a native currently residing in Arizona. She gave a demonstration of the process of preparing the dish. During this time, the team was able to observe the overall preparation steps in order to collect data on what subsystems the system could be broken up into in order to achieve the goal of reducing the preparation time.

From these observations, the team determined that the dispensing the cocoyam and the rolling of the cocoyam were really the only subsystems present and that these two actions were where the time reduction for the overall process can be maximized.

3.2.1 System Level Benchmarking

The overall existing design for the system is the traditional method of preparation as presented by Jacky Nwana. This was the only system that really reflected the subprocesses together in a cohesive system. As such, the team decided to research other native's preparation methods in benchmarking to discover any details that may differ between the traditional methods,

3.2.1.1 Existing Design #1: Jacky Nwana's Method

This design was our physical observation of the process as demonstrated in Phoenix by Jacky Nwana [22]. She started the process with raw ingredients and continued through beginning the cooking process. Based on conversations with our client, the team was able to specifically pinpoint the time in the process where the device should fit. This was identified as when Nwana began scooping the prepared cocoyam into a leaf and then rolled it by hand. After this, the prepared portion was placed into a pot for cooking, but the client identified this transferal of the product was not necessary in the design.

This system meets many of the requirements because it is the baseline design for the creation of the new system that will introduce an ease of use and automation of the cocoyam rolling process. The requirement is does not meet is being faster than the current method, due to the fact that it is the same method.

3.2.1.2 Existing Design #2: Ekwang – Precious Kitchen

Another system design is the Ekwang prepared by Precious Kitchen [23]. Her recipe for the cocoyam differs in contents compared to Jacky Nwana's recipe. Her technique varies slightly from the demonstration that the team was able to watch. Instead of rolling the entire roll from the center evenly, she rolls the cocoyam from one side to the other, starting on the left and moving towards the right. When the initial roll is complete, she loosely wraps the remaining amount and places the roll directly into the pan. This method also meets the requirements of the project except for being faster than the current method, because it is another iteration of the same method.

3.2.1.3 Existing Design #3: Kwacoco Bible – Precious Kitchen

Kwacoco Bible is prepared in a different way from Ekwang, but also contains a cocoyam mixture wrapped inside of a banana leaf [24]. As opposed from a small roll, the amount of cocoyam placed inside of, the Kwacoco Bible dish is three times, if not more, the amount of cocoyam used in Ekwang.

Additionally, the technique used in this system is a centered start of a roll, much like Jacky Nwana's method, and then the roll is loosely continued until the entire banana leaf is used. At the end, the ends are then folded under the roll, something unique between the Ekwang and Kwacoco Bible dishes. This method also meets the requirements of the project except for being faster than the current method, because it is another iteration of the same method.

3.2.2 Subsystem Level Benchmarking

The subsystems identified in the system include a dispensing mechanism, a rolling mechanism, and a reservoir. These subsystems were used to identify benchmarking designs.

3.2.2.1 Subsystem #1: Dispensing Mechanism

In this distinct subsystem, cocoyam is inserted into the device. It is then moved through the system to the end which has variable volume dispensing settings. The cocoyam is measured into the proper setting's size and then dispensed into the rolling vessel for further processing.

3.2.2.1.1 Existing Design #1: Spoon Dispensing

The traditional preparation of this dish features an individual using intuition and visually determining the amount of cocoyam to dispense into a leaf. In this design, there is a bowl or some large container that holds all the cocoyam that will be prepared into the dish. The individual then inserts the spoon into the bowl and will scoop the desired amount of cocoyam for the leaf that has been previously prepared for the next rolling step. As the current method that is utilized, it meets many requirements such as reliability, durability, lightweight, low cost, safe to use, simple, and mobile. However, since the client wanted to improve upon this system, the goal is to improve upon specifically the speed and adjustability of the dispensing of this method.

3.2.2.1.2 Existing Design #2: Server 88750 Single Dry Food Dispenser 2 Liter

Figure 8: Server 88750 [25]

The Server 88750, as shown in Figure 8, is a device that utilizes a simple handle to actuate the dispensing mechanism, It has a 2L capacity which allows for the storage of the product to be dispensed. The dispenser is also capable of being mounted and being removed for cleaning. Since the device is self-contained, it meets the safety requirement. The device is also simple as the handle is a common device, reliable since these types of devices are common, and lightweight due to the plastic material. However, where this device lacks is the adjustable dispensing and its cost. [25]

3.2.2.1.3 Existing Design #3: Bulk Food Dispenser

Figure 9: Bulk Food Dispenser [26]

This bulk food dispenser, as seen in Figure 9, is similar to the Server 88750. There is a handle that is actuated by an individual in order to begin the dispensing process. Product is dispensed from a reservoir and out the nozzle. This design differs from the Server 88750 in that it is placed at an incline, which can assist with the flow of product out of the nozzle. This design meets the requirements of safe to use, simple, lightweight and mobile due to not requiring the device to be mounted. However, the device is not adjustable in dispensing a set quantity and the cost of the device. [26]

3.2.2.2 Subsystem #2: Rolling Mechanism

In this subsystem, cocoyam has been dispensed into a leaf that is prepared in the rolling device. The device then moves the leaf with the cocoyam through the rolling process so that the final product is the cocoyam wrapped tightly within the leaf and is then the final dish, Ekwang and Kwacoco Bible, that is now able to be removed from the system and placed into a different vessel for cooking.

3.2.2.2.1 Existing Design #1: Hand Processing/Rolling

The current traditional method of completing the rolling is by hand. The individual secures the cocoyam in the leaf and forms it into a cylinder along an outer edge of the cocoyam. The edge is then folded down to create the first portion of the roll into the cocoyam. The cocoyam and leaf are spun along an axis as the individual holds onto the combination. This process of rolling continues until the entire leaf encapsulates the cocoyam and the final dish, Ekwang, is now ready to be transferred for cooking.

3.2.2.2.2 Existing Design #2: Kitchen Magic Roll Sushi Maker Meat and Vegetable Rolling Tool Stuffed Grape & Cabbage Leaf Rolling Machine

Figure 10: Dolma Roller [27]

This device in Figure 10 was referenced by the client as a preferred device to base the final design off of. This rolling machine features a plastic base with a handle and belt to wrap the contents placed on the device [27]. This device meets certain requirements including safe to use, simple, low cost, lightweight, and mobile. However, the device is not durable and the leaves must be of a certain size and type (grape leaves) which does not suggest easy use with a variety of filling volumes, which would be dispensed into this device from the dispenser subsystem.

3.2.2.2.3 Existing Design #3: Yomo Maker Kit

Figure 11: Yomo Maker Kit [28]

The device in Figure 11 is used to create sushi rolls that are consistent. Depending on the amount that the device is filled will vary the diameter of the final product. This device assumes that there is a certain area of the base wrapping material in order to create the roll. Because of the size of the roll for the Ekwang, this system would be too large for this specific dish. Additionally, the action of rolling is not a fluid rolling motion but rather a wrapping, multi-motion movement. This device meets some requirements, including safe to use, lightweight, and mobility. However, it is not a simple process to roll, is not faster than the traditional method, and may not reliably produce the same size product. [28]

3.2.2.3 Subsystem #1: Reservoir

Prior to being dispensed, the cocoyam is placed in a reservoir of sorts. From this reservoir, it is then dispensed and rolled into the final product.

3.2.2.3.1 Existing Design #1: Bowl

The current system in as demonstrated features a bowl as the vessel that contains the cocoyam mixture. It is simple but effective. Depending on the amount that is desired to be prepared, an individual may use any size bowl that is available at the time of preparation. This meets all requirements, granted that the bowl being used is a robust material, and the bowl was clean prior to use.

3.2.2.3.2 Existing Design #2: Funnel

Figure 12:Nopro Plastic Funnels [29]

Another possibility for housing the pre-rolled cocoyam is a funnel. A simple plastic funnel, like ones made by Nopro in Figure 12, allow for a variety of sizes to contain the cocoyam *[29]*. This design would require a direct connection to the dispensing mechanism because of the hole on the bottom which allows for the transfer of materials through a smaller cross-sectional area. This design is low cost, safe, simple, and mobile. However, the volume a funnel is able to hold is related to the cost, and therefore a funnel large enough to contain as much product as the client wants would increase the price. Additionally, some funnels are thin and not durable enough to handle pressure and constant reuse.

3.2.2.3.3 Existing Design #3: Hopper

Figure 13: Tremie Hopper [30]

The Tremie Hopper in Figure 13 features a square shaped base and circular opening [30]. The opening can also be cut to create a larger opening for faster discharge. This hopper is similar to a funnel, except it is much larger and is angled to the opening using a trapezoidal shape rather than a cone like a traditional funnel. This model in particular is over budget on its own, but provides another shape to reference when generating concepts. The client also specified that this shape is much easier for the African communities to recreate, and he would prefer this shape to others when designing a hopper opening on the system. This design does not meet certain requirements including weight, cost, and mobility. This design does meet other requirements including reliability, durability, safe to use, and simplicity.

3.3 Functional Decomposition

The goal of the rural food processor is to receive the cocoyam, dispense the cocoyam, and then roll the cocoyam in order to form the proper traditional dish. A black box model was created to show the overall process of turning the cocoyam into the rolled dish through the device. The functional decomposition shows a detailed overview of how the device will achieve the task.

3.3.1 Black Box Model

The black box model presents an input material (bolded solid line), energy (solid line), and signal (dotted line) on the left-hand side. These point to the box which represents the device that is being created to perform the task specified within the box. There is then an output material, energy, and signal which defines the end of the process.

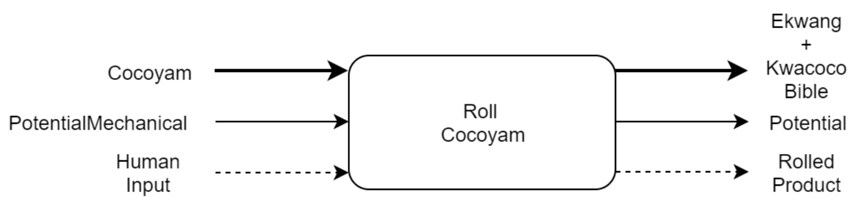

Figure 14: Black Box Model - System

Figure 14 represents the overall device inputs and outputs that the team decided were important to the process. However, in contemplating the processes that the system will undergo, the team decided to create a black box for each of the specific actions that the system is comprised of.

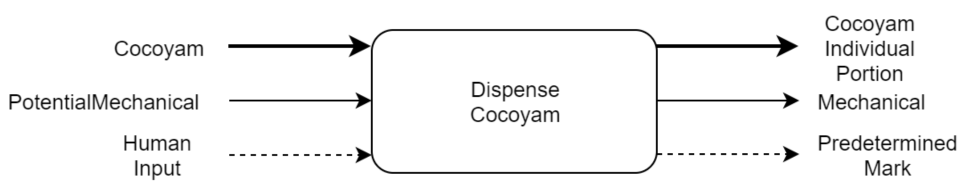

Figure 15: Black Box Model - Dispenser

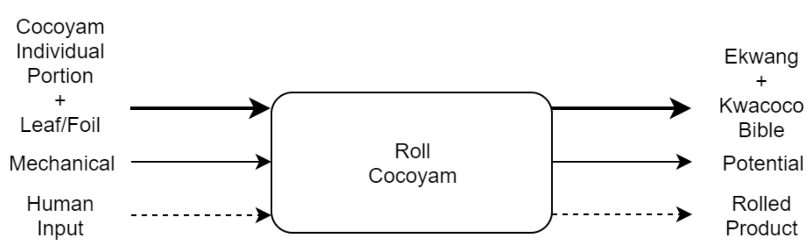

Figure 16: Black Box Model - Roller

In the black box models above in Figures 15 and 16, the dispensing of the cocoyam and the rolling of the cocoyam into the final product are split into two distinct black box models. The dispensing process is directly linked to the rolling process because the outputs of dispensing are the direct inputs of the rolling, with the exception of the output signal of the dispensing and input signal for the rolling. By creating these models, the team was more easily able to work towards creating the functional decomposition for the entire system.

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The team determined that a functional diagram for the project represented in two stages to represent the two subsystems would be the easiest way to define the processes. Moving forward, this decision also drove the team decision to run through concept generation and concept evaluation twice, one for each subsystem, since the final product would be easily combined into the final system.

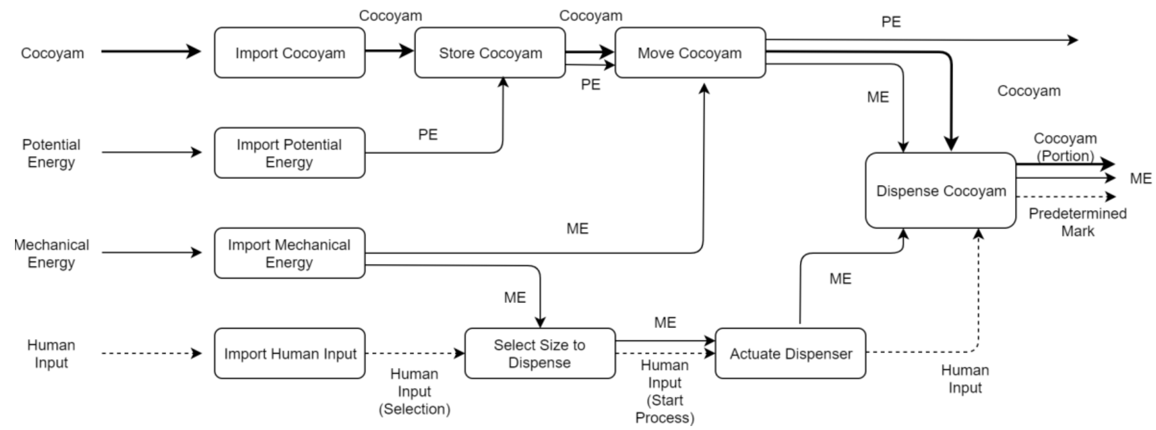

Figure 17: Functional Decomposition - Dispenser

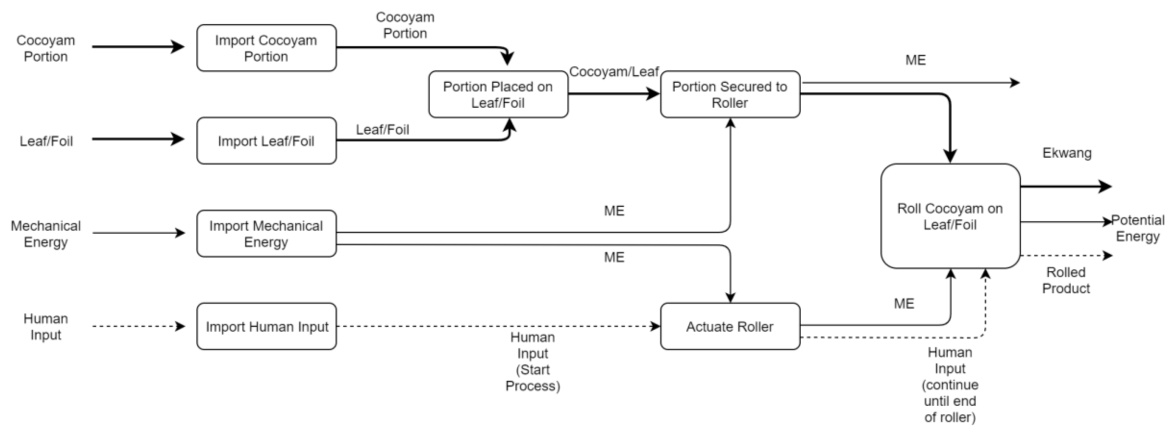

Figure 18: Functional Decomposition - Roller

Like in the black box model, the two functional decompositions in Figures 17 and 18 interface as the output of the roller is the input of the roller. The exception is a leaf to house the cocoyam is introduced to the system at the rolling stage, and the initiation for the system is human input with will be the decision to begin rolling by the individual operating the machine.

This model assisted the team in defining where the focus will be in concept generation. By having two distinct subsystems within the project, the team made the decision to complete concept generation and evaluation twice, once for each subsystem. This would allow for the best idea of each to be selected without having too many variants between the systems. The team established that the interfacing of the systems would not be a major concern since the required interface is a direct dispensing of the cocoyam from the dispenser to the roller. By having this established, the team proceeded to generate concepts based on these functional decompositions for each of the subsystems.

4 CONCEPT GENERATION

4.1 Full System Concepts

These concepts encompass the three main subsystems defined in the system.

4.1.1 Full System Design #1: Conveyor Belt

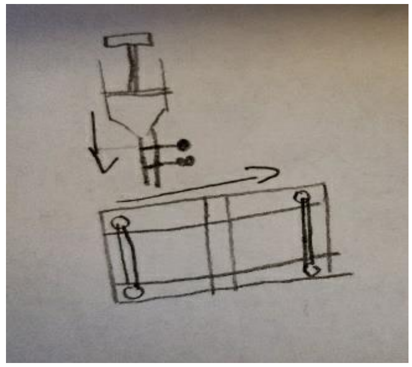

Figure 19: Full System Design 1

This full system design closely represents the final design chosen by the team. This design uses a flat plate with a revolving belt to tightly role the Cocoyam into the banana leaves. A sliding roller handle is mounted above the plate to begin the initial fold and push the semi-completed role forward. Before the cocoyam is rolled it is dispensed from a hopper directly approve straight onto the leaf. Some of the cons to this design are the complexity of parts, limited width to place leaf, and that this device would not be inherently easy to use. The pros to this device consisted of the durability of the design, repeatable roll size, and easily mounted to any surface.

4.1.2 Full System Design #2: C-Shaped Plow Roller

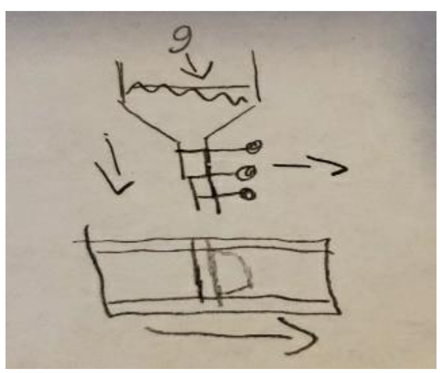

Figure 20: Full System Design 2

This design is a full system representation of a plow shaped roller system. This design uses a set of gates at the bottom of the hopper that can be moved into different positions to easily measure out the desired amount of cocoyam. The larger hopper above will hold the cocoyam which will then be pushed down in the hopper with a plunger. Mounted to the handled will be a “c” shaped plow that will force the leaf to fold onto itself. The cons to this system are the lack of durability in the measuring device high center of gravity with a large hopper, and difficulty in getting the c shape correct. The pros greatly outweighed the cons with a quickly adjustable dispenser, faster dispensing from the hopper, simple to build, and improved time to roll the cocoyam.

4.1.3 Full System Design #3: Screw Dispenser

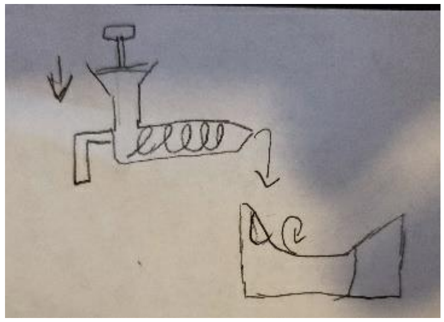

Figure 21: Full System Design 3

This design uses a screw to move the grated cocoyam out of a hopper and onto a covered platform. After the paste has reached the leaf on the platform the user would simply fold one edge and push it down the slope. This is a robust but complicated design, the cons are the complexity of the screw, the design utilizes a small hopper, and does not have a way to measure the amount being dispensed. The pros of the system consisted of being able to dispense as much as the user wanted, high durability, and how easily it could be used by anyone.

4.2 Subsystem Concepts

4.2.1 Subsystem #1: Dispenser System

The dispensing system is defined as the part of the system where the cocoyam travels until it is portioned into the proper amount for each roll.

4.2.1.1 Design #1: Multiple Flow Gate Dispenser

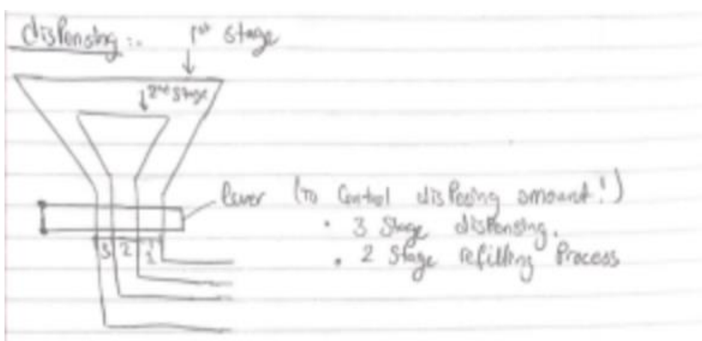

Figure 22: Multiple Flow Gate Dispenser

Quickly measuring multiple volumes is the highlight of this design. This design uses a sliding gate to allow for different size flows to be utilized. The design measure quickly and is robust but struggles in accuracy and controllability.

4.2.1.2 Design #2: Two Flow Gate Dispenser

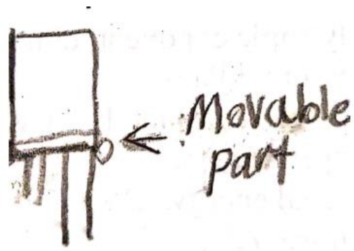

Figure 23: Two Flow Gate Dispenser

This design also features a sliding gate. For this design as the gate is moved the user can chose one of two tube with the flow they desire. This allows for them to easily adjust how much they want dispensed. The downside to a device like this is the inability for the user to premeasure a given amount along with there only being two options for flow instead of many.

4.2.1.3 Design #3: Screw Dispenser

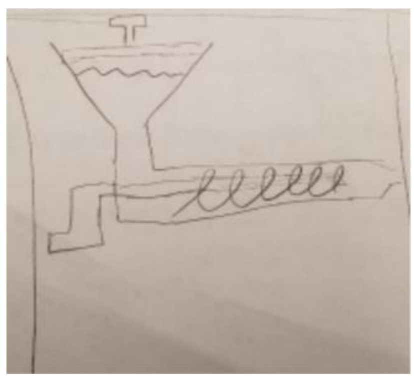

Figure 24: Screw Dispenser

This design gathers inspiration from an injection molding machine by using a screw to push the grated cocoyam forward. The screw dispenser would allow for a continuous stream of material while the user turn the handle. The downside to this is that there would be no way to pre-measure the amount of material being dispensed. The design is robust and easy to learn how to use but lacks in mechanical ability

4.2.2 Subsystem #2: Rolling System

The rolling system is the system that encompasses the entire rolling process from the end of dispensing to the final product.

4.2.2.1 Design #1: Preformed Contour

Figure 25: Preformed Contour

This design utilizes a silicon sheet and preformed contour system to roll the cocoyam. After dispensing the paste onto the leaf, the leaf will be pushed down one side of the contour causing it to roll onto itself. The cons are the inability to reliably wrap the cocoyam, the need for a preformed mold, and how hard it would be to teach the technique to the user. The pros are the use of readily available materials, simple to build, and can be adapted to form different sizes rolls.

4.2.2.2 Design #2: C-Shaped Roller

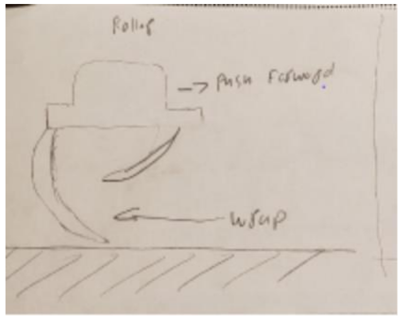

Figure 26: C-Shaped Roller

The roller concept pictured uses two c shaped fins to roll the leaf. As the handle is pushed forward the lowest c will push the leaf up forcing it to follow the curve until the leaf intersects with the second c causing it to roll onto itself. The cons for this design consist of being able shape the fins just right and being able to manage the proper amount of friction. The pros are the ability to easily wrap the cocoyam and ease of use for beginners.

4.2.2.3 Design #3: First Roll Divot Base

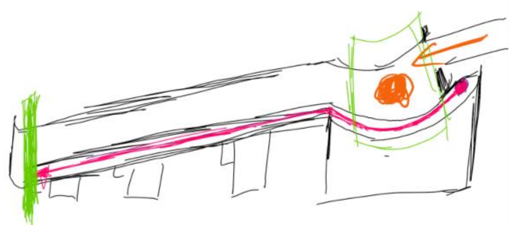

Figure 27: First Roll Divot Base

Using a small divot were a leaf and cocoyam can be staged allows the user to simply fold the leaf over and create the first roll. This allows for quick rolling but causes issues being able to learn how to use the device along with the time to produce one roll not being improved upon compared to hand rolling. These cons are offset by the simplicity and durability of the design.

4.2.3 Subsystem #3: Reservoir/Hopper System

The reservoir/hopper system is a subsystem that will contain the cocoyam prior to being dispensed.

4.2.3.1 Design #1: Pivot Hopper System

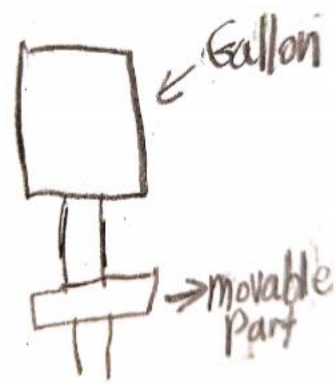

Figure 28: Pivot Hopper System

The Pivot Hopper features a large storage hopper that can be easily filled from the top. With a large hopper the customer will not need to refill as often. To get the material out of the hopper a pivoting fin system will be used to dispense the cocoyam. This system features a large hopper that offer longer uses but has a complicated system to dispense the cocoyam. The fin system would be hard to create and perfect making this design less possible.

4.2.3.2 Design #2: Descriptive Title

Figure 29: Gravity Fed Hopper

This hopper system uses gravity to push the cocoyam down the slope into the measuring gates. This design is incredibly simple but has some possible issues when feeding the cocoyam. Cocoyam in rather viscous depending on what recipe is being used. With a high viscosity the cocoyam may not feed evenly and consistently into the measuring gates. Causing mismeasurements and increased times.

4.2.3.3 Design #3: Plunger Hopper System

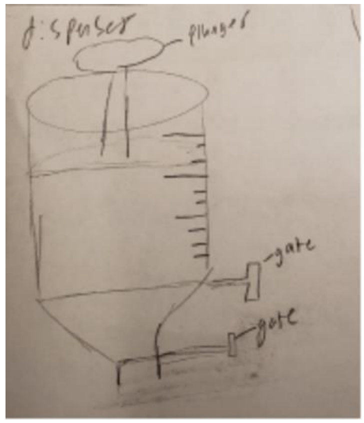

Figure 30: Plunger Hopper System

This design combines the best features of other designs to more accurately meet the customer requirements. Design 1 relied on gravity which could cause issues, so this design implements a plunger to push the material down into the gate system. With the hates in place the customer can measure out the amount of cocoyam or the can remove the gates and use the plunger to supply as much as they desire. The one downside to this design is the possibility of breaking the gates and the small size of the hopper.

5 DESIGNS SELECTED – First Semester

This section details how the team evaluated concepts and did design selection. The team started with very broad customer requirements which were then translated into engineering requirements and used to rank each design. Tools such as the gallery method, Pugh charts, and decision matrices were used to select a final design. Due to the system consisting of two unique parts the roller and dispenser, the team chose to do two of each evaluation method for those parts. Doing two of each evaluation method allowed for the most applicable criteria to be applied to each system. Once this one was done the winning design from each was combined into a final design and represented with a CAD model.

5.1 Technical Selection Criteria

To identify the key technical requirements the team met with the customer and disused the overall scope and wishes of the project. Mr. Zama stated during this time his desire increase number of Ekwang that could be rolled, that he wanted a cheap but durable device that could both measure and roll the Ekawg, along with a device that was simple and safe to use and under forty-five dollars. With these in mind the team created the following engineering requirement: minimize number of parts, multiple dispenser settings, low cost to build, and minimize time to produce one roll. Minimizing the number of parts along with decreasing the time to roll one roll were picked as the most important requirements.

The customer requirements were then placed into the Pugh charts, available in Appendix A and B, one for the roller mechanism and one for the dispensing mechanisms. The criteria used to evaluate the designs in the Pugh charts were the customer requirements. The customer requirements used were: reliability, durability, safe to use, speed, and adjustable dispensing/roll size. The designs the team created using the gallery method were them compared to the datum of a spoon and hand rolling. Once the designs were ranked using the customer requirements, the designs were then placed into a decision matrix and scored using the engineering requirements of design strength, low weight, capacity, minimize number of parts and low price. This allowed for the team to get a more quantitative result that closely match the need of the requirements. Decision matrices can be found in Appendix C and D.

5.2 Rationale for Design Selection

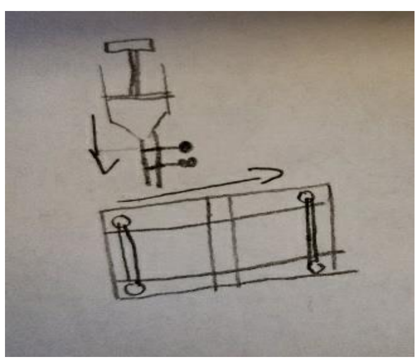

Figure 31: Full System Design 1

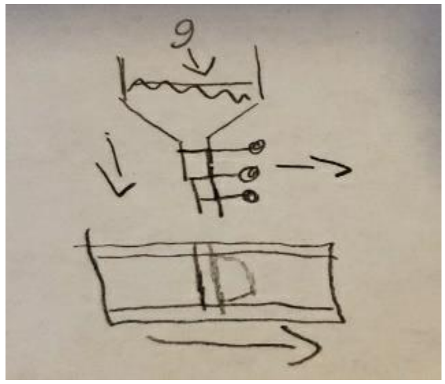

Figure 32: Full System Design 2

The top two designs that were selected after using the tools previously mentioned were full system designs one and two in figures 31 and 32. These designs are very similar to each other with the main difference being the shape of the roller mechanism. These designs were the most plausible and efficient designs the team created. The Pugh charts and decision matrices used to evaluate the team's designs did not feature any full systems but the subsystems. Full system designs one and two are a combination of the highest scoring elements in each subsystems decision matrix. The first design features a plunger fed hopper that is metered using a gate system the feeds cocoyam onto a conveyer belt system that rolls the leaf. While the second design features a gravity fed hopper with a similar gate system that feed cocoyam onto a c shaped roller system. The first design excels in decreasing the time to produce one roll and can be easily taught to someone. The first design does struggle in the ease to manufacture and net weight of the design. The second design features a c shaped roller which allows for easy rolling along with a quick learning curve. This design struggles in the complexity of designing the c shape correctly to roll the cocoyam.

To further evaluate the designs a force calculation along with a costing calculation were performed. The force calculation modeled the handle and roller system. To do this the team treated the handle as a simply supported beam with a centralized 10lb force [31]. This allowed for the team to gather data on the expected forces the design might be subjected to. With the maximum amount of shear of .045kN in mind the team could also look into different material and choose the best for this scenario. See Appendix E for diagrams.

The next calculation the team did was a costing calculation. The cost to build the device was dependent on the material selected. The initial estimates using stainless steel were in the hundreds of dollars range while using abs plastic with a 10 percent infill was only around fifty dollars. With the force calculation, the team was able to determine that abs plastic would be sturdy enough to build our product out of. To further lower the price, the team wanted to pick the design with the minimum number of parts to use less material.

After considering all these factors, full system design two scored the highest out of all the deigns. This design is robust and safe while also being relatively affordable to manufacture. The C shaped roller will be somewhat complicated to perfect but offers the quickest way to uniformly roll the cocoyam. This design also closely represents the customer requirements and suggestions the best.

6 CLIENT REQUIREMENT CHANGES

After presenting the current design to the client, he determined that he would like to make some modifications to the project. Instead of the system having to prepare both Ekwang and Kwacoco Bible, the system will only be required to prepare Ekwang, the smaller and more time consuming of the two dishes. Additionally, a continuous flow of product from the dispenser to the roller is desired instead of the initial requirement of specific, pre-set, dispenser settings. This alters the path the team was originally considering regarding designs. Moving forward, the team will re-evaluate customer and engineering requirements and determine what requirements are now of the greatest importance.

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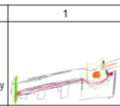
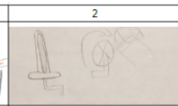
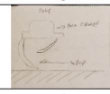
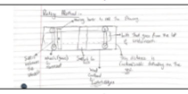
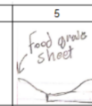
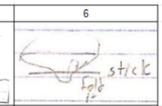
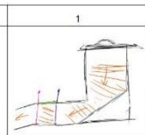
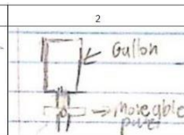
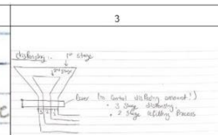
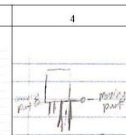
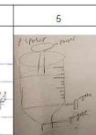
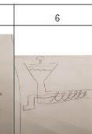
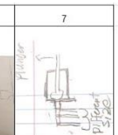
8 APPENDICES

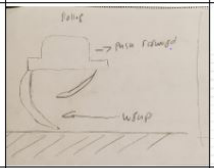
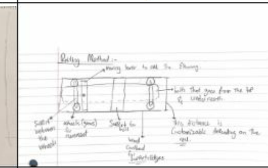
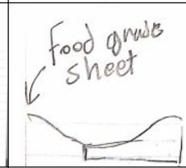
8.1 Appendix A: Pugh Chart Roller

		DATUM	1	2	3	4	5	6
criteria	concepts	Current Method: Roll by hand						
1. realibilty			1	0	1	1	0	-1
2. durability			1	0	1	1	1	1
3. lightweight			0	1	0	-1	0	1
4. safe to use			0	0	0	0	1	1
5. simplicity			1	-1	1	1	1	-1
6. low cost			-1	1	1	0	1	1
7. mobility			0	1	1	1	0	1
8. faster than hand rolling			1	0	1	1	1	0
Total			3	2	6	4	5	3

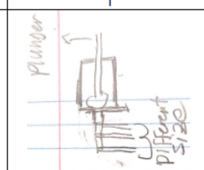
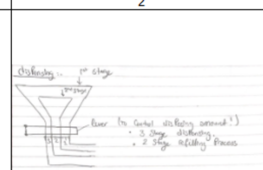
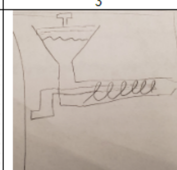
8.2 Appendix B: Pugh Chart Dispenser

		DATUM	1	2	3	4	5	6	7
criteria	concepts	Current Method: Spoon							
1. realibilty			1	1	1	0	1	1	1
2. durability			0	0	0	0	0	-1	0
3. lightweight			-1	-1	-1	-1	-1	-1	-1
4. safe to use			0	0	0	0	0	1	1
5. simplicity			0	0	1	-1	1	1	0
6. low cost			0	0	0	0	0	0	0
7. adjustable dispensing			1	1	1	1	1	0	1
8. mobility			1	1	1	1	1	1	1
9. faster than hand rolling			1	1	1	1	1	1	1
Total			3	3	4	1	4	3	4

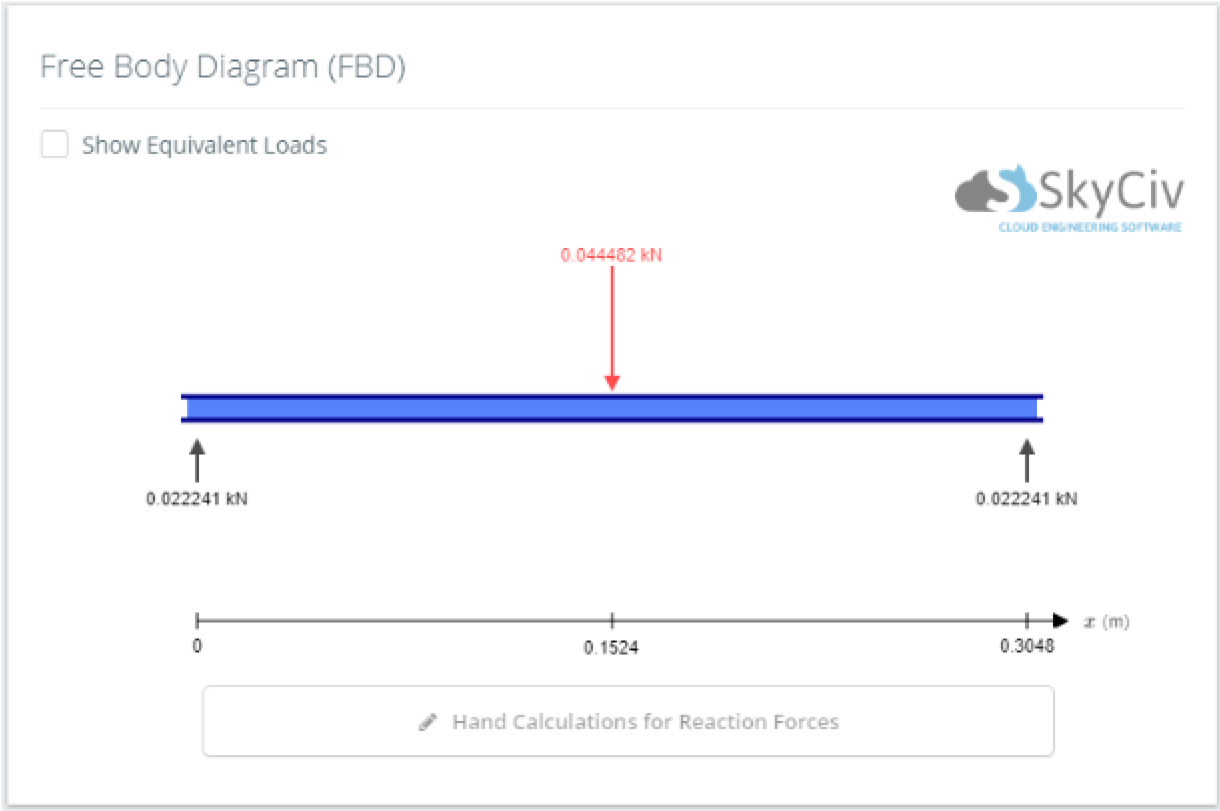
8.3 Appendix C: Decision Matrix Roller

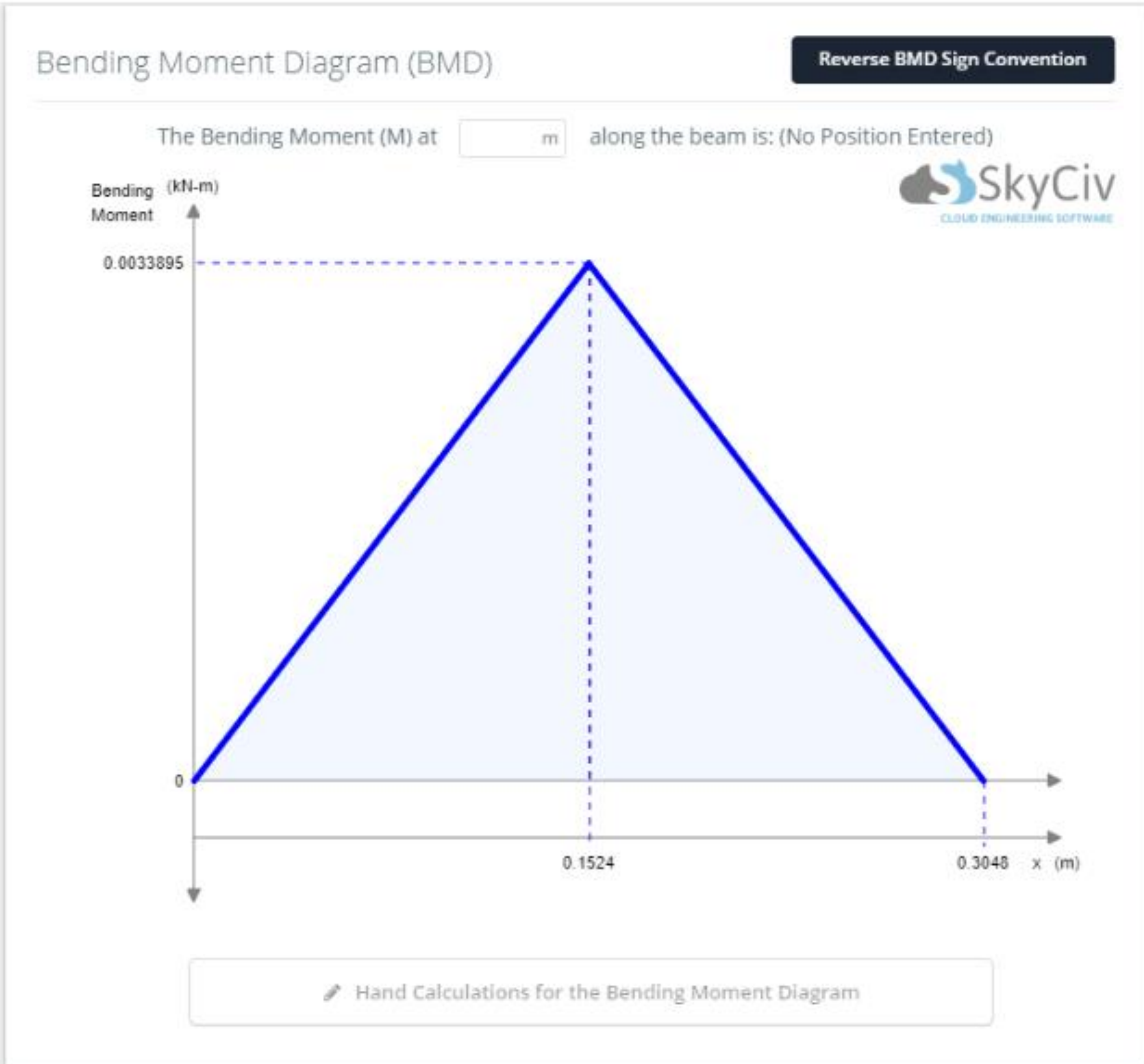
			DATUM	1	2	3
criteria	weight	concepts	Current Method: Roll by hand			
1. low weight	12.82			3	1	3
2. base footprint	4.22			5	3	3
3. minimize number of parts	24.62			3	3	5
4. smooth edges	6.82			3	3	5
5. low price	12.82			3	3	5
6. minimize time to produce one roll	10.94			5	5	1
7. Design strength	10.72			3	5	1
8.Simple to use / learn	13.62			3	5	1
9. Roll size adjustment	3.42			1	3	5
Total	100			323.48	344.92	324.8

8.4 Appendix D: Decision Matrix Dispenser

			DATUM	1	2	3
criteria	weight	concepts	Current Method: Spoon			
1. low weight	12.82			1	3	5
2. base footprint	4.22			5	5	5
3. minimize number of parts	24.62			5	3	3
4. smooth edges	6.82			3	3	3
5. low price	12.82			3	1	1
6. minimize time to produce one roll	10.94			5	3	1
7. Design strength	10.72			3	5	5
8.number of dispenser settings	13.62			3	3	1
9.capacity	3.42			5	3	3
Total	100			360.76	304.24	280.76

8.5 Appendix E: Free Body Diagram and Max bending Moment




Bending Moment Diagram (BMD)
Reverse BMD Sign Convention
The Bending Moment (M) at m along the beam is: (No Position Entered)
SkyCiv
Bending Moment (kN-m)
0.0033895
0
0.1524
0.3048
x (m)
Hand Calculations for the Bending Moment Diagram