Brick Production Machine

Design Final Report

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F17 ME415 TEAM#2

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Abstract

This first report addresses the customer needs concerning an affordable and efficient brick making machine in Uganda and the general solutions developed by a team of engineering students at Washington State University through the intermediate of Dwaine. Dwaine represents the a non-profit group with the sole goal of improving housing developments within the region. The traditional technique consist of mixing dirt and water before manually putting is mold and oven cook it using firewood. This process is cheap but very slow, it takes 2 to 3 weeks to make 7,000 bricks. The students came up with a mechanism that would replace the manual labor from the mud mixing step to the final form of the brick. On top of prioritized engineering specifications (brick output, manufacturability and ease of use), team standards of energy efficiency, environmental respect, consideration of human oversight and involvement while making quality building material are included. The design outlines of the machine allows the production of bricks on a continuous basis. Ideally its size would allow it to fit under a small barn like structure and if necessary, several machines should be fit next to each others. Team 2 has been tasked to design the lower extrusion and main casing subsystem. Raw material arrives from the top of the housing through a hopper. An auger drives it while the reduced cross section area forces the compression and formatting of the material before passing it to the nozzle, mold and conveyor subsystem. During the prototype building phase, the allocated budget was $800 to be shared between the Power, Extruder and Nozzle teams. The ½ scale prototype of the extrusion screw subsystem was designed to stay below a maximum of $480 with a large margin including everything single pieces necessary for the assembly, shipping and handling cost and additional labor cost. The prototype met all the requirement during the test but revealed some fragilities. The final product will be full scale, made out of stronger material and the supporting structure will have more cross beams. The price will increase but so will the lifespan of the system. Testing the prototype confirmed that the design of the system can successfully build pressure to force caly through the nozzle. While some parts were modified and overengineered for the prototype, the full scale model will be up to specifications as well as referenced to cost analysis.

Introduction

The brick manufacturing project involves the client's representative Dwaine and the design team consisting of Washington State University students currently enrolled in the ME 415. Dwaine is representing a group in Uganda that seeks address the expensive cost of building bricks through the creation of a new brick production site in Uganda. Currently, the kiln-fired, red-clay bricks used for building materials are produced by hand. Therefore, it is the request of Dwaine and the goal of the students to design a machine that can form the bricks at a faster rate while considering other design specifications.

The brick production machine (BPM) will be located within the brick production site in Uganda. Uganda is a "landlocked; fertile, well-watered country with many lakes and rivers" (1). Additionally, the local climate of Uganda is tropical which indicates a strong presence of rain and moisture (1). These geographical details primarily relate to the material protection required to ensure that the BPM can operate without completely degrading. Economically, Uganda is currently engaged in a annual housing deficit of 140,000 houses as well as a backlog of 1.6 million houses primarily in rural areas (2). This existing and increasing deficit in partly due to an “Inadequate supply of affordable building materials…(and poor) options of massively producing affordable building materials” (3). Imported materials such as cement “tend to be rather expensive and largely not affordable” (5). The current trend in building material production within Uganda is handmade mud bricks. However, this process has significant drawbacks including environmental destruction (soil for bricks, wood for thermal energy), a time consuming and laborious process and poor brick quality (4).

The brick production machine was divided in six different subsystems, following the necessary step to provide the finished product:

- Power transmission
- Raw material feeding
- Upper mixing auger and hopper
- Lower extrusion and main casing
- Nozzle, molds and conveyor
- Cutter and palletizing for drying

Team #2 is responsible for the design of the lower extrusion screw and main casing. The extrusion screw is an enclosed auger that builds pressure within the barrel and forces the material through the die. The screw primarily governs the brick extrusion rate (in/s),and is controlled by power, design properties and raw material composition. Power requirement of the screw is determined by screw geometry and raw material (wet clay) properties. Design properties relate to the material selection and maintenance process of the screw. Raw material composition involves the state and composition of the material that is being feed into the screw from the hopper. At the exit of the housing, the clay is compact and shaped as a rectangular extrusion

Thus, the BPM needs to incorporate the use of local and readily available materials such as red clay or mud, have the capability to produce a large amount of bricks within a day () and possess a design that is easy to manufacture in Uganda and maintain on site.

A prototype was built first to test the ability of the design. Team 2 planned a complete assembly including the processing of the different pieces. It is half scaled to allow Team 2 to test the design against every requirements applicable to the final design.

Customer Requirements and Engineering Specifications

Customer Requirements:

- Safety - translates into limiting the number of hazards to ensure employee safety
- Brick Output - highest possible number of bricks produced per day.
- Manufacturability - Because we are working in Uganda we want to ensure they can produce the machine we are designing for them and replacement parts if needed in the future, off the shelf parts are incredibly useful for this.
- Simple maintenance - we want a design that is simple enough for anyone to be able to repair and simple enough parts that they can be reproduced in Uganda.
- Durability - Long lifespan is always a high priority, no one wants to have to continually repair the machine.
- Footprint - the client has provided a known footprint that we need to restrict ourselves to.
- Simplicity - the simpler the design the easier it is for everyone to understand and operate.
- Reliability - goes with durability, but we also want to ensure the design will produce high quality bricks because these will be produced for public and private buildings.
- Autonomous - making the machine autonomous will help keep employees safe and the quality of the bricks will have the same tolerances.
- Low noise - keeping the machine under 85 dB will prevent enforcing earplugs in the work force, this results in helping with safety.

Engineering Specifications:

- Number of Hazards - a specifications that results into safety, more hazards results into more opportunities for workers to harm themselves.
- Bricks per minute - the more bricks we produce the more pleased the client will be, however, we have to follow our standards especially for safety otherwise if the extruder is moving too fast it can create more hazards or lower the quality of the bricks.
- Number of off the shelf parts - correlates to simplicity and manufacturability, if the workers don't have to machine custom parts it makes their job easier.
- Minimum maintenance period - the simpler the design the faster employees can fix the machine and get it back up and running.
- Average Cycle life -
- Floor space - directly connected to our client requirement of the machine footprint, if the machine is too large they won't be able to house it in their facility.
- Number of parts - the less parts usually relates to a cheaper result along with simpler maintenance. Also if there is less moving parts, that will help reduce the number of hazards.
- Hopper size - correlates with our desired client requirement of brick output, if there machine is capable of producing more bricks than it is allowed to store raw material our efficiency will decrease.
- Decibel level - is a result of safety and number of hazards.
- Weight - a limited weight could correlate with less parts, simplicity, and safety

- Price - All of our clients requirements eventually relate to our overall price, but the biggest factors in price is reliable, manufacturability, and automation. If we buy materials that are more reliable, than our overall machine will be made to last longer. If the parts for our brick extruder are hard to machine then cost will rise quickly. Automation will help reduce labor however, automation adds more parts and drives the cost up.

Extrusion Screw Design and Power Requirements			
Variables	Value	Variables	Value
An input is indicated by a cell of this color			
An output is indicated by a cell of this color			
r_o (in)	5.75		
r_i (in)	1.75		
Q_1		Q_2	
A_1 (in^2)	94.2478	A_2 (in^2)	16
v_1 (in/s)	1	v_2 (in/s)	5.21
W (pitch) (in)	6		
sec	6.78367		
rpm	8.84477		
V (Volume of Screw, in^3)	565.487		
density (lbs/in^3)	0.06366		
# of screws	8		
Coefficient of Friction (Wet Clay on Steel)	0.35		
d_m (Mean Diameter, in)	2.875		
Weight (wet clay, lbs)	287.977		
Torque (minimum,lbs-in)	5065.32		
HP (Horsepower)	8.67991		

We specified: safety, brick output, and manufacturability to be our top 3 client requirements because we believe those 3 will drive the importance of the remaining requirements. Safety is always an ethical standard to concern, the client referred to the brick output several times which helps us understand the importance of being able to produce a large volume per day, and being able to manufacture our design in Uganda is very important because we want them to be able to reproduce any parts required and be self sustainable. Using the house of quality we were able to cross correlate our Client Requirements with our Engineering Specifications to give each engineering specification a ranking amongst the others. Our top rated engineering specification was Bricks per minute, followed by number of off the shelf parts and floor space. This makes since because we need a design that produces the desired number of bricks along with fit within the given space and is easy enough to assemble.

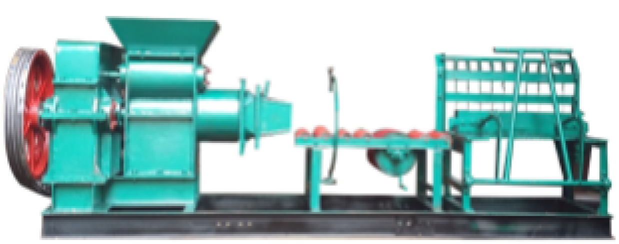
Benchmarks

There are a number of brick making machines on the market with similar brick output rates to what the customer has specified. For our machine to be successful, we need to analyze the performance of these similar machines and optimize areas where they fall short. We will be using the customer requirements to form a benchmark comparison. We choose three different machines for our benchmarks. The first is a non-vacuum extruder similar to the one currently operating in Thailand. The second is higher quality vacuum extruder that produces higher quality bricks at a similar rate as its non-vacuum counterpart. The third machine is a manually operated hydraulic press. Having a variety of quality for our benchmarks will broaden our scope on the project and adjust our machine as the customer sees fit.

Vacuum Brick Extruder

Vacuum Brick Extruder (6)

- Price: $2000
- Safety: 1 hazard, Enclosed motor.
- 2000-4000 Bricks/hour
- Most parts are replaceable and easily found online
- It would be difficult to create replacement parts for this machine however not impossible
- Durability: 1 year warranty
- Dimensions: 1900 x 850 x 900 mm or 6.2 x 2.8 x 3 feet
- Most complicated machine listed due to its vacuum compartment.
- Because of its vacuum chamber, it pulls out all of the air in the mixture making the bricks much more consistent structurally when they exit.
- Automated extrusion, still need cutting and mixing machines for full automations.
- Because it is a mechanized extruder, it will be producing a fair amount noise however the exact value was not given.



Non-Vacuum Brick Extruder

Non-Vacuum Brick Extruder (7)

- Price: $2000-$2800
- Safety: 2 Hazards- Open Hopper and Open Belt
- 2000-3000 Bricks/hour
- Most parts are replaceable however, order and shipping times are very long.
- It would be difficult to create replacement parts for this machine however not impossible.

- Durability: 2 year warranty
- Dimensions: 3300 x 800 x 1000 mm or 10.8 x 2.6 x 3.3 feet
- Very simple screw extrusion and wire cutting assembly.
- The machine can reliably extrude bricks, however due to the lack of vacuum chamber, the consistency of the brick will be lacking compared to the vacuum extruder.
- Automatically extrudes the bricks. This machine also includes a wire cutting assembly that is manually operated.
- Similar to to the vacuum extruder, the machine will produce a fair amount of noise however the exact value is not specified.

Manual Hydraulic Press Brick Machine

Manual Hydraulic Brick Press (8)

- Price: $800-$1200
- Safety: 1 Hazard- Pinch point in the manual press
- 900-1200 Bricks/Day
- Simple to manufacture, most complicated part is the mold.
- Because of how simple this machine is, it would be very easy to create and replace parts that break.
- Durability: One year warranty
- Dimensions: 600 x 400 x 800 mm or 2.0 x 1.3 x 2.6 feet
- Very simple design and the easiest machine on our list to understand.
- This machine uses a mold, so the bricks shape will be consistent. However, the mold has to be filled for every brick making it almost impossible to create a consistent mass brick.
- There is very little automation on this over just filling a box and pressing it by hand.
- This is a manual machine with no motors so the noise level will be very quiet comparatively.

JZ300 Solid Brick Making Machine

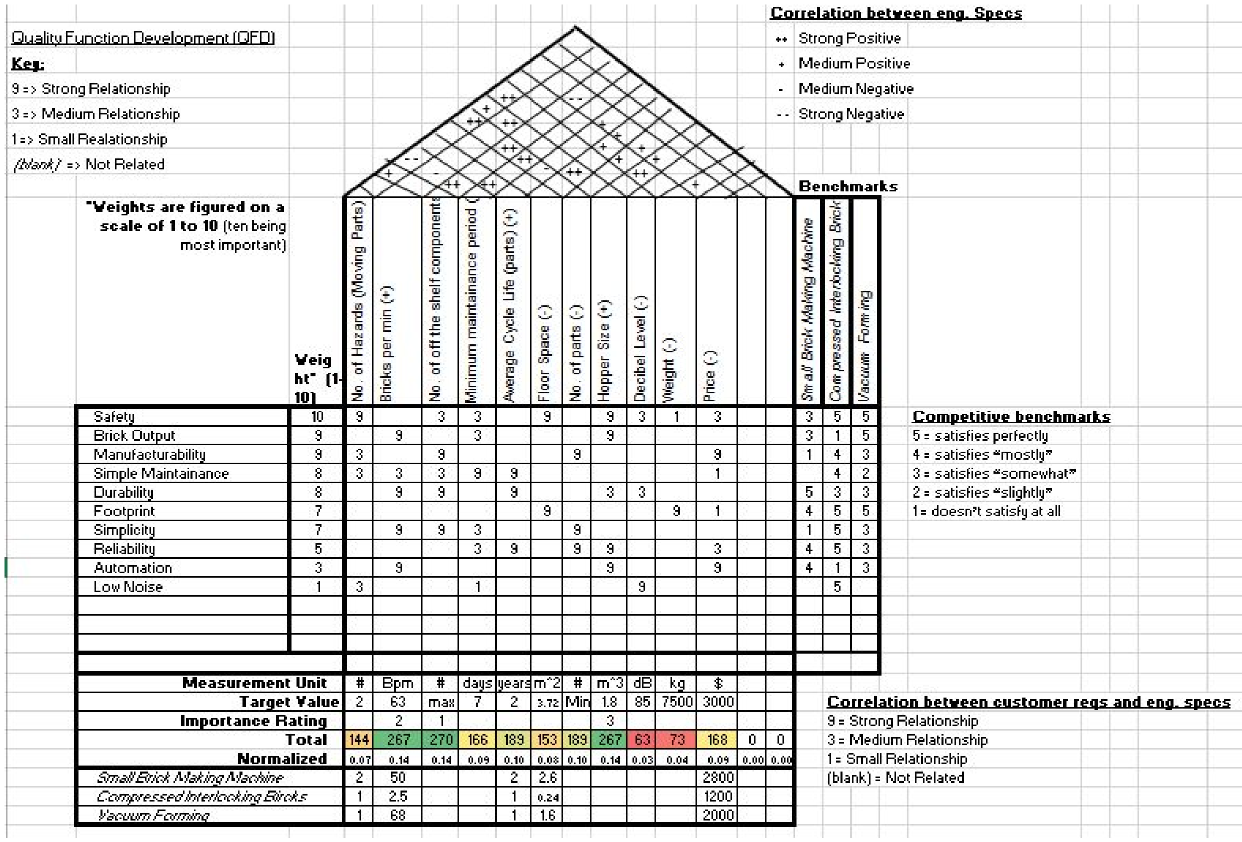
- Price : $16000 - $19000
- Safety: 2 Hazards - Open hoppers and open power transmission gears
- 4000 - 6000 bricks/hour
- Method: non vacuum extruder using an auger
- Requires 4 to 5 operators

- Strong applicability, lower energy consumption, the extruder only requires 30 KW
- Large tolerance of raw material, clay, fly ash and dirt
- Possibility to produce multi holes bricks and solid bricks
- It is widely used in small and medium budget brick owners.Suitable for family workshops. Also, its compact design and manual clutch makes machine operation very easily.

From these benchmarks, we can see that the extruders fall short in safety, ease of maintenance, and simplicity while the press lacks brick output capacity. The machine currently in Thailand is very similar to the screw extruder. This type of extruder is much more simple than the vacuum extruder however it sacrifices brick quality. Vacuum extruders offer the possibility to create hollow bricks. Non vacuum extruders do not require an extraction system so the bricks are pushed out and the hardness is lower that using vacuum. However the machine is much less complex, easier to design, use and repair. To meet our customer requirements, we will need to be innovative to create a machine that optimizes all of the above benchmarks. These benchmarks are quantified and analyzed in further detail in the house of quality.

(The chosen design for the machine is now a non vacuum extruder, the subsystem of the lower and main casing is composed of an auger driving the clay, comparable to the JZ300 brick machine.)

House of Quality



Quality Function Development (QFD)

Key:

9 => Strong Relationship
3 => Medium Relationship
1 => Small Realationship
(blank) => Not Related

Correlation between eng. Specs

++ Strong Positive
+ Medium Positive
- Medium Negative
- - Strong Negative

"Weights are figured on a scale of 1 to 10 (ten being most important)

	Weight" (1-10)	No. of Hazards (Moving Parts)	Bricks per min (+)	No. of off the shelf components	Minimum maintainance period (	Average Cycle Life (parts) (+)	Floor Space (-)	No. of parts (-)	Hopper Size (+)	Decibel Level (-)	Weight (-)	Price (-)			Small Brick Making Machine	Compressed Interlocking Brick	Vacuum Forming
Safety	10	9		3	3		9		9	3	1	3			3	5	5
Brick Output	9		9		3				9						3	1	5
Manufacturability	9	3		9				9				9			1	4	3
Simple Maintainance	8	3	3	3	9	9						1				4	2
Durability	8		9	9		9			3	3					5	3	3
Footprint	7						9				9	1			4	5	5
Simplicity	7		9	9	3			9							1	5	3
Reliability	5				3	9		9	9			3			4	5	3
Automation	3		9						9			9			4	1	3
Low Noise	1	3			1					9						5	
Measurement Unit		#	Bpm	#	days	years	m^2	#	m^3	dB	kg	$					
Target Value		2	63	max	7	2	3.72	Min	1.8	85	7500	3000					
Importance Rating			2	1					3								
Total		144	267	270	166	189	153	189	267	63	73	168	0	0			
Normalized		0.07	0.14	0.14	0.09	0.10	0.08	0.10	0.14	0.03	0.04	0.09	0.00	0.00			
Small Brick Making Machine		2	50			2	2.6					2800					
Compressed Interlocking Bircks		1	2.5			1	0.24					1200					
Vacuum Forming		1	68			1	1.6					2000					

Competitive benchmarks

5 = satisfies perfectly
4 = satisfies "mostly"
3 = satisfies "somewhat"
2 = satisfies "slightly"
1 = doesn't satisfy at all

Correlation between customer reqs and eng. specs

9 = Strong Relationship
3 = Medium Relationship
1 = Small Relationship
(blank) = Not Related

Specific design standards added to the subsystem are:

- Possibility to open the casing
- Covered power transmission to avoid hazard
- System must include an auger

Specific benchmarks added

Benchmarks	JZ300 Solid Brick Making Machine
Safety	3
Brick Output	6
Manufacturability	2
Simple Maintenance	4
Durability	5
Footprint	3

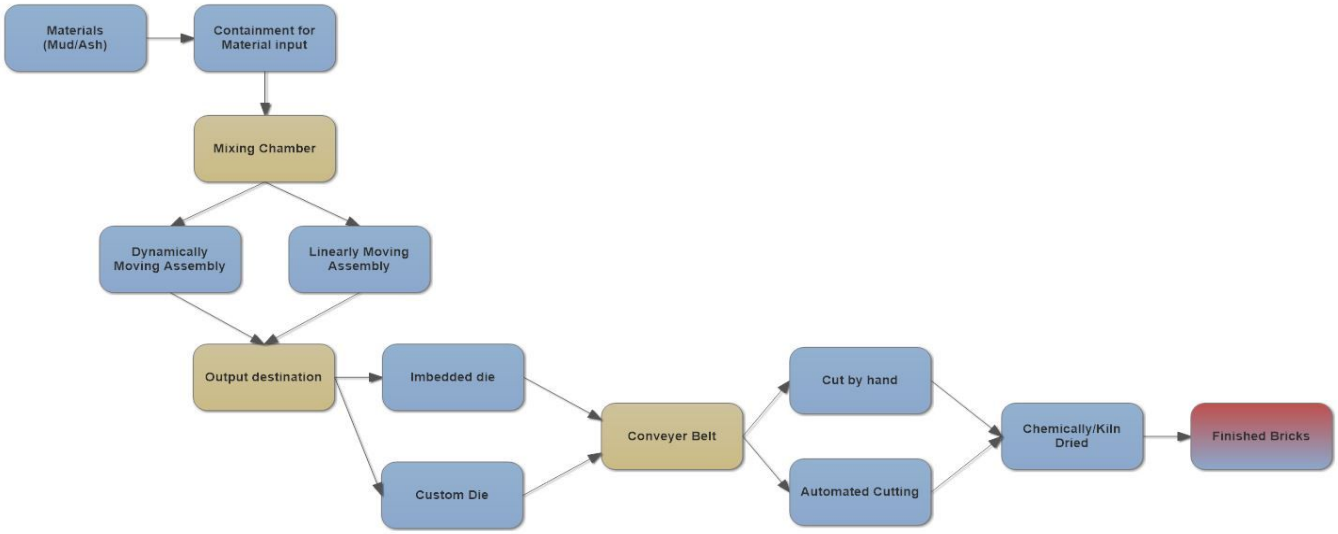
Simplicity	3
Reliability	5
Automation	4
Low Noise	4

Main takeaways from the HOQ include the top three design specifications (# of off the shelf components, Brick output and hopper size), the target values for our machine and the current benchmark engineering specifications. While hopper size dictates the automation and human involvement and brick output is the primary goal, the HOQ identifies off-the-shelf components are the second highest priority. The theory behind this relates to simplicity, easy maintenance and manufacturability. By incorporating a high number of off-the-shelf (or local) components then the machine is easier to manufacture on-site, easier to repair and can significantly reduce costs from transportation and unique component fabrication.

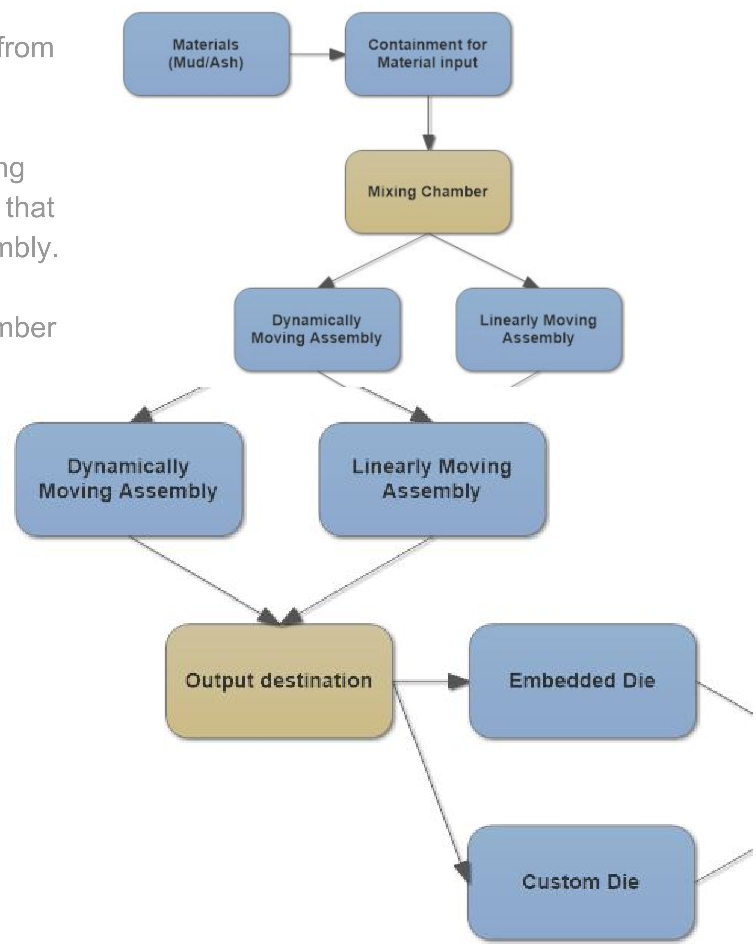
In regards to trade-offs amongst engineering specifications, there are very few areas of compromise considering client requirement and team standards. These areas include hopper size, weight, decibel level, floor space and the possibility to open the auger casing of the subsystem. The majority of these areas involve the geometry and density of the design. Specifications such as these can are more flexible as the target value was dictated by a previous model that is in Thailand. While it may seem of utmost importance to design a machine that closely resembles the JZ300 machine. Team #2 would rather focus on a machine that meets the required brick output, manufacturability expectations, easy maintenance, reliability and most importantly safety than focus on complementary specifications.

The HOQ above provides boundaries and guidelines for the design phase. The table identifies priorities and tradeoffs, allowing designers to build a machines that meets the client’s requirements without getting distracted with “bells and whistles”.

System Decomposition



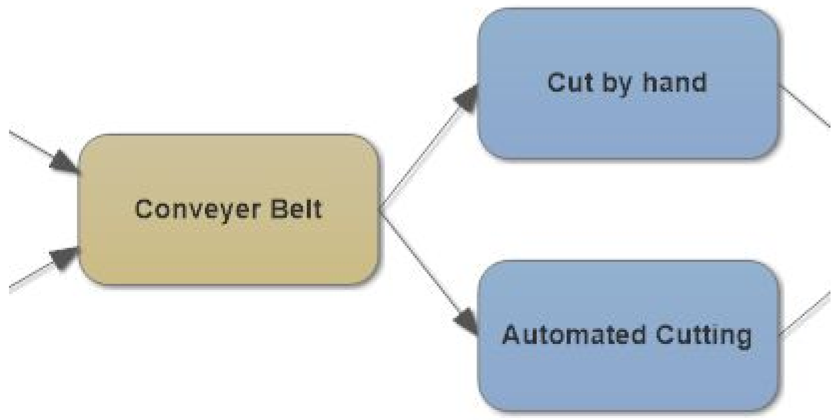
While there was talk about mud/clay/ash being used to create the bricks the recipe has not been developed to produce the optimal outcome from the desired found materials. Regardless of the material being used the machine would have a containment where to put the material. There are different types of contaminants that can be chosen from such as hopper, open vs closed, depending on the location and other requirement as well as next sub system the input would be decided up on. The driving force of the machine is the output of the bricks, and that determines the specifications of the each sub assembly.



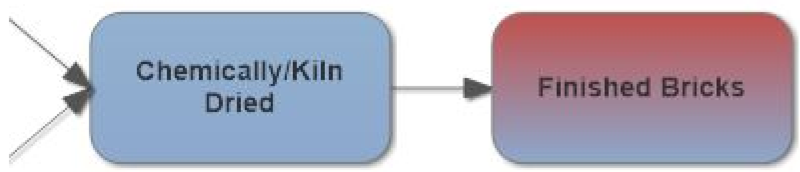
Containment would depend on how the mixing chamber would be designed, as well as the mixing chamber would depend if the material is being processed dynamically or linearly. The mixing chamber is the second place the material would arrive and if it is determined that we need to add ash to pull the moisture out of the clay or mix the mud with clay versus having a clean input of clay, the mixing chamber would change as the requirement dictates.
The dynamically moving or linearly moving assembly is the heart of the machine. It is where after the material is mixed and is being transported from the body to the output.

Dynamically moving is something that of a spiral design that rotates or has a geometric action to push the material to the output destination. Forcing the particles of the material by motion while the forcing agent stays in one place and is continuous.
Linearly moving is while the object that forcing the material to move is moving as well, such as pressing it out towards the output destination.
From the output destination material is formed by a die to extrude the desired form. Selecting an embedded die, would be a basic output die that is embedded within the system and a custom die would be something that is modified from the original shape and could be place and interchanged.

After the material is exported from the output by a standard or a custom die the extrusion line would be placed on a conveyor belt, whether it is manual or an automated platform. There the line would be cut into specified size for the bricks to take their final shape.



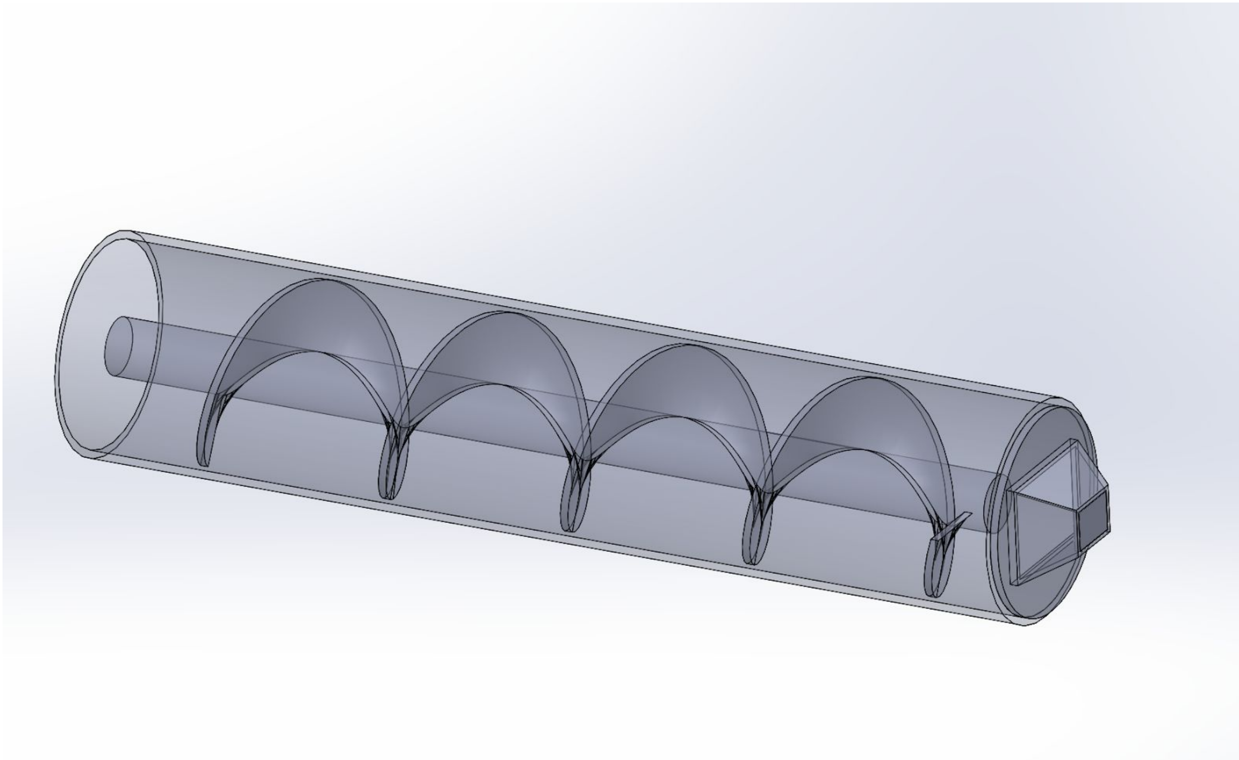
The bricks would be almost complete, the final step would be to dry the material and add structure to the molded brick and be used in construction. The material can be dried by using a chemically enhanced solution or a kiln, after which the result are the finished bricks.



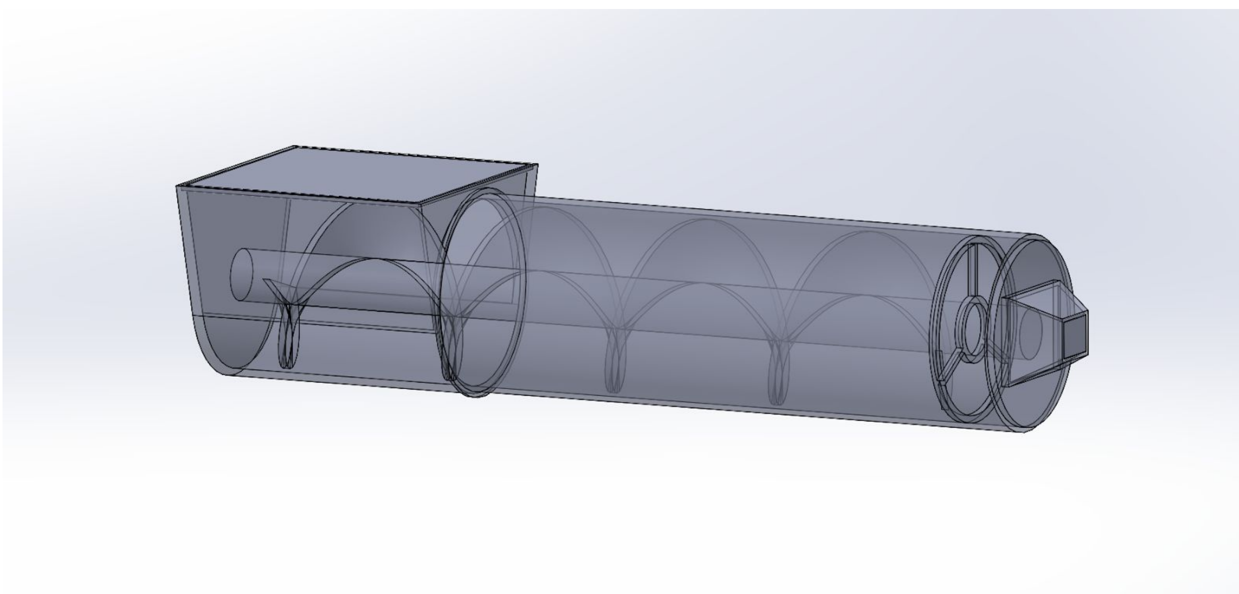
Concept Generation

Extrusion screw concept generation involved the research into existing extrusion screw technology. From this initial research, two types of extrusion screw configurations were considered viable for the brick extrusion, single screw and double screw configurations. The team decided that single-screw configuration would be best for the BPM as the mechanical simplicity allows for simple power delivery, easy maintenance and design simplicity. Therefore, the team further researched the design theory and specifications of single-screw extrusion. This research yielded basic design principles. Additionally, the research revealed that extrusion screw design is primarily dependent on the properties of the material being extruded. This lead the team to pursue designs for a single-screw extrusion subsystem for wet clay.

Concept One: Straight barrel with no hopper feed.



Concept Two: Barrel with Hopper Feed.



Concept Selection

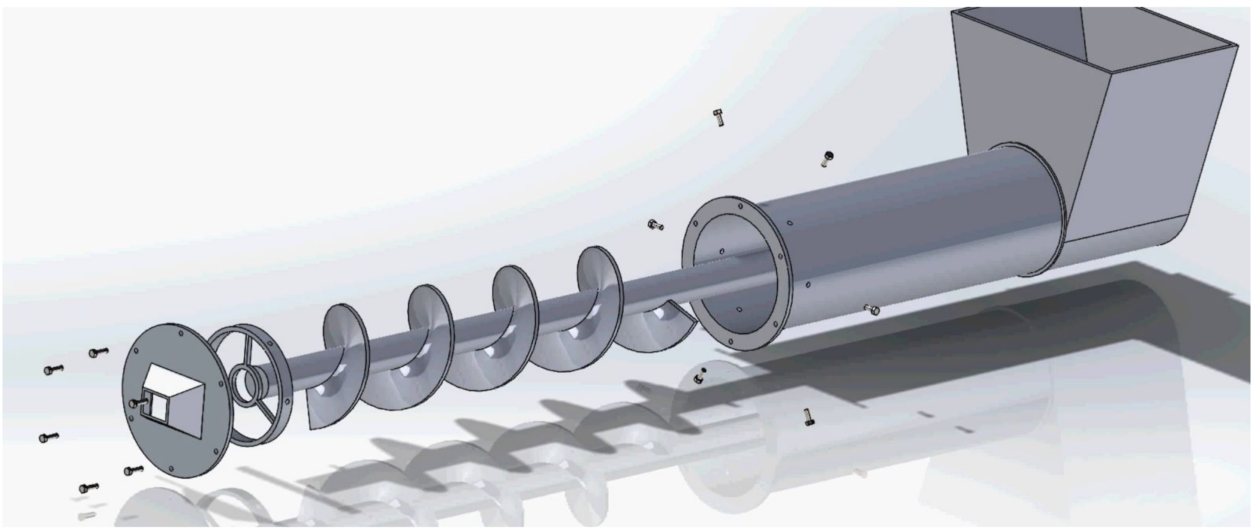
The concepts were rated on which would produce the most realistic model and provide the most accurate results of required power and torque. We first experimented with changing the geometry of the conveyor screw, but quickly realized that if we wanted to find parts off the shelf we would have to match the given geometries. We noticed a general trend was that the screw's pitch should be square, meaning a revolution would expand the same distance as its diameter. The simplicity of a model is important, but if the model is too simple it won't show the most accurate results which is why we rated each concept on simplicity and accurate results. Another consideration was the ratio of time commitment given to each concept, which resulted into rating them based on: time effective, accurate results, correct material, and easy to model. Correct material is included because we learned that changing the liquid from water to clay increased the calculation time immensely. Lastly, we wanted to make sure our results were representing our sub-system to the fullest, making sure it shows how it preforms with other subsystems, which is why the concepts were also rated on utilizing the nozzle and hopper.

		Concepts	
Criteria	Weight	Straight Barrel	Hopper Fed
Simplicity	5	8	6
Cost	1	0	0
Easy to Model	3	9	6
Time Effective	6	7	5
Accurate Results	9	5	7
Correct Material	8	5	7
Utilizes Nozzle	5	9	9
Utilizes Hopper	5	0	9
Presents Results Clearly	4	9	9
Net Score		275	323
Rank		2	1

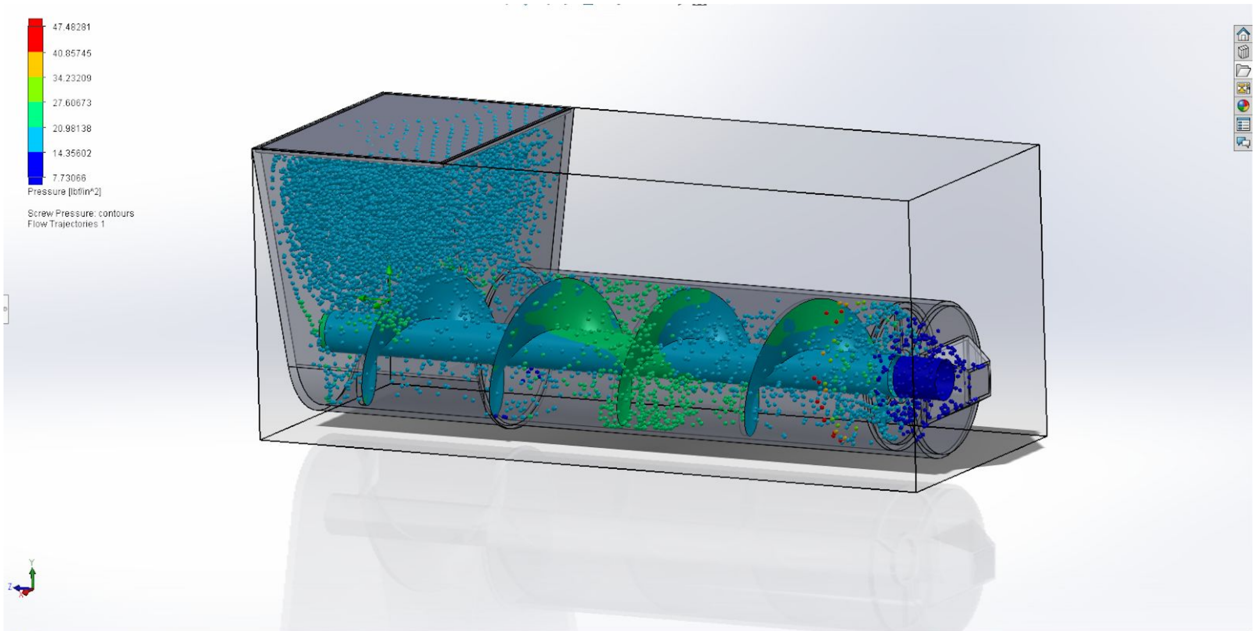
The advantages of the first concept was that it was simple and time effective. However, its cons were that we didn't believe it represented the full range of the results considering it didn't show the effect gravity has on the feed. The disadvantages to Concept Two are, it wasn't as easy to model, and it wasn't the most time effective when it came to adding more accurate material to the system. However, the results were more accurate and showed the full sub-system.

Chosen Design Description

We started with designing the auger based off of what is produced in the market. We gave the shaft a 3.5 inch diameter and the disk diameter is 12 inches. The barrel was created using 12 ½ inner diameter with a ⅜ inch wall thickness. The hopper was created using ½ wall thickness and would most likely be machined. The size of the hopper didn't have the biggest effect to our model therefore, we didn't strictly specify the size of it, currently the hopper is 24 inches tall, 18 inches wide at the top, and 18 inches long. At the end of the screw towards the nozzle, we made sure there was a long enough shaft that could be supported by an end support within the pipe. The end support is a three spoke design, similar shape as the mercedes logo, that supports the shaft in the center and is is screwed into the barrel from the outside. On both ends of the auger, there will be sealed bearings mounted to reduce any friction. Our subsystem will connect to the mixing hopper by creating a notch within the hopper we made and will slide into the end of their mixer hopper, then it will be joined with fasteners. In our models we used a simple nozzle to simply show our subsystem results, however, the actual nozzle will be connected to the end of our barrel with pins to make it easy to remove for cleaning rather than the bolts we used in our exploded view.



In the Flow Simulation, we changed various parameters several times to get the best results. First we tested the simulation with water for the liquid and slowly changed the global mesh and the goals we wanted to achieve. We first started with goals that showed the mass flow and pressure differences throughout the pipe. We thought we would have to import the results into the FEA Simulator to calculate torque but we learned that we could add torque goals, which we did. The mesh determined how long the calculation time took. With water we started with a mid size mesh, which took from 5 to 10 mins to calculate. However, once we tried plugging in Slurry, a non-newtonian liquid, the calculation time increased to 48 hours. To change the calculation time, we decreased the global mesh to be more coarse, and added local meshes to show results where they weren't being represented in the global mesh. Reducing the number of goals also helped reduce the overall calculation time. Once we achieved results we liked and thought were reasonable, we started changing the parameters of the liquid slurry to make it more identical to clay. After searching online looking through various sources we couldn't find a definite number for the viscosity of clay so we ended up modeling the concept twice with different viscosity equations.



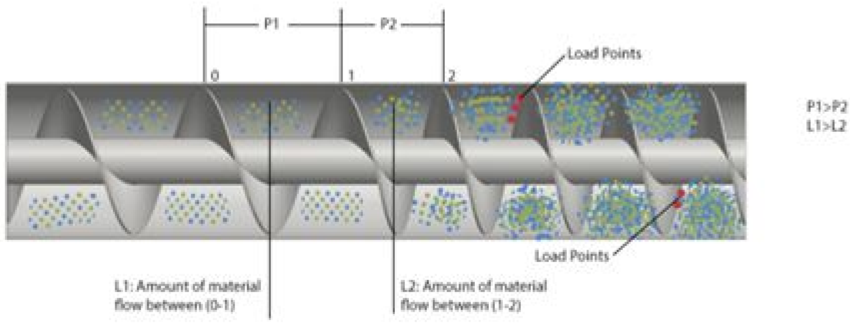
From this mockup we have learned that clay acts differently within an extrusion screw compared to water because its non-newtonian characteristic properties. Working with the Power Team, we have come to results that we will be given a 15 HP motor to overcompensate for our required 9 HP to achieve our desired brick output. Depending on which viscosity method is better, we currently have an RPM range from 32 to 100 to look more into.

Item Description	Vendor	Part #	Quantity	Unit Cost	Subtotal Cost	Shipping Cost	Total Cost	Shipping Time
12" Screw Conveyor	McMaster	5266K27	1	$550.76	$550.76	$5.00	$555.76	1-2 Weeks
12" ID Steel Pipe	MetalsDepot	T212250	4	$282.33	$1,129.32	$5.00	$1,134.32	1-2 Weeks
2" ID Bearings	McMaster	5709k91	2	$39.51	$79.02	$5.00	$84.02	5 Days
12"x24"x1/2" Steel Sheet	McMaster	6544K78	2	$164.02	$328.04	$5.00	$333.04	5 Days
1/2" Bolts	McMaster	92186A386	20	$2.97	$59.40	$5.00	$64.40	5 Days
1/2" Nuts	McMaster	95505A615	1	$9.35	$9.35	$5	$14.35	5 Days
						Overall Total:	$2,185.89	

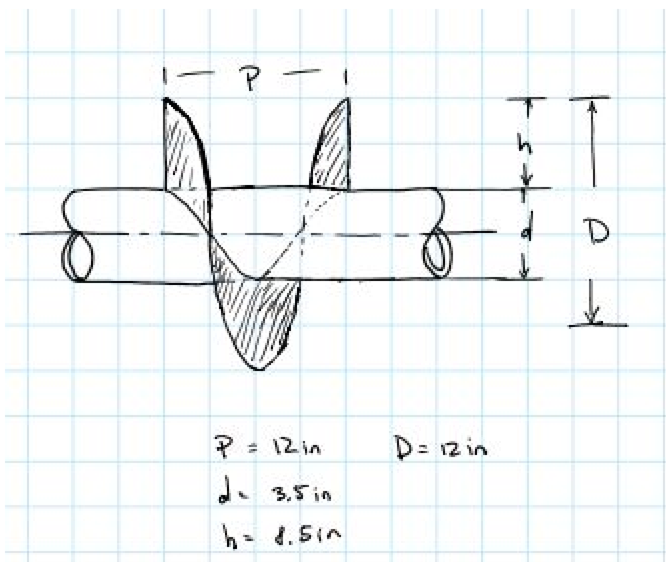
Bill of Materials: an approximation of how much our subsystem is expected to cost.

Engineering Analysis

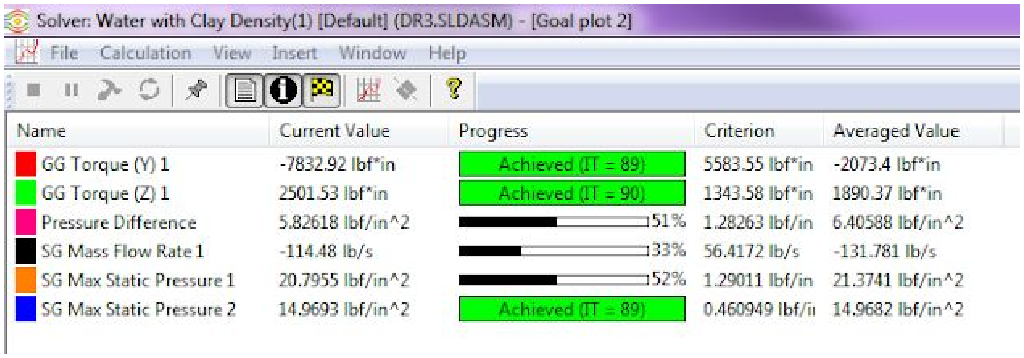
Considering our team's sub system is the auger/conveyor screw, we chose to approach our engineering specifications and Design Standards with *Solidworks Flow Simulation*. We used this approach because it provided educated estimates of the desired parameters for free. The university already has access to Solidworks and building an actual prototype would have been incredibly expensive. The overall goal we set for our beta prototype was to determine the maximum torque and power required to reach our desired brick output. In the flow simulator we used parameters we knew, the inlet mass flow needed to reach our desired brick output and the atmospheric pressure at the nozzle. We designed the pipe/barrel of the extruder based on how large the Nozzle Team needed it to be. They chose to extrude the bricks out at the dimensions of 10 inches by 4 inches, which requires our barrel to exceed a 10 inch diameter to be able to compress the clay into bricks. Currently, our prototype design has a 12 ½ inch diameter. This allows our design to have a Conveyor Screw with a disk diameter of 12 inches and a radial clearance of a quarter inch. One of our next goals is to see how the clearance height affects the flow rate.



While designing the auger screw itself we have ran into few issues such as what pitch angle should we use to get the most out of the auger. The model that we design uses a 45 degree pitch for highest volume delivery of clay mixture and highest durability of the auger screw itself. The conveyor screw is 12' in diameter the pitch length is also 12 inch; both pitch and length between the flights allows for the highest distribution of force within the spiral flight of the screw.



The shaft itself is designed to be proportional to the screw, since our design consists of 12 inch auger the shaft has to be 3.5 in, to be able to support the load that the clay is exerting.
While running the simulation we were able to determine the torque needed to support the wet clay at 110 lb/ft^3. The determined torque yielded to be at 2501.53 lbf*in as shown below.



Solver: Water with Clay Density(1) [Default] (DR3.SLDASM) - [Goal plot 2]

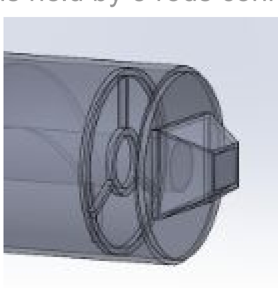
File Calculation View Insert Window Help

Name	Current Value	Progress	Criterion	Averaged Value
GG Torque (Y) 1	-7832.92 lbf*in	Achieved (IT = 89)	5583.55 lbf*in	-2073.4 lbf*in
GG Torque (Z) 1	2501.53 lbf*in	Achieved (IT = 90)	1343.58 lbf*in	1890.37 lbf*in
Pressure Difference	5.82618 lbf/in^2	51%	1.28263 lbf/in	6.40588 lbf/in^2
SG Mass Flow Rate 1	-114.48 lb/s	33%	56.4172 lb/s	-131.781 lb/s
SG Max Static Pressure 1	20.7955 lbf/in^2	52%	1.29011 lbf/in	21.3741 lbf/in^2
SG Max Static Pressure 2	14.9693 lbf/in^2	Achieved (IT = 89)	0.460949 lbf/i	14.9682 lbf/in^2

$$\frac{1}{\tau_{\text{Auger}}} = n_0 \frac{128\hbar}{\pi^3} \left(\frac{m_h^{3/2}}{m_e^{1/2} m} \right) \left(\frac{2\langle p \rangle^2}{m E_{c'v}} \right) \left(\frac{e^2}{\epsilon a} \right)^2 \times \frac{D^2}{\rho E_{\text{opt}}} \frac{1}{E_{c'v} E_{cc'}^2} \left(\int_0^b \frac{x^4 \sqrt{b^2 - x^2}\, dx}{(1+x^2)^6} \right) \times \left(1 + \frac{1}{e^{E_{\text{opt}}/k_B T} - 1} \right), \tag{16}$$

While running the simulation we have encountered an issue with solving the flow of the fluid. The software was able to solve the simulation with ease when running water or a common liquid yet had extreme difficulty with the wet clay. The solution was to be calculated for over 48 hours. Due to time constraint we decided to use values for the fluid, to create a fluid containing the properties that of a clay yet having the capability with software computation. Some of the property adjustments that were made are density, specific heat, specific volume, thermal conductivity, viscosity. The viscosity was adjusted from a liquid to create a non-newtonian fluid with ability to be calculated with the hardware that is owned.

The concept of the auger was design so that it could be easily accessible for cleaning and maintenance. We designed the housing to incorporate the rotation and support of the rotating shaft. A stationary bearing was placed on the end of the shaft and near the nozzle. The bearing is held by 3 rods connections to support the weight of the auger at its end.



While most of the design was set towards the solidworks model and solution of the flow simulation, we did not need to have in depth calculations done by hand since solidworks engine was able to provide us with the necessary values given the correct requirements. The Prototype design will help back check our calculations to calculate what our actual full scale model will output and it will also help us decide which formula for clay viscosity is more accurate.

Design Standards

Energy Efficiency- having an efficient unit in terms of energy while producing the desired outcome in the amount of bricks/day created a reduce in electrical costs and in result a cheaper production cost per brick
Environmentally Friendly- using electric motor or a motor that uses renewable energy
Human Oversight and Involvement- have a limited human involvement in the process of extrusion while still incorporating humans into the production process. This is due to the fact that the overarching problem is economic development and quality of life stability through the scope of lower building material costs.
Quality Building Material- consistently create a quality brick, that would have stable attributes day to day resulting in high quality and dependable buildings.

These standards will guide the design to be more energy efficient, deriving the design to chose a motor that has just the right amount of power that we would need vs a "the stronger the better". Choosing an electric motor and a low waste byproduct due to being environmentally friendly. Having a low human involvement would decrease variability in the product, thus creating a more automated system, while still incorporating a need for employment within the production site. Quality building materials would set a goal to ensure quality before creating quantity, and balancing out the cost per brick.

Specific Challenges

Limited to the footprint that our client provided, a current concern is the design scope. Particularly, if this machine will incorporate a process to chemically dry or heat all the bricks produced. This problem is to be determined later, the client will need to decide on which approach we will need to take in order to harden the bricks and if they have to dry within the same area as the machine. Another consideration is it might be a challenge to find "off the shelf parts" in Uganda because we don't know exactly what they have access to yet.

One of the biggest challenges will be providing the machine that can create the amount of bricks desired while still being within the budget. While we do not know the cost associated with this project the request was as cheap as possible. That creates an issue with our building material quality standard. Since we are expecting to produce something that is of a certain quality, that means it is most likely will be at a larger cost than expected. We will address the issue as it becomes more and more clear.

Another issue that will arise is the desired outcome of the brick per minute vs the achievable amount of bricks per minute. Since for more bricks we will need more powerful engine, the more powerful engine the faster the material is being pushed through, the faster it is being pushed through, the higher the dislocation of the extrusion after exiting the die. Possibly creating pockets of air trapped inside.

Failure Modes and Effects Analysis (FMEA)

Failure Mode and Effects Analysis

System: Auger

Prepared by: Peter Benne

Date: 10/23/2017

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure Mode	Severity	Potential Cause(s) of Failure	Occurrence	Current Design Control (Prevention)	Current Design Control (Detection)	Detection	RPN	Recommended Action(s)	Responsible Person / Target Completion Date	Actions Taken / Effective Completion Date	Revised RPN: S	O	D	RPN
Auger	To increase the pressure of the mud	Wearing Down, Disk fracture	Production stopped until part is reparied or replaced	8	Normal Use. Accelerated by incorrect mixture or large objects	4	Make sure mixutre is correct and no large objects get passed the hopper	Inspect the auger for wear and replace if neccissary	5	160	increase auger hardness by heat treating/buying heat treated to reduce wear and determine RPM and auger diameter that	Peter Benne Nov. 3					
Housing	Contain the mud and house the auger.	Wearing Down, Housing fracture	Production stopped until part is reparied or replaced	10	Normal Use. Accelerated by incorrect mixture or large objects	2	Make sure mixutre is correct and no large objects get passed the hopper	Routine inspections to examine for any major damage.	5	100	Inrease Hardness of the Housing to decrease the wear on the housing. Determine the RPM and auger diameter to minimize wear. (analysis)	Benson Hull Nov. 3					
Auger	To increase the pressure of the mud	Center shaft Fracture	Production stopped until part is reparied or replaced	8	Fatigue. Large objects or a auger clogging creating a large torque on the auger	1	Make sure mixutre is correct and no large objects get passed the hopper	Routine inspections to examine for any major damage.	10	80	Make sure the FOS of the center shaft is large enough to prevent fracture over a long period of time (analysis)	John Zender Nov. 3					
End Shaft Support	Hold the extruder end of the auger in place	Wearing down or shearing off	Auger detached from exturder end. Heavy wear on housing and auger.	8	Normal wear, large objects hitting it as it flows through	2	Make sure mixutre is correct and no large objects get passed the hopper	Loud noises, and increased power requirments	4	64	Make sure the FOS of the apple slicer is large enough to prevent fracture over a long period of time	Bogdan Tkachov Nov. 3					
Auger and housing	Contain and push mud down the housing.	Clogging	Temporaily stops production until the clog is cleared.	3	incorrect mixture of clay and water. Large objects blocking the flow	7	Making sure the mixture is correct	If the flow stops.... There might be a clog	3	63	Install an acrylic or glass to see if the mud is clogged. Increasing Detection	Mathilde Idoine Nov. 3					
Bearings	To let both ends of the auger rotate with little friction/wear	Bearing wearing down or exploding	Increased wear on the apple slicer and housing. Machine will not run well potential	7	Normal Use wear, large objects passing through the housing,	2	Make sure mixutre is correct and no large objects get passed the hopper	Loud noises, and increased power requirments	4	56	Set up a protecting device around the extuder bearring to decreases the wear and pressure on it.	Peter Benne Nov. 3					

Our FMEA tabulates all foreseeable failure modes and ranks them with a risk priority number. This number represents the risk of each failure by combining the severity, occurrence, and ease of detection.

Auger and Housing: Auger and housing wearing down were determined to have the highest RPN of 160 and 100 due to the continuous abrasion with the clay. In order to reduce the effects of this, a harder or heat treated metal could be used to increase the lifespan of these parts.

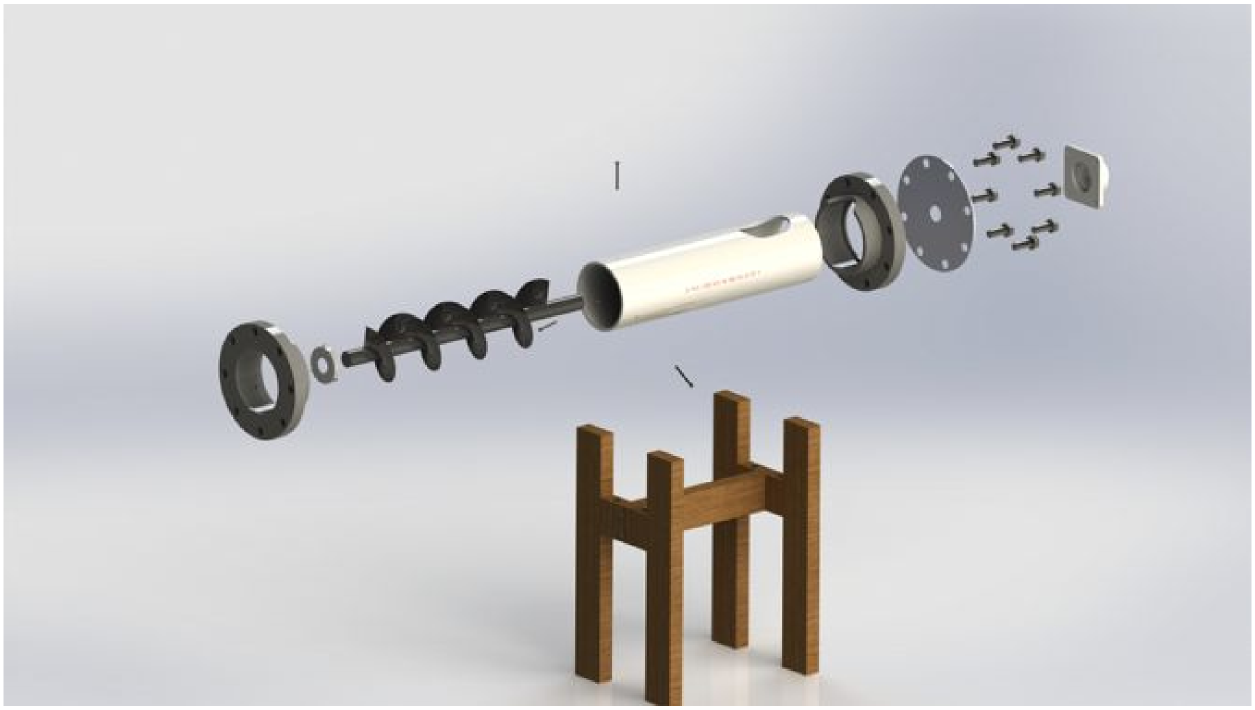
Auger Shaft: The failure of the auger shaft took the third highest RPN of 80 due to its severity and difficulty to detect. A significant FOS should be used when designing/buying the auger to ensure a near infinite life of the auger shaft.

End Shaft Support: The auger end shaft support is our fourth riskiest failure location with a RPN of 64. To reduce its RPN, the support should have a significant FOS to ensure large rocks or clumped clay are unable to damage it.

Auger clogging: The auger clogging was designated a RPN of 63 due to its occurrence rating. We expect this to be the most common failure for our subsystem due to the amount of variables that affect it. An acrylic window could be installed within the housing to give a visual clue as to when the machine clogs. Also, ensuring the correct ratio of water and clay will greatly reduce the amount of clogs that occur.

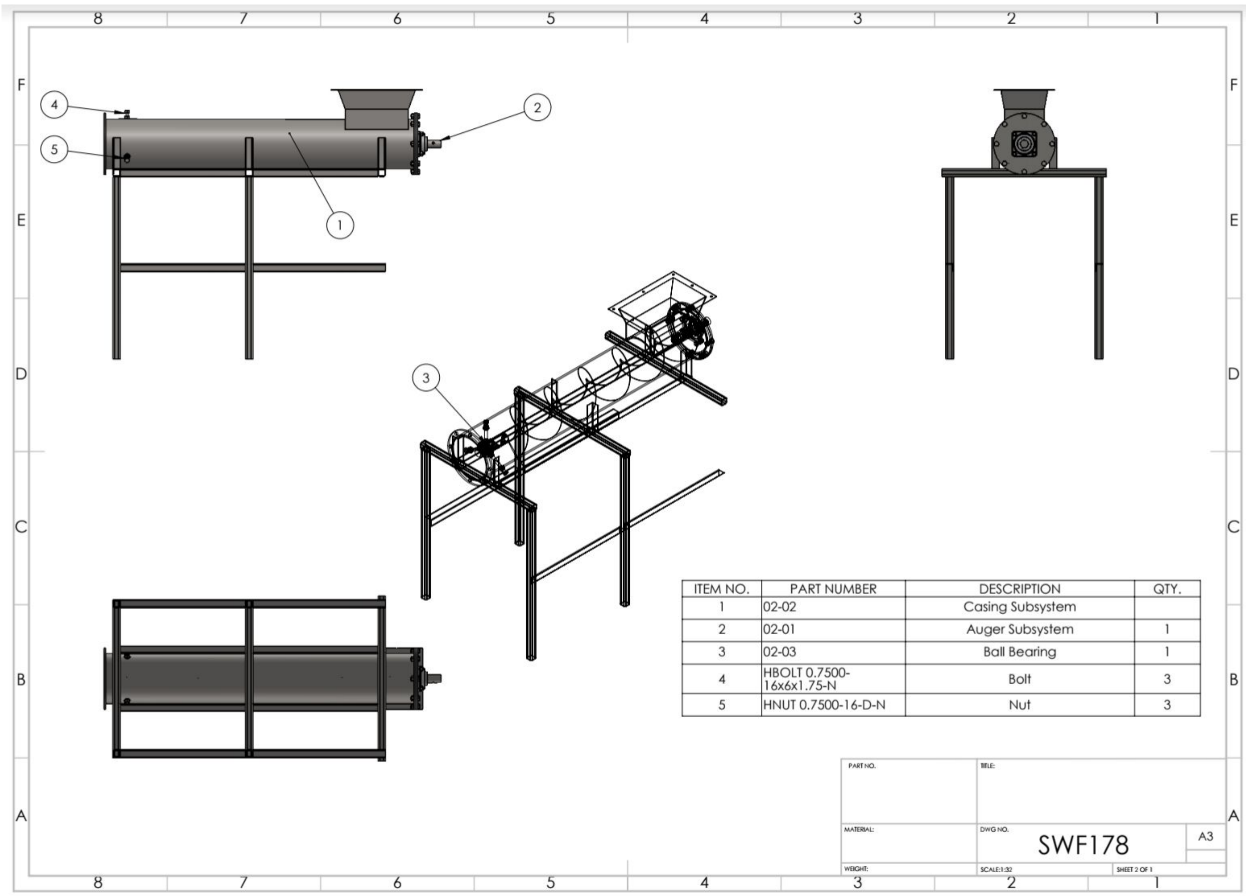
Bearing: The failure of the bearings that allow the auger to rotate smoothly is our least risky mode of failure. A metal shield will be made to relieve the pressure of the bearing in the end shaft support. This shield combined with double sealed bearings will nearly eliminate bearing failure.

Prototype Design



The designed prototype is a 1:2 scale of the extrusion subsystem with a few material substitutions. Instead of designing and fabricating an extrusion screw, the prototype incorporates the use of a post hole digger to move clay and build pressure. The barrel of the subsystem is a PVC pipe that is capped at either end with a pipe flange. The flange allows the prototype to to seal on end of the barrel and incorporate the die feature. Bearings are also mounted at either end of the barrel to ensure smooth operation and efficiency of the extrusion screw. Due to the size reduction and consequent weight reduction, the frame is made of wood and fastened by wood screws. The prototype is designed to test the model equations used for the controlling extrusion with the primary goal of confirming extrusion speed from the die.
A manufacturing plan for the prototype is described in the appendix A.

Validation Plan



The goal of our prototype is to determine what our output is and make sure that our calculations are similar to our experimental values. This will help us determine what the actual output will be of our full scale model.

The validation for our prototype changed once we saw our output results. The results of our machine heavily depended on the clay composition. The more water we added the greater the mass flow, but the extra water resulted in poor quality output that wouldn’t hold the rectangular shape. Our new validation plan resulted into testing the machine and verifying it could hold the pressure and stay water tight, along with produce something, which the prototype met all of those new requirements.

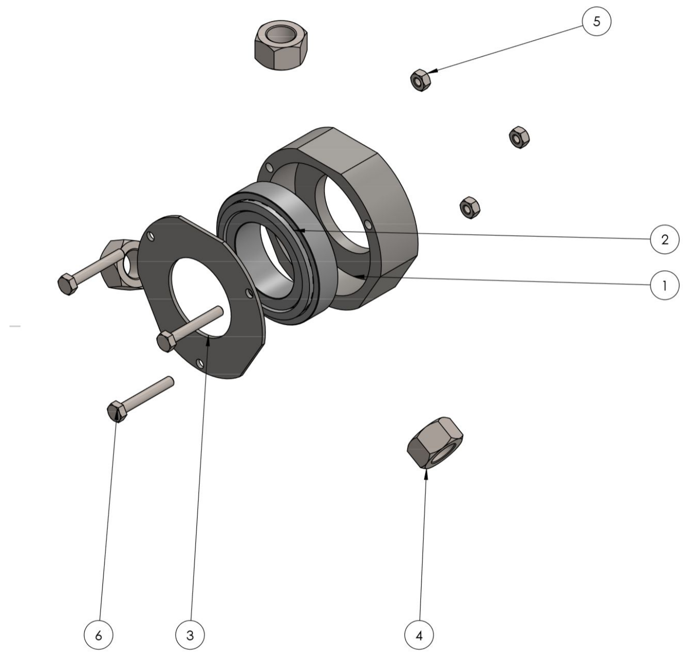
Bill of Materials for the Prototype

Bill of Materials (EXTRUSION PROTOTYPE)

Item of Description	Vendor	Part	Quantity	Unit Cost	Subtotal Cost	Shipping Cost	Total Cost
Schedule 40 PVC Pipe (5ft)	McMaster	48925K25	1	53.36	53.36	10	63.36
Auger (6" D, 1.5" S, 28" L)	XtremepowerUS	Spare Blade (6") 28" length	1	45.95	45.95	N/A	45.95
Flange (6.625" OD)	McMaster	4881K241	2	26.31	52.62	10	62.62
Ball Bearing (R24 1-1/2" S, 2-5/8 OD)	McMaster	60355K512	1	43.09	43.09	10	53.09
Flange Mounted Ball Bearing (1-1/2" S, 5-1/8")	McMaster	5967K88	1	94.9	94.9	10	104.9
Socket Head Screw (3/8"-16)	McMaster	90044A151	3	2.32	6.96	10	16.96
Nut (Black, Ultra Resistant Coated Steel- GR 5 (3/8"-16) **3**	McMaster	98797A031 (Pack of 5)	1	5.29	5.29	10	15.29
Washer (316 SS, 7/16")	McMaster	90107A032	1	8.59	8.59	10	18.59
2" x 4" x 96"	Home Depot		3	3.18	9.54	5	14.54
Steel (3" D, 3" thick)	McMaster	7786T36	1	23.34	23.34	10	33.34
Labor							
Machine	Coug Shop		1	25	25	25	25
Weld	Coug Shop		1	25	25	25	25
				TOTAL	**393.64**	**135**	**478.64**

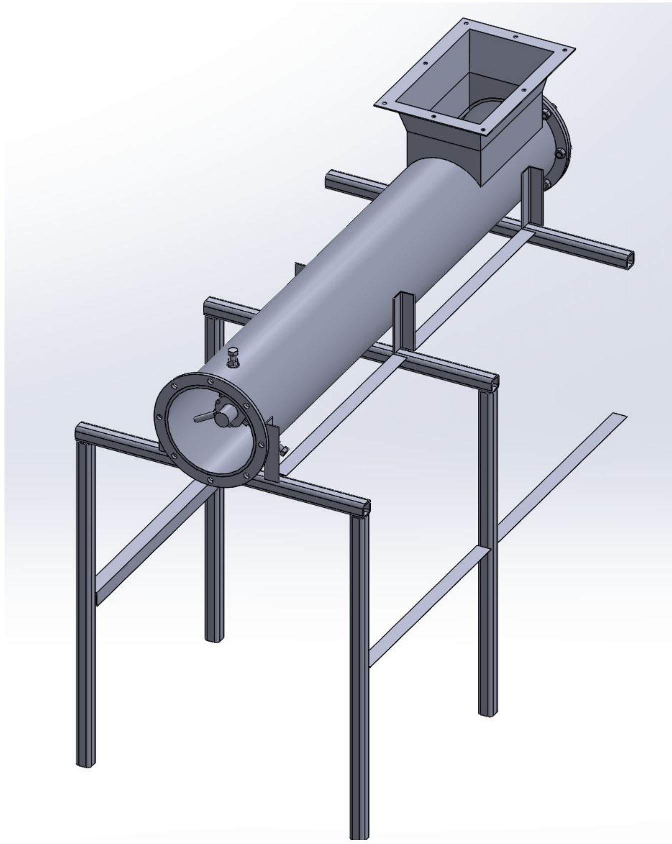
Built and Tested Prototype

Using the materials we proposed in the previous section we built a functional prototype that demonstrated well. The end result was a very clean and professional design. Using the PVC pipe and fittings made the assembly easy to put together and take apart for cleaning. The post digging auger was easy to modify to our needs and it fitted inside the pipe perfectly. The design of the bearing housing on the nozzle side changed a bit to make it easier to manufacture and assemble (shown below).



Final Design

Our final design would have a very similar design to our prototype. The main changes we would make include: switch to full scale rather than the half, and increase the structure strength of the frame by adding more cross beams. Additionally, all of the materials would have much higher strength and hardness. Those changes result in a much greater overall cost, however, the lifespan of the machine will drastically increase and the output production will improve due to the new maximum pressures and horsepower available.



Bill of Materials for Final Design

Part	Qnty	Material	Description	Vendor - Part #	Price ea.	Subtotal
12" Extrusion Auger	1	Steel		McMaster Carr - 5866K26	$532.97	$532.97
12" ID Steel Pipe (1/4 wall)	1	Steel	12" ID Sch 40 pipe, 4 feet long	MetalsDepot - T212250	$1,129.32	$1,129.32
2" ID Bearings	1			McMaster Carr - 5709K91	$39.51	$39.51
4 Bolt Flange-Mounted Bearing Housing	1	Steel		McMaster Carr - 5967K93	$107.93	$107.93
Steel Plate	1	Steel	12"x24"x1/2"	McMaster Carr - 6544K78	$333.04	$333.04
Steel Pipe Slip on Pipe Flange	2	Stainless Steel	19" OD 12"ID	MSC -04315818	$820.71	$1,641.42
2" Steel Rod	1	Hardened 4140 Steel	2' long	McMaster Carr - 8935K15	$76.77	$76.77
3" Steel Rod	1	Hardened 4140 Steel	6" long	McMaster Carr - 8935K24	$52.15	$52.15
5" Steel Rod	1	Hardened 4140 Steel	2" long	McMaster Carr -8960K64	$66.46	$66.46
M22 x 45	20	Steel		McMaster Carr - 91280A822	$3.26	$65.20
M22 x 2.5 Hex Nut	20	Steel		McMaster Carr - 92497A750	$2.78	$55.60
					Total	$4,100.37

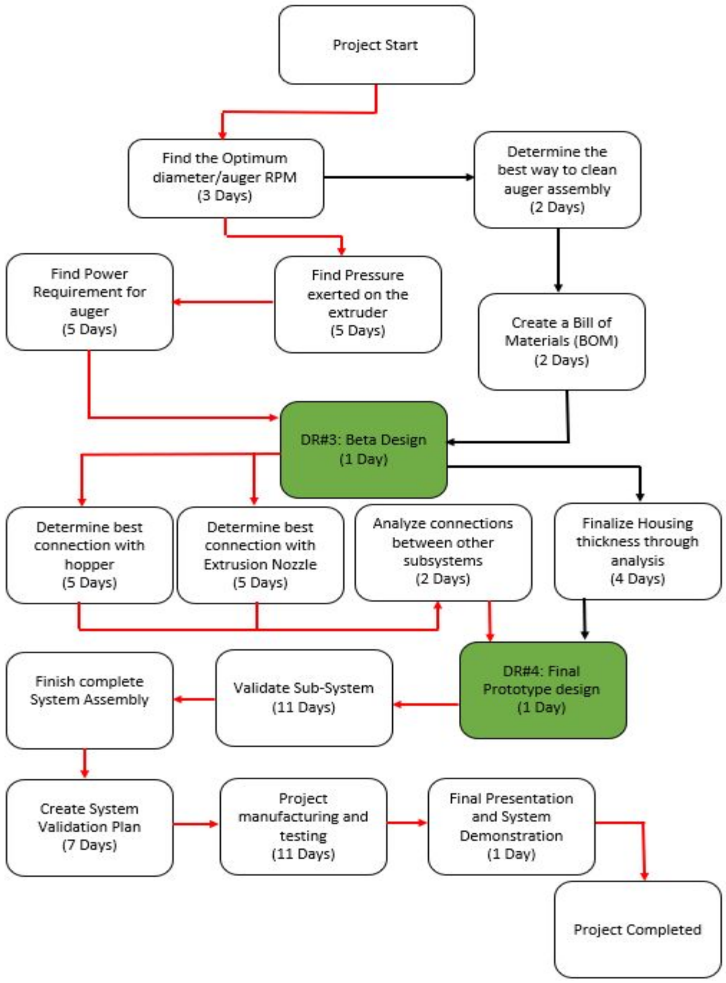
Cost Analysis

The total cost of the Brick Production Machine is $39,902.86. Therefore, the extrusion subsystem cost is $4,100.37 (Bill of Materials, Above) or 11% of the total Machine cost. The extrusion system cost share doesn’t reflect the importance of the subsystem within the overall operation of the entire system. In comparison, all other subsystems are complementary to the extrusion subsystem with assumption that the machine is expected to extrude formed clay for bricks. Thus, the extrusion subsystem should be the last subsystem to undergo a component audit with the goal of lowering overall cost.

McMaster Carr is the vendor we chose for the majority of our parts because of convenience, however, there might be a cheaper option for ordering parts separately.

Project Planning

The graph above gives a visual representation of the tasks that still need to be completed over the course of our project. The flow chart to the right takes the tasks that are in the table above and shows the order that they need to be completed as well as the critical path (Red line). These tables and graphs are used to keep the project moving and ensures that deadlines are easier to see and meet.



Summary and Conclusions

The goal of the brick manufacturing project of WSU is to improve the brick production process by designing (and constructing) an automated brick production machine that raises the production rate while increasing the quality of the products. Ideally the BPM receives the raw material and renders ready-to-use bricks. According to our client interview and subsequent HOQ process the principal factors of influence over the BPM design concern safety, brick output, manufacturability and prices. Additionally, team standards such as energy efficiency and human involvement will further influence the concept process and final design.

The extrusion screw subsystem is designed to extrude material by rotating the screw which pressurizes the housing with the wet clay material (modeled as non-newtonian) and forces the wet clay through the die at a specific rate that matches output expectations. The subsystem must be effectively designed to extrude bricks before it is integrated with the other subsystems. Essentially, the extrusion screw this one of the most important mechanical subsystems within the BPM.

While Uganda faces a larger systematic housing deficit, the effective engineering of the extrusion screw subsystem within the BPM will allow the machine to help alleviate the housing issues through the reduction of brick price without causing other damage to the environment or citizens of Uganda.

Reference

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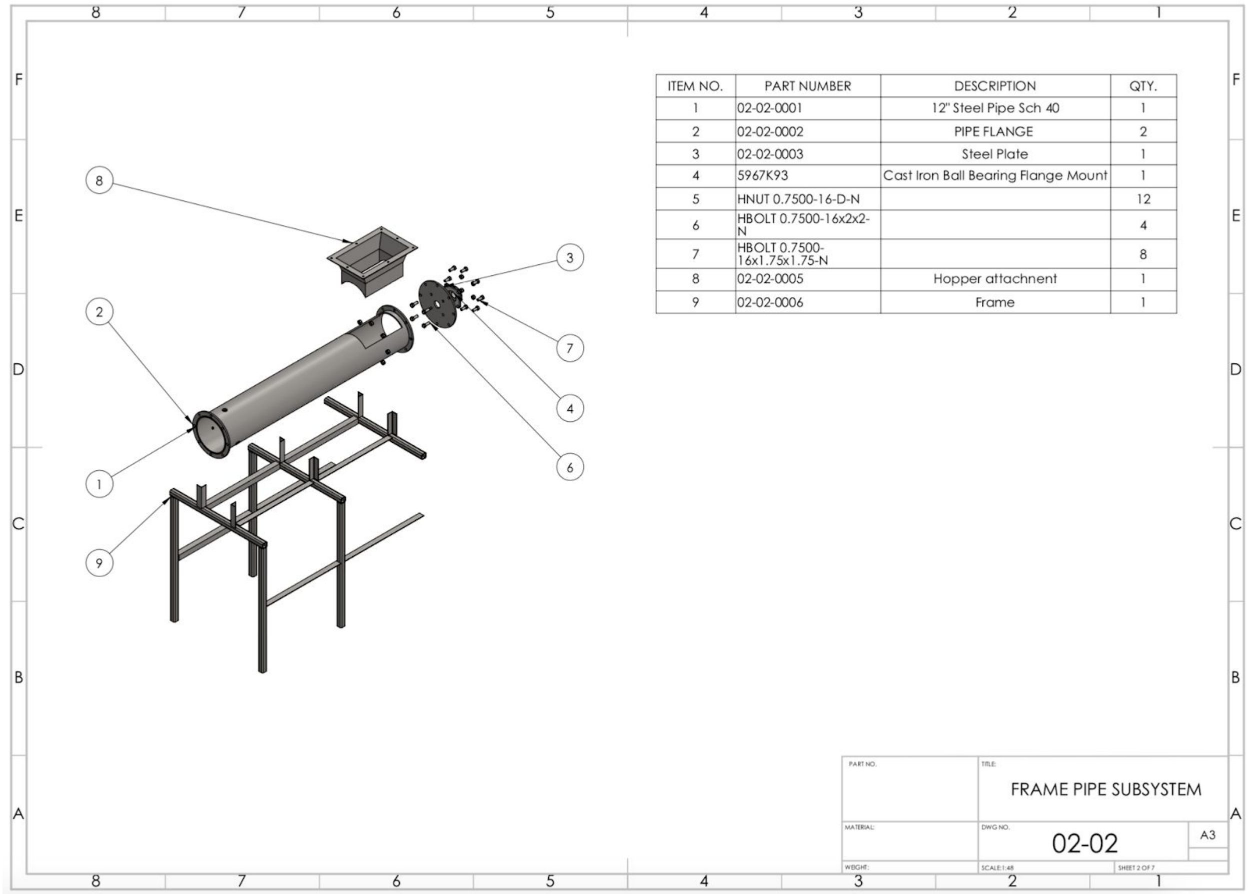
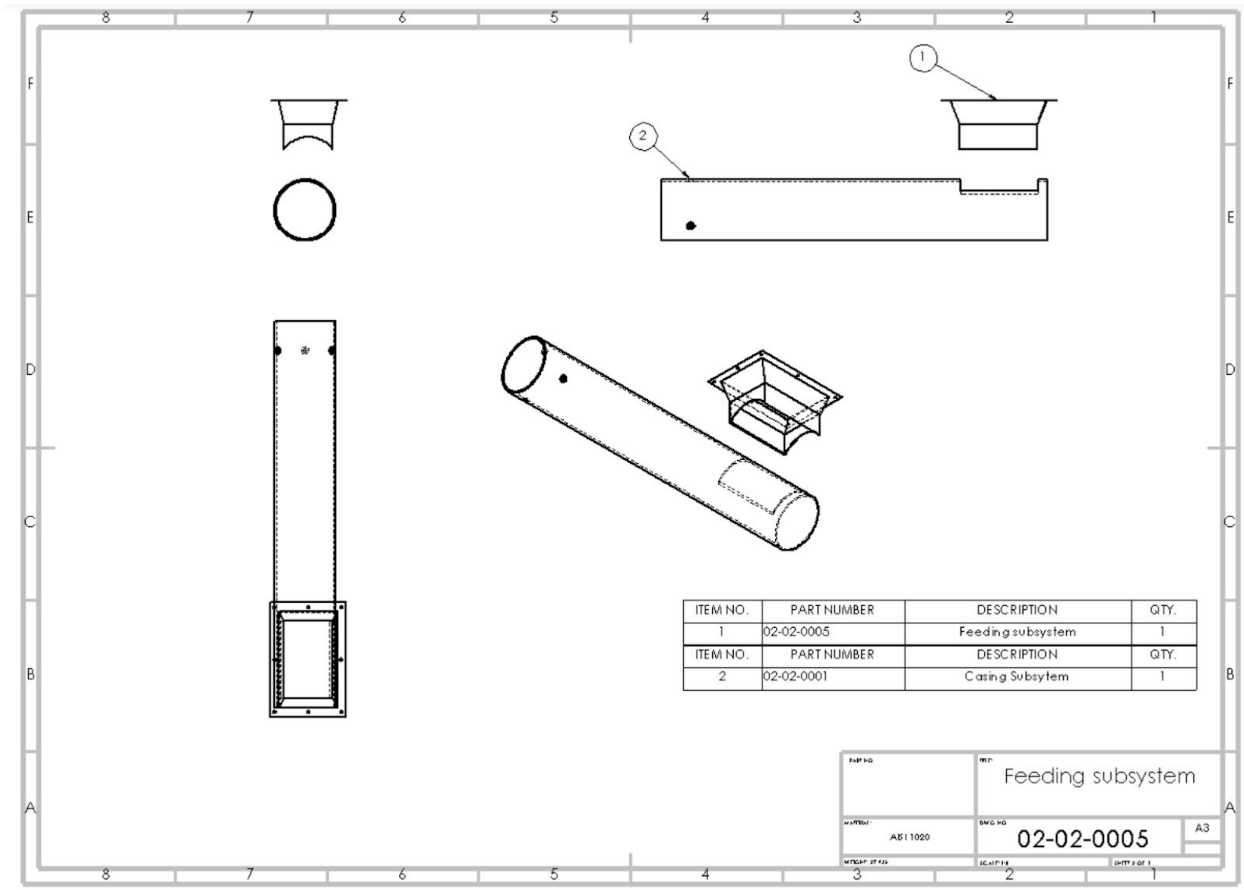
Appendix A

Manufacturing plan for prototype



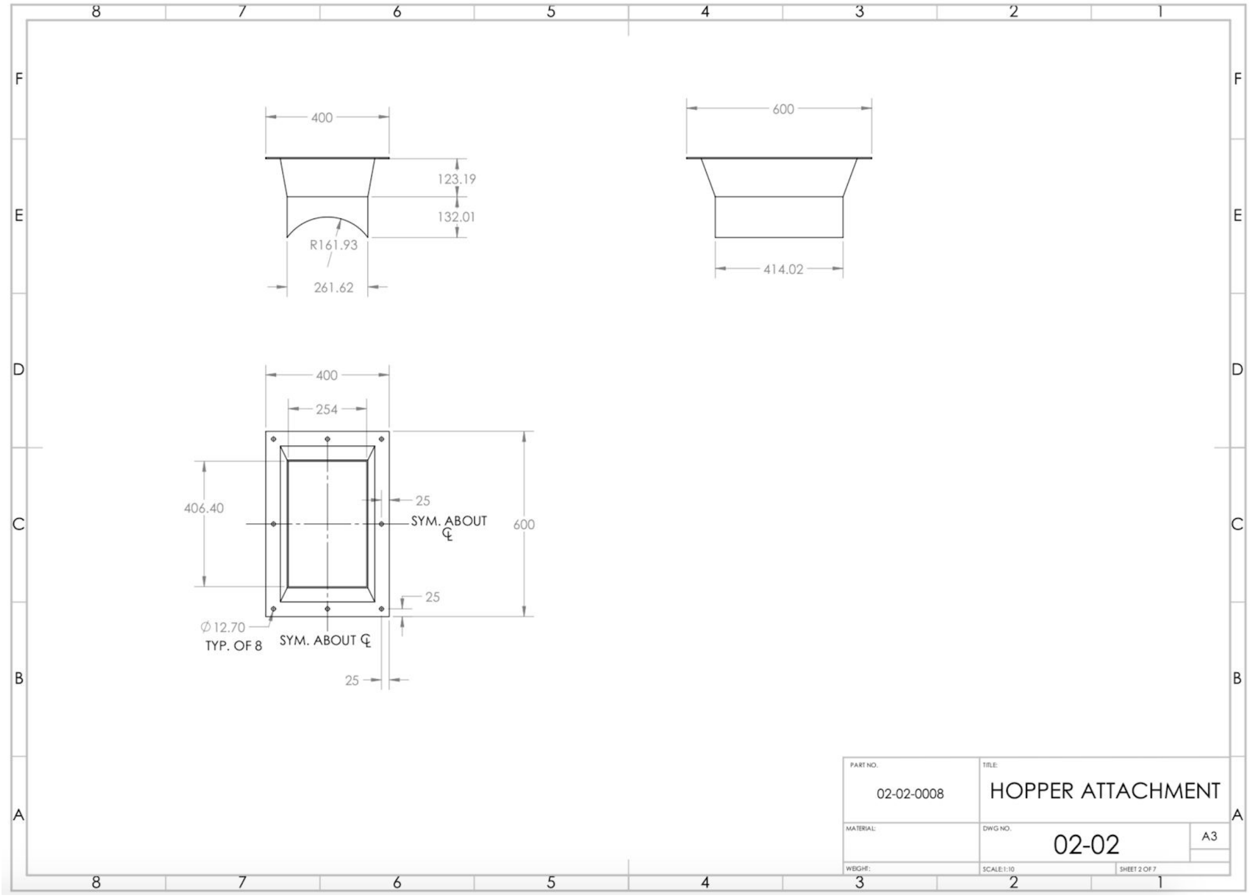
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-02-0001	12" Steel Pipe Sch 40	1
2	02-02-0002	PIPE FLANGE	2
3	02-02-0003	Steel Plate	1
4	5967K93	Cast Iron Ball Bearing Flange Mount	1
5	HNUT 0.7500-16-D-N		12
6	HBOLT 0.7500-16x2x2-N		4
7	HBOLT 0.7500-16x1.75x1.75-N		8
8	02-02-0005	Hopper attachnent	1
9	02-02-0006	Frame	1

Process 1: exploded view of frame, hopper, and outer system.



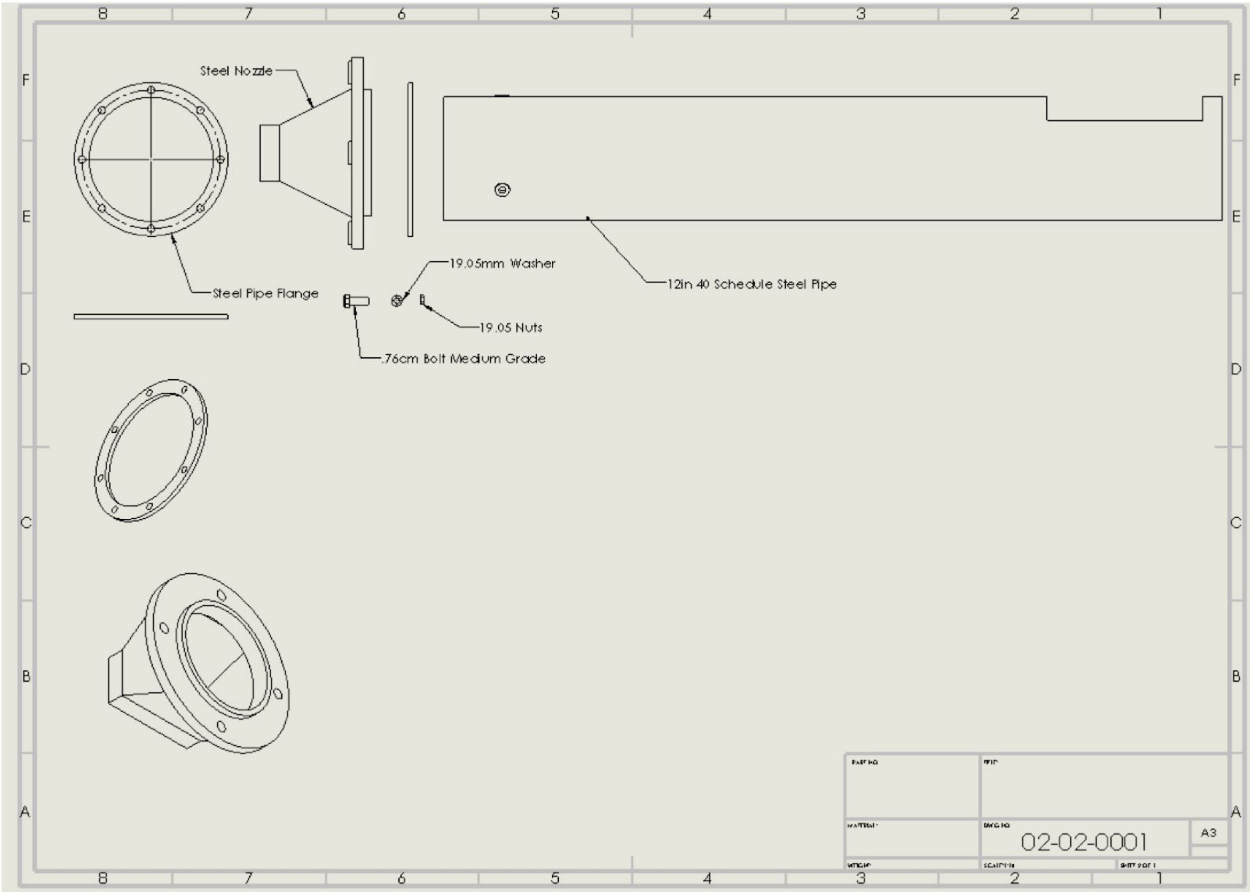
- Welding required to mount hopper to pipe.
- Process description: Note that the directional position of the feed auger relative to the hopper does not impact the assembly. Ensure auger outlet is over the hopper so that raw material feeds into the mixer.

Process 2: Mating the hopper subsystem to the extrusion subsystem

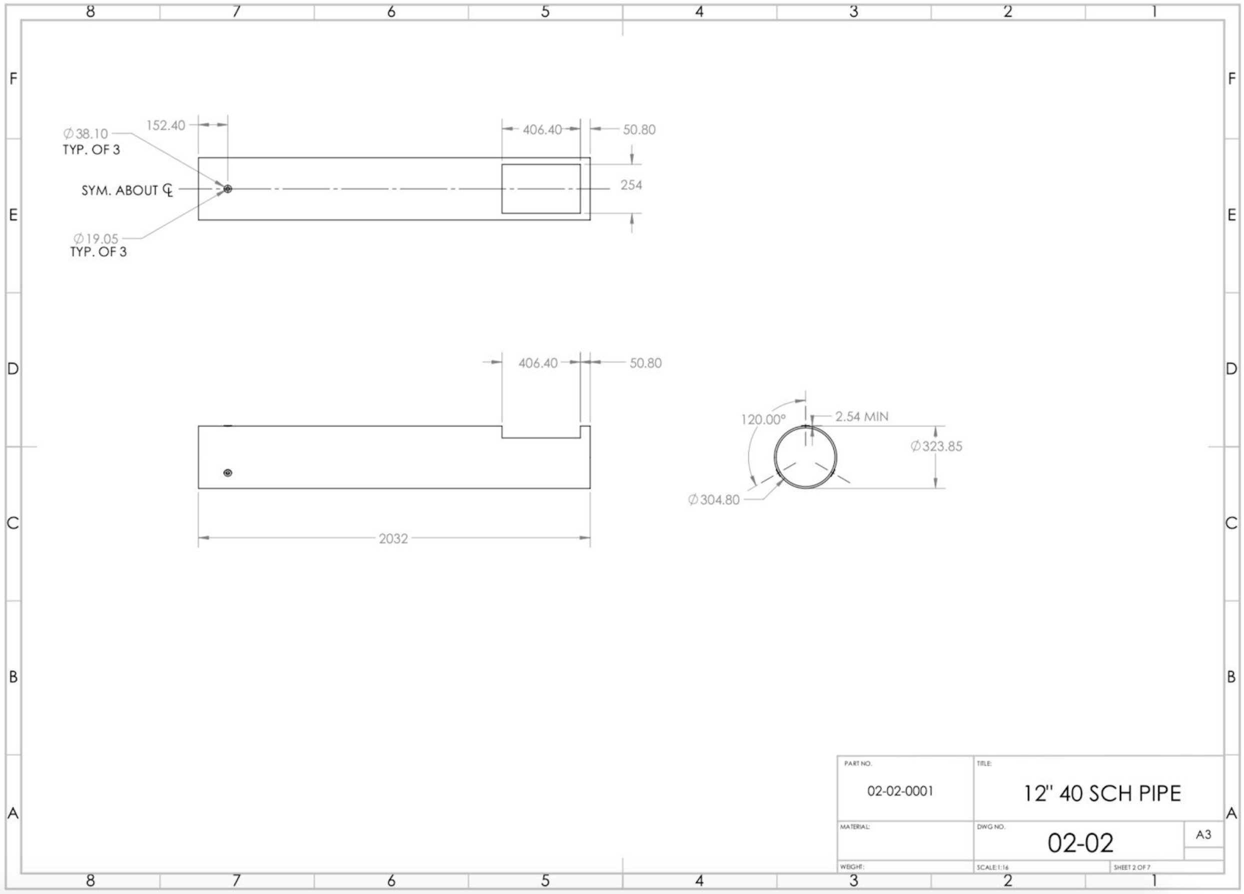


- Hardware needed
  - Bolts
  - Washers
  - nuts
- Tool needed
  - Torque Wrench
  - Metric socket
  - Crescent wrench
  - Welder
- Process description
  - Insert bolt through washer
  - Insert bolt with washers through holes
  - Hand tighten nuts onto bolts
  - With the crescent wrench holding onto the nut, tighten the bolts until the torque wrenches "clicks", indicated that the desired torque has been reached

Process 3: Mating the Nozzle/Initial Cut/Roller subsystem to the Extrusion subsystem



- Hardware needed
  - M22 Bolt Medium Grade x8
  - M22 Washer x8
  - M22 Nuts x8
- Tool needed
  - Torque Wrench
  - Metric socket
  - Crescent wrench
- Process description
  - Insert bolt through washer
  - Insert bolt with washers through holes
  - Hand tighten nuts onto bolts
  - With the crescent wrench holding onto the nut, tighten the bolts until the torque wrenches “clicks”, indicated that the desired torque has been reached



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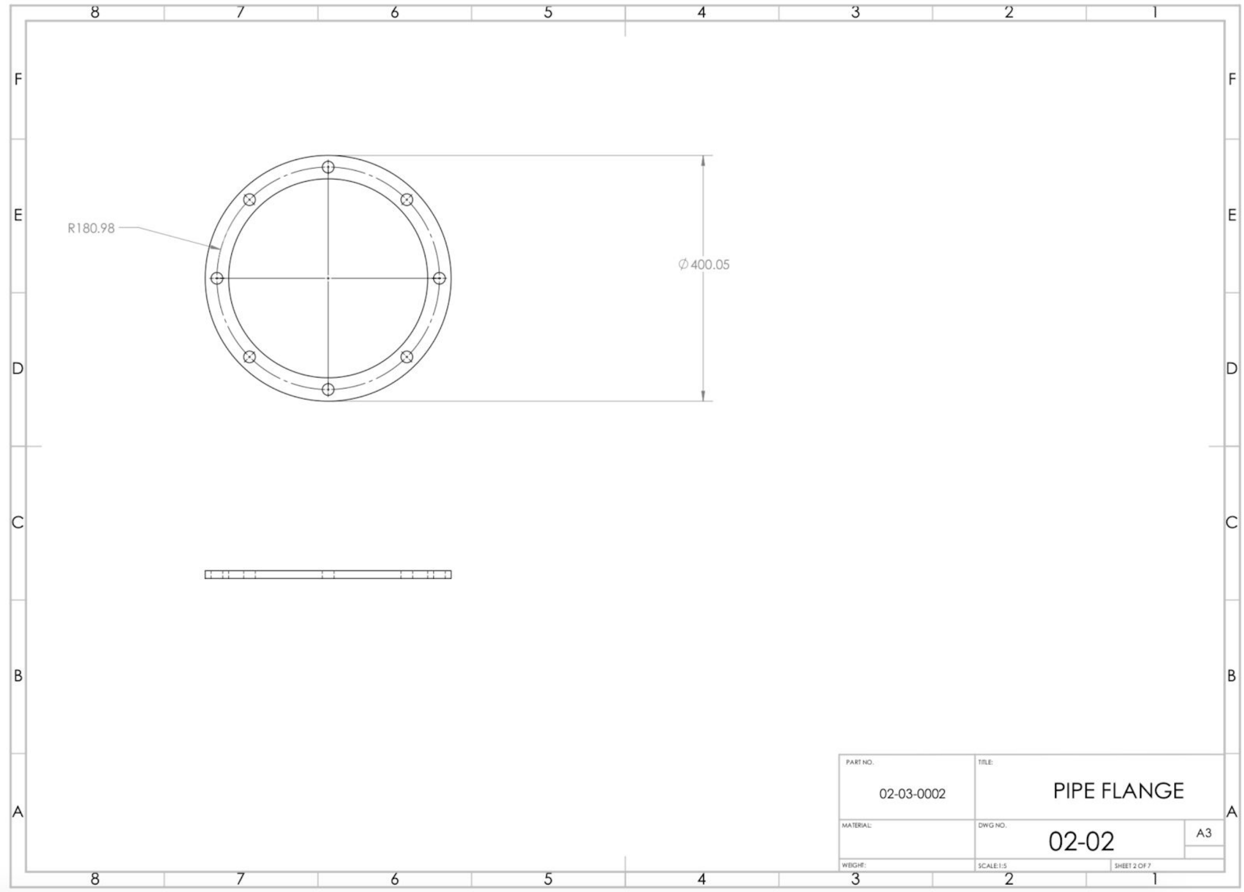
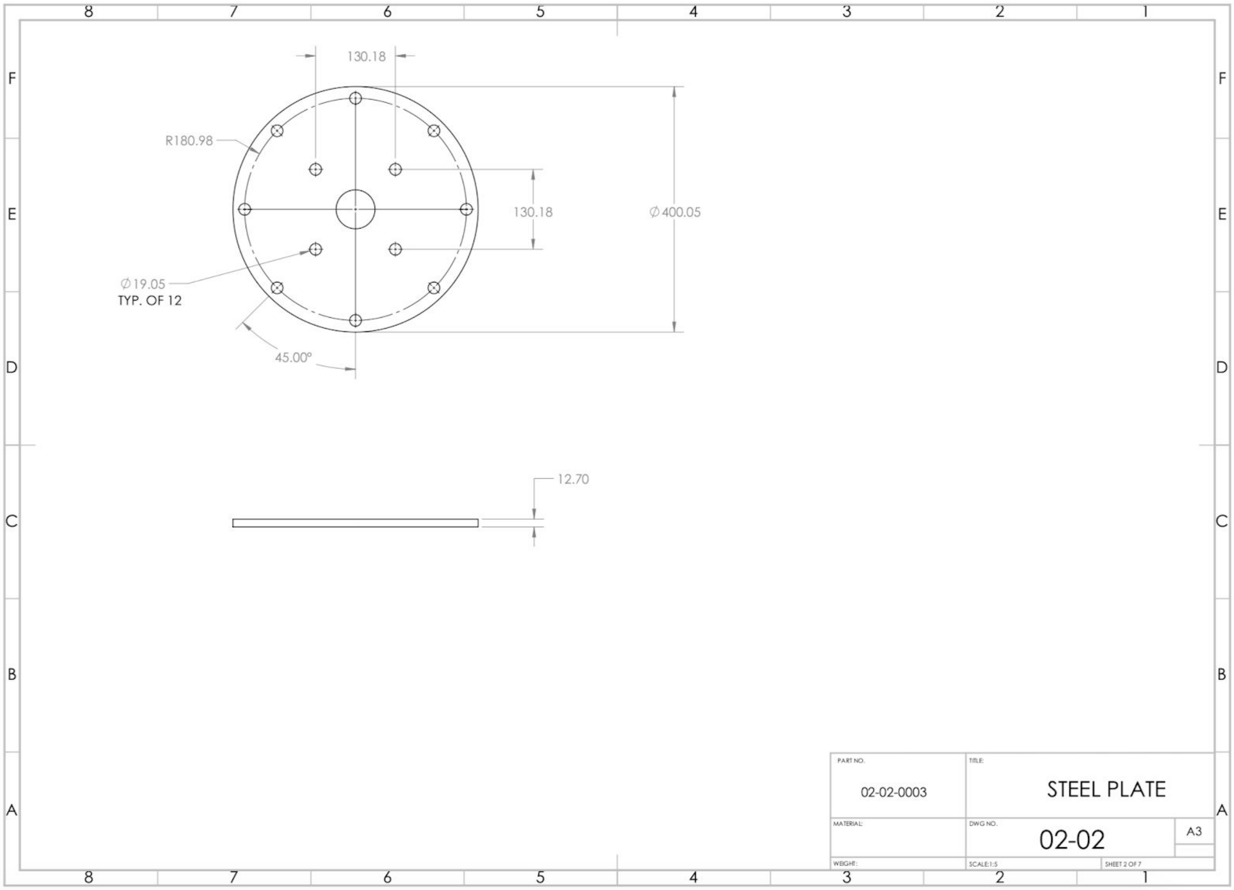


This steel flange was the original design for the prototype, which was swapped with a PVC pipe flange from McMaster Carr. For the final design we have swapped it again with a steel pipe flange listed above in our Final Design BOM.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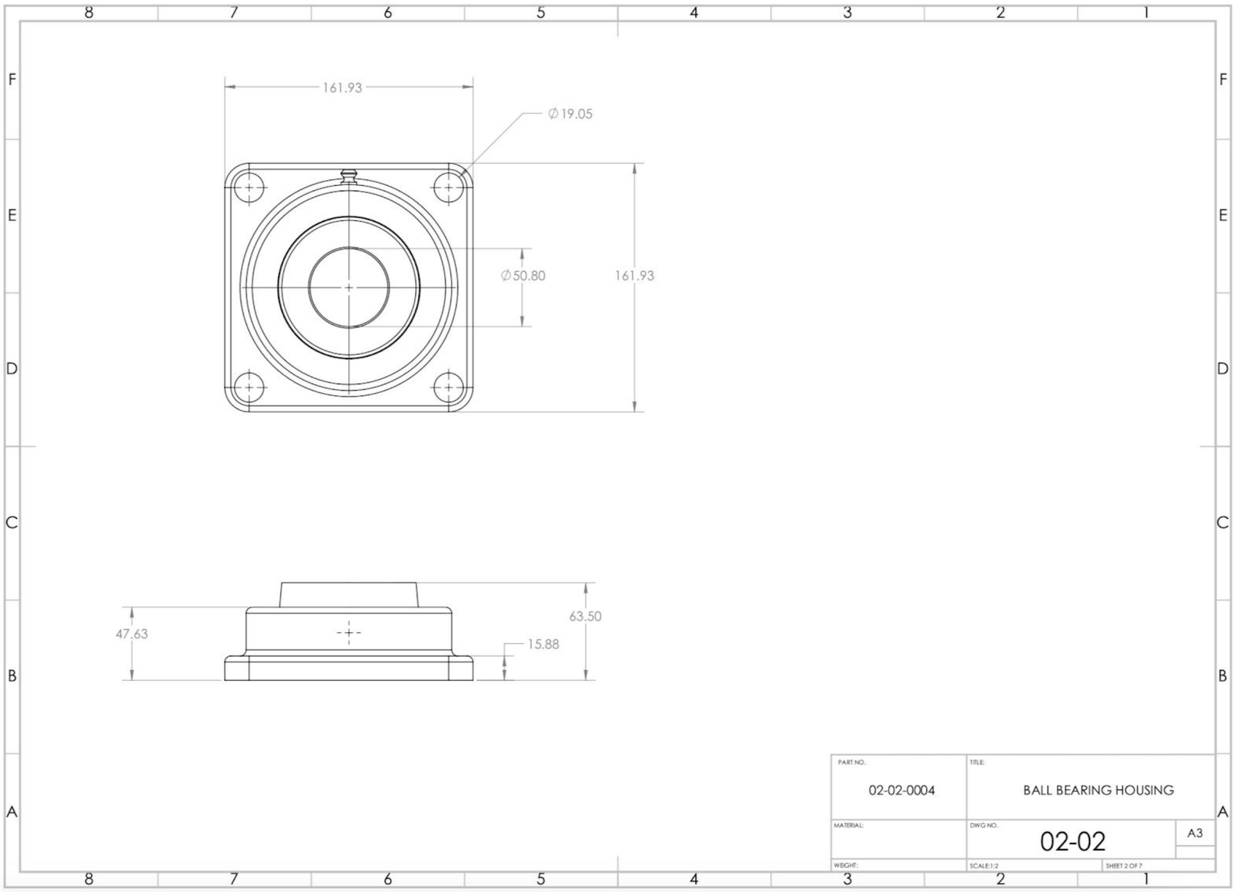
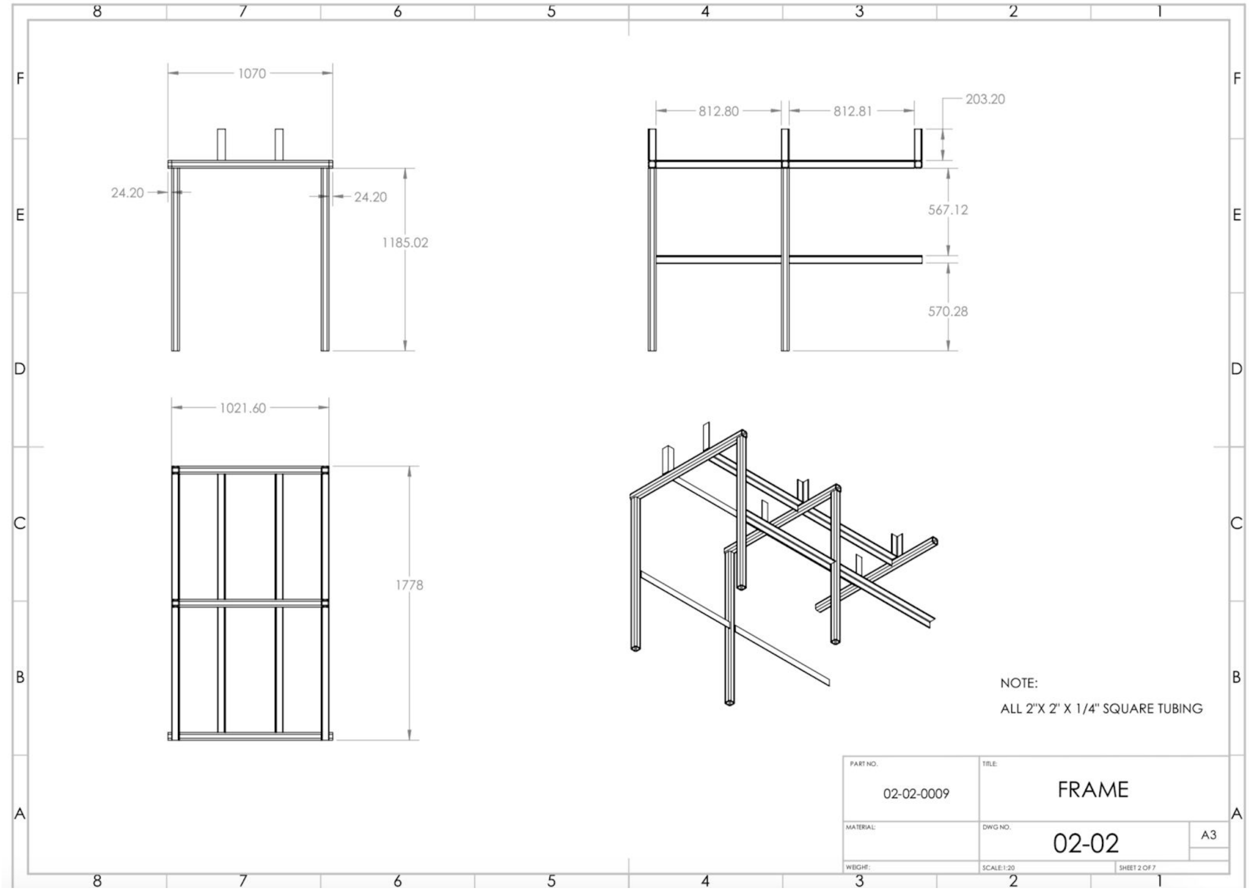
PART NO.
02-02-0003
TITLE:
STEEL PLATE
MATERIAL:
DWG NO.
02-02
A3
WEIGHT:
SCALE:1:5
SHEET 2 OF 7


161.93
∅19.05
∅50.80
161.93
63.50
47.63
15.88
PART NO.
02-02-0004
TITLE:
BALL BEARING HOUSING
MATERIAL:
DWG NO.
02-02
A3
WEIGHT:
SCALE:1:2
SHEET 2 OF 7


1070
24.20
24.20
1185.02
812.80
812.81
203.20
567.12
570.28
1021.60
1778
NOTE:
ALL 2"X 2" X 1/4" SQUARE TUBING
PART NO.
02-02-0009
TITLE:
FRAME
MATERIAL:
DWG NO.
02-02
A3
WEIGHT:
SCALE:1:20
SHEET 2 OF 7

TEAM BIOS

Benson Hull

- From Redmond, WA (A stone's throw from Microsoft Main Campus)
- Engineering allows me to work with people to solve large challenges that our society faces
- Internship at Nelson Irrigation as a Manufacturing Engineer
  - Assisted in R&D Manufacturing
  - Highlight: I got to work with a UR robotic arm
- Internship at Dibble Engineers as a Structural Engineer
  - Assisted in designing residential real estate developments
  - Takeaway: Architects love windows
- President of Sigma Nu
  - Oversee 110 men, 60 tenants, Large annual budget, $3.2M property
  - Worst thing I ever had to do was fire someone
- Hobby: Intermural Football and Softball, snowboarding
- Favorite beer: Mack and Jacks (Amber Ale)

John Zender

- Hobbies: 3D Printers, Solidworks, Basketball
- I chose Mechanical Engineering because I love designing and moving parts.
- Last summer I was working at Redpoint Structures as a Solidworks Drafter.
- From Bellingham WA
- Favorite Beer: Wanderer (Bellingham Company)

Bogdan Tkachov

- I chose engineering because I enjoy creating and improving things, and want to do what I enjoy
- Hoping to work for Boeing
- Currently working for Schweitzer Engineering
- I love snowboarding and going on hikes

Peter Benne

- I Enjoy engineering because its fun to know about new technology and how it works
- Member of Formula SAE team
- Long term goal of getting a Masters in Robotics engineering.
- Hobbies include skiing and Mountain Biking
- As a side project, I've been working on developing and prototyping an improved collection system to increase to efficiency of automated blueberry harvesters.

Mathilde Idoine

- Art is my jam.
- I am still trying to figure out why I'm studying engineering.
- I've had an internship with Dassault Systemes.
- I want to step a foot on every continent, so far I'm missing South America and Antarctica.
- My favorite wine is Chateau Margaux 1995.
- People say that sorority girls all look the same, I disagree, find me!