Mechanical Engineering Design Project Class

Mechanical Engineering & Materials Science

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Sanitation System for Underdeveloped Countries

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Washington University in St. Louis
SCHOOL OF ENGINEERING & APPLIED SCIENCE

A sanitation system which can flush under 150cc of water and costs less than $300. The sanitation system is free of any electrical component and is purely a mechanical design. It is a closed system such that it does not pose any public health concerns. The waste is collected in a closed area for recycling, and sunlight and heat containment is used to treat the waste.

MEMS 411 Design

Sanitation System

Anish Agrawal, Dylan Lesher, Reid Schur, Mutian Tang

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1 INTRODUCTION

1.1 PROJECT PROBLEM STATEMENT

This project involves the creation of a sanitation system for use in impoverished areas with little access to water or electricity. A satisfactory sanitation system for this project must use minimal water (less than 150cc), no electricity, and must be sanitary. In order to be sanitary, the waste must be sealed away from the user to prevent bacteria from entering the air. This sanitation system must provide a sanitary solution to waste management for toilets.

1.2 LIST OF TEAM MEMBERS

Sanitation
Anish Agrawal
Dylan Lesher
Reid Schur
Mutian Tang

2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS

2.1 A SHORT DESIGN BRIEF DESCRIPTION THAT DESCRIBES THE PROBLEM

Design a sanitation system which can flush with less amount of water and is economically viable for under developed communities.

The following table describes the needs of the customer.

Table 1 Customer interview with needs and importance scores.

Customer Data: Sanitation System (SS) Customer: Anish Agrawal Address: Biratnagar, Nepal Date: 24 September 2016			
Question	**Customer Statement**	**Interpreted Need**	**Importance**
What do you use for sanitation?	We just use empty land outside.	Waste is hazardous for the health of the people and environment.	5
By using empty land, how has that effected your neighborhood’s health?	The children are often sick and the adults are susceptible to diseases all the time.	Need a safer option for sanitation	5
Would you pay for a safer sanitation option?	Yes! However, I make $2/day. Considering this, I can only pay less than $200 for it which I am willing to take a loan to pay for.	The design should be cost effective and should cost less than 5cents/use	5
Do you have access to sufficient water?	No. Access to water is very limited and we have to walk quite a bit to get it from the community tap.	The design should use less than 150cc of water.	5
Do you have access to other amenities such as electricity?	No, our village do not have access to electricity yet. However, the government is planning to install stations for electricity. Not sure how long would that take.	The design needs to achieve all kinds of mechanism mechanically.	4
If you have a toilet, how often would you be willing to clean the waste?	I will be willing to clean it as many times as necessary.	The waste could be cleaned every 6-12 months.	3

2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

The following design fits the description of the value proposition most closely.

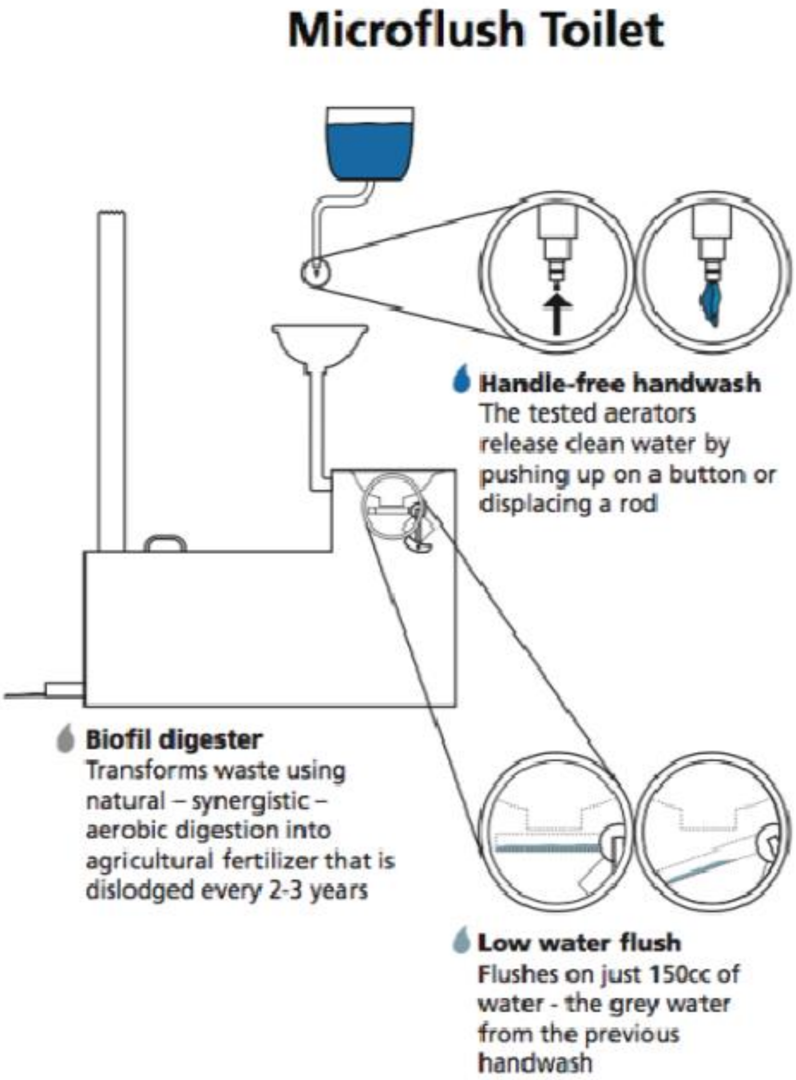


Figure 1: Microflush toilet design of Global Sustainable Aid Project [1].

The above design claims to achieve the flushing mechanism in as little as 150 cc of water and the costs of the final product is to be sold for under $300 with an appropriate profit to the local craftsman/entrepreneur who makes the structure. A complete detail of the design can be found in reference 1.

The following toilet design is an innovative toilet that uses no water and filters the water from the waste itself for cleaning and gardening purposes. However, it needs regular maintenance and is expensive as well. It is limited to a single-family usability and needs the waste to be taken out every week.

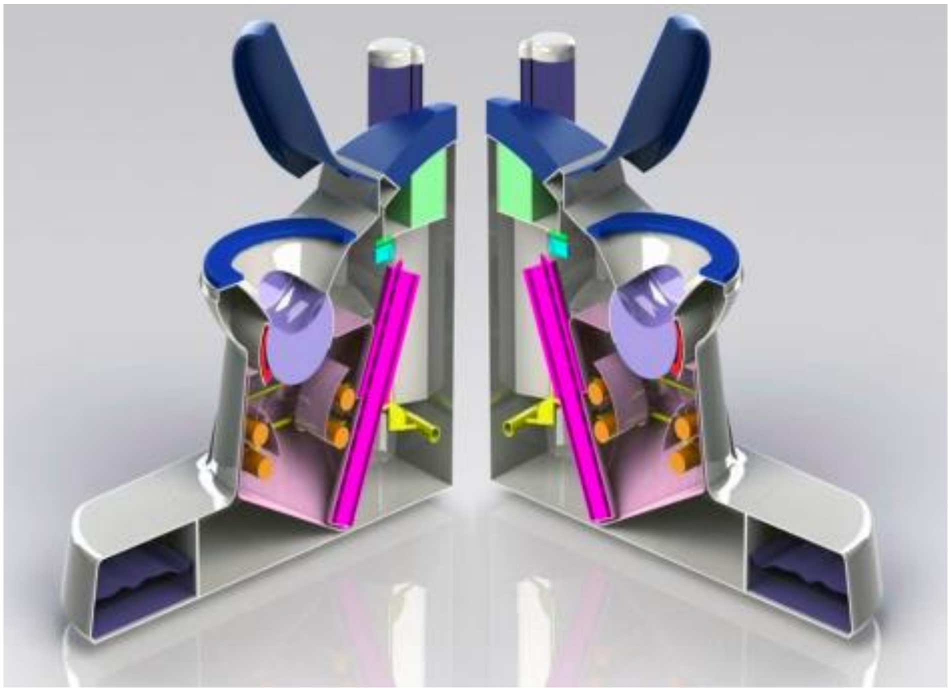


Figure 2: Design of toilet by Cranfield Water Science Institute [2].

The video link below describes the functionality of the design.

https://youtu.be/iX0jAn-iNng

Alison Parker, a lecturer in International Water and Sanitation at Cranfield Water Science Institute, says her team's new design is meant to serve poor urban areas, as those will be easiest to accommodate. She said, "It will be very hard to carry out the scheduled maintenance" in remote areas, Parker tells Tech Insider, mostly because the toilet needs maintenance every six months at a minimum to replace certain parts. "Instead, the toilet will be used in dense urban areas where several factors make providing good sanitation very challenging, but where it would be possible to facilitate visits from a maintenance technician."

Since this design uses no water, it can be considered as a competitor to our design idea. However, the cost constraint can restrict its usability for the demography we are focusing on.

3 CONCEPT DESIGN AND SPECIFICATION – DESIGN REQUIREMENTS

3.1 OPERATIONAL REQUIREMENTS ALLOCATED AND DECOMPOSED TO DESIGN REQUIREMENTS

3.1.1 List of identified operational and design requirements

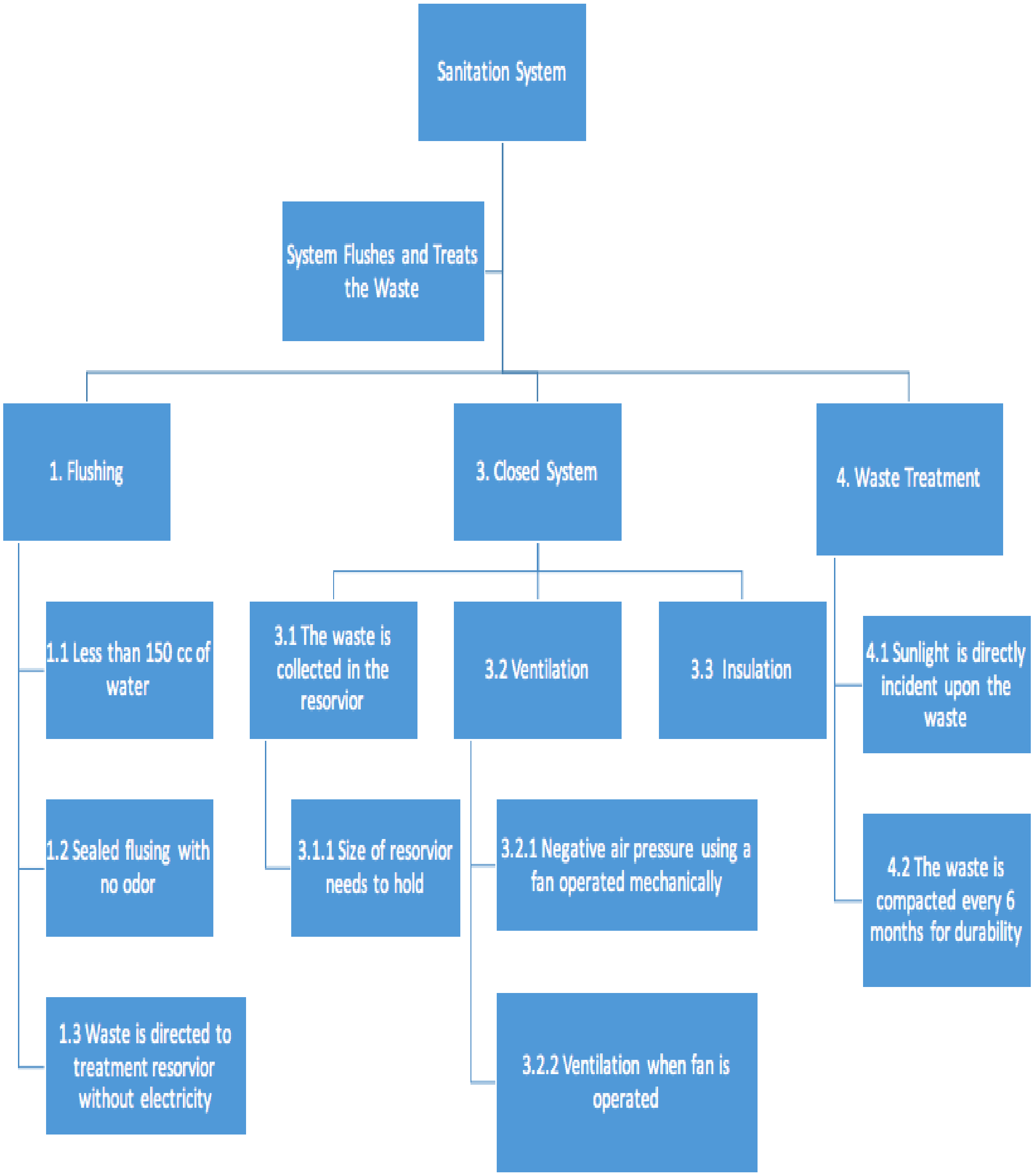


Figure 3: Operational requirements decomposed.

The following table lists the identified operational needs for the design.

Table 2 Operational needs decomposed with level of importance.

Need Number	Need	Importance
1	SS flushes in less than 150cc of water	5
2	SS has sealed flushing with no odor	5
3	SS flushes the waste to the waste treatment reservoir	5
4	SS is closed system with reservoir that can hold 5 years of waste	5
5	SS has proper ventilation for waste management	5
6	SS is a closed system with proper insulation	5
7	SS treats waste by incenting the sunlight directly on to waste	4
8	SS has portable opening to compact the waste every 6 months	2

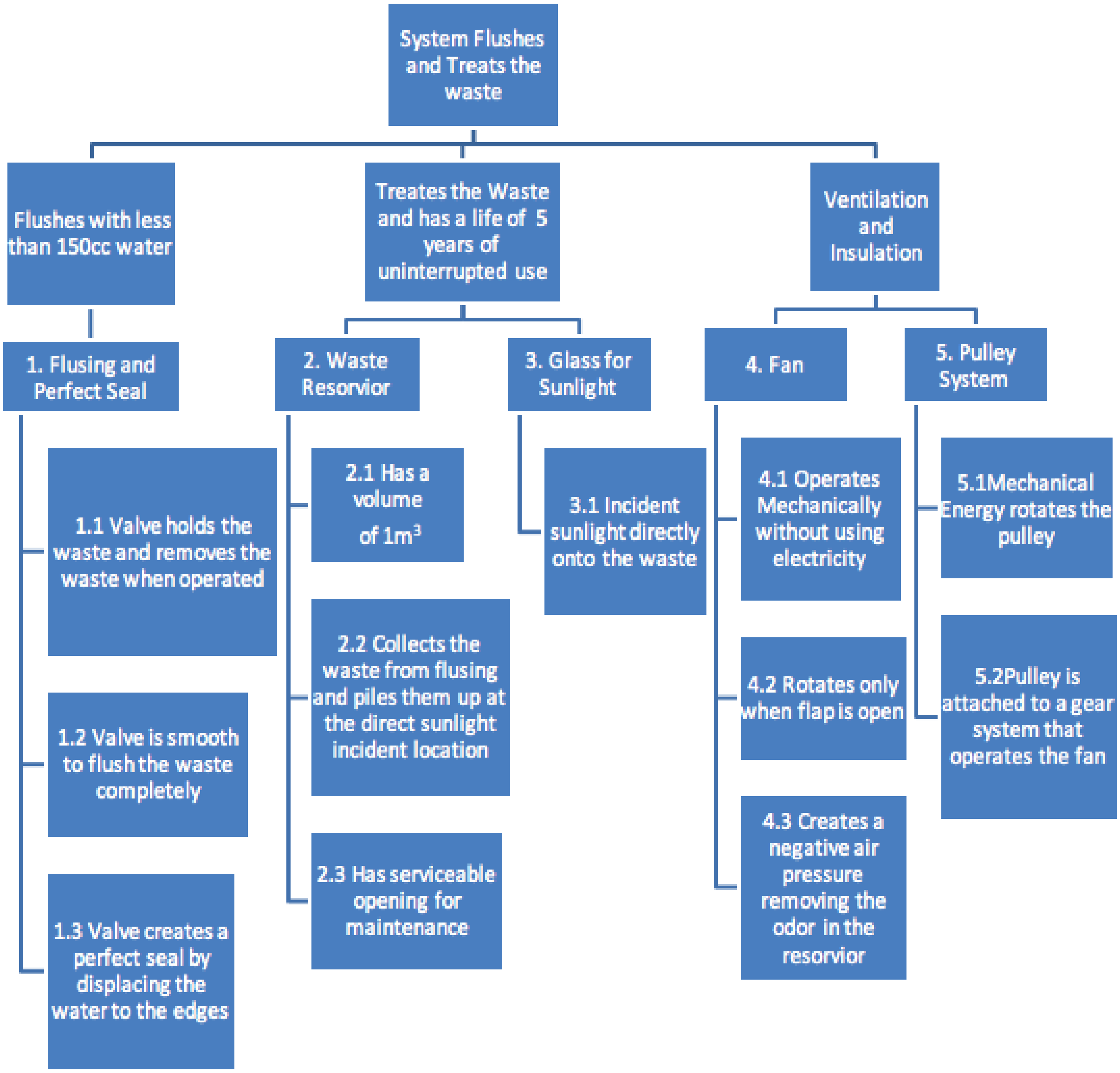


Figure 4: Operational requirements decomposed into design requirements.

Design Requirements – Identified Metrics

Table 3 Design metrics associated to the operational needs.

Metric Number	**Associated Needs**	**Metric**	**Units**	**Minimum Value**	**Max Value**
1	1,2	Volume of water	cm^3	150	200
2	3	Incline Slope	Angle	25	60
3	3,4	Length of Reservoir	m	2	2.5
4	3,4	Breath of Reservoir	m	1	1.5
5	3,4	Height of Reservoir	m	1	1.5
6	7,8	Area of Glass	m^2	0.25	0.56
7	2,3,4	Flapper Radius	cm	4	10
8	5	Fan Speed	rad/s	120	240
9	6	Interior Temperature	Celsius	100	200

3.1.2 Functional allocation and decomposition

The following are the high-level Project Management Improvement functional requirements. Requirements that are in scope and out of scope of this project are noted.

Requirement	In Scope	Out of Scope
Framework		
1. Define project management processes	x	
2. Manage Scope	x	
3. Manage Requirements	x	
4. Manage Budget	x	
5. Manage Risk	x	
6. Manage Communication	x	
7. Manage Roles	x	
8. Manage Project Schedule	x	
9. Standardize Development Methodologies		x
10. Manage Project Change		x
11. Manage Quality		x
12. Manage Implementation		x
13. Improve Project Management tools		x
14. Improve strategic DoIT processes		x
Tools		

1. Provide consistent tools and templates	**x**	
2. Enable collaborative communications and knowledge management tools	**x**	
3. Provide a division-wide project management system	**x**	
4. Define a common DoIT vision and purpose for CBS data		**x**
Project Management Skills		
1. Ensure informed sponsorship, empowered project management and supportive line management	**x**	
2. Define roles in the project, including those roles customer personnel will play	**x**	
3. Ensure that project managers are well trained and follow certain minimum standard practices	**x**	
4. Put the right teams together	**x**	
5. Give the project team, consisting of DoIT and customer staff, the freedom to succeed		**x**
6. Develop an Office of Project Management to help achieve consistency		**x**
7. Make project managers responsible and accountable for following standard processes	**x**	
Communications		
1. Recognize that communication is central to Project Management success	**x**	
2. Build personal relationships across organizational lines	**x**	
3. Ensure everyone involved has a clear vision of the project's aims and scope	**x**	
Culture		

1. Minimize adverse impact of transformative learning or change	**x**	
2. Create a culture that values project management	**x**	
3. Institutionalize practices	**x**	
Thinking		
1. Develop project management thinking skills	**x**	
2. Bridge potential gaps in understanding between DoIT and the customer		**x**
3. Assess interdependencies between projects, especially scope changes		**x**
4. Align staff with goals and communicate the overall objective so that people understand where they fit		**x**
Politics		
1. Understand and manage the politics of the project		**x**
2. Pursue targeted, strategic project selection		**x**
3. Pay close attention to good customer relations at all levels of DoIT		**x**

3.2 FOUR CONCEPT DRAWINGS

Since the sanitation system consists of different parts which drive the success of the entire project, we decided to focus on different concepts for specific different design needs. For example, to achieve an effective waste treatment reservoir, it is necessary for the sunlight to incident on the waste directly. This is one component of the entire design but can be achieved by different processes. Similarly, an effective sealed valve to separate the environment from the waste while flushing the waste with 150cc of water can be achieved by different valve designs. Again, this is only one component of the project. Therefore, we here present 6 different designs to achieve the most effective design. The associated design metrics are included in concept scoring section.

Concept 1: Waste Reservoir - #1

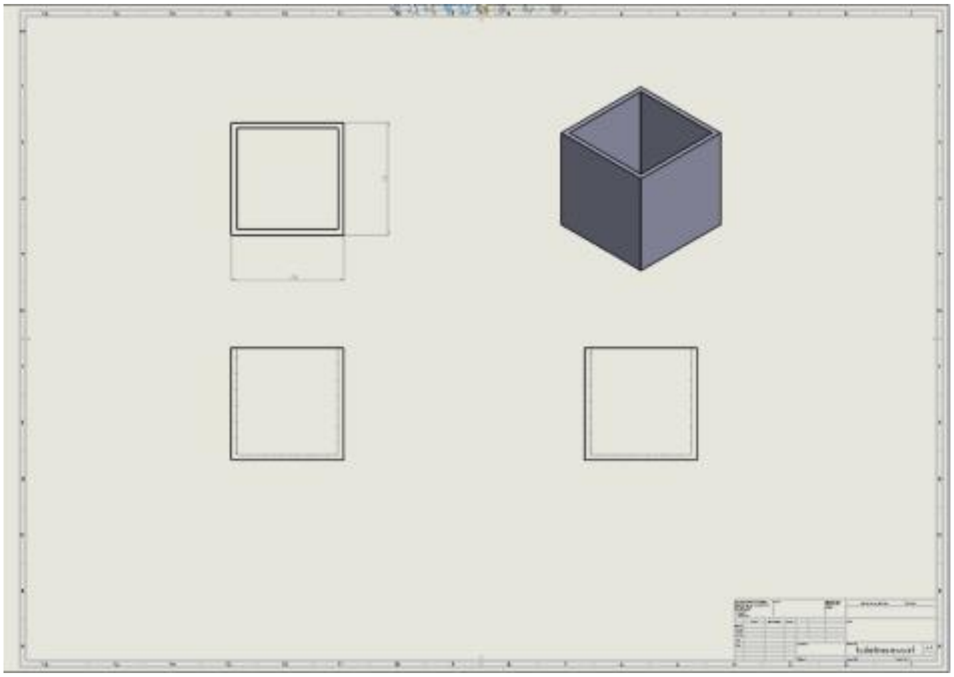


Figure 5: Concept design 1 for the waste reservoir.

Concept 2: Waste Reservoir - #2

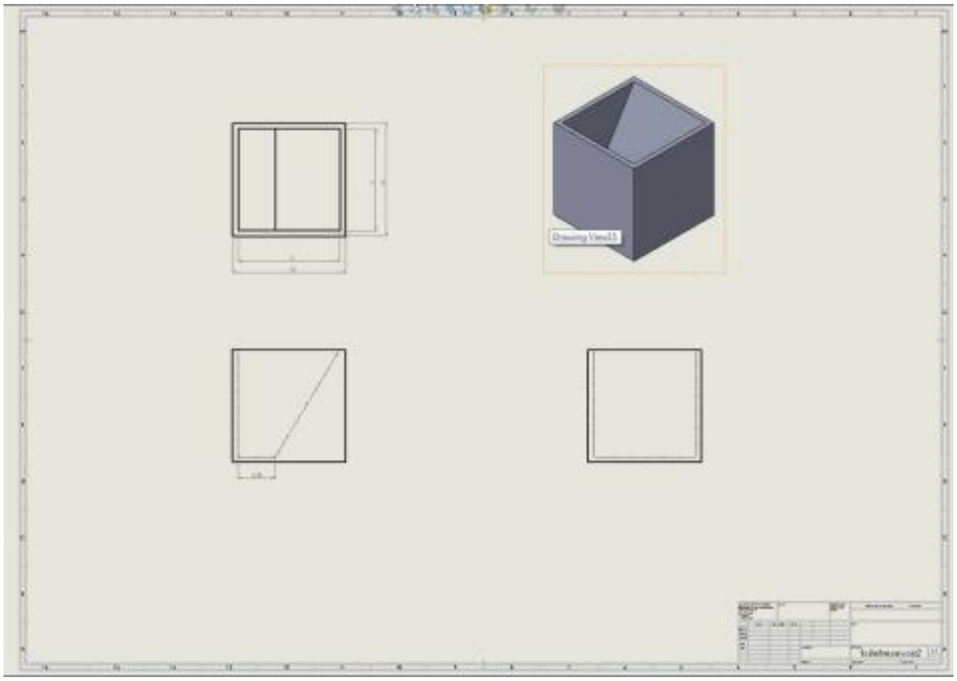


Figure 6: Concept design 2 for the waste reservoir.

Concept 3: Flapper - #1

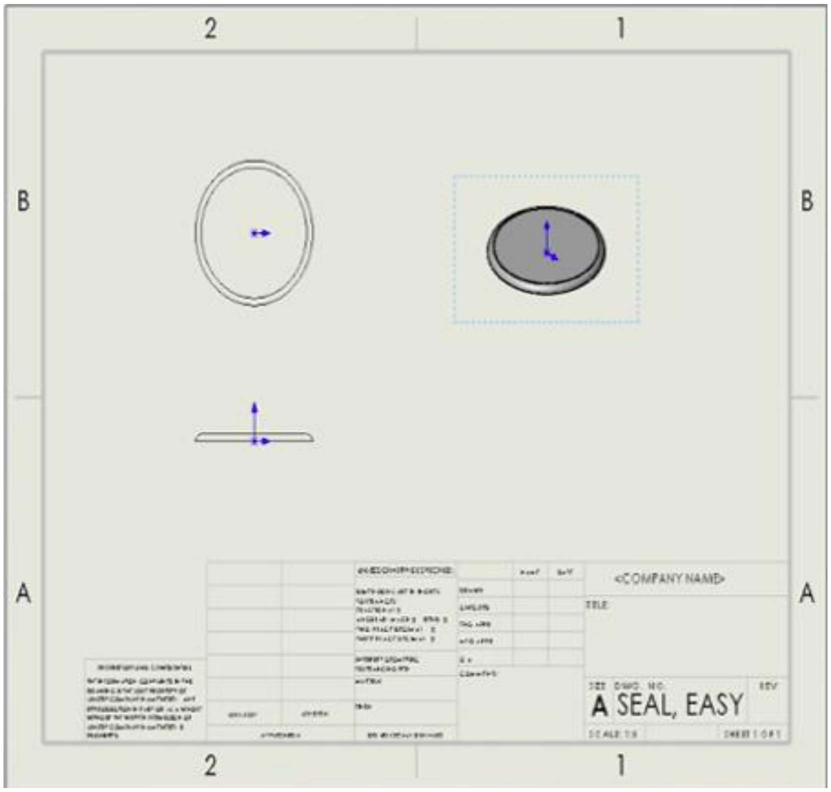


Figure 7: Concept Design 1 for the seal.

Concept 4: Flapper - #2

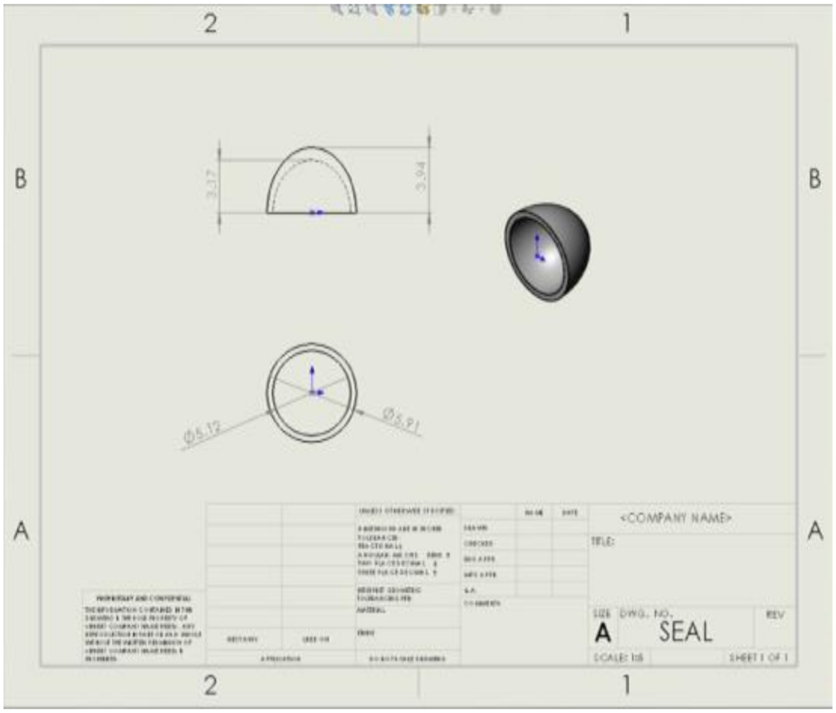


Figure 8: Concept design 2 for the seal.

Concept 5: Fan System - #1

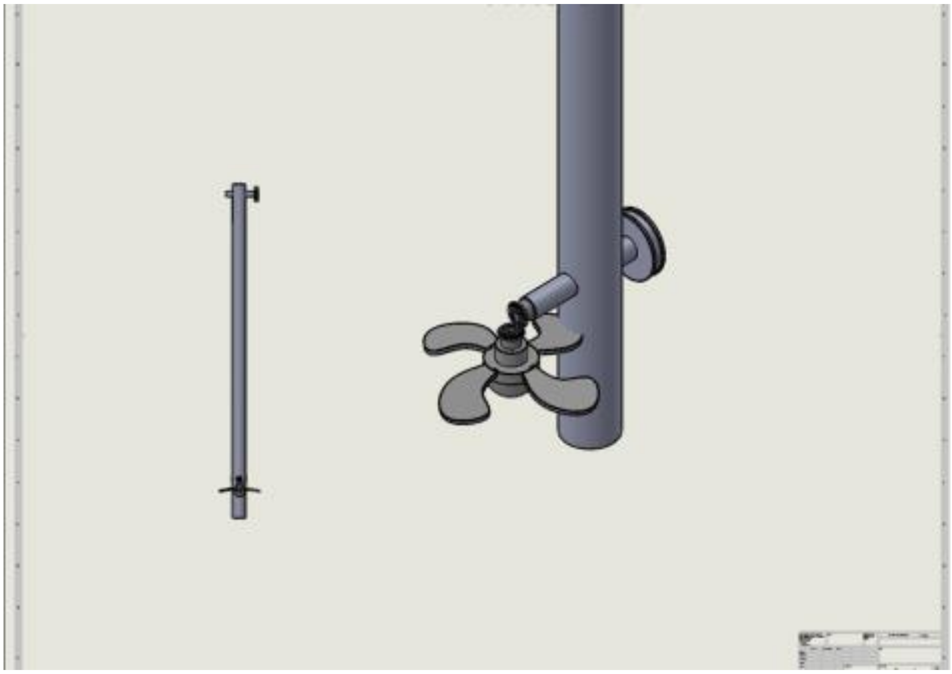


Figure 9: Concept design 1 for the fan system.

Concept 6: Fan System - #2

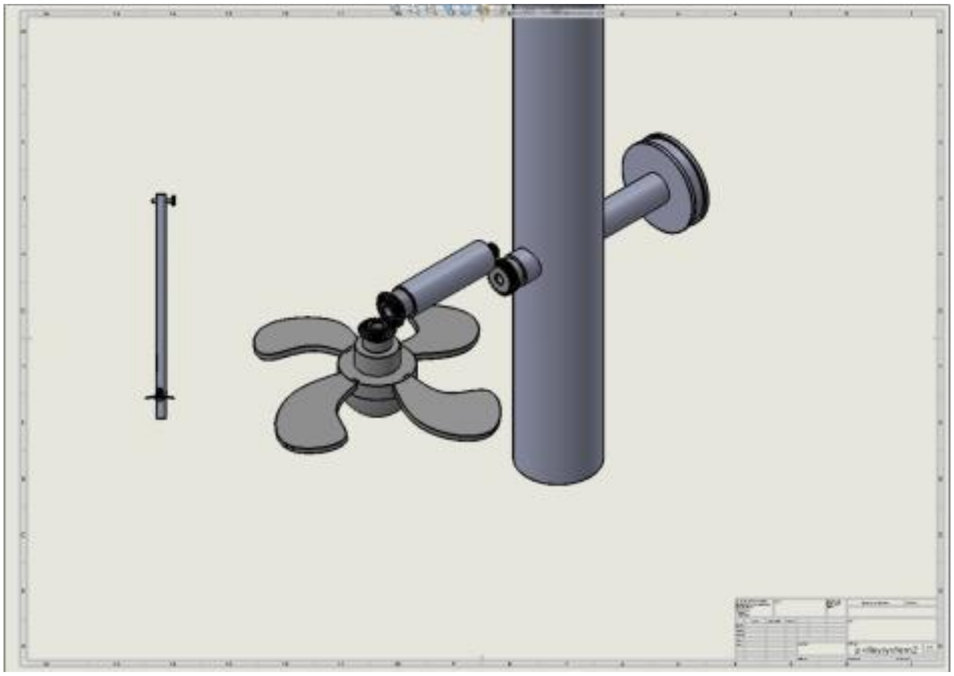


Figure 10: Concept design 2 for the fan system.

3.3 CONCEPT SELECTION PROCESS

3.3.1 Preliminary analysis of each concept’s physical feasibility based on design requirements, function allocation, and functional decomposition

Concept 1: Waste Reservoir - #1

Design 1 is a simple thin walled cube. This is the reservoir for the waste. It needs to be large enough to allow waste collection for an extended period of time. Benefits of this design include its simplicity of design and construction. The primary flaw with this design is the buildup of waste directly below pot. Waste will build up over time and eventually prevent further use of the toilet, even though there may still be unused space within the reservoir.

Concept 2: Waste Reservoir - #2

Design 2 is similar to design 1, but it includes a partially slanted base. This slant will help the waste slide towards the back of the reservoir, effectively dealing with the waste buildup problem associated with design 1. The downside to this slanted base is that it decreases the volume of the reservoir. This will either increase the frequency the reservoir must be cleaned, or require a larger reservoir.

Concept 3: Flapper - #1

The flapper is responsible for flushing the waste and maintaining a seal between the reservoir and the user. Flapper 1 is a simple flat pan design. This design is easy to produce and operate. Furthermore, waste that hits the pan will stay in place. The flapper also needs to create a seal. Our seal design requires water to rest on the edge between the flapper and the pot. Flapper 1 might require more water to make the seal, since the water is free to flow over the entire flapper.

Concept 4: Flapper - #2

Flapper 2 is similar to flapper 1, except that the shape is conical instead of flat. This design will force the water to the edge of the flapper onto the area where a seal is required. This would minimize the amount of water needed to make an adequate seal. This design has several drawbacks however. The conical shape would also have the same effect on waste landing on the flapper, and it might even be pushed onto the side of the pot, creating a mess requiring clean up. This shape would also be harder to produce.

Concept 5: Fan System - #1

The fan system is responsible for maintaining negative air pressure in the reservoir. This sketch shows the mechanism for turning the fan. An upper pulley allows for lifting a weight. A second, lower pulley is also attached to the mass, and is turned as the mass is dropped. Motion is translated through gears to the fan. Right angle gears allow for the fan to be placed in a vertical venting tube exiting the reservoir. This design has relatively few moving parts. The downside to this system is that the speed of the fan cannot be specified.

Concept 6: Fan System - #2

This design adds a gear box to Fan System 1, allowing for the speed of the fan to be set. This can be used to optimize the ventilation of the reservoir. However, this design is more complicated, driving up cost, assembly complexity, and likelihood of failure.

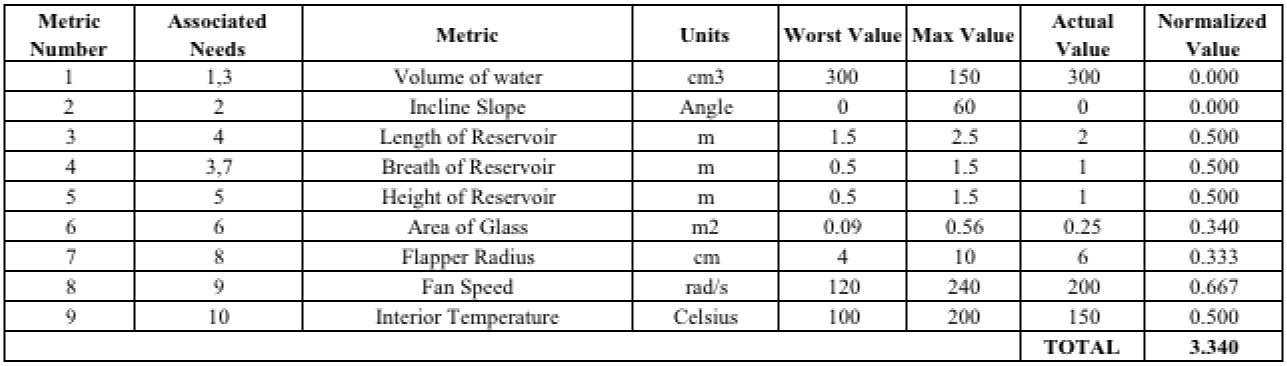
3.3.2 Concept scoring

Since there are 6 designs, there are 8 possible combinations we can achieve for the designs.

The 8 combinations are as follows:

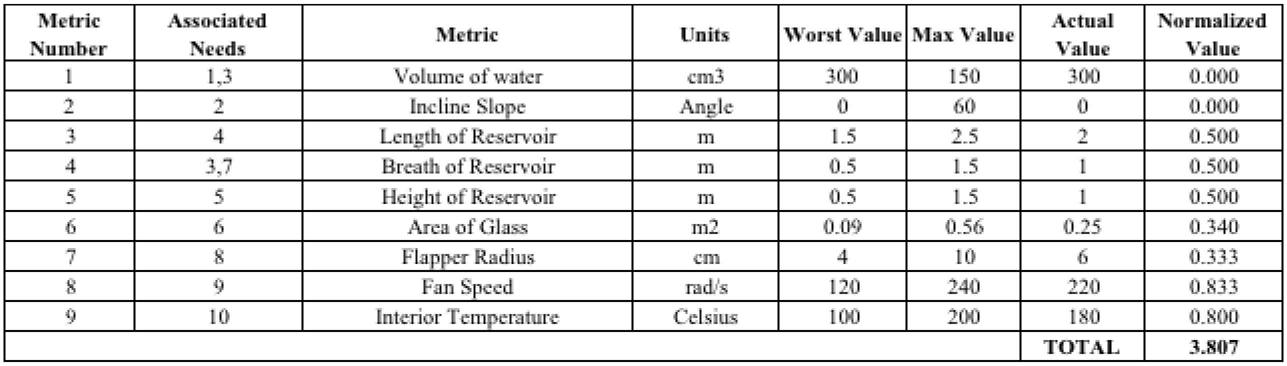
1. Designs 1,3,5
2. Designs 1,3,6
3. Designs 1,4,5
4. Designs 1,4,6
5. Designs 2,3,5
6. Designs 2,3,6
7. Designs 2,4,5
8. Designs 2,4,6

Table 4 Design Metric for Design 1,3,5



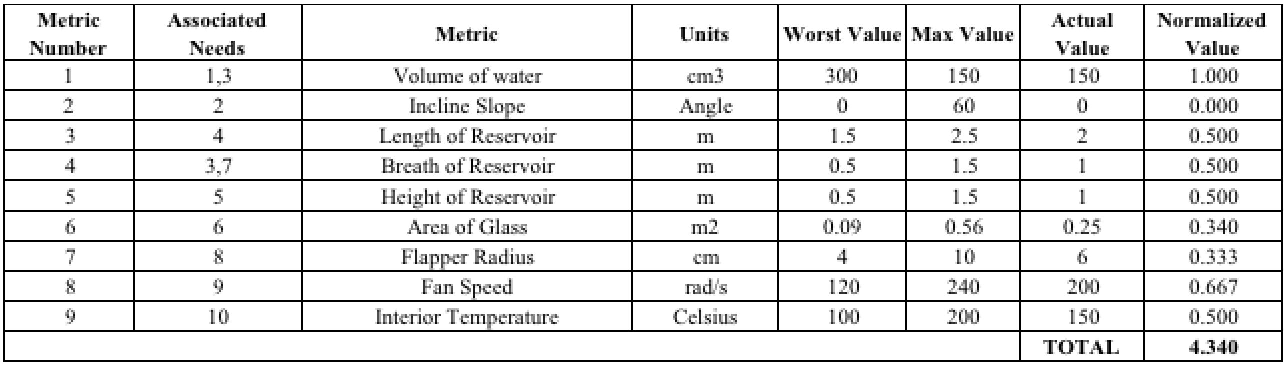
Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	1,3	Volume of water	cm3	300	150	300	0.000
2	2	Incline Slope	Angle	0	60	0	0.000
3	4	Length of Reservoir	m	1.5	2.5	2	0.500
4	3,7	Breath of Reservoir	m	0.5	1.5	1	0.500
5	5	Height of Reservoir	m	0.5	1.5	1	0.500
6	6	Area of Glass	m2	0.09	0.56	0.25	0.340
7	8	Flapper Radius	cm	4	10	6	0.333
8	9	Fan Speed	rad/s	120	240	200	0.667
9	10	Interior Temperature	Celsius	100	200	150	0.500
						TOTAL	**3.340**

Table 5 Design Metric for Design 1,3,6



Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	1,3	Volume of water	cm3	300	150	300	0.000
2	2	Incline Slope	Angle	0	60	0	0.000
3	4	Length of Reservoir	m	1.5	2.5	2	0.500
4	3,7	Breath of Reservoir	m	0.5	1.5	1	0.500
5	5	Height of Reservoir	m	0.5	1.5	1	0.500
6	6	Area of Glass	m2	0.09	0.56	0.25	0.340
7	8	Flapper Radius	cm	4	10	6	0.333
8	9	Fan Speed	rad/s	120	240	220	0.833
9	10	Interior Temperature	Celsius	100	200	180	0.800
						TOTAL	**3.807**

Table 6 Design Metric for Design 1,4,5



Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	1,3	Volume of water	cm3	300	150	150	1.000
2	2	Incline Slope	Angle	0	60	0	0.000
3	4	Length of Reservoir	m	1.5	2.5	2	0.500
4	3,7	Breath of Reservoir	m	0.5	1.5	1	0.500
5	5	Height of Reservoir	m	0.5	1.5	1	0.500
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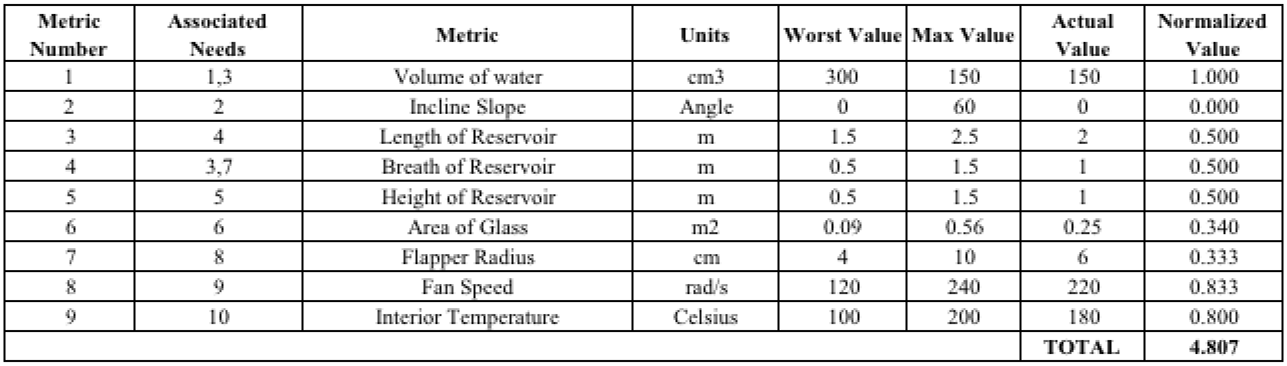
8	9	Fan Speed	rad/s	120	240	200	0.667
9	10	Interior Temperature	Celsius	100	200	150	0.500
						TOTAL	**4.340**

Table 7 Design Metric for Design 1,4,6



Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
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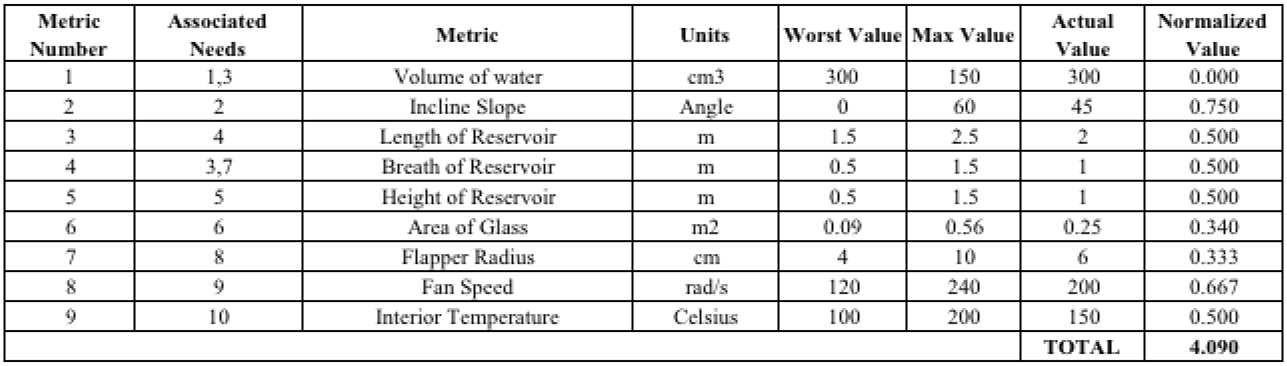
8	9	Fan Speed	rad/s	120	240	220	0.833
9	10	Interior Temperature	Celsius	100	200	180	0.800
						TOTAL	**4.807**

Table 8 Design Metric for Design 2,3,5



Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
1	1,3	Volume of water	cm3	300	150	300	0.000
2	2	Incline Slope	Angle	0	60	45	0.750
3	4	Length of Reservoir	m	1.5	2.5	2	0.500
4	3,7	Breath of Reservoir	m	0.5	1.5	1	0.500
5	5	Height of Reservoir	m	0.5	1.5	1	0.500
6	6	Area of Glass	m2	0.09	0.56	0.25	0.340
7	8	Flapper Radius	cm	4	10	6	0.333
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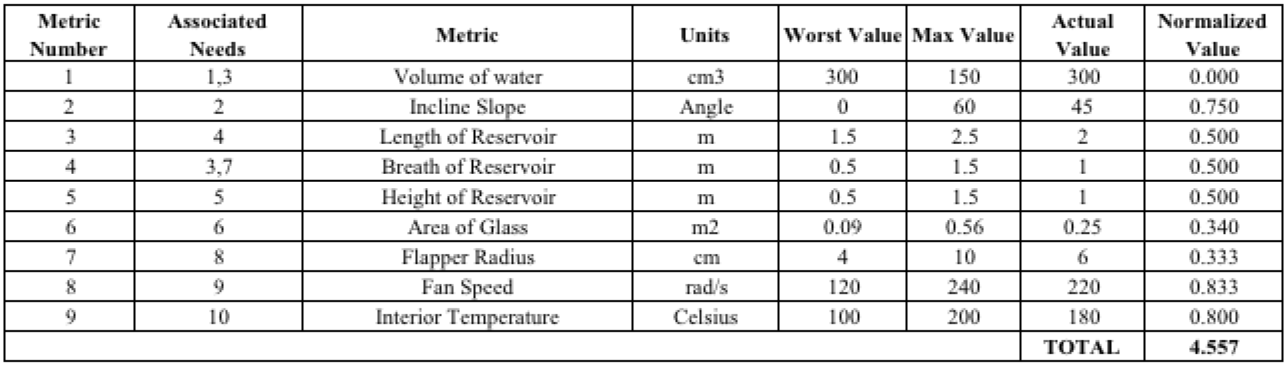
9	10	Interior Temperature	Celsius	100	200	150	0.500
						TOTAL	**4.090**

Table 9 Design Metric for Design 2,3,6



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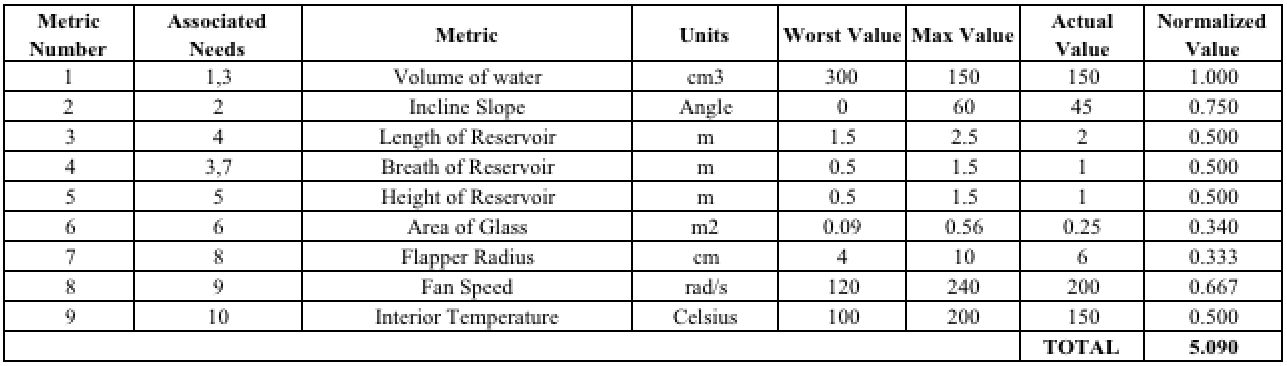
8	9	Fan Speed	rad/s	120	240	220	0.833
9	10	Interior Temperature	Celsius	100	200	180	0.800
						TOTAL	**4.557**

Table 10 Design Metric for Design 2,4,5



Metric Number	Associated Needs	Metric	Units	Worst Value	Max Value	Actual Value	Normalized Value
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5	5	Height of Reservoir	m	0.5	1.5	1	0.500
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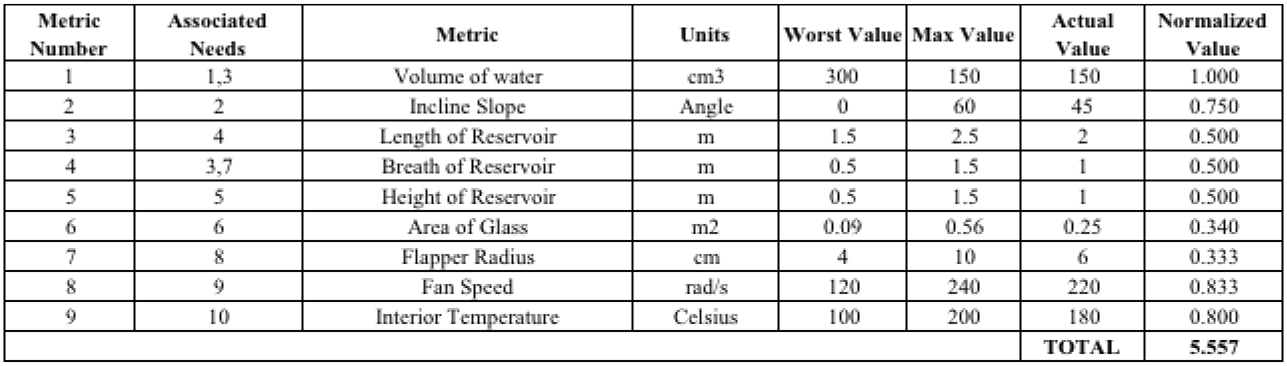
7	8	Flapper Radius	cm	4	10	6	0.333
8	9	Fan Speed	rad/s	120	240	200	0.667
9	10	Interior Temperature	Celsius	100	200	150	0.500
						TOTAL	**5.090**

Table 11 Design Metric for Design 2,4,6



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9	10	Interior Temperature	Celsius	100	200	180	0.800
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3.3.3 Final summary

WINNER: Combination of Concept 2, 4, 6

Looking at the design metrics, the combination of designs 2,4,6 gives the highest normalized value making it the winner of the combination of designs. The sanitation system (toilet) can be regarded as three individual parts which are reservoir, flapper (Valve), and fan system. Therefore, we started to design each part individually, and then compared each part to its own group of designs and apply the better design to form a winning combination as a final design. For the reservoir, concept 2 has several advantages compared to the reservoir concept 1. For our goals of the reservoir, it should spread out the waste to reservoir's bottom and make it similar to a flat ground so that the sunlight could reach to the waste directly. Reservoir concept 2 is easy to get the waste to its bottom since waste could slide on the reservoir's inclined surface. However, reservoir concept 1 is a regular reservoir which has a flushing valve that connects to it directly without any spreading out process. Thus, the waste would reach to a single point on the bottom from the waste flushing valve and therefore form like a cheesecake that sunlight could not reach to because of the toilet outer structure standing right above the location of the waste piled up. If the sunlight would does not reach to the surface of waste directly, it would not kill the germs and bacteria and then it will be dependent solely on the temperature generated inside the reservoir to treat the waste.

For the selection of flapper, we also had two concepts of design. Concept 4 has several advantages over the concept 3. This design would create more pressure on the top of the flapper since it has a larger area compared to the flapper concept 3. This would minimize the amount of water needed to make an adequate seal. Concept 4 is more stable for protecting the flushing system away from leaking water from the tank into the bowl. A leaking flapper can waste significant amount of water over time. Therefore, the quality of sealing would be an important goal we have to consider about the valve design.

In comparison to the two concepts of fan's design (ventilation process), the reason that fan concept 6 is the winner because we can control the speed of the fan. This controlling process makes sure that the fan is going fast enough to adequately pull the air out of the system. Unlike concept 5, this design shows how long the fan will run based on one drop of the mass. With fan concept 6, customer can set the speed of the fan to a constant value which depends on the weather and waste's odor there is inside the waste reservoir. Therefore, customer can tailor it for best fluid flow, and increasing the amount the fan will spin from one drop of the mass.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

Sanitation System Performance Goals

1. Seat of the sanitation is compatible with both of squatting and seating.
2. Toilet flushing system deals with waste of no more than 1.48kg for per person.

   (Average waste for an American is 0.685 kg per time of using toilet)
3. Toilet flushing water is under 150 cm^3 per time.
4. There is a perfect seal separating the environment and the waste.
5. Reservoir of the toilet has volume of 1 m^3.
6. Toilet flushing system (PPC tube and incline) is visible on an MRI.
7. Waste stored in the reservoir could remove once in six months.
8. Both of flushing process and ventilating process can be finished in 15 sec.
9. Reservoir of the sanitation kills 90% percent of germs and bacteria via high temperature and ultraviolet light.
10. Ventilating process is able to ventilate all odor.

3.5 DESIGN CONSTRAINTS

3.5.1 Functional

- The system flushes in less than 150cc of water.
- The system is durable and can be used up to 5 years with limited maintenance for a family of 4.
- The system has proper ventilation and sealing for odorless usage.
- The system has insulation and effective waste treatment mechanism.

3.5.2 Safety

- The system should not have any leakage from the reservoir so that the bacteria could affect the environment.
- There is no health concern for the user when using the sanitation system.

3.5.3 Quality

- The system must be able to be locally fabricated and therefore, it must obey restrictions and local laws for hazardous materials.

3.5.4 Manufacturing

- The materials used in this system must be easily found, sturdy, and easy to fabricate.
- The system must be designed in such a way so that a person with basic masonry skills could assemble the system providing an effective way of solving sanitation problems in rural areas.

3.5.5 Timing

- The gear system should be able to spin the fan for at least 5 minutes (estimated usage time).

3.5.6 Economic

- The biggest economic design constraints for this system is that it should cost less than $150 for the entire structure. Since the system is focused for people living in the developing countries, it needs to be affordable for the poorest people.

3.5.7 Ecological

- The system must be able to form compost from the waster with the application of sunlight and heat containment. This is important for the success of the design.

3.5.8 Aesthetic

- The system must be as compact as possible, but does not need to be very aesthetically pleasing. The only aesthetic concern for the design of this machine was the seating area for the user which can be accomplished by using an actual toilet seat for the full-scale model.

3.5.9 Life cycle

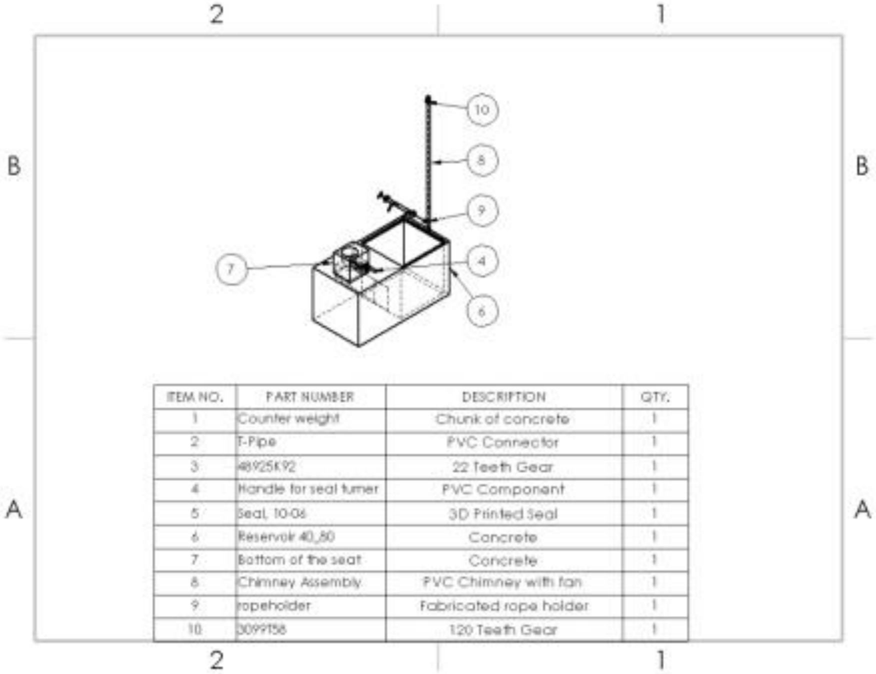
- The system should last more than 15-20 years with 5 initial years of low maintenance.
- The 5 initial years of low maintenance usage will be sufficient for family of 4.

3.5.10 Legal

- The system does not have any sort of patent infringement or legal concern. The closest deign competitor is the design by Global Sustainable Aid Project. GSAP has made their design as an open source design available to anyone.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT DRAWING



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Counter weight	Chunk of concrete	1
2	T-Pipe	PVC Connector	1
3	48925K92	22 Teeth Gear	1
4	Handle for seal turner	PVC Component	1
5	Seal, 10-06	3D Printed Seal	1
6	Reservoir 40_80	Concrete	1
7	Bottom of the seat	Concrete	1
8	Chimney Assembly	PVC Chimney with fan	1
9	ropeholder	Fabricated rope holder	1
10	3099T58	120 Teeth Gear	1

Figure 11: Embodiment drawing with part list.

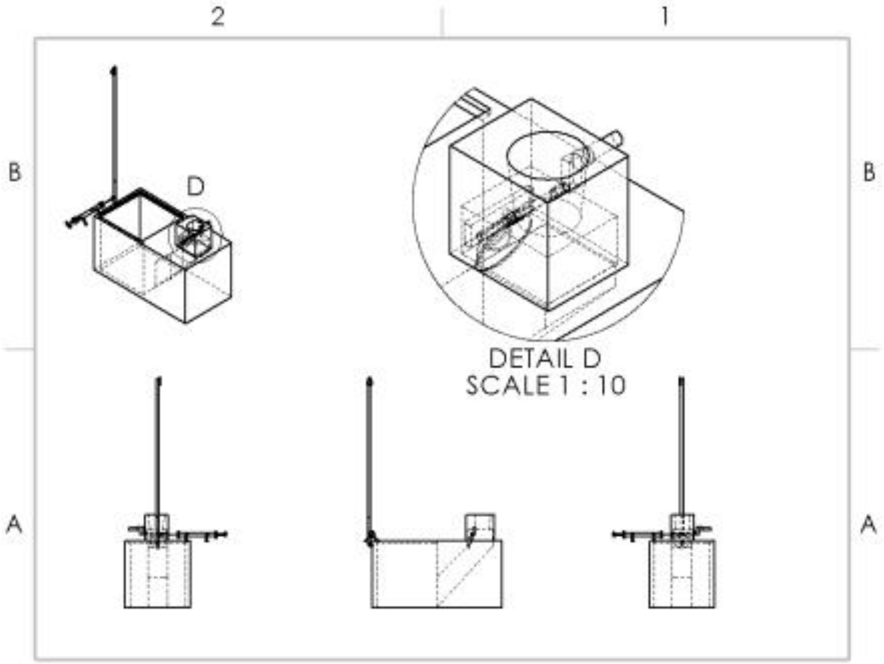


Figure 12: Embodiment drawing different views.

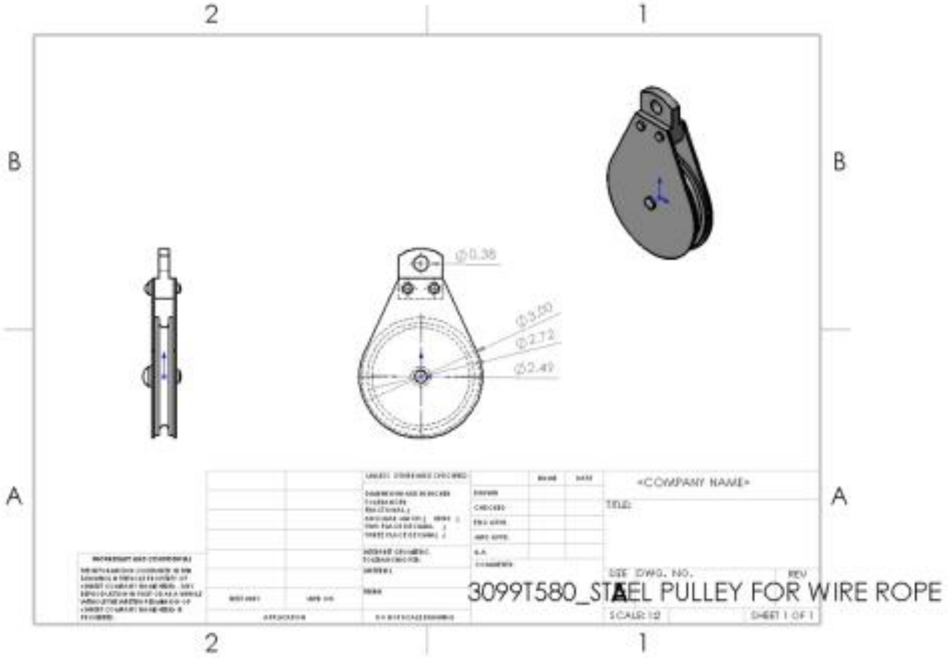


Figure 13: Embodiment drawing of pulley.

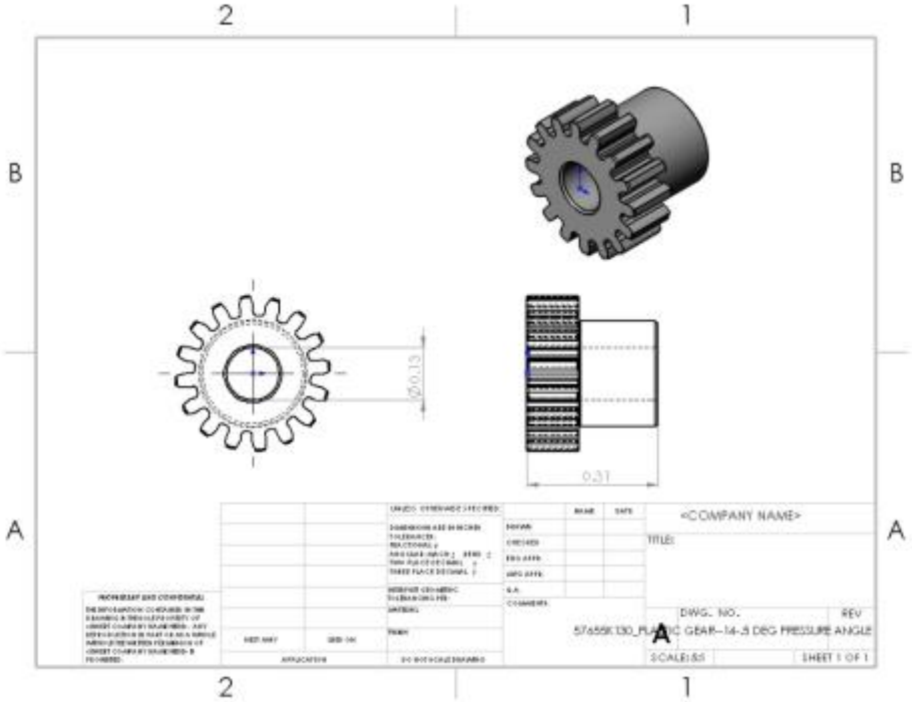


Figure 14: Embodiment drawing of gear.

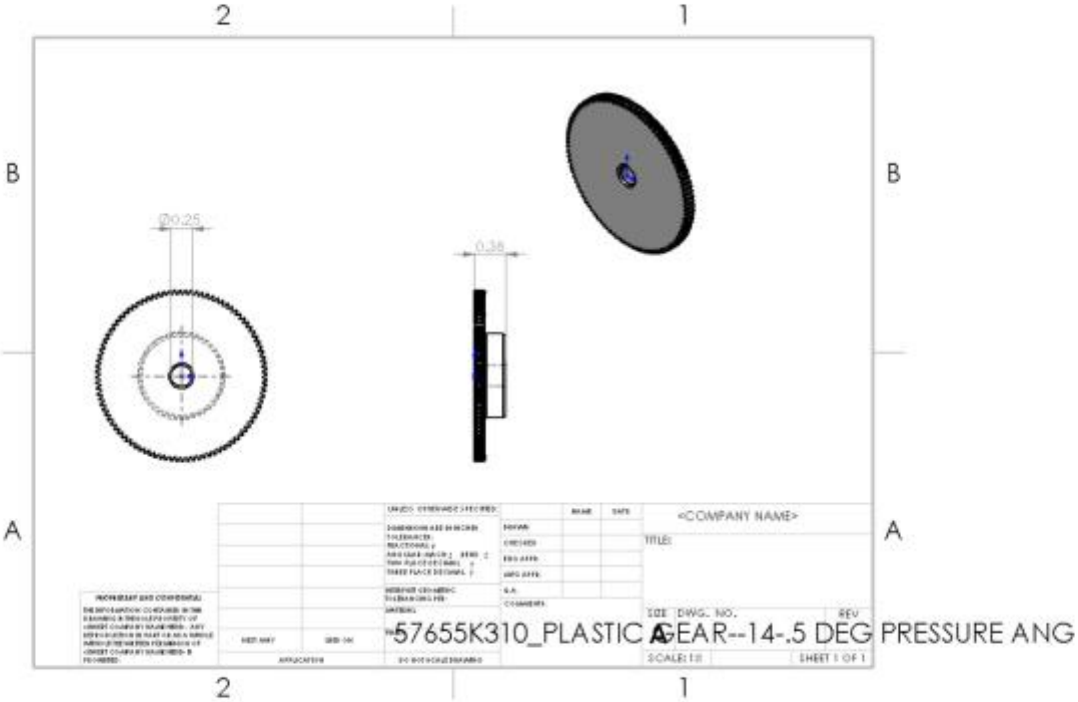


Figure 15: Embodiment drawing for plastic gear.

4.2 PARTS LIST

Table 12 Tentative part list with source, model number and price.

Part	Source	Model No.	Quantity	Unit Cost
Steel Pulley for Wire Rope	http://www.mcmaster.com/#3099t58/=14hvoid	3099T58	1	$14.17
Plastic Gear - 14-1/2 Degree Pressure Angle	http://www.mcmaster.com/#57655K13	57655K13	1	$7.51
Plastic Gear - 14-1/2 Degree Pressure Angle	http://www.mcmaster.com/#57655k31/=14hvpsd	57655K31	1	$9.68
11 in. x 14 in. Non-glare Styrene Sheet	http://www.homedepot.com/p/11-in-x-14-in-Non-glare-Styrene-Sheet-1S11143A/202771350	1S11143A	1	$4.60
Corrosion-Resistant White PFA Threaded Fitting	http://www.mcmaster.com/#45505k175/=14hvrpa	45505K175	1	$41.73
1/8 Pipe Size, Unthreaded Pipe, 2' Length	http://www.mcmaster.com/#45375k731/=14hvsil	45375K731	1	$24.83
Standard-Wall White PVC Unthreaded Pipe	http://www.mcmaster.com/#48925k92/=14hvszi	48925K92	1	$3.25

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

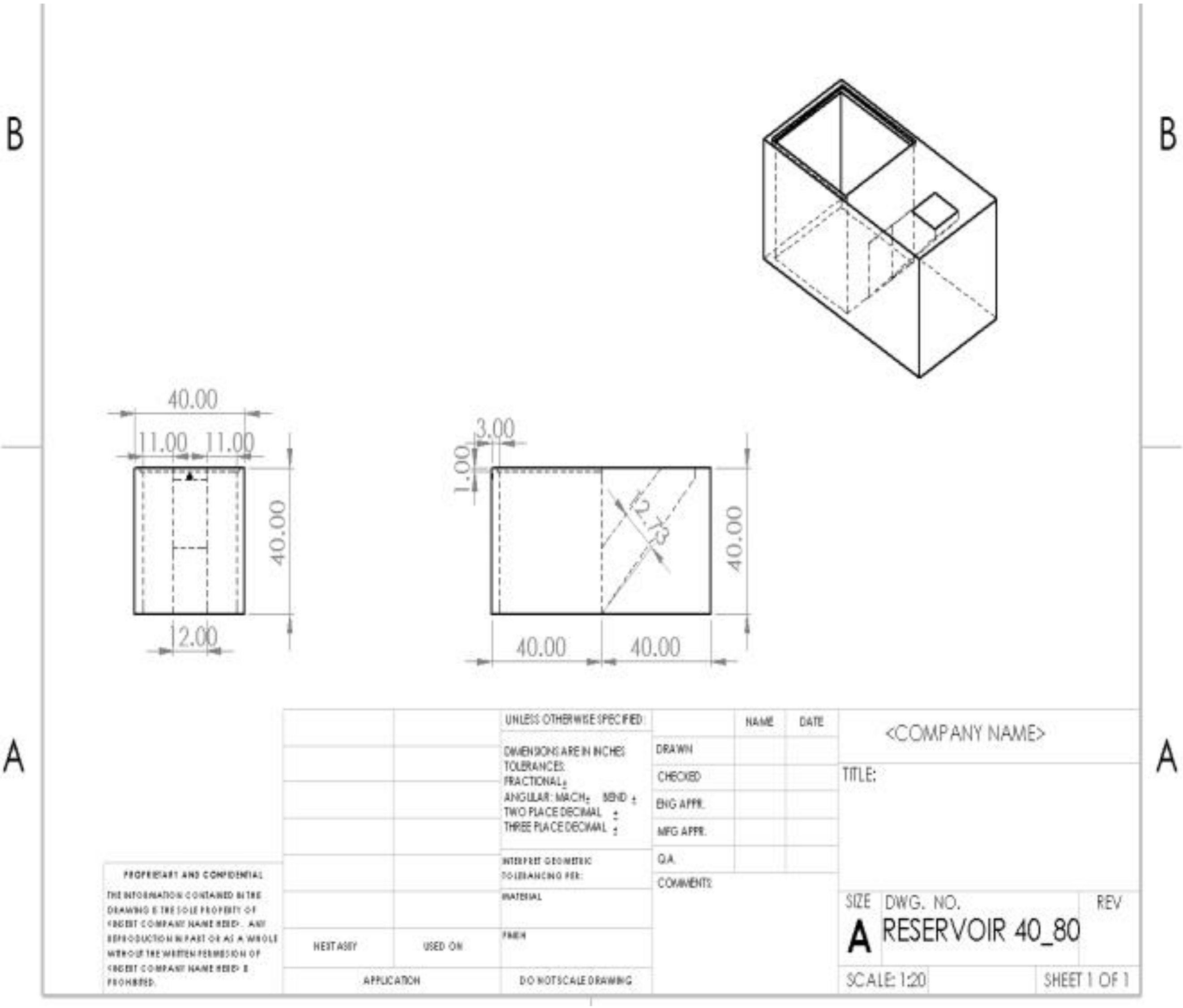


Figure 16: Embodiment drawing for manufactured reservoir.

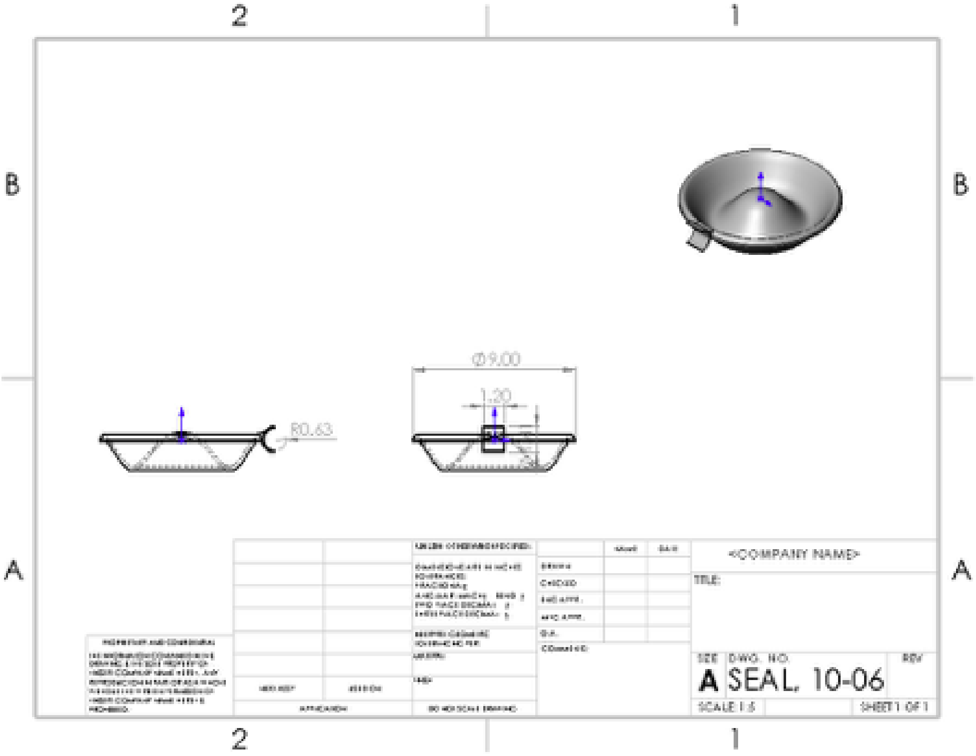


Figure 17: Embodiment diagram of 3D printed seal.

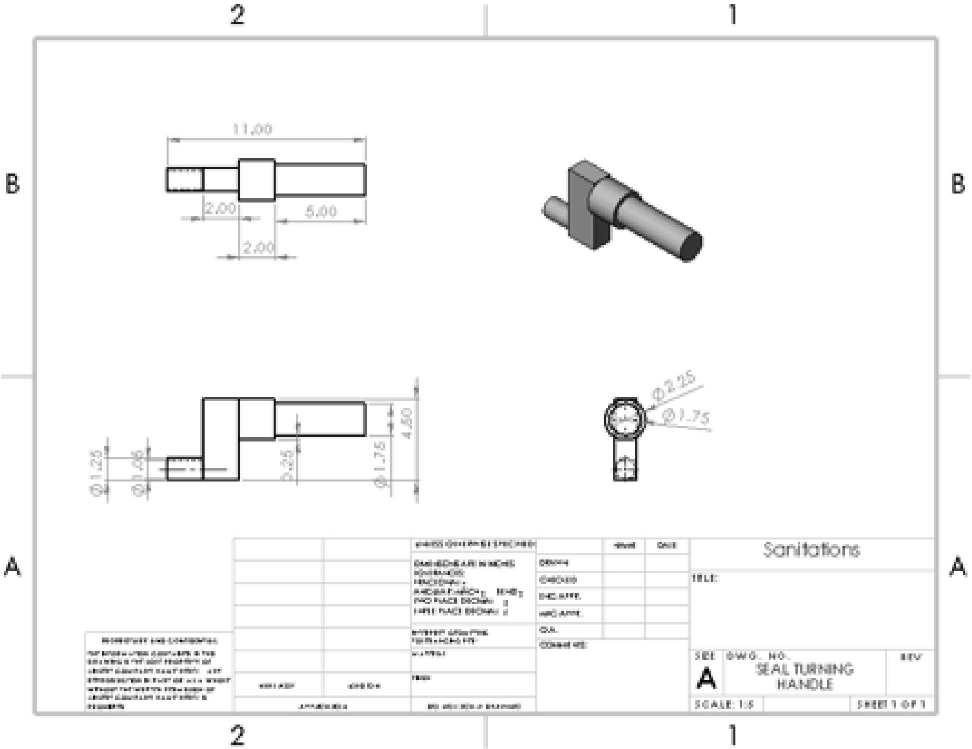


Figure 18: Embodiment diagram for pipe fitting.

4.4 DESCRIPTION OF THE DESIGN RATIONALE FOR THE CHOICE/SIZE/SHAPE OF EACH PART

11. Valve

The shape and size of the valve is designed to reduce the consumption of water and keep it under 150cc in addition to making a perfect seal. The valve would be 3D printed since this design is a novel one and there is nothing available to this in the market at present.

12. Counterweight attachment to the Valve

The counter weight will be made out of the concrete and is attached to the valve with a pvc pipe and a t-shape pvc. The counterweight’s volume is kept at 16 ounces so that it could hold up to 1.1 kg of weight on the valve.

13. Reservoir

The dimensions of the reservoir is selected to be 1 m^3 in the full scale model. This will hold up to 5 years of usage for a family of 4 people. Since, the design of the reservoir is convenient for periodic maintenance, the usage can last much longer than 5 years.

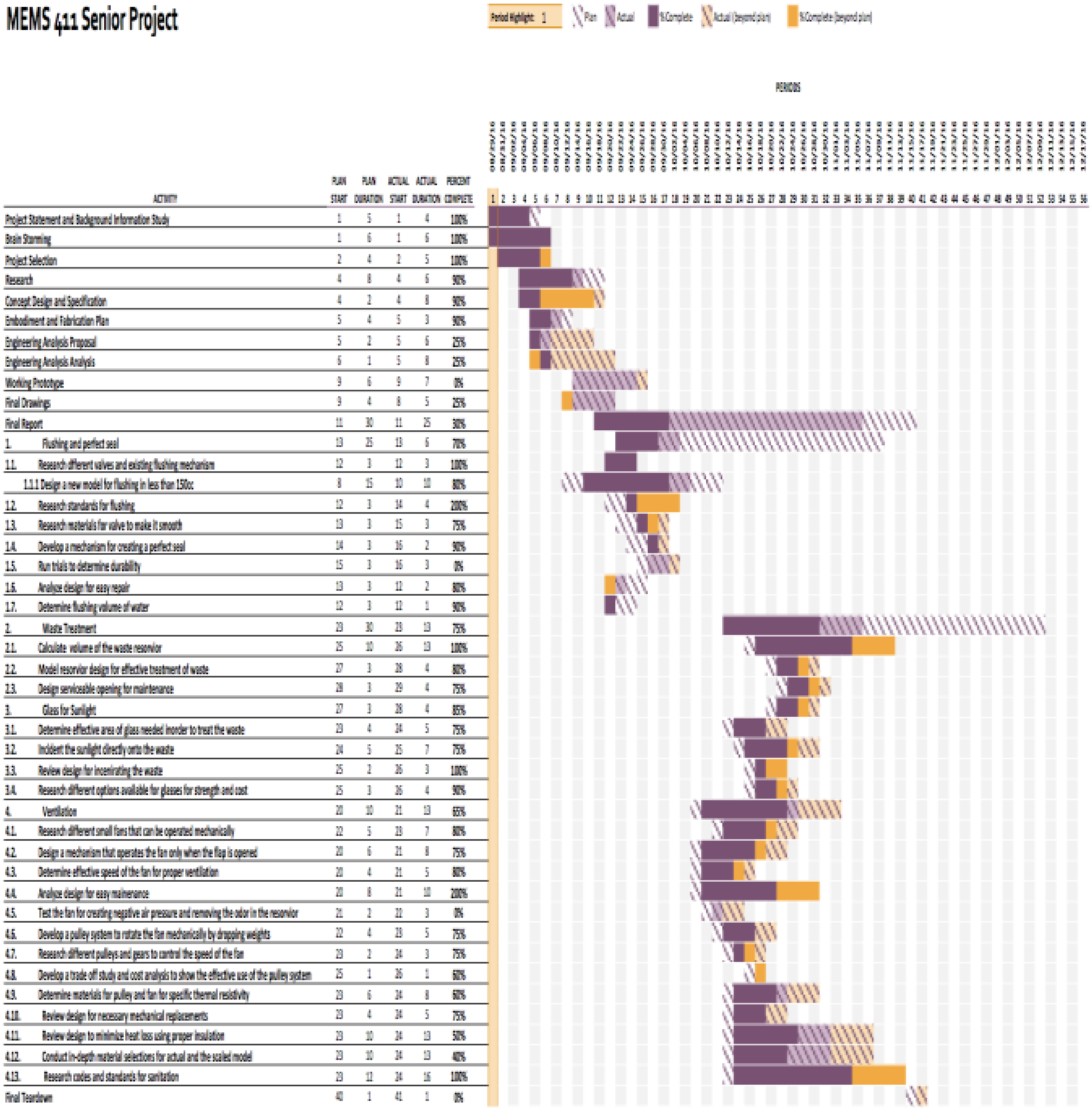
14. Ventilation System

A small fan is placed within the ventilation shaft to draw air out of the reservoir. This will minimize the foul air that can escape into the chamber where the user is sitting. The fan is run by a belt connected to a falling mass system. The falling mass system allows the fan to be run without the use of electricity. The falling mass system consists of a mass on a weight suspended by a pulley. As the mass falls, the other end of the rope uncoils from a rope holder, like a garden hose coiler. The holder spins as the rope is released, and that motion is translated through a shaft to the belt, and then to the fan. Along the shaft is a transmission consisting of two gears. The gears will increase the speed of the fan to ensure proper ventilation of the chamber.

15. Miscellaneous

The different attachments have been made using pvc fittings. The dimensions of the pvc differs depending on the application of it and the scale. For treating the waste, we needed the sunlight to incident on the waste directly without any obstruction. We choose to use plexi glass on top of the reservoir to create insulation but also allow the sunlight to incident on the waste directly. The plexi glass for the scale model has a dimension of 14”X12”. The chosen plexi glass’s cost is relatively cheaper and therefore, we decided to use this one.

4.5 GANTT CHART



MEMS 411 Senior Project

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Project Statement and Background Information Study	1	5	1	4	100%
Brain Storming	1	6	1	6	100%
Project Selection	2	4	2	5	100%
Research	4	8	4	6	90%
Concept Design and Specification	4	2	4	8	90%
Embodiment and Fabrication Plan	5	4	5	3	90%
Engineering Analysis Proposal	5	2	5	6	25%
Engineering Analysis Analysis	6	1	5	8	25%
Working Prototype	9	6	9	7	0%
Final Drawings	9	4	8	5	25%
Final Report	11	30	11	25	30%
1. Flushing and perfect seal	13	25	13	6	70%
1.1. Research different valves and existing flushing mechanism	12	3	12	3	100%
1.1.1 Design a new model for flushing in less than 150cc	8	15	10	10	80%
1.2. Research standards for flushing	12	3	14	4	200%
1.3. Research materials for valve to make it smooth	13	3	15	3	75%
1.4. Develop a mechanism for creating a perfect seal	14	3	16	2	90%
1.5. Run trials to determine durability	15	3	16	3	0%
1.6. Analyze design for easy repair	13	3	12	2	80%
1.7. Determine flushing volume of water	12	3	12	1	90%
2. Waste Treatment	23	30	23	13	75%
2.1. Calculate volume of the waste reservoir	25	10	26	13	100%
2.2. Model reservoir design for effective treatment of waste	27	3	28	4	80%
2.3. Design serviceable opening for maintenance	28	3	29	4	75%
3. Glass for Sunlight	27	3	28	4	85%
3.1. Determine effective area of glass needed inorder to treat the waste	23	4	24	5	75%
3.2. Incident the sunlight directly onto the waste	24	5	25	7	75%
3.3. Review design for incinerating the waste	25	2	26	3	100%
3.4. Research different options available for glasses for strength and cost	25	3	26	4	90%
4. Ventilation	20	10	21	13	65%
4.1. Research different small fans that can be operated mechanically	22	5	23	7	80%
4.2. Design a mechanism that operates the fan only when the flap is opened	20	6	21	8	75%
4.3. Determine effective speed of the fan for proper ventilation	20	4	21	5	80%
4.4. Analyze design for easy mainenance	20	8	21	10	200%
4.5. Test the fan for creating negative air pressure and removing the odor in the reservoir	21	2	22	3	0%
4.6. Develop a pulley system to rotate the fan mechanically by dropping weights	22	4	23	5	75%
4.7. Research different pulleys and gears to control the speed of the fan	23	2	24	3	75%
4.8. Develop a trade off study and cost analysis to show the effective use of the pulley system	25	1	26	1	60%
4.9. Determine materials for pulley and fan for specific thermal resistivity	23	6	24	8	60%
4.10. Review design for necessary mechanical replacements	23	4	24	5	75%
4.11. Review design to minimize heat loss using proper insulation	23	10	24	13	50%
4.12. Conduct in-depth material selections for actual and the scaled model	23	10	24	13	40%
4.13. Research codes and standards for sanitation	23	12	24	16	100%
Final Teardown	40	1	41	1	0%

Figure 19: Gantt chart for the project.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 A form, signed by your section instructor

This section is not applicable.

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

Our design does not contain any high stress areas. As such, a failure analysis simulation was not deemed the best analysis that could be performed.[1] Instead, a motion analysis of the ventilation system was created. The aim of this study was to determine the best combination of variables involved in the system, including the hanging mass weight and angle of the ramp. These variables would be difficult to solve for without the use of simulation software and Mathematica.

5.2.2 Summary statement of analysis done

Shown in the figure below is the setup of the engineering analysis. There are three components: the spool-fan system, and two rings representing the supports holding up the spool. The moment from the falling mass is shown in this image. The friction forces are modeled with mates, and the drag moment cannot be seen in this view.

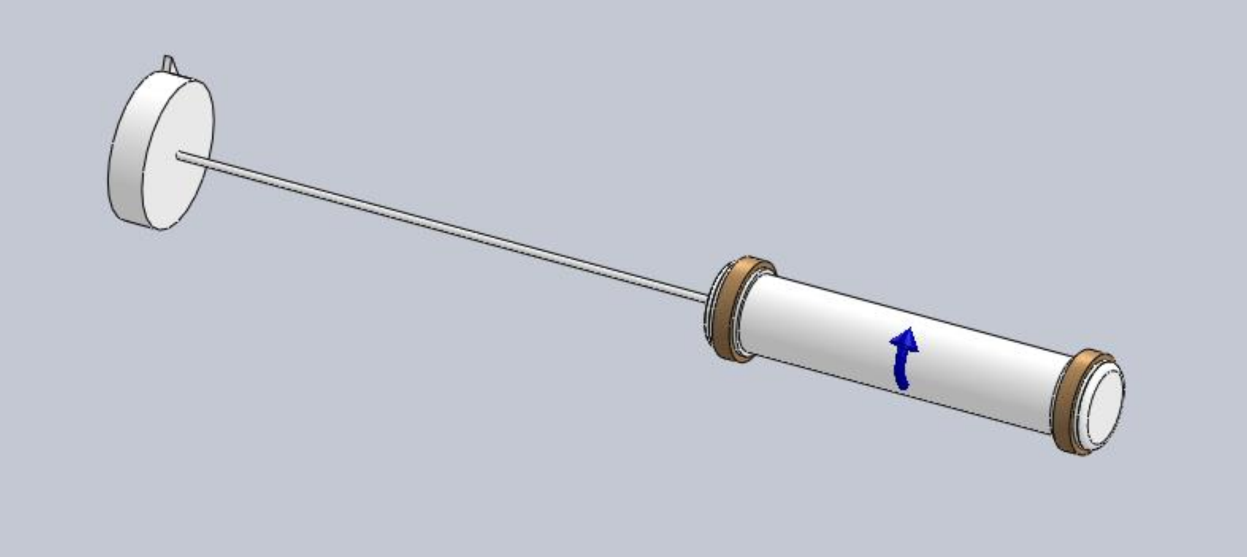


Figure 20: Engineering analysis of the fan system.

In order to use the data from the experiment, an equation was needed to calculate the slope of the ramp to achieve a run time of one minute. The basic equation for displacement is given by Equation 1, where x is the displacement, x0 is the initial displacement, v0 is the initial velocity, t is time, and a is acceleration.

---

[1] Reports can only be created from simulations. Since our project does not involve any high stress areas, a simulation was not a good application of Solidworks for our project. Instead a motion analysis was done, which only yielded the plot we needed.

$$x - x0 = v0t + \frac{at^2}{2} \qquad Eq.1$$

In our model, x0 and v0 are equal to zero, since there is no initial motion, and the start of the ramp is located at x=0. x can be assumed to equal 3ft, since that is the horizontal distance of our ramp. This new equation solved for time is shown in Equation 2.

$$t = \sqrt{\frac{2x}{a}} \qquad Eq.2$$

The acceleration is given by Newton's second law, F=ma. Assessing the forces acting on the sliding mass and solving for the acceleration yields Equation 3. g is the acceleration due to gravity, theta is the angle of the ramp, I is the moment of inertia, alpha is the angular acceleration (found with Solidworks), *r0* is the outside radius of the spool, and m is the sliding mass.

$$a = gsin\theta - \frac{I\alpha}{r0m} \qquad Eq.3$$

Plugging Equation 3 into Equation 2 yields Equation 4. This equation was used to calculate theta, the angle of the ramp. Alpha and the mass come from the Solidworks simulation, while the other values are constants or parameters.

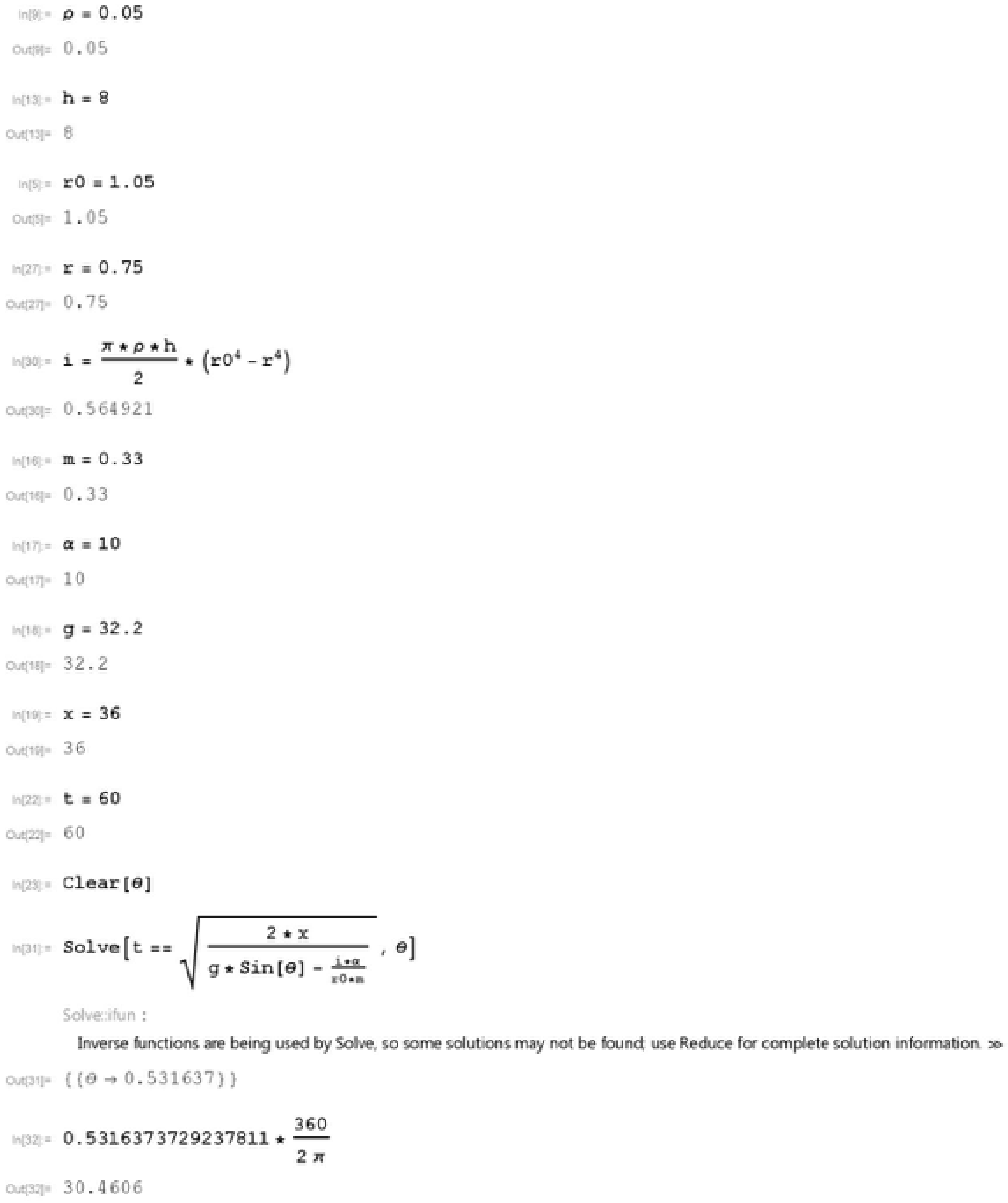
$$t = \sqrt{\frac{2x}{gsin\theta - \frac{I\alpha}{r0m}}} \qquad Eq.4$$

5.2.3 Methodology

A simplified Solidworks model of the ventilation system was created. It featured only the string spool, shaft and fan. Several forces were applied to the system. A moment was applied to the spool to simulate the force applied by the mass on a string. Two friction forces were also applied to the spool to emulate the loose fit of the spool mounting unit. Finally, a drag force was applied to the fan to represent air resistance. Different torques were applied to the system, and the angular velocity and acceleration of the system were measured. These values were used with a formula we derived to calculate the incline of the ramp in order to achieve a runtime of approximately one minute.

The calculations for the moment of inertia and solving for the angle theta were done using Mathematica. The code is shown below.

Matlab Code for Engineering Analysis:



```
In[9]:=  ρ = 0.05
Out[9]=  0.05

In[13]:= h = 8
Out[13]= 8

In[5]:=  r0 = 1.05
Out[5]=  1.05

In[27]:= r = 0.75
Out[27]= 0.75

In[30]:= i = (π * ρ * h)/2 * (r0^4 - r^4)
Out[30]= 0.564921

In[16]:= m = 0.33
Out[16]= 0.33

In[17]:= α = 10
Out[17]= 10

In[18]:= g = 32.2
Out[18]= 32.2

In[19]:= x = 36
Out[19]= 36

In[22]:= t = 60
Out[22]= 60

In[23]:= Clear[θ]

In[31]:= Solve[t == Sqrt[(2 * x)/(g * Sin[θ] - (i * α)/(r0 * m))], θ]

         Solve::ifun :
           Inverse functions are being used by Solve, so some solutions may not be found; use Reduce for complete solution information. >>

Out[31]= {{θ → 0.531637}}

In[32]:= 0.5316373729237811 * 360/(2 π)
Out[32]= 30.4606
```

5.2.4 Results

After numerous iterations, a combination of variables finally yielded a satisfactory angle theta. A mass of 0.33 pounds (150 grams) gives an angular acceleration of approximately 10 rad/s2, seen in the figure below. When plugged into Equation 4, this yields angle of approximately 30.5 degrees. This is a reasonable value for the angle of the ramp.

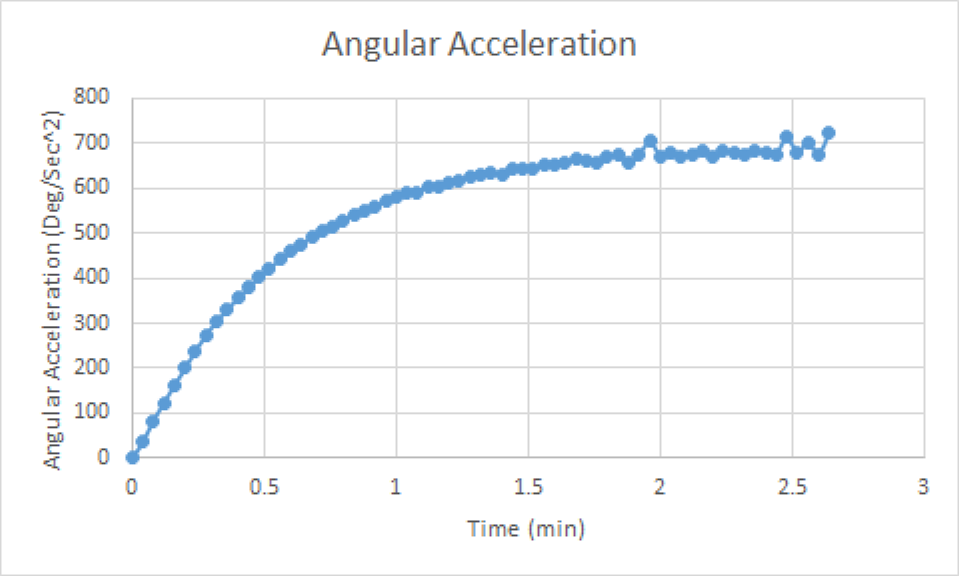


Figure 21: Angular acceleration vs time of the fan.

5.2.5 Significance

This simulation has shaped our final design in two ways. First, it has informed our decision about the size of the mass that should be used. For our setup, the mass should be approximately 150g. This value may change after testing however, since the actual friction, drag, and moment of inertia are likely to vary from the theoretical values. The second way the study influenced our design is by giving us an angle for the ramp. Using the value of 30 degrees will give us the confidence to fine tune the value of the mass to achieve the longest run time possible.

5.2.6 Summary of code and standards and their influence

Since our product is designed for the developing world, standards are less likely to be necessary. Standards can still provide useful information on designing a product, however, to ensure safety and functionality. We purchased NSF P1575 on incinerating toilets before our design changed, no longer featuring incineration. If we had used the standard, we would have had to take several aspects of it into consideration. First, the whole assembly would have had to be resistant to the heat. This includes both destruction of the toilet itself, and loss of function due to the heat. Some elements of our prototype may have needed replacement or different materials selection. For example, the plastic seal may not have been able to handle the high heat without damage or decreased life. This would require a different material choice, such as metal. To know for certain, these aspects would have been tested according to the standard; a lit cigarette would have been placed within an inch of the material in question for 2 minutes. Any burning or loss of function is considered a failure.

Another important aspect of the standard is the containment of waste products. No leakage can occur of human waste, or waste products from the combustion of the human waste, including smoke and smell. Even though we are not using an incinerating toilet, control of smell and human waste are still important for our design. That is where the 3D printed seal comes into play. Water seals the gap between the seal and the pot, creating an airtight seal. When the toilet is flushed, this seal is momentarily broken, but the ventilation system should be running to minimize the amount of foul air entering the chamber with the user. If the system was an incineration based unit, the water would have to be thermally insulated from the chamber, or else it would evaporate. If full insulation would not have been possible, a new seal would likely have been needed.

5.3 RISK ASSESSMENT

5.3.1 Risk Identification

We approached risk identification by knowing that risks are heavily tied to the project constraints. Naturally, we made decisions with causation mentality, with an “if-then” logic flow. It was determined early in project development that the driving constraints were budget allowances, schedule deadlines, safety, manufacturability, and functional needs. Failure to comply with these constraints would result in consequences affecting the quality of the overall project and satisfaction of the customer. Even before the design stage of the project, these risks were taken into consideration. Initial risks were identified by looking at a constraint and predicting what would happen if it were exceeded. Some consequences were direr than others. For example, if we exhausted the budget before we bought all of the necessary parts, the device would not be complete and the whole project would fail. If we created a dangerous machine, someone could get hurt, which could result in legal disputes. The extent of damage done by failing to meet the requirements is an indicator of priority. The risks were identified often in the order of severity. Some risks were initial and steady, like our budget constraints. Other risks were continuously changing, like our project schedule deadlines. Some risks that were identified in the course of the project are listed below, and are categorized by the type of risk.

1. Money

- Failure to stay under budget
- Designing a system with many parts
- Relying on third parties to deliver parts or services
- Shipping costs across providers

2. Time

- Failure to meet a project deadline
- Designing a system that was difficult to manufacture
- Waiting on feedback from testing or interviews

3. Personal

- Designing a non-environment friendly system
- Failure to meet functional needs demanded by the customer

- Aesthetic appeal

4. Unexpected

- Part failure and defects
- Sickness or injury
- Worker morale and happiness

5.3.2 Risk Impact or Consequence Assessment

The difficulty in analyzing the consequences of each risk stems from the interdependency of one risk with many other risks. One risk may be affected by three or more others, and may be inversely proportional. There is also a probability aspect of assessment. Each risk can be ranked by the likelihood of it happening, from low to high probability. Each risk was analyzed by both its short term and long term impact on the quality of the project, the customer, and the project group. Each risk can also be ranked by the impact to the project, from critical to low impact. The system was designed to minimize as many risks as possible.

Probability

1. Money

   The project was designed so that the probability of any money related risks was minimized. The probability that we would exceed the budget was low, because we designed the project around the budget, and chose parts accordingly. The probability of exceeding the budget increased when parts failed, resulting in the team having to spend more money to replace the part.

2. Time

   The project was scheduled to be completed within the time allotted. There was a medium probability that intermediate deadlines would not be met. This was due to the team's other commitments with school and work. The project was designed to use as few parts as possible, which minimized the manufacturing time. The probability of failing to meet manufacturing time was medium. The probability of waiting for a third party before we could continue with our project was high. There were many points in the project when we had to consult with an outside source. The large number of consulting meetings increased the chance that we would fail to meet the deadline, due to waiting on an outside party. The probability that parts we ordered would have a long shipping time was medium. The team ordered parts during the holiday season, which increased the chance that shipping times would be delayed.

3. Personal

   The project was designed with adaptability and safety in mind. The probability that the machine we created would be dangerous was high because of the high speed nature of our pitching wheels. There was an increased risk of parts breaking and flying off, injuring someone. We reduced this risk by gluing the shafts, adding collars, and machining a higher tolerance to reduce wiggle in the system. The probability was low that we would design a machine that did not meet the needs of the customer, because fulfilling the design challenge requirements was the main reason for making the machine. The probability that it would fail to have an aesthetic appeal was high, because of the strict time restraint and machining capability of the team.

4. Unexpected

The probability that a part would break is undetermined. It is, however, related to the quality of the parts. The crumpling system motors were cheap, low-quality motors that had a higher probability of failing than our pitching wheel motors, which were of high quality. The probability that team members would get sick was undetermined, but likely low. The probability that team morale would become low was high, because the project was stressful with many late nights spent manufacturing.

Impact

1. Money

The impact of exceeding the budget was critical. If we exceeded the budget, there was a chance that the device would be unfinished. If we had an incomplete machine, we would fail to meet the customer needs, and that was unacceptable. Choosing a shipping provider that was expensive or making a machine with many parts would have the same impact.

2. Time

The impact of not meeting a project deadline was critical. If we failed to meet a deadline, the project would become delayed as we tried to catch up, and increase the chance of delivering an incomplete machine. Failing to meet manufacturing deadlines and waiting on consulting meetings would have the same impact.

3. Personal

The impact of designing a dangerous machine was high. If we designed a machine that ended up hurting someone, legal issues and liabilities would result. If we designed a machine that did not meet the customer needs, the project would be a complete failure, and thus meeting the customer needs had a critical impact. The impact of not making an aesthetically appealing device was very low. As long as it functions to the customer needs, first generation devices do not need to look nice.

4. Unexpected

The impact of a part breaking was variable, depending on which part broke. If a screw sheared, it would be relatively easy to replace. If a motor broke, it would affect the performance of the machine, and its ability to meet the customer needs. Critical parts have a high impact when breaking, and other parts have a low impact when breaking. The impact of sickness or injury to the project is medium. It would increase the time needed from the remaining members. This would also affect the team morale. Team morale had a medium impact because well-rested workers make better parts and are less likely to stab each other.

5.3.3 Risk Prioritization

Risks were prioritized based on their probability and impact to the project. It was determined that delivering an incomplete project to the customer was unacceptable. This resulted in ranking money- related and time-related risks high in priority. Also high in priority was addressing the needs of the customer. Even if we produced a device within the allotted time and budget, it would not mean anything if the device did not perform to the customer's specifications. Team and customer safety was also prioritized high. Risks are shown below in the form of a heat map with their level of impact and their likelihood of occurrence.

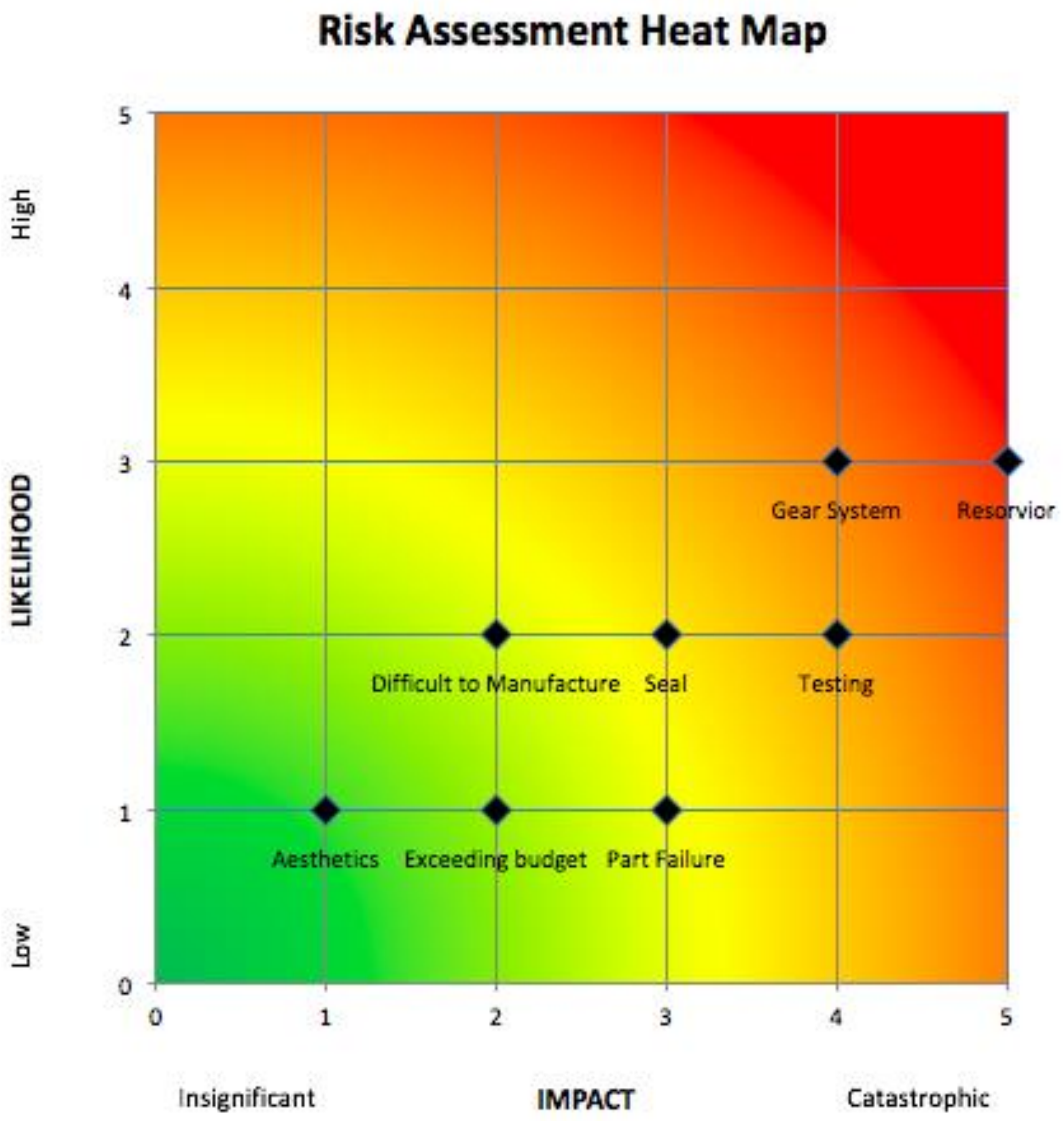


Figure 22: Heat map of the identifies risks.

6 WORKING PROTOTYPE

6.1 A PRELIMINARY DEMONSTRATION OF THE WORKING PROTOTYPE

This section is not applicable..

6.2 A FINAL DEMONSTRATION OF THE WORKING PROTOTYPE

This section intentionally left blank.

6.3 AT LEAST TWO DIGITAL PHOTOGRAPHS SHOWING THE PROTOTYPE

Figure 23: Front view of the final prototype.

Figure 24: Side view of the final prototype.

The above images show the final prototype from different angles. The key features seen are the pot (orange traffic cone), seal and counterweight system, reservoir chamber, and ventilation system. The ventilation system consists of the falling mass, ramp, ductwork, fan, and spool.

6.4 A SHORT VIDEOCLIP THAT SHOWS THE FINAL PROTOTYPE PERFORMING

The following video clip shows the final prototype.

https://youtu.be/ze2v6L6jyFM

6.5 AT LEAST 4 ADDITIONAL DIGITAL PHOTOGRAPHS AND THEIR EXPLANATIONS

This image shows the pot and seal. Waste is deposited into the pot, where it slides down to rest on the seal. The small hole in the pot allows for the input of water to the chamber.

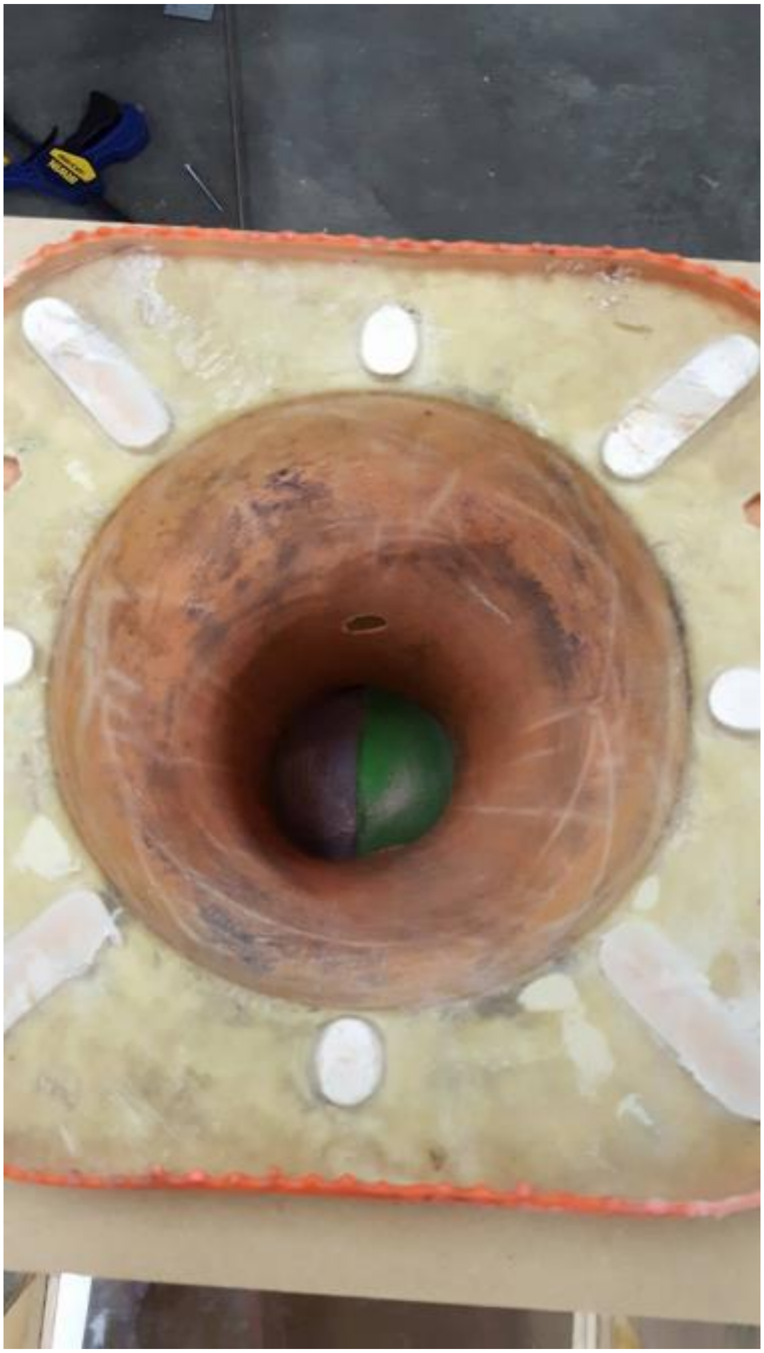


Figure 25: Top view of the prototype with pot and seal.

This second image is a close-up of the seal and counterweight system. The seal is designed to minimize the amount of water needed to create a seal. The counterweight keeps the seal closed against the pot, and returns the seal to the closed position after it is used.

Figure 26: Picture of the seal with the counterweight that holds the waste.

The next image is of the fan. It is recessed within the ventilation shaft so that when it spins, air will be drawn up out of the reservoir. The purpose of this is to prevent the user from coming into contact with this hazardous air.

Figure 27: Picture of the fan inside the reservoir.

The final image is of the mechanism powering the fan. It consists of a mass, connected to a spool by a string. When the mass slides down the ramp, the spool spins, turning the attached fan.

Figure 28: Picture of fan rotational mechanism attached to a pulley and weight.

7 DESIGN DOCUMENTATION

7.1 FINAL DRAWINGS AND DOCUMENTATION

7.1.1 Engineering drawings

See Appendix C for the CAD models.

7.1.2 Sourcing instructions

Table 13 Parts with sourcing instruction and its usability.

Part	**Sourcing**	**Use**
Base	Cut the wood in the required dimension and then use nails and glue to attach the pieces together. Refer to CAD model in appendix C.	The base works as a reservoir and also hold the entire top structure.
Seal	3D print. Refer to appendix C for dimensions.	Holds the waste and creates a seal so that odor from the reservoir does not escape and pollutes the air.
Cone	Cut a traffic cone from the top with the required dimension. Alternatively, it can be 3D printed as well.	Serves as the pot for the toilet and holds the waste before it is flushed.
Fan Rotation Support	Cut pieces of wood in the required dimensions and them attach them together with screws and glue. Refer to appendix C.	It holds the fan axle and provides support for the fan axle to rotate with the help of pulley and dropping weight.
Fan Tube	Use PVC fittings to create the fan tube. Refer to appendix C for the required fittings.	It holds the fan and provides ventilation for the sanitation system.
Fan	3D print. Refer to appendix C for dimension.	It creates negative air pressure to remove the odor from the waste.

7.2 FINAL PRESENTATION

7.2.1 A live presentation in front of the entire class and the instructors

This section intentionally left blank.

7.2.2 A link to a video clip

The following video shows the final prototype with the team and explanation.

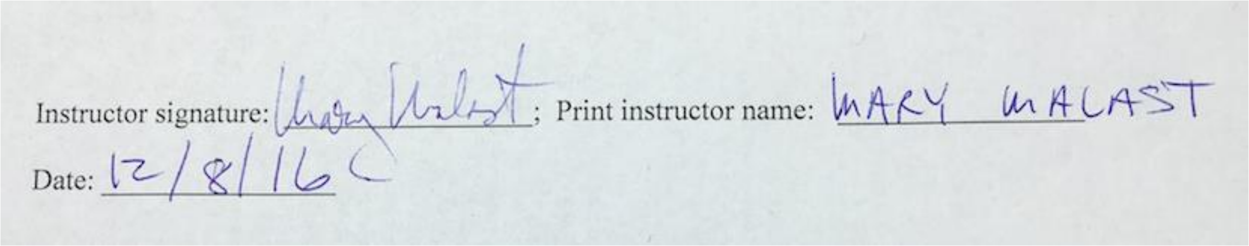
https://www.youtube.com/watch?v=IRU3Ut6vwig&feature=youtu.be

7.3 TEARDOWN

The prototype was set to be disassembled in the following ways:

- The wood screws will be removed from the frame and the wooden frame will be disassembled. The wood pieces will be returned to the scrap wood pile in the basement.
- The plastic PVC and washers will be thrown away (since they have been drilled and modified).
- The 3D printed part will be discarded since it is of no use to any other project.
- The traffic cone will be discarded since it is cut in half and is no longer useable.
- The Teflon spray, insulating foam and pvc cement would be asked to be kept in the cabinet.
- The small box of concrete in the design laboratory, Jolley 110 for future projects.
- The cone used for hand washing with the pipe will be taken by Dylan.
- The shop will be cleaned for any mess remaining.

This Tear Down was approved by Professor Mary Malast on 12/8/16 at 1:01 p.m.



Instructor signature: Mary Malast; Print instructor name: MARY MALAST

Date: 12/8/16

8 DISCUSSION

8.1 USING THE FINAL PROTOTYPE PRODUCED TO OBTAIN VALUES FOR METRICS, EVALUATE THE QUANTIFIED NEEDS EQUATIONS FOR THE DESIGN. HOW WELL WERE THE NEEDS MET? DISCUSS THE RESULT.

Using the design metrics from Section 3.1.1, the Final Prototype was scored at 4.357. Our winning combination was scored at 5.557. However, our final prototype scored below the score. This difference between the two scores is due mostly to the fan speed and inside temperature of the reservoir. The concept designed envisioned a gear system with high gear ratio that could achieve high fan speed with dropping weights. However, in the prototype, the fan was operated by a pulley system rather than the gear for simplicity. The temperature inside the reservoir was not also tested since the materials used for the prototype were not feasible to maintain insulation.

8.2 DISCUSS ANY SIGNIFICANT PARTS SOURCING ISSUES? DID IT MAKE SENSE TO SCROUNGE PARTS? DID ANY VENDOR HAVE AN UNREASONABLY LONG PART DELIVERY TIME? WHAT WOULD BE YOUR RECOMMENDATIONS FOR FUTURE PROJECTS?

All the parts were easily sourced from Home Depot. No vendor was used for delivery.

8.3 DISCUSS THE OVERALL EXPERIENCE:

8.3.1 Was the project more of less difficult than you had expected?

The project was more difficult than expected. The main difficulty that arose involved the ventilation system. We ran into trouble trying to create it while keeping cost down and making it easy to build (for people in developing countries). We ended up abandoning the gear system due to anticipated problems with tolerances. However, the idea was brought up after the fact by Professor Malast to 3D print a combined fan-gear unit, that would cost minimally more than the fan and combine the functionality of both.

8.3.2 Does your final project result align with the project description?

It aligns well with the exception of ventilation system. The ventilation system does not run as long as anticipated. The runtime would be longer for the full-size version due to increased drop height and increased moment of inertia, but it is unlikely to be the full 2 minutes anticipated.

8.3.3 Did your team function well as a group?

Our team worked very well as a group, as we were able to come to sensible decisions for our project by discussing all aspects thoroughly. There was no hostility and each team member was very willing to work hard on the project.

8.3.4 Were your team member's skills complementary?

Yes. We had people who were talented at talking and presentations, as well as those who were better at designing and problem solving.

8.3.5 Did your team share the workload equally?

While we did our best to distribute workload equally, it was difficult at times to get all the team members to come together and work together because of our busy schedules. This led to some inequalities in workload at times. However, the team shared the load equally for the entirety of the project.

8.3.6 Was any needed skill missing from the group?

No. All the skills which were required for the project were present to one or another group member.

8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

We worked with the original briefing.

8.3.8 Did the design brief (as provided by the customer) seem to change during the process?

No, the design brief was mostly consistent.

8.3.9 Has the project enhanced your design skills?

Yes, we have become more comfortable with not only general design, but also the process as a whole. We learned a lot about some of the issues we could encounter and some analysis points that we could have looked into earlier. We found that this will take much more practice too, as one project cannot possibly be enough to perfect design skills.

8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?

Yes, we all feel more confident about our capabilities as project designers than we did before this project. This experience showed us that we are able to accomplish challenging goals and that we tend to learn quickly from our mistakes.

8.3.11 Are there projects that you would attempt now that you would not attempt before?

Though we do not have any specific projects in mind that we had previously not felt ready for, we have certainly increased our confidence in taking on challenging projects.

9 APPENDIX A - PARTS LIST

Table 14 Final part list.

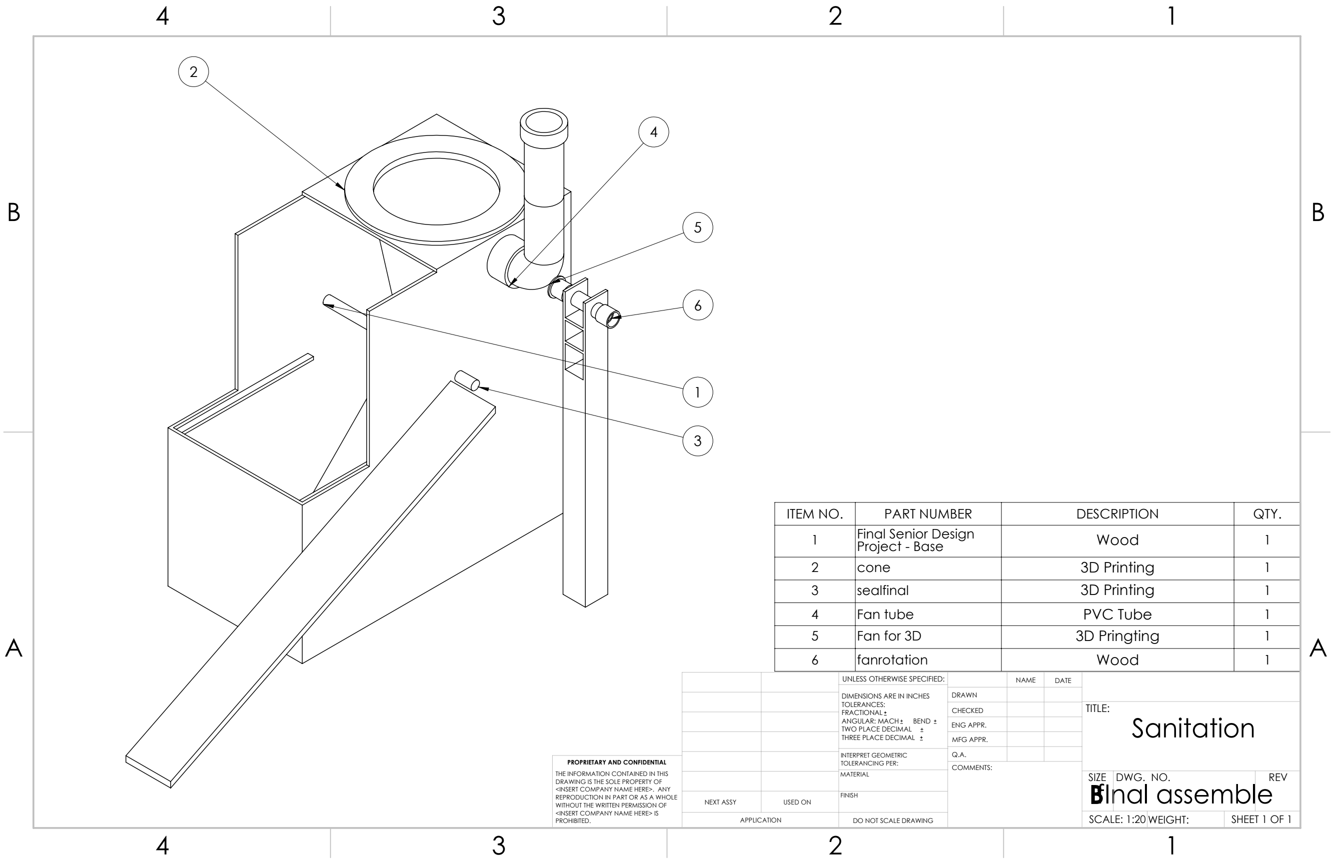
Part	Quantity
9.3 oz. Advanced Dry Lube with Teflon	1
3/4 in. O.D. x 5/8 in. I.D. X10' Vinyl Tube	1
#18 x 325 ft. White Twisted Polypropylene Mason Twine	1
1/2" Copper Pressure Tee	1
3/4 in. Nickel-Plated Fixed Pulley	1
1/2 in. Schedule 40 PVC 90-Degree Elbow	2
1/2 in. Schedule 40 PVC Tee	1
1/2 in. X 2 in. PVC Pipe	1
2 in. X 2 ft. PVC-PW/DWV Sch. 40 Plain-End Pipe	1
8oz Clear Heavy Duty PVC Cement	1
1/2 in. PVC Sch. 80 Slip Cap	1
.093 in. x 11 in. x 14 in. Clear Acrylic Sheet	1
Pestblock with Quick Stop Straw	1
1/8 in. x 12 in. Round Rod Cold-Rolled Plain	1
1/4 in. x 48 in. Aluminum Round Rod	1
1/4 in. x 2 ft. x 4 ft. Medium Density Fiberboard	2

10 APPENDIX B - BILL OF MATERIALS

Table 15 Bill of materials.

Part	Price	Quantity	Total Cost
9.3 oz. Advanced Dry Lube with Teflon	$4.48	1	$4.48
3/4 in. O.D. x 5/8 in. I.D. X10' Vinyl Tube	$8.98	1	$8.98
#18 x 325 ft. White Twisted Polypropylene Mason Twine	$3.61	1	$3.61
1/2" Copper Pressure Tee	$0.98	1	$0.98
3/4 in. Nickel-Plated Fixed Pulley	$2.36	1	$2.36
1/2 in. Schedule 40 PVC 90-Degree Elbow	$0.27	2	$0.54
1/2 in. Schedule 40 PVC Tee	$0.35	1	$0.35
1/2 in. X 2 in. PVC Pipe	$1.32	1	$1.32
2 in. X 2 ft. PVC-PW/DWV Sch. 40 Plain-End Pipe	$4.65	1	$4.65
8oz Clear Heavy Duty PVC Cement	$8.39	1	$8.39
1/2 in. PVC Sch. 80 Slip Cap	$0.38	1	$0.38
.093 in. x 11 in. x 14 in. Clear Acrylic Sheet	$4.45	1	$4.45
Pestblock with Quick Stop Straw	$7.25	1	$7.25
1/8 in. x 12 in. Round Rod Cold-Rolled Plain	$1.18	1	$1.18
1/4 in. x 48 in. Aluminum Round Rod	$5.61	1	$5.61
1/4 in. x 2 ft. x 4 ft. Medium Density Fiberboard	$6.42	2	$12.84

11 APPENDIX C - CAD MODELS



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Final Senior Design Project - Base	Wood	1
2	cone	3D Printing	1
3	sealfinal	3D Printing	1
4	Fan tube	PVC Tube	1
5	Fan for 3D	3D Pringting	1
6	fanrotation	Wood	1

Figure 29: Final CAD assembly drawing of the prototype.

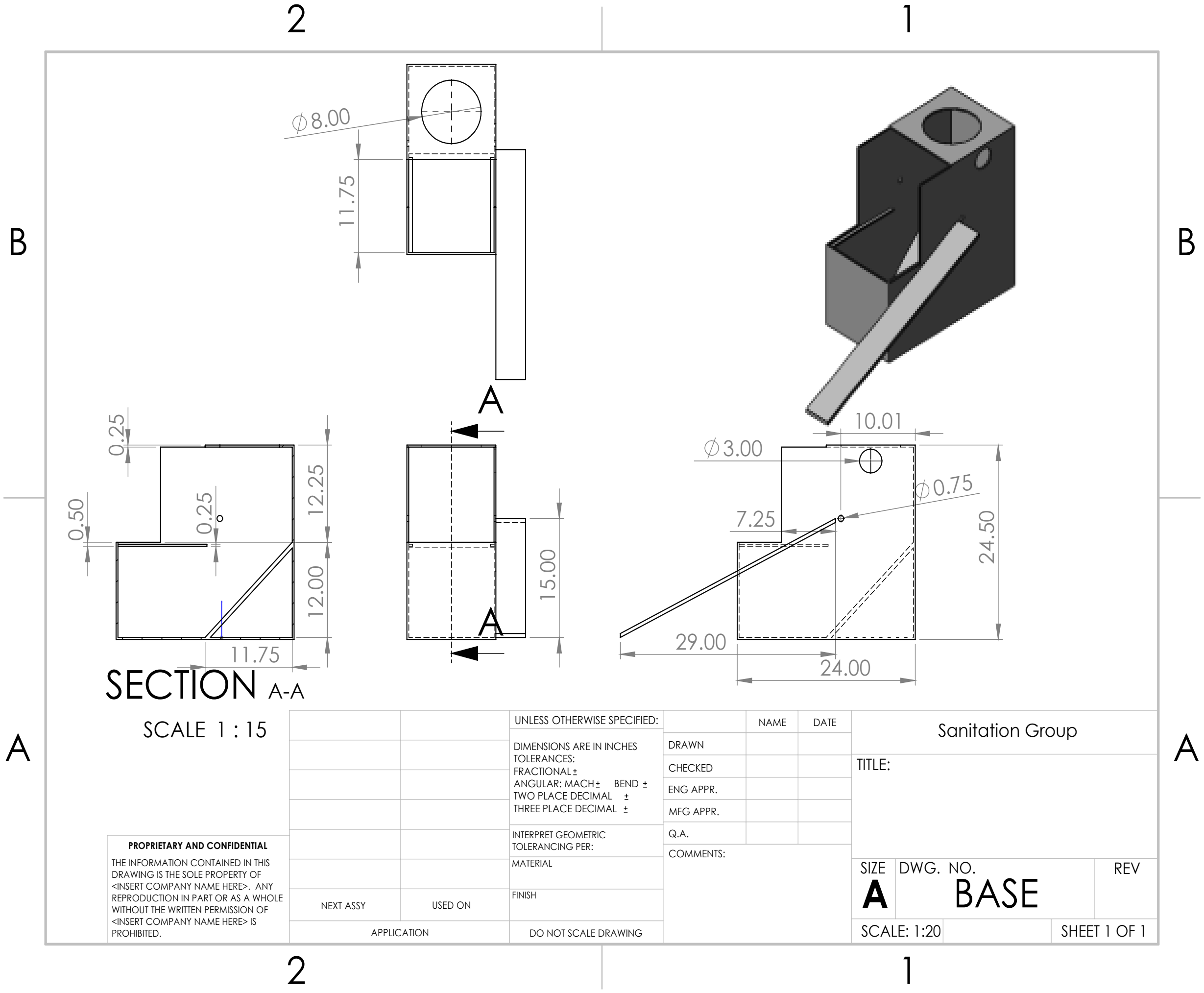


Figure 30: CAD drawing of the base.

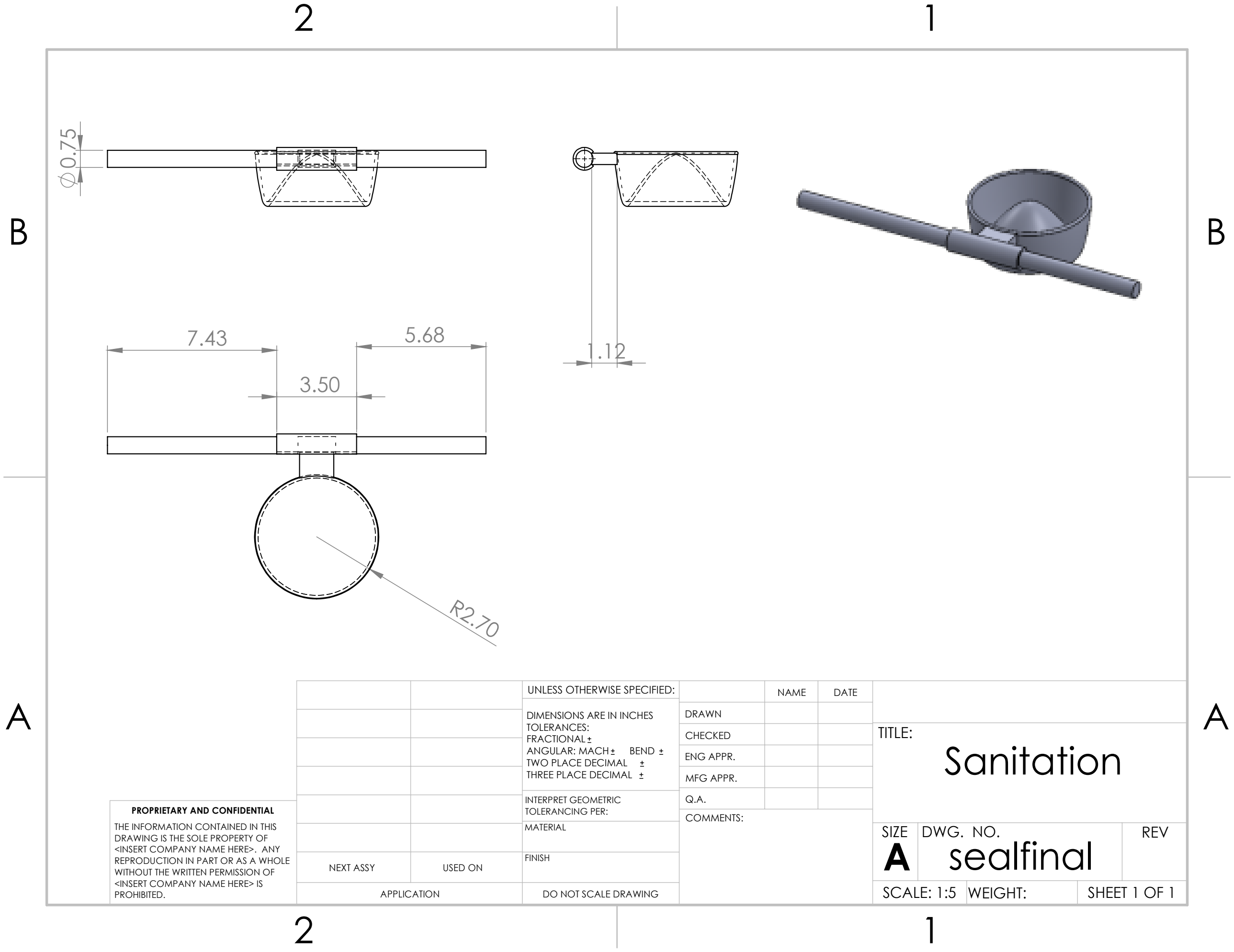


Figure 31: CAD drawing of the seal.

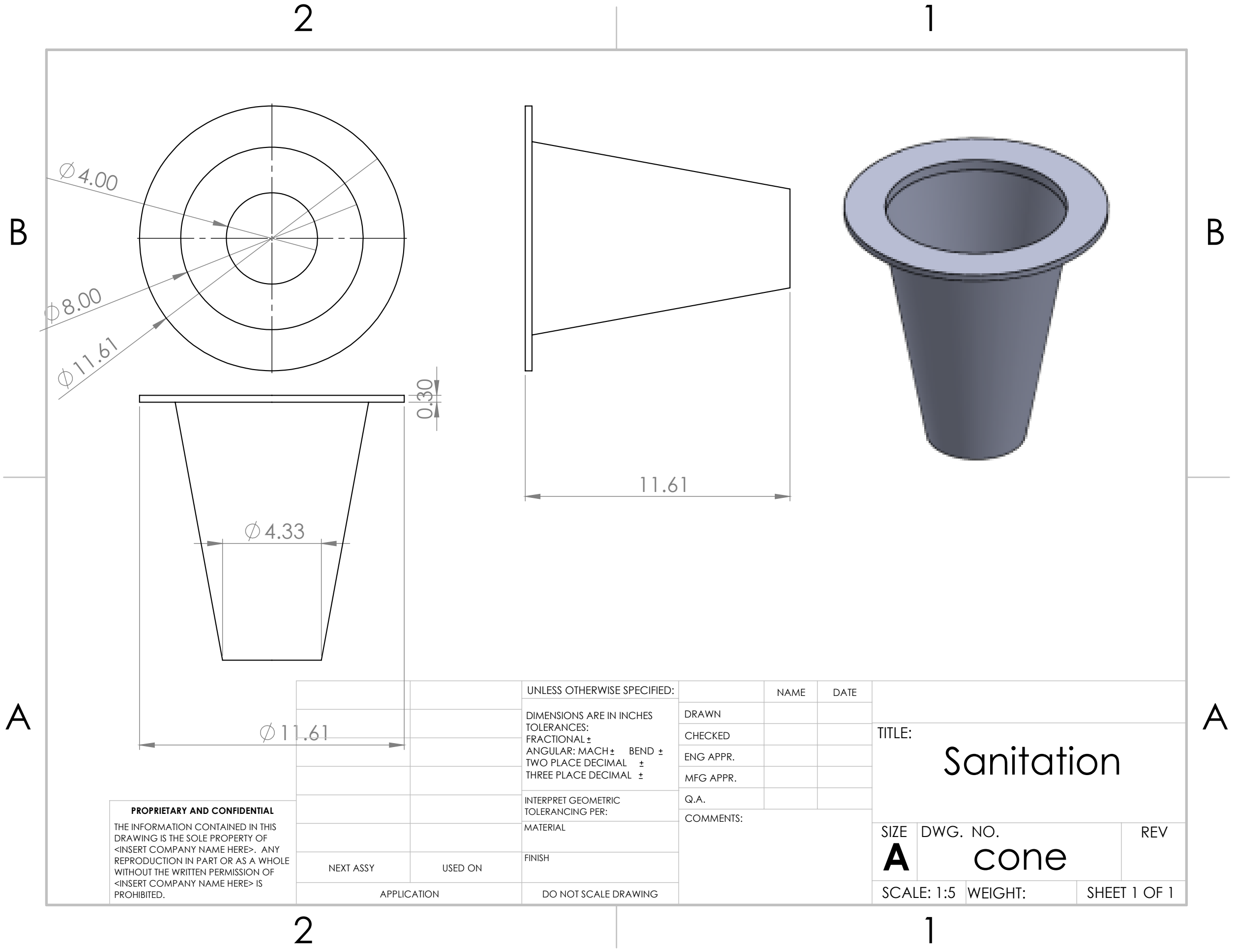


Figure 32: CAD drawing of the cone.

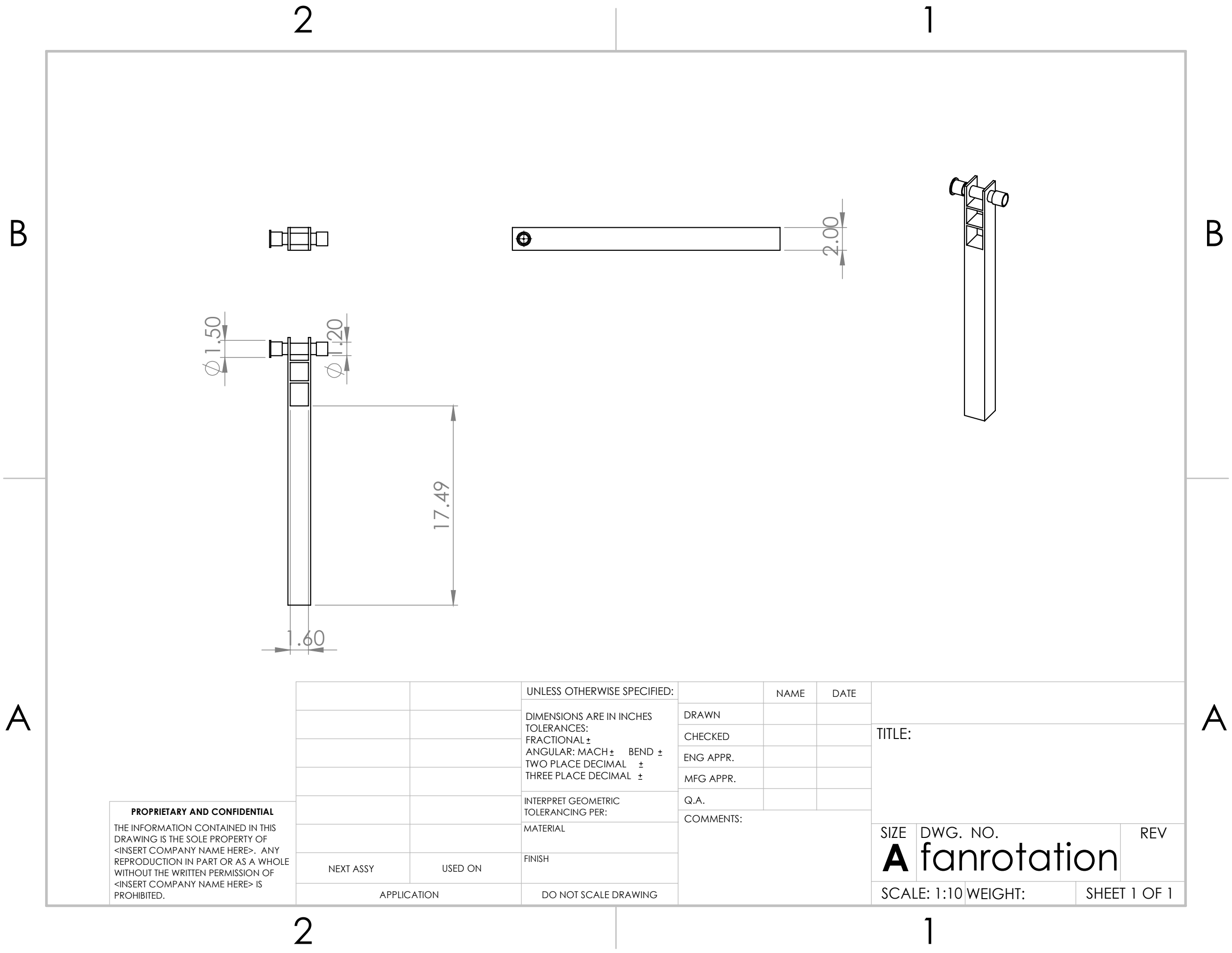


Figure 33: CAD drawing of the support for rotating the fan by dropping weight.

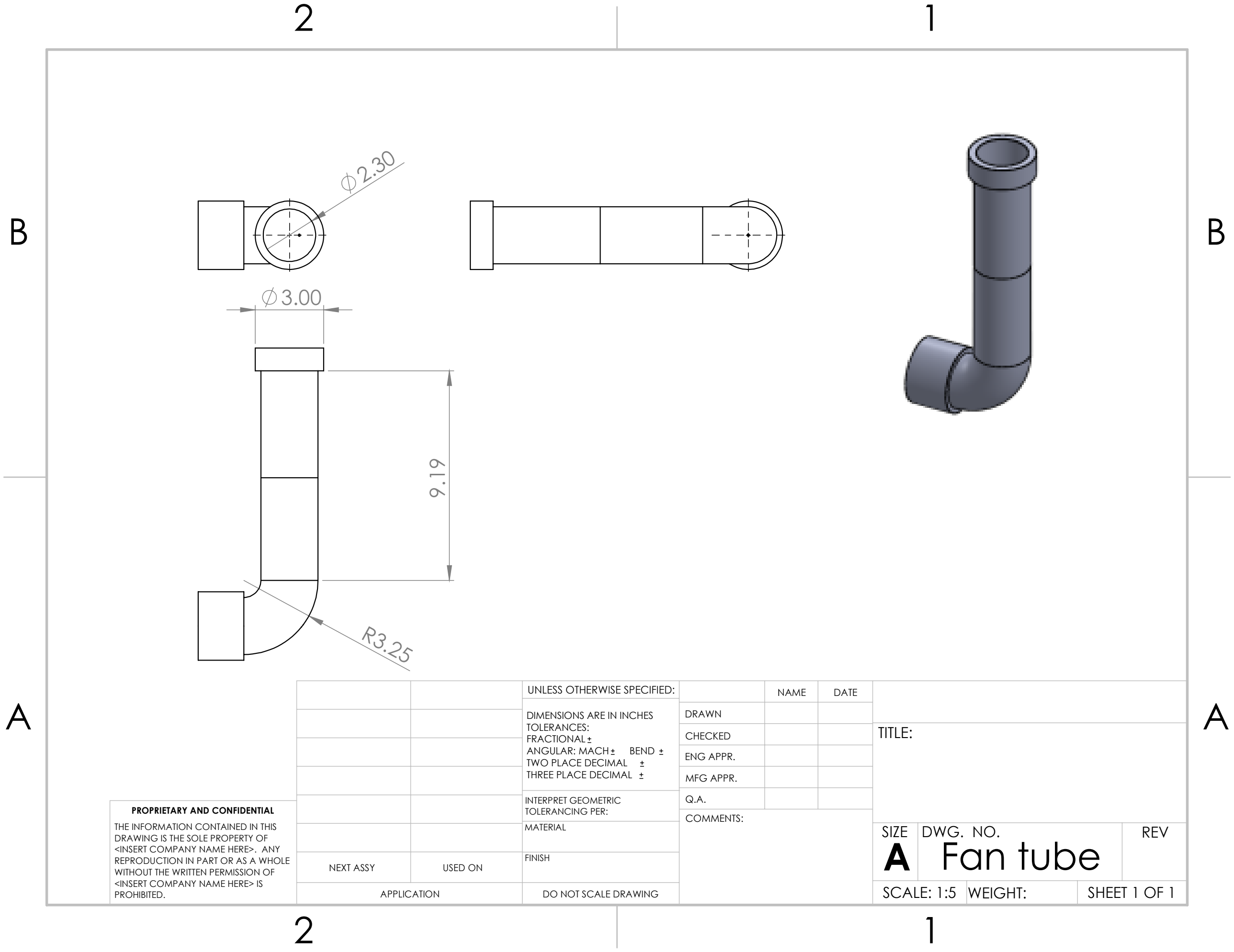


Figure 34: CAD drawing of the tube which holds the fan and provides ventilation.

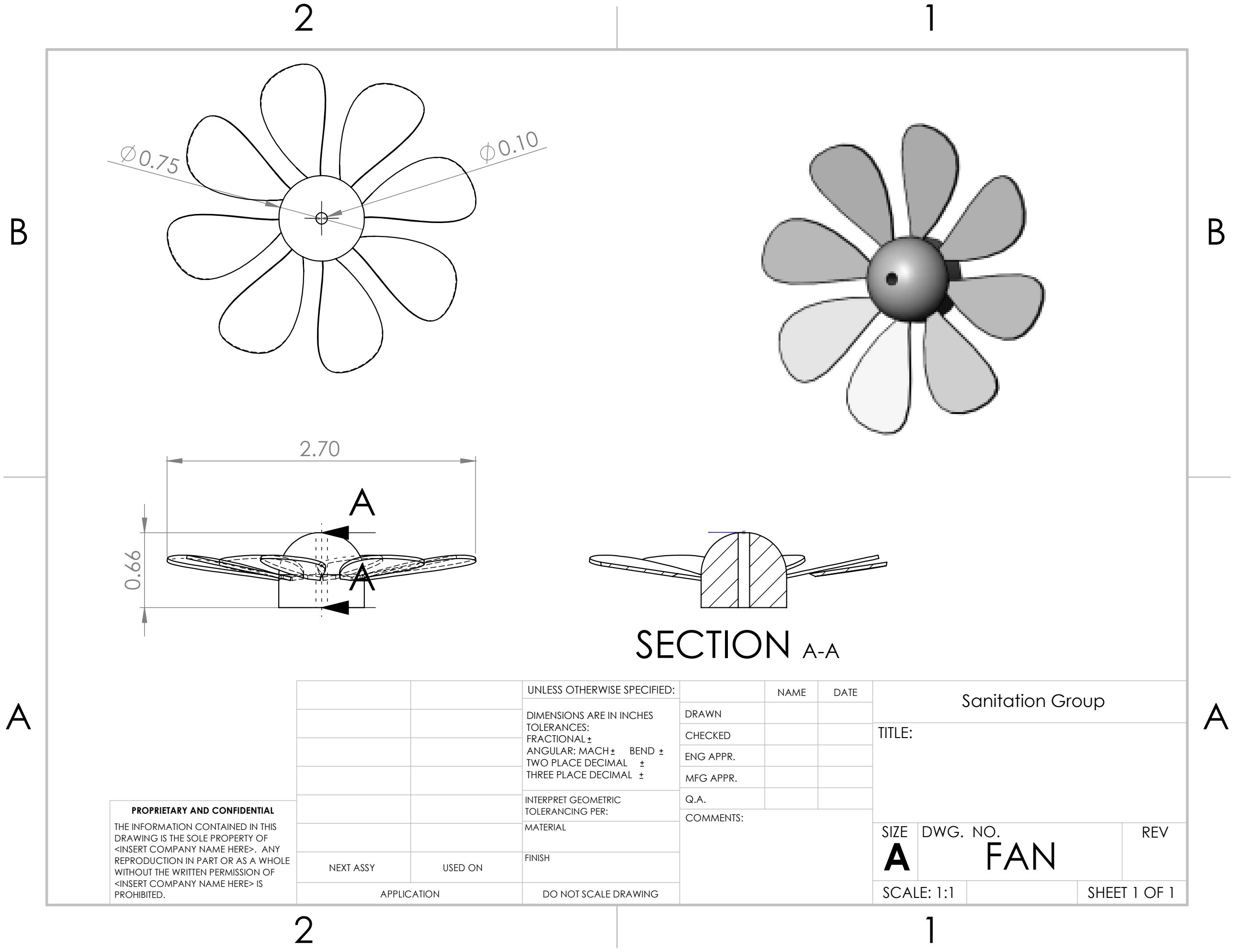


Figure 35: CAD drawing of the fan.

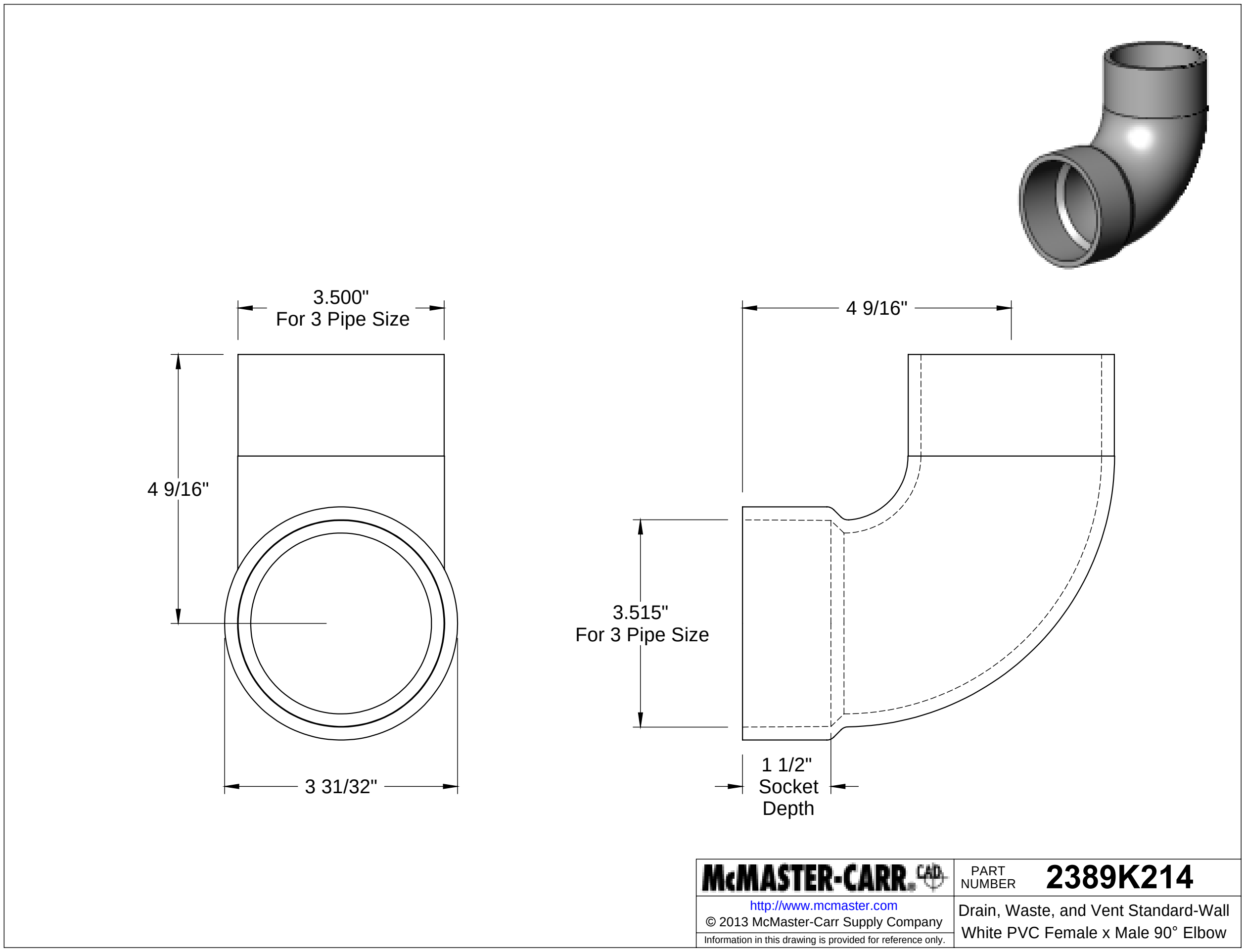


Figure 36: CAD drawing of the 90 degree PVC.

12 ANNOTATED BIBLIOGRAPHY

1. Mecca, S. *Microfranchising Rural Sanitation: A Sustainable Development Model For A Scale-up Of A Sustainable Technology*. N.p., n.d. Web. 08 Dec. 2016

The GSAP Microflush toilet system, a locally sourced-locally fabricated toilet that features a macro-organism enhanced aerobic filter-digester and an innovative valve that flushes on just 150 cc of water has proven to be an effective sustainable sanitation solution for developing world tropical communities. This paper examines a sustainable model for bringing the technology to scale by bringing together the building and microfinance functions necessary for the neediest of households to own such a toilet.

2. "Reinventing the Toilet – Helping to Solve Sanitation Issues in Low Income Countries." *Reinventing the Toilet – Helping to Solve Sanitation Issues in Low Income Countries*. N.p., n.d. Web. 08 Dec. 2016.

Designed for single-household use, the toilet is designed to accept urine and feces as a mixture. The toilet flush uses a unique rotating mechanism to transport the mixture into the toilet without water while simultaneously blocking odor and the user's view of the waste. Following release of unbound water, the residual solids are transported by a mechanical screw into a gasifier which converts them into ash and energy. The energy powers the membrane processes and there may be extra energy available for charging mobile phones or other low voltage items. The toilet will be rented by the households and maintenance will be undertaken with a trained operative responsible for the franchised area.