Mac Organic Waste
A Bicycle- Powered Composter

Course: BREE 495- Engineering Design 3

Instructor: Dr. Clark

Due: Monday, April 16th 2012

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

LIST OF SYMBOLS

τ – Torque (N m)

M – Torque (N m)

σ – Shear strength (kPa)

d – Diameter (m)

h – Height (m)

n – Number of teeth (*unitless*)

r – Radius (m)

P – Power (W)

ω – Angular velocity (rad s^{-1})

m – Mass (kg)

g – Gravitational acceleration (m s^{-2})

D – Distance from the point of action of a force to the center of rotation (m)

N – Normal reaction force (N)

L – Length (m)

V – Volume (m^3)

Q – Load (kg)

$\dot{m}$ - Mass flow rate (kg $week^{-1}$)

SRT – Solids retention time (days)

q – Heat transfer rate (W)

q – Load per unit length (kg m^{-1})

x – Distance (m)

R-value – Rating of insulation (resistance) (m^2 K W^{-1})

ρ – Density (kg m^{-3})

k – Thermal conductivity (W m^{-1} K^{-1})

T – Temperature (K)

t – Thickness of material (m)

h – Convective heat transfer coefficient (W m^{-2} K^{-1})

EXECUTIVE SUMMARY

Composting is the aerobic breakdown of organic matter by microorganisms, into a product that is stable to use as a fertilizer. Compost adds to the structural integrity of soil as well as reduces the need for artificial fertilizers. The goal of the project at hand was to design a composter for the composting club Gorilla Composting, at McGill University's Macdonald Campus. The requirements are: sufficient capacity, easy to use, easy to maintain, achieve low moisture content, and capable of maintaining sufficient temperature, especially during the winter. Studies on various rotatable composter designs and design parts were investigated. Various calculations pertaining to the compost recipe and the design of the composter were also done, taking into consideration various assumptions as well as optimum design conditions. The output was the design of a bicycle-powered composter. Built using a gear reduction method, the gear sets of the gearing system of the assembly amplify the torque, initially produced by a recreational pedaller pedalling at about 65 rpm, to turn a cylindrical drum 0.725 m in length and 1.2 m in diameter. Ventilation holes, 3 cm in diameter, allow for aeration of the compost pile to optimize the composting process. They are located 29 cm radially outward from the center of the circular ends of the drum. Moreover, the drum was covered in insulation to reduce heat loss from the pile by convection. A wooden base member serves to support the drum and mounts wheels to assist the rotation of the drum about the axis through its circular ends. A prototype under real world circumstances was not built and thus components of this composter requiring adjustments are known. It is essential that the parts of the assembly be maintained as well as lubricated as and when needed. Rotation of the drum by pedalling is important to maintain aeration within the compost pile to prevent the build-up of odors. The design of this bicycle-powered composter would greatly benefit Gorilla Composting by optimizing the composting process of their collected organic wastes, reducing work to be done, and provide a composter that could attract more volunteers.

INTRODUCTION

Aerobic composting is defined as the biological decomposition of organic substrates under optimum conditions of variables such as temperature, moisture, carbon to nitrogen ratio and pH to produce carbon dioxide, water, heat and a final product, compost, that is sufficiently stable to store and apply to land without the occurrence of adverse environmental effects (Haug, 1981). Today, composting is attracting a considerable amount of interest from an environmental-ecological, hygienic and energetic point of view. (Chiumenti et al, 2005) It transforms organic matter into products useful for agriculture and is characterized by high nutrient contents, soil structuring properties and low phytotoxicity. Moreover, pathogenic organisms and seeds are destroyed due to high temperatures reached during the process thus making it a hygienic product to use. The energy for the process is derived from the destruction of biochemical bonds in the organic matter. (Chiumenti et al, 2005)

Using compost as fertilizer reduces the need for other sources of nitrogen and trace minerals, improves the soil structure, and betters the moisture retention capacity of the soil, thus improving the yield of crops (Hansen, 2004). It also serves as an environmentally friendly alternative to landfilling. The process produces considerably less greenhouse gas emissions: landfilling produces 25 times the global warming potential of compost (Lou et al, 2009).

Various composting systems such as static piles, windrows, and in-vessel systems exist. In addition to this, composting equipment pertaining to size reduction and mixing of the compostable material has also been designed.

Gorilla Composting is a student-run organization at the Macdonald Campus of McGill University. They collect compostable material from various buildings on the university campus. Figure 1 (Annex A) shows a map of the different collection sites. Composting improves the school of environment's credibility. Moreover, the visibility of compost bins on campus contributes to raising awareness among people, and thus instills a sense of responsibility and accountability in them. (Kieu, Padamsi, 2011)

The current Gorilla Composting composters are seven wooden bins. They are made up of walls of metal mesh reinforced with planks and a hinged cover of varying degree of waterproofness. Also, the facilities are limited in size which sometimes leads to the occasional refuse of organic waste by the club. (Kieu, Padamsi, 2011) Maintenance and frequent operations of the composter are carried out by the volunteers. As such, care given varies over time due to the requirements of students' schedule: there are downtimes during exam periods, the winter and the summer. This causes the process to be inhibited, as lack of turning causes the compost to lack oxygen. (Kieu, Padamsi, 2011)

Thus the goal of the given task at hand was to design a composter that would be of a sufficient capacity, easy to maintain, easy to use and be capable to combat temperature and moisture regulation problems, especially during downtimes. Various background studies on composting systems were used to come up with an appropriate design of a composter that would satisfy the required optimum conditions of the composting process, as well as the client's needs. Calculations and computer drawings associated with each part of the design assembly are described in detail and finally, recommendations on the composting process and the composter are presented.

BACKGROUND

Composting- Science

In the composting process, microorganisms break down organic matter aerobically into carbon dioxide, water, heat and humus which is a relatively stable end product. (Cornell Composting, 1996) Composting is one of the best known processes for the biological stabilization of organic wastes (Gabhane et al, 2012). Parameters such as temperature, carbon to nitrogen ratio, pH, moisture content, oxygen concentration and other nutrients of the compost pile are integral in achieving optimum conditions for the process. (Cornell Composting, 1996)

Temperature

The composting process proceeds in three phases, namely the mesophilic or moderate temperature phase (couple days), the thermophilic or high temperature phase (few days to several months) and the cooling and maturation phase (several months). At 55^{o}C, pathogens harmful to humans and plants are destroyed. However, at 65^{o}C, composting microbes may be killed, which would inhibit the decomposition. It is therefore essential that temperatures be kept lower than 65^{o}C during the composting process. (Cornell Composting, 1996) This can be achieved through mechanical turning or forced negative or positive aeration (Chiumenti et al, 2005)

Carbon to Nitrogen Ratio

Carbon, nitrogen, potassium and phosphorus are present in most compostable materials. (Chiumenti et al, 2005) Carbon and nitrogen are the most important elements required for microbial decomposition. Carbon is the energy source and basic building block, making 50% of the mass of microbial cells. Nitrogen is the crucial component for nucleic acids and proteins that are necessary for cell growth and function. The ideal carbon to nitrogen ratio for the composting process is 30:1. Low ratios, meaning excess amounts of nitrogen, lead to the production of odorous ammonia gas. High ratios, meaning excess carbon, lead to an insufficient amount of nitrogen available for the optimal growth of the microorganism population. This will cause the compost to remain cool and the process to proceed at a slower rate. As composting proceeds, the carbon to nitrogen ratio gradually decreases to 10-15:1 for the finished product due to the loss of carbon through the emission of carbon dioxide. Therefore, a higher initial ratio is best to choose. However, in choosing the ratio, bioavailability of the materials needs to be considered. For example, a newspaper is slower to break down as compared to other types of paper as it is made up of cellulose fibres, which are highly resistant. (Cornell Composting, 1996)

pH

In terms of pH, a value between 5.5 and 8.5 of the starting mixture is optimal for compost microorganisms. (Cornell Composting, 1996) These values take into consideration that bacteria prefer a pH close to neutral while fungi prefer acidic conditions. (Chiumenti et al, 2005) As bacteria and fungi digest organic matter, they release organic acids which accumulate in the early stages of the process. A drop in pH encourages the growth of fungi and the breakdown of cellulose and lignin. (Cornell Composting, 1996) Further into the process, the pH increases to between 8 and 9 as a result of the release of carbon dioxide, the aeration of biomass and the production of ammonia from the degradation of proteins. Finally at the end of the process, a slightly alkaline or neutral pH is achieved. (Chiumenti et al, 2005)

Moisture Content

Water is an essential element that is integral for the survival of microorganisms involved in the composting process for the following reasons:

- Water is used for the exchange of nutrients through cellular membranes
- It is a medium for extracellular enzymes and soluble substrates; and
- It is a medium for all reactions. (Chiumenti et al, 2005)

Microbial decomposition occurs most rapidly in the thin liquid films found on the surfaces of organic particles. The moisture content of compost affects its temperature changes. Water has a high specific heat than most molecules and drier compost mixtures tend to heat up and cool off more quickly than wetter mixtures. The optimal moisture content for the composting process is 50-60%. Moisture contents less than 30% inhibit bacterial activity while values above 65% result in low decomposition, odor production and nutrient leaching. (Cornell Composting, 1996)

Oxygen Concentration

Within a composting mass, the concentration of oxygen available to microorganisms continuously decreases. It is thus fundamental that oxygen be reintroduced throughout the process in order for it to proceed normally. (Chiumenti et al, 2005) Greater than 10% oxygen is vital for maintaining aerobic composting. If the average concentration falls below 5%, an anaerobic response develops. (Cornell Composting, 1996) This results in the production of methane and hydrogen sulfide gases. The greatest need for the reintroduction of oxygen occurs at the beginning of the composting process when metabolism of organic matter by microorganisms is at its peak. It is thus important that oxygen concentrations of between 5 and 15% be maintained during that time. (Chiumenti et al, 2005)

Other Nutrients

Phosphorus, calcium and oligo-elements stimulate microbial activities and catalyze different biochemical reactions in the compost pile. Ratios of carbon to phosphorus of 100-200:1 and carbon to sulfur of 100-300:1 are optimal for the composting process. (Chiumenti et al 2005)

According to a study by Gabhane et al (2012), additives are mixtures of different amounts of various microorganisms, mineral nutrients or readily available forms of carbon, enzymes and pH balancing compounds, all of which help in enhancing microbial activity. The effect of various additives, such as fly ash, phosphogypsum, jaggery, lime and polyethylene glycol on microbial growth, enzymatic activities, organic matter degradation, bulk density and quality of finished compost are investigated. The composting material used was a mixture of vegetable waste and garden biomass in equal ratio. Results showed that jaggery and polyethylene glycol were the two best additives for the composting process. They were helpful in facilitating composting as they influenced the growth of microbes and cellulose activity. They were also found to contain higher amounts of organic matter. Due to the presence of sugar in jaggery and readily available carbon in polyethylene glycol, a boost in microbial growth was achieved which led to an increase in thermophilic temperatures and an extension of the thermophilic phase to 5 days instead of the normal duration of 3-4 days. The two additives also showed an increase in the total nitrogen content which indicates a faster rate of organic matter degradation. To summarize, jaggery and polyethylene glycol were both very beneficial to the composting process.

Composting- Structures

Composters are used to decompose organic matter rapidly and efficiently. One invention entails a composter that is manually rotatable on its short or long axis. The septagonal cross- sectional drum is provided with steps, which may be either handholds or footholds, which are designed to allow a person to rotate the composter even if it contains a large amount of relatively dense compost material. The steps may extend either radially inwards or outwards towards the axis of rotation of the composter. Their presence allows a person to achieve a sufficient amount of leverage in order to rotate the composter. Moreover, the composter includes indicia, specifically the days of the week, on the outer surface of the drum in order for the rotational state of the composter to be tracked over time, thus optimizing the process. The septagonal cross section allows for each day of the week to be indicated on each face of the drum. The invention also contains a sealable door. The drum is supported on a support member. In preferred embodiments of this invention, support members could either be one that has a surface that engages the surface of the container in a sliding manner, or a horizontal shaft connected to either ends of the drum using bearings which allows for the rotation of the drum about the axis of rotation. This composter invention allows for careful controlling of the process through the use of the handholds and indicia, thus aiding in optimizing the composting process. (Buss, Heath, 1998)

Although aerobic decomposition is an exothermic process, the occurrences of low ambient temperatures in the winter require external heating of the systems to maintain the desired temperatures. One composter invention incorporates low cost rigid panels to form an insulated composting container shaped in a cylinder with a polygonal cross section. The preferred embodiment of this invention comprises eight panels, forming an octagonal cross section, which promotes mixing at a high fill level, an improvement over cylindrical containers. A rigid frame serves as a base member to support the panels and allow for the rotation of the composter. An interesting aspect of this design is an internal manifold of sheet aluminum or stainless steel consisting of holes small enough to ensure that compost does not fall through it. Running the entire length of the cylinder, the main function of the manifold is to deliver air from an air supply to the composter when the composter is in a stationary or rotational state. The end surface of the drum includes a small port that allows pressurized air from a delivery system to enter the manifold and, ultimately, the compost. Another aspect of the composter is a door that eases entry and removal of material to be composted. Each L-shaped structure of aluminum sections are incorporated along the longitude in order to maintain the relative position of the drum panels and to provide strength to resist forces and moments exerted due to the contained waste during use. Moreover the elements are supported by highly rigid structural hoops concentric with the cross section of the container. They maintain the position of the structural elements and the panels in their cross sectional shape during unloading and loading. They also provide a means of supporting and rotating the container in use. Edges of the panels of the drum are bonded using a mating structural element. This serves to avoid leakage between the drum panels as well as the door. Rollers, that facilitate the rotation of the container, use the structural hoops as tracks. The combination of light weight and insulating properties, as well as the corrosive resistance of galvanized steel as the principal material for the invention, makes its construction particularly beneficial. (Windle, Neal, 2006)

Another invention, also a rotatable composter, consists of a drum member with cylindrical side surfaces and two end surfaces. It also comprises of an opening, a door, through which waste material may be loaded and unloaded, ventilation holes to allow aeration of the waste material and indentations to serve as handholds on the outside of the drum member. These handholds, which are spaced evenly along the circumference of the drum, are used to manually rotate the drum as well as act as lifting members on the inside of the drum to allow for efficient mixing of compostable material. The composter is also provided with a base member that supports the cylinder. It comprises of four rollers, two of the rollers being provided at each end surface of the drum. These end surfaces are also provided with tracks to receive the rollers. The door, which is provided with hinges and a locking mechanism, may be provided on either of the end surfaces of the drum to allow for loading and unloading. A variant to this invention uses a member that acts as a base with rollers to allow rotation of the drum as well as a leachate collection system. A hollow plastic member, the base is slightly bowl shaped for the collection of compost juice from the ventilation holes and the door, which ultimately drains into the center trough of the member. This juice, once diluted with water, can serve as an organic fertilizer. (Emond, Pierre, JR 1992)

The objective of this invention was to provide a composter which can allow for turning over of the composting material at regular intervals as well as be readily emptied. The composter, in one form of its invention, consists of a container mounted in an elevated position and rotated about a horizontal axis. It is provided with a hinged door on the circumference of the cylinder allowing for composted material to be emptied under the effect of gravity. The door may be an open mesh door in order to ensure that only completely composted material would be emptied while partly composted large material would be retained in the container for further treatment. The end surfaces of the vessel contain fly wire fitted openings to allow the escape of any excessive heat out of it. The drum is also made up of non-slip tracks, located towards the end surfaces of the container. The tracks are in contact with the driving wheels provided on axles which are part of the base member. The base member of the composter is also fitted with a fly-proof aeration drain. The main function of this drain is to collect excessive fluid formed within the container during the composting process. (Whiteside, Peter, 1980)

DESIGN DETAIL

Assumptions

The first assumption used was pertinent to the organic waste production rate on campus. Gorilla Composting (2012) recorded a weekly loading rate of 34 kilograms. However, following a waste audit, the group estimates that the potential maximum production of the campus is 295 kilograms per week. This number would be reached if people properly disposed of their wastes and there was collection everywhere. This is currently not the case, since compostable material still ends up in garbage cans, and various locations, such as the food laboratory, which do not send their remains to composting.

The second assumption pertains to the solid retention time. A duration of three weeks was chosen. This is 1.5 times the time it takes for organic waste to be composted in a windrow. (Alberta Environment and Olds College, 1999)

Since the data collected is given in units of mass, a conversion factor must be used to calculate the volume. The density used is 540 kilograms per meter cube, which is the average density of food, which composes most of the organic waste gathered. (Canada Service Plan, 2010) No extra volume was given to the composter, because this is the lower value of the range of density. There will be denser waste, and thus the volume taken would be less. The volume of the composting vessel was chosen based on half of the maximum potential production rate. This choice was made as a compromise between what is presently collected, and what could be collected. This would also allow assumptions to be verified and adjustments on the design to be made by the time a second unit is necessary. Finally, installation of a second drum would allow organic waste to be processed via a batch system: all new compost goes to one vessel while the content of the other one decomposes, and the roles of the containers are switched when the former is filled and the latter is finished.

Drum Exterior

The first aspect of the design of the bicycle-powered composter is the exterior of the drum. Figure 3 (Annex A) shows the isometric view of the drum. The vessel is 0.725 m in length and 1.2 m in diameter. As can be seen in figures 3 and 4 (Annex B), the drum also consists of ventilation holes 3 cm in diameter, to allow for aeration, to optimize the composting process. The holes are located 29 cm from the center of the cylinder and are covered in fly mesh to prevent the entry of insects into the compost pile. Present on one of the end surfaces of the drum is also a two-staged door. Figures 6 and 7 (Annex A) show the isometric views of the loading and unloading position of the drum. The two-staged door is advantageous to the people operating the composter as it allows for efficient loading of compostable material into the drum as well as unloading and cleaning of the finished compost at the end of the composting process. Moreover, one side of the base member, as will be seen later, can be opened when the drum is being unloaded. The exterior of the drum is also covered in insulation to reduce heat loss by conduction and convection. Various equations pertaining to calculations such as the maximum potential load of the compost pile after three weeks, the dimensions of the cylinder, the shear strength and moment distributions across the cylinder and the heat transfer between the compost pile and the surrounding environment with and without insulation were calculated for this aspect of the design assembly.

As mentioned earlier, the volume of the vessel was chosen based on half the maximum potential production. This original value, Q_{max}, was calculated using the following equation: (King, 2011)

$$Q_{max} = \dot{m} * SRT \quad (1)$$

Where,

Q_{max} = maximum potential load of compost (kg)

$\dot{m}$ = mass flow rate (kg week^{-1})

SRT = solids retention time (weeks)

Half of this value was chosen for the potential load of the compost in the drum. The result was then used to calculate the volume of the cylindrical drum using the following equation:

$$V = \frac{Q}{\rho} \quad (2)$$

Where,

V = volume of the cylindrical drum (m^3)

Q = half of the maximum potential load of compost (kg)

ρ = density of compost (kg m^{-3}) (Canada Service Plan, 2010)

A low surface area to volume ratio was required in order to reduce heat loss by convection. Thus, using a trial and error approach, through the use of various values of the radii of the cylindrical drum, the following equation (Math Open Reference, 2009) was used to calculate the length of the cylindrical drum:

$$L = \frac{V*4}{\pi*d^2} \quad (3)$$

Where,

L = length of the cylinder (m)

V = volume of the cylinder (m^3)

π = 3.1415…

d = diameter of the cylinder (m)

Figure 8 (Annex A) shows the free body diagram of the cylindrical drum when the compostable material is inside the drum. Equilibrium functions of force and moment were used in order to calculate the normal forces of the wheels on which the drum would rotate. These values were thus calculated using the following equations:

$$N_2 = \frac{Q}{2} \tag{4}$$

$$N_1 = Q - N_2 \tag{5}$$

Where,

N_1 and N_2 = normal reaction forces by the wheels (N)

Q = half of the maximum potential load of compost (kg)

Next, the shear strength, to calculate the maximum shear, and moment distributions, to calculate the maximum moment, across the cylinder, were calculated using the following equations (McKyes, 2012):

$$\sigma = N_1 - qx \tag{6}$$

Maximum shear occurs at $x = \frac{L}{2}$

Where,

σ = shear strength of the cylindrical drum (kPa)

N_1 = normal reaction force by the wheel (N)

q = load per unit length of the compost in the drum (kg m^{-1})

x = distance from one end of the drum with respect to its length (m)

L = length of the cylinder (m)

$$M = \int_0^x (N_1 - qx)\, dx = \left[N_1 x - \frac{qx^2}{2}\right]_0^x \tag{7}$$

Maximum moment occurs at $x = \frac{L}{2}$

Where,

M = moment produced by the drum (N m)

N_1 = normal reaction force by the wheel (N)

q = load per unit length of the compost in the drum (kg m^{-1})

x = distance from one end of the drum with respect to its length (m)

L = length of the cylinder (m)

As mentioned previously, insulation was used to reduce the convective heat loss from the compost pile and thus maintain composting temperatures throughout the process. The following equations (Mydlarski, 2011), assuming no edge effects, were used to calculate the heat transfer rate of the compost pile without and with insulation, respectively:

Without insulation,

$$q = \frac{(T_i - T_\infty)}{\left(\frac{x}{k} + \frac{1}{h}\right)\left(\frac{1}{d\pi L}\right)} \tag{8}$$

With insulation,

$$q = \frac{(T_i - T_\infty)}{\left(\frac{x}{k} + \frac{1}{h} + R\text{−}value\right)\left(\frac{1}{d\pi L}\right)} \tag{9}$$

Where,

q = heat transfer rate (W)

T_i = temperature inside the compost at the wall (K)

T_∞ = temperature of the outside air (K)

k = thermal conductivity of the material (W m^{-1} K^{-1})

d = diameter of the cylindrical drum (m)

L = length of the cylindrical drum (m)

h = convective heat transfer coefficient (W m^{-2} K^{-1})

R-value = rating given to insulation (m^2 K W^{-1})

Drum Interior

The interior of the cylindrical drum consists of six vanes, constructed from 40 cm long and 8.9 cm high, 5.08 cm by 10.16 cm (2 in. by 4 in.) wooden beams, spread along the circumference of the cylinder. One recommendation would be the installation of triangular reinforcements to prevent the weight of the compost from breaking the vane. The main advantage of the vanes is to help in the efficient mixing of organic matter. In the absence of the vanes, organic matter would simply slide along the sides of the cylinder and material would not mix properly. Figures 9 and 10 (Annex A) present the isometric and front views, respectively, of the interior of the drum. Calculations were made to deduce the torque that would be required for a particular mass of compost in the drum, at a particular point in time during the turning process, to shear off a vane. The equation (McKyes, 1989) is as follows:

$$\tau_{SF} = \frac{(\pi * \sigma_{undrained} * d^2 * h)}{2} + \frac{\pi * \sigma_{undrained} * d^3}{12} \qquad (10)$$

Where,

τ_{SF} = turning torque for complete soil failure (N m)

π = 3.1415…

$\sigma_{undrained}$ = undrained shear strength of the soil (kPa) . This value is approximately 10-20 kPa for cohesive soils (McKyes, 1989)

d = overall diameter of the vane (m)

h = height of the vane (m)

Gears

Another aspect of the design of the bicycle-powered composter is the gearing system. It utilises a gear reduction method with the use of eight gear sets from old bicycles. The method allows for the achievement of a high mechanical advantage and an amplification of torque, which ultimately turns the composter at approximately 1.23 revolutions per minute. Figures 11 and 12 (Annex A) present the isometric and front views, respectively, of the gear system. Bicycle chains run between each individual gear and the last gear is welded onto the drum. The gear sets and their chains are held in place by 5.08 cm by 10.16 cm (2 in. by 4 in.) rectangular wooden beams and are allowed to rotate freely through the presence of ball bearings. The last gear of the gearing system is welded to the drum. Equations relating variables such as angular velocity, torque and number of teeth on each gear, were used in order to calculate the appropriate gear ratios and torques to achieve torque amplification. The following assumptions were made for this aspect of the design:

- The frictional coefficient between each gear and its corresponding chain are negligible.
- The average power produced by a recreational pedaller is 100W. (Berger, 2007)
- The average angular velocity produced by a recreational pedaller is 65rpm (6.81rad/s). (Wikipedia, 2011)

To calculate the initial torque produced by a recreational pedaller, the following equation (Delson, 2004) was used:

$$\tau_{in} \;=\; \frac{P_{in}}{\omega_{in}} \tag{11}$$

Where,

τ_{in} = input torque produced by a pedaller (N m)

P_{in}= input power produced by a pedaller (W)

ω_{in}= average input angular velocity produced by a pedaller (rad s^{-1})

To calculate the output torque to rotate the cylindrical drum, the following equation (Delson, 2004) was used:

$$\tau_{out} \;=\; m * g * D \tag{12}$$

Where,

τ_{out} = output torque required to rotate the drum (N m)

m = mass of the drum and the compostable material. However since the drum is symmetrical, the mass of the drum may be neglected for this calculation (kg)

g = gravitational acceleration (m s^{-2})

D = the distance from the center of mass of the drum to the center of mass of the compost matter in the drum i.e. the centroid of a quarter circle. This equation (eFunda, 2012) used to calculate it is as follows:

$$D \;= \frac{4}{3} * \frac{r}{\pi} \tag{13}$$

Where,

r = radius of the cylindrical drum (m)

π = 3.1415…

Lastly, the following relation (Delson, 2004) was used to calculate output torques, output angular velocities from each gear, as well as radii and number of teeth, where necessary, of each gear:

$$\frac{\tau_x}{\tau_y} = \frac{D_x}{D_y} = \frac{n_x}{n_y} = \frac{\omega_y}{\omega_x} \tag{14}$$

Where,

τ = torque (N m)

D = distance from the point of action of the force to the center of rotation (m)

n = number of teeth on a gear (unitless)

ω = angular velocity (rad s^{-1})

Frame

The frame of the assembly is made up of wooden beams and is approximately of the dimensions 145.5 cm in length, 79.4 cm in width and 62.9 cm in height. Figures 13 and 14 (Annex A) show the isometric views of the frame. Figure 14 shows the view of the frame when one part of it is open. A hinge and locking mechanism will be constructed for this purpose. The main advantage of being able to open one side of the frame is the ease of unloading finished compost at the end of the composting process. Residing in the frame are also four 10.16 cm (4 in.) and four 6.35 cm (2.5 in.) rubber wheels. The wheels are all bolted to the frame and assist in the rotational motion of the cylindrical drum.

Assembly

Attaching Parts Together

Figures 15, 16 and 17 (Annex A) present the dimetric, front and rear views, respectively, of the bicycle-powered composter. Figures 18 and 19 (Annex A) show the isometric view of the loading and unloading position of the drum. Wood and either nails or screws, can be used to hold the various components together. Screws are easier to pull out, which is handy in case of mistakes, but they usually cost more than nails and take more time to put in. On the other hand, nails can be more dangerous during the assembly, since they have to be installed with hammers or nail guns. Care and precaution should be employed if these tools are used.

Regardless of whether nails or screws are used, they should be galvanized. This is particularly important since they are likely to be exposed to water, and normal steel would oxidise and deteriorate faster. If nails are used, they should be 16d, otherwise called 16 penny, which are commonly used to frame lumber together. They are 8.89 cm (3.5 in.) long and if screws are used, they should be equivalent in size. (Framing Basics, 2009) Two nails or screws should be used each time, and they should be inserted longitudinally. In other words, nails should go through the end of the beam. Care should be given to make sure that no pointy end sticks out of the wood. (Icreatables, 2010)

Since the wheels, hinges and latches (locking mechanism) are sitting on less than 8.89 cm (3.5 in.) of wood, the nails or screws employed should be shorter i.e. less than 3.81cm (1.5 in.)

These moving components come with plates with holes for nails and screws, which should all be filled accordingly.

Insulation

Insulation can be easily acquired in three forms: plates, sheets and foam-in-cans. Sheets should be used, because they are flexible and can thus be wrapped around the curved surface of the drum. Plates are too rigid and foam is more expensive. The sheets come in bundles of five or eight and have various dimensions, thermal resistances and costs. Table 1 presents the specifications of various bundles of sheets.

Thermal resistance (m^2K/W)	Sheets per pack	Thickness (cm or in)	Area dimensions per sheet (in x in or m x m)	Price per pack (CAD)
R22	8	24.13cm (9.5 in.)	0.3874m x 1.1938m (15.25” x 47”)	35.49
R31	8	24.13cm (9.5 in.)	1.219m x 0.610m	72.73
R31	8	24.13cm (9.5 in.)	1.219m x 0.406m	51.11
R14	8	8.89cm (3.5 in.)	0.5842m x 1.1938m (23” x 47”)	35.49
R22	5	13.97cm (5.5 in.)	0.5842m x 1.1938m (23” x 47”)	45.00
R20	10	15.24cm (6.0 in.)	1.194m x 0.381m	30.84

Table 3- Various insulation resistances available at Reno Depot on March 25 2012

Sufficient insulation must be bought. Area is a factor, and heat transfer resistance must be sufficiently high. The rotary drum has a surface area of about 5 m^2. When wrapping the drum with insulation, there are areas that must be left uncovered for proper functioning. On the circular ends, insulation must be clear cut at the ventilation holes, and at the hinges, lest it blocks air circulation and hinge rotations. On the curved rectangular side, there should not be any insulation where the wheels travel, otherwise turning may be a problem.

Cost Estimate

An idea of how much capital investment is required is an important criterion in determining the feasibility of the project. As such, steps were taken to compile a ballpark figure. For the wooden structural frame and wheels, the lowest prices for the materials were recorded at Reno Depot on 25 March 2012. The price of nails and taxes were not included.

The quantity of wooden beams required was not calculated based upon the sum of the lengths of each part, but based on the length of each individual part, mixed and matched to use the most of the 3.05m (10 ft.) beams, as will be seen in table 2 below, available. The unit of beams required includes the vanes. The excess plywood can be used for the foundation, as will be mentioned in the recommendations.

As barrels can be procured from various manufacturers and quotations are only available upon request, $100 is set aside for that. Likewise, bicycles, and their gears and chains, can be acquired from many places, and donations are not impossible. With so much possible variances, the estimation in table 2 below can only be a ballpark figure. Labor costs were not taken into consideration for the cost estimate as the composting operations at Gorilla Composting are done by volunteers.

Item	**Price per unit (CAD)**	**Units required**	**Total (CAD)**
10.16 cm (4 in.) rubber wheel	10.19	4	40.76
6.35 cm (2.5 in.) rubber wheel	3.39	4	13.56
5.08 cm x 10.16 cm x 25.4 cm (2 in. x 4 in. x 10 in.) wood	5.34	6	32.04
0.9525cm x 121.92cm x 243.84 cm (3/8 in. x 4 ft. x 8 ft.) plywood	13.67	1	13.67
Mosquito net (91cm x 213cm)	11.99	1	11.99
R22 Insulation 13.97cm thick, 20.32 cm x 38.74cm x 119.38 cm (5.5" thick, 8" x 15.25" x 47")	35.49	2	70.98
Barrel	100	1	100
TOTAL			**283**

Table 4- Cost estimate of designing a bicycle-powered composter

RECOMMENDATIONS

As no prototype was built to test in under real world circumstances, the factors pertaining to the design of this composter to be adjusted for are not accurately known. Furthermore, since the compost recipe may not have been accurately represented in Gorilla Composting's sample, some calibrations may be required. Improvements upon the waste audit plans could also be implemented.

For the composter's structural integrity, there are two cases to be aware of. One is longitudinal bending of the vessel component, depending on the chosen material and its thickness. The risk of bending is especially important when the drum is being turned. Aluminum structural elements installed along the container would help in the overall strength and stiffness of the structure. (Windle, Neal, 2006)

Another structural factor is the foundation. Different soils have different bearing capacities, and the emplacement chosen for the composter may not be sufficient to hold the weight involved. The melting period is the main concern, when the ground is muddy and weakest. There are two methods to avoid such a situation. First, the soil could be tested for bearing capacity and the contact area with the composter could be enlarged if needed. This expansion could be affected by adding plywood under the wooden structure. Another way would be to lay an inch thick sheet of gravel under the composter. The soil underneath would have to be dug out so that the top of this layer is even with the surrounding surface. This is to prevent loss of gravel. (Clark, 2012)

During operation, there are several aspects to keep an eye on. First, to reduce composting time, the organic waste to be loaded should be cut in small pieces. Around two to three centimeters in length would be sufficient. This would allow better contact of the composting organisms with the material to be composted. Care should be given to citruses, in particular, since their peels are coated with biocides that inhibit decomposition. (Susteco, 2009-11)

While ensuring that there is no large matter to be loaded, screening for foreign objects could also be done. This means removing anything that does not compost. Plastic bags are the predominant problem on campus. Second, the space inside the cylindrical drum should not be filled completely. Elsewise, turning would be severely hindered and the purpose of rotating would be defeated. Third, waste can be spilt on the ground, which should be recuperated or disposed of. Otherwise, vermin may be attracted to this easily attained source of nutrients. (Susteco, 2009-11) For the same reason, the door of the vessel should be kept closed. Fourth are adjustments to the decomposing content. Extra aeration by extra rotations of the drum should be given if the inside smells rotten. Likewise, if the moisture content is too high, the compost keeper should pedal more. Vice-versa, if it is too dry inside, less pedalling should be done. Finally, if the content smells like ammonia, it means there is insufficient carbon for the nitrogen present in the decomposing matter. Addition of materials with high carbon content would resolve this issue.

For winter operation, attention should be given to the internal temperature of the composter. In order to limit heat loss, the frequency of loading should be minimized by loading bigger quantities each time. (Compost Guy, 2010) This is similar to opening a garage door the least possible in winter. Turning should also be minimized to only what is necessary to prevent anaerobic conditions characterized by rotting odours. Bringing in cold air would contribute to cooling the content.

There is much room for improvement on this bicycle-powered composter. One idea is to install a mesh screen to the door to serve as a second one. This way, the composter could be more easily aerated during the hotter days. Moreover, this extra barrier could be used to screen the compost during unloading. The material that would pass through the door is more likely to be the compost that is finished or ready for curing; what would not have been composted would be retained inside.

Since the volume of the drum was based on half the theoretical maximum organic waste production on campus in order to allow for a batch system, a variant to the bicycle-powered composter idea is to use the same bicycle and associated gears for the turning of both vessels. This could be done by putting the closed, circular end of each drum close to each other and, instead of fusing the final gear to the cylinder, using a latch system. When one drum would need to rotate, that gear could be latched onto that drum. Only one vessel could be rotated at once, and both would have to be close enough to each other to maintain an even tension on the chains.

A criterion for any of Gorilla Composting composter is lack of electrical power. However, in case electricity becomes available, turning could be done by an electric motor, which could be activated, automated or turned on manually. Automation software could be written in the program LabVIEW. The simplest is based on one input, which could be temperature, moisture content, oxygen level, or time of day. If the parameter for turning is met, then the program would activate the electrical motor.

Finally, a long-term vision of composting would require getting the employees of the school involved. Students are, in the large scale, ephemeral, generally staying only three to four years. (Dance et al, 2004) Transmitting the composting knowledge and experience so frequently can become problematic. Furthermore, getting the staff involved would also eliminate certain downtimes in caring, since exams they do not have. Facilities employees are also present in the summer.

CONCLUSION

The design of the bicycle-powered composter was to design a machine for Gorilla Composting that could be easy to use and maintained, provide a sufficient capacity for all the collection organic matter to reside and allow for efficient temperature and moisture regulation especially during downtimes, especially the winter season. The design comprised of various calculations pertaining to each part of the assembly of the composter. Load calculations were performed to calculate the maximum shear and moment distributions along the length of the cylinder, while heat transfer calculations were done to calculate the effect on its rate by the use of insulation. Moreover, equations were used to calculate the maximum torque required for a certain mass of compost to shear off a vane at a particular point in time during the turning process in order to allow for the efficient mixing of compost. Lastly, gear ratios and output angular velocities were calculated to find the output torque from each gear, amplified to turn the cylindrical drum at an appropriate angular velocity of the drum of about 1.23 rpm. A cost estimate of all the required materials for the building of the assembly, and recommendations pertaining to the maintenance of the structural integrity of the parts of the assembly were provided. The design of the bicycle-powered composter would greatly benefit Gorilla Composting in the optimization of the current composting process as well as provide the club with a design that would attract more volunteers to help in the operation of the new facility.

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ANNEX A- ILLUSTRATIONS

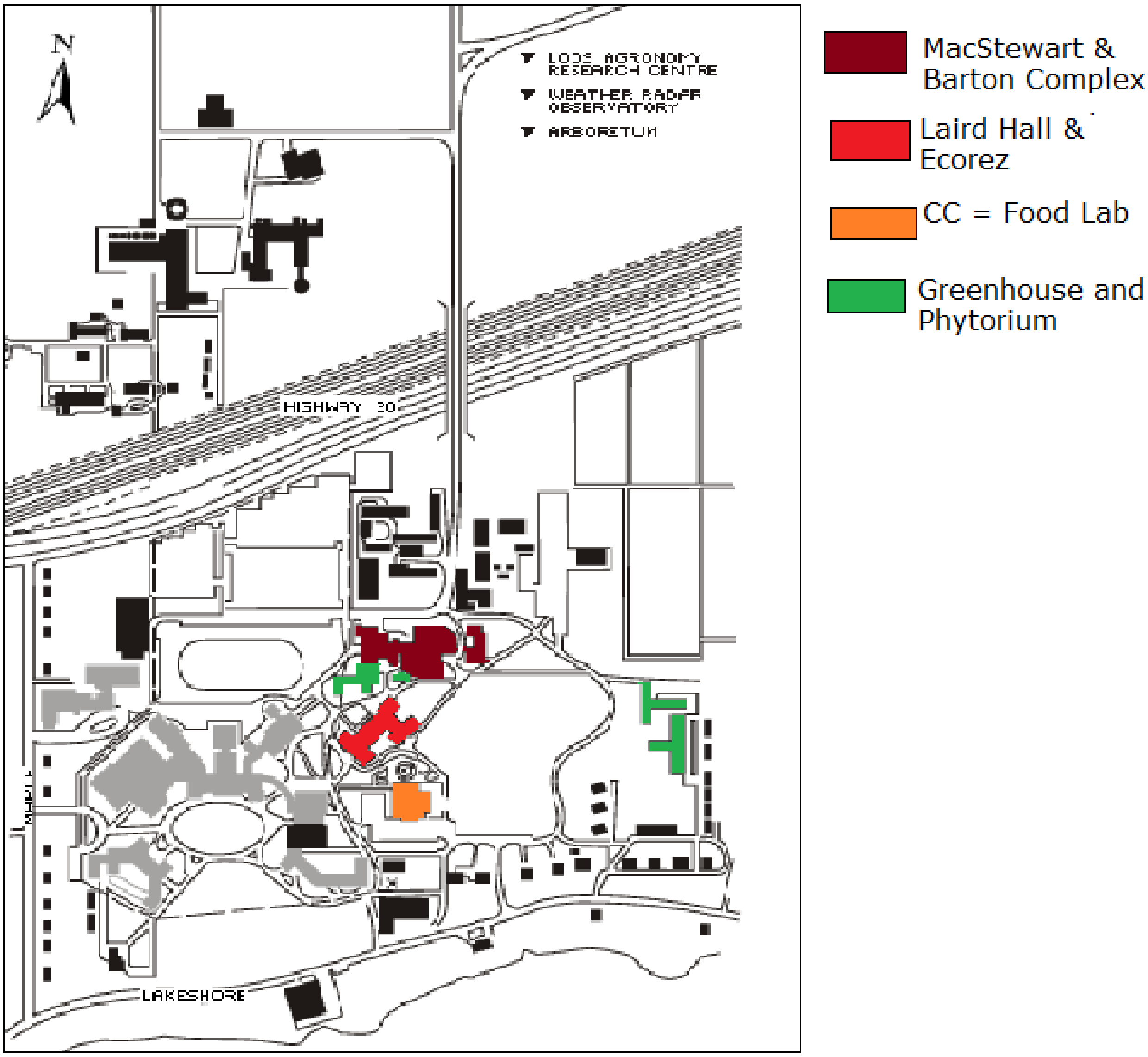

Figure 2 Map of waste collection sites for composting- Macdonald Campus- McGill University. Source: Design 2 report

Figure 2- Existing composting facilities at Gorilla Composting- Macdonald Campus- McGill University. Photo credits: Tam Kieu

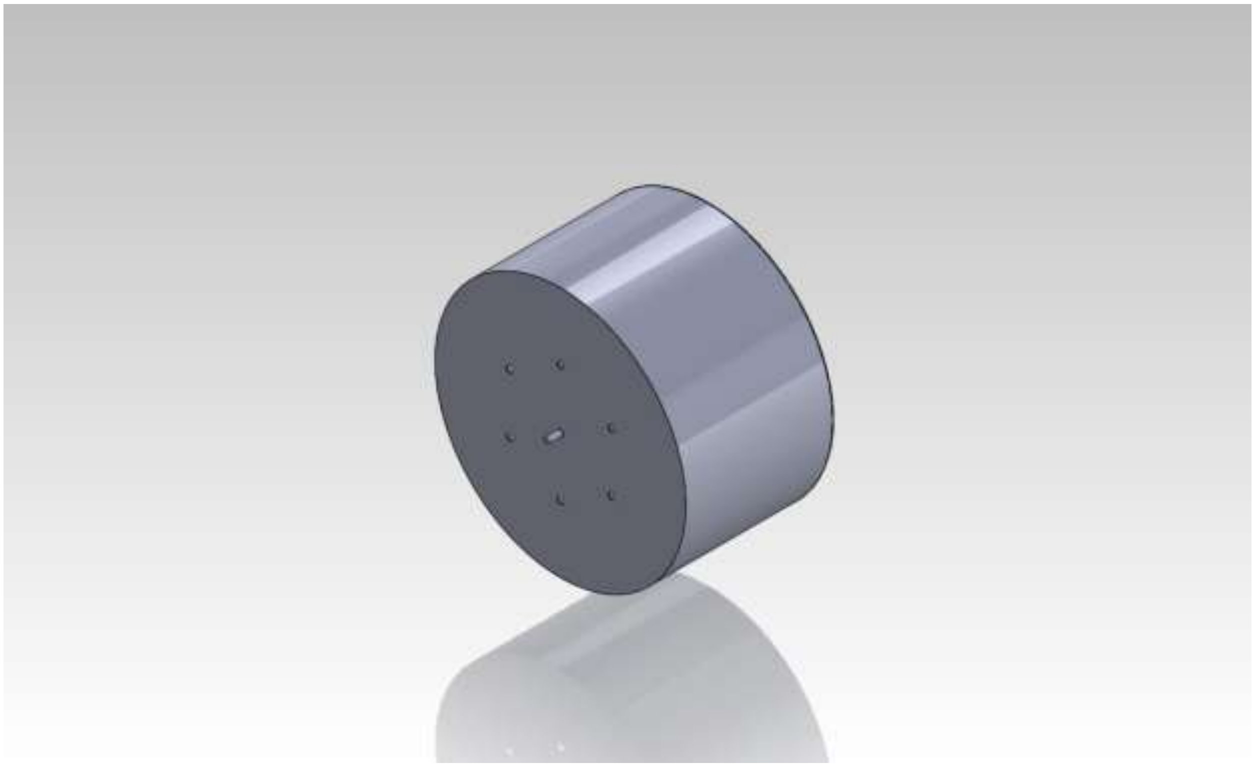

Figure 3- Isometric view of the cylindrical drum of the bicycle-powered composter.

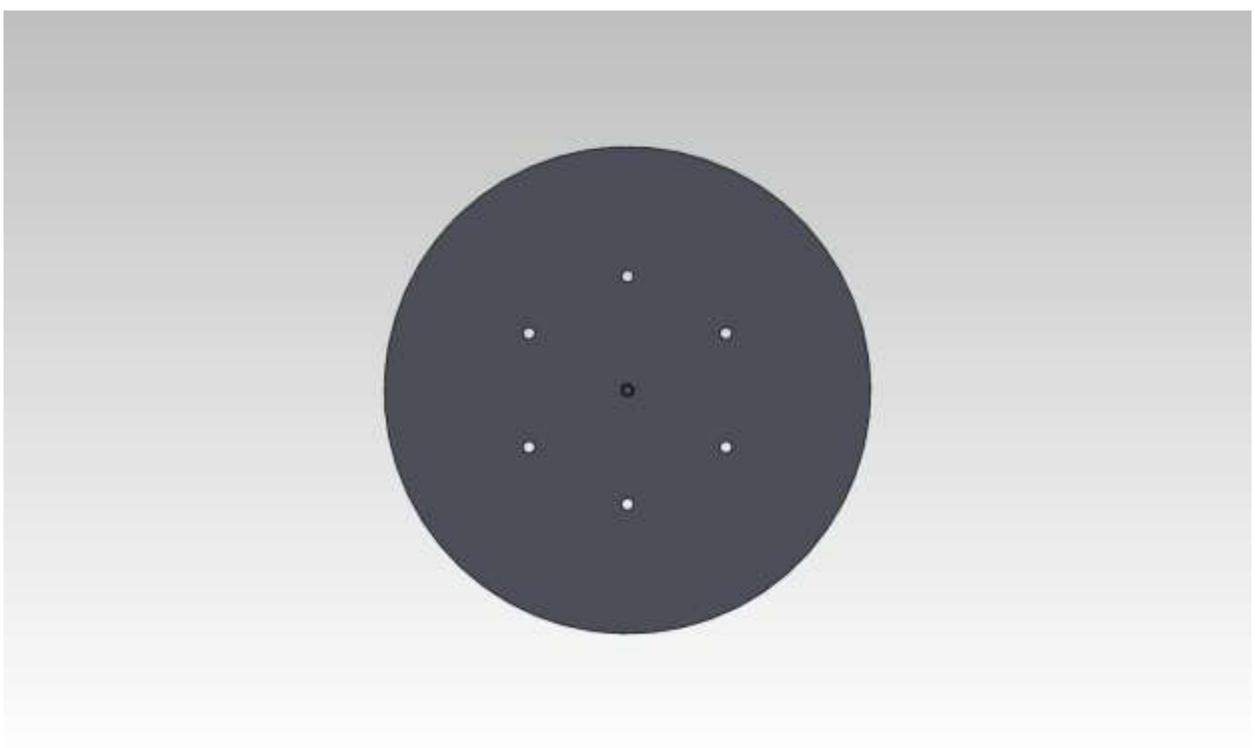

Figure 4- Front view of the cylindrical drum of the bicycle-powered composter.

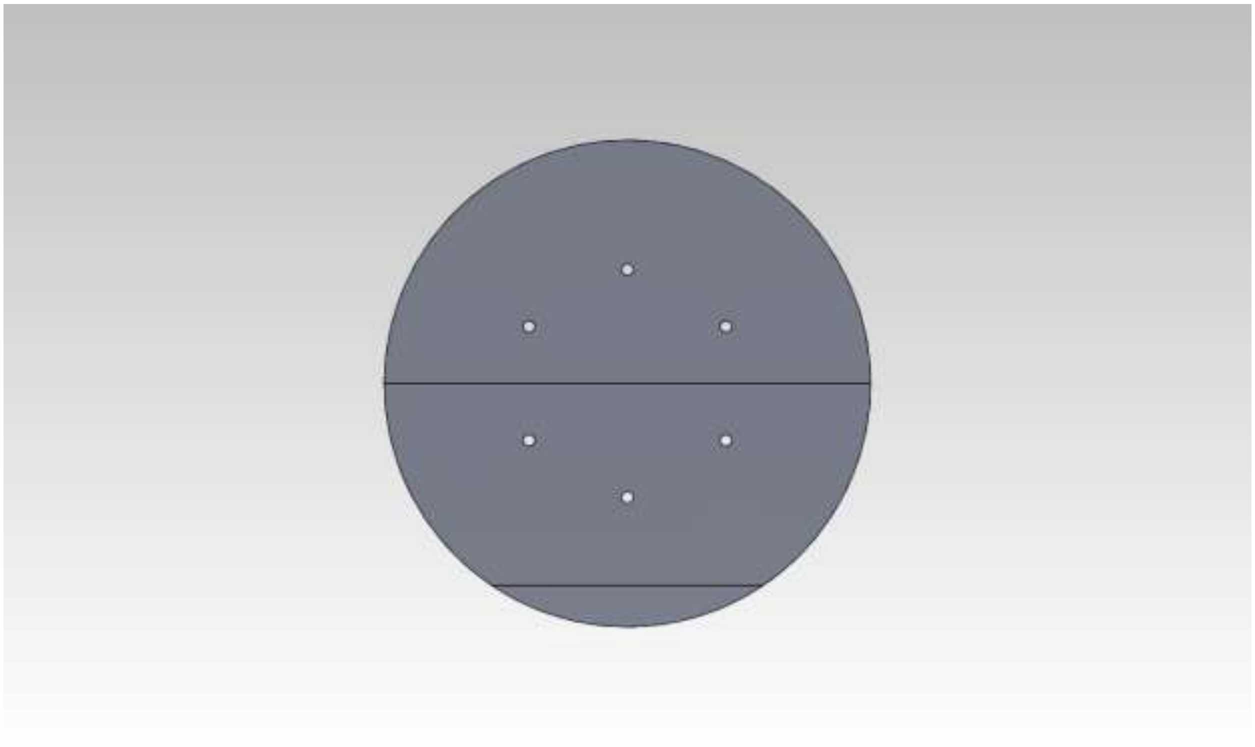

Figure 5- Rear view of the cylindrical drum of the bicycle-powered composter.

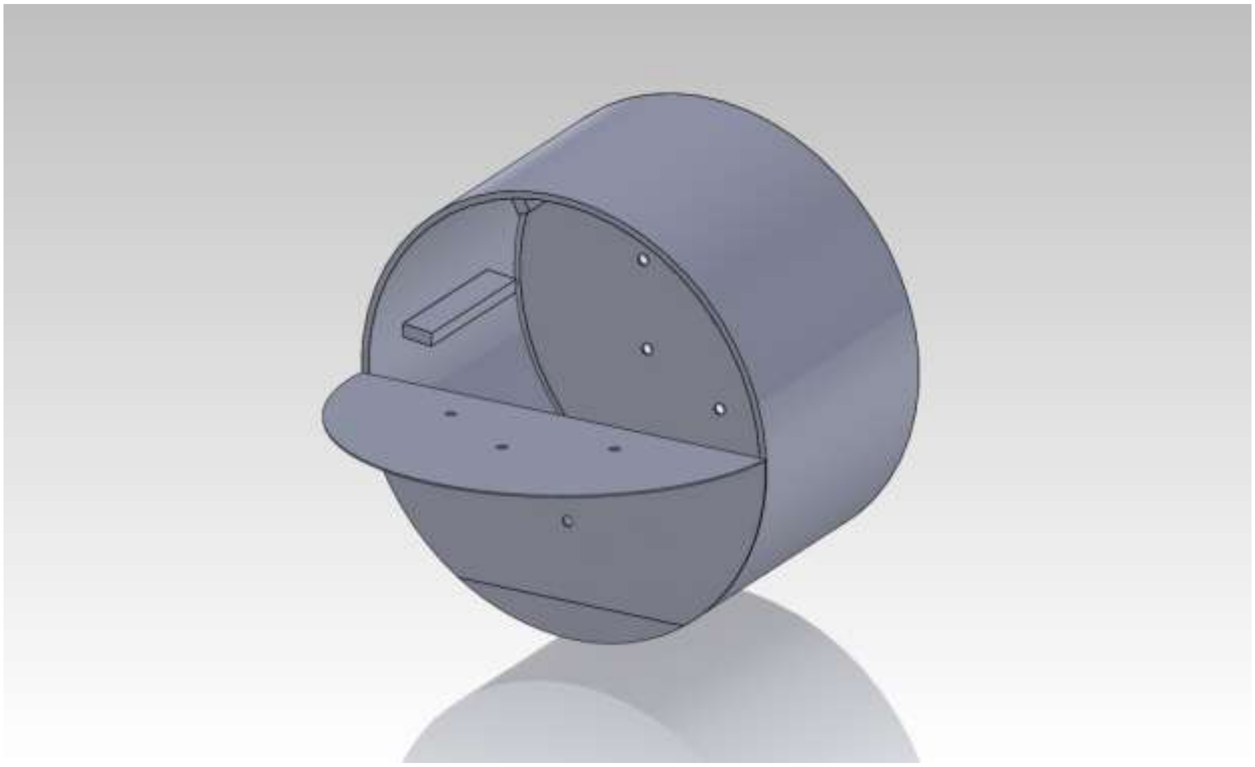

Figure 6- Isometric view of the loading position of the cylindrical drum of the bicycle-powered composter.

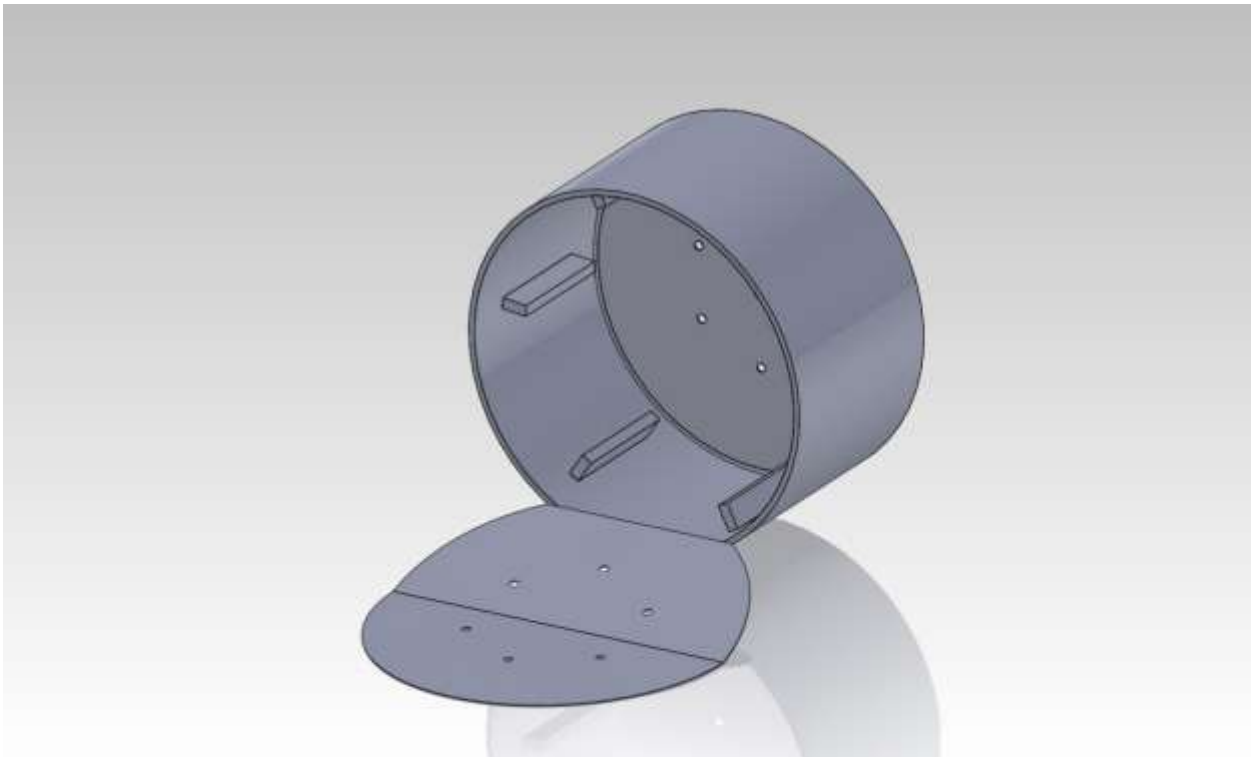

Figure 7- Isometric view of the unloading position of the cylindrical drum of the bicycle-powered composter.

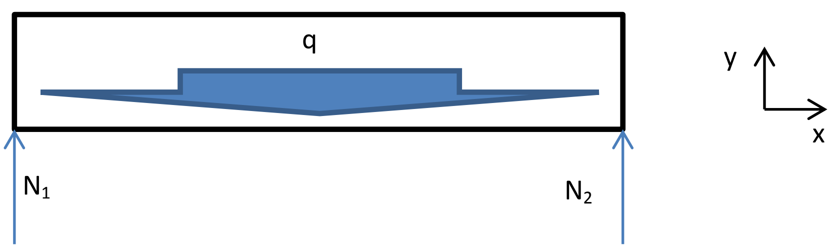

Figure 8- Free Body Diagram of the cylindrical drum of the bicycle powered composter

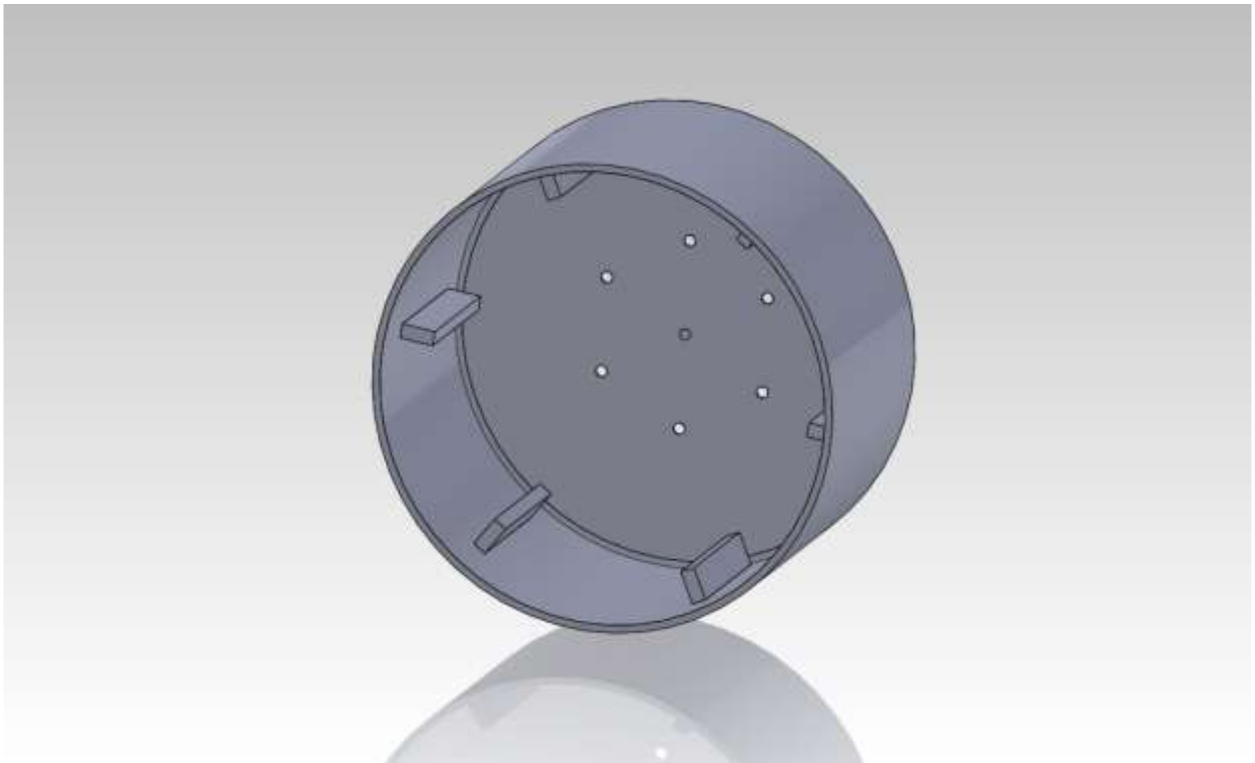

Figure 9- Isometric view of the interior of the cylindrical drum of the bicycle-powered composter.

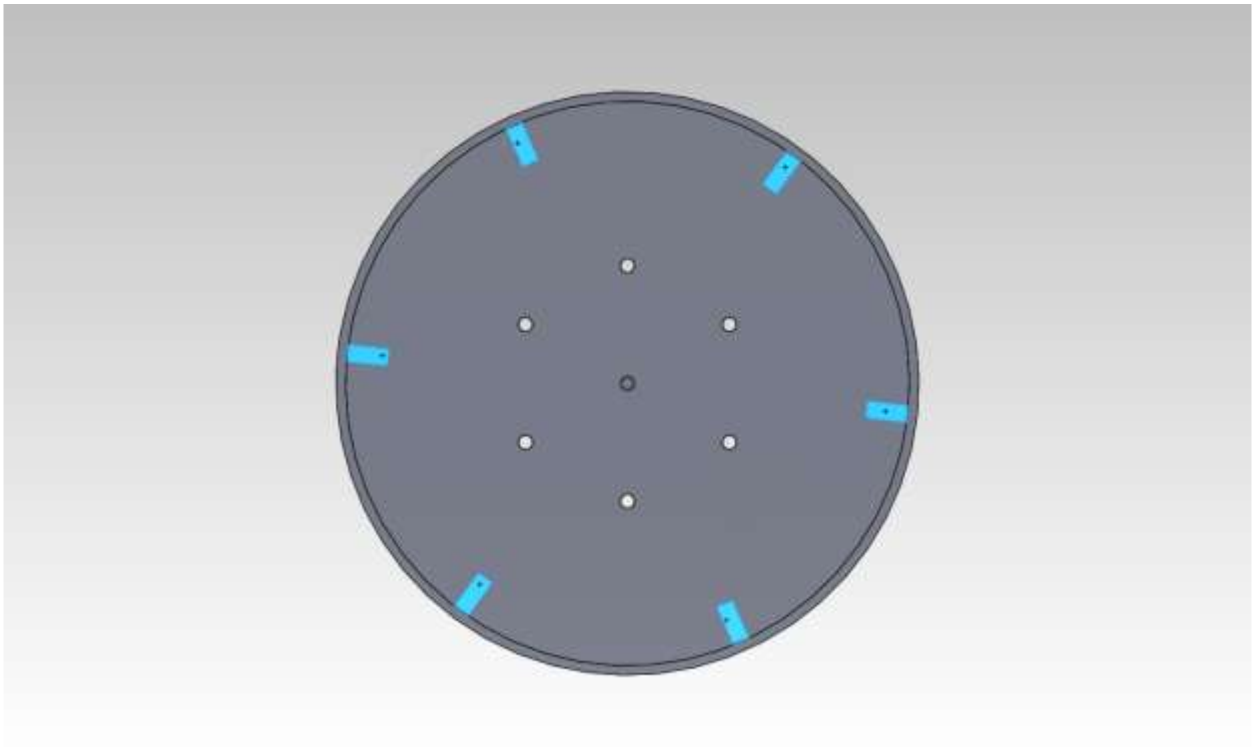

Figure 10- Front view of the interior of the cylindrical drum of the bicycle-powered composter.

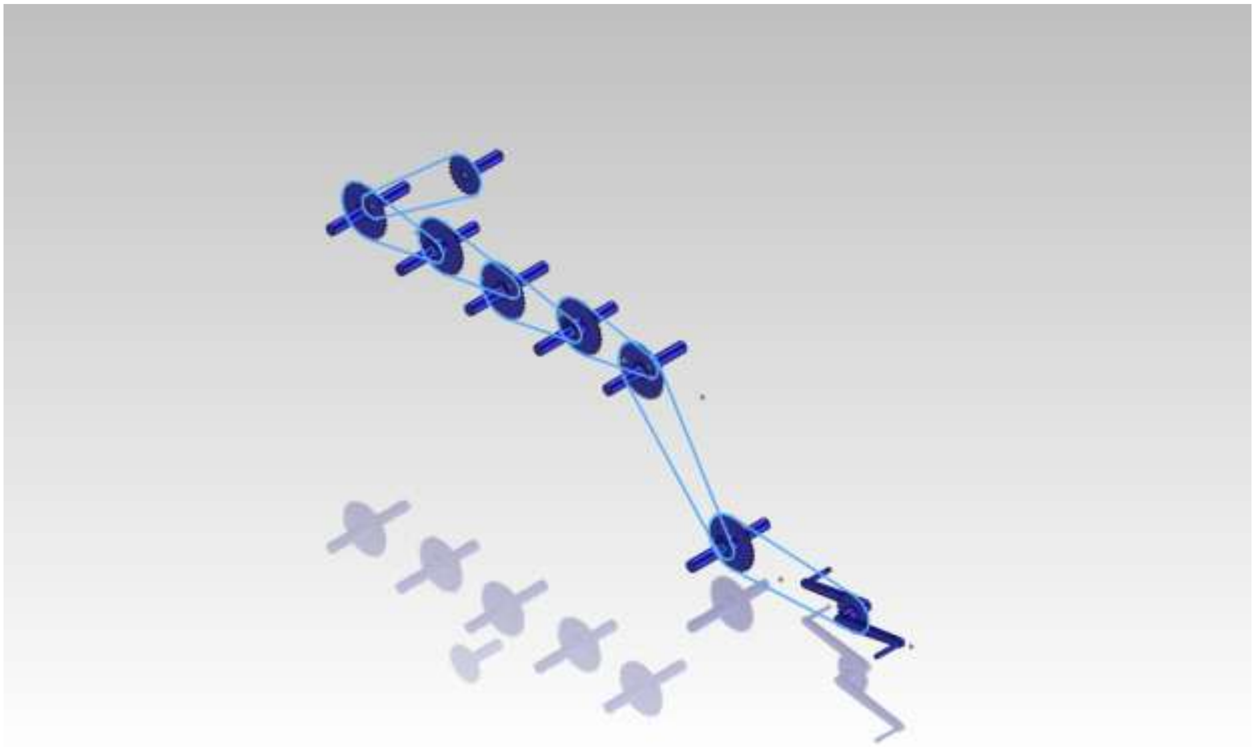

Figure 11- Isometric view of the gearing system of the bicycle-powered composter.

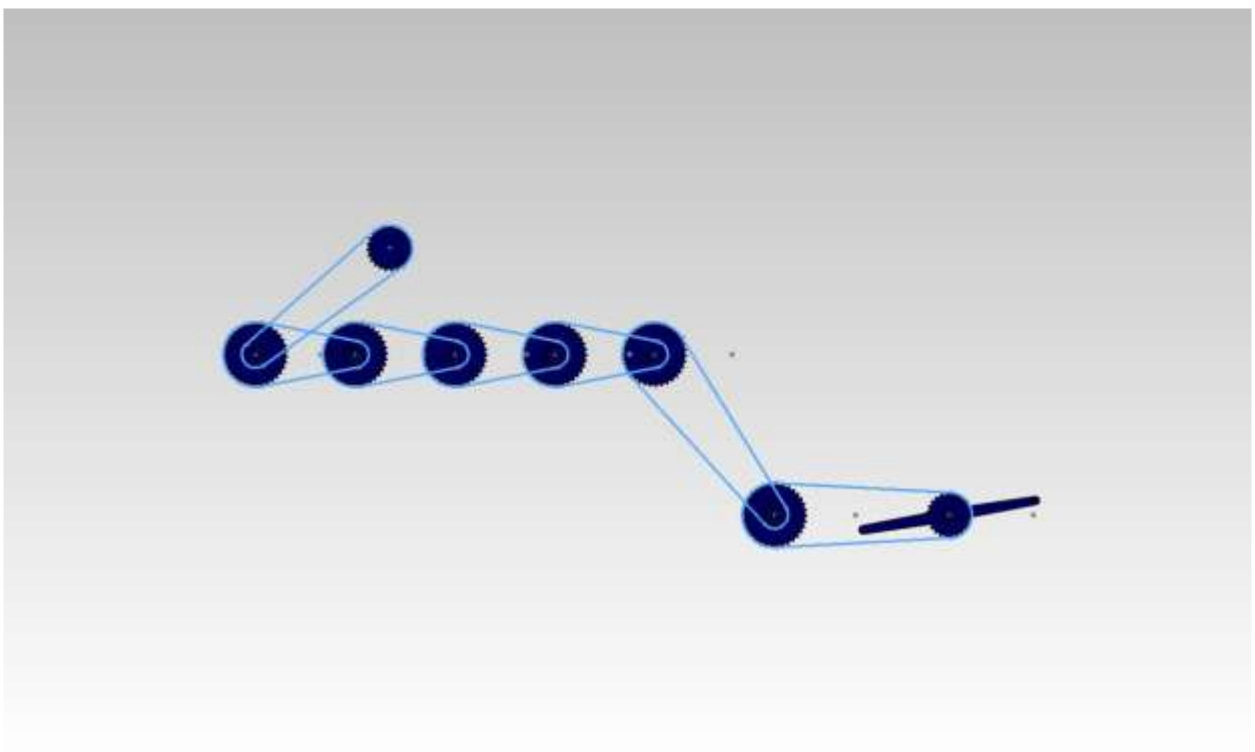

Figure 12- Front view of the gearing system of the bicycle-powered composter.

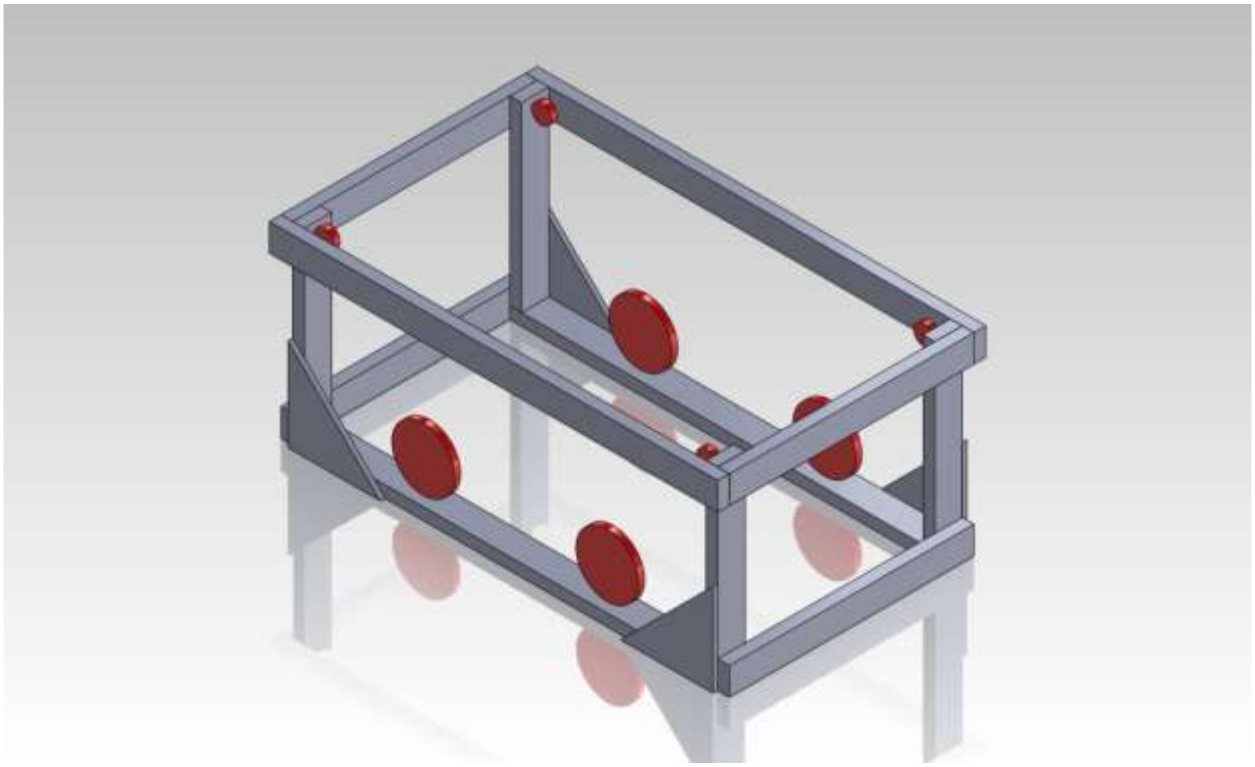

Figure 13- Isometric view of the frame (closed) of the bicycle-powered composter.

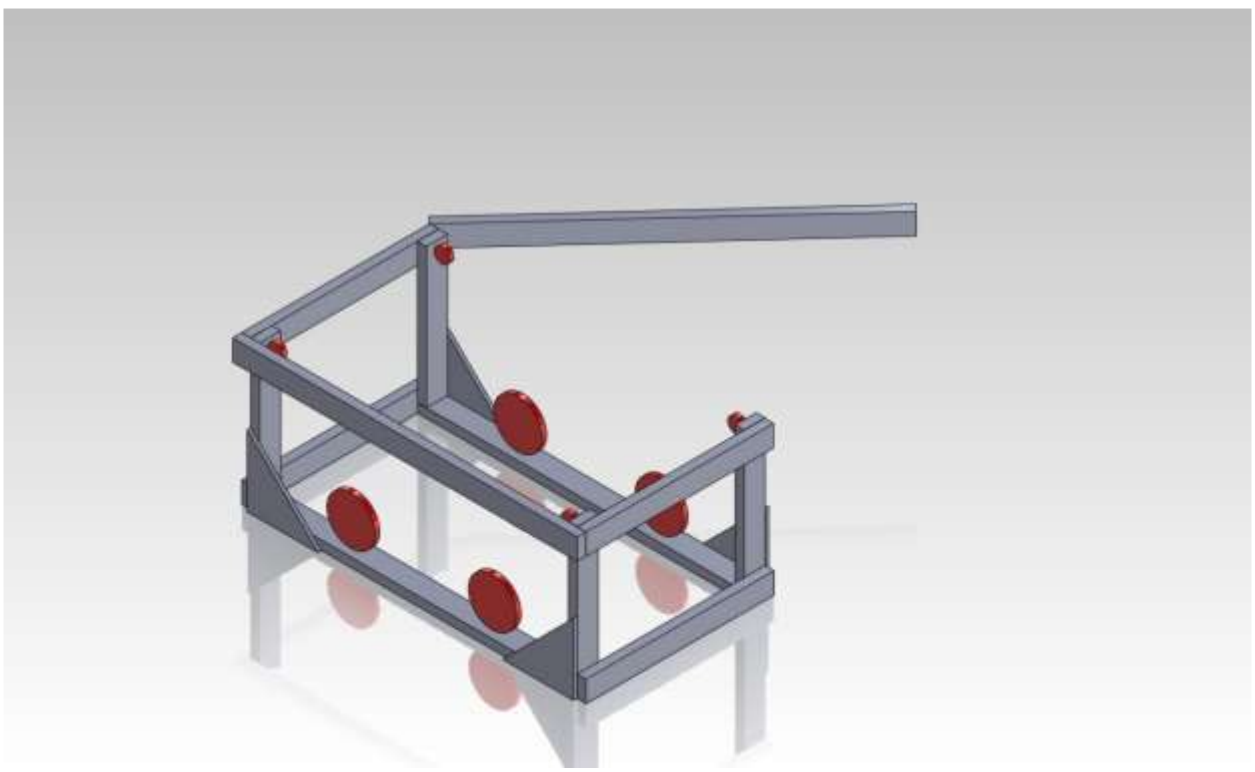

Figure 14- Isometric view of the frame (open) of the bicycle-powered composter.

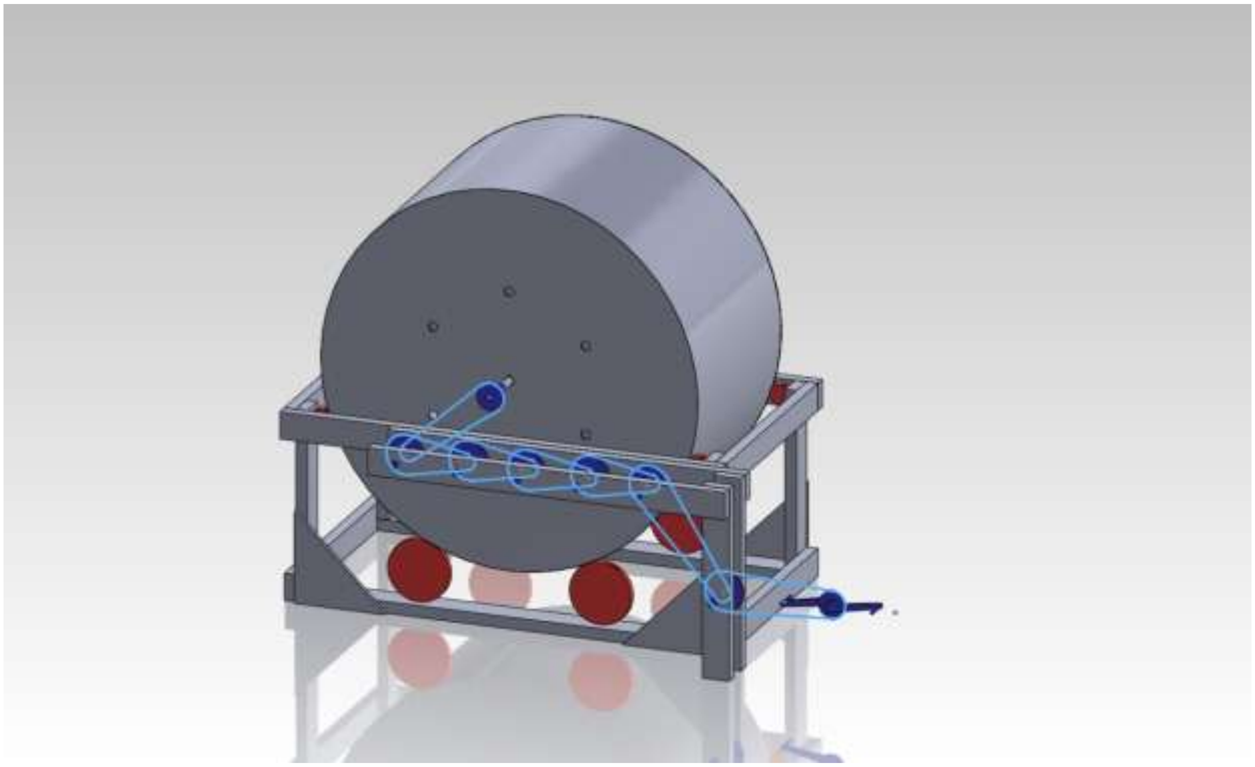

Figure 15- Dimetric view of the assembly of the bicycle powered composter.

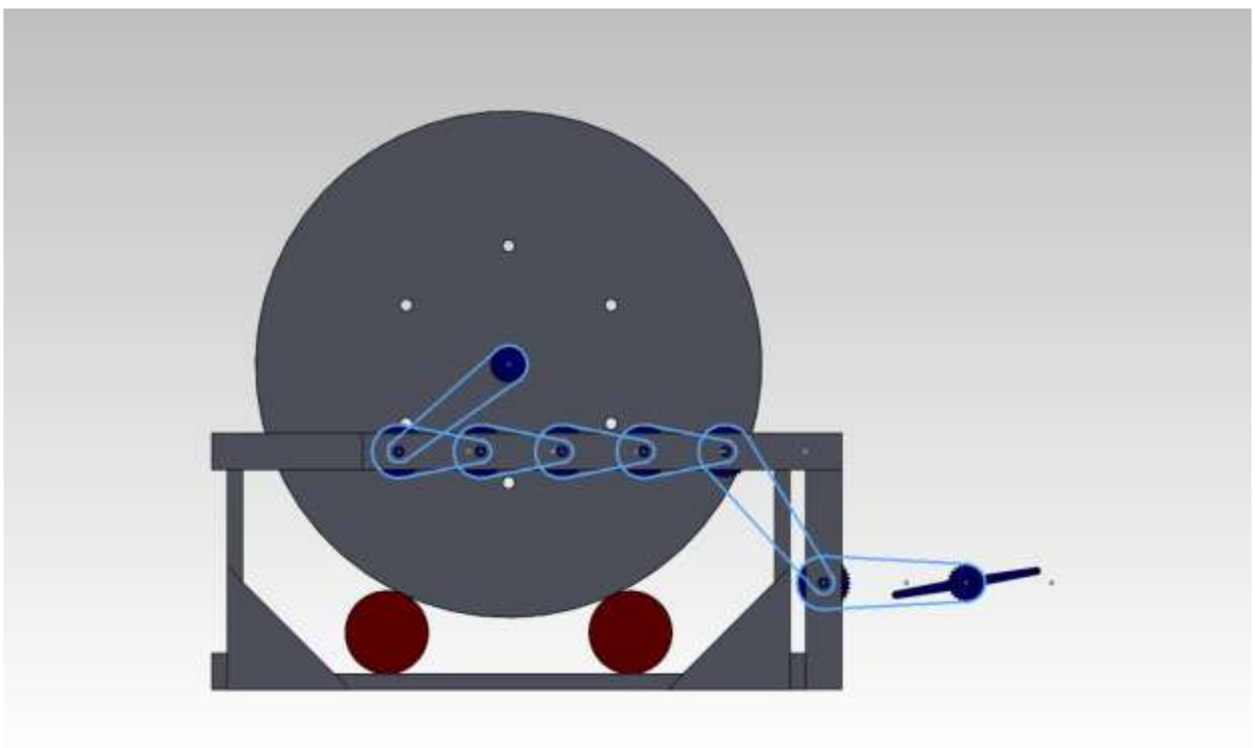

Figure 16- Front view of the assembly of the bicycle-powered composter.

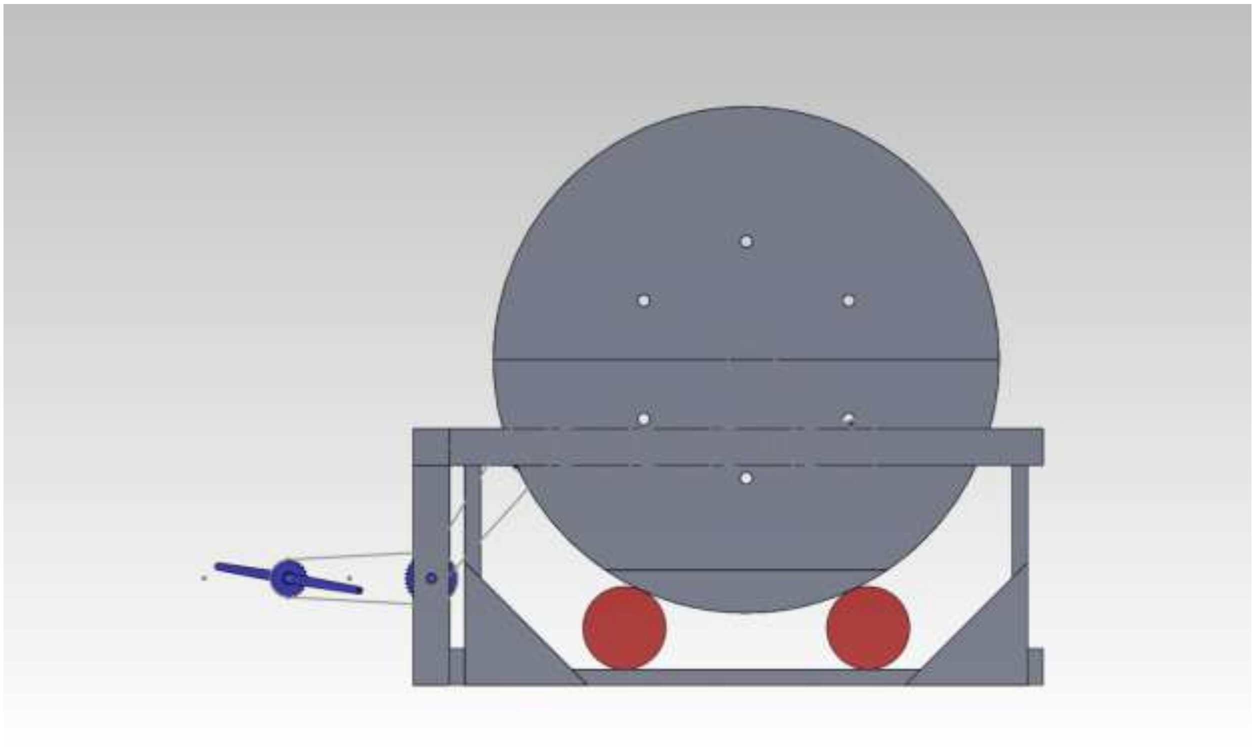

Figure 17- Rear view of the assembly of the bicycle-powered composter.

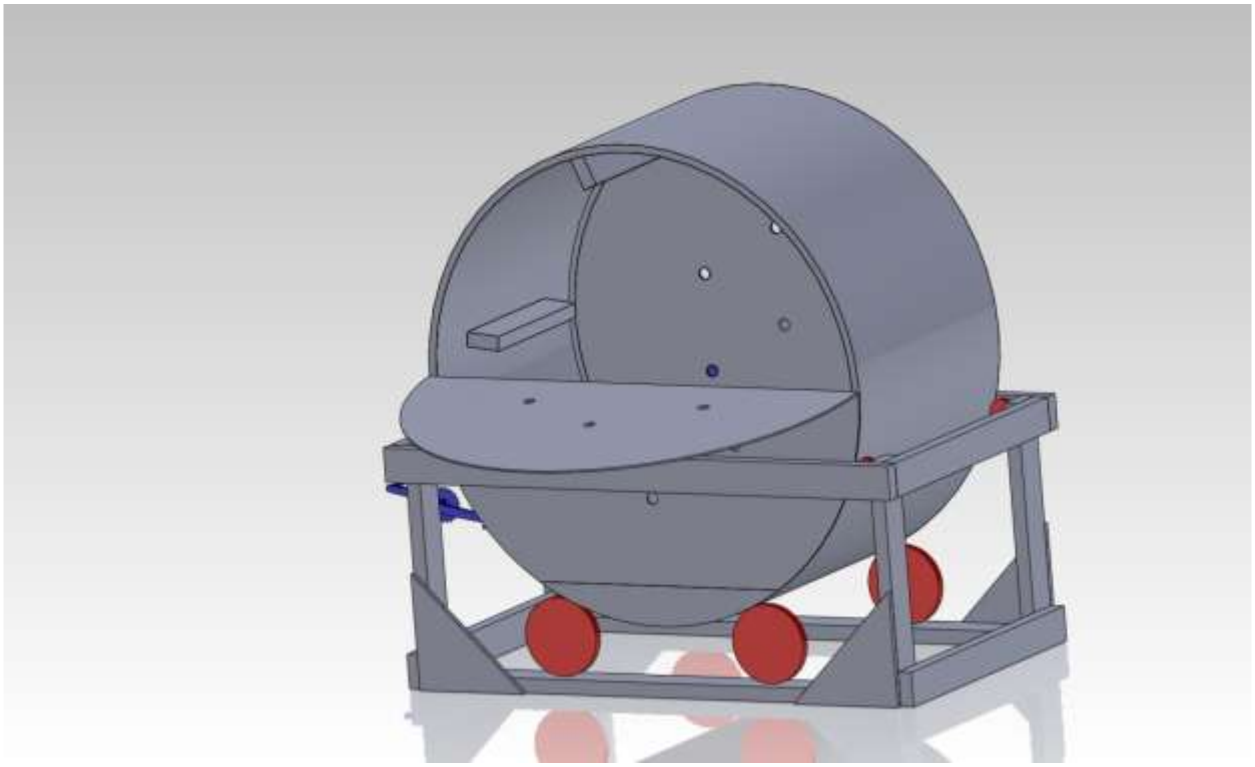

Figure 18- Isometric view of the loading position of the assembly of the bicycle-powered composter.

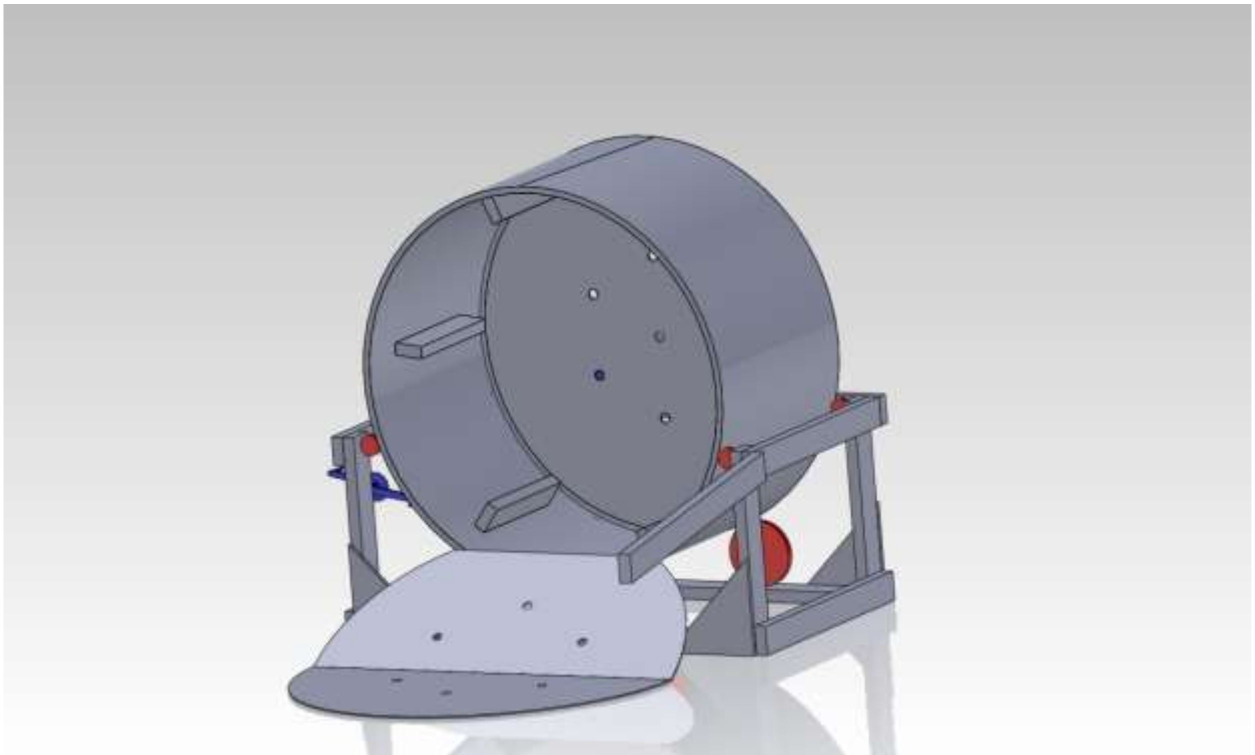

Figure 19- Isometric view of the unloading position of the assembly of the bicycle-powered composter.

Thermal resistance (m^2K/W)	Sheets per pack	Thickness (cm or in)	Area dimensions per sheet (in x in or m x m)	Price per pack (CAD)
R22	8	24.13cm (9.5 in.)	0.3874m x 1.1938m (15.25" x 47")	35.49
R31	8	24.13cm (9.5 in.)	1.219m x 0.610m	72.73
R31	8	24.13cm (9.5 in.)	1.219m x 0.406m	51.11
R14	8	8.89cm (3.5 in.)	0.5842m x 1.1938m (23" x 47")	35.49
R22	5	13.97cm (5.5 in.)	0.5842m x 1.1938m (23" x 47")	45.00
R20	10	15.24cm (6.0 in.)	1.194m x 0.381m	30.84

Table 5- Various insulation resistances available at Reno Depot on March 25 2012.

Item	Price per unit (CAD)	Units required	Total (CAD)
10.16 cm (4 in.) rubber wheel	10.19	4	40.76
6.35 cm (2.5 in.) rubber wheel	3.39	4	13.56
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0.9525cm x 121.92cm x 243.84 cm (3/8 in. x 4 ft. x 8 ft.) plywood	13.67	1	13.67
Mosquito net (91cm x 213cm)	11.99	1	11.99
R22 Insulation 13.97cm thick, 20.32 cm x 38.74cm x 119.38 cm (5.5" thick, 8" x 15.25" x 47")	35.49	2	70.98
Barrel	100	1	100
TOTAL			**283**

Table 6- Cost estimate of designing a bicycle-powered composter.