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Design of a Self-Regulated Commercial-Scale Composter

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Abstract

In countries such as Canada, waste management is an ongoing challenge, with a large proportion of organic waste being sent to landfills. As the growing concerns of climate change and other environmental issues continue to arise, industries are looking for ways to reduce their GHG emissions and the improvement of their waste management. The city of Montreal in particular is a major contributor to poor organic waste management within Canada, with about half of its organic waste going to landfills. Restaurants are a primary producer of organic waste and with Montreal's vibrant restaurant community, a self-regulated commercial-scale composter is a great solution to help restaurants divert their organic waste from going to the landfill. This project is able to service smaller restaurants, versus similar past projects that focused on much larger volumes of compost. Originally, this design was going to be a solution for condo buildings, however, Montreal has a plan to service all apartment buildings by 2025. Furthermore, in the food industry, there is a lesser chance of other non-organic materials that may be mixed in the compost stock.

On top of environmental benefits, this design provides restaurants to eventually profit off of the compost they will be processing, allowing for a strong economic benefit. Therefore, the target market of restaurants was deemed the most applicable industry for a commercial-scale composter.

This design requires less complexity with lower costs - a key aspect to achieving this was from the implementation of an arduino-centered control system that involves a simple-to-use interface that emulates the typical amount of work of taking out the trash. Given that this project involved a lot of materials and is beyond our budget to build, a prototype bench scale design was created as a model.

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List of Acronyms and Abbreviations

ABS	Acrylonitrile Butadiene Styrene
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
CCME	Canadian Council of Ministers of the Environment
CH2O	Formaldehyde
CH_4	Methane
CMM	Communauté métropolitaine de Montréal
CO_2	Carbon dioxide
EQA	Quebec Environment Quality Act
FWD	Food Waste Disposer
GHG	Greenhouse Gas
GWP	Global Warming Potential
H_2S	Hydrogen sulphide
HDPE	High Density Polyethylene
HVAC	Heating, Ventilation, and Air Conditioning
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MC	Moisture Content
MSW	Municipal Solid Waste
N_2O	Nitrous oxide
NH_3	Ammonia
NH_4^+	Ammonium
OSHA	Occupational Safety and Health Administration
PP	Polypropylene
UOW	Urban Organic Waste
USD	United States Dollar
VOC	Volatile Organic Compound
WTE	Waste-to-Energy

2. Introduction

2.1. General Context

In industrialized countries such as Canada, landfilling continues to be the most common practice of disposal for municipal solid waste (MSW) because of its relatively low cost (Environment Canada, 2009). A global heat map of solid waste generation per capita is presented in Figure 1 (Rajendran et al., 2019). From this figure, it is evident that daily waste generation per capita is far greater in developed countries. Canada is among the developed countries that produces significantly more waste and this is, in part, due to the socioeconomic status and purchasing power among our population (Rajendran et al., 2019).

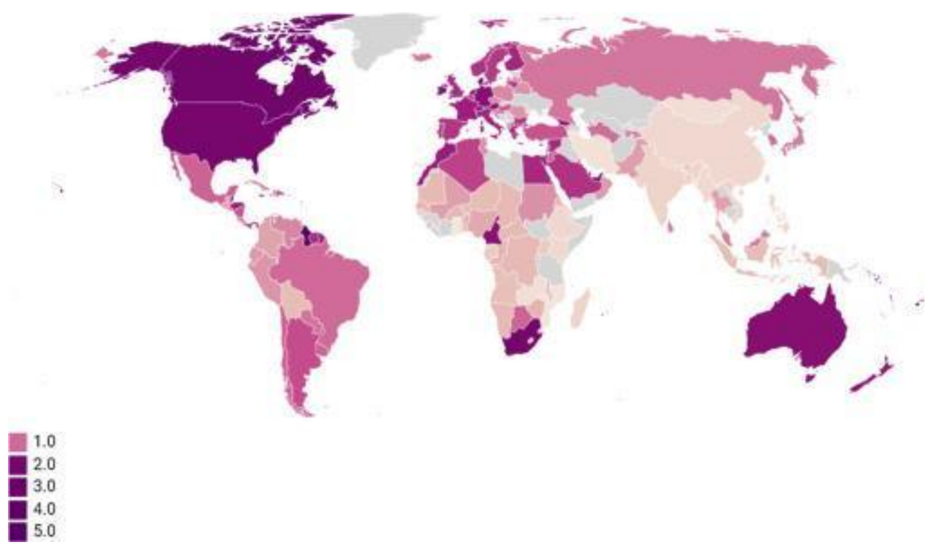


Figure 1: Global heat map of per capita daily solid waste generation (Rajendran et al., 2019).

There is growing concern over the availability of land for new landfill sites and the environmental and social implications (e.g. groundwater pollution, odor emissions, and release of GHGs) associated with landfill operation. In 1989, the Canadian Council of Ministers of the Environment adopted a national goal of 50% landfill diversion for all MSW by 2000 (Wagner and Arnold, 2008). In Quebec, organic materials make up the largest proportion of waste materials produced by households, with an overall share of 47% (City of Montreal, 2018). Diverting and recovering the resources in organic material in Quebec would not only make it possible to reach a 50% landfill diversion goal, it would allow nutrients to be readily recycled back into the environment—using methods and processes that produce much less pollution than landfilling.

The City of Montreal, along with 81 other municipalities of the Communauté métropolitaine de Montréal (CMM), have made it a priority to recover organics with the goal of reclaiming 60% of total organic waste by 2020 (City of Montreal, 2018). It is unclear whether-or-not this goal has been achieved, but it was very ambitious considering that the 2016 organics recovery rate was approximately 20% and 7% in 2002 (City of Montreal, 2018). Landfilled organic wastes emit greenhouse gasses (GHGs) which can be costly to recover, generate leachate that can be hazardous in ground and surface water, and bring landfills to capacity much faster (City of Montreal, 2018). According to the United Nations (2019), many more North Americans live in urban areas than rural areas—approximately 82% of the population as of 2018. Cities experience perhaps the greatest pressure in terms of space availability for waste treatment and implications from pollution because of the population density within an urban area. In response, many Canadian cities have adopted systems and technologies to separate, collect, and treat organic material separately from MSW.

According to Recyc-Quebec, development of organic waste recovery has been relatively slow because of the cost for municipalities to collect, construct, and maintain organic treatment facilities (Recyc-québec, 2006). Centralized organic treatment facilities are not only expensive but create odor and noise nuisances from truck dumping, temporary storage, and the operations themselves (Haug, 1993). Onsite treatment of urban organic waste (UOW) can help resolve these issues and substantially reduces costs and emissions associated with centralized treatment systems. Currently, there is no obligation for the CMM to divert organic waste from the food service sector (City of Montreal, 2018). This presents a missed opportunity to significantly increase organic waste recovery within Montreal.

2.2. Summary of Work Plan

Our team set the goal to provide a solution for urban organic waste recovery within Montreal that can be applied in areas where municipal organics recovery is currently not provided. Namely, our design proposal is intended for the food service industry with our client as The Ceilidh Restaurant at Macdonald Campus.

Based on a preliminary analysis, we have identified the following design needs that the proposed solution must meet:

- Minimize human labour input through automation
- Effectively collect, store, and convert organic waste into one-or-more value-added product(s)
- Operate optimally within specific scale and conditions
- Uses only readily available and sustainably-sourced feedstock (incl. additives)
- Minimize energy requirements and pollution created within the design. This includes accounting for the embedded energy of the materials in the construction of the design.
- Be durable, safe and easy to maintain

2.3. Structure of Report

The contents of this report are structured to provide an overview of the work completed in both BREE 490 and BREE 495. In BREE 490, our work began with a problem statement: organic solid waste (OSW) is not being sufficiently diverted from landfills in Montreal. Mid-sized condo buildings were identified as significant sources of OSW in landfills as they fell within a gap of municipal waste management services (City of Montreal, 2018). A commercial scale composter for implementation in condo buildings with nine or more units was our design team's solution to this problem statement. Building on this, design criteria were developed and refined following an extensive literature review covering the topics of (1) Organic Waste Resource Recovery, (2) Composting principles, (3) Existing solutions, (4) Past design projects, and (5) Materials. Building on findings from the literature review, the team defined specific design objectives using tools like objective trees, attribute tables, and pugh charts. The design process included a discussion on the environmental, social, occupational health and safety (OHS), and economic impacts of our proposed solution. A presentation of the final design showcased the conceptualized composting unit consisting of an HDPE composting drum, control system, user interface, and storage container. The work completed in BREE 490 was concluded with a summary of challenges and recommendations to be addressed in the latter half of the design project. These challenges were classified as falling under the OHS, economic, social, or environmental aspects of our design. Most notably, a challenge faced as our design team approached the end of the semester was the revelation that Montreal would begin organic waste collection for larger apartment buildings (including 50-unit condominiums) by 2025 (Brennan, 2021).

The work completed throughout BREE 495 will constitute the primary contents of this report. Picking up where we left off, our team decided to adapt our design to a different underserviced contributor of OSW in Montreal landfills: restaurants. This will be discussed in further detail in **Section XX.** This report will continue with a summary of key literature review findings from BREE 490 supplemented with information collected throughout the course of BREE 495. This includes a review of three relevant design alternatives and a review of the economic, social, environmental, and OHS considerations. Next, the Specifications and Analysis section will provide a more in-depth review of compost optimization processes, our design methodology, and a structural and material analysis. The results and discussion section will present the final design including the introduction of our 3D-printed bench-scale prototype. A brief profitability analysis will ensue followed by concluding remarks.

3. Literature Review and Further Research

3.1. Summary of Literature Review from BREE 490

During the process of coming up with the design of our composter, an extensive literature review was conducted, covering different types of organic waste resource recovery currently available to us and composting principles such as oxygen, temperature, and other requirements necessary to create an optimal environment for the composting system. According to Rajendra et al. (2019), there are four main factors of interest in waste management: technology, economics, sociocultural aspects, and politics. From these factors, it can be determined whether or not a waste management practice is effective or not.

The current waste-to-energy (WTE) technologies are anaerobic digestion, fermentation, incineration, pyrolysis, and gasification (Rajendra et al., 2019). The table below summarizes its conditions, main products and by-products.

Table 1: Current waste-to-energy (WTE) technologies and corresponding optimal condition, main products, and by-products (Rajendran et al., 2019).

Conversion Process	Conditions	Main Products	By-Products
Anaerobic digestion	35–55°C, anaerobic environment, pH 6.5–7.5	Biogas (around 60% CH_4 and 40% CO_2)	Digestate (used as fertilizer/for soil amendment)
Hydrogen fermentation	35–55°C, anaerobic environment, pH 5.5–6.5	Biohydrogen (around 60% H_2 and 40% CO_2)	Volatile fatty acids (used for downstream chemicals)
Ethanol fermentation	30–35°C, anaerobic environment, pH 4.5–6.0	Ethanol and CO_2	Remaining feedstock (used as animal feed)
Incineration	800–1000°C, air, oxygen	Heat, electricity	Ash
Gasification	800–900°C; air, oxygen, or steam; 1–30 bar	Syngas (CO, CH_4, N_2, H_2, CO_2)	Ash
Pyrolysis	400–1200°C, the absence of oxygen	Syngas, bio-oil	Biochar (used for soil amendment, activated carbon)

Many of these technologies were determined to be unsuitable to our needs or economically feasible. The two main options that had both relatively low operating cost and initial investment were composting and vermicomposting. However, our biggest obstacle to overcome was the social acceptability and awareness of using worms to assist in the biodegradation process. Even though studies have proven to show that vermicomposting yields products with greater nutrient availability, shortens composting duration time, and releases less pollutants into the atmosphere, it was determined that these factors are not enough to overcome most people's perceptions of using worms. Therefore, aerobic composting was the direction taken by our team.

Once the type of composting has been determined, it was important to research the process and requirements necessary to drive the decomposition of organic materials. This includes oxygen, temperature, types of microorganisms, pH levels, moisture content, carbon to nitrogen ratio, and surface area. Since it is an aerobic process, a certain amount of oxygen is required to stimulate the decomposition. An oxygen level below 5% causes the microorganisms to die off, and provokes a switch to an anaerobic process, allowing odors to release. The optimum temperature range for microbial succession is between 40-60°C. If temperatures move away from this range, it is generally due to oxygen levels dropping below 5%. Organisms that are naturally occurring in organic materials include bacteria, actinomycetes and fungi. Certain microorganisms produce cellulolytic and lignolytic enzymes, which are crucial in breaking down certain types of organic material. Others consume metabolites and control pH and oxygen levels (Vargas-Garcia, 2006). Research has shown that deliberately inoculating compost piles with specific species of bacteria has proven to improve degradation of organic materials. The process of decomposition is most effective when the pH level is between 6.0 and 8.0. Too high of a pH level causes nitrogen to be driven off as ammonia (Haug, 1993), while too low of a pH slows down the decomposition process and microorganisms begin to die off. Moisture content (MC) affects oxygen uptake rate, free air space, microbial activity, and temperature. Optimal MC in composting is between 40-60% (Haug, 1993). The carbon to nitrogen ratio has a significant effect on the composting process. Carbon is essential as a source of energy, while nitrogen is needed to synthesize protein. The optimal C:N ratio ranges from (20:1) and (30:1) (City of Westlake, 2021).

Refocusing of the composter towards the restaurant industry

The initial target system of our urban waste recovery system was condo buildings within Montreal. We adjusted from large residential buildings and focused on the food industry for a number of reasons. Firstly, the city of Montreal, has announced plans to service condo buildings by 2025, so the need for our product was deemed unnecessary. Secondly, the food service industry faces substantial waste management costs with an opportunity to divert a lot of it into organic waste recovery. Finally, there is a lot less risk in terms of user buy-in and proper feedstock.

To gather more information about how the restaurant business works and what their waste removal system is like, our team reached out to get insight into the successes and failures of the past composting project “Big Hanna”, which was part of McGill’s SPF venture, as well as interviewing a café within Montreal. Big Hanna will be discussed in further detail under Section XX

In order to get valuable feedback from a member of the foodservice industry, an interview was conducted with the manager of Leaves House Café, located on McGill College in downtown Montreal. This café was chosen since their primary motivation is to promote sustainable alternatives. This is achieved through selling vegan products, using plant-based milks, and using products with compostable and recyclable packaging. Composting is accomplished wherever it is controllable, such as coffee grinds. However, all other food wastes go into the general bin since it is the clients that throw away their wastes. It was determined that the budget spent by most cafés and restaurants is within the range of $50,000 to $200,000 on equipment alone. Therefore, the premise of paying $100,000 to $150,000 for a commercial composting bin is not possible within most restaurant’s budgets. Accordingly, our target clients had to be narrowed down even further.
To finalize our target system, we focused specifically on The Ceilidh Restaurant of McGill’s MacDonald campus and asked if they would like to work with us as a client. We modeled our design criteria and constraints off of their situation.

3.2. Comparison of Design Alternatives

Before beginning design and prototyping for our self-regulated composter, we conducted a review of current commercial composter designs already available on the market. It appears that there are just as many faulty designs as there are composters currently being marketed (i.e. many). The guiding document used was an on-site technical review conducted by Metro Vancouver (2012). In late 2011, Metro Vancouver staff conducted seven on-site interviews at compost operations around Canada. The interviews were intended to collect data on the installation and operation requirements, costs, maintenance needs, and overall user satisfaction of a variety of different composters (Metro Vancouver, 2012).

The technologies ranged from low to high-tech, self-regulated units capable of processing between 20 to 100 tonnes of organic waste annually. Late in this report, we estimate that our composter needs a capacity of 5-15 tonnes of organic waste annually. As such, we picked out three promising designs from Metro Vancouver's review and conducted more research on user satisfaction. We found that many of the composters that had been reviewed by Metro Vancouver were no longer being manufactured, so we chose products that have now been on the market for more than ten years and are continuing to be used.

The three designs we reviewed were: (1) the Jora, (2) the Big Hanna, and (3) the Kean University Composter. The designs differed substantially in capital costs, with the Jora at under $1,250 and the Big Hanna at nearly $150,000 (Metro Vancouver, 2012). Some of the composters had long processing times (up to three months) for the Kean University composter, but both the Big Hanna and the Jora took about eight weeks. The Jora is a low tech system and the other systems are relatively high tech. However, it is important not to discredit low tech systems like the Jora, because they often perform more closely to the manufacturer's promises than high tech systems. Most importantly however, our team sought to identify the best and worst design features through user reviews. With this information, we obtained a good understanding of common issues with composters and how we could build on previous successes.

3.2.1. Design 1: Jora

The Jora is a Swedish technology composter being used at Cercle Carré (a housing cooperative) in Old Montreal. Cercle Carré owns two units, with each unit able to process 40 kg per week of organic material in 3-4 weeks. An additional four week curing period is required. A nice feature of the Jora is that the curing can happen in one compartment while the other is being loaded. As such, the system is considered a batched composting system and appears to work very well (Metro Vancouver, 2012). A 75% reduction in mass after the eight-week period was observed. The unit is manually turned regularly by volunteers and bins are positioned below the composter to collect leachate. The most common complaint was that the compost was heavy when full and difficult to turn using the bin lever (located on the side) (Metro Vancouver, 2012). The unit is run by volunteers who regularly turn the compost and wood pellets (at a 10% ratio to food scraps) are purchased as an additive. It is estimated that yearly operating costs are in the range of $55 CAD per year.

3.2.2. Design 2: Kean University Composter

Mu et al., (2017) explored the environmental and economic effect of implementing an in-vessel compost system for food waste generated by Kean University in New Jersey. A cost benefit analysis determined that the composting system was capable of generating a profit of $13,200 (USD) a year by selling vegetables grown with compost to the student cafeteria at Kean University. The composter (pictured in Figure 2) was designed to hold a capacity of 1000 lbs (450kg) of food scraps and 250lbs (125kg) of wood chips per day (4:1 ratio). Food waste collected was primarily from the student dining halls and consisted of proteins, fruits, vegetables, grains, seafood, and bones. Compost collected from the system initially had too high of an ammonium content to grow plants; thus, the compost had to be plied for a minimum of 20 days to further decompose before being applied to the local farm. For each 575kg of food waste and wood chips fed to the system, 125kg of mass was lost as various emissions (22% reduction in weight). Compost was rotated hourly and aerated every 15 minutes automatically. Weighing inputs, adding feedstocks, and extracting compost were carried out manually. Economic analysis of the composter determined that the investment cost was $12,533 per year and operational cost was $15,919 per year. Labour cost constituted *91%* of the total operational cost.

a)

b)

Figure 2: a) The Jora composter (Metro Vancouver, 2012) and b) In-vessel composting system at Kean University (Mu et al., 2017)

3.2.3. Design 3: the Big Hanna

McGill's downtown campus purchased an in-vessel composter called the Big Hanna T240. The unit was installed in 2010 and could process at least 60 tonnes of organic waste annually (Metro Vancouver, 2012). The system was operated and maintained by a paid student. The unit was located outside in a covered storage area but a biofilter (containing woody material) was still used before exhausting above the roof. The Big Hanna was fully automated with data logging features, temperature activated rotating drums, and heating blankets. Wood pellets were used at a 10% ratio and the final product volume reduction was estimated to be 90% (Metro Vancouver, 2012).

The capital cost of the unit was approximately $142,000 and operating costs are estimated to have been $2,100 per year. A series of grants and funds through McGill University and the Quebec government helped cover the start-up costs. It is worth noting that the Quebec government was the first province to offer a funding program (up to $20,000) for on-site composting equipment through the Ministry of Environment (Metro Vancouver, 2012). It appears that this funding is still available and is administered through Recyc-Quebec (Recyc-Quebec, 2022).

We reached out to the McGill Food & Dining Services and the original project coordinators for the Big Hanna installation and start-up. We were informed that unfortunately the Big Hanna was decommissioned because it was damaged in flooding in 2012. Currently, McGill uses a dewaterer to remove the moisture content from food scraps and pays Compost Montreal to haul it away. If 90% of the weight is reduced from dewatering then we estimate that McGill pays Compost

Montreal to haul away 6 tonnes annually at approximately $800 per year plus the annual operating costs of the dewatering machine (Compost Montreal, n.d.).

3.2.4. Past Design Projects

In addition to reviewing current design solutions regarding the problem of global food waste by established companies, past design projects conducted by Bioresource Engineering students at McGill University and other universities were reviewed for further inspiration and critique. Three projects in particular were focused on: (1) compartment and automated rotary drum composter (Chloe, Michael, Amelie, 2008), (2) Low maintenance in-situ composting unit (Ashfield & Fortin, 2016), and (3) Compostomatic (Yves, Catherine, Ajo, 2012).

The main goal of the first project was to make the composting system more automated and effective in terms of organic degradation and its energy requirements. Additionally, the social implication of odor on the community was important. Their design opted for a compartmented drum composter under a semi-continuous batch process. They accommodated for a medium sized composting facility such as eco-quartier Jeanne-Mance in Montreal. Specifications of the design include integrating batch and continuous composting, providing adequate temperature and humidity conditions, automated bulking agent calculations, material durability, etc.

The second project had a more unique approach that included an in-sink food waste disposer (FWD) in combination with the automated composting unit. The food waste is to be initially grinded in the FWD, then directed to the composting unit through a plumbing tube where the scraps are degraded into a class A compost product. The composting unit is an above-ground placement, where it is easy to install outdoors with the option of insulation or placed in a basement. The design incorporates three compartments; the first compartment is being filled, the second is full and in the composting/microbial degradation phase, and the third goes through the curing phase. This allows for an easy rotation flow and prevents contamination with new food waste that has yet to reach pathogen inactivation temperatures.

The third past project that was looked at was the compostomatic, a compost designed for a 283-condominium unit. Its structure was made from concrete with steel rebars for reinforcement. Other design elements include door, slab, drainage system, biofilters, ventilation system, and a lid. Requirement specifications included minimizing cost of the system, aesthetically pleasing, and reduced odor emissions. They determined that a circular shape provided optimum mixing of the organic material. Additionally, a batch composting system with two compartments was used. They calculated that it would take approximately 21 to 28 days for active composting to finish in the first bin. Therefore, residents were to put their waste into the first bin for an entire month while the second bin goes through the second phase.

All of the past design projects had a much larger footprint and handling capacity than would be appropriate for a small restaurant such as The Ceilidh. However, there were design features included in some of the past projects that we included in our PUGH charts. For example, a rotary mixing drum, a mixing wand, and multi-compartment composting were all considered as possible design features in our project (Chloe, Michael, Amelie, 2008; Ashfield & Fortin, 2016; Yves, Catherine, Ajo, 2012).

3.3. Economic, Social, Environmental, and Occupational Aspects

3.4. Economic

An important aspect of any design project is economic feasibility—from both a buyers and sellers perspective. Table 2 breaks down the design team (seller) perspective. The sales price was determined by calculating the cost of goods sold (COGS) and adding a margin of 70%. The perspective of the design team is that of a single composter unit being sold to The Ceilidh as a non recurring transaction. The final sale price of the composter is considerably affordable in the case of The Ceilidh—as we have seen projects with similar objectives cost upwards of $140,000 upfront. In speaking with The Ceilidh and the VP Sustainability of MCSS, it would be a reasonable expectation for the project to be wholly funded by McGills SPF fund.

The full determination of the COGS is available in Appendix F. COGS include the outright materials cost—which is summarized in Table 10 (Appendix F)—and any other costs associated with manufacturing and fabrication of the steel components and assembly of the final unit. Table 3 is equally important as it showcases the economic feasibility of using the composter our team designed. From The Ceilidhs perspective, even without funding, we anticipate a short payback period of only three years. While the investment won't generate material revenue, there are hard cost savings associated with implementing the composting unit. According to Yemen (2007), restaurants in Toronto can pay between $100 and $1500 monthly for waste management services. Our team conservatively estimated that The Ceilidh would spend $175 per month on waste management—the majority of which would be food scraps/waste. This equates to roughly $1400 annually. If they reduced their waste enough—by diverting their food waste using our composter—they would likely be able to use McGill facilities waste management for free or a lesser charge. An important consideration for The Ceilidh are costs relating to the annual operation and maintenance (O&M) beyond initial capital investment. A more detailed breakdown of the O&M costs can be found in Table 16 (Appendix F). Even without SPF funding and the combined cost of delivery, installation, and annual O&M, the project can reasonably expect $1,727.19 in net savings within a five year horizon. The economic feasibility from both the buyer and seller perspective has been confirmed.

Table 2: Composter Cost Analysis

	Year 1
Revenues	
Sales (70% margin)	$ 1,945.72
TOTAL	**$ 1,945.72**
Expenses	
Materials	$ -
SS 304 (2.5mm)	
cylinder	$ (132.20)
lid	$ (26.44)
bottom plate	$ (26.44)
legs (all 4)	$ (79.32)
mixer	$ (105.76)
freight	$ (134.76)
Control System Hardware	$ -
Control System Components	$ (72.89)
Wifi Serial Transceiver, Wires, Resistor	$ (19.67)
Transistors	$ (4.56)
Arduino Uno	$ (35.00)
Steel fabrication	$ -
Labour	$ -
Laser Cutting	$ (75.00)
Machining	$ (60.00)
Fabrication	$ (135.00)
Welding	$ (150.00)
Composter Assembly	$ -
Labour	$ -
One assembler	$ (87.50)
TOTAL COGS	**$ (1,144.54)**
PROFIT BEFORE TAXES	**$ 801.18**

Table 3: Client Payback Analysis

	Year 1	Year 2	Year 3	Year 4	Year 5
Revenues					
Savings	$ 1,400.00	$ 1,435.00	$ 1,470.88	$ 1,507.65	$ 1,545.34
TOTAL	**$ 1,400.00**	**$ 1,435.00**	**$ 1,470.88**	**$ 1,507.65**	**$ 1,545.34**
Expenses					
Composter Unit Purchase Price	$ (1,945.72)	$ -	$ -	$ -	$ -
Delivery cost (local)	$ (50.00)	$ -	$ -	$ -	$ -
Installation		$ -	$ -	$ -	$ -
Labour	$ (140.00)	$ -	$ -	$ -	$ -
Ducting Estimate	$ (250.00)	$ -	$ -	$ -	$ -
Operation & Maintenance					
Labour					
Loading Compost	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Managing Compost Product	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Cleaning	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Incidental	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Materials	$ -	$ -	$ -	$ -	$ -
Additives (saw dust readily available from shop + compost produced)	$ (96.00)	$ (98.40)	$ (100.86)	$ (103.38)	$ (105.97)
Utilities	$ -	$ -	$ -	$ -	$ -
Electricity	$ (1.53)	$ (1.57)	$ (1.61)	$ (1.65)	$ (1.69)
TOTAL	**$ (3,003.25)**	**$ (632.97)**	**$ (648.80)**	**$ (665.02)**	**$ (681.64)**
PROFIT/LOSS BEFORE TAXES	**$ (1,603.25)**	**$ 802.03**	**$ 822.08**	**$ 842.63**	**$ 863.70**
TOTAL VENTURE P/(L)	**$ (1,603.25)**	**$ (801.22)**	**$ 20.86**	**$ 863.49**	**$ 1,727.19**

3.5. Social

Composting can have a lot of social benefits in communities. With climate change becoming more of a pressing issue, people feel more compelled to change their lifestyle in order to lower their environmental impact. Composting could be one extra thing for people to take care of and it is also an extra task for restaurants to manage. If participation in the composting program is voluntary, it could be hard to get all the restaurant staff on board to participate. Proper training and basic education can be implemented so restaurant staff have a high level understanding of how to deal with the compost and load it onto the commercial composter. This is a serious consideration because our compost design does not yet include mechanisms for detecting and separating contamination. Putting the wrong items in the compost bin may not only lead to inefficient biodegradation, but also contamination of the whole pile, resulting in everything going to waste

(Gay et al., 2021). Therefore, a proper instruction manual with a clear list of materials may be provided for restaurant staff - since most of the restaurant waste is organic, there is a lesser chance of other forms of solid waste getting mixed into the composter.

Another major social concern for people around the composting system, is the potential bad smell, making things uncomfortable for them. To mitigate this, we wanted to design a proper odor management system and provide adequate air fresheners if needed.

3.6. Environmental

The environmental impact of our design is one of the most critical aspects to be considered. While looking at each material, we analyzed its recyclability, GHG emissions, and the embedded impact of the materials and identified actions we could take (Figure 3).

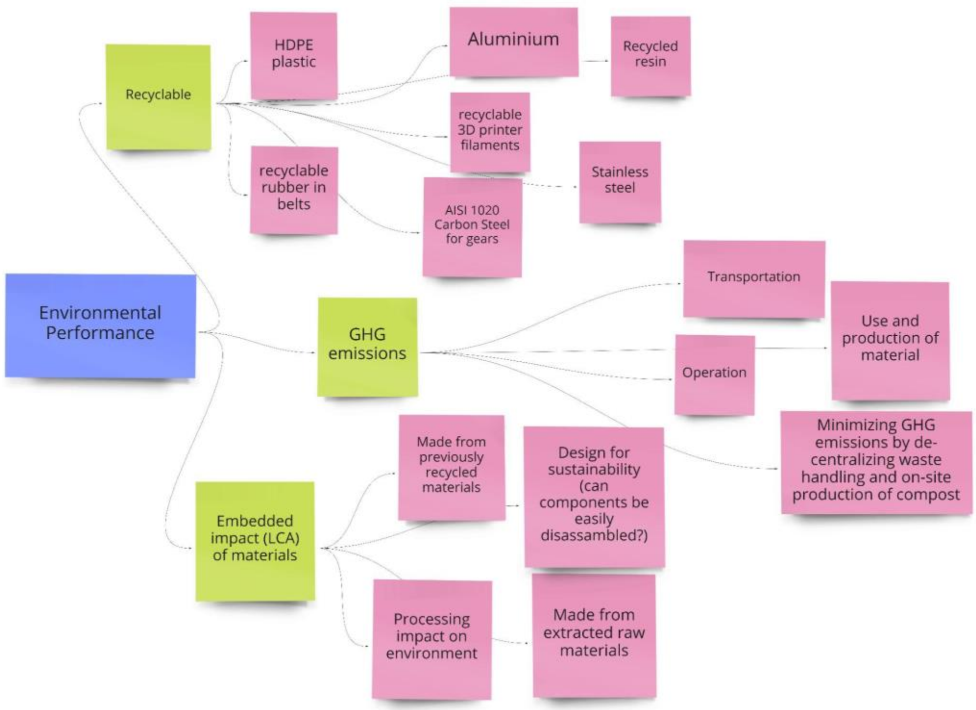


Figure 3: Environmental aspects and specific measures that can account for each

3.6.1. Recyclable

The material that we decided on was highly dependent on its recyclability. Our options, as seen from Figure 3, were HDPE plastic, recycled rubber (for belts), aluminum, recyclable 3D printer filaments, stainless steel, AISI 1020 carbon steel (for gears), and recycled resin. A comparison of each material was made using a Pugh Chart, with the baseline design, the most common basic design currently available in the market, being a stainless-steel rotating drum compost. The main materials that we focused on were virgin HDPE, recycled HDPE, and aluminum.

According to Norgate, Jahanshahi, & Rankin (2007), out of the materials that are currently used by society today, metals have the greatest potential for unlimited recycling. However, they are "non-renewable", and therefore their supply is finite. HDPE is accepted at most recycling centers globally and is one of the easiest polymers to recycle (Taylor-Smith, Thomson., 2020). It is more cost-efficient to produce a product from recycled HDPE than virgin plastics. It has also been demonstrated that HDPE can be recycled at least 10 times, and the material properties over the entire period of reuse do not alter. In terms of metals, both aluminum and stainless steel are one hundred percent recyclable (Melbourne Metal Recycling, 2019).

3.6.2. GHG emissions

To evaluate our design's impact on greenhouse gas emissions, several factors must be examined. That includes transportation of compost, use and production of materials, and operation of the machine. Our goal is to minimize GHG emissions by decentralizing waste handling and on-site production of compost. To determine the GHG emissions, the Life Cycle Assessment (LCA) of the materials provided by Norgate, Jahanshahi, & Rankin (2007) was reviewed. According to the results of their study, aluminum had a greater Global Warming Potential (GWP), with a value of 22.4 kg CO_2e/kg, compared to stainless steel, with a value of 6.8 CO_2e/kg.

In regard to GHG emissions of plastics versus metals, their production process was considered (Koons, 2018). HDPE plastics are produced from petroleum in an energy intensive process called polymerization. The use of fossil fuel to make the plastic releases greenhouse gasses. Furthermore, it is a limited resource that scientists believe will be largely gone within the next few hundred years. However, even though plastic production causes negative environmental impacts, it only uses a fraction of the energy needed to produce metals. Aluminum is a metal that is found naturally on Earth and is always found combined with other compounds. The extraction of separating aluminum is a highly energy intensive process that also requires the burning of fossil fuels. To compare the production process, 1 kg of Polyethylene plastics produce approximately 4 kg CO_2 and 1 kg aluminum produces 10.63 kg CO_2 (Pongrácz, Eva., 2007). By comparing each option from our research, we concluded that HDPE plastic was the best product for our design.

3.7. OHS

When designing composting processes, occupational health and safety is a critical aspect that should be considered. Given that the design is a machine with moving parts, potential injuries include pinches, cuts and scratches to loss of fingers and limbs. Hearing damage and stress can also be an issue, from loud noises (*Composting Safety and Health Cornell Waste Management Institute*, 2021).

As pathogenic organisms may be present in the compost feedstock, the compost itself may also contain pathogenic organisms and, as a result, may pose a risk to human health. To reduce any health and safety risks, it's essential to have an educated workforce trained on process control, process hazards, hygiene practices, signs and symptoms of overexposure or overexertion and emergency response. Practicing proper process control is important, as well as recognizing the beginning of any trends that may lead to process failures. Better process control will produce more consistent and predictable exposures and hazards, which can lower risks. Practicing good personal hygiene frequently is always needed, in order to protect the worker and their family, as well as to provide proper protective equipment to match the hazards of the specific site (*Composting Safety and Health Cornell Waste Management Institute*, 2021).

4. Specifications and Analysis

4.1. Optimizing Compost Process Parameters

4.1.1. Optimizing Compost Process Parameters

Minimizing the time it takes to convert urban organic waste into usable compost poses many benefits in terms of meeting our design needs. Benefits include the ability to load the composter more frequently and minimize the amount of space (footprint) needed for the compost unit itself. Within this section, our team considered several compost process parameters and translated this into design constraints and criteria that are summarized in Table 4 and are further elaborated in the following subsections. In addition, the Canadian Council of Ministers of the Environment (CCME) Guidelines for Compost Quality (2005) were used to ensure that the compost produced could meet suggested quality standards.

Table 4: Summary of design criteria to optimize compost process

Criteria Name	Description
Initial Drying Process	- A mechanism is needed to dry the feedstock mixture from 68% to 55- 60% moisture content (Haug, 1993)
Water Addition Process	- Once the conversion process has commenced, water must be added back to maintain moisture levels between 45-60% (CCME, 2005)
Semi-Continuous Process	- There should be the ability to add new feedstock every 7 days to the active composting unit. A separate area for curing is required (criteria from The Ceilidh)
Aeration Process	- Delivery of approx. 0.07 m^3 of air per minute per 100 kg of organic waste in the initial phase of composting and lower rates in following stages. Pauses between forced aeration to ensure that thermophilic temperatures are sustained (Adhikari, 2011)
Thermal Inactivation	- Allow the pile to be held at 60°C for 25 minutes between mixing (CCME, 2005)

4.1.2. Weight and Volume of Organic Waste to be Treated

In the first few weeks of operation, The Ceilidh tracked their organic waste generation for our team. They generated approximately 150 litres of organic waste weekly. Considering that this was the beginning of their operations, we added a 50% margin to our composter capacity for a total of 225 litres (112.5 kg) per week.

Kitchen food scraps are often too wet and high in available nitrogen content to be composted without any additives (Haug, 1993). A readily available bulking material that absorbs moisture, acts as a carbon source, and allows air movement throughout the pile is needed. Sawdust was chosen because it is inexpensive, an excellent source of carbon, and is also extremely absorbent (Haug, 1993). We also identified that a priority for The Ceilidh was to have an environmentally-friendly way to deal with their organic waste, and not necessarily generate large amounts of compost. As such, we decided to recycle uncured compost as additive for the next batch (Haug, 1993). This not only helps reduce moisture and provide inoculum of beneficial composting microbes, but helps make the amount of finished compost a more manageable amount for a small restaurant.

To calculate the quantity of sawdust and compost needed for a C:N ratio between 20 and 30, Equation 1 by Haug (1993) was used. The minimum amount of sawdust needed (for a C:N ratio of 20) was calculated as 9 kg (30 L) of sawdust and 32 kg (105 L) per 112.5 kg (225 L) of food waste—or 1 L sawdust for every 7.5 L of food waste and 1 L of dry compost for every 2 L of food waste.

$$C/N\ Ratio = \frac{Q_1(C_1 * (100 - M_1) + Q_2(C_2 * (100 - M_2) + +Q_3(C_3 * (100 - M_3)}{Q_1(N_1 * (100 - M_1) + Q_2(N_2 * (100 - M_2) + Q_3(N_3 * (100 - M_3)} \quad (1)$$

$$Q: Wet\ weight\ of\ Material, C: Carbon\ (\%), N: Nitrogen\ (\%)$$

Equation 1 allows us to calculate the mass percentage of available carbon and nitrogen of a composition of three materials (M_1, M_2, and M_3) by using the known properties of each material separately.

4.1.3. Moisture Requirements

The importance of moisture content is directly tied to the ability of the compost to reach thermophilic temperatures and inactivate potentially harmful pathogens (CCME, 2005). As such, optimal moisture content in the feedstock must be ensured.

$$\%\ Moisture = \frac{(Q_1 * M_1) + (Q_2 * M_2) + (Q_3 * M_3)}{Q_1 + Q_2 + Q_3} \quad (2)$$

$$Q: Wet\ weight\ of\ Material, M: \%\ Moisture\ content$$

Equation 2 proposed by Haug (1993) allows us to calculate the resulting moisture content of two materials by using the observed moisture properties of each material separately. The resulting moisture content of the food waste/dry compost/sawdust mixture was calculated to be approximately 59%. The feedstock characteristics are summarized in Table 5. As previously stated, to maintain optimal conditions for microbial activity, the moisture content must be between 40-60%.

Table 5: Summary of feedstock characteristics for SMART composter

Ingredient	% Moisture	% Carbon	% Nitrogen	Weight (kgs.)	Volume (litres)	Source
Food waste	69	36	2.4	112.5	225	(Adhikari et al., 2011)
Dry Compost	40	22	1	32.0	105	(Composting Safety and Health Cornell Waste Management Institute, 2021).
Hardwood (chips, shavings, and so on)	0	50.4	0.09	9.0	30	(Barthod et al., 2018)
	Calculated mixture weight:			153.5	(kilograms)	
	Calculated mixture moisture content:			59.0	(percent)	
	Calculated mixture C/N ratio:			20.2	(masses as specified)	
	Calculated mixture volume:			360	(litres)	

Once compost processes begin and thermophilic temperatures are reached, significant moisture removal can occur (Haug, 1993). Dehydration can happen to the extent that reaction rates are impacted unless water is added back. As such, our team included a mechanism for ensuring proper moisture levels throughout all stages of the process as part of our design criteria. The mechanism is a soil humidity probe that is inserted into the compost pile along with the temperature probe. When the moisture sensor reads below 40% moisture, a mister is activated which is attached to a small, clear tank that is manually refilled.

4.1.4. Temperature

As shown in Figure 4, an ideal feedstock at ideal conditions could reach 60°C by the second day and would hold this temperature for at least 18 hours before the temperature begins to decline – meaning this phase of composting could be completed in four days. We believe it is safe to assume that with less-than-ideal conditions, our composting process will achieve a similar temperature profile within a seven day period—which would allow for weekly refilling. In further work, our team would like to test this assumption and better characterize the temperature profile specific to our design parameters and feedstock.

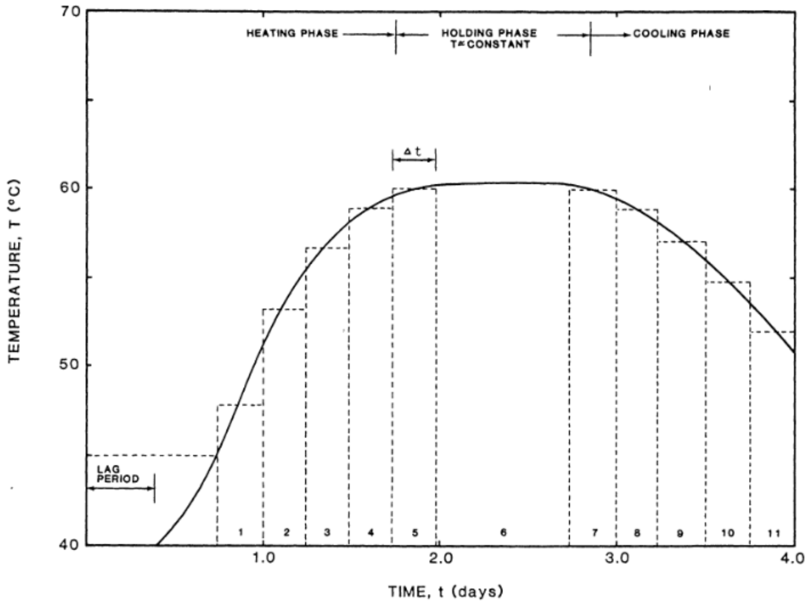


Figure 4: Idealized time/temperature profile for a batch composting system (Haug, 1993)

As summarized by Haug (1993) a temperature between 55°C and 60°C that is evenly distributed and held "for a day or two should be sufficient to kill essentially all pathogenic viruses, bacteria, protozoa (including cysts), and helminth ova to acceptably low levels." To account for adequate thermal inactivation, we would need to ensure even distribution through mixing. However, once mixing is completed, it would also be ideal to hold off from mixing to ensure the compost pile does not cool. To determine the amount of time to hold off on mixing, we examined thermal inactivation for coliform bacteria shown in Figure 5.

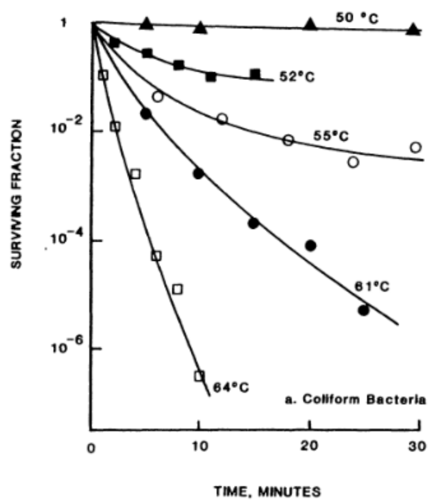


Figure 5: Thermal inactivation of coliform bacteria in composting sludge (Haug, 1993)

To achieve a 99.9% reduction of coliform bacteria at 60°C, the pile would need to be held at that temperature for approximately 25 minutes between mixing. We made this a design criteria for further prototype testing.

4.1.5. Aeration

If the aeration rate is insufficient during the composting process, oxygen level will decrease and anaerobic conditions could result. Conversely, if there is too much aeration, the compost pile will cool down which slows the rate of decomposition (Rasapoor et al., 2009). During the initial stage of decomposition, oxygen demand is at its highest because of the rapid increase in microbial population (Zucconi and de Bertoldi, 1986). A review of previous studies show suggested aeration rates for organic waste composting are anywhere between 0.04 L/min to 0.6 L/min (per kg of organic waste)(Adhikari, 2011). The upper rate of 0.6 L/min is required in the initial stages of composting because of rapid increase in microbe populations, so this rate is used in order to ensure our aeration equipment can supply the upper limit of our requirements. At 0.6 L/min for 112.5 kg of organic waste, 67.5 L (or 0.07 m^3) of air per minute is required until thermophilic temperatures are reached. It is likely that following this phase, a significantly reduced level of oxygen is needed and will be explored in further testing.

It is important to note that Adhikari (2011) reported that under "uncontrolled forced aeration, ventilation rates often either exceed or do not meet the microbial requirements resulting in a temperature drop below thermophilic levels". To account for this, we decided to add active controlled aeration that is based on continuous oxygen and temperature readings into our design criteria.

4.1.6. Compost Quality

Quality of compost is a frequently discussed topic (Adhikari, 2011). Poorly stabilized compost can continue to produce odor, develop toxic compounds, and have negative impacts on plant growth (CCQC, 2001). Unfortunately, methods to evaluate the stability (or maturity) of compost varies from region-to-region and there are no universally agreed upon standards. However, there are parameters for regulatory compliance in Canada that include testing for trace contaminants (e.g. heavy metal concentrations) and biological pathogens (*Escherichia coli*, *Salmonella*, etc.)—this includes guidelines published by the Canadian Council of Ministers of the Environment (CCME, 2005). Within these guidelines, several design criteria were added to help ensure that the compost created from our unit is stable and high quality. These design criteria include allowing the compost to cure for 21 days and following compost testing guidelines. The amount of compost cured will depend on the volume reduction of feedstock, which has been documented to be anywhere between 22-85% reduction (Adhikari, 2011; Haug, 1993; Hubbe, 2010; Mu et al., 2017). The initial stage of composting will be considered finished once additional mixing does not result in a temperature rise (and therefore an increase in microbial activity) (Haug, 1993).

4.2. Design Process

4.2.1. Objective Tree

The design needs (identified in a previous subsection) of our project were transformed from vague statements to specific requirements using the "Objective Tree Method". To do so, our team reviewed each of the design need statements and asked ourselves "how, what, and why". For example, the first design need statement is, "Minimize human labor input through automation". At a high-level, this statement is important for economic, OHS, and process optimization reasons. The high-level categories are represented in the blue squares in Figure 6. The green squares in the figure represent a more specific reason for the design need (i.e. minimizes operating costs or heavy-lifting needed). Finally, the pink squares represent what we specifically plan to do to meet this design need. This was continued for all of our design need statements and an overall objective tree can be found in Figure 15 (Appendix E).

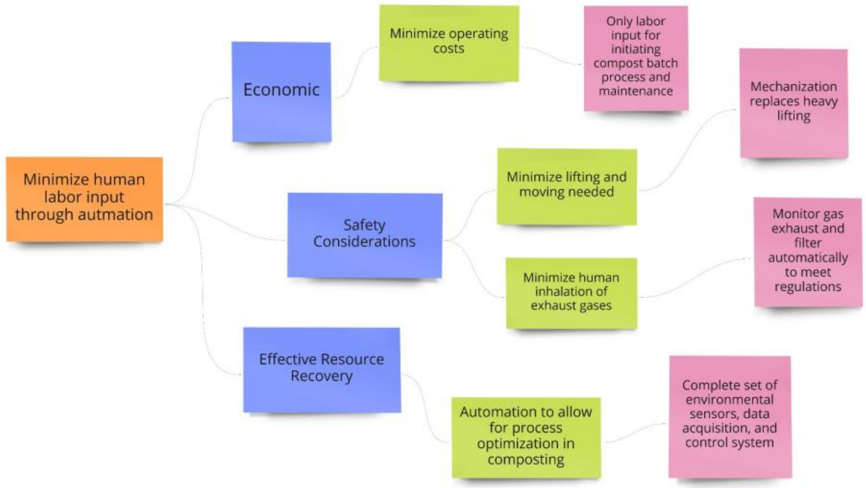


Figure 6: Objective tree for design need statement: "minimize human labour input through automation"

4.2.2. Attribute List and Pugh Chart

Following the identification of design criteria through the use of an Objective Tree and related calculations, an attribute table—observed in Appendix C—was developed. The attribute table identified three subsystems that our final design would include: (1) the composting drum, (2) the HVAC systems and user interface, and (3) the end-product storage container. Attributes were categorized into their respective subsystems and included a combination of what our team had observed in existing solutions and our own ideas. Columns following the specified attribute reflected different methods of implementation; for example, an attribute of our composting drum subsystem was the material of the drum itself. The options we most carefully considered were stainless steel, aluminum, and recycled HDPE, with stainless steel being our baseline material. Initially, our team determined recycled HDPE was best suited for our design needs by using a Pugh chart. Completion of the attribute table brought clarity to the direction of our design. Through further discussion and analysis of the materials in mind, the most suitable material was replaced by stainless steel, with the main reasoning behind this being the durability of the material. The next step was to create feasible design combinations of these attributes and thoroughly compare them with one another—these combinations are also outlined in Appendix C.

With eight different feasible designs, our team used Pugh Charts to select the most preferable attributes to incorporate into our final design. The Pugh Charts used to determine the preferred material and mixing mechanism to be used in the compost drum can be seen in Table 5.a,b.

Table 6. Pugh Charts for (a) most preferable compost drum material and (b) mixing mechanism

(a)

Materials								
Stainless Steel (Baseline)			**Virgin HDPE**		**Recycled HDPE**		**Aluminium**	
Evaluation criteria	**Weight factor**	**Baseline**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Environmental performance	3	0	-1	-3	1	3	1	3
Cost	4	0	1	4	1	4	-1	-4
Ease of maintenance	3	0	1	3	1	3	0	0
Safety and social	3	0	-1	-3	-1	-3	0	0
Durability	2	0	-1	-2	-1	-2	-1	-2
Score		0		-1		5		-3

(b)

Mixing Mechanism								
Rotating Drum (Baseline)			**Steel Auger**		**Mixing Wand**		**Chopping Blades**	
Evaluation criteria	**Weight factor**	**Baseline**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Ease of maintenance	3	0	1	3	1	3	1	3
Performance	4	0	1	4	0	0	1	4
Cost	2	0	-1	-2	-1	-2	-1	-2
Safety and social	3	0	1	3	1	3	-1	-3
Durability	2	0	0	0	-1	-2	-1	-2
Score		0		5		2		0

4.2.3. Risk Assessment Matrix

A risk assessment matrix—pictured by Figure 7— was used to critically review our final design and as a preventative measure. Having consulted existing literature, previous projects, and stakeholders (The Ceilidh, Leaves Cafe, & Big Hanna Project Team) our team derived 18 principal risks. These risks were classified into design, social, environmental, economic, and OSHA brackets. For each risk, the design team estimated the relative impact and likelihood, derived a mitigation strategy, and placed the corresponding number on the risk assessment matrix.

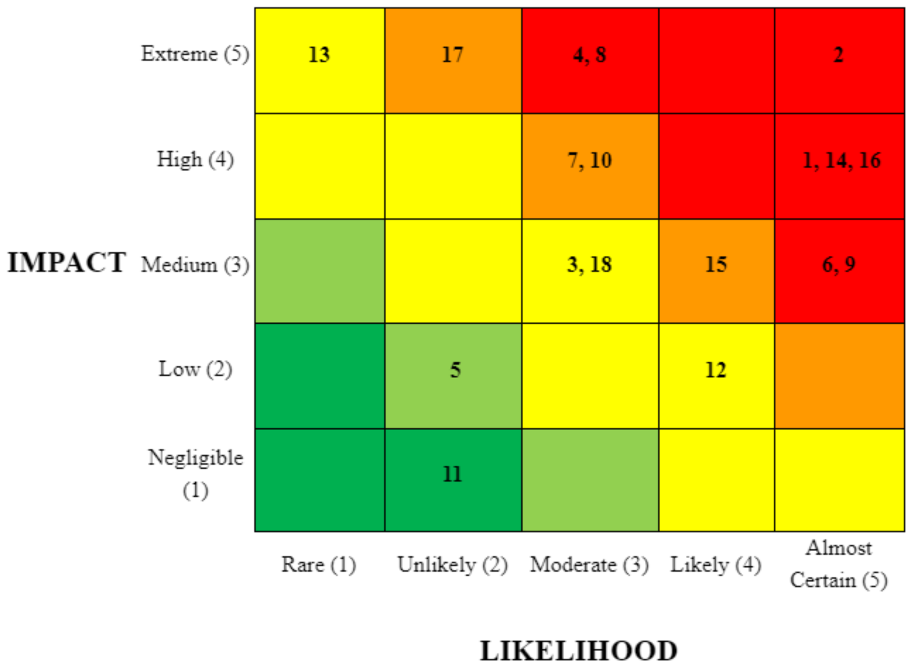


Figure 7: Risk assessment matrix: impact and likelihood of risks relating to design, social environmental, economic, and OSHA aspects of composter design

4.2.3.1. Design

Design risks considered for our composter include: (1) Site requirements not being met, (2) Inappropriate compost capacity, (3) Equipment is hard to clean, (4) Components are difficult to replace, (5) Producing low quality compost, and (6) Moisture and leachate problems arise.

To mitigate the risk of not meeting site requirements our design team consulted The Ceilidh and found that the design would need to fit within a 0.4 m^3 space. Additionally, adequate ventilation was identified as an area of concern—our team determined that it would be feasible to feed the outlet ventilation of the composter into the same exhaust path as the newly installed fume hood. Consulting The Ceilidh and collecting data on their food waste production during their initial weeks of operation was the primary mitigation strategy used to address risk No. 2. In response to risk No. 3, our team tried to limit the use of small-moving parts as best we could. Where small moving parts exist, they are designed to avoid contact with the compost feedstock or any byproducts of the composting process. Risk No.4 brought our design teams attention to the importance of using standardized components whenever possible. Risks No. 5 and No. 6 are both reduced by applying the compost principles discussed in Section XX to our final design.

4.2.3.2. Social

Social risks considered for our design include: (7) Low acceptance, (8) Policy change, (9) Additional barriers stemming from restaurant business, and (10) User behaviour leading to contamination.

In the case of The Ceilidh, risk No.7 is addressed by consultation. It was important to consider The Ceilidh's intended use, motivation, and overall expectations for the composter throughout all stages of the design. After speaking with them, we determined the primary motivation behind using a composter would be to divert food waste from landfills as a sustainable practice. Risk No. 8 stemmed from a challenge our design team faced towards the end of BREE 490. Originally, we were designing a commercial scale composter for condo buildings not serviced by the City of Montreal. However, during the late stages of our design process, the City of Montreal announced that they would be managing compost produced by the condos we were targeting—rendering our solution obsolete. We recognize that as the prominence of sustainability increases in policy making decisions, that restaurants could be serviced at a municipal level in the future. There isn't much that can be done to mitigate the risk of policy change, however our team wanted to recognize both the likelihood and impact of such an event occurring. Risk No. 9 is to be expected when designing anything for use in a commercial kitchen. Restaurants are strictly regulated, and are done so differently under varying authorities. The Ceilidh falls under the jurisdiction of the Town of Sainte-Anne-de-Bellevue who saw no issue with our proposed design. Risk No. 10 would be an issue with any composter operated by more than one person. We anticipate that individuals using a "shared composter" won't be as careful about separating contaminants from their feedstock given the lack of "ownership" over their compost. Having spoken with The Ceilidh, their team would be trained to only discard compostable food-scraps into 5-gallon buckets to later be fed into the composter.

4.2.3.3. Environmental

Environmental risks included: (11) Resource intensity of manufacturing compost is greater than food waste diversion offset, (12) Transporting compost product leads to scope 3 emissions, and (13) Flooding/Natural disasters.

The primary objective of the composter is to divert food waste from landfills and lower the GHGs emitted from food-waste as a result. Risk No. 11 addresses the possibility of having a net impact adverse to the primary objective. That is to say, the emissions of manufacturing, transporting, installing, and operating the composter run the risk of being greater than the "emissions-saving" capacity of the composter over its lifecycle. To mitigate this risk, our design team advises that a complete life cycle assessment (LCA) for the composter be conducted. Provided the design team's time and resource constraints, we were unable to conduct an LCA for inclusion in this report. Risk No. 12 falls under Risk No. 11 however, our design team felt it was important to address on its own. If the compost produced needs to be transported long distances, then the emissions from that transportation may negate the desired effect of the composter to begin with. Our team addressed this risk by working with The Ceilidh; they indicated that compost produced during their operation could be provided to Mac farms, student clubs, or be used as a bulking agent for the composter itself. Finally, the design team felt it necessary to include risk No. 13 provided the fate of the Big

Hanna project. To mitigate the risk of flood damage to our composter, the final design included stilts—as can be seen in **Figure 8**. The stilts also served to increase maintenance access.

4.2.3.4. Economic

The primary economic risks of our design were (14) Unattractive payback period and (15) Too costly to operate and maintain. Both risk No. 14 and No. 15 are addressed in Section XX.

4.2.3.5. OHS

Finally, risks relating to OHS included (16) Air quality is poor surrounding composter, (17) Operation includes heavy lifting, and (18) Moving parts do not have adequate safety protections.

A primary concern of the stakeholders that our design team engaged with was air quality and odour—hence risk No. 16. Provided the size of the proposed compost design and the batch frequency, the design team doesn't anticipate VOC concentrations to exceed the acceptable limits presented in **Table 7.** Furthermore, in addressing risk No. 1, our design team included a ventilation outlet to feed into the existing exhaust path of the newly installed fume hood. Risk No. 17 was a primary concern with our original design for commercial scale condo service. However, provided the smaller nature of the restaurant scale composter we don't anticipate heavy lifting as being an issue.

Table 7: Acceptable volatile organic compound (VOC) levels, determined for 8-hour working conditions—indoors (Atia, 2004; OSHA U.S. Department of Labor, 2019; ACGIH, 1993)

VOC	Acceptable Level (ppm)
CH_4 - Methane	1000
NH_3 - Ammonia	25 - 50
CO_2 - Carbon dioxide	5000
N_2O - Nitrous oxide	25 - 50
CH_2O - Formaldehyde	75

Finally, risk No.18 addresses the concern for operator safety when moving parts are involved. As food scraps are top loaded into the composter using a 5-gallon bucket, loading the composter presents a low risk to operator safety. Similarly, compost being removed from the drum is done using a hinged door. The greatest safety concern was the mixing wand. Our design team suggests using a sensor on both the hinged lid and door to stop the mixing if it detects that the door/lid is open.

4.2.4. Schematic and Prototyping

Figure 8 shows the CAD drawing and schematic for our prototype. The footprint was determined by the amount of space available in the waste room at The Ceilidh.

Figure 8: Section and dimensioned schematic of prototype composter

4.3. Structural Analysis and Materials

4.3.1. Mixing

The mixing wand used has three rectangular paddles attached to a main axial rod. To choose an appropriate motor for the mixing rod, calculation for the approximate power required to move the mixer was needed. Equation 3 was used and was adapted from formulas found in Shigley's Mechanical Engineering Design (Shigley et al., 2004).

$$H = T \times \omega$$
$$H\text{: } power\ (W), T\text{: } torque\ (N * m), \omega\text{: } angular\ velocity\ (rad/s) \qquad (3)$$

The total calculated weight of organic waste when the unit is full is 155 kg. Because each paddle is a framed rectangle, we calculated that the hollow portion of each paddle made up approximately 80% of its cross section. That means that approximately 20% of the organic material (31 kg) would be moved by the paddles each rotation. As a safety precaution, we added 30% for a 40.5 kg maximum weight against the mixing system. As such, each paddle would move about 13.5 kg of organic material per rotation. The torque was calculated using Equation 4 (Shigley et al., 2004).

$$T = F \times d_c$$
$$T\text{: } torque\ (N * m), F\text{: } force\ on\ each\ paddle\ (N), : d_c\text{: } distance\ from\ center \qquad (4)$$

Calculations are shown in Appendix C. Using a total paddle distance of 20 cm from the center of the shaft, the torque was calculated as 80 N*m. We wanted a relatively slow turnover of organic material so we decided that a speed of 8 seconds for a full rotation would be reasonable (0.785 rad/s). From this, the power requirement was calculated to be 62.4 W or 0.1 HP. This is a relatively low powered, high-torque motor. If only 20% of the material is turned each rotation, the mixer would need to complete at least five full rotations for a more complete mixing (approximately 1 minute of mixing). Existing composter designs that have a mixing component tend to run their mixer for one minute each hour, which is in line with our calculations (Metro Vancouver, 2012).

4.3.2. Forced Aeration

As mentioned in a previous section, approximately 0.1 m^3 of air per minute (~6 m^3/h) will need to be delivered to the composter unit. High powered computer fans (such as the Corsair ML120 PRO Premium[5]) deliver ~80 m^3/h. As such, one of these fans would need to be run for 5 minutes each hour.

4.3.3. Force Calculation on Material

The pressure applied to the bottom plate of the stainless steel cylinder was calculated to be 7.7 MPa (shown in Appendix C). For stainless steel 304, this is well within the maximum allowable stress shown in Appendix A (123 MPa at temperatures up to 90°C).

The legs of the cylinder would have an even distribution of the force on each of the four legs. Because the area of each leg is ten times smaller than the bottom plate of the composter, the pressure on each leg is much higher: 192 MPa (calculations shown in Appendix C). Our team considered using recycled HDPE for cylinder legs but because its yield stress is much lower, we ultimately decided to use stainless steel 304 for the cylinder leg construction as well.

4.3.4. Energy Requirements

The energy requirements of the highest-powered components of the composter were calculated to get a better idea of the annual electricity requirements of the composter. We found that a total of 21 kWh per year would be needed for big components.

The energy usage for running the 63 W mixing motor for approximately 24 minutes each day is equal to 0.025 kWh per day or 9 kWh per year. Using a high-powered computer fan for the forced aeration would mean a draw of 5 W for approximately two hours each day, or 0.01 kWh per day (4 kWh per year). The Arduino Uno control board would be continuously running and has a power consumption of 7 kWh per year.

4.4. Control System

We've shown that the constraints to be met to achieve a successful composting process require a lot of management which can result in labor that could account for 90% of operating costs (as shown in the Kean University compost project) (Mu et al., 2017). By creating a system that requires a comparable level of human intervention to taking out the trash, significantly higher organic waste recovery in our cities becomes possible. Our design team determined that an arduino-centered control system would satisfy most of our needs while mitigating cost and complexity. Following this decision, a process flow diagram was created to outline the relationship between users, sensors, data acquisition, and system interfaces—shown in **Figure 9**.

[5] https://www.amazon.ca/dp/B01G5I6O4Q?psc=1&th=1&linkCode=gs2&tag=appualsca1-20

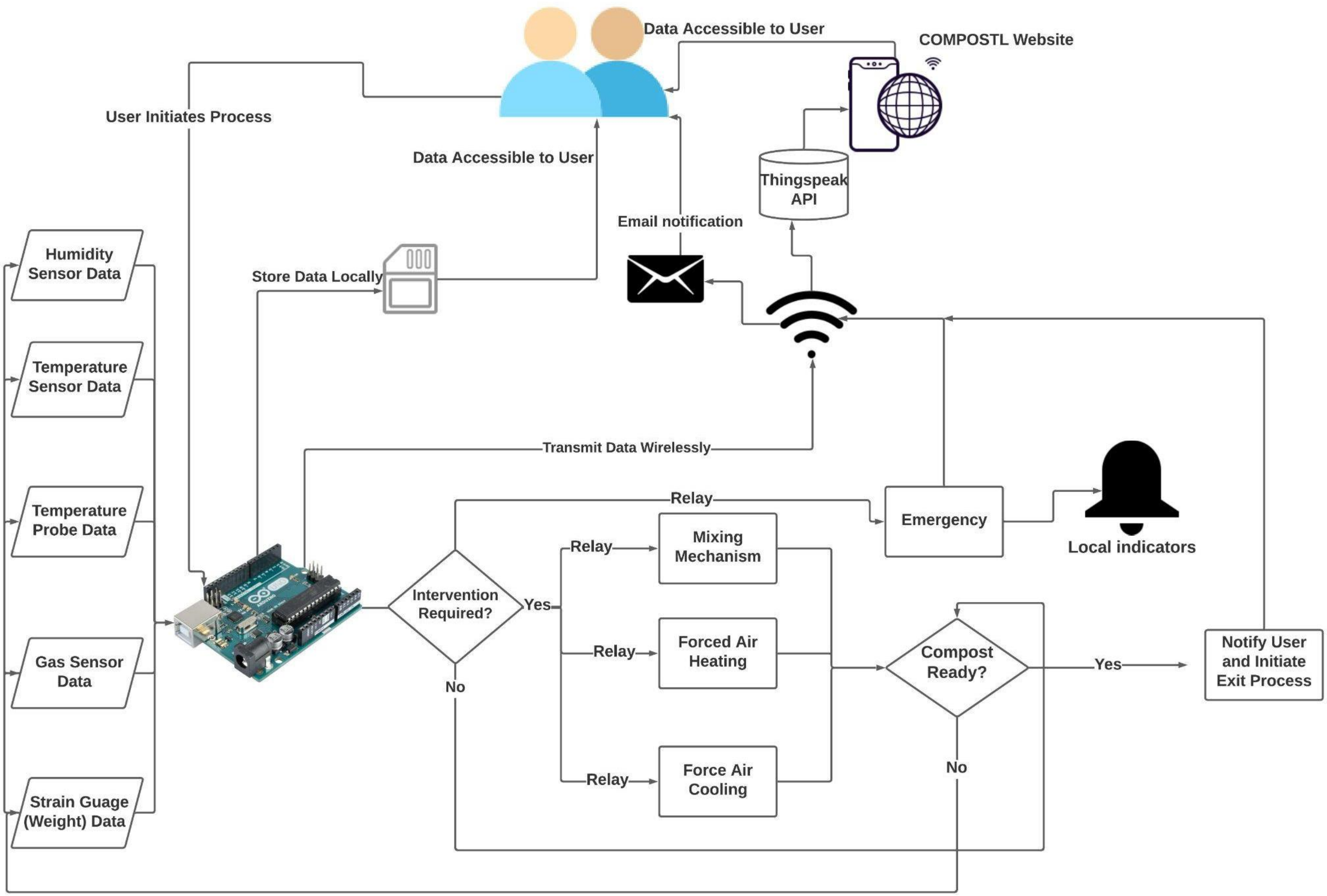


Figure 9: Arduino centered control system

5. Results and Discussion

5.1. Presentation of Resulting Design

Our design consists of a semi-continuous, self-regulated, in-vessel composter. The system is designed for installation in restaurants and in particular will be used for the Ceilidh restaurant on Macdonald campus. Originally the design was going to be made out of HPDE metal, however, it was decided that stainless steel would be a better fit, given its solid durability. The body of the cylinder measures 60 cm high and the total height including the legs, measures 160 cm. The diameter of the cylinder is 50cm, with the legs' diameter measuring out to be 5 cm.

The main features consist of a hinged lid for loading the organic material, as well as the housing control box. On the top, there is an entry hole point for the wired sensors.

On the side of the cylinder, there are inlet and outlet holes, this feature will allow the restaurant to connect the composter to its air exhaust ducting. Lastly, there is a hinged door on the lower part of the cylinder's body for loading and unloading the compost.

Inside the body, there are three rectangle paddles that are attached to an axial road which is powered by a motor. There is a control system designed to manage the composting process by restaurant managers, without any complex steps. This main technology is called an arduino-centered control system which involves a combination of sensors, data acquisition, and system interfaces that the user can implement daily. Given the world is continuously growing to digitize everything to improve processes, this addition would be an advantage for restaurant employees to manage with ease.

5.1.1. Manufacturing processes, parts list, and operational processes

Manufacturing of the composting unit would begin with ordering the parts and materials listed in Table 8. The cost of manufacturing, fabrication and assembly and stainless steel can be found in Table 9 and Table 10, respectively. Upon receipt of the sheet metal, the material would be sent to a fabricator for laser cutting, machining, fabrication, and welding of the unit. Once the framing and body of the composter have been assembled at the fabricator, our team would equip the control system hardware including sensors, the fan, and motor. Freight between sheet metal supplier and fabricator is anticipated to take up to two months. Once the fabricator receives the material we estimate that the total work required wouldn't exceed a week with up to five hours of direct labour required. From there, local delivery or pick-up of the composting unit would take place and one of our design members would be able to assemble the control system hardware. From there it would be ready for delivery and installation at The Ceilidh restaurant.

Table 8: Bill of Materials

Item	Amount	Approximate Price
Stainless Steel 304 (2.5 mm)		$ 370.38
cylinder	1 m^2	
lid	0.2 m^2	
bottom plate	0.2 m^2	
legs (all 4)	0.6 m^2	
mixer	0.8 m^2	
Control System Hardware		
Control System Components: W5100 Ethernet Shield, Temperature Probe Sensor DS1B20 x 3, Wemos D1 Ethernet Shield, 5V fan x 2, Humidity Sensor, Humidity Switch Controller, Servo Motor	1	$ 72.89
Wifi Serial Transceiver, Wires, Resistor	1	$ 19.67
Transistors	1	$ 4.56
Arduino Uno	1	$ 35.00
Corsair ML120 Pro Premium Fan	1	$ 56.13
Parallel Shaft DC Gearmotor, 1/2 hp, 17 rpm At 1112 in.-lbs. Torque	1	$ 954.18
	Total	$ 1,512.81

Table 9: Stainless Steel Cost Estimate

m^2	mm (thickness)	m (thickness)	Volume (m^3)	Density kg/m^3	Mass (kg)	Cost /kg[6]	Cost
1	2.5	0.0025	0.0025	8000	20	$6.61	$132.28
0.2	2.5	0.0025	0.0005	8000	4	$6.61	$26.46
0.2	2.5	0.0025	0.0005	8000	4	$6.61	$26.46
0.6	2.5	0.0025	0.0015	8000	12	$6.61	$79.37
0.8	2.5	0.0025	0.002	8000	16	$6.61	$105.82
		Total	**0.007**		**56**		**$370.38**

[6] Source: https://sciencing.com/weld-inconel-2396.html

Table 10: Manufacturing Fabrication, & Assembly

Expense	Hours/Weight/Amount	Cost/Rate	Total Annual
Materials			$0.00
SS 304 (2.5mm)			
cylinder	20.00	$6.61	$132.20
lid	4.00	$6.61	$26.44
bottom plate	4.00	$6.61	$26.44
legs (all 4)	12.00	$6.61	$79.32
mixer	16.00	$6.61	$105.76
freight		$134.76	$134.76
Control System Hardware			$0.00
Control System Components: W5100 Ethernet Shield, Temperature Probe Sensor DS1B20 x 3, Wemos D1 Ethernet Shield, 5V fan x 2, Humidity Sensor, Humidity Switch Controller, Servo Motor	1.00	$72.89	$72.89
Wifi Serial Transceiver, Wires, Resistor	1.00	$19.67	$19.67
Transistors	1.00	$4.56	$4.56
Arduino Uno	1.00	$35.00	$35.00
Steel fabrication			$0.00
Labour[7]			$0.00
Laser Cutting	0.50	$150.00	$75.00
Machining	0.50	$120.00	$60.00
Fabrication	1.50	$90.00	$135.00
Welding	2.00	$75.00	$150.00
Composter Assembly			$0.00
Labour			
One assembler	3.50	$25.00	$87.50
		TOTAL	**$1,144.54**

[7] Source: https://www.thefabricator.com/thefabricator/article/shopmanagement/costing-and-pricing-it-right

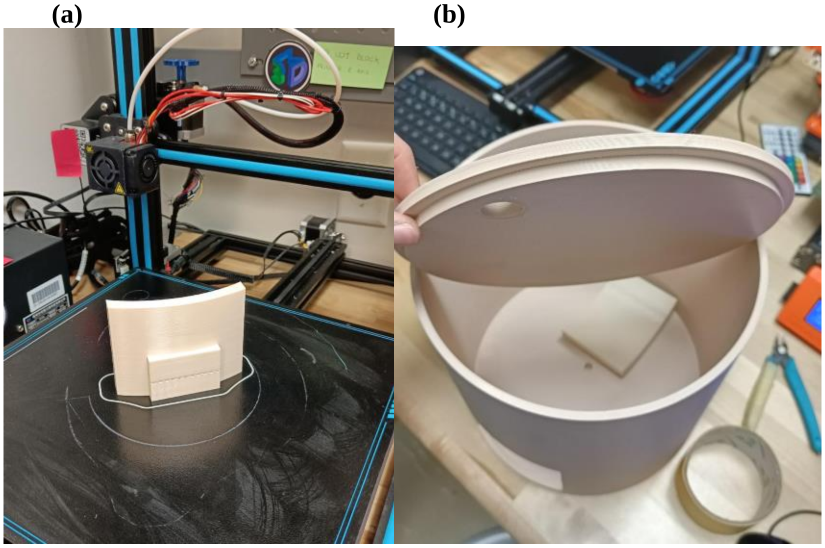
5.2. Prototyping

5.2.1. Bench-scale design

To begin our process of prototyping, tests were conducted with different temperature probes, humidity sensors, motors, and microcontrollers. The visualization was done remotely by collecting data using the live COMPOSTL website. Throughout the testing process, it was discovered that much more aeration and mixing would be required at the beginning of the composting process. It was also decided to add atmospheric odor sensors to help control ventilation, since it is a crucial design feature for the Ceilidh and any indoor in-vessel composter. With the help of the M3D printing club at MacDonald campus, a bench-scale version of the design was 3D printed. The design preserved the surface-area-to-volume ratio of the full-scale design, as it is imperative for mimicking heat dissipation and mixing conditions.

Figure 10: 3D printed bench scale design of the composter; (a) the door, (b) the lid and the drum

(a) **(b)**



5.2.2. 3D design small-scale rotating composter

A CAD drawing of the final version of the design was made to further visualize the composter. AutoCad was the program used to achieve the drawings.

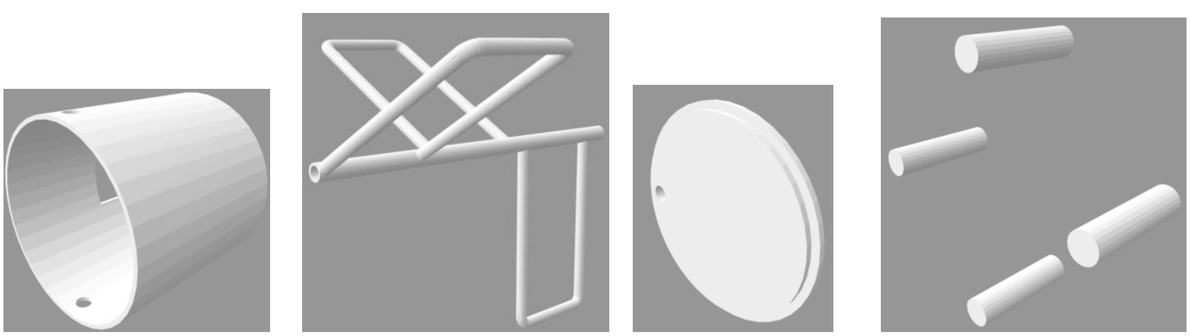


Figure 11(a): drum **(b) mixing auger** **(c) lid** **(d) legs**

6. Conclusion

The purpose of our design was to tackle the problems of organic solid waste diversion from landfills within Montreal. Throughout BREE 490, we went through the process of coming up with a design and determining our target client. After careful consideration, our initial decision was mid-sized condo buildings, as we realized they were an under-serviced component of the organic-waste issue. A comprehensive literature review was undertaken, and evidence supported the feasibility of implementing residential-scale, in-vessel compost systems in condo buildings of up to 50 units. Consequently, a design process swiftly took shape, and decision making tools such as attribute tables, objective trees, and pugh charts were implemented to come up with an optimal final design. Over time, the design that was arrived at included a composting drum made from recycled HDPE material with an Arduino centered control system, and mixing auger. Throughout the design process, we had come across many obstacles of which numerous discussions took place to determine how we would overcome them. One example was the realization that manually loading a “full-capacity” batch would involve lifting up to 60 lbs overhead - far exceeding what is recognized as acceptable by OSHA guidelines. Other questions regarding the level of gaseous emissions were also in need of re-evaluation. The biggest barrier that we faced was learning that the intended application of our system - the diverting of organic waste produced by condo buildings from landfills - was already an intent that the city of Montreal were planning to service in the near future.

BREE 495 was where the re-evaluation of our design and target clients took effect. Our goal was restructured to provide a solution for urban organic waste recovery within Montreal that can be applied in areas where municipal organics recovery is currently not provided. The food service industry at first glance seemed like the best option, since there are large amounts of organic waste produced, with less of a possibility of contamination with other products that cannot be mixed within a composter. However, further research and conduction of interviews proved that the dimensions of our design was far too large to fit within most restaurant and café spaces, as well as not being economically feasible. Our solution to this issue was to narrow our clients even further, and focusing on the Ceilidh Restaurant at MacDonald Campus and structuring the dimensions to fit within the space of the restaurant, while still being large enough to be considered a commercial composting system. Furthermore, the base material chosen for the drum was stainless steel rather than recycled HDPE, namely due to their properties and difference in durability.

Following the finalization of the design, risk assessments and the social, economical, and environmental implications of our design was evaluated. Subsequently, mathematical formulas for mixing force and aeration were calculated in order to create an accurate 3D model and prototype of the composter. Our hopes with our design is to create a fully functioning and optimal composting system to service our local community within the MacDonald Campus to promote the idea of implementing a circular economy by possibly collaborating with the farm located near the campus and using the finished compost from the waste products of the Ceilidh restaurants to use as fertilizer to grow more food for the community.

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7. Appendices

7.1. Appendix A: Material Properties

Number	Material	Condition	Strength (Tensile) Yield S_y, MPa (kpsi)	Ultimate S_u, MPa (kpsi)	Fracture, σ_f, MPa (kpsi)	Coefficient σ_0, MPa (kpsi)	Strain Strength, Exponent m	Fracture Strain ϵ_f
1018	Steel	Annealed	220 (32.0)	341 (49.5)	628 (91.1)†	620 (90.0)	0.25	1.05
1144	Steel	Annealed	358 (52.0)	646 (93.7)	898 (130)†	992 (144)	0.14	0.49
1212	Steel	HR	193 (28.0)	424 (61.5)	729 (106)†	758 (110)	0.24	0.85
1045	Steel	Q&T 600°F	1520 (220)	1580 (230)	2380 (345)	1880 (273)†	0.041	0.81
4142	Steel	Q&T 600°F	1720 (250)	1930 (280)	2340 (340)	1760 (255)†	0.048	0.43
303	Stainless steel	Annealed	241 (35.0)	601 (87.3)	1520 (221)†	1410 (205)	0.51	1.16
304	Stainless steel	Annealed	276 (40.0)	568 (82.4)	1600 (233)†	1270 (185)	0.45	1.67
2011	Aluminum alloy	T6	169 (24.5)	324 (47.0)	325 (47.2)†	620 (90)	0.28	0.10
2024	Aluminum alloy	T4	296 (43.0)	446 (64.8)	533 (77.3)†	689 (100)	0.15	0.18
7075	Aluminum alloy	T6	542 (78.6)	593 (86.0)	706 (102)†	882 (128)	0.13	0.18

Table 11: Results of tensile tests of some metals (Budynas, Nisbett, & Shigley, 2008)

Table 3 ASME Design Stresses for Types 304N and 316N (7)						
	Maximum Allowable Stress Section I, Section III Class 2 and 3, and Section VIII, Division 1 ksi[a]				Stress Intensity Section III, Class 1, and Section VIII, Division 2 ksi	
Temperature °F (°C)	Grade 304N		Grade 316N		Grade 304N	Grade 316N
75 (24)	20.0	20.0	20.0	20.0	23.33	23.33
100 (38)	20.0	20.0	20.0	20.0	23.33	23.33
200 (93)	17.9	20.0[b]	19.4	20.0[b]	23.33	23.33
300 (149)	15.7	19.0[b]	17.8	19.2[b]	22.6	23.33
400 (204)	14.1	18.3[b]	16.5	18.8[b]	20.4	22.33
500 (260)	13.0	17.8[b]	15.4	18.6[b]	18.7	22.2
600 (316)	12.4	17.4[b]	14.6	18.6[b]	17.8	21.1
650 (343)	12.2	17.3[b]	14.2	18.6[b]	17.55	20.5
700 (371)	11.9	17.15[b]	13.9	18.6[b]	17.2	20.1
750 (399)	11.75	16.9[b]	13.6	18.5[b]	16.9	19.6
800 (427)	11.55	16.6[b]	13.3	18.4[b]	16.65	19.2
850 (454)	11.3	16.3[b]	13.1	18.3[b]	...	...
900 (482)	11.05	15.9[b]	12.8	18.1[b]	...	...
950 (510)	10.8	15.6[b]	12.6	17.8[b]	...	...
1000 (538)	10.55	15.0[b]	12.4	17.4[b]	...	...
1050 (566)	10.3	12.4[b]	12.2	15.8[b]	...	...
1100 (593)	9.75	9.75	11.7	12.4[b]	...	...
1150 (621)	7.7	7.7	9.8	9.8	...	...
1200 (649)	6.05	6.05	7.4	7.4	...	...

Table 12: Design stresses for stainless steel types 304N & 316N (Nickel Development Institute & American Iron and Steel Institute)

Table 5 Suggested Maximum Service Temperatures in Air (1)				
AISI Type	Intermittent Service		Continuous Service	
	°C	°F	°C	°F
201	815	1500	845	1550
202	815	1500	845	1550
301	840	1550	900	1650
302	870	1600	925	1700
304	870	1600	925	1700
308	925	1700	980	1800
309	980	1800	1095	2000
310	1035	1900	1150	2100
316	870	1600	925	1700
317	870	1600	925	1700
321	870	1600	925	1700
330	1035	1900	1150	2100
347	870	1600	925	1700
410	815	1500	705	1300
416	760	1400	675	1250
420	735	1350	620	1150
440	815	1500	760	1400
405	815	1500	705	1300
430	870	1600	815	1500
442	1035	1900	980	1800
446	1175	2150	1095	2000

Table 13: Service temperatures of stainless steel grades in air (Nickel Development Institute & American Iron and Steel Institute).

Metal	Process	GER (MJ/kg)	GWP (kg CO_2e/kg)	AP (kg SO_2e/kg)	SWB (kg/kg)
Nickel	Flash furnace smelting and Sherritt-Gordon refining	114	11.4	0.130	65
	Pressure acid leaching and SX/EW	194	16.1	–	351
Copper	Smelting/converting and electro-refining	33	3.3	0.040	64
	Heap leaching and SX/EW	64	6.2	–	125
Lead	Lead blast furnace	20	2.1	0.022	14.8
	Imperial smelting process	32	3.2	0.035	15.9
Zinc	Electrolytic process	48	4.6	0.055	29.3
	Imperial smelting process	36	3.3	0.036	15.4
Aluminium	Bayer refining, Hall–Heroult smelting	211	22.4	0.131	4.5
Titanium	Becher and Kroll processes	361	35.7	0.230	16.9
Steel	Integrated route (BF and BOF)	23	2.3	0.020	2.4
Stainless steel	Electric furnace and Argon–Oxygen decarburisation	75	6.8	0.051	6.4

Table 14: Environmental impacts for "cradle-to-gate" metal production (Norgate, Jahanshahi, & Rankin, 2007)

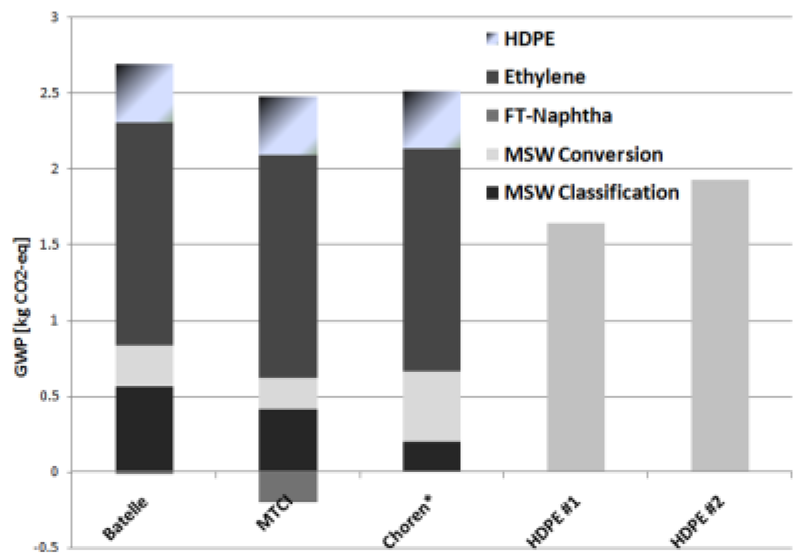

Figure 12: Comparison of the system-wide global warming potential (GWP) of producing 1 kg of HDPE from MSW with its fossil-based counterpart (Nuss, Bringezu, & Gardner, 2012)

7.2. Appendix B: Design Conceptualization

System	Attribute	1	2	3	4
Composting Drum	Outer compartment material	recycled HDPE	stainless steel	recycled aluminum	••••
	Outer compartment orientation	vertical	horizontal	••••	••••
	Frame	wood	cast iron	stainless steel	••••
	Mechanism for mixing	none	steel auger	rotating drum	mixing wand
	Loading mechanism	mechanic arm lifts and empties bin	mailbox 'style' opening for small loads	top slides open	••••
	Watertight and airtightness	rubber gaskets	bathtub caulking	marine epoxy	••••
	Food shredding mechanism	none	steel auger	chopping blades	••••
	Mechanism for adding bulking agent	movement sensor + motorized hopper	Mechanical trigger every time door is opened	Manual, everytime food is added	By weight (strain gauge sensors)
	Heating elements	none	electric resistance	forced air	hot water
	Overall shape	square	cylindrical	rectangular	spherical
HVAC Systems and User Interaction	Aeration/Cooling	Active: through perforated tube	Actived: Forced air paired with mixing	Passive: done through mixing/rotation	••••
	Exhaust system	vented outside	vented inside with filter	••••	••••
	Humidity system	Non-contact: moisture meter	Contact: soil moisture probe (ensure it is rust-proof)	Sampling area with parallel plate capacitance	••••
	Temperature probe	Non-contact: IR imaging	Contact: temp. probes	••••	••••

	Data logging	Arduino with micro SD and ethernet shield	Raspberri Pi/MySQL database	Arduino with Micro SD, local storage and interactive display	Raspberry Pi USB/SD local storage and interactive display
	Data display	Screen	Website? App?	Plug in display	••••
	Alarm systems/ User alerts	Raspberry Pi SMS alert with Twilio	Arduino + GSM Shield + SIM Card (service provider)	Audio/Visula Alarm on actual system	Raspberri Pi/Arduino email notification
	Deal with odourous gases	mineralization	filtration	••••	••••
				••••	••••
Storage Container	Mechanism for unloading	Lifted onto cart with wheels	comes with frame with wheels	Move using a dolly	••••
	Level Sensor	Ultrasonic	Laser	By Weight	••••
	Container material	recycled HDPE	stainless steel	recycled aluminum	HDPE

Figure 13: Self-Regulated Commercial-Scale Composter: Attribute table used to conceptualize design

System	Attribute	Combo 1	Combo 2	Combo 3 **	Combo 4**	Combo 5**	Combo 6	Combo 7**	Combo 8
Composting Drum	**Outer compartment material**	recycled HDPE	recycled HDPE	recycled HDPE	stainless steel	stainless steel	aluminum	aluminum	recycled HDPE
	Outer compartment orientation	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal
	Frame	stainless steel	cast iron	stainless steel	stainless steel	cast iron	stainless steel	cast iron	stainless steel
	Mechanism for mixing	steel auger	mixing wand	steel auger	steel auger	mixing wand	steel auger	mixing wand	steel auger
	Loading mechanism	top slides open	mailbox style opening	top slides open	top slides open	mailbox style opening	mailbox style opening	top slides open	top slides open
	Watertight and airtightness	rubber gaskets	marine epoxy	bathtub caulking	rubber gaskets	marine epoxy	rubber gaskets	bathtub caulking	bathtub caulking
	Food shredding mechanism	steel auger	chopping blades	steel auger	steel auger	chopping blades	steel auger	chopping blades	steel auger
	Mechanism for adding bulking agent	Manual, everytime food is added	By Weight	By Weight	Manual, everytime food is added	By Weight	Manual, everytime food is added	By Weight	By Weight
	Heating elements	Forced Air	Forced Air	Forced Air	Forced Air	Forced Air	Forced Air	Forced Air	Forced Air
	Overall shape	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical

HVAC Systems and User Interaction	**Aeration/Cooling**	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing	Actived: Forced air paired with mixing
	Exhaust system	vented inside with filter	vented inside with filter	vented outside	vented inside with filter	vented outside	vented inside with filter	vented outside	vented inside
	Humidity system	Non-contact: moisture meter	Contact: soil moisture probe (ensure it is rust-proof)	Non-contact: moisture meter	Non-contact: moisture meter	Contact: soil moisture probe (ensure it is rust-proof)	Non-contact: moisture meter	Contact: soil moisture probe (ensure it is rust-proof)	Non-contact: moisture meter
	Temperature probe	Non-contact: IR imaging	Contact: temp. probes	Contact: temp. probes	Contact: temp. probes	Non-contact: IR imaging	Contact: temp. probes	Non-contact: IR imaging	Contact: temp. probes
	Data logging	Arduino with Micro SD, local storage and interactive display	Raspberri Pi/MySQL database	Arduino with micro SD and ethernet shield	Arduino with Micro SD, local storage and interactive display	Raspberri Pi/MySQL database	Arduino with Micro SD, local storage and interactive display	Raspberri Pi/MySQL database	Arduino with Micro SD, local storage and interactive display
	Data display	Screen	Website? App?	Website? App?	Plugin	Website? App?	Plug in	Website? App?	Plugin
	Alarm systems/ User alerts	Audio/Visula Alarm on	Raspberri Pi/Arduino	Raspberri Pi/Arduino	Raspberri Pi/Arduino email	Raspberri Pi/Arduino	Audio/Visula Alarm on actual system	Raspberri Pi/Arduino	Audio/Visula Alarm on actual

		actual system	email notification	email notification	notification	email notification		email notification	system
	Deal with odourous gases	filtration	filtration	mineralization	mineralization	filtration	mineralization	filtration	mineralization
Storage Container	**Mechanism for unloading**	comes with frame with wheels	comes with frame with wheels	comes with frame with wheels	comes with frame with wheels	comes with frame with wheels	comes with frame with wheels	comes with frame with wheels	comes with frame with wheels
	Level Sensor	Ultrasonic	Ultrasonic	By weight	Ultrasonic	By weight	Ultrasonic	By weight	By weight
	Container material	recycled HDPE	recycled HDPE	HDPE	recycled HDPE	HDPE	recycled HDPE	HDPE	HDPE

Figure 14: Feasible Design Attribute Combinations

7.3. Appendix C: Specifications and Analysis Calculations

$$T = F \times d_c$$
$$T: torque\ (N\ m), F: force\ on\ each\ paddle\ (N), : d_c: distance\ from\ center$$

$$T = 40.5\ kg \times 9.81\ \frac{m}{s^2} \times 0.2\ m$$
$$T = 79.5\ N\ m$$

$$H = T \times \omega$$
$$H: power\ (W), T: torque\ (N * m), \omega: angular\ velocity\ (rad/s)$$

$$H = 79.5\ N * m \times 0.785\ rad/s$$
$$H = 62.4\ W\ or\ 0.1\ HP$$

$$F = M \times a$$
$$F: Force\ (N), M: Mass\ (kg), a: acceleration\ (\frac{m}{s^2})$$

$$F = 153.5\ kg \times 9.81\ \frac{m}{s^2}$$
$$F = 1506\ N$$

$$P = \frac{F}{area}$$
$$P: Pressure\ (Pa), F: Force\ (N), area\ (m^2)$$
$$P_{plate} = \frac{1506\ N}{0.2\ m^2} = 7.7\ MPa$$
$$P_{cylinder\ leg} = \frac{1506\ N\ \div\ 4}{0.01\ m^2} = 191.8\ MPa$$

7.4. Appendix D: Control System

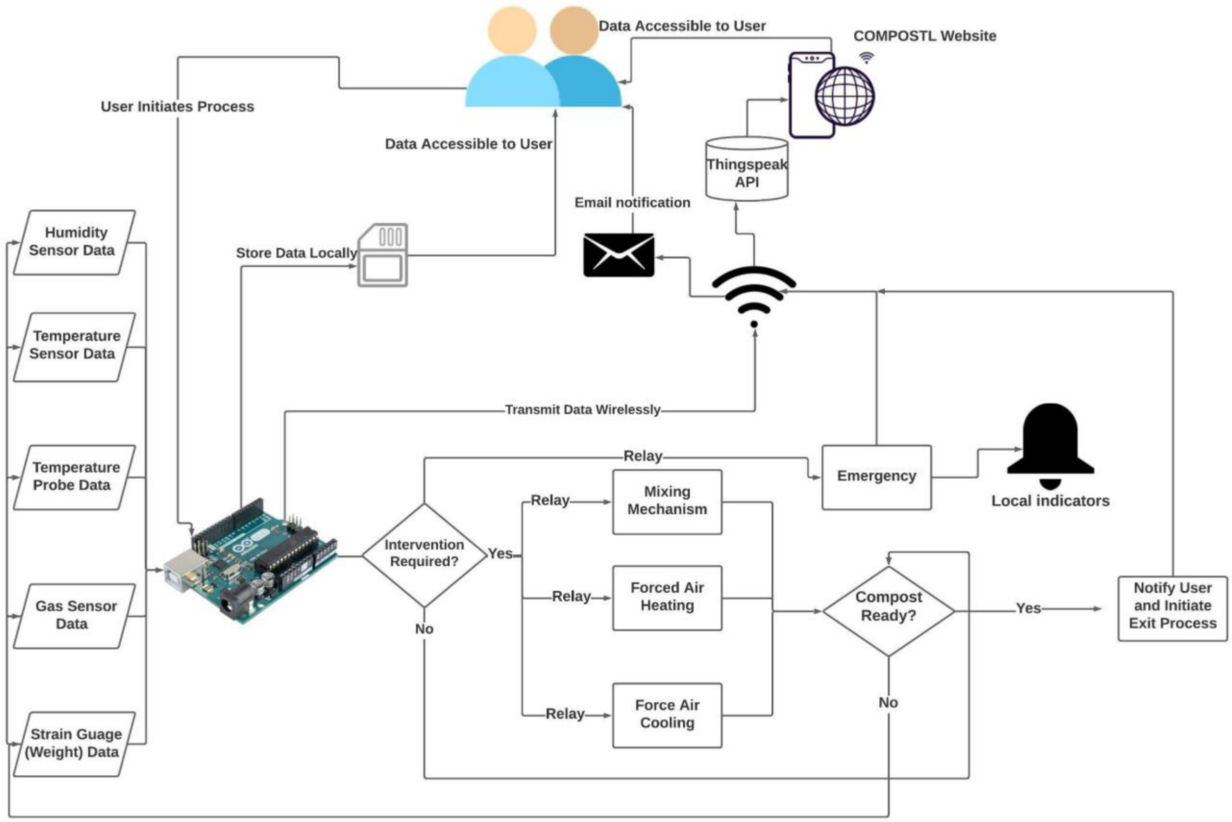

Figure 9: Arduino centered control system for self regulating compost design

7.5. Appendix E: Full Objective Tree

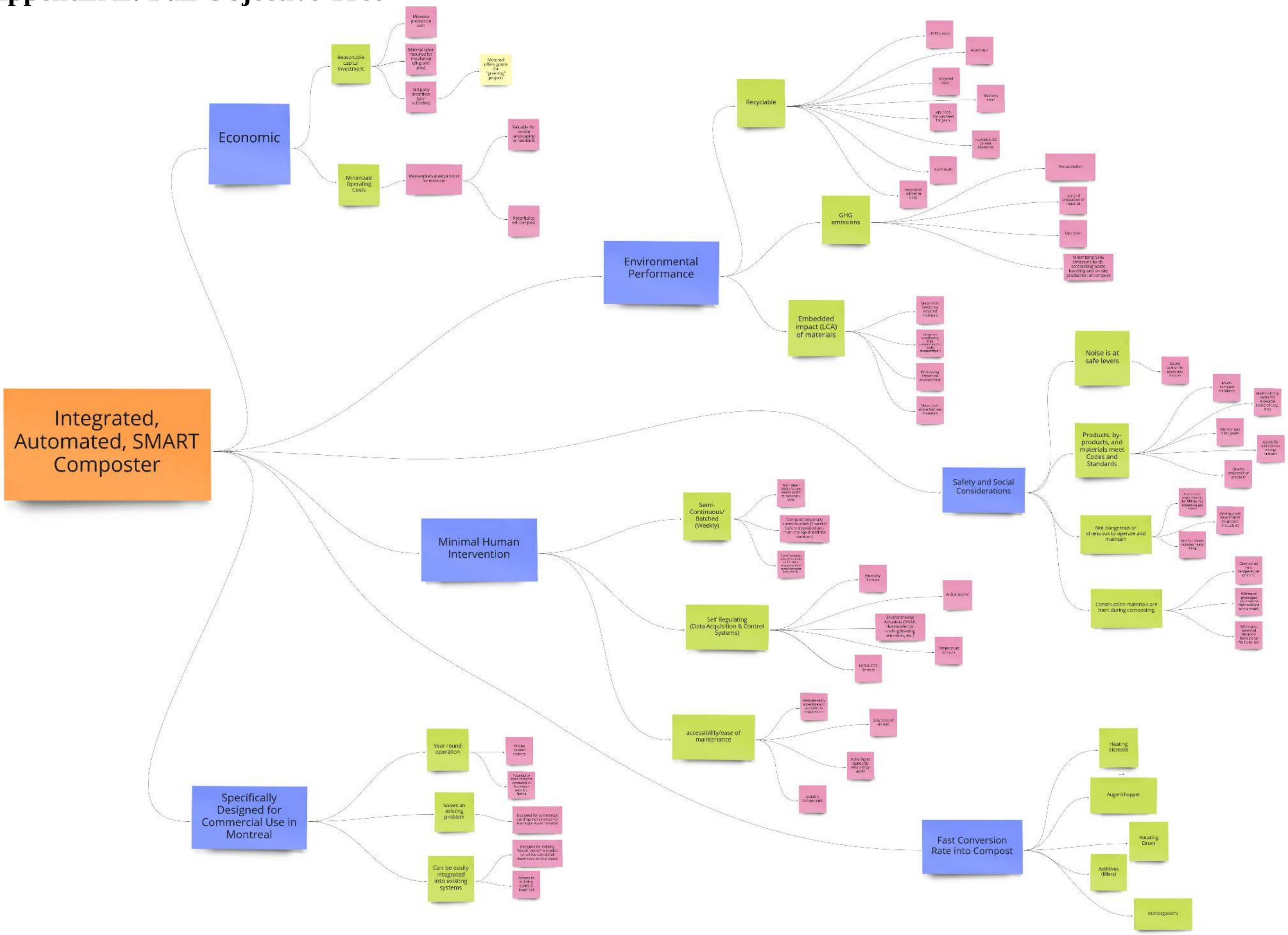

Figure 15: Complete objective tree. Vector-format pdf available upon request.

7.6. Appendix F: Economic Analysis

Table 2: Composter Cost Analysis

	Year 1
Revenues	
Sales (70% margin)	$ 1,945.72
TOTAL	**$ 1,945.72**
Expenses	
Materials	$ -
SS 304 (2.5mm)	
cylinder	$ (132.20)
lid	$ (26.44)
bottom plate	$ (26.44)
legs (all 4)	$ (79.32)
mixer	$ (105.76)
freight	$ (134.76)
Control System Hardware	$ -
Control System Components: W5100 Ethernet Shield, Temperature Probe Sensor DS1B20 x 3, Wemos D1 Ethernet Shield, Humidity Sensor, Humidity Switch Controller, Servo Motor	$ (72.89)
Wifi Serial Tranceiver, Wires, Resistor	$ (19.67)
Transistors	$ (4.56)
Arduino Uno	$ (35.00)
Steel fabrication	$ -
Labour	$ -
Laser Cutting	$ (75.00)
Machining	$ (60.00)
Fabrication	$ (135.00)
Welding	$ (150.00)
Composter Assembly	$ -
Labour	$ -

One assembler	$ (87.50)
TOTAL COGS	**$ (1,144.54)**
PROFIT BEFORE TAXES	**$ 801.18**

Table 3: Client Payback Analysis

	Year 1	Year 2	Year 3	Year 4	Year 5
Revenues					
Savings	$ 1,400.00	$ 1,435.00	$ 1,470.88	$ 1,507.65	$ 1,545.34
TOTAL	**$ 1,400.00**	**$ 1,435.00**	**$ 1,470.88**	**$ 1,507.65**	**$ 1,545.34**
Expenses					
Composter Unit Purchase Price	$ (1,945.72)	$ -	$ -	$ -	$ -
Delivery cost (local)	$ (50.00)	$ -	$ -	$ -	$ -
Installation		$ -	$ -	$ -	$ -
Labour	$ (140.00)	$ -	$ -	$ -	$ -
Ducting Estimate	$ (250.00)	$ -	$ -	$ -	$ -
Operation & Maintenance					
Labour					
Loading Compost	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Managing Compost Product	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Cleaning	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Incidental	$ (130.00)	$ (133.25)	$ (136.58)	$ (140.00)	$ (143.50)
Materials	$ -	$ -	$ -	$ -	$ -
Additives (saw dust readily available from shop + compost produced)	$ (96.00)	$ (98.40)	$ (100.86)	$ (103.38)	$ (105.97)
Utilities	$ -	$ -	$ -	$ -	$ -
Electricity	$ (1.53)	$ (1.57)	$ (1.61)	$ (1.65)	$ (1.69)
TOTAL	**$ (3,003.25)**	**$ (632.97)**	**$ (648.80)**	**$ (665.02)**	**$ (681.64)**
PROFIT/LOSS BEFORE TAXES	**$ (1,603.25)**	**$ 802.03**	**$ 822.08**	**$ 842.63**	**$ 863.70**
TOTAL VENTURE P/(L)	**$ (1,603.25)**	**$ (801.22)**	**$ 20.86**	**$ 863.49**	**$ 1,727.19**

Table 8: Bill of Materials

Item	Amount	Approximate Price
Stainless Steel 304 (2.5 mm)		$ 370.38
cylinder	1 m^2	
lid	0.2 m^2	
bottom plate	0.2 m^2	
legs (all 4)	0.6 m^2	
mixer	0.8 m^2	
Control System Hardware		
Control System Components: W5100 Ethernet Shield, Temperature Probe Sensor DS1B20 x 3, Wemos D1 Ethernet Shield, 5V fan x 2, Humidity Sensor, Humidity Switch Controller, Servo Motor	1	$ 72.89
Wifi Serial Tranceiver, Wires, Resistor	1	$ 19.67
Transistors	1	$ 4.56
Arduino Uno	1	$ 35.00
Corsair ML120 Pro Premium Fan	1	$ 56.13
Parallel Shaft DC Gearmotor, 1/2 hp, 17 rpm At 1112 in.-lbs. Torque	1	$ 954.18
	Total	$ 1,512.81

Table 9: Stainless Steel Cost Estimate

m^2	mm (thickness)	m (thickness)	Volume (m^3)	Density kg/m^3	Mass (kg)	Cost /kg[8]	Cost
1	2.5	0.0025	0.0025	8000	20	$6.61	$132.28
0.2	2.5	0.0025	0.0005	8000	4	$6.61	$26.46
0.2	2.5	0.0025	0.0005	8000	4	$6.61	$26.46
0.6	2.5	0.0025	0.0015	8000	12	$6.61	$79.37
0.8	2.5	0.0025	0.002	8000	16	$6.61	$105.82
		Total	**0.007**		**56**		**$370.38**

[8] Source: https://sciencing.com/weld-inconel-2396.html

Table 10: Manufacturing Fabrication, & Assembly

Expense	Hours/Weight/Amount	Cost/Rate	Total Annual
Materials			$0.00
SS 304 (2.5mm)			
cylinder	20.00	$6.61	$132.20
lid	4.00	$6.61	$26.44
bottom plate	4.00	$6.61	$26.44
legs (all 4)	12.00	$6.61	$79.32
mixer	16.00	$6.61	$105.76
freight		$134.76	$134.76
Control System Hardware			$0.00
Control System Components: W5100 Ethernet Shield, Temperature Probe Sensor DS1B20 x 3, Wemos D1 Ethernet Shield, 5V fan x 2, Humidity Sensor, Humidity Switch Controller, Servo Motor	1.00	$72.89	$72.89
Wifi Serial Transceiver, Wires, Resistor	1.00	$19.67	$19.67
Transistors	1.00	$4.56	$4.56
Arduino Uno	1.00	$35.00	$35.00
Steel fabrication			$0.00
Labour			$0.00
Laser Cutting	0.50	$150.00	$75.00
Machining	0.50	$120.00	$60.00
Fabrication	1.50	$90.00	$135.00
Welding	2.00	$75.00	$150.00
Composter Assembly			$0.00
Labour			
One assembler	3.50	$25.00	$87.50
		TOTAL	**$1,144.54**

Table 15: Delivery & Installation

Expense	Hours/Weight/Amount	Cost/Rate	Total Annual
Delivery cost (local)	1.00	$50.00	$50.00
Installation			$0.00
Labour	4.00	$35.00	$140.00
Ducting Estimate	1.00	$650.00	$250.00
		TOTAL	**$440.00**

Table 16: Operation & Maintenance

Hours/Weight/Amount	Hours/Weight/Amount	Cost/Rate	Total Annual
Labour[9]			
Loading Compost	8.00	$ 16.25	$ 130.00
Managing Compost Product	8.00	$ 16.25	$ 130.00
Cleaning	8.00	$ 16.25	$ 130.00
Incidental	8.00	$ 16.25	$ 130.00
Materials			$ -
Additives[10]	32.00	$ 3.00	$ 96.00
Utilities			$ -
Electricity	21.00	$ 0.073[11]	$ 1.53
		TOTAL	**$617.53**

[9] Estimated hour per week is required to operate and maintain the composter. For two semesters of operation, this is approximately 32 hours annually.

[10] Additives like sawdust and wood chips can be sourced for free from the Macdonald Campus Shop - however for incidences where additives aren't available and estimated $96.00 can be budgeted each year to spend on additional additives.

[11] https://www.energyhub.org/electricity-prices/#:~:text=by%20Maritime%20Electric.-,Qu%C3%A9bec,as%20it%20was%20in%202020.