RAINWATER CATCHMENT AND
STORAGE FOR THE MCGILL SCHOOL OF ENVIRONMENT

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Abstract

The McGill School of Environment building will soon undergo renovations with the goal of being certified by the Living Building Challenge, which involves following strict imperatives in terms of water use. The scope of this project was to design a rainfall catchment system along with long term storage methods. A review of the literature was completed for materials involved in tank design and a water usage overview of the building was developed. Using a combination of historical rainfall data and future precipitation estimates, the SARET model developed for similar building use was modified and applied to the system to give an estimate of tank sizes needed. A life cycle analysis was performed based on literature HDPE and steel results. Economic considerations combined with the LCA led the team to recommend the DuroMaxx storage tank, as proposed by Soleno.

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ABBREVIATION AND ACRONYMS

GWP – Global Warming Potential

LBC – Living Building Challenge

LCA – Life Cycle Analysis

MCA – Multi-Criteria Analysis

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I. Introduction

Located on 3534 University Street in Montreal, the McGill School of Environment building will undergo renovations ans aims to complete the Living Building Challenge, and hence obtain the Living Building certification. The MSE building is dedicated to both classrooms and office space, with the goal of introducing an educational pathway to the design to promote sustainability after renovations. If successful, it would be the first non-residential building in the province of Quebec to be granted the Living Building certification.

McGill University's Sustainable Construction Officer, M. Philippe St-Jean, gathered motivated students in fall 2017 to participate in a preliminary system design for the MSE building renovation project. Three bioresource engineering undergraduate students joined M. St-Jean in January 2018 to work on the design of the rainwater catchment and storage components of the MSE building for their capstone project. To comply to the design requirements of the project, the team met regularly with Andrew Stein, who supervised all teams working towards the water petal of the certification. The undergraduate students also collaborated with Stuart Casgrain, Master's candidate in the Integrated Water Resources Management program, to run a specific model in order to have accurate sizing of the design components. Finally, the team consulted their mentor Dr. Shiv Prasher about technical aspects of their design. In the later stages of the consulting process, professionals from Soleno Inc. gracefully provided product information and preliminary drawings. These allowed the team to discuss more in-depth environmental impacts, as well as costs.

A. Vision Statement

Our vision is a sustainable university campus that eliminates reliance on external use of resources. The catchment and storage of rainwater enhances a building's connection to its environment and creates a positive impact on municipal infrastructure.

II. Literature Review

A. Catchment

Depending on the purpose of the system, it can range from different sizes and can be composed of a wide range of technologies. Indeed, rainwater harvesting systems can either be passive or active systems (Environmental Protection Agency, 2013).

Passive systems are typically of small volume, ranging from 50 to 100 gallons which are specifically designed to capture rooftop runoff (Environmental Protection Agency, 2013). An example of a passive system is a rain barrel. In residential areas, rain is easily captured by letting it flow through gutter downspouts into rain barrels where it is stored until further use. Due to their small scale, residential passive rainwater harvesting systems do not have any connections to the plumbing system of the household. The water is simply extracted through a water tap when needed. The rainwater is mainly used for outdoor applications such as irrigation and car washing, as it lacks appropriate treatment for indoor uses (Environmental Protection Agency, 2013). This type of system usually comprises an overflow to ground surface or to the existing stormwater collection system.

Active systems are typically of larger volumes ranging from 1,000 to 100,000 gallons and usually operate using more complex technologies. Indeed, active systems such as cisterns provide water quality treatment to a certain extent and are connected to a distribution system using pumps (Environmental Protection Agency, 2013). The design of such systems is done through a more complex process than the design of passive systems. Indeed, there is the need to determine the suitable cistern size based on water availability and demand of the household in question. This step requires an in-depth study of historical regional precipitation data in order to determine if enough rainwater will be available to meet the household's demand. Optimal materials and location of the cistern need to be determined as well, with the addition of a water quality treatment system. Moreover, engineering the piping and distribution system as well as related drainage configurations needs to be done (Environmental Protection Agency, 2013). Treatment systems vary in complexity depending on the targeted end-use of the harvested water. They can be composed of simple first flush diverters, ultraviolet lights, or even ozone treatment and reverse osmosis (Texas Water Development Board, 2005).

Regardless of the type of system employed, the rainwater will go through three main stages. Rainfall will first be captured at the catchment level, typically a rooftop. The amount of collected water will depend on the catchment area and rainfall depth. The harvested water will then be conveyed through a conveyance network, passing by a filtering mesh that keeps large debris from continuing the path towards the storage facility. The latter's design can vary depending on the materials used, on its location, and on whether a filtration device is employed.

Regarding the McGill School of Environment, the system required will need to be an active one. Indeed, the water will need to go through different filtering systems before entering the tank.

1. *Catchment Area*

The catchment area is the first point of contact for rainfall (Guelph, 2014). For most systems that include a tank as a storage facility, the catchment area is the roof surface (Guelph, 2014). There are several important factors to consider when designing a rainwater harvesting system.

First, the sizing of the catchment area will determine how much rainwater will be harvested. The amount of harvested water can be easily calculated using the following formula (Extension, N.D.):

$$Harvested\ water = catchment\ area * rainfall\ depth$$

The harvested water is calculated in liters, the catchment area in square meter and the rainfall depth are in millimeters.

Second, the slope of the roof of the household will also have an impact on the way rainwater is harvested. In fact, the steeper the slope, the faster water will be collected, which will more easily clean the roof of contaminants. However, roofs with a lower slope cause the water to move slower, which raises the risks of contaminants to remain on the catchment surface (Extension, N.D.). In the latter case, a primary filtration system might need to be considered.

2. *Conveyance Network*

A conveyance network must be put in place as one downspout is not enough to collect all the rainwater. Indeed, rainwater can discharge from different parts of the roof depending on its shape. A conveyance network is therefore necessary to collect as much water as possible and convey it to one central location, the storage tank (Guelph, 2014). The gutters through which the water will flow need to be designed based on the flow during the highest intensity rain of the area (C. f. S. a. Environment, N.D.). The support they need in order not to sag from the water load must be designed based on the construction of the household (C. f. S. a. Environment, N.D.). Being located in Montreal, the gutters of the McGill School of Environment roof will have to comply with Chapter III of the Quebec Construction Code and Chapter I of the Safety Code of Quebec, which discuss regulations concerning plumbing. MSE gutters will also need to comply with the federal Plumbing Code.

Moreover, the conveyance network is typically the medium for a primary filtration. In fact, a coarse mesh if usually placed at the roof to prevent the passage of debris into the network (C. f. S. a. Environment, N.D.). A first-flush diverter located before the tank prevents the first flush of water from entering the tank. This filter is necessary as the first flush is often contaminated by pollutants present on the roof (Huhn, 2015).

B. Storage Tank

1. *Location*

At the end of the first phase of the design process, it was concluded that the optimal location for a storage facility for the McGill School of Environment building would be underground.

In fact, the advantages of an underground system are many. Indeed, it would use up space that wouldn't be used otherwise, and above-ground space could then be considered for different purposes like plantation and entertainment. Additionally, underground cisterns provide frost protection, which is an important factor to consider when constructing in Montreal. Invisibility and cooler water temperatures are also provided by the underground conditions. Moreover, there will be little to no chances of algae growth, as the cistern will not be exposed to the sun (OSE, 2015).

Unfortunately, placing a cistern underground also has some disadvantages. Indeed, high costs are associated with the process of placement of the cistern. Excavation, backfill, underground conduits, electrical wires, as well as machinery and their skilled operators are costly, which could lead an underground system to cost around twice the price of an above-ground system. Additionally, the cistern is more difficult to access, making maintenance and repair more difficult (OSE, 2015). Finally, a pump system will be necessary to get the water out of the tank and into the distribution system which will direct it to the fixtures. This is a great disadvantage for the McGill School of Environment project as the LBC certification limits the use of energy inside the building (Institute, 2017a).

2. *Components*

A literature review of an underground cistern's components was conducted during the first semester of work on the MSE Project. The findings were the following:

First, treated rainwater enters the tank through a delivery point that is usually located at the top of the tank. A service way will be available to access the inside of the cistern for maintenance purposes. A vent pipe is also a necessary component for effective pumping, as well as for the effective intake of a high volume of water during extreme weather events. A fine-mesh screen covers the pipe to prevent small animals and insects from entering the system. As for the pump line, it oversees directing the harvested water to the plant material via the distribution system using a pump. Additionally, an electric line is required for a sump pump. To prevent the pump from burning out when the cistern is empty, a float switch is left to float in the storage tank to indicate when the water level is too low. When it is, the float switch turns to the "OFF" position, which turns off the pump. An overflow pipe is also an essential component of a storage tank. It must be large enough to carry runoff in a "100-year storm". As for the tank walls, they come in different shapes and sizes depending on the user's needs (OSE, 2015). The material of which they're made also varies from a tank to another. If the tank is placed underground, the material chosen needs to be able to withstand both the inward pressure from the soil and the outward pressure from the stored water (OSE, 2015)

3. Material

Another important factor to consider when designing a storage tank is the material it will be made of. A "Red List" containing forbidden materials was imposed on us by the requirements of the Living Building Challenge. Indeed, The Living Building Challenge aims to eliminate the use of worst-in-class materials and chemicals with the greatest impact on ecosystems and on human health. Some of the items on that list include mercury, chlorine, lead and volatile organic compounds in wet-applied products (Institute, 2017b). Polyvinyl Chloride (PVC), a very common material in plumbing, is an additional one (Institute, 2017b). LBC suggests alternatives to this material such as concrete, steel, vitrified clay and a few specific plastics (Institute, 2017b). Regarding the McGill School of Environment project, PVC is going to be replaced with Polyethylene and variations.

Thorough research was therefore conducted in order to determine the most suitable material to achieve the MSE building renovation goals. Four different materials seemed appropriate, which are presented in the table II-1. The information was gathered from Greg Kowalsky and Kathryn Thomason, 2015 (Greg Kowalsky and Kathryn Thomason, 2015).

Table II-1. Possible tank materials.

MATERIAL	ADVANTAGES	DISADVANTAGES
Concrete	Strong, long-lasting, less likely to grow algae, suitable for large volumes, can be poured on-site into different shapes and sizes, low maintenance.	Lime leak into water, subject to cracking, cannot be easily moved, expensive, high carbon footprint.
High Density Polyethylene (HDPE)	Durable, pre-made, lower cost, corrosion-proof, easy to transport.	Lightweight, not strong enough for volumes larger than around 10 m^3.
Cross-Linked Polyethylene (XLPE)	More stress-resistant than HDPE, corrosion and chemical resistant, resistant to impacts at low temperatures, suitable for use with potable water.	Doesn't conduct heat properly.
Steel Reinforced Polyethylene (SRPE)	Stronger than non-reinforced HDPE even though it is lightweight, smooth interior, suitable for use with potable water.	Steel can corrode and give the water an unpleasant taste.

After weighing the advantages and disadvantages of the possible materials, the final chosen material was steel reinforced polyethylene (SRPE). Indeed, the costs and carbon footprint associated to concrete cisterns are critical disadvantages. As for high density polyethylene, a single tank cannot reach the volume of water that the MSE cistern will need to hold. Towards the end of the first phase of the design process, the team decided to select cross-linked polyethylene as the material of choice. Further research over the material was therefore conducted, and it was found that not enough research has been conducted on the application of cross-linked polyethylene to storage tanks, which could pose possibly important unknown risks to our building. Hence, the team decided to go with the second preferred option, steel reinforced polyethylene.

The reason why the team was first hesitant to select this material is because its disadvantage is non-negligible: the fact that steel can corrode and give the water an unpleasant taste. However, after discussing this matter with our client, we were informed that a water purification system will be located not only prior to the tank, but also subsequently. This would solve the problems induced by the corroding steel. The final product has a layer of HDPE covering the steel as well, solving this issue (Soleno, 2018a).

III. Design Approach

A. Design Criteria

The Living Building Challenge is the most stringent sustainable building certification currently designed in the world. It consists of seven petals, each including specific imperatives for a total of twenty key components needed to achieve the certification. The petals are the following: Site, Water, Energy, Health, Materials, Equity, and Beauty (Institute, 2018). The materials petal includes a red list of materials that encompasses all components used in the other petals.

The focus of this project is the Water petal, which is comprised of a single imperative: Net Positive Water (05). Minimizing impact on the site and water resources, as well as mimicking their "natural hydrological conditions" as much as possible are key criteria. These translate into three requirements: only water from the site can be used, the water must be treated without the use of chemicals such as chlorine, calcium hypochlorite or sodium hypochlorite and finally all water collected and used by the building's occupants must be treated on site. Landscape must also be designed to allow proper infiltration of storm water (Institute, 2017d). Since the Living Building Challenge does not approve of drilling wells for drinking water (Institute, 2016), the main source of water will be rainfall catchment systems on the rooftops.

Included in the scope of the project, the team is allowed an initial water purchase (Institute, 2017d). In other words, it will be possible to fill up the storage tank only once at the beginning of the evaluation period. After the initial purchase, all water must be coming from the site. In order to prove that the building is water-sufficient, metering the sources of water is mandatory during the performance period. Monitoring techniques are outside the scope of this harvest and storage design and will be evaluated at a later date.

B. Tank Size Calculations

The tank size is a function of many elements of the building. In order to arrive to the final volume, the team gathered information, adapted the data to the specific conditions of the project, modified and run a rainwater harvesting model and selected a result that gives 100% reliability rate. More detail can be found in Rainwater Catchment and Storage for the McGill School of Environment (Ethier, 2018). In this report, we use the previously obtained results to respond to the current demand of the client, which is to design a tank in a system that does not recycle its grey water. We will therefore summarize the findings explained in the previous report and apply them to the latest client request.

1. Gathering of information

Precipitation data was obtained from Environment Canada, specifically the Pierre Elliott Trudeau Airport Weather Station. Although there is a station closer to the MSE building, we chose the airport station (located less than 20 km away) since their collection of data is more complete.

In order to get the volume of precipitation, we had to look at the area of the roof, precipitation data and roof obstacles. We were informed by the client that the only obstacle on the roof will be the solar panels. The absence of trees present or planned around the building suggests the debris accumulation on the roof will be low year-round. The presence of solar panels will also not interfere with the rainwater harvest since all the water that falls on them will then fall on the roof and be collected by the system. From these negligible obstacles, we assumed a collected water volume equal to the area of the roof (143 m^2) multiplied by the yearly precipitation volume.

The number of occupants was based on the client's estimates, given in the table IV-1. Standards of Full-Time equivalent give estimates on the number of times a day occupants use the water facility of a building. However, the Water petal team thought these standards do not accurately represent a student population that only uses the building a few hours day, therefore decreasing their reliance on the water facility. Stuart Casgrain estimated the use of the MSE building by looking at the study done by Davis and Nutter in 2010 (Davis & Nutter, 2010).

Moreover, non-LBC buildings typically use conventional water fixtures that meet standard. In the case of the MSE building, where water needs to be minimized as much as possible, all the water fixtures will use significantly less water than their conventional alternatives.

2. Explanation of the SARET model

In order to provide an accurate tank size that can take into account the variability of the precipitation data and the building occupant's use of the water facilities, we used the Storage and Reliability Estimation Tool (SARET) to estimate the required tank size. The model was developed by the Sustainable Water Resource Engineering Laboratory at Drexel University in order to add the missing components of other models already in place, since it takes into account the specific location of a building and generates 25 years of data, from the historical data, to give a reasonably accurate representation of the precipitation situation of the particular location (SWRE, 2017).

3. Modifications to the model

In an attempt to get a reliable answer from the model, the team modified some of the parameters to better represent the local situation of the project. First, the team wanted to extrapolate historical data to estimate its future trends in order to represent the impact of climate change in future precipitation data. To do so, the historical data from Environment Canada was combined with precipitation factors taken from climate change scenarios developed for the Government of Canada. The one selected was the Representative Concentration Pathway (RCP) 8.5 scenario, in which the factors most impacting climate change such as primary energy consumption, greenhouse gas emissions and carbon dioxide concentration in the atmosphere continue to drastically increase in the next hundred years (Government of Canada, 2017).

The precipitation data had to be modified to represent liquid as well as solid precipitation. The rainwater catchment system is only designed to capture liquid precipitation, i.e., no snow or ice can be captured. Therefore, estimates for liquid precipitation, or snow melt, are taken into account for the winter months. With increasingly varying weather patterns, the temperature is expected to rise above freezing a few times per winter season, leading to some capture of snow melt. Finally, the number of simulations was increased from 100 to 50,000 in order to improve the accuracy of the results and ensure more precise reliability rates. More details on the aforementioned modifications can be found in (S. Casgrain, Largy-Nadeau, J., Robertson, A. , 2018).

4. Results

Table III-1 . Reliability Rates Based on Tank Size According to the SARET MODEL

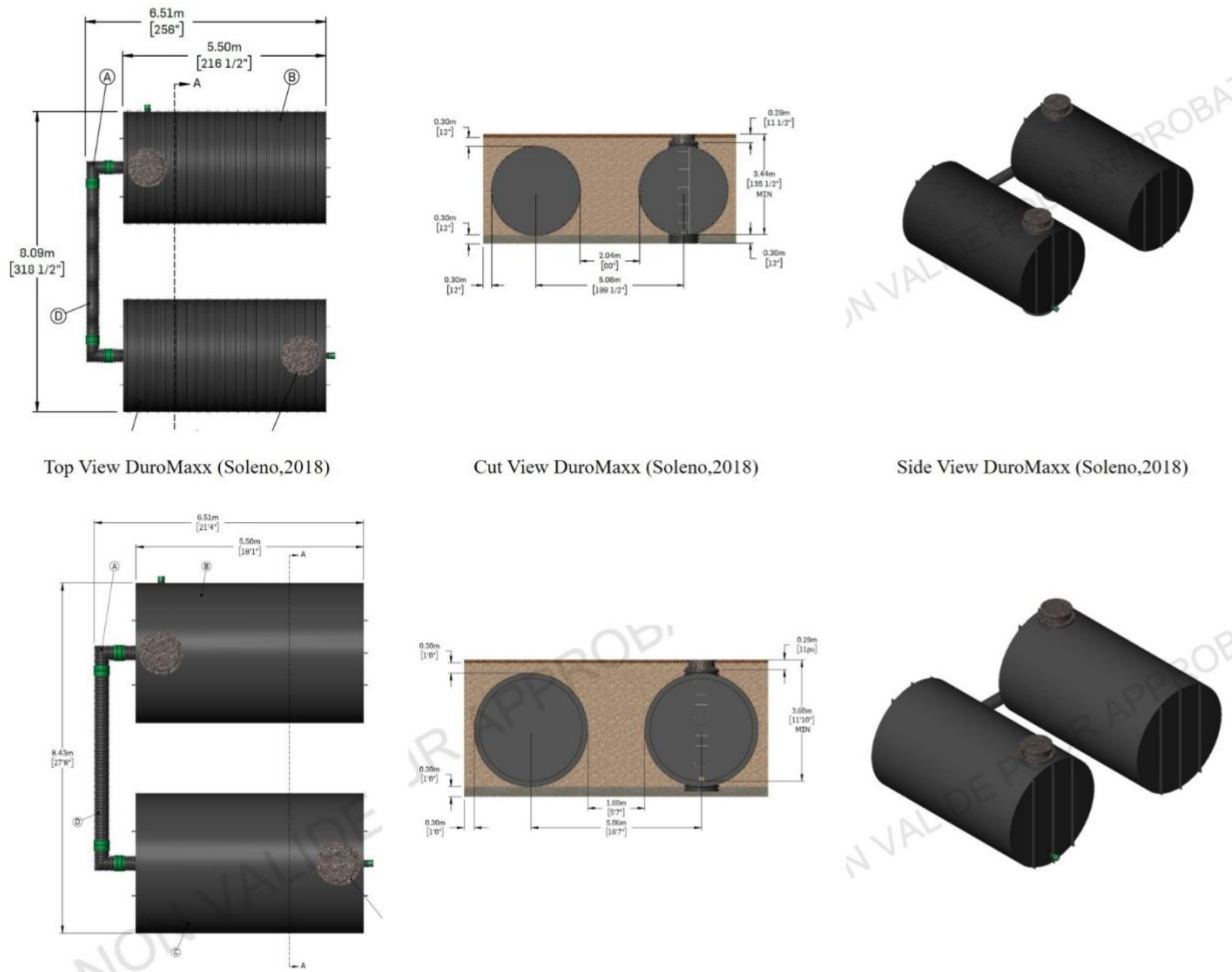
Cistern Size (m^3)	Number of Reliable Simulations	Percent of Reliability	Cistern Size (m^3)	Number of Reliable Simulations	Percent of Reliability	Cistern Size (m^3)	Number of Reliable Simulations	Percent of Reliability
28	0	0.000%	44	46746	93.492%	59	49945	99.890%
29	1	0.002%	45	47633	95.266%	60	49961	99.922%
31	22	0.044%	46	48235	96.470%	61	49972	99.944%
32	150	0.300%	47	48641	97.282%	62	49978	99.956%
33	743	1.486%	48	48960	97.920%	63	49979	99.958%
34	2524	5.048%	49	49214	98.428%	64	49983	99.966%
35	6141	12.282%	50	49395	98.790%	65	49987	99.974%
36	11749	23.498%	51	49534	99.068%	66	49989	99.978%
37	18658	37.316%	52	49633	99.266%	67	49992	99.984%
38	26008	52.016%	53	49712	99.424%	68	49994	99.988%
39	32246	64.492%	54	49772	99.544%	69	49995	99.990%
40	37199	74.398%	55	49828	99.656%	70	49996	99.992%
41	40994	81.988%	56	49863	99.726%	72	49997	99.994%
42	43634	87.268%	57	49897	99.794%	73	49998	99.996%
43	45477	90.954%	58	49928	99.856%	75	49999	99.998%
						82	50000	100.000%

5. Tank

After deciding on SRPE as the tank's most appropriate material, market research of Canadian and American companies showed that DuroMaxx, a product developed by Contech Solutions, was likely to be the best existing choice. One of its major distributors in Canada is Soleno, which has offices in Quebec as well as manufacturing plants in Ontario (Soleno, 2018). DuroMaxx pipes are originally meant for stormwater management and drainage, however Soleno provides a range of DuroMaxx products, including storage systems. Coordination with an engineering team at Soleno led to the following designs, which include two tanks of approximately 40 m^3 each, connected by elbows and connectors (Soleno, 2018). As the design team could not certify the use of the pipes for drinking water, some monitoring of water quality before and after the tank storage step will be necessary to guarantee health and safety at the potable water fixtures. Two alternatives that match the sizing requirements were presented to the team: DuroMaxx and Weholite. The DuroMaxx system is made of steel reinforced polyethylene and Weholite of high-density polyethylene only. Weholite also has high strength and can be used in underground systems, however it requires a much higher thickness of material to minimize risk of cracking or collapse (Soleno, 2018). This added amount of material necessary translates to higher up-front and environmental costs, as shown below. The prices presented here are for the most conservative estimate of tank sizing, 80 m^3 and include the total cost of the product, delivered to Montreal. The prices per length are for an inner diameter of 3,000 mm (3 m) (Soleno, 2018).

Size (m^3)	Material (type)	Price Total ($)	Price per additional meter of length ($/m)
80	Weholite	69,500	3,768
80	DuroMaxx	103,600	

Both proposed designs follow standard ASTM D3350 "Standard Specification for Polyethylene Plastics Pipe and Fittings Materials" and the DuroMaxx product line also follows standard ASTM A653/ASTM A653A "Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process" for the galvanized steel fraction.



Top View DuroMaxx (Soleno,2018) Cut View DuroMaxx (Soleno,2018) Side View DuroMaxx (Soleno,2018)

Top View Weholite (Soleno,2018) Cut View Weholite (Soleno,2018) Side View Weholite (Soleno,2018)

Figure V-1. Views of Duromaxx and Weholite Tanks.

IV. Design Implementation

A. <u>Legislation</u>

During the first semester of work on the McGill School of Environment project, research was conducted regarding legislations surrounding every aspect of our project, notably the use of rainwater for drinking purposes. A number of laws were noted as problematic. Indeed, it was thought that a derogation would be needed for the law cited in article 1.2 of the “Règlement sur la qualité de l’eau potable”, which requires a constant presence of disinfectant in the water, notably chlorine, a forbidden chemical under the LBC constraints (LegisQuebec, 2017).
Additionally, article 6 of the “Règlement sur la canalisation de l’eau potable, des eaux usées et des eaux pluviales” notes that if a building is connected to a municipal aqueduct, the water exited into

the municipal system must be exempt of any risks of contamination (Montreal, 2018). As the water used in the building will not be collected from the municipal system, but from rainwater and recycled grey water, the article requires the building to implement measures that will prevent risks of contamination.
Finally, article 89.6 of the same document states that rainwater needs to be exited through the municipal drain or to an approved "point de rejet des eaux pluviales" (Montreal, 2018). However, a storage tank for drinking water does not qualify as one.

Consequently, the team did thorough research over the procedure of asking for a derogation from the borough of Ville-Marie, where the building is located, to obtain an exemption from abiding to these problematic articles. If the process is not successful, the team would have to ask for an exemption from the Living Building Challenge directory, which would only be obtained if the team proves that they have tried and failed to get a derogation from the city first.

This semester, the team looked deeper into the legislation process in order to provide the necessary information to the client, and also to other individuals who would be interested in obtaining such a certification. However, it is to be noted that the following is specific to the McGill School of Environment Building, located on the McGill Campus in the borough of Ville-Marie in Montréal, Québec.

An important, yet challenging, aspect of the regulatory process is to have architectural plans and all the information necessary to the realization of the project before submitting to the regulatory authorities named below. The regulation process is an iterative process since there can be many backs and forth with the plans and the adherence to the regulation. The challenge involved is that plans are needed to go to tender, but all the regulatory aspects and approvals are needed to draw the final plans. Therefore, interested bidding companies have to be aware of the iterative process and the possible change in plans. It is also to be noted that the following information on the regulation process may change at any time. The team encourage any person in pursuing such a certification to do their own research before starting their project in order to prevent any surprises.

The first step of the legislation part of such a project it to contact the Water Services of the City of Montreal, particularly by the Water Management Regulation Section (WMRS). This regulatory body is focused on the water-related regulations. Once enough information is gathered by the team, the WMRS can be contacted to discuss the project and they can help pinpoint components that would go against the regulation. The WMRS of the City of Montreal is a useful resource for this project and contact information can be found in Appendix A.

The second step is to contact the McGill Building Services, once plans are completed. Since the project involves a building on the McGill Campus, the project will be presented to this body, which will decide if the project is accepted or not. For the project components that are not compliant with the current building code, proofs will be required from the design team to prove that such modification make sense and are safe for the future occupants. Proofs will be presented to the Building Services and, if accepted, they will then be in charge of presenting these demands to higher authorities. The contact information is provided in the Appendix A.

The final step is to take the project to the administrative office of the borough where the building of interest is located. In this case, the permit services of the Ville-Marie borough will have to be contact to get the construction permit. The required documents regarding the water components will need to be sent to the WMRS of the City of Montreal by email for final approbation. The contact information is provided in the Appendix A.

As previously mentioned, this process is iterative. Presenting the plans to the City of Montreal and the McGill Building services can be lengthy and plans might need to be adjusted before the final acceptance of the project.

For the current project, plans will be adjusted with the information presented in this report and from the other teams involved in the other petals of the project. Then, the plans will be presented to McGill and the City of Montreal. Since this project is still in its design phase, the remaining information regarding the regulation process is not available at the time of writing.

B. Roof Description

The roof of the McGill School of Environment is a flat roof that occupies an area of 143 m^2. Its flat nature makes its slope negligible for our design purposes, as it is only large enough to allow drainage into the downspouts.

During the first phase of the design process, our client mentioned the possibility of a green roof. The presence of vegetation would be an obstacle to the catchment of rainwater, as the plants would absorb most of the water that comes in contact with the roof. The presence of solar panels was an additional issue, as it was unsure at which angle each would be positioned, and how it would affect the collection of rainwater.

Following a meeting with the client during the second phase of the design process, the green roof project was abandoned. No vegetation will be reducing the amount of collected water. As for the solar panels, the client informed the team that they would be placed at an angle that wouldn't affect the collection of rainwater.

C. Building's Water Demand:

In order to confirm the use of rainwater as a sufficient source of water for the building occupants, the estimated annual building water demand will be calculated.

The data is based on the Stuart Casgrain's report (S. Casgrain, 2018).

Occupant water use: 9,5L/FTE
Other water use: 10L/weekday for watering plant

Table IV-1: Estimated Yearly water Demand of the MSE Building.

Type of day	FTE	Period	Calculations	Estimated Yearly water demand
On peak	20	Weekdays, sep-april, 175 days	[(9.5 L/FTE*20 FTE) + 10L]* 175 days	35 000 L
Off peak	5	Weekdays, May-august 85 days	[(9.5 L/FTE*5 FTE) + 10L]* 85 days	4887.5 L
Weekend	1.1	Weekend, All year round, 104 days	[(9.5 L/FTE*1.1 FTE)]* 104 days	1086.8 L
Total	-	364 days	-	**40 974.3 L** **41 m^3**

From the preliminary information on the roof, it was calculated that 64.5 m^3 would be harvest in a year using the original roof area of 96 m^2. However, the final volume of harvested water will be higher as the final roof area after the renovation will be of 143 m^2.
Therefore, it is confirmed that the water harvest meets the water demand of the building. One can observed that the calculated water demand is lower than the tank size chosen. The reason behind this choice is that the SARET model takes into account climate change and modelled a high number of possible weather scenarios, and hence predict for the worst. In order to have a 100% reliability rate as asked by the client, the team decided that the SARET suggest was a safer alternative.

V. LCA

The following section attempts to present a preliminary Life Cycle Assessment (LCA) of the two models suggested by the company Soleno (Soleno, 2018b). As no thorough LCA has been done by either Soleno or their suppliers thus far, the team gathered data from the available literature to this day and made conversions to better represent the systems under observation. As previously stated, the results are approximate, and hence more research on the systems components will be needed to have exact results. Based on the ISO 14040, the preliminary LCA comparing the Duromaxx and Weholite systems is presented below.

A. <u>Goal and scope</u>

A.1. Goal of the Study

The present study is intended to give a better understanding of the environmental impacts of two systems designed to store large quantities of water underground, the Duromaxx tank and the Weholite tank. Both tanks are supplied by Soleno and are sized to store 80 m^3 of water. This study will also allow the readers to make an enlightened decision based on the environmental impact of both products.

This study is intended to the professionals in the water storage field, to anyone interested in environmental certification for buildings as well as the stakeholders involved in the decision-making process of renovation or construction of buildings.

A.2. Scope of the study:

A.2. i. Function of the product system

In order to do a proper comparison of the products using an LCA, the products must have the same function. In this case, both products are used for the same primary purpose; store large quantity of water underground for the water demand of the McGill School of Environment. Both systems have the same characteristics when it comes to their performance; they both designed to prevent corrosion, root intrusion and biological growth, as well as being unaffected by the presence of chemicals (Soleno, 2018a).

A.2.ii. Functional unit

The function unit is defined in this study by a storage tank with a water storing capacity of 80 m^3.

A.2.iii. Reference flow:

DuroMaxx unit: one (1) storage tank, which is made of 181.85 kg of steel and 709.15 kg of HDPE. For the simplicity of the study, only these two materials of the unit have been studied. More information on this matter will be discussed in the following subsection *System Boundaries*. The calculations of the mass of each material are presented in the Appendix.

Weholite unit: one (1) storage tank, which is made of 2701 kg of HDPE. For the sake of the study, only HDPE, the main material of the unit, has been studied. More information on this matter will be discussed in the following subsection *System Boundaries*. The calculations of the mass of the material are presented in the Appendix.

A.2. iv. System boundaries

The current study looks at the two main materials of the storage tank. Therefore, the system boundaries will be explained for each material.

HDPE:

The team based its analysis on the study of Du Fei et al. (Du, Woods, Kang, Lansey, & Arnold, 2013), in their publication entitled 'Life Cycle Analysis for Water and Waste Water Pipe Materials.' In this study, the group only focused on the Global Warning Potential (GWP) aspect of the LCA. Hence, the team will only present results on this category. The phases observed for the LCA were the production, transport, installation, use and recovery/disposal. Production and installation were used as is for this study. Transport was modified by the team to better represent the travel distance from each manufacturer to the city of Montreal, where the installation will take place.

Based on the carbon dioxide equivalent calculations done in the study (Du et al., 2013), a weight for the transportation fraction of the product based on 1 kilogram of HDPE was found to be 7.9457 * 10^{-2} kg CO_2 per kg of HDPE. This value was then normalized to a basis per kilometer of distance traveled during shipment, again taken from the study to be 322 km. The normalized factor was taken to be identical for both tanks, effectively incorporating the steel fraction of DuroMaxx into the kg of HDPE used as a measure.

Table V-1: Transportation calculation summary for Weholite and DuroMaxx (Soleno, 2018b)

Product	Closest Municipality from Production	Distance from Montreal (km)	Normalized factor (kg CO_2/ kg HDPE) /km	Final CO_2 (kg CO_2/ kg HDPE)
Weholite	Huntsville, Ontario	590	24.676 * 10^{-5}	0.1456
DuroMaxx	Montgomery, Alabama	2230	24.676 * 10^{-5}	0.5503

The use was discarded from Du Fei et al.'s study since it is dependent on the water flow and the topography of the terrain. Therefore, it is not included in this study either. This can also be justified by the fact that the use will be the same for each tank: same amount of water coming and coming out. Finally, Du Fei et al. assumed the pipe will stay in the ground after its useful life. Hence, no analysis has been done on this last phase. For the scope of the study, the team will also omit the last phase. However, recycling HDPE is possible and will be implemented at the end of the useful life of the chosen tank.

Steel:

The data for the steel comes from the study published by World Steel Association entitled 'Life Cycle Inventory Study.'

In order to be consistent with the data for the HDPE material and to be able to appropriately compare the results, the team will use the cradle-to-gate GWP results. Cradle-to-gate includes the beginning of the life of the product (extraction of raw material) to the moment when the product is finished and ready to use. It does not include the transportation from the site of product to the site of use. Therefore, as the transport phase is not included in this study, the team will approximate

the kg of CO2 from the transportation phase by using the distance between the manufacturing plant of Duromaxx and the city of Montreal (assume steelwork is next to the HDPE plant).
Recycling is omitted here to be consistent but will be perform at the end of the useful life of the Duromaxx tank (the Weholite tank does not contain any steel).

B. Life cycle inventory analysis

As mentioned previously, the current study uses data from other studies to give approximate results for the two tanks under observation. The following section will explain how data from HDPE and Steel studies was converted to represent our situation.

B.1. HDPE
The study 'Life Cycle Analysis for Water and Waste Water Pipe Materials' used 12-inch diameter HDPE pipes to conduct their analysis. Since the unit was per kilometer of pipe, the team first found the volume of HDPE used to manufacture a 1 km pipe and then its mass by using the density. Once the mass per kilogram of HDPE was found, the team converted the results of the production and installation phases of Du Fei et al. which were in Kg CO2 per km to kg CO2 per kg of HDPE (Du et al., 2013). For the transport phase, refer to table V-1. The last step was to multiply the factor by the mass of HDPE per unit in order to find the GWP of the HDPE for each unit.

HDPE GWP Conversion from length of 12-in pipe to mass in kg

Inside diameter: 30,5 cm
Inside radius r_i=15,25 cm
Outside diameter: 33,55 cm.
Outside radius r_o=16,775 cm.

Area of the pipe

$$A_{pipe} = A_o - A_i = \pi r_o^2 - \pi r_i^2 = \pi\left(r_o^2 - r_i^2\right) = \pi\,(16{,}775cm^2 - 15{,}25cm^2)$$

$$A_{pipe} = 153{,}43\ cm^2 = 0{,}01543m^2$$

Per km

$$Volume\ per\ km = 0{,}01543m^2 * 1000\ m/km = 15{,}43m^3/km$$

$$Mass\ per\ km = vol\ per\ km * density = 15,43\frac{m^3}{km} * 138{,}66\frac{kg}{m^3} = 2139{,}52\ kg/km$$

According to table 5-2

$$Production\ phase = \frac{215 * 10^3\frac{KgCO_2}{km}}{2139{,}52\frac{kg}{km}} = 100{,}50\frac{KgCO_2}{kg}$$

$$Installation\ phase = \frac{2{,}81\ * 10^3\,\frac{KgCO_2}{km}}{2139{,}52\,\frac{kg}{km}} = 1.31\,\frac{KgCO_2}{kg}$$

C. Life cycle impact assessment

The table shows the results of Global Warming Potential per unit.

Global Warming Potential (GWP) represents the impact on climate change per unit. In other words, it is a reflection of the greenhouse gases release per unit throughout their observed life and their potential adverse effect on global warming. Although not mentioned in Du Fei et al. study, it is usually based on 100-year time scale (which is assumed here) (D. M. o. t. Environment, 2005).

Table V-2. Total Global Warming Potential (GWP) per unit.

	HDPE						Steel			Total
Product	Production (kg CO_2 /kg_{HDPE})	Installation (kg CO_2 /kg_{HDPE})	Transport (kg CO_2 /kg_{HDPE})	Total of 3 phases (kg CO_2 /kg_{HDPE})	Mass (Kg /unit)	GWP HDPE	Cradle to gate & transp. (kg CO_2 /kg_{steel})	Mass (kg/ unit)	GWP Steel	kg CO_2 /unit
Duromax x	100.4898	1.31337	0.5503	102.35	709,15	72 584	3,25	181.85	591	73 175
Weholite	100.4898	1.31337	0.1456	101.95	2701	275 364	0	0	0	275 364

D. Life cycle interpretation

From the results displayed on table X, it is easy to notice that HDPE plays a large role in the GWP compared to steel, the other material used in the tank fabrication. Therefore, the Weholite tank, which is only made of HDPE and uses a bigger volume of it to conserve its structural integrity, poses a greater threat to global warming than its opponent the Duromaxx tank. Indeed, the Weholite as a GWP more than three times the potential of the Duromaxx tank.

From the table, it is also noticeable that the phase having the biggest impact is the production phase.

E. Conclusion and recommendations

E.1. Study limitations

This study was highly limited and is only provided to give a preliminary estimate of the GWP of the two tanks using available data. The main limitations are discussed in this section.

In a first place, the study only observes one LCA category, the Global Warming Potential. Usually, a LCA will observed the products under many categories, such as eutrophication, acidification potential, eutrophication potential and others, and will compare each products using different categories. Using only one category gives a limited overview of the overall environmental impacts and could omit other important environmental considerations.
In a second place, not all life phases were observed during this study.
In a third place, many assumptions were made to simplify the LCA, but appropriate information rather than assumptions could change the results. For example, the team assumed that the production phase was the same for both tanks. However, they might be made differently even if they are made from the same material. Since the production phase it the most GWP generating phase, it could significantly change the results if they production differs for the two models.

E.2. Overall conclusion

From the study, the Duromaxx tank has the lowest global warming potential.

E.3. Opportunities for improving

At this study showed, more information is needed in the literature to give environmental information on water storage tank.

VI. Multi-Criteria Analysis (MCA)

Economical and financial analysis are great tools to evaluate a project and different methods exist to perform such evaluations. The storage tank to be chosen will be used to implement the vision of sustainable buildings, and can therefore be considered as a public project since it will not generate profits. By its nature, this project cannot be evaluate by the traditional methods such as the payback method (PM), return on investment (ROI) or the net present value (NPV), for example. Therefore, the Multi-Criteria Analysis (MCA) will be used. This method can take into consideration non-monetary parameters, such as the global warming potential and the travelled distance, and compare these parameters to evaluate different projects and find the optimal solution based on the weights associated with each parameters. This section will present the MCA on the two tanks and determine the optimal tank that should be selected for implementation.
The four chosen parameters chosen to conduct this analysis are the cost of the tank (which includes the delivery of the tank), the volume to be excatated, the Global Warming Potential from the previous section, and the delivery distance (from production plant to the MSE building). Is it to be noted that only one monetary parameter was included in this analysis for two reasons. The first reason being that no profits are generated from the use of the tank. The second being that the other

sources of cost related to each tank, such as the installation and the maintenance, do not have pricing information. The team also assume that such actions would have a similar cost for each tank, which would not provide significant differences between the two tanks.

Observed Parameters and associated values

Table VI-1. Observed Parameters and Associated Values.

Option	Cost (CAD)	Volume (m3)	GWP (kg CO2)	Distance (km)
Duromaxx	69 500	196.97	73 075	2230
Weholite	103 600	214.03	275 364	590

A multi-criteria analysis consists of four major steps: 1) cost to benefits conversion, 2) normalization, 3) Weighting, and 4) Scoring. The steps will be explained and the additional tables used to realized this analysis can be find in appendix XB.

Step 1: Costs to benefits conversion.

In order to compare parameters that are presented in different units, the first step is to convert the cost parameters to benefits. Here, a cost value is defined when a lower value is deemed desirable and a high value is undesirable. One the opposite, a benefit value is when the highest value is desirable. This step is done by taking the inverse of each cost value. It is to be noted that all parameters (cost, volume, GWP, and distance) are cost parameters, therefore all value will be converted.

Step 2: Normalization

The values of each option for each parameter is then normalized. In this case, linear normalization was perform. This step allows the comparison of the options within each parameter.

Step 3: Weighting.

The MCA is dependent on the important attributed to each parameter. In this analysis, the ranking method was used and parameters were ranked as follow (most to least important):

1. Cost;
2. GWP;
3. Distance travelled;
4. Excavated volume.

The reasoning behind this ranking is the following: because we are performing an economical analysis, the cost of the project is the most important factor. Then, the GWP is placed second since the environmental impact of a product also plays a crucial part in the success of and LBC project.

The distance travelled follow the GWP since the LBC certification imposes certain limit on the travelled distance. Finally the excavated volume was ranked last since excavation will also be performed for the foundations.

Step 4: Scoring.
The final step combines the elements of the three previous steps and association a value to each option. The scoring method used here is the TOPSIS-method and the highest value is therefore the preferred option. Results are shown in the table below.

Table VI-2. MCA results of the two tank options using the TOPSIS-method.

Option	Results
Duromaxx	0.4415
Weholite	0.4297

Conclusion
The MCA compared four parameters from the two options given by Soleno. According to the rank chosen and the TOPSIS-method for scoring, the MCA confirmed the choice of the Duromaxx tank for this project.

VII. Design Considerations and Recommendations

A. Environmental

Steel reinforced high-density polyethylene is a relatively new material, with a lot of potential in water distribution and storage systems. To understand its environmental risks and compare them with a material made of high-density polyethylene alone, a life cycle analysis was suggested. Direct contact with the distributing company affirmed that manufacturers have yet to take steps towards documenting their fabrication process in terms of environmental impact guidelines, however the brochure of the desired product (Soleno, 2018b), DuroMaxx, shows that they take sustainability in consideration in their design and materials. Indeed, their high strength and durable products are advertised as water management strategies that can be used in LEED building certification. Although their examples of applications mostly relate to stormwater and drainage, the design can be used for collection. High quality material that is backed up by previous literature done on HDPE and SRPE (Soleno, 2018a), combined with water treatment systems placed before and after the tank that will guarantee potable drinking water quality work together in giving the team confidence that the SRPE product currently on the market is safe to use in the McGill School of Environment's new drinking water system. The lack of available data from manufacturers and distributors oriented the team towards existing literature to estimate approximate results. Again, the accessible works hardly ever combined steel reinforced materials with high density polyethylene. Most of the research was found to be on high density polyethylene alone and on comparisons of steel with lighter materials in various industries. Limited by equipment (adapted software) and time constraints, the Life Cycle Analysis performed here focuses on comparing two existing products.

The Living Building Challenge is based on strict guidelines, created to improve on existing sustainability construction certifications. By its nature, an LBC-certified building should push the standards for new construction and renovations in its neighborhood as well as improve living conditions for its inhabitants. In the case of the water petal, minimizing impact on the landscape and reducing the water demand are the main goals. Whether by removing reliance on city infrastructure and therefore increasing resilience or using rainwater that would otherwise be removed towards a stormwater management facility, the new McGill School of Environment will be the first building on McGill University's downtown campus to be LBC certified.

Along with these benefits, some non-negligible concerns arise, especially in terms of material selection. The life cycle analysis of steel reinforced polyethylene and high-density polyethylene included in this report aims to set a baseline for future applications of SRPE. It must be noted that plastics, however durable and whatever their purpose, are still for the most part sourced from fossil fuels. Including recycling as an end of life strategy for both the high-density polyethylene and the steel, thanks to Soleno Recycling's position as biggest recycling company of HDPE in Quebec (Soleno, 2018b), has significantly improved the impact of these materials by giving them future uses. The virgin material sourced in the United States still contributes to other environmental impacts through extraction, manufacturing and transport that could not be represented here.

B. Social

The number of stakeholders involved in the McGill School of Environment renovations project is high, in part due to McGill's status as a public institution. The innovative designs and management changes involved with its use are the pioneers in a transition towards sustainable buildings at McGill. As a meeting place for faculty, students and professionals, these people deserve to be represented in the discussion. For many of them, it is their first exposure to the Living Building Challenge and open mindedness is therefore required to make this project possible. Still in its first stages, this project will serve to make aware contractors, engineers and decision-makers alike. Since the beginning, the MSE renovation was founded on open communication between client and student teams working on the system's components, encouraging regular updates and an integrative design approach between the uptake, treatments and storm water management systems.

McGill is today situated on traditionally Indigenous territory and the renovations in the School of Environment have the potential to impact the broader community of downtown Montreal by leading the way towards a sustainable campus and neighborhood. One of the goals for the involvement of students in the projects was the creation of an educational pathway, starting with student's ideas based on cutting-edge research and reaching out to the surrounding population with tours and visits once the site is finished. This wholesome approach to building design will hopefully encourage more similar projects in the future.

C. Economic

The current project aims to achieve the LBC certification. Although using the municipal water is a cheaper alternative to rainwater collection and storage, it is not allowed by this environmental certification. Therefore, the cheaper alternative of municipal water was never considered as an option. As mentioned previously, the catchment component will be quite inexpensive since it will use the roof drain that is already in place. Some more pipe work will be needed to connect the roof drain to the filtration system and storage tank, but the preliminary state of the whole water network design do not provide enough information on the pipe work needed. Therefore, the economic analysis only considers the tank component at this stage.

From the discussion with the company Soleno, they suggested two tank models for this project, Duromaxx and Weholite tanks. The price of each model differed greatly from one another as a result of the type of material used to build each system. However, in order to have a more inclusive economic comparison between the two systems, the team performed an MCA. The parameters evaluated were the cost, the distance travelled between the factory and the destination, the GWP and the excavated volume needed for installation. The MCA confirmed the choice of the Duromaxx tank, which was the cheapest too. This result is also in line with the LCA, which indicates that the Duromaxx system is the best environmental and economical choice.

Conclusion

During the previous semester, the design team gathered information on the rainwater catchment and storage components through a literature review, examined the law articles at the municipal, provincial, and federal levels, find a tank size with a 100% reliability rate with the SARET model and determined the possible tank materials to be used for the underground tank.

This semester, for the second and last part of the design project, significant progress has been made in order to advance the project. First, a more comprehensive literature review on storage tanks and especially rainwater catchment was performed. The SARET models have been review and a tank size of 80 m^3 was confirmed. This sizing decision is a conservative one but ensures the availability of water to the building occupants through the years while considering climate change potential. The legislation component of the project has been observed with more depth, and now gives an outline of the regulatory process with the corresponding contact information. Throughout the semester, the team contacted many tank suppliers in order to find a suitable product for the project. The company Soleno suggested two interesting 80 m^3 models, the Duromaxx tank and the Weholite tank, which has been evaluating to select the more appropriate models in terms of environmental, economic and social considerations. Indeed, a preliminary life cycle analysis has been performed using available data and showed that the Duromaxx model had a lower global warming potential than the Weholite model. Furthermore, a multi-criteria analysis was performed as an economic analysis and also demonstrate that the Duromaxx was to best option.

The team can conclude that the progress made this semester can now be combined with the other components of the water petal for the renovation of the McGill School of Environment building. Although more decisions will need to be taken by the client and the rest of the stakeholders, the present report gives an appropriate approximation of the design needed for the rainwater and catchment component.

The design team hopes that the realization of the Living Building Challenge will create more awareness for green buildings and hence incite stakeholders to look at new alternatives for a more sustainable development of local communities.

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APPENDIX A.

Contact Information for the Regulatory process

Ville de Montréal
Service de l'eau
Section - Réglementation de la gestion de l'eau
reglementation_eau@ville.montreal.qc.ca
http://ville.montreal.qc.ca/portal/page?_pageid=6497,81367601&_dad=portal&_schema=PORTAL

McGill Building Services
Facilities Operations and Development
Project Management
https://www.mcgill.ca/facilities/management

Ville de Montréal - Arrondissement Ville-Marie
Direction de l'aménagement urbain et des services aux entreprises
800, Boulevard de Maisonneuve Est,
17e étage
ville.montreal.qc.ca/villemarie

APPENDIX B.

Precisions on the economic analysis (Multi-Criteria Analysis).
The MCA was performed by following the steps presented in the Lecture 5-21 by Omid Rouhani in the class CIVE 324 – Sustainable Project Management at McGill University during the term of Winter 2018.

Table B1: Observed Parameters and Associated Values.

Option	Cost	Volume	GWP	Distance
Duromaxx	69500	196,970466	73075	2230
Weholite	103600	214,02927	275364	590

Table B2: Converting cost to benefits.

Option	Cost	Volume	GWP	Distance
Duromaxx	1,43885E-05	0,0050769	1,36846E-05	0,00044843
Weholite	9,65251E-06	0,00467226	3,63156E-06	0,00169492

Where each value is the inverse of its corresponding value in Table B1.

Table B3: Normalization.

Higest value of each column	1,43885E-05	0,0050769	1,36846E-05	0,00169492
Option	Cost	Volume	GWP	Distance
Duromaxx	1	1	1	0,26457399
Weholite	0,670849421	0,92029686	0,265376011	1

Linear normalization was performed. Each value was found by dividing the corresponding inverse value by the highest inverse value of each parameter.

Table B4: Weight

Ranks	1	4	2	3
1/rank	1	0,25	0,5	0,33333333
Wj	0,48	0,12	0,24	0,16
Option	Cost	Volume	GWP	Distance

The weight for each category were determined by the ranking method. W_j = (1/rank)/(sum of 1/rank).

Table B5:
Scoring TOPSIS

Option	Cost	Volume	GWP	Distance	Max value	Min value	Dp Value	Cp
Duromaxx	0,48	0,12	0,24	0,04233184	0,48	0,04233184		0,44148593
Weholite	0,322007722	0,11043562	0,063690243	0,16	0,32200772	0,06369024		0,42969109
Dp+ Duromaxx	0	0,1296	0,0576	0,19155342			0,61542946	
Dp- Duromaxx	0,19155342	0,00603234	0,039072702	0			0,48647555	
Dp+ Weholite	0	0,04476275	0,06672792	0,0262465			0,37112959	
Dp- Weholite	0,06672792	0,00218513	0	0,00927557			0,27962228	

Where:

$$D_p^+ = \sqrt{\sum_{j=1}^{n}(x_{pj} - Max\ value)^2}$$

$$D_p^- = \sqrt{\sum_{j=1}^{n}(x_{pj} - Min\ value)^2}$$

$$C_p = \frac{D_p^-}{D_p^+}$$

Where
P= row of option n
J= parameter j