Final Design Report

Green Retrofit of a Church Parking Lot in Verdun

BREE 495 - Engineering Design 3
Professor Grant Clark

Blake Andrew Bissonnette – 260233046
Ulysse Blau – 260538147
Nathalie Buzaglo – 260396944
Jinhao Dong – 260483146

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Green Retrofit of a Parking Lot in Verdun, Québec

Abstract

The St. Willibrord Parish owns a parking lot that is located next to the St. Willibrord Church, in Verdun, Québec. Due to a lack of maintenance and a relatively old age, the parking lot needs to be retrofitted. Over the last two semesters, assessments were carried out based on the client and community needs, similar case studies, and identifying more sustainable technologies. These were compiled to deliver a meaningful design option for a future retrofit. The proposition features a maximum number of parking spaces, a large canopy cover with a diversity of trees that are allowed to grow in uncompacted soil, and a maximum storage of water on site. The parking lot is designed to filter, store and slow down stormwater on and off site which in turn, decreases the pressures on the municipal stormwater system.

1. Introduction

The St. Willibrord Church owns a parking lot that is located next to it, in Verdun, Québec. The parking lot has reached the end of its useful life and is need of rehabilitation. The needs associated with the retrofitting of the parking lot include eliminating ponding, reducing the potential for frost heaving, and diminishing pollutant runoff. The team's goal is to create a sustainable drainage system for the parking lot that would also cater to the community. The team is constrained in three principal domains; administrative, design, and social. On the administrative side, the Church lacks any funding for the project to be completed thus fully relies on donations to complete the project. The Church also requires low maintenance to minimize further expenditure to keep the site in good condition. The parking lot is currently leased to the City of Verdun for $300.00/month. Due to maintenance requirements stipulated in the lease agreement, the church is responsible for repairs and maintenance, although these responsibilities are performed by the City. Since the Church does not want to lose the $300.00/month lease with the City through an overhaul of the current lot that would signal to the City that it is the Church's responsibility to maintain the site, the design had to be worked on without their involvement for the meantime.

ARUP, an engineering consulting firm, mandated a group of bioresource engineering students from McGill University to research and design a sustainable retrofit. During the Fall 2014 semester, information was gathered about the site through an infiltration test, vegetation identification and site measurements. The group surveyed the users of the parking lot to understand how the site was used and how it could be improved. Existing technologies were researched based on green retrofit case studies across North America. Two potential designs were compared to the existing scenario and to a conventional scenario using asphalt. The preferred solution was a design involving a swale running North to South down the center of the lot, channeling water from the parking to a bioretention cell (raingarden).

The swale design was worked on throughout the beginning of the Winter 2015 semester, through improvements and modelling. During parking simulation, the group realized that the swale was taking too much space and was preventing the cars from turning into parking spaces without hitting other parked cars. Therefore, it was decided to re-evaluate the design and determine a new model that contained more trees and permeable pavers for infiltration rather than a swale and raingarden.

2. Swale and Raingarden (Old) Design

2.1 Analysis and Specifications

The design features a vegetated swale and raingarden to channel and store water. Underneath these systems there is a drainage system to reduce the potential for overflow.

Swales are broad and shallow channels which are densely vegetated that are predominantly used alongside of roadways and appropriate for small drainage areas. The purpose of a swale is to store and convey runoff, as well as remove pollutants (SuDS, 2007). In parking lots, swales are used to direct the water to bioretention areas (EPA, 2008). Trees are planted in the swale in order to provide a canopy for the parking area, reducing the heat island effect.

The raingarden (also known as bioretention cells, bioretention basin and bioretention filters) collects, infiltrates and filters incoming water, while decreasing the water flow off-site (SuDS, 2007).

The drainage system consists of a perforated pipe running along the swale that directs percolated water towards the raingarden. The bioretention cell has an overflow mechanism where any overflow would be caught and drained into the sewer system.

Table 1. The ranked objectives of the retrofit and their basis for measurement

Objective	Basis for Measurement	Units
Lower discharge quantity offsite	Discharge of water to sewers	Liter; Cubic meter; per time
Cost effective	Design cost omitting funding for the project	Dollar
Maximize parking spaces	Number of spaces	Square meter
Low maintenance	Simplicity of upkeep	Dollar; hour
Increase green space	Area of plant coverage	Square meter
Decrease heat island effect	Material and plant selection	Watt per square meter
Increase discharge quality offsite	Removal of total suspended solids	ppm
Increase Lifetime	Material integrity	Year

According to the objectives listed in **Table 1**, the design was able to meet the following criteria:

- Lower discharge quantity offsite
- Increase discharge quality offsite
- Decrease heat island effect
- Increase of green space

However, this design did not fulfill the most important criteria: Optimization of parking spaces. This is demonstrated in the testing section.

2.2 Prototyping

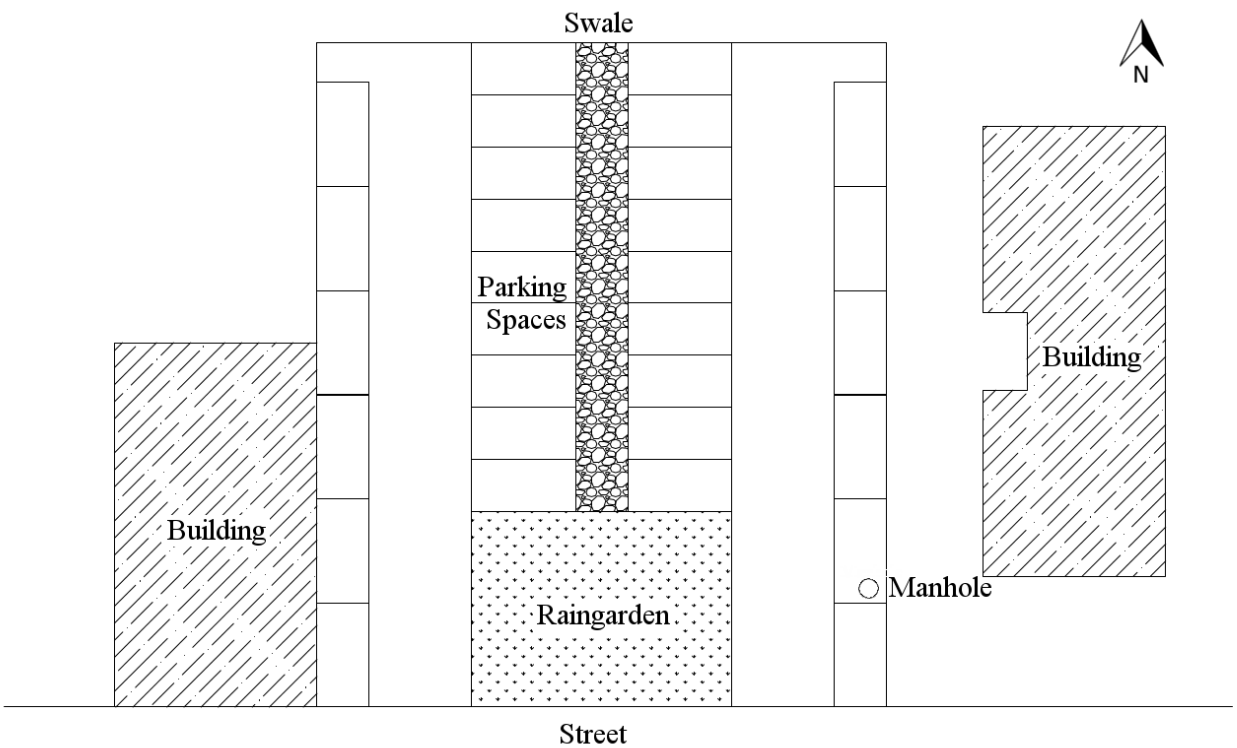

Figure 1, Original conceptual design; swale (dark hatch) and bioretention cell (dotted hatch).

An initial model of the parking lot was created with AutoCAD®. *Figure 1* depicts how the swale (dark hatch) and bioretention cell (dotted hatch) are oriented in the parking lot. The swale is used to collect water from the east and west side of the lot and convey the water South, to the raingarden. The raingarden has an underdrain that connects to the existing manhole and has an overflow that leads to the same area. The swale and bioretention cell are sized to the minimum dimensions to conserve as much space as possible in order to fulfill the initial criteria of maximizing parking space, while still abiding to LEED requirements of reducing runoff by 25% (SuDS, 2007; LEED, 2005)**.** The swale, shown in *figure 2*, is trapezoidal in shape, having a base width of 0.5 m, total top width of 2.9 m, depth of 0.4 m with a freeboard of 0.15 m and a length of 28.84 m (ASABE, 2013b). With no vegetation or check dams the swale would be able to hold close to 27 m^3 of water, with no consideration of infiltration. The bioretention cell's dimensions are 10.3 m x 10.3 m with a total surface area 106 m^2. The total water holding capacity of the bioretention cell is 67.6 m^3.

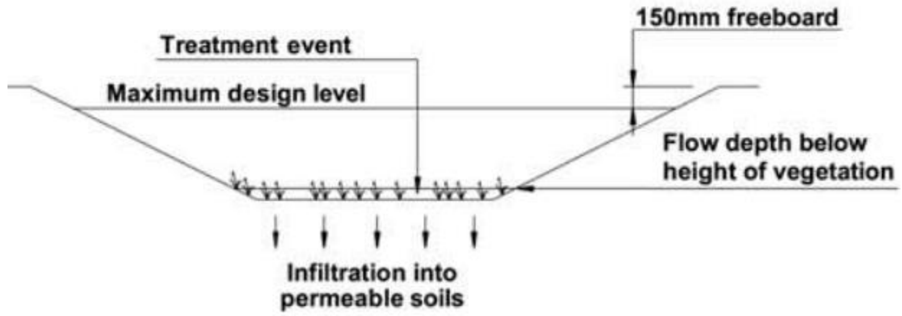

Figure 2, Typical dry swale cross section (SuDS, 2007).

2.3 Testing

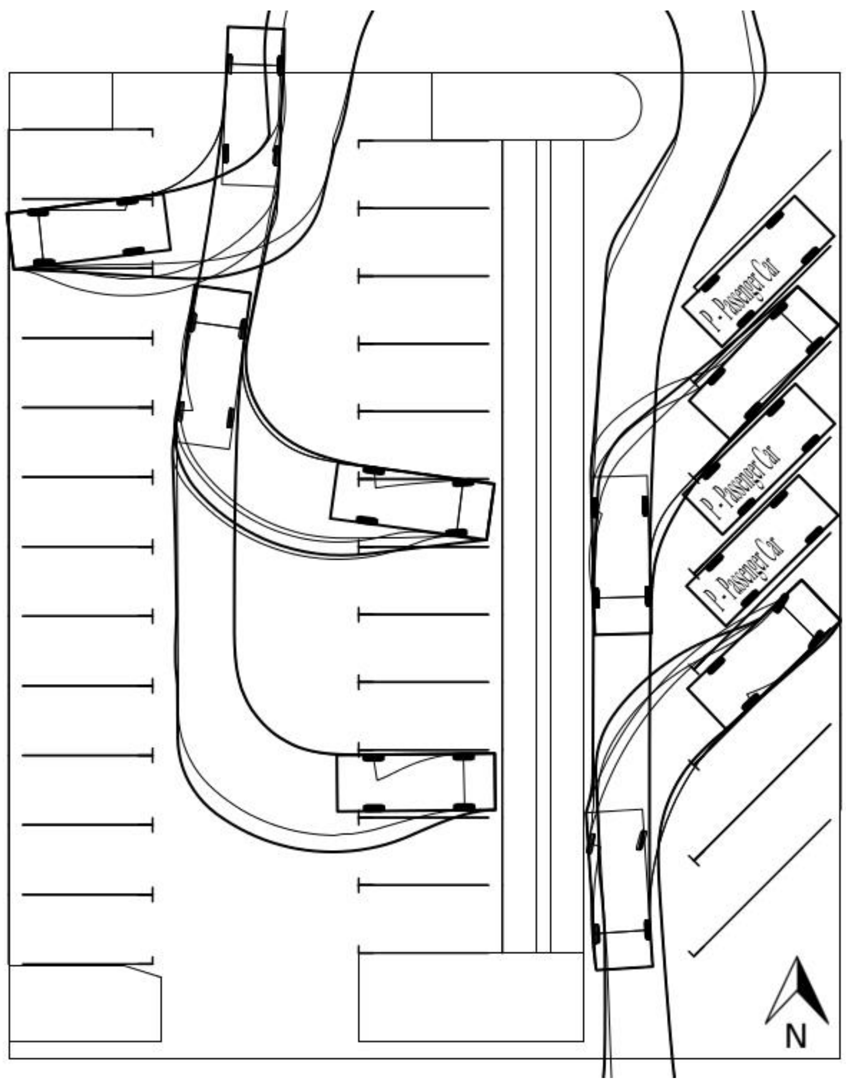

Figure 3, Vehicle Tracking of the design.

From the several parking orientations tested with Vehicle Tracking (AutoCAD® plug-in), many complications were encountered. Even though the minimum requirements for the parking spaces were taken from the MTQ standards, the simulated cars had difficulty maneuvering around the parking lot (MTQ, 2006). With the parking orientation in *Figure 3*, the vehicles were able to maneuver well at the cost of losing more parking spaces. The opposite was true with the 90 degree parking spaces, this orientation maximized the amount of spaces at the cost of the passenger cars hitting other parked cars. The swale in *Figure 3* is placed closer to the Eastern side to increase the space on the west side where the perpendicular parking spaces needed a wider alleyway. Upon consultation with the team's engineering mentor, internalizing traffic within the lot was very important to consider. If the City decided to remove the back alleyway for one reason or another, turning around would be far more difficult. Lastly, the initial thoughts were to place snow in the bioretention cell and swale, however the team's mentor said that the snow could jeopardize the system; increasing compaction and damage to the vegetation (DEP, 2012).

3. Silva Cell™ (New) Design

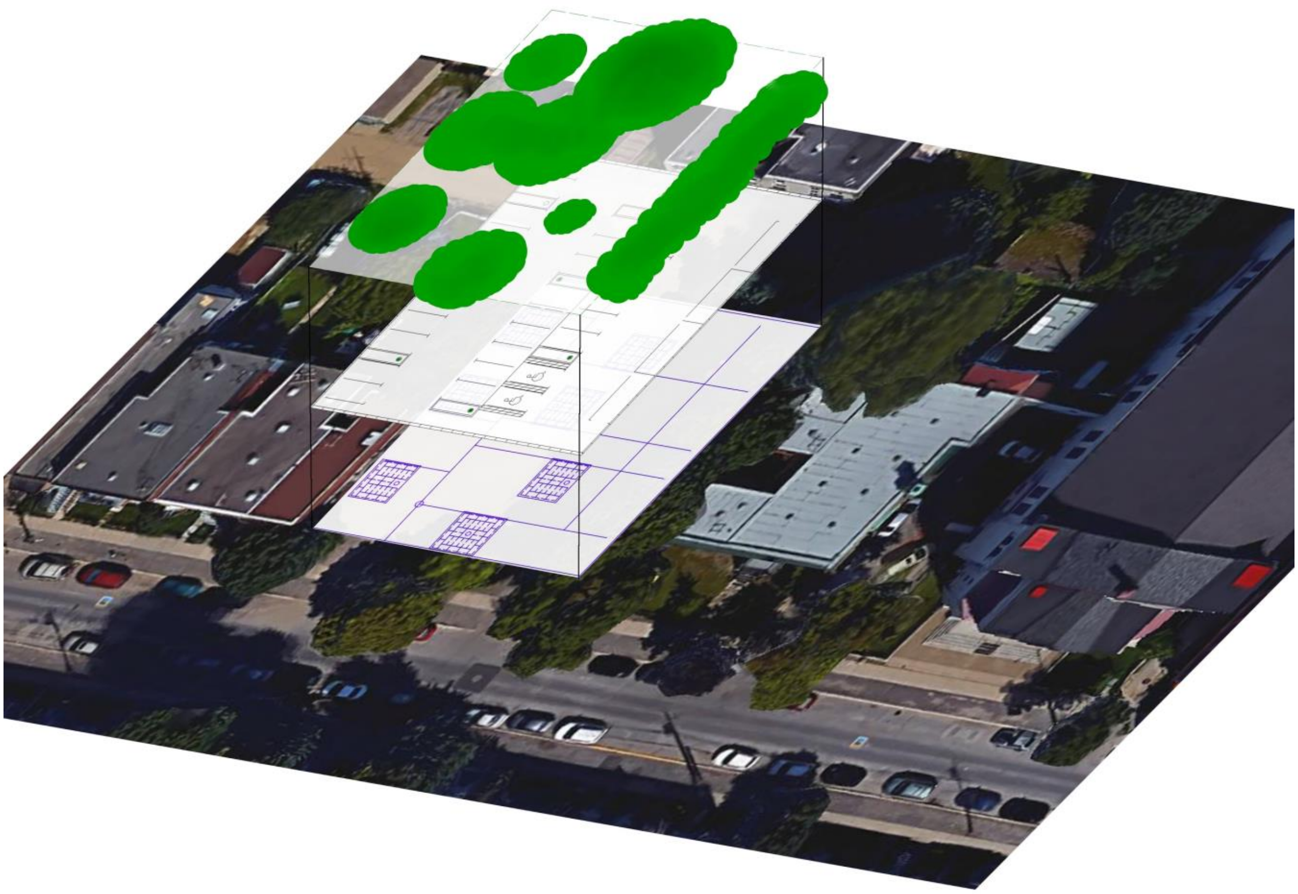

Figure 4, Three dimensional view of the design.

3.1 Analysis and Specifications

3.1.1 Description of the Design

The new design, shown in *Figure 4*, features permeable pavers and trees that provide areas for water to infiltrate the site, as well as being filtered by the trees. However, trees have great difficulty growing in compacted soil, which is usually the case in a parking lot or along city streets. A solution came from the use of Silva Cells™; a cage-like design that allows roots to grow within the cell, while being protected from compressive stresses. Surrounding the uncompacted soil in the Silva Cells™ is gravel and above lies the permeable pavers. The rainwater falling on these pavers infiltrate at high rates and moves through the subsurface layer containing either a gravel bed or the Silva Cells™. After being filtered through, the water slowly flows to perforated pipes toward a manhole situated near the exit of the parking lot (South West side), eventually reaching the sewage system. A Hydrobrake is a device that allows only a certain amount of water to exit the manhole. It can be found in Appendix B. This mechanism allows the water to back-up into the subterranean storage basin, thus promoting water storage on site. The water not used by the trees are slowly released to the sewer system at a fixed flow rate to the sewage system. During very intense storms, if the constructed manhole, gravel and soil void space are saturated, overflow would reach the manhole in the South East side.

Table 2. Bill of Materials

Item No.	Part Name	Part Description	Quantity	Unit
1	Permeable pavers	96 units per pallet (6.4 m^2/pallet)	171	pallet
2	Silva Cells	1 unit = 0.3 m^3	558	unit
3	Silva Cell - Anchorage	6 per lower level Silva cell	1272	unit
4	Silva Cell - Root barrier	0.46 m x 0.61 m - 6 per tree pit	42	unit
5	Silva Cell - Geotextile	Type IV - 4.57 m x 109.8 m	640	m^2
6	Silva Cell - Soil	25 m^3 of soil per tree pit	175	m^3
7	Gravel - Permeable Pavers	ASTM No. 8 Joint fill	6.5	m^3
8		ASTM No. 8 Stone	48	m^3
9		ASTM No. 57 Stone	95.5	m^3
10		ASTM No. 2 Stone	1624	m^3
11	Gravel - Silva Cell	ASTM No. 8 Joint fill	1.5	m^3
12		ASTM No. 8 Stone	9.5	m^3
13		ASTM No. 57 Stone	19	m^3
14		ASTM No. 2 Stone	57	m^3
15	Geotextile	Type IV - 4.57 m x 109.8 m	6	roll
16	Trees	*Acer campestre*	1	unit
17		*Aesculus flava*	1	unit
18		*Gleditsia triacanthos var. inermis*	1	unit
19		*Malus x 'Snowdrift"*	1	unit
20		*Sophora japonica*	1	unit
21		*Ulmus parvifolia*	1	unit
22		*Zelkova serrata*	1	unit
23	Piping - Conveyance	150 mm x 3040 mm	72	unit
24	Pipe - Cross fitting	150 mm	3	unit
25	Pipe - Coupling fitting	150 mm	51	unit
26	Pipe - Tee fitting	150 mm	6	unit
27	Manhole	Precast manhole	1	unit
28	Manhole adapter	150 mm	2	unit
29	Hydrobrake	S Series	1	unit
30	Concrete Curb - Tree pit	5.1 m x 1.5 m	93.1	m
31	Concrete Curb - Perimeter	35 m x 32.7 m	135.2	m

The Bill of Materials in **Table 2**, lists all materials used in the project. The titled items are described in detail below.

3.1.1.1 Permeable Pavers & Curb Sections

The entire surface of the parking lot will be covered with permeable pavers. These pavers allow water to infiltrate through the joints, preventing ponding and runoff due to their infiltration rate of 10,000 mm/s (Techo Bloc, 2014). They also facilitate respiration, allowing air exchange to the soil and gravel layers. In order to prevent the pavers from moving, concrete curbs are installed around the perimeter of the parking lot and the tree pits. According to Techo-Bloc, a permeable paver company, utilizing the pavers provides an opportunity to obtain LEED Credits 5.1 and 5.2 (LEED, 2005). A typical section can be found in Appendix B.

3.1.1.2 Gravel

The gravel provides a foundation for the permeable pavers to rest on and acts as an infiltration basin. The coarser gravel is placed at the bottom of the profile leading up to a finer aggregate where the permeable pavers rest. The entire gravel layers will be underlain with a geotextile, which lies above the original soil at 1.95 m deep (Appendix B).The compacted gravel bed brings two main advantages. Firstly, it provides a strong sub-base for the permeable pavers and protects the parking lot against heaving due to the depth of the bed (BNQ, 2007). Secondly, the gravel bed has a void ratio of 30%, which will be used as water storage during heavy rain events (Bettes, 1996). This storage allows the parking lot to hold the equivalent of five times its area during a 1 in 100 year, 24 hour storm event.

3.1.1.3 Silva Cells™

Silva Cells™ are a patented, modular suspended system that provides a space that can be filled with soil creating a compaction-free environment for the roots to grow (*Figure 5*). It is generally used in urban areas. DeepRoot, the company manufacturing the Silva Cells™, suggests that for every square meter of canopy, the tree needs 2.2 m^3 of soil (Mike James, DeepRoot Green Infrastructure, personal communication, April 8th, 2015). A typical section can be found in Appendix B.

Figure 5, Silva Cell™ (DeepRoot, 2015).

3.1.1.4 Soil

The soil will fill in the Silva Cell™'s 92% void space (DeepRoot *et al*., 2014), providing a nutritive environment for trees to grow and can be considered an integral part of this design's operation. The soil fulfils many functions such as holding nutrients and organic matter for tree growth as well as sequestering pollutants and heavy metals in non-available forms. The soil can also filter and treat water (Brady & Weil, 2008).

In order for a young tree to grow in a healthy manner, a soil free of heavy metals is needed (Maryam Kargar, McGill University, personal communication, February 20th, 2015). To assess the soil quality on the site, many tests can be done to find the current chemical (nutrients, pH, trace metals, CEC values, and salts) and physical (soil texture, infiltration rate) characteristics of the soil. A phytotoxicity test could help in understanding which pollutants and heavy metals are already present in the current vegetation.

In the case of the St. Willibrord parking lot, the underlying soil could not be tested for infiltration and soil texture classification as digging the asphalt was required and not allowed. When the soil is tested, if its contents are not suitable for plant growth, it should be replaced. The original soil can be dumped in a landfill, at a steep cost of \$300.00/ft^3 or remediated for a cost ranging between \$50.00 to \$100.00/ft^3 depending upon the level of contamination (Technician, Sanexen, personal communication, March 27th, 2015). The soil mix should be made of 45% sand, 45% topsoil and 10% attributed to organics (Mike James, DeepRoot Green Infrastructure, personal communication, April 8th, 2015). If the City of Montréal is involved with this project, a soil donation could be awarded to the Church (e.g. the Ville-Marie Station) (Maryam Kargar, McGill University, personal communication, February 20th, 2015). If not, many companies such as Jardin-Jasmin sells planting mix for about \$52.00/m^3 (Jardin Jasmin, 2015).

3.1.1.5 Trees

The trees are an integral element in this design. A study showed that trees eight years after being planted have the capacity to evapotranspire all of the runoff from a 5 mm storm event over three days. When these same trees reach maturity, this value increases to 13 mm (Marritz, 2014). Trees cool the area through evapotranspiration and shade made by their canopy. LEED Credit 7.1 requires the site to provide a minimum coverage of 50% of the hardscape including shade and low albedo pavers (LEED, 2005) in order to reduce the heat island effect. Trees act as windbreaks and provide shelter for wildlife, while improving the surrounding air quality by intercepting pollutants and producing oxygen through photosynthesis (Bolund & Hunhammar, 1999). LEED Credit 5.1 and 5.2 are applicable in this project as there will be a restoration and protection of habitat (e.g. birds) initiative providing at least 20% vegetated open space within the project's boundaries (LEED, 2005). Another advantage of using trees is their ability to reduce noise pollution and increase the site's aesthetic value (Bolund & Hunhammar, 1999). They filter the air and are proven to bring health benefits to the community (ACTrees, 2011; Bolund & Hunhammar, 1999). The root system hosts a multitude of ecosystem services including filtration of percolated water while providing a medium for sorption of particulates on soil and organic matter surfaces.

The seven chosen trees, represented in **Table 3**, are planted in island-like tree pits to maximize canopy cover and address LEED Credits 5.1, 5.2 and 7.1 (LEED, 2005). Each tree is growing in its own Silva Cell™ system in order to reduce competition between roots. Seven different trees were chosen to tie diversity with the foundations of the church community, explained in the results section. The trees are placed in accordance to their light requirements and were chosen according to their canopy cover and foliage density to maximize shade. All the trees are yellow in the fall except for the Chinese Elm and Japanese Zelkova which have purple and red tinted foliage, respectively. The seven tree species were selected for their salt tolerance, hardiness and ability to handle urban pressures.

Table 3. Characteristics of the seven tree species chosen, based on their average height, crown spread, preferability of soil, environmental/anthropogenic tolerances and lighting requirements.

Tree species	Average Height	Crown Spread	Foliage	Soil Tolerances	Tolerances	Light requirement
Acer campestre Hedge Maple	9 to 10.5 m	9 to 10.5 m	Dense	clay; loam; sand; acidic; alkaline; well-drained	Drought tolerance: High Aerosol salt tolerance: Moderate Soil salt tolerance: Moderate	part shade/part sun; full sun
Aesculus flava Yellow Buckeye	18 to 23 m	7.5 to 10.5 m	Dense	clay; loam; sand; acidic; well-drained	Drought tolerance: Moderate Aerosol salt tolerance: Moderate	full sun
Gleditsia triacanthos var. *inermis* Thornless Honeylocust	15 to 22 m	10.5 to 15 m	Open	clay; loam; sand; acidic; occasionally wet; alkaline; well-drained	Drought tolerance: High Aerosol salt tolerance: High Soil salt tolerance: Good	part shade/part sun; full sun
Malus x 'Snowdrift' Snowdrift Crabapple	4.5 to 7.5 m	4.5 to 7.5 m	Dense	clay; loam; sand; acidic; occasionally wet; alkaline; well-drained	Drought tolerance: Moderate Aerosol salt tolerance: Moderate Soil salt tolerance: Moderate	full sun
Sophora japonica Scholar Tree	12 to 21 m	12 to 21m	Moderate	clay; loam; sand; acidic; occasionally wet; alkaline; well-drained	Drought tolerance: High Aerosol salt tolerance: Moderate	full sun
Ulmus parvifolia Chinese Elm	12 to 15 m	10.5 to 15 m	Moderate	clay; loam; sand; acidic; occasionally wet; alkaline; well-drained	Drought tolerance: High Aerosol salt tolerance: Moderate	part shade/part sun; full sun
Zelkova serrata Japanese Zelkova	16.5 to 24 m	15 to 24 m	Moderate	clay; loam; sand; acidic; occasionally wet; slightly alkaline; well-drained	Drought tolerance: High Aerosol salt tolerance: Moderate	full sun

(University of Florida, 2013)

3.1.1.6 Drainage System

The drainage system is designed to allow excess water which percolates through the system to flow off-site at a controlled, constant rate. It provides storage during more intense rain events and in turn irrigates the trees in the landscape. The tree pits are directly connected to 150 mm, Schedule 80 PVC perforated pipe laterals which attach to a main line and a collector (Appendix B). The perforations allow water to move freely into the drainage system. During a storm event, the rain falls on the permeable pavers and infiltrates through the joints, it then percolates through the subbase and subgrade. The water collected, flows towards a manhole situated at the South West area of the parking lot (Appendix B). This manhole will be prefabricated and placed in the site when the drainage lines are being laid. Within the manhole, a Hydrobrake controls the discharge rate leading to the sewer system (Appendix B). In the case for intense rain events, the Hydrobrake permits the system to back-up into the pipes where the gravel and soil media act as temporary sub-terranean detention basins (Hydro International, 2015). In the case where gravel and soil voids are filled with water, the rain falling on the parking lot will be directed towards a pre-existing manhole in the South East corner; acting as an overflow.

3.1.1.7 Geotextile

A geotextile is a mesh of plastic material, either woven or non-woven. In the present case, it is used to prevent fine materials from being transported into the drainage system and allowing only partial percolation into the original sub-grade. It also acts as a soil separator form the aggregate base (Techo-Bloc, 2010).

3.1.2 Calculations

In order to precisely size different parts of the design, calculations were performed using industrialized norms.

3.1.2.1 Impermeability

The permeable paver surface has a degree of impermeability, apart from the extremely quick infiltration rate. Using site and climatic information, the formula $q = CiA$ is used, where i is the intensity of the rainfall event, A is the drainage area and C is the runoff coefficient which is directly proportional to the surface characteristics (ASABE, 2013a). **Table 4** is a compilation of the existing to proposed site characteristics. The original asphalt surface provides high impermeability, where permeable pavers are substantially lower. According to the ICPI (2008), the runoff coefficient of permeable pavers ranges from 0% to 30%. An initial runoff coefficient of 30% is chosen to estimate the worst case scenario. The corrected impermeable area is then calculated to determine how much area is actually impermeable. With this value, the site's total runoff coefficient can be determined (ASABE, 2013a). The above calculation does not take into account infiltration. From the initial briefing, LEED credits are of interest for this project. For LEED Credit 6.1, the project fall under case 2; *existing imperviousness is greater than 50%*, which can be seen as the corrected runoff coefficient, C, in **Table 4** (LEED, 2005). Intensity - Duration - Frequency curves from the Pierre-Elliott Trudeau airport in Montréal, found in *Figure 11* in Appendix A, were used to model the amount of water the site is currently receiving (Environment Canada, 2012). The main criterion for LEED Credit 6.1 is to model the site with a 1 in 2 year, 24 hour storm event, though consultation with the mentor and standards increased that storm event to a 1 in 10 and 1 in 25 year, 24 hour storm event due to climate change uncertainty (By-law 01-168, 2001; see *Figure 9* in Appendix A). To achieve LEED Credit 6.1, the project should achieve a reduction of the discharge volume off site by at least 25% in order to acquire the certification (LEED, 2005). All of the storm events are in Appendix A; *Figure 10*, **Tables 8**, **9**, **10**, and **11**.

Table 4. Runoff Coefficients based on surface characteristics.

	Existing			Proposed		
	A (m^2)	C_{ini}	A_{corr} (m^2)	A (m^2)	C_{ini}	A_{corr} (m^2)
A_{total}	1144.5	-	-	1144.5	-	-
$A_{permeable}$	38.865	0.3	11.6595	1144.5	0.3	343.35
$A_{impermeable}$	1105.635	0.85	939.78975	0	0	0
$A_{corr,\ imp}$			**951.44925**			**343.35**
Runoff Coefficient, C		C_{corr}	**0.831323067**		C_{corr}	**0.3**

3.1.2.2 Infiltration

Apart from the above calculations, the capacity of the system had to be accounted for. The site is modelled as a large trench under two initial assumptions; the excavated site is overlain with uniformly sized gravel and there are no Silva Cells™ placed in the site (Bettes, 1996). These simplified calculations give a rough estimate of the site's capability over a wide range of storm events. To carry out the computations, four more assumptions are required to simplify the procedure. A safety factor of 5 is used to assume no damage or any inconveniences due to flooding; clay is assumed to be the original soil texture resulting in an infiltration rate of 1.2 mm/h; the porosity of the gravel is based on uniform fill of 30%; the entire area of 1144.7 m^2 is to be assumed as the drainage area (Bettes, 1996). For three-dimensional systems, the following hydraulic equations are able to determine the maximum depth of water in the system. This allows us to know how deep the gravel sub-base needs to be.

$$h_{max} = \left(\frac{A_b}{P} - \frac{i \cdot A_D}{P \cdot q}\right) \cdot \left(e^{-\left(\frac{P \cdot q \cdot D}{n \cdot A_b}\right)} - 1\right)$$

where,

A_D is the drainage area (m^2)
P is the perimeter (m)
i is the intensity of the storm event (m/h)
D is the storm event duration (h)
q is the infiltration rate of the original soil (m/h)
A_b is the area of the base (m^2)

The resulting depth of water ranges from 0.1 m to 0.3 m as the storm events increase in rarity and duration. The volume of water for these storm events range from 12 m^3 to 136 m^3 and required a storage depth of 0.03 m to 0.4 m. The storage space is considered to be the sub-base that the pavers are placed on. Based on the design, the gravel medium is actually 1.85 m in depth which provides a very large capacity to store water within the site.

The second part of the infiltration capacity is the time it takes to half-empty the water from the site. In the case of a slow infiltration rate, the site must have ample storage within the gravel basin so as to increase the water's residence time. To ensure that the system is capable of handling a rainfall event, the infiltration rate into the original soil should be affiliated to the half-empty storage time; taken as 24 hours (Bettes, 1996). The half-empty storage time is as follows,

$$t_{½} = \left(\frac{n \cdot A_b}{q \cdot P}\right) \cdot log_e\left(\frac{h_{max} + \frac{A_b}{P}}{0.5 \cdot h_{max} + \frac{A_b}{P}}\right)$$

The water depth increases as a function of the storm duration, frequency and intensity. The deeper the maximum water depth is, the more time it takes for the water to percolate through the original clay soil, providing no outflow to the municipal sewer system. Based on the maximum water depths given above, the $t_{1/2}$ ranges from 12.4 hours to 36.5 hours, where depths of 0.2 m and 0.3 m resulted in draining times greater than 24 hours. If the clay is to be assumed as semi-impermeable, where only partial infiltration is considered, the outflow of water from the system must be governed by an allowable discharge rate to the municipal sewer system which is 35 L/(s·ha) or 0.401 L/s (By-law 01-168, 2001). With the depth of water at 0.1 m, the system allows full infiltration to occur within 48 hours. For a depth of 0.2 m and 0.3 m, the permitted outflow are 0.016 L/s and 0.215 L/s, respectively, over 48 hours. Both of these flow rates are below By-law 01-168 standards. These flow rates account for infiltration of 0.382 L/s through the clay surface.

3.1.2.3 Water Quality

Since no water quality tests could have been performed, the data can only be assumed to be correlated to other sites that have permeable pavers with the same type of winter maintenance and climatic conditions. In accordance to LEED Credit 6.2, 90% of all stormwater intercepted must be treated to a minimum of 80% based on total suspended solids (LEED, 2005). Techo-Bloc (2014) states that the interlocking permeable pavers reduce total suspended solids by 81% and have installed these systems in winter conditions with no issues. Smith (2000) determined with monitored sites that removal rates of total suspended solids had a median of 95% based on infiltration trenches and porous pavements. ICPI (2008) states that the range of removal of total suspended solids is from 60 to 90%. Based on standardized values from industry it can be safely assumed that LEED Credit 6.2 will be acquired.

3.1.2.4 Silva Cell™ and Soil Volume Calculation

Each tree needs a minimum of space for its root to grow in order to survive, especially in an urban environment. The minimum volume advised by Dr. Pierre Jutras is 5 m^3 (Jutras, 2008). However, a volume of 18 m^3 should be prefered for better health (Jutras, 2008). As said previously, for every square meter of canopy, the tree needs 2.2 m^3 of soil (Mike James, DeepRoot Green Infrastructure, personal communication, April 8th, 2015). Well-spread root system brings stability to the tree and is directly correlated to nutrient and water assimilation. The final design features tree pits which offer a volume of 25 m^3, ensuring a longer life, high filtration efficiency and creating a more windfirm environment.

3.1.3 Objectives

The objectives shown in **Table 1**, that the design achieves, are listed below:

<u>Lower discharge quantity offsite:</u> The stormwater is stored in the soil and gravel media and absorbed by the tree roots, thus reducing the amount of water leaving the site. In order to satisfy the LEED 6.1 criteria, there must be a reduction in water quantity by 25%, however this objective was surpassed (LEED, 2005). With the Hydrobrake, the speed at which the water is released into the sewer system is controlled, causing a reduction in pressure on the current infrastructure, and thus pressure on its maintenance.

<u>Increase discharge quality offsite:</u> The creation of ecosystem zones contribute to the biodegradation of chemical pollutants, volatile organic compounds and the sequestration of heavy metals that are carried in rainwater and surface water. The roots and soil surfaces contributed to the above mentioned, as well as chelation of metal ions, adsorption of chemicals to organic matter and clay surfaces (Brady & Weil, 2008). With all mechanisms of remediation this leads to an increase in water quality discharged from the site.

Decrease heat island effect: The addition of canopy cover by the trees on site shade more than half of the parking area (51.27%), which allows for the certification of LEED Credit 7.1 (LEED, 2005). This lowers the ground and air temperatures in the immediate vicinity and reflects solar radiation from the leaf and paver surfaces (e.g. lighter in color).

Increase in green space: The addition of trees on site increases the green space of the area.

Maximize parking spaces: This design offers a maximum number of parking spaces, including two spots reserved for handicapped persons.

The objectives that the project is not able to meet were:

Cost effective: The major drawback of this design is the cost compared to the size of the area being retrofitted.

Low maintenance: The permeable pavers require bi-annual surface sweeping as well as broken pavers being replaced. The pipes need to be cleaned out every 10 years and the trees need to be pruned in order to have a desirable shape for parking areas. All of this contributes to a high maintenance cost.

The design has an average lifetime of 20 years and is therefore not a met or unmet objective (Smith, 2006).

3.2 Prototyping

The final orientation of the parking lot is very close to the current situation, although there are two handicap spots and internal laneway at the North end.

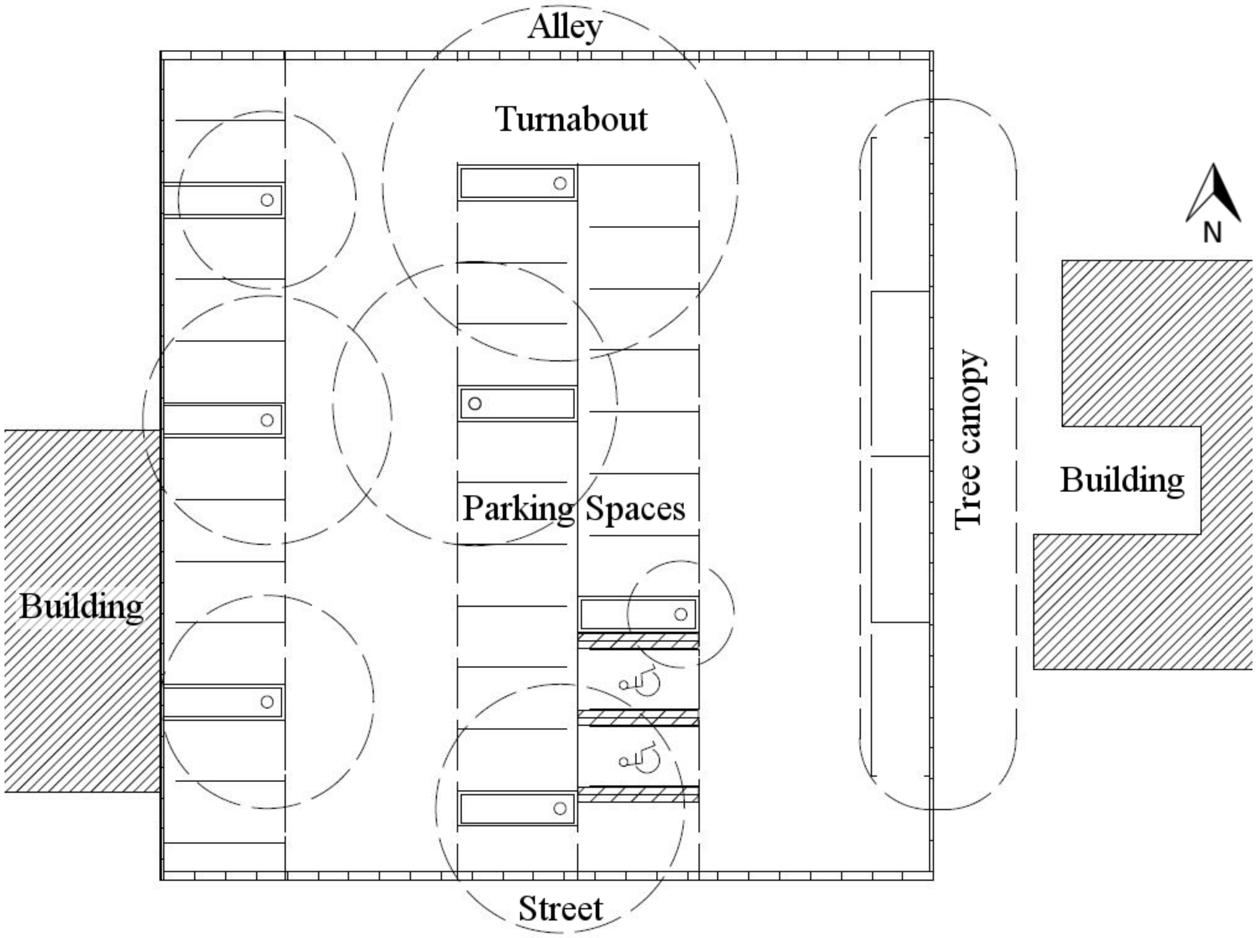

Figure 6, Final prototype of the design featuring permeable pavers, Silva Cells™, and trees.

Figure 6 is a depiction of the final prototype of the design which features both permeable pavers and Silva Cells™ to optimize runoff reduction. The four columns of parking spaces, account for 33 parking spots, including 2 handicapped spots in the middle-east column. Each perpendicular parking spot is 2.6 m wide and 5.1 m long, each parallel spot is 2.5 m wide and 6.5 m long, and each handicapped spot is 4 m wide and 5.1 m long (MTQ, 2006). As requested by the team's mentor, a turnabout is added at the north end of the parking lot. Adding handicapped parking spaces and an internal laneway resulted in the loss of 4 spaces, compared to the current 37 spaces.

The placement of seven trees is intended to maximize the canopy cover of the whole parking lot. Dotted circular lines in *Figure 6* show the canopy cover of the proposed trees and existing trees on the east side of the parking lot. Each tree pit is 1.2 m wide and has the same length as a parking space in order to fit them in between the parking spaces. There are concrete curbs around each tree pit, which add 0.15 m to the width. The curbs around the tree pits serve two purposes; they protects the tree pit from car bumpers and hold permeable pavers in place. The curbs around the perimeter of the parking lot hold the permeable pavers in place.

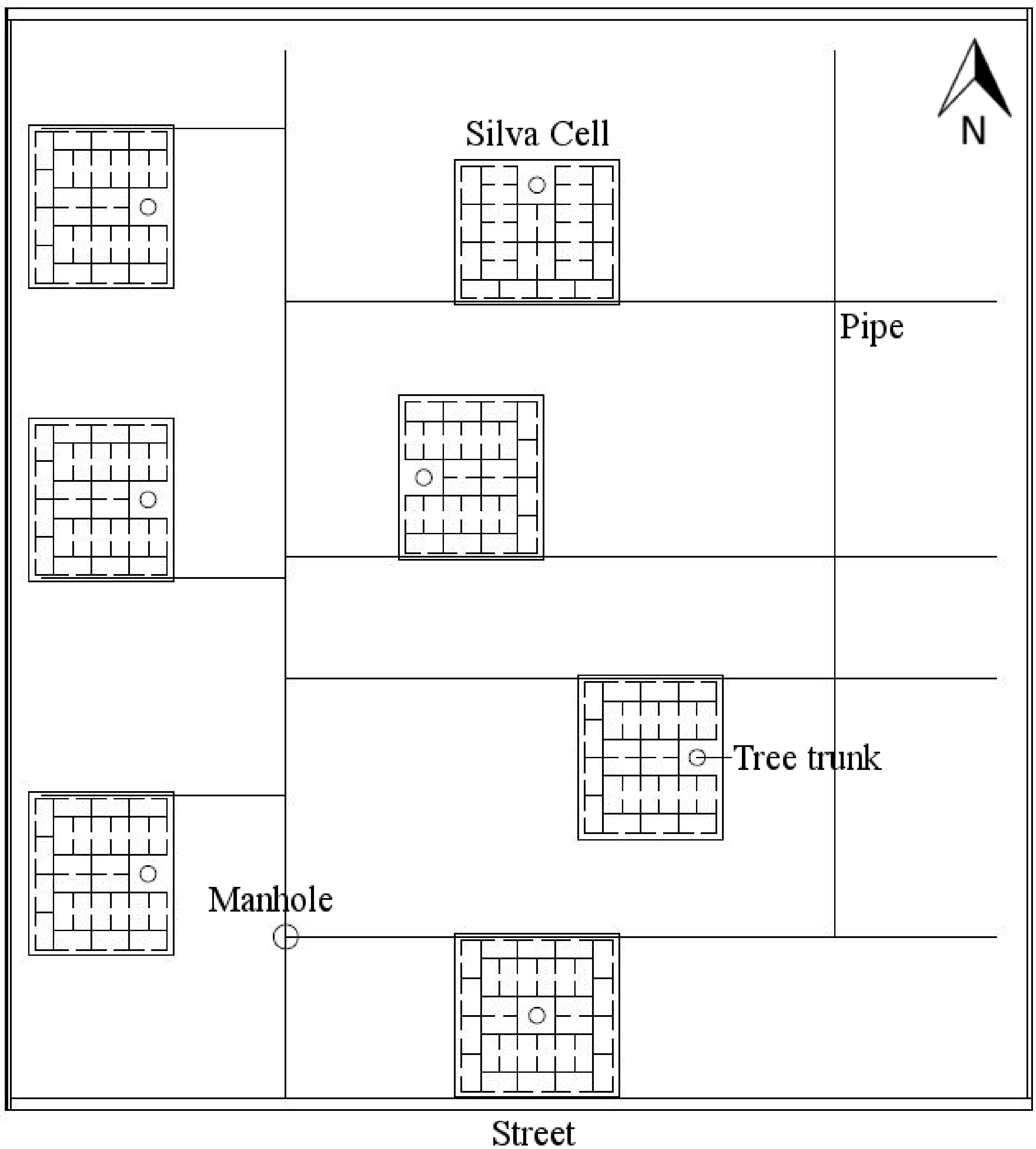

Figure 7, Silva Cell™ and pipe placement.

Each tree root ball is surrounded by Silva Cells™ to promote tree growth. An underdrain lies besides them. *Figure 7* illustrates the underground infrastructure. The Silva Cell™ structure is represented by enclosed squares and the pipelines is represented by solid straight lines. The whole parking lot will be excavated to the same depth and then filled with either Silva Cells™ or gravel layers. The Silva Cells™ cannot be placed under the alleyway as they are designed to withstand vertical loads and not dynamic loads (Mike James, DeepRoot Green Infrastructure, personal communication, April 8th, 2015). This results in two different tree pit designs. The one right above the street has Silva Cells™ surrounding all four sides because it is placed in the middle of the parking spots. The other tree pits only have Silva Cells™ on three sides of the tree. There is a depth of three Silva Cells™ in each tree pit. Each Silva Cell™ is 0.3 m high, 0.6 m wide and 1.2 m long. They are filled with a growing medium in order to allow for tree root growth, while also allowing the support of parked cars on the surface. Each Silva Cell™ on the bottom level is anchored into the existing soil with galvanized spikes. Permeable pavers and their beddings are placed on top of the top Silva Cell™ layer.

Permeable pavers allows water to infiltrate directly into the gravel media. To ensure their stability, they require three bedding layers beneath them. Every layer is made of differently sized gravel, the smallest being at the top and the coarsest at the bottom. The coarse gravel provides larger void space that maximizes water storage. A detailed section can be found in Appendix B. Each tree pit is wrapped with geotextile to prevent soil from entering adjacent gravel layers and jeopardizing the system's hydraulic conductivity.

Each tree pit has a perforated pipe acting as an underdrain that leads to a collector drain towards the manhole. The perforated pipes drain excess water coming from the tree pits and the gravel layers. Geotextiles are wrapped around the perforated pipes to prevent clogging. Every pipe is connected to the three main lines which are located on the South end of the parking lot and under the drive lanes, collecting stormwater from the individual tree pit underdrains and convey the water to a manhole placed in the South West corner of the parking lot. Two inlets inside the manhole collect water from the mainlines and an outlet discharges the water to the municipal sewer system. A Hydrobrake is located before the outlet and acts as a small vortex that allows a specific discharge rate (Hydro International, 2015). During an intense storm event, water flows into the manhole at a higher rate than at the exit, creating a backflow of water into the main line and the perforated pipes. Thus, the tree pits, gravel beds, pipes and the manhole are inter-connected and serve as one large water storage system. The water stored on-site will either infiltrate into the ground or slowly drain out to the municipal sewer system.

3.3 Testing

The layout of the parking spots was validated with Vehicle Tracking software. *Figures 12* and *13* in Appendix C shows that for standard car and parking space dimensions, the vehicles can maneuver without a problem (Dada & Furuya, 2010; MTQ, 2006).

Potential failures were examined in order to identify when and how they could occur. Four failure modes common to permeable paving systems and one failure mode specific to the Verdun area were identified during the planning and regulations, designing, construction and commissioning, and the operations and maintenance phases.

Proper organization throughout each of the above phases, with special attention to the construction phase, is required to ensure the permeable system operations in the long term. Improper sediment control during and immediately following construction can lead to siltation of the paving system (MPCA, 2013). Siltation is defined as the transportation of fine particulates by water, air or traffic that wash into the joints, base and subbase. This settlement of finer particles jeopardizes the infiltration capacity and decreases storage capacity (Smith, 2006). During the commissioning, the proper order of the works is critical for the immediate and long term performance of the system (MPCA, 2013).

The Lakeview Neighbourhood in Mississauga, Ontario provides a very detailed analysis of the failure modes with permeable pavers. This project was the first of its kind in this area so multi-departmental and public consultation were used at each design step. This allowed all of the stakeholders to be at the same level of understanding throughout the process. During the design phase, the concepts were reviewed by the municipal departments to determine the site's utilization, future maintenance and overall functionality (CVC, 2014). With respect to the design project, the engineering mentor briefly discussed that the City of Montréal and Verdun, utility companies, and the neighbourhood are all important to consider.

Another project similar to the St. Willibrord project is the IMAX retrofitted parking lot. During the IMAX's design phase, there were low-bearing capacity soils which required a high-strength geotextile to support the pavement (CVC, 2013). This is the same case with the St. Willibrord lot as the subgrade is clay. The Lakeview neighbourhood had several fences and driveways, which were targeted in the planning phase before any designs were undertaken (CVC, 2014). The St. Willibrord parking lot has an apartment building and residential lawn on the west side, sidewalk along the southern perimeter, municipal alleyway along the north and a fence line and tree line on the east. A critical concern for the project is excavating to a depth close to 2 m next to the apartment foundation, which will require careful planning prior to any construction. At the IMAX parking lot, designated snow storage areas were not sufficient enough which is important to consider as the St. Willibrord lot is small and snow storage is minimal, especially if the lot is full of vehicles. (CVC, 2013) During the winter of 2013, the mild weather caused snow to melt and the meltwater could not empty into the overflows due to slush and ice buildup, so meltwater ran off-site (CVC, 2013). The St. Willibrord parking lot will have snow stored in the same place as where it is currently; blocking the alleyway in the north east corner, and covering a few spots on the west side.

During the construction phase of the IMAX parking lot, the design had slight changes from the *as-designed* drawings and consultation with the City and the contractor allowed for diplomatic solutions for all parties to be attained. It was found that experienced workers with low impact development projects provides to be a sound resource for other contractors, client and other stakeholders. Incorrect material was delivered to the site, which was not used, so it is imperative to have construction supervision at all times. Utilities were major construction obstacles; power lines, telecommunications and water lines (CVC, 2014; CVC, 2013). The system must be created with two constraints; a larger washed stone sub-base to resist breakdown into fine particles and promoting larger pore spaces to transfer any sediments into the deeper regions of the profile; acquire uniformly sized gravel, providing a more constant infiltration rate (University of Guelph & Toronto and Region Conservation, 2010). On the St. Willibrord site, the only overhead constraint is a power line. Other constraints are mainly subterranean which include the subway system that runs underneath the southeastern corner of the lot, drainage pipe and tree roots on the east site and most importantly the state of the soil under the asphalt; there is no historical record of how the old church was dismantled and disposed of.

For operations and maintenance of the IMAX parking lot, snow removal caused damage to a curb section and the curb had to be replaced at the client's expense. Marking stakes were later used and the snow removal contractor was given specific areas to place the snow and other places to avoid (CVC, 2013). Contracts for the snow removal will explicitly stipulate to the contractors where the snow must be placed and areas to be avoided (CVC, 2013; Smith, 2006).

As for the flood risk in the Verdun area, the literature does not cover sewer main back-ups and how this affects permeable paver systems. The potential to carry debris and particles from the sewers back into the site and foul the gravel layers in reverse. This could cause surface flooding to occur as the permeable nature of the gravel in the vicinity of the perforated PVC pipes would suffer in relation to a decreased hydraulic conductivity (Smith, 2006).

3.4 Operations and Maintenance

It is widely accepted that permeable pavers clog over time. Eventually the surface of the joints seal due to sedimentation which drastically reduces the infiltration rate through the system. Through regular maintenance schedules, the clogging of the pavement can be minimized. Many of the studies perform are laboratory experiments and does not demonstrate the cleaning practice with conventional equipment (University of Guelph & Toronto and Region Conservation, 2010). According to the IMAX retrofit (CVC, 2013), there are two maintenance schemes to be concerned with, the perforated pipes and permeable pavement. For the perforated pipes, seasonal maintenance includes cleaning debris and litter by the use of hydraulic pressure and annual maintenance is required for the pavers, where the stone fill in the joints must be level with the paver surface, to decrease promotion of clogging (CVC, 2013; Smith, 2006; STEP, 2015). For the permeable pavement, regular maintenance includes reducing heavy traffic so as not to compact the voids and having no construction equipment or material storage on the paved surface. During the winter months, the snow blade should not be placed on the pavers to decrease any potential damage to the paving system and kept at a minimum height of 1 inch (Smith, 2006). The ploughed snow should be placed in a designated area and if required, high permeable bedding stone is applied over the site to provide for vehicle traction on the surface (CVC, 2013). Every two years, surface sweeping should be carried out and every year spring inspections are required to ensure the infiltration performance (STEP, 2015; CVC, 2013; Smith, 2000). Inspections should be carried out after an intense rain event, the vegetation must be managed so as to decrease sediment deposition, and reparation of damaged or heaved pavers must be completed (STEP, 2015; Smith, 2006).

According to DeepRoot *et al*. (2014), the design life of Silva Cells™ is 100 years and do not require any maintenance when correctly designed and installed, although the frames and decks should be inspected before installation. In the tree opening areas, the operator should check for standing water, trash and other debris every spring, fall, and after major storm events. The Silva Cells™ laterals should be checked annually to ensure proper movement of water into the main lines, by using cameras fed through the piping network. For the trees, most maintenance is performed throughout the year, spring, fall, and after major storms. Checks for pruning, tree safety (no broken or hanging branches) and tree health (disease and animal damages). Certain trees selected must be pruned for vehicular or pedestrian clearance beneath the canopy (University of Florida, 2013). During the growing season, monthly maintenance should be performed by removing weeds and keeping the mulch layer 50 mm thick (DeepRoot *et al*., 2014).

3.5 Cost estimation

The estimation of the cost includes material, construction and maintenance costs. The total cost of the project comes to $674,282.40 and can be found in Appendix D. An overhead cost of 10% was taken into account, where taxes, inflation rates, discounts rates and labor were not taken into account during the analysis. The most expensive item on the material list is the Silva Cells™ which come to $183,645.00. The costs can be greatly reduced if engineered or structural soil is used. The average cost of structural soil ranges between $35.00 USD to $42.00 USD per Imperial ton (Bassuk, 2008). Although, since the density of the structural soil is not given, it is hard to create a comparison of the two scenarios. The second most expensive cost is the permeable pavers which attains a cost of $71,810.00. With the engineering mentor's help, the Techo-Bloc company offered to donate the pavers to this project, which offsets the final cost considerably. Moreover, the companies selling the trees would offer a discount of 20% for the Church. The total discounted cost comes to $594,783.20. With the current financial situation that the Church is in, the project materials would have to be totally donated by companies and the

City of Verdun and Montréal would have to subsidize the project greatly in terms of labor costs, consultants and more. The complete cost analysis can be found in Appendix D.

3.6 Results

Throughout the two semesters, the engineering design team under the consultation of their engineer, architects as well as academics mentors, worked on assessing the needs of the client and of the community in order to produce a design that would remediate current issues while providing a more welcoming environment. The proposed solution features a maximum number parking spaces, a large canopy cover with a diversity of trees that are given a sufficient amount of uncompacted soil to grow and offers maximum storage of water on site. To address the stormwater issue, the parking lot is designed to filter, store and slows down water movement on and off site. The final design is shown in *Figure 8*. **Table 5** is a compilation of stormwater calculations based on two storm durations at four different frequencies. **Table 6** is a cost summary of the components of the project.

The land has been enhanced in order to provide a joint space for the Church and community at large. Trees have been planted to create an aesthetically pleasing environment for religious and communal events held by the Church. There are seven trees planted in order to tie in the environmental space with Saint Willibrord himself, who had passed away on November the 7th and whose feast day is celebrated on the very same day. Being the patron of epilepsy and convulsions, trees offer a particular symbolism in accordance to their leaf movement in the summer and stillness in the winter; symbolizing his spiritual and physical security. The Church's outreach to the community is represented in the trees' branched network and the diverse tree species represent the welcoming nature of the church, which caters to all ethnicity or creed, in their philanthropic activities.

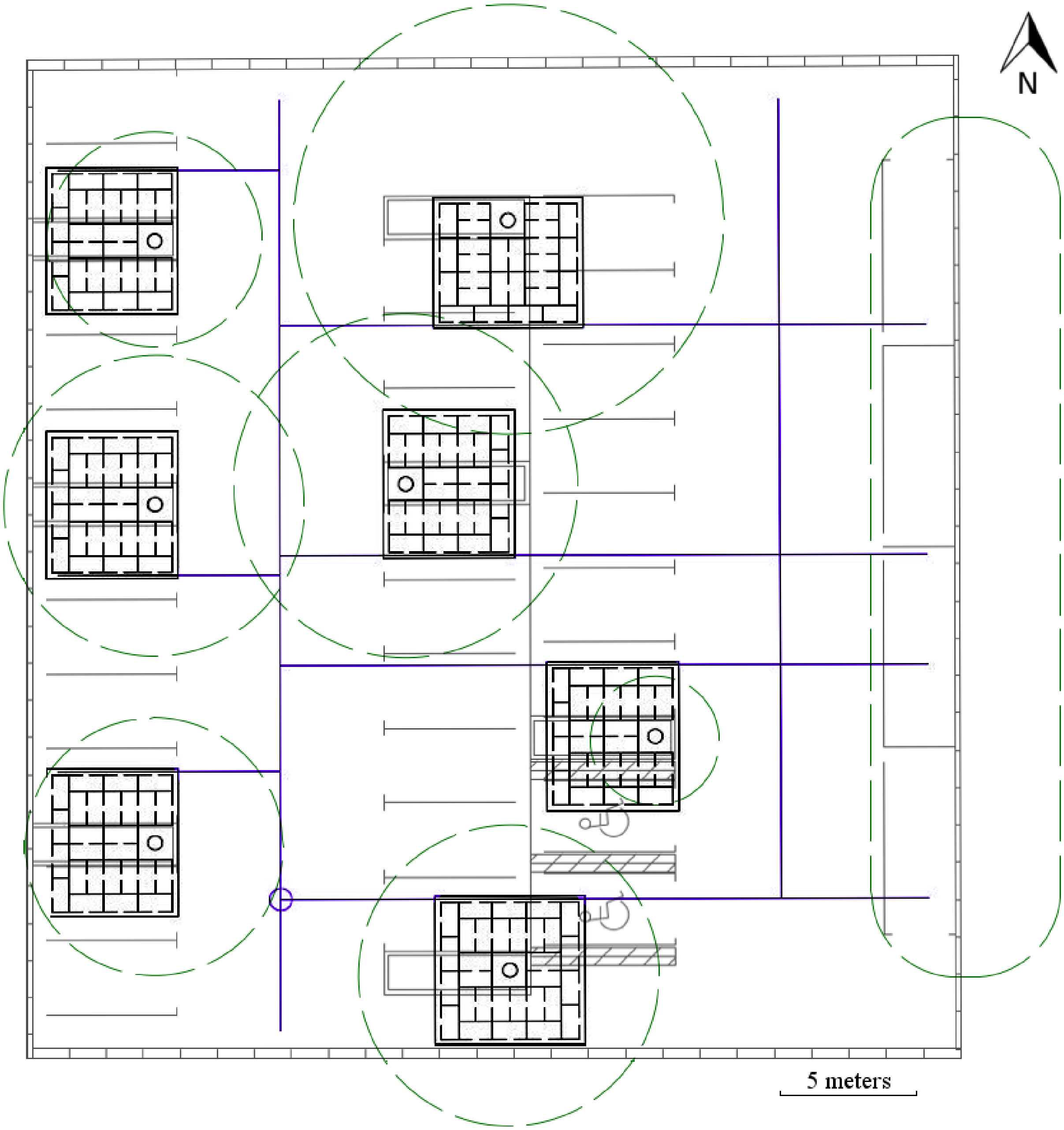

Figure 8, Final Design.

Table 5. Design summary of 60 minute and 24 hour storm events, presence of surcharge, half empty storage time and discharge to the sewers.

Duration	Frequency	Climate Change	Intensity (mm/hr)	Flow Rate at Catchment Boundary (L/s)	Total Flooding Volume (m^3)	Actual Storage Volume (m^3)	Surcharge	Half Empty Storage Time (hr) (< 24 hr)	Discharge to Sewer (L/s) over 48 hours	Allowable Discharge (L/s)
60 min	1 in 2	-	20.5	4.5	16.22	630	No	OK	-	0.401
	1 in 10	-	32	7	25.31	630	No	OK	-	0.401
	1 in 25	10%	10.78	9.7	34.8	630	No	OK	-	0.401
	1 in 100	10%	49.5	10.9	39.15	630	No	24.6	0.016	0.401
24 hr	1 in 2	-	2.25	0.5	1.78	630	No	OK	-	0.401
	1 in 10	-	2.8	0.62	2.22	630	No	24.6	0.016	0.401
	1 in 25	10%	3.85	0.85	3.05	630	No	24.6	0.016	0.401
	1 in 100	10%	4.84	1.1	3.83	630	No	36.5	0.21	0.401

Table 6. Cost summary of the project.

Project Components	Total Cost	Percentage of Total Cost (%)	Percentage of Total Discounted Cost (%)
Full cost of materials	$477,472.60	70.8	-
Discounted materials	$397,973.40	-	66.9
Pre-construction	$3,350.60	0.5	0.6
Excavation and site preparation	$100,127.50	14.8	16.8
Operations and maintenance	$93,331.70	13.8	15.7
Total Cost	$674,282.40		
Total Discounted Cost	$594,783.20		

3.7 Optimization

There are always modifications that could be done to improve a design; the process is never complete. The resulting design could be improved in a multitude of ways; structural design in terms of community needs, water storage and shading, testing, social integration, construction materials, more in-depth risk analysis, cost efficiency, by-laws, safety, and end-of-life development would further benefit this design.

Several tests were not completed due to a lack of resources. As previously mentioned, soil tests were not performed on the parking lot. Further tests could help determine the soil texture, Atterberg limits, water table depth, infiltration rate, as well as soil pollutants present. Tests on the current water quality and more accurate discharge rates could be analyzed in order to provide a better current versus retrofitted design scenario, as well as better design for LEED criteria for a green retrofit. For example, LEED Credits 1.1 and 1.2 in Water Efficiency states to reduce potable water consumption by at least 50% and to only use rainwater or recycled water to water the plants. Since the trees will be relying solely on precipitation, these credits should apply to this project, but more research is required (LEED, 2005). Also with the new version of LEED, Version 4.0, there are new changes to the credits (e.g. trees) that would have to be reviewed before the project could move forth with an application for LEED certification (Macdonagh, 2013). There are two trees in the design that were not found as large trees when nurseries were called; the Chinese Elm and the Scholar Tree. They are considered more rare but particularly good in urban environments. Another nursery in Prince Edward Island did have a Scholar tree, but they were saplings (Kevin Cook, The Honey Tree, personal communication, April 8th, 2015) and compared to the older trees in the design (10 - 20 years old), this tree would have difficulty getting the proper sunlight in order to compete with the larger trees. For the Chinese Elm, one nursery use to have it in stock but recently stopped supplying the tree to consumers (Frans Peters, Humber Nurseries, personal communication, April 8th, 2015). So two new trees would have to be implemented in the design, whilst still having seven different tree species. Another nursery was contacted and *Tilia cordata var*. 'Greenspire', *Ginkgo Biloba*, and *Celtis occidentalis* are preferred suggestions from the technician (Tom Whitcher, Sheridan Nurseries, personal communication, April 8th, 2015).

Completing a more broad survey of the community's perspective is also required to understand their needs in terms of a public parking lot and what is preferred aesthetically. Engaging stakeholders proves beneficial when commencing a project in order to have an outcome that satisfies all parties. The City of Verdun and Montréal have yet to be introduced to the project and their involvement would be an asset to everyone involved. In the few social surveys that the group performed, bike racks were mentioned as an addition to the parking lot and the group thought to implement them in the north east corner of the parking lot. In meetings with the mentor and architects with W.A.N.T.E.D., benches at the South end of the parking lot were thought to be an inviting option that would bring people into the parking lot. The bike racks suggested would correspond to LEED Credits 4.1 and 4.2, which would create a safe area for people living in the apartments to store their bicycles (LEED, 2005). Decorative iron fences around the perimeter of the tree pits were thought of and could be implemented to protect the trees from cars, snowploughs, and other machinery. Different colored permeable pavers would be used to create the parking lines and designate different zones (such as parking and driving lane), as well as to create patterns in the driving lane to break up the uniformity.

While the total cost of the project was obtained, a more in-depth cost analysis is still needed. Further additions to the project, such as bike racks, benches and fences have not been added to the total and the possibility of funding from the City of Montréal, Verdun, and DeepRoot have not been accredited to the cost. Construction estimates also do not fully represent the real cost of such a project, where additional costs occur for scheduling errors, broken components, extra time, and lack of understanding of the complexity of the task at hand.

The team was careful to include appropriate by-laws and standards while designing, however there are other technicalities that may have been overlooked or that have been misunderstood or implemented improperly. The review of the project by certified engineers is needed in order to ensure the design satisfies all criteria.

In terms of safety, the team thought to include a sidewalk on the east end in order to provide a safe passageway for residents or commuters to walk in the parking lot. Although with this sidewalk, the amount of parking spaces would be reduce by 4. In the future, a community survey would indicate if a sidewalk would be used by the pedestrians.

As for the operations and maintenance manual, a proper compilation of all the components would be beneficial for the client to understand the amount of work that is required. If the client fully understands what is required, then this knowledge can be properly explained to (a) contractor(s) on how to perform the work; the frequency of operations and how to perform the tasks with the proper equipment. Some of the maintenance and care can be done at no cost by creating a sense of belonging between the new parking lot and the community.

Another important component of the project is knowing how much the project would cost for decommissioning and how the project would be decommissioned. Since the project is relatively simply constructed, the permeable pavers would be removed, the gravel would be hauled away and the Silva Cells™ could be reused for another purpose. As for the cost, it could be assumed that part of the installation cost of the project as there could be a re-sale of the materials after decommissioning, if in good condition.

4. Conclusion

The St. Willibrord Parish owns a parking lot and due to its relatively old age, a retrofit is required. Over the past year, engineering students from McGill University developed a sustainable and meaningful retrofit for the parking lot based on the client and community needs and similar case studies. The parking lot is designed to filter, store and slow down stormwater on and off site which in turn, decreases the pressures on the municipal stormwater system. According to the objectives this parking lot features a maximum number of parking spaces, a large canopy cover with a diversity of trees that are allowed to grow in uncompacted soil, and a maximum storage of water on site.

Although, the refinement and verification of the design by a professional engineer is needed for the project to become a reality one day. It is found that more tests and surveys are necessary to further the project's progress. After review, the transformation of the current deteriorated parking lot into a lively communal space that serves the public will mirror the benefits that the St. Willibrord church provides to the community.

5. Acknowledgements

This immense work would not have been possible without the tremendous help of professionals who gave their time, advice, and input to the design team. The team would like to acknowledge their mentor Charles Ormsby from ARUP, Professor Grant Clark from McGill University, architects Paula Meijerink and Thierry Beaudoin from W.A.N.T.E.D., Father Gregory Nuñez, Maryam Kargar Ph.D. student from McGill University, Professor Benoît Côté from McGill University, as well as all the students from BREE 490/495 and all others who showed interest in the project.

6. Competition Entered

The team applied for a grant with RBC's Blue Water Project. The proof of submission is located in Appendix E.

The team plans on entering the AGCO National Student Design Competition and the James Dyson Award after the completion of the project.

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Chapter 7: Collecting and Testing Materials, *Articles 7.1* General
Chapter 7: Collecting and Testing Materials, *Article 7.3* Sewer Lines
Chapter 7: Collecting and Testing Materials, *Article 7.4* Aggregates and Recycled Materials
Chapter 8: Delivering and Handling Materials, *Article 8.1* Defective or Damaged Materials
Chapter 8: Delivering and Handling Materials, *Article 8.2* Transporting, Unloading, Handling and Storing Materials
Chapter 8: Delivering and Handling Materials, *Article 8.3* Handling during Cold Weather
Chapter 8: Delivering and Handling Materials, *Article 8.4* Exposure to Sunlight
Chapter 8: Delivering and Handling Materials, *Article 8.5* Rubber or Elastomer Gaskets
Chapter 9: Excavation and Backfilling, *Article 9.1* Excavating Trenches
Chapter 9: Excavation and Backfilling, *Article 9.2* Backfilling and Compaction
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9. Appendices

Table of Contents

Appendix A: Water quantity, old design impermeability coefficients, infiltration calculations

Table 7. Runoff coefficients based on surface characteristics of the old design.

	Existing			Proposed		
	A (m^2)	C_{ini}	A_{corr} (m^2)	A (m^2)	C_{ini}	A_{corr} (m^2)
A_{total}	1144.5	-	-	1144.5	-	-
$A_{permeable}$	38.865	0.3	11.66	151	0.2	30.2
$A_{impermeable}$	1105.635	0.85	939.79	993.5	0.875	869.31
$A_{corr,\ imp}$			**951.45**			**899.51**
Runoff Coefficient, C		C_{corr}	**0.83**		C_{corr}	**0.79**

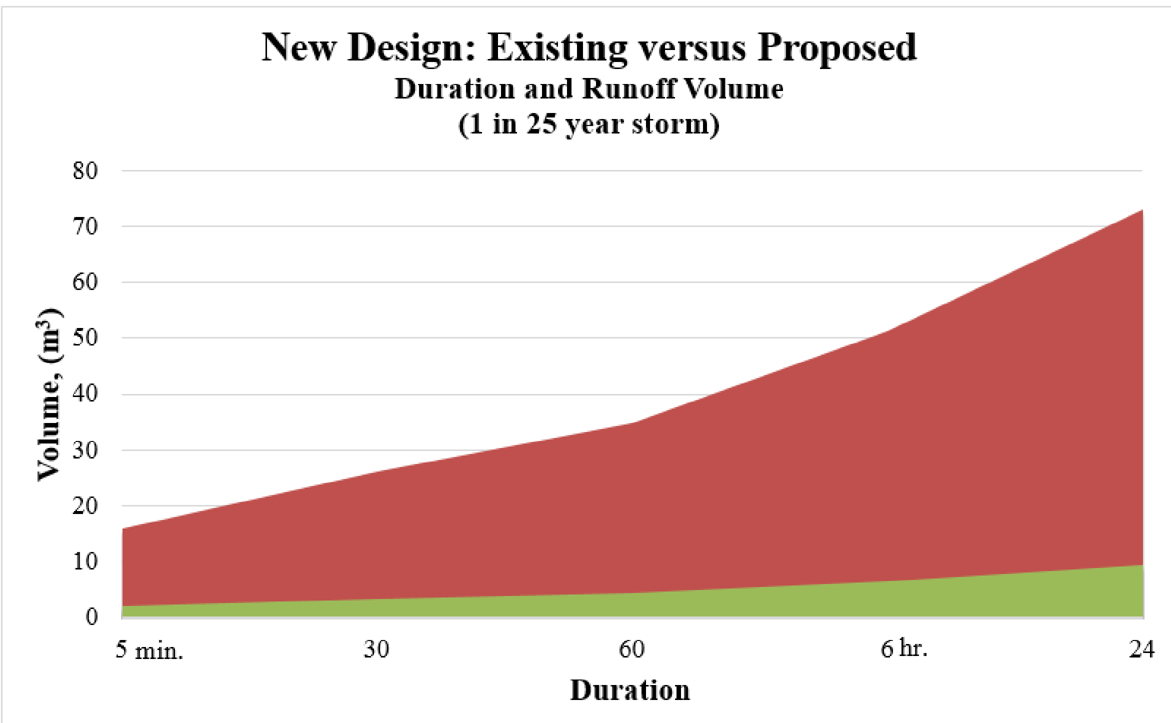


Figure 9, The runoff volume as a function of storm event duration of existing to proposed scenario for a 1 in 25 year storm event.

Soakaway Design

This design follows the methodology proposed in CIRIA Report 156 - Chapter 4, Section 4.4.2(d) Plane infiltration systems

Select Safety Factor

Safety Factor: 5 — Assumed : No damage or inconvenience due to flooding
Note: See CIRIA Rep. 156 Table 4.6

Calculate Effective/Adjusted Infiltration Coefficient (q) of the Ground

Infiltration Coefficient 0.006 m/h — Assumed : clay (based on ground investigation results)
Note from CIRIA Rep. 156 Table 4.4 (m/h)

q = 0.0012 m/h

Identify Porosity of Fill Material (n)

n = 0.3 — Assumed: Uniform gravel fill or engineered soil
Note: See CIRIA Rep. 156 Table 4.7

Identify Area to be Drained (A_D)

A_D = 1144.5 m^2 — Assumed: Full area of parking lot to be drained into the soakaway system

Select the Dimensional Characteristic

Trench length: 32.7 m — Assumed: Full area of (Ctrl) t used for storage with a medium providing 30% void ratio

Trench width: 35 m

Area of the base (A_B) = 1144.5 m^2

Perimeter (P) = 135.4 m

Calculate Parameter b

$B = Pq/A_B n$ 0.00047322 h^{-1}

Figure 10, Soakaway design calculations for a three dimensional infiltration system.

Table 8. Maximum depth of water in the three dimensional infiltration system for a 1 in 2 year storm event.

Duration		Intensity	b	a	h_{max}	Storm Volume
(min)	(hrs)	(m/hr)	(h^{-1})	(m)	(m)	(m^3)
5	0.08	0.125	0.000473	-872.04	0.03	11.92
15	0.25	0.055	0.000473	-378.964	0.04	15.74
30	0.50	0.035	0.000473	-238.085	0.06	20.03
60	1.00	0.021	0.000473	-139.47	0.07	24.03
120	2.00	0.013	0.000473	-83.1185	0.08	29.76
360	6.00	0.006	0.000473	-32.0499	0.09	39.49
720	12.00	0.004	0.000473	-16.2011	0.09	48.07
1440	24.00	0.002	0.000473	-7.39614	0.08	61.80
					$h_{max} = 0.1$	

Note: Site drainage through infiltration only, no outflow to sewer

Table 9. Maximum depth of water in the three dimensional infiltration system for a 1 in 10 year storm event.

Duration		Intensity	b	a	h_{max}	Storm Volume
(min)	(hrs)	(m/hr)	(h^{-1})	(m)	(m)	(m^3)
5	0.08	0.160	0.000473	-1118.58	0.0	15.26
15	0.25	0.085	0.000473	-590.282	0.1	24.32
30	0.50	0.050	0.000473	-343.744	0.1	28.61
60	1.00	0.033	0.000473	-220.475	0.1	37.20
120	2.00	0.019	0.000473	-125.382	0.1	43.49
360	6.00	0.009	0.000473	-51.4208	0.1	58.37
720	12.00	0.005	0.000473	-28.528	0.2	72.10
1440	24.00	0.003	0.000473	-14.4401	0.2	89.27
					$h_{max} = 0.2$	

Note: Site drainage through infiltration only, no outflow to sewer

Table 10. Maximum depth of water in the three dimensional infiltration system for a 1 in 25 year storm event accounting for climate change.

Duration		Intensity	b	a	h_{max}	Storm Volume
(min)	(hrs)	(m/hr)	(h^{-1})	(m)	(m)	(m^3)
5	0.08	0.248	0.000473	-1734.92	0.1	23.61
15	0.25	0.110	0.000473	-766.381	0.1	31.47
30	0.50	0.072	0.000473	-495.189	0.1	40.92
60	1.00	0.044	0.000473	-301.481	0.1	50.36
120	2.00	0.025	0.000473	-165.885	0.2	56.65
360	6.00	0.011	0.000473	-69.0306	0.2	75.54
720	12.00	0.007	0.000473	-38.0373	0.2	90.64
1440	24.00	0.004	0.000473	-21.3784	0.2	116.33
					$h_{max} = 0.2$	

Note: Site drainage through infiltration only, no outflow to sewer

Table 11. Maximum depth of water in the three dimensional infiltration system for a 1 in 100 year storm event accounting for climate change.

Duration		Intensity	b	a	h_{max}	Storm Volume
(min)	(hrs)	(m/hr)	(h^{-1})	(m)	(m)	(m^3)
5	0.08	0.303	0.000473	-2122.34	0.1	28.85
15	0.25	0.138	0.000473	-960.09	0.1	39.34
30	0.50	0.080	0.000473	-553.302	0.1	45.64
60	1.00	0.048	0.000473	-332.474	0.2	55.39
120	2.00	0.030	0.000473	-204.627	0.2	69.24
360	6.00	0.014	0.000473	-88.4015	0.3	94.42
720	12.00	0.008	0.000473	-49.6598	0.3	113.31
1440	24.00	0.005	0.000473	-26.4148	0.3	135.97
					$h_{max} = 0.3$	

Note: Site drainage through infiltration only, no outflow to sewer

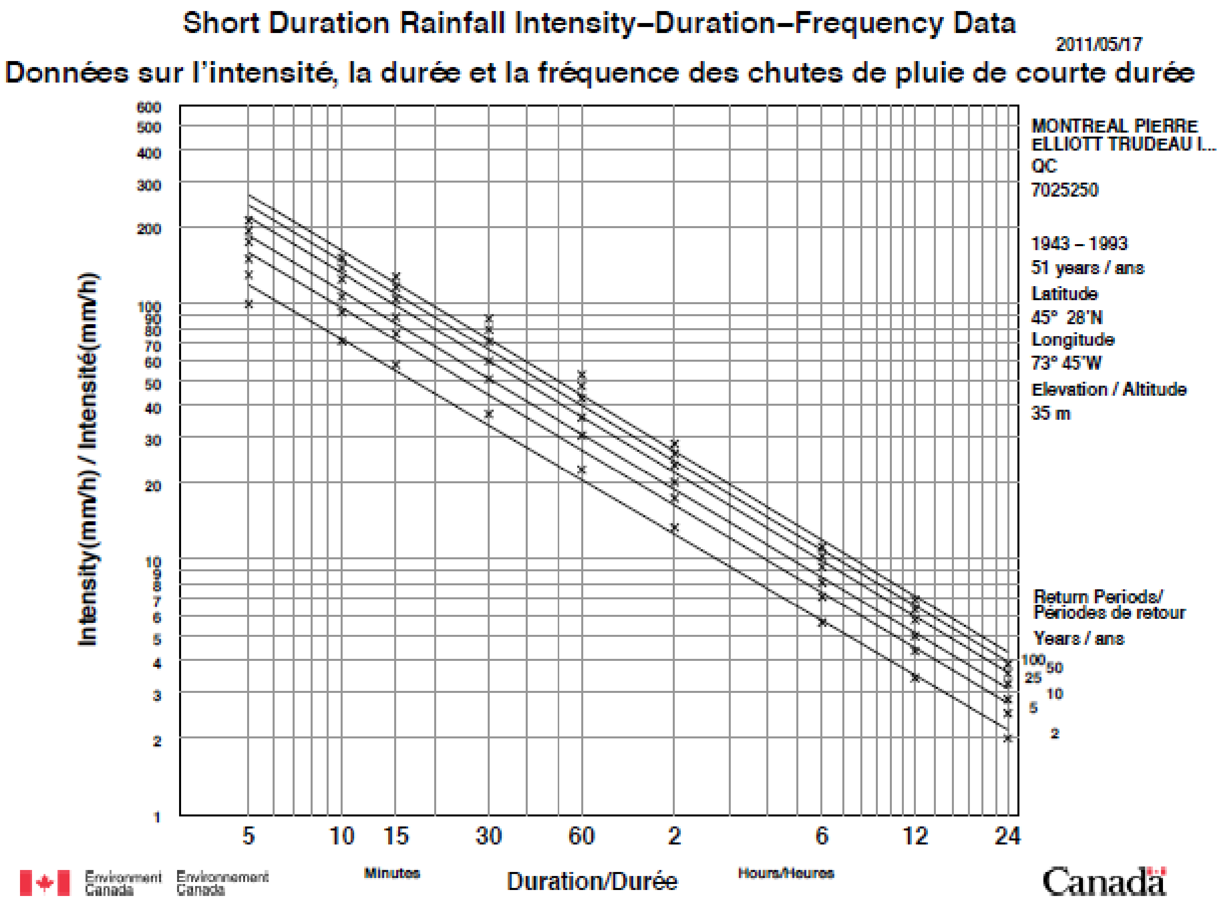


Figure 11, Intensity-Duration-Frequency (IDF) curves recorded by the Pierre Elliott Trudeau Airport (Environment Canada, 2012).

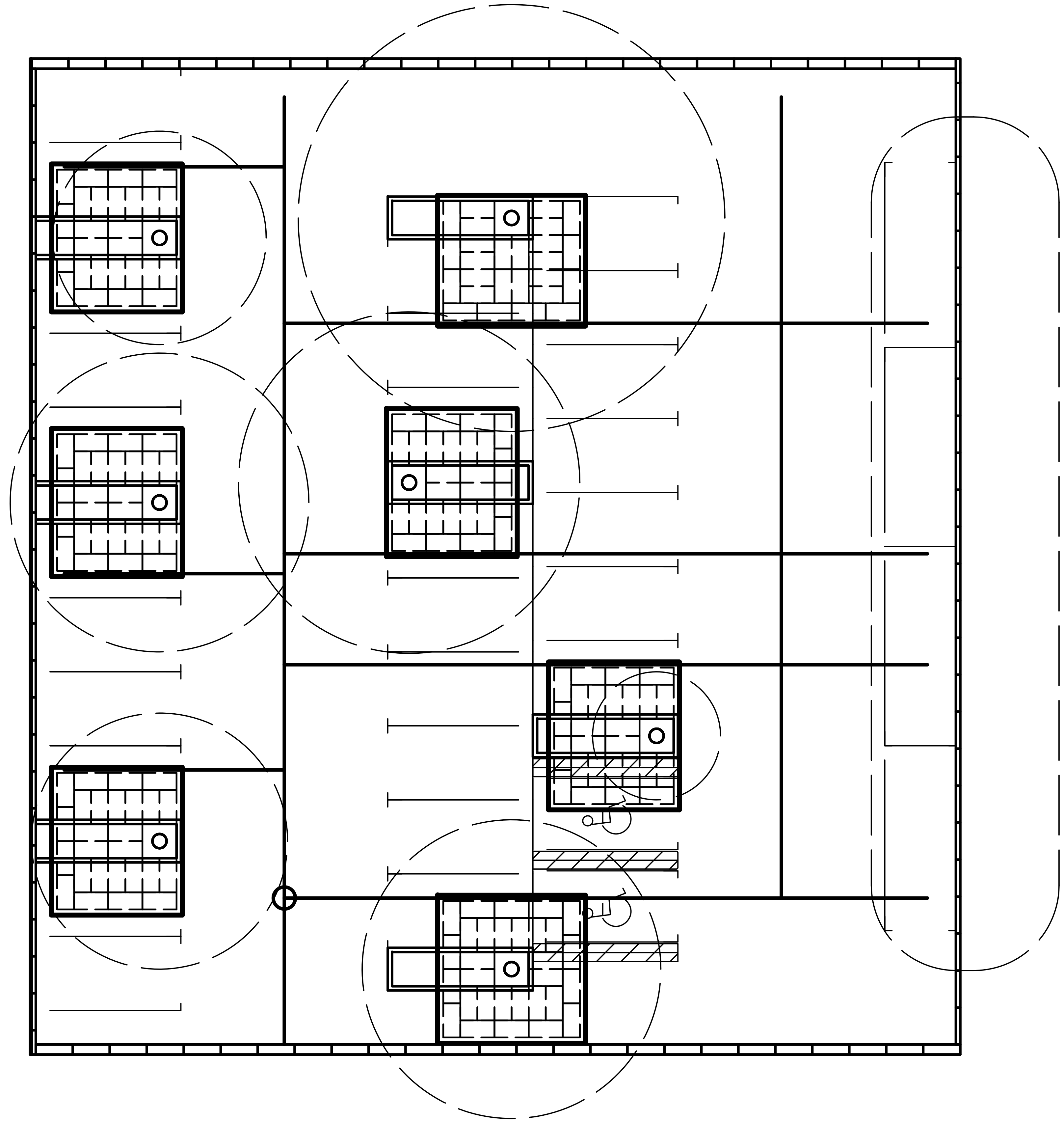
Table 12. Half-empty storage time for the three maximum water depths for the 4 different storm events. The $t_{1/2}$ must be less than 24 hours.

Storm Event	h_{max} (m)	$t_{1/2}$ (hr)	Check
1 in 2	0.1	12.4	OK
1 in 10	0.2	24.6	Not acceptable
1 in 25	0.2	24.6	Not acceptable
1 in 100	0.3	36.5	Not acceptable

Table 13. Infiltration and discharge into the municipal sewer system based on maximum height for the storm event.

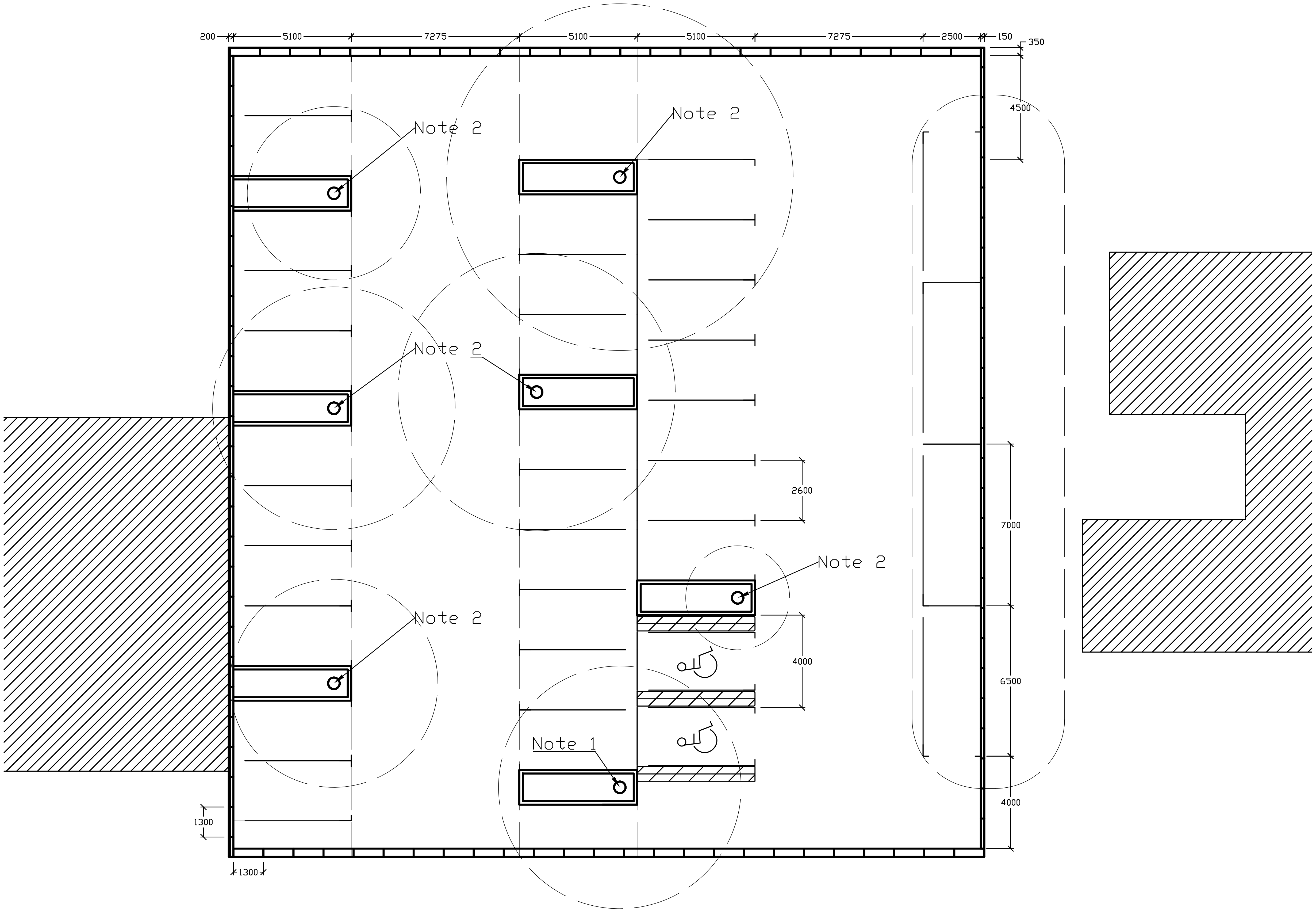
Storm Event	Storm Volume (m^3)	Infiltration Rate (m^3/hr)	Drainage in 48 hr, with no infiltration (m^3/hr)	Drainage in 48 hr, with infiltration (m^3/hr)	Discharge to Sewers (L/s)
1 in 2	34.34	1.37	0.72	-	-
1 in 10	68.67	1.37	1.43	0.06	0.016
1 in 25	68.67	1.37	1.43	0.06	0.016
1 in 100	103.01	1.37	2.15	0.78	0.21

Appendix B: Prototyping of the design with AutoCAD®, standard sections, plan views and details



project	projet
BREE490 Engineering Design **Design Project**	
drawing	dessin
Overall Plan View	
Scale	Echelle
1:175	
Date	Date
04/12/2015	
Design Team	
DB3	
Drawn By	Dessiné par
Jinhao Dong	
Drawing no.	No. du dessin
PV-1	

11X17 format (431x279mm)

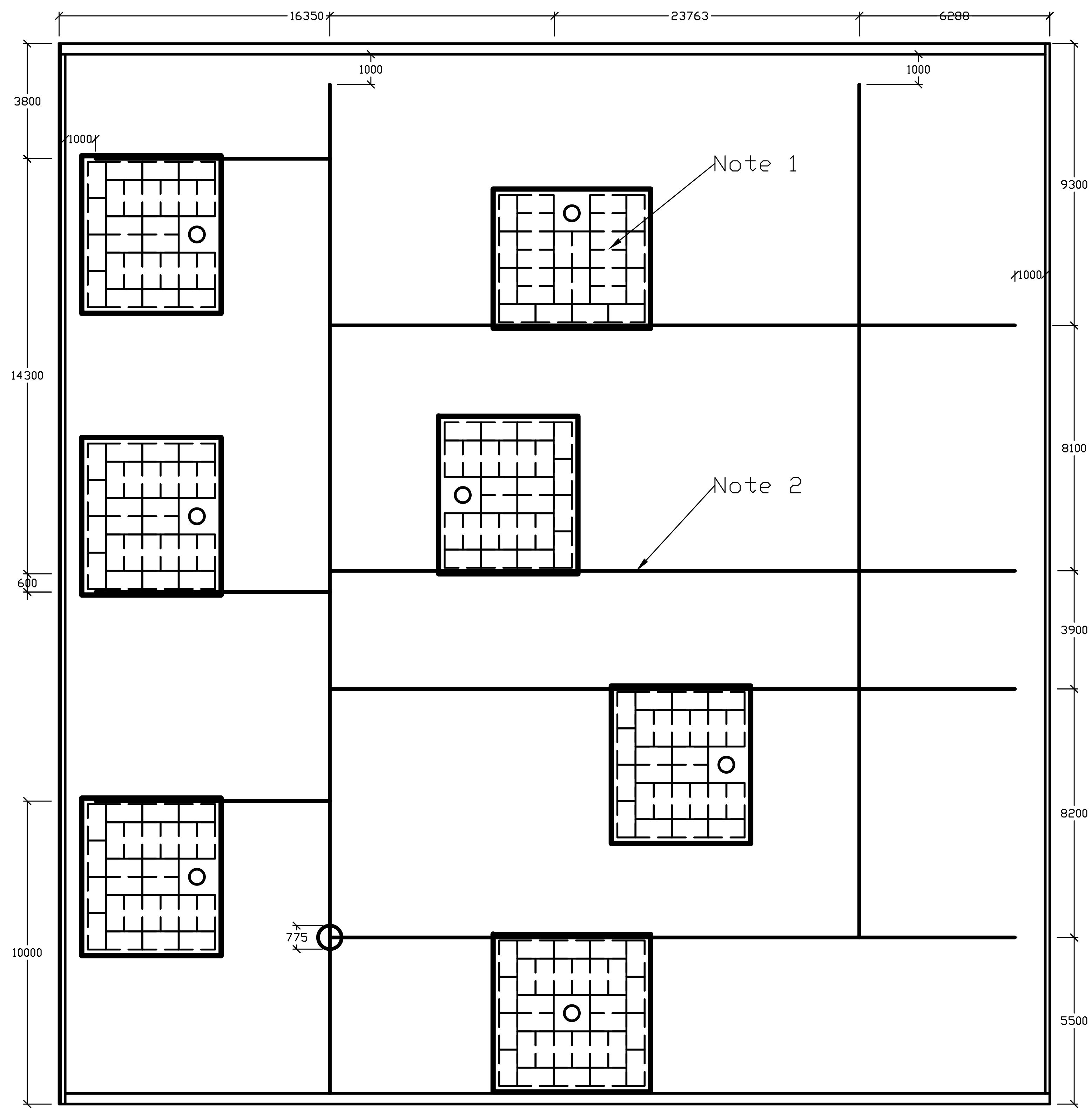


1: Tree pot Type 1
2: Tree pot Type 2

project / projet	BREE490 Engineering Design **Design Project**
drawing / dessin	Plan View of Above ground Infrastructures
Scale / Echelle	1:175
Date / Date	04/12/2015
Design Team	DB3
Drawn By / Dessiné par	**Jinhao Dong**
Drawing no. / No. du dessin	**PV-2**

11X17 format (431x279mm)

1: Underground tree pots
2: Drainage pipes



project | projet

BREE490
Engineering Design

Design Project

drawing | dessin

Plan View
of
Underground
Infrastructures

Scale | Echelle

1:175

Date | Date

04/12/2015

Design Team

DB3

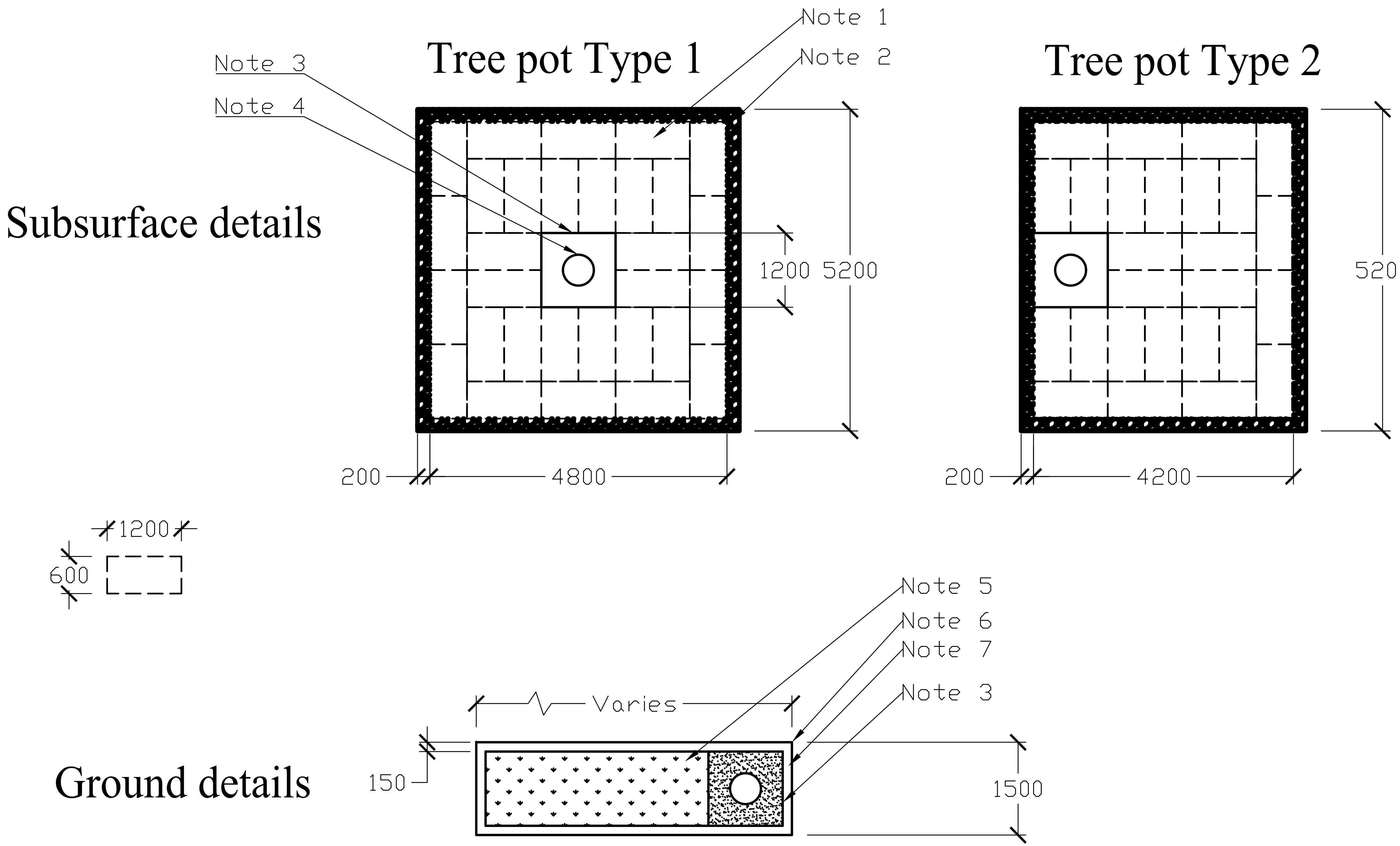
Drawn By | Dessiné par

Jinhao Dong

Drawing no. | No. du dessin

PV-3

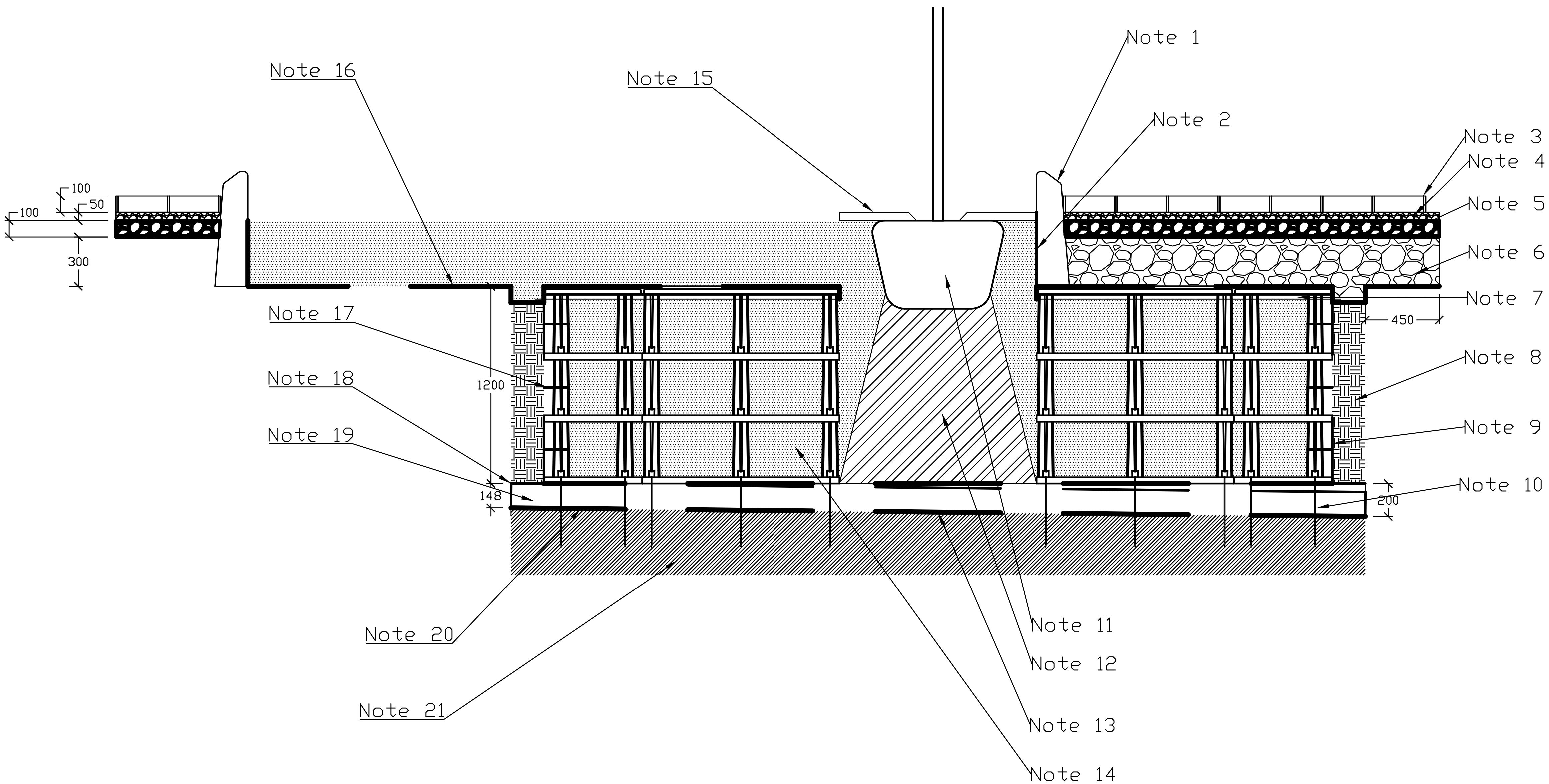
11X17 format (431x279mm)



1: Silva cells
2: Gravels
3: Boundary of tree pot opening
4: Tree
5: Growing medium
6: Boundary of curbs
7: Concrete curbs

project / projet	BREE490 Engineering Design **Design Project**
drawing / dessin	Detailed Plan View of Tree pots, Silva Cells and Gravels
Scale / Echelle	1:75
Date / Date	04/12/2015
Design Team	DB3
Drawn By / Dessiné par	**Jinhao Dong**
Drawing no. / No. du dessin	**PV-4**

11X17 format (431x279mm)



1: Concrete curb type 1
2: DeepRoot UB18-2 Root Barrier
3: Paver
4: Bedding course 50mm No.8 stone ASTM D448
5: Base course 100mm No.57 stone
6: Subbase course 300mm No.2 stone AST M D448
7: 25mm air space between Silva Cell deck and planting soil
8: Backfill, installed in 200mm lifts, 100mm from top of decks, compacted to 95%
9: Geotextile, 150mm below backfill at base, overlap 200mm at top of cells
10: Anchor each Silva Cell to ground with (4) 400mm spike, <10mm dia.
11: Tree root package
12: Planting soil, tamped to max. 85% compaction Below root package
13: Geotextile on compacted subgrade
14: Planting soil, silt and clay less than 12% combined weight.
Hydraulic conductivity 2.5" - 4.5"/hour under 85% compaction. ASTM D2434, ASTM F1815
15: Mulch layer
16: Geotextile, 450mm overlap past excavation or until next concrete curb
17: 5mm x 350mm zip ties, attaching geotextile to Silva Cell at each level
18: 150mm pipe
19: Aggregate base 200mm, compacted to 95%
20: Subgrade and pipe at 1% slope
21: Existing soil

project / projet

BREE490
Engineering Design

Design Project

drawing / dessin

Detailed Section View
of
Tree pot, Silva Cells, pavers
and pipes

Scale / Echelle

1:30

Date / Date

04/12/2015

Design Team

DB3

Drawn By / Dessiné par

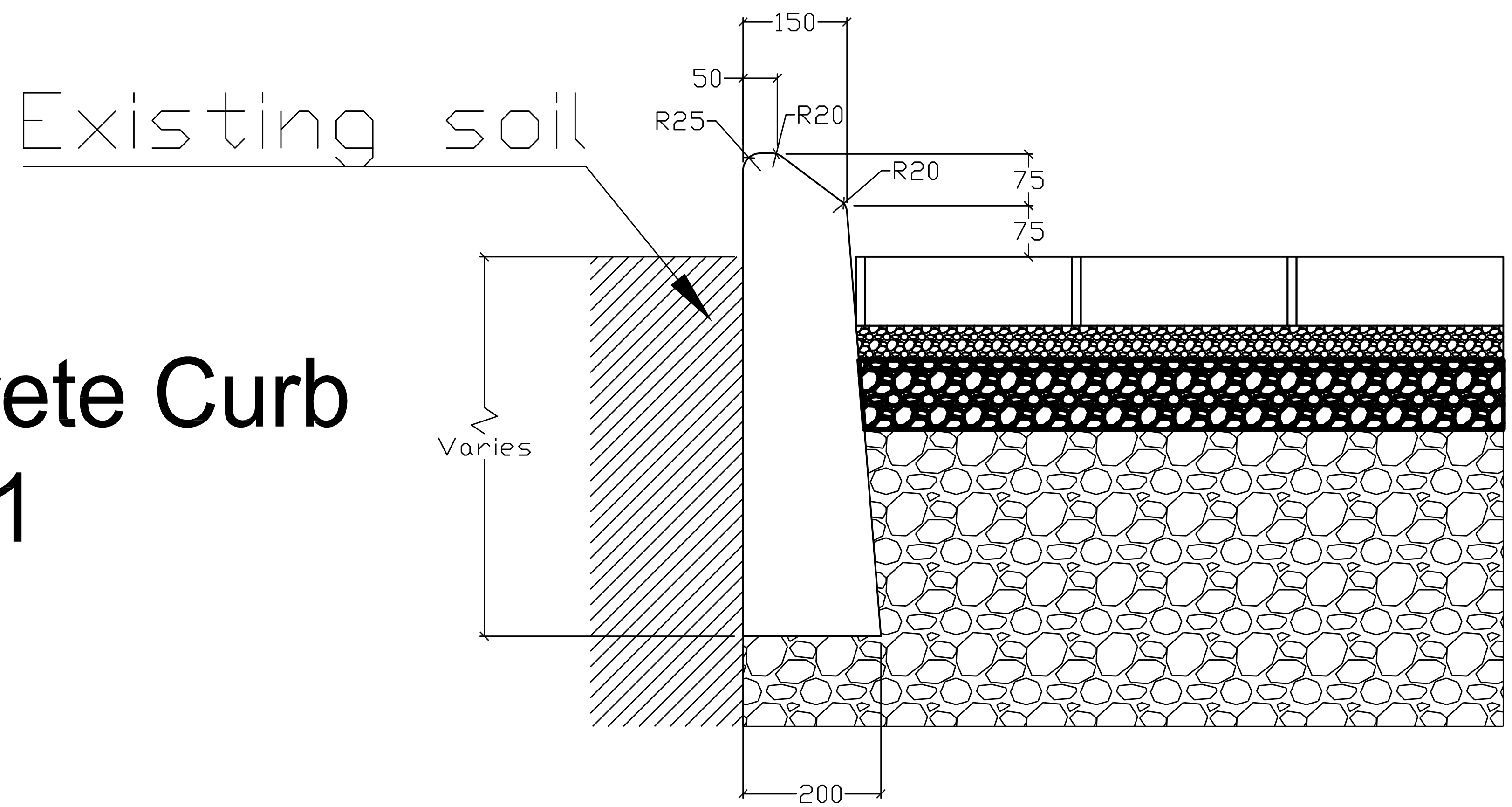
Jinhao Dong

Drawing no. / No. du dessin

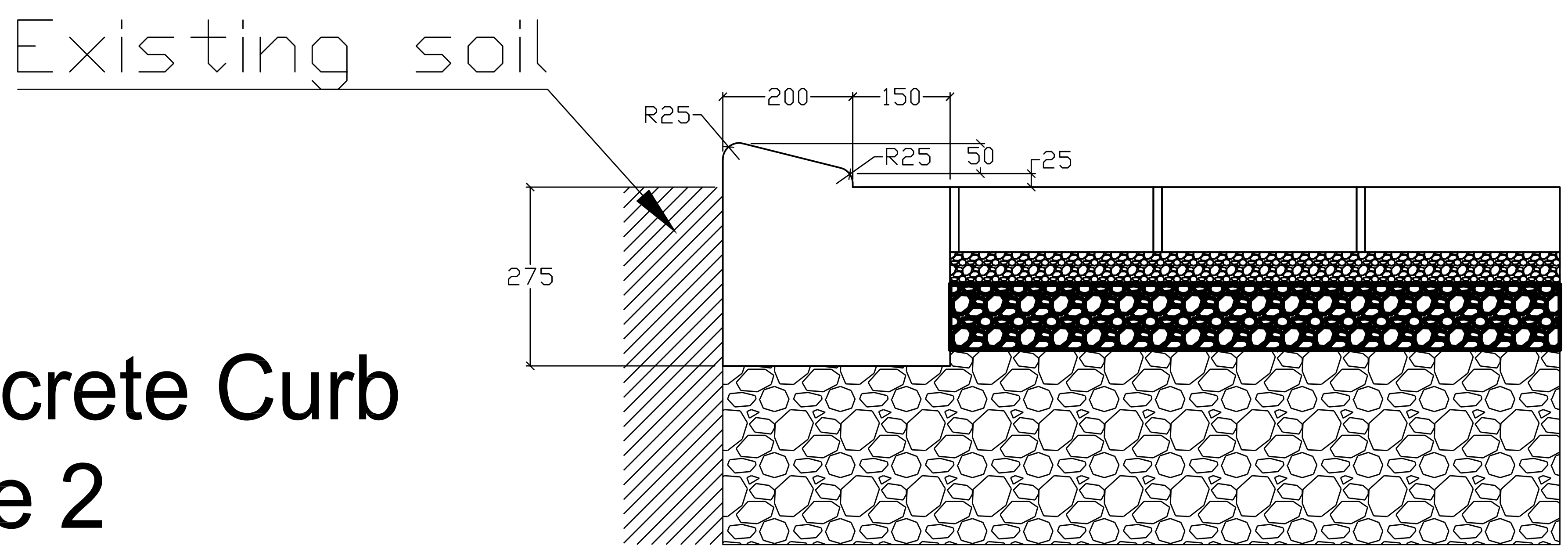
SV-1

11X17 format (431x279mm)

Concrete Curb
Type 1

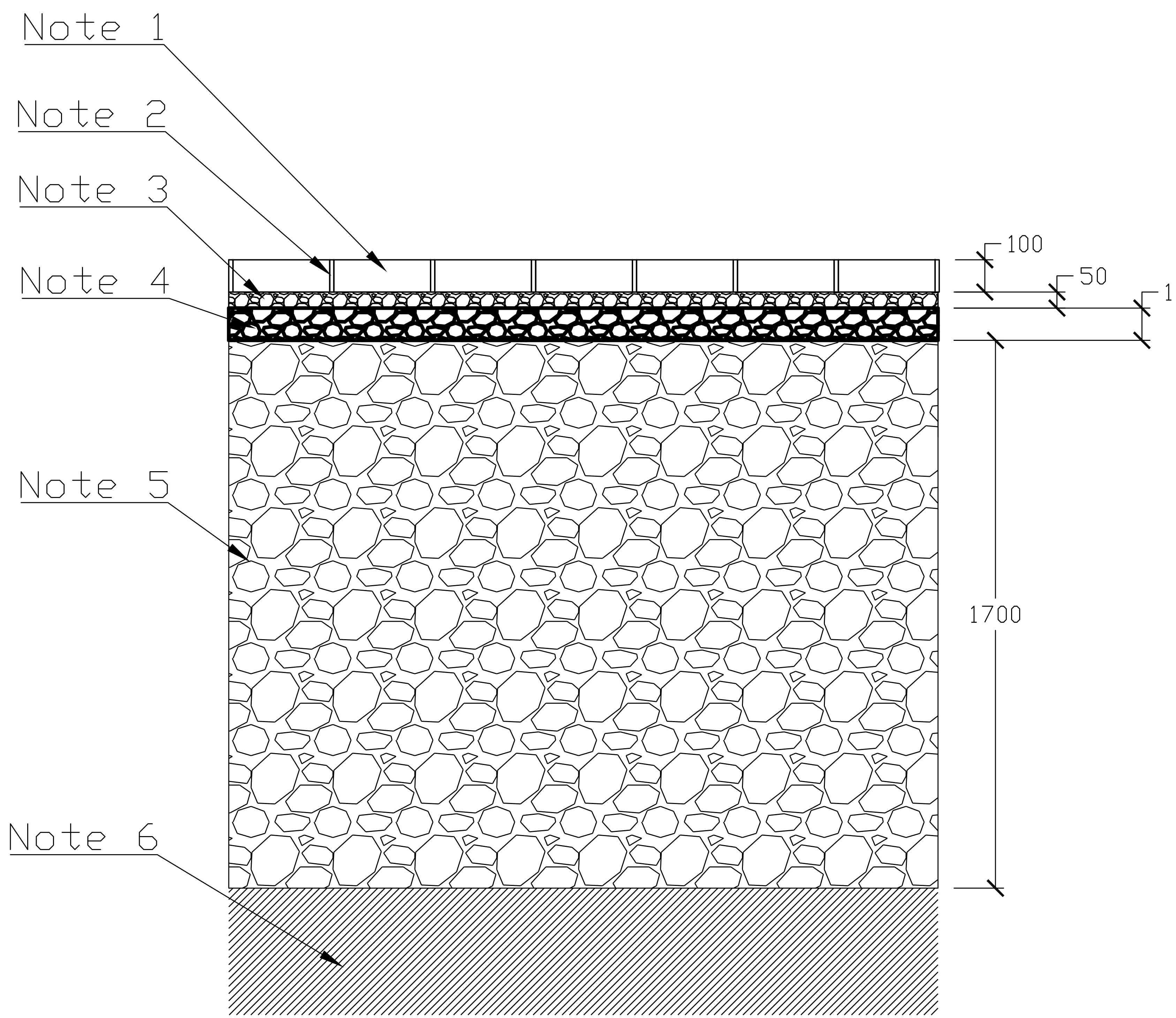


Concrete Curb
Type 2



project	projet
BREE490 Engineering Design **Design Project**	
drawing	dessin
Detailed Section View of Concrete Curbs	
Scale	Echelle
1:10	
Date	Date
04/12/2015	
Design Team	
DB3	
Drawn By	Dessiné par
Jinhao Dong	
Drawing no.	No. du dessin
SV-2	

11X17 format (431x279mm)



1: Pavers inflo
2: Joint filling, No.8 filling
3: Bedding course 50mm
No.8 stone
4: Base course 100mm
No.57 stone
5: Subbase course 1700mm
No.2 stone
6: Existing soil

project / projet
BREE490
Engineering Design

Design Project

drawing / dessin
Detailed Section View
of
Pavers

Scale / Echelle
1:16

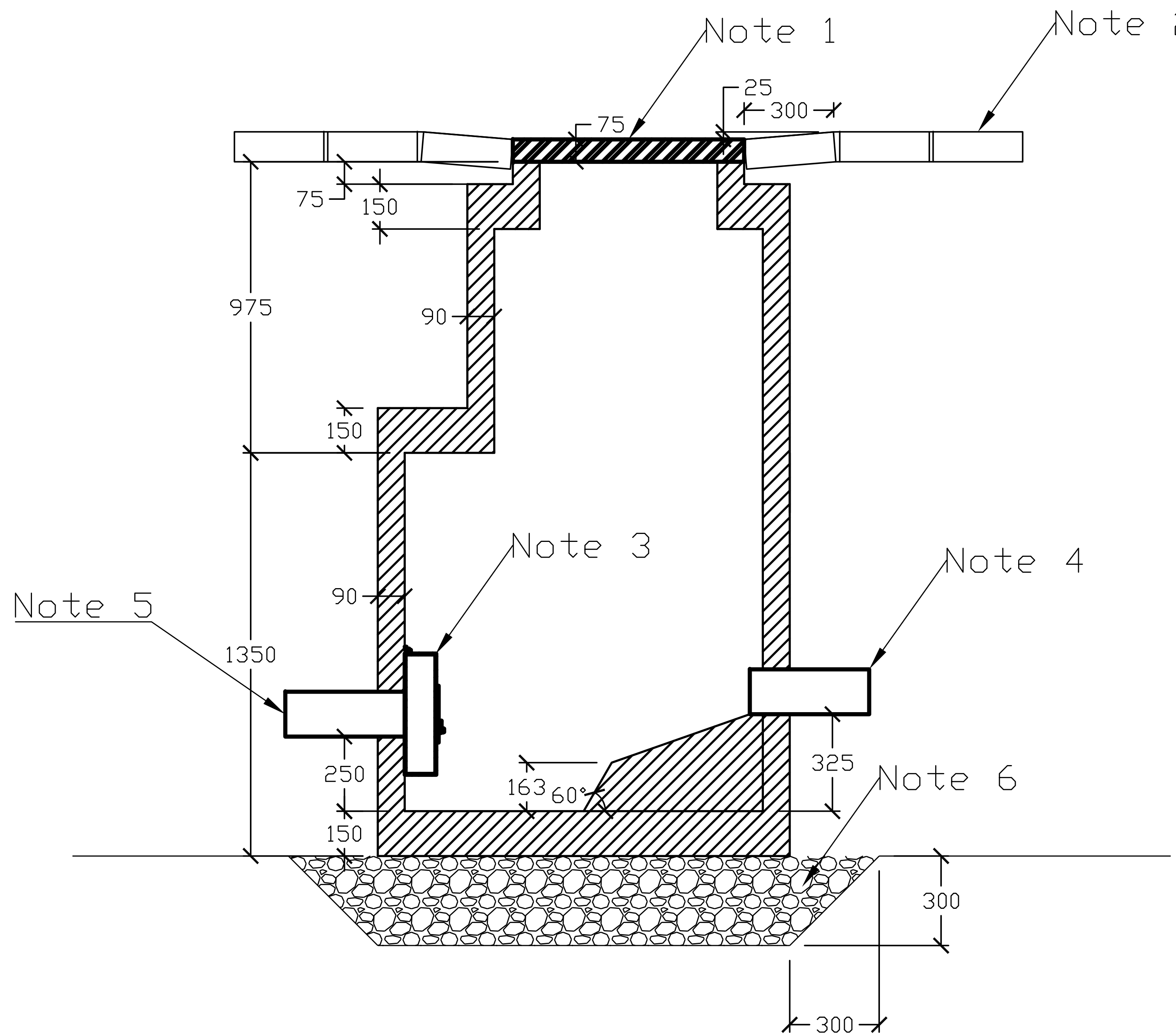
Date / Date
04/12/2015

Design Team
DB3

Drawn By / Dessiné par
Jinhao Dong

Drawing no. / No. du dessin
SV-3

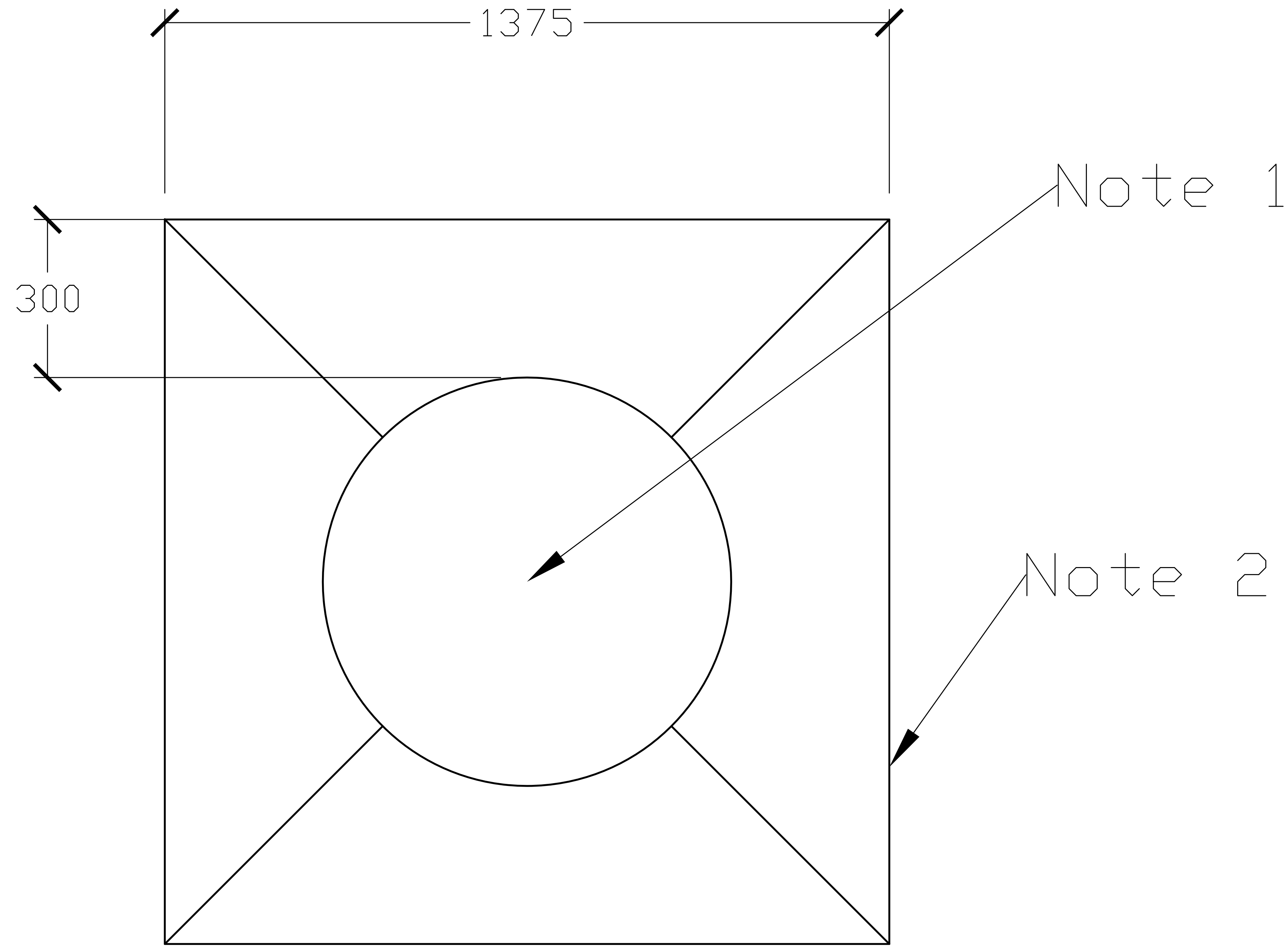
11X17 format (431x279mm)



1. 75 mm manhole grid
2. Pavers and joints
3. Hydrobrake
4. 150mm inlet pipe
5. Outlet pipe
6.300mm gravel bed

project / projet	BREE 490 Engineering Design **Design Project**
drawing / dessin	Section view of Manhole
Scale / Echelle	1:20
Date / Date	04/12/2015
Design Team	DB3
Drawn By / Dessiné par	**Jinhao Dong**
Drawing no. / No. du dessin	**MH-1**

11X17 format (431x279mm)



1. 775 mm manhole grid
2. Edge of slope

project | projet

BREE 490
Engineering Design

Design Project

drawing | dessin

Plan view
of
Manhole

Scale | Echelle

1:10

Date | Date

04/12/2015

Design Team

DB3

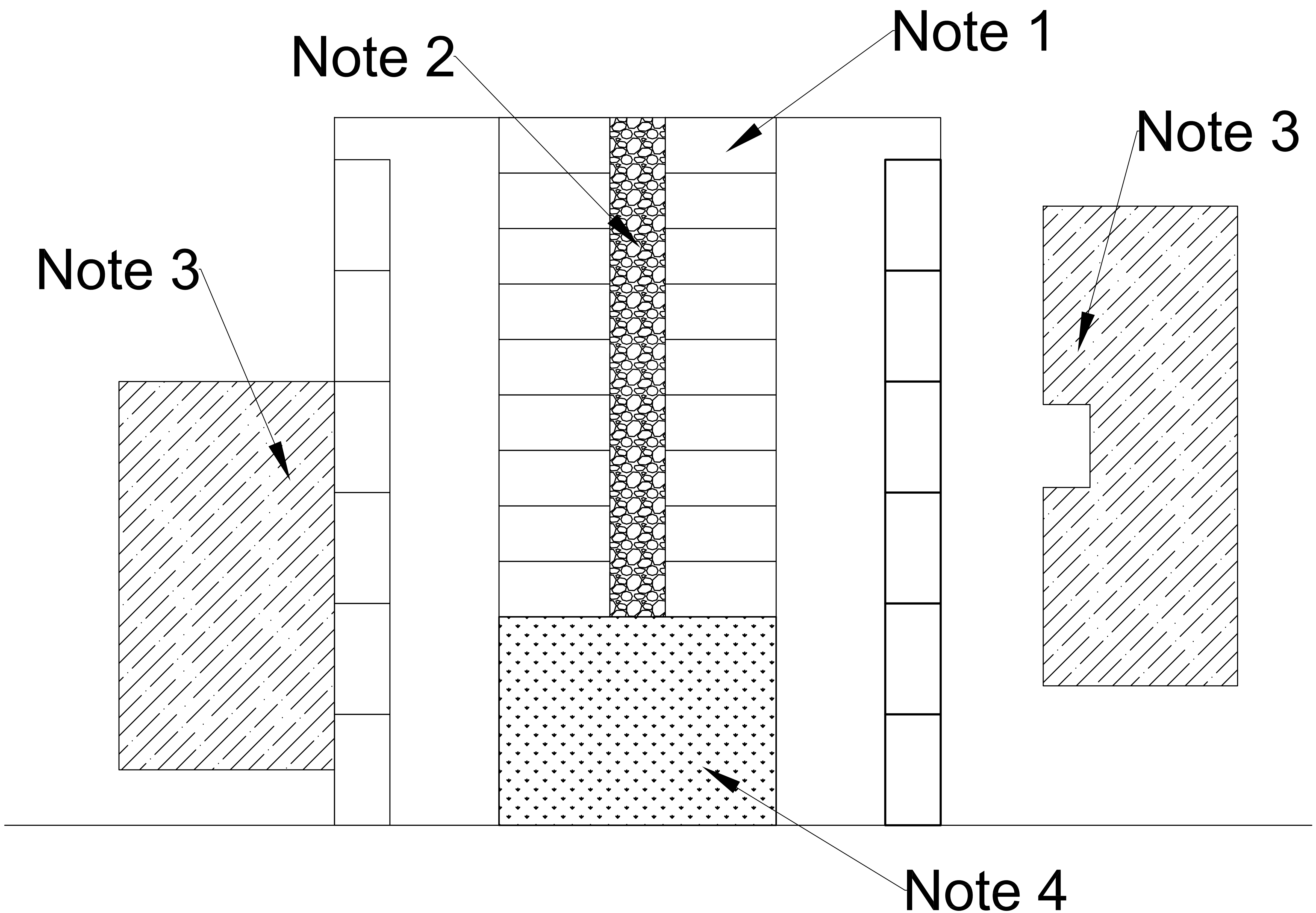
Drawn By | Dessiné par

Jinhao Dong

Drawing no. | No. du dessin

MH-2

11X17 format (431x279mm)



1: Parking spaces
2: Swale
3: Surrounding buildings
4:Bioretention cell

project	projet
BREE 490 Engineering Design **Design Project**	
drawing	dessin
Conceptual Plan View of Previous Design	
Scale	Echelle
1:175	
Date	Date
04/12/2015	
Design Team	
DB3	
Drawn By	Dessiné par
Jinhao Dong	
Drawing no.	No. du dessin
PVP	

11X17 format (431x279mm)

Appendix C: Vehicle Tracking simulation of parking spaces with standard car and parking space dimensions

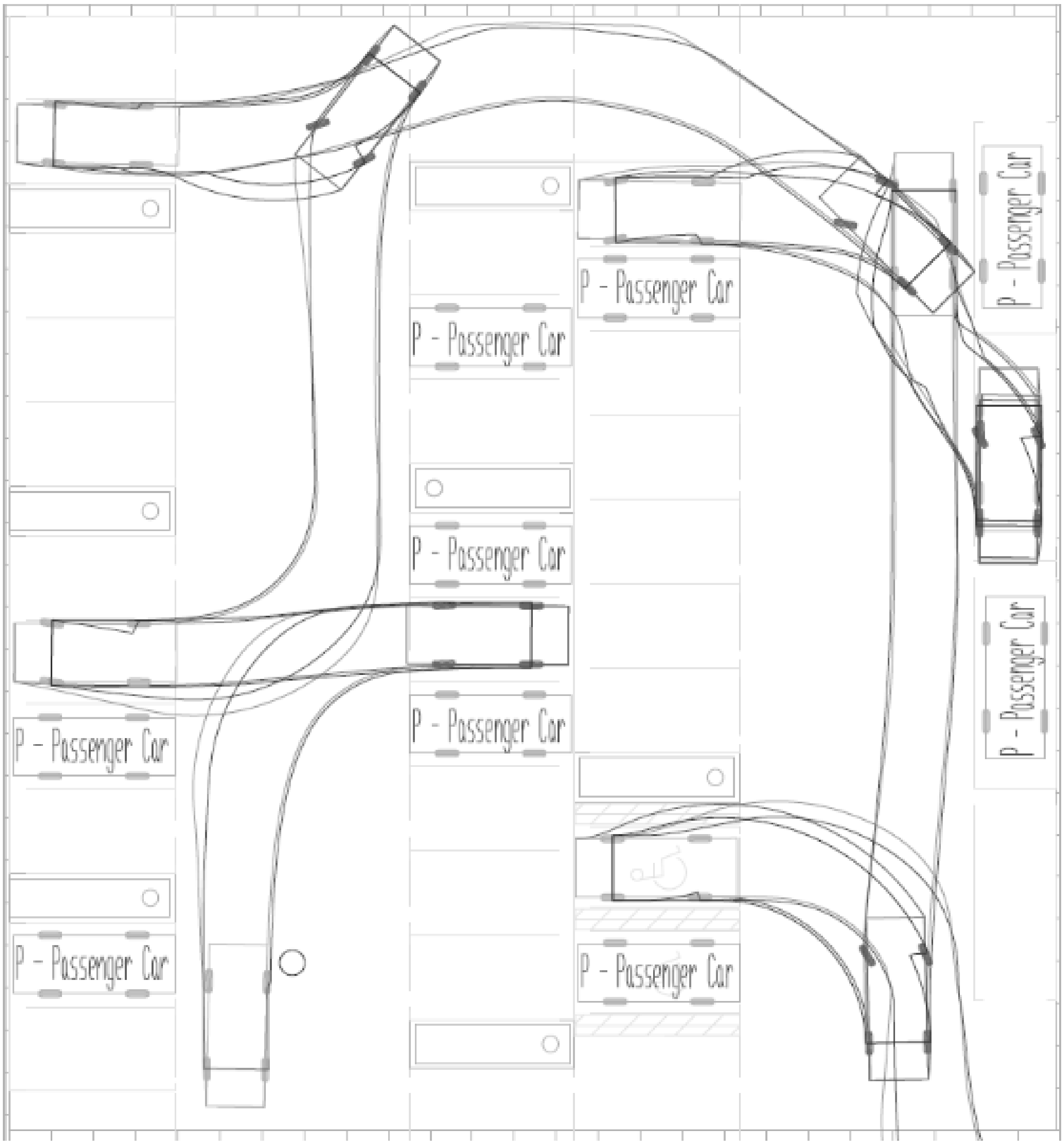


Figure 12, Vehicle Tracking simulation of the final design of the parking lot.

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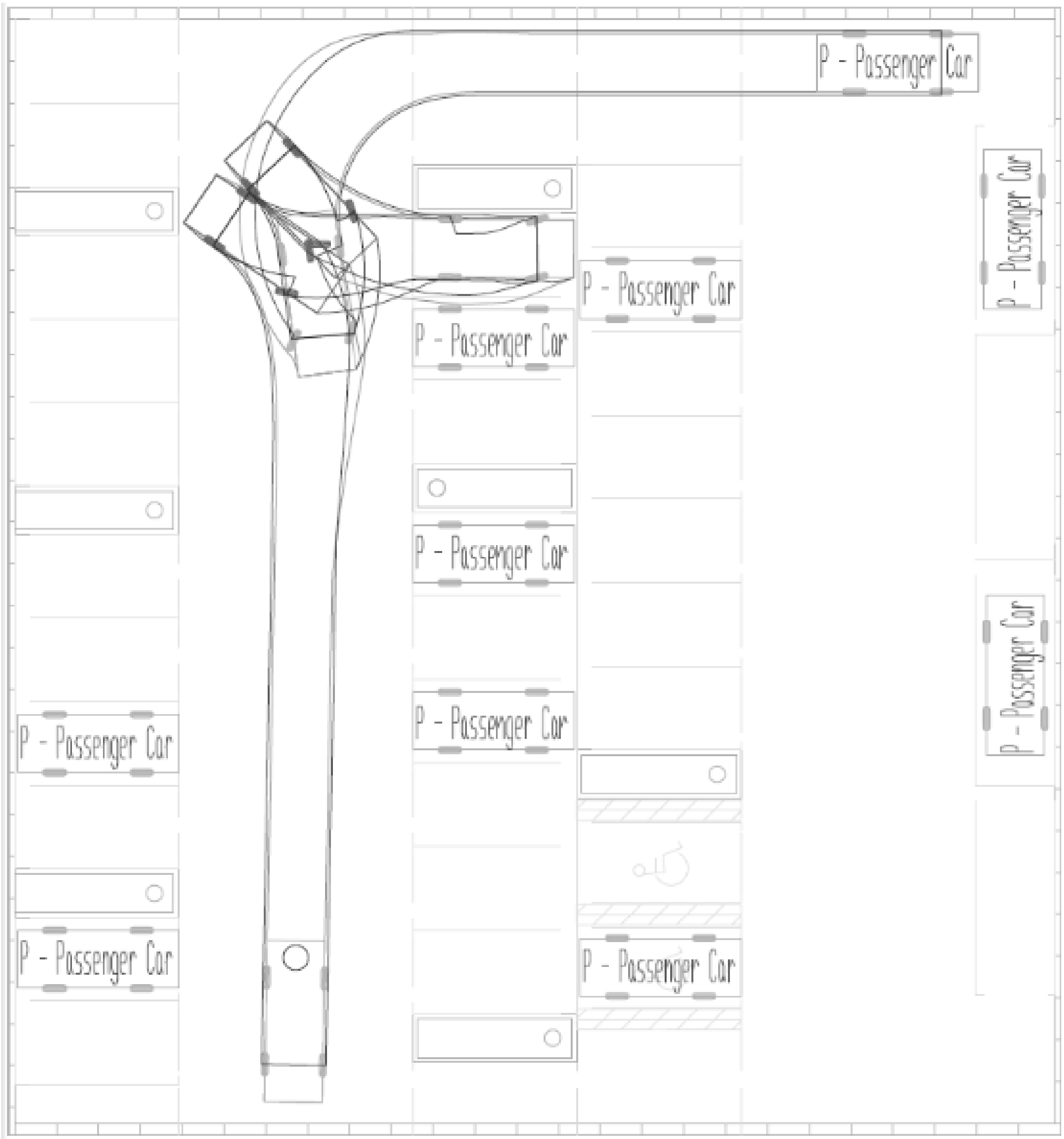

Figure 13, Alternative simulation of the final design of the parking lot with Vehicle Tracking.

Appendix D: Cost analysis of the project

Table 14. Material cost analysis for the St. Willibrord Parish. Costs do not include labor, taxes, discount and inflation rates.

Construction Materials	Description	Quantity	Unit Price	Total Cost	Discounted Cost
Permeable pavers	96 units/pallet (6.4 m^2/pallet)	171	\$5.83/ft^2	\$71,810.00	\$0.00
Silva Cells	1 unit = 0.3 m^3	558	\$430.00/m^3	\$148,995.00	\$148,995.00
Silva Cell - Anchorage	6 per lower level Silva cell	1272	\$2.00/m^3	\$693.00	\$693.00
Silva Cell - Root barrier	0.46 m x 0.61 m - 6 per tree pit	42	\$36.00/m^3	\$12,474.00	\$12,474.00
Silva Cell - Geotextile		640	\$10.00/m^3	\$3,465.00	\$3,465.00
Silva Cell - Soil	27 m^3 of soil per tree pit	175	\$52.00/m^3	\$18,018.00	\$18,018.00
Permeable paver - Joint gravel	ASTM No. 8 Joint fill (1,700 kg/m^3)	6.5	\$30.00/tonne	\$332.00	\$332.00
Permeable paver - Base gravel	ASTM No. 8 Stone	48	\$30.00/tonne	\$2,448.00	\$2,448.00
Permeable paver - Subbase gravel #1	ASTM No. 57 Stone	95.5	\$30.00/tonne	\$4,871.00	\$4,871.00
Permeable paver - Subbase gravel #2	ASTM No. 2 Stone	1624	\$45.00/tonne	\$124,136.00	\$124,136.00
Silva Cell - Joint gravel	ASTM No. 8 Joint fill (1,700 kg/m^3)	1.5	\$30.00/tonne	\$77.00	\$77.00
Silva Cell - Base gravel	ASTM No. 8 Stone	9.5	\$30.00/tonne	\$485.00	\$485.00
Silva Cell - Subbase gravel #1	ASTM No. 57 Stone	19	\$30.00/tonne	\$969.00	\$969.00
Silva Cell - Subbase gravel #2	ASTM No. 2 Stone	57	\$45.00/tonne	\$4,361.00	\$4,361.00
Geotextile	Type IV - 4.57 m x 109.8 m	6	\$4.00/m^2	\$4,579.00	\$4,579.00
Hedge Maple	*Acer campestre*	1	\$220.00	\$220.00	\$176.00
Yellow Buckeye	*Aesculus flava*	1	\$430.00	\$430.00	\$344.00
Thornless Honeylocust	*Gleditsia triacanthos var. inermis*	1	\$370.00	\$370.00	\$296.00
Snowdrift Crabapple	*Malus x 'Snowdrift"*	1	\$290.00	\$290.00	\$232.00
Scholar Tree	*Sophora japonica*	1	\$300.00	\$300.00	\$240.00
Chinese Elm	*Ulmus parvifolia*	1	\$300.00	\$300.00	\$240.00
Green Zelkova	*Zelkova serrata*	1	\$400.00	\$400.00	\$320.00
Piping - Conveyance	150 mm x 3040 mm	72	\$13.90/ft	\$10,008.00	\$10,008.00
Pipe - Cross fitting	150 mm	3	\$399.00/unit	\$1,197.00	\$1,197.00
Pipe - Coupling fitting	150 mm	51	\$28.00/unit	\$1,428.00	\$1,428.00
Pipe - Tee fitting	150 mm	6	\$49.00/unit	\$294.00	\$294.00
Manhole	Precast manhole	1	\$1,500.00/unit	\$1,500.00	\$1,500.00
Manhole adapter	150 mm diameter	2	\$230.00/unit	\$460.00	\$460.00
Hydrobrake		1	\$5,000.00/unit	\$5,000.00	\$5,000.00
Concrete Curb - Tree pit	5.1 m x 1.5 m	93.1	\$62.00/m	\$5,773.00	\$5,773.00
Concrete Curb - Perimeter	35 m x 32.7 m	135.2	\$62.00/m	\$8,383.00	\$8,383.00
Overhead	10%	-	-	\$43,406.60	\$36,179.40
Cost				\$477,472.60	\$397,973.40

Table 15. Pre-construction materials required for prior investigation.

Pre-construction Materials	Unit Price	Total Cost
Test Pits	$33.00/pit	$66.00
Infiltration Tests	$1236.00/pit	$2,472.00
Stakeout of Utilities	-	$508.00
Overhead	10%	$304.60
Cost		$3,350.60

Table 16. Excavation and site prepatation costs during construction.

Excavation & Site Preparation	Description	Unit Price	Total Cost
Excavator	Soil to be removed: 2290 m^3	$30.00/$m^3$	$68,700.00
Loading	15% of excavation	$0.60/$m^3$	$1,374.00
Hauling	65 hours	$175.00/hr	$11,375.00
Compaction of native soil	Area: 1144.7 m^2	$3.00/$m^2$	$3,435.00
Proctor test		$152.00/test	$152.00
Nuclear density test		$44.00/test	$176.00
Sub-base compaction	Area: 1144.7 m^2	$3.00/$m^2$	$3,435.00
Base compaction	Area: 1144.7 m^2	$2.00/$m^2$	$2,290.00
Compaction tests		$44.00/test	$88.00
Overhead			$9,102.50
Cost			$100,127.50

Table 17. Operations and maintenance costs based on different frequencies required for the parking lot.

Operations & Maintenance	Description	Unit Price	Total Cost
Surface sweeping	Frequency: Bi-annually	$676.00/test	$676.00
Paver replacement	Frequency: 8 years		$66.00
Clean out of pipes	Frequency: 10 years		$84.00
Rehabilitation	Frequency: 30 years		$84,021.00
Overhead			$8,484.70
Cost			$93,331.70

Appendix E: RBC Blue Water Project submission and response

Thank you for submitting a 2015 Community Action Grant through the RBC Blue Water Project. While we appreciate the merits of the proposals we receive and recognize the good work performed, we regret that the RBC Foundation will not be supporting your organization at this time. Unfortunately, not all organizations that submit an application can be funded.

We are impressed as always by the number of strong proposals we receive for RBC Blue Water Project. It is exciting to recognize the breadth of support both in Canada and internationally, for our common goal of creating a culture of water stewardship.

Please visit our website www.rbc.com/bluewater for on-going information regarding the RBC Blue Water Project.

We appreciate your interest and wish you success with your fundraising efforts.

Sincerely,

Cameron Miller on behalf of the RBC Blue Water Project Team