UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC Botanical Garden Redevelopment: Multi-Purpose Building and Overflow Parking - Detailed Design

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UBC Botanical Garden Redevelopment

Multi-Purpose Building and Overflow Parking - Detailed Design

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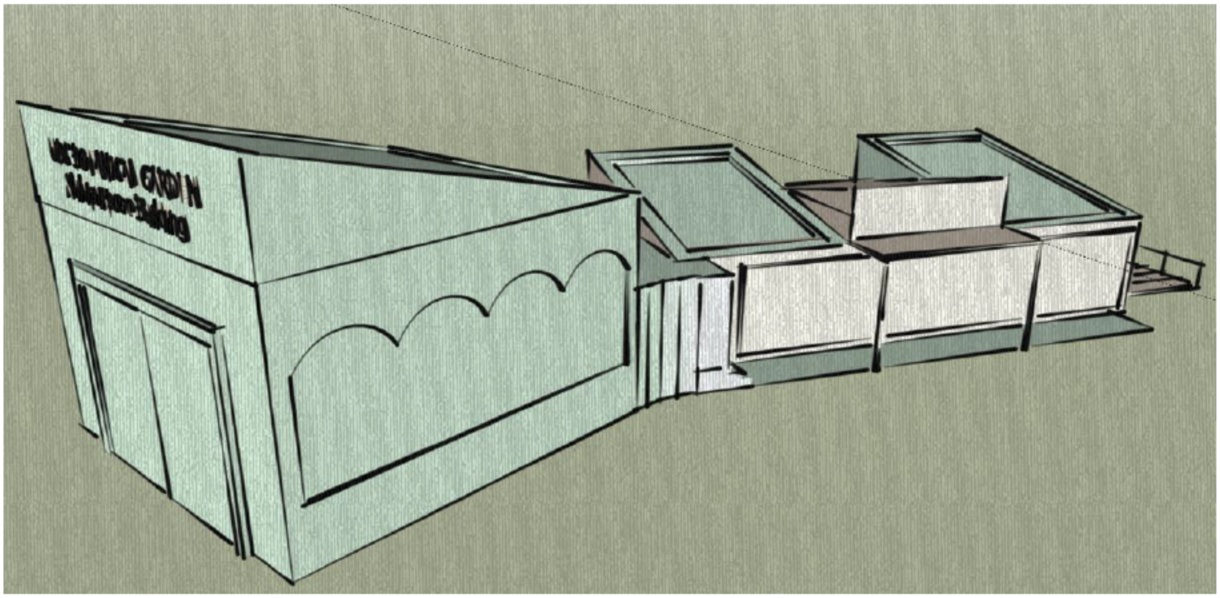
CIVL 446 - Engineering Design and Analysis II

G4 Consulting Ltd.



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Executive Summary

G4 Consulting Ltd. has been contracted to prepare a detailed design of a Multipurpose Building and Overflow Parking as part of the UBC Botanical Gardens Redevelopment Plan. The design presented herein this report meets the Botanical Gardens mission statement while upholding UBC's sustainability goals.

The Multipurpose Building required the most design attention due to its coherent complexity relative to the overflow parking. A reconfiguration of the current parking was carried out as well as changes to the road configuration on SW Marine drive to accommodate the extra demand from the addition of a multipurpose building. The structural engineering discipline was the focus of the design, while geotechnical and environmental engineering were secondary disciplines addressed. The structural aspect involves column sizing, material choice, and structural systems that should be used. Geotechnical incorporates a foundation system for the Multipurpose Building and a site investigation for the overflow parking. Lastly the environmental discipline includes best management practices for managing storm water runoff including the design of a green roof and a permeable road surface.

Autodesk Revit software was utilized to create a three dimensional model of the Multipurpose Building from a conceptual sketch created using SketchUp. This model was used to generate a construction schedule as well as the cost estimate. Our team at G4 Consulting has determined the best and most efficient schedule for completion would be to start the construction in September 2014 with a completion date of April 2015. A cost estimate for the project was also determined using the Revit model and RS means data and the project will cost $2,823,137.09 with the schedules future dates (i.e. inflation) taken into consideration.

While the full details are beyond the scope of this contract, sufficient technical information is provided to carry out this project.

Table of Contents

List of Figures and Tables

List of Figures

List of Tables

1 Introduction

1.1 Project Overview

The University of British Columbia Botanical Garden (UBCBG) was originally established in 1916 with its primary purpose being a teaching and research facility. The Garden has been an important component to the surrounding area and the local community with an internationally renowned collection of flora. The UBC Botanical Garden and Centre for Horticulture, formed in 2000, focuses in promoting research and horticulture training. G4 Consulting has prepared this detailed report outlining a proposal for a multipurpose building facility with many functions and an interesting design, and overflow parking to accommodate extra demand by users of the building.

The Multipurpose Building will provide a venue for education, entertainment and everything in between to come together on a beautiful and environmentally mindful development within the UBC Botanical Gardens. Offsite development to deal with the increase of volume of vehicles includes a re-arrangement of the existing parking lot to maximize capacity and restructuring of the SW Marine Drive around Stadium Road to provide street side parking.

Limitations of this project include uncertainty in project budget and time constraints to perform detailed designs for every engineering component. G4 Consulting has developed a preliminary project cost estimate for the client's consideration, while funding for this project is highly dependent on sponsors. Although not all components were discussed in this report, the main design components that were included in this report can be applicable and replicable for various technical designs related to this project. This report has been submitted for exclusive use by the UBC Botanical Garden and may not be used by any third party without written consent from G4 Consulting.

1.2 Engineering Disciplines

The G4 Consulting team has approached this detailed design in three general civil engineering sub-disciplines which come together to form the finished project. Each sub-discipline is spearheaded by two specialists of G4 Consulting. G4 Consulting meets at least twice a week for progress meetings and to ensure proper communication and mutual understanding throughout the design process.

1.2.1 Structural Engineering

The structural engineering team deals with the structural modelling, analysis and design of the structure that supports and resists the loads. It will be undertaking calculations to approximate the size of beams, columns and slabs. Autodesk Revit software is used to render a three-dimensional model of the building itself.

1.2.2 Geotechnical Engineering

Geotechnical specialists address engineering problems associated with the foundation, ground stability and various ground conditions such as seepage for the project. G4 Consulting uses standard foundation design for this scale of project to ensure the building load is effectively dissipated into the ground below.

1.2.3 Environmental Engineering

Environmental engineering integrates science and engineering principles to improve or preserve the natural environment. G4 Consulting environmental engineers emphasize on storm water management in this project. Designs such as a green roof and permeable surfaces which promotes infiltration and lesser surface runoff are implemented in this project.

2 Conceptual Layout

2.1 Design Concept Rationale

2.1.1 The Design Components

As part of the UBC Botanical Garden Revitalization Project, G4 Consulting Ltd. has developed a concept for the Multipurpose Building and overflow parking to accommodate extra demand by the building users. While upholding the Botanical Garden's goals, objectives, and its mission statement, the G4 Consulting team decided that this component would be the most beneficial to the Garden as it will increase the visitorship, in turn bring in additional revenue that is much needed for the garden to perform ongoing upgrades, keep up with the maintenance and operating costs, and raise awareness of the garden. A unique and innovative design for the Multipurpose Building was chosen as it would provide the necessary means to provide research and education, an event space using state-of-the-art technologies and fixtures to ensure the best experience, and to provide a second entrance point to the Garden. This in turn provides an amenity building that was lacking before. Overflow parking was chosen as an additional component as the current parking capacity would not meet the increased demands from the addition of a multipurpose building.

2.1.2 The Component's Location on Site

The Multipurpose Building will be located in the North Garden on the east side of the Great Lawn, next to the existing service yard to provide easy access for the public, and at the same time not overwhelming the garden. The location, shown in the figure below, takes advantage of the pond to enhance the visitors experience and allow for a more natural and pleasant experience.

Figure 1: Location of Building in North Garden

2.2 Concept For The Multipurpose Building

G4 Consulting has created a concept for the Multipurpose Building using the preliminary design from the proposal phase (CIVL 445) of this project and optimized this structure to meet the needs of the client while upholding the garden's mission and sustainability practices. G4 Consulting brainstormed as a team and developed a 6300 square foot (400 square metre) Sketch Up concept that was determined to be the most beneficial option for the garden. This concept was then realized in detail using Autodesk Revit software and is presented in Figures 2 to 12 below.

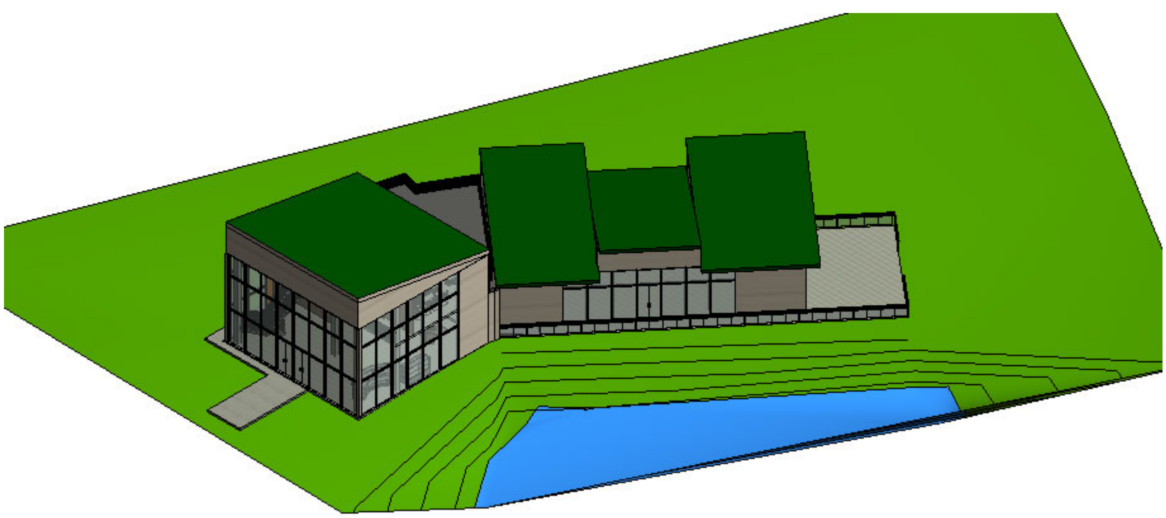


Figure 2: 3D Exterior View - Front-Side 1

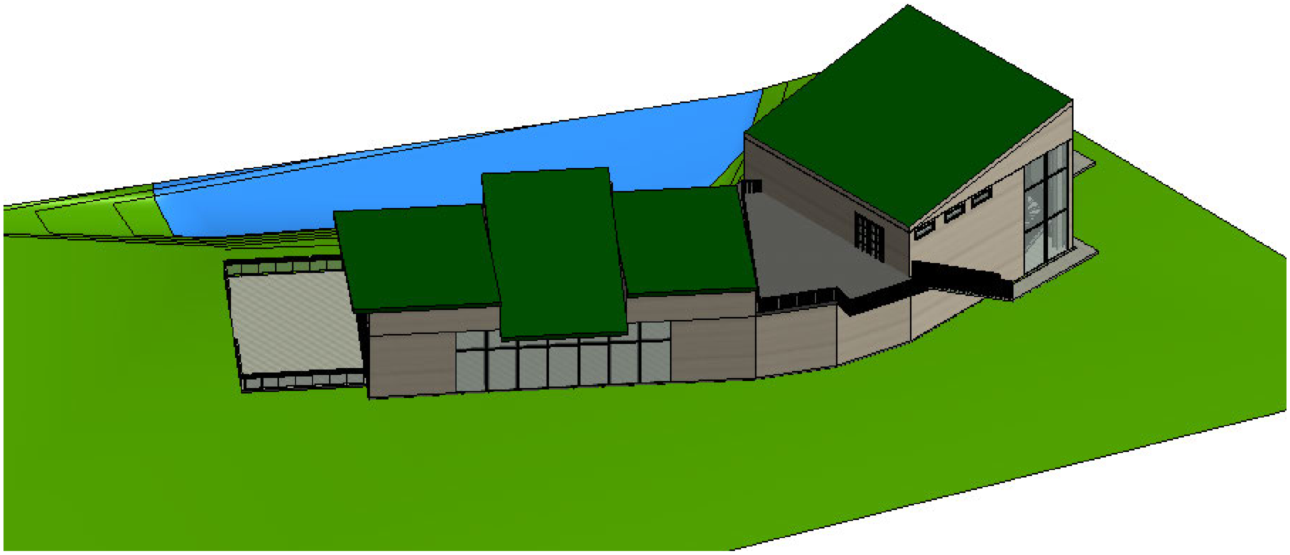
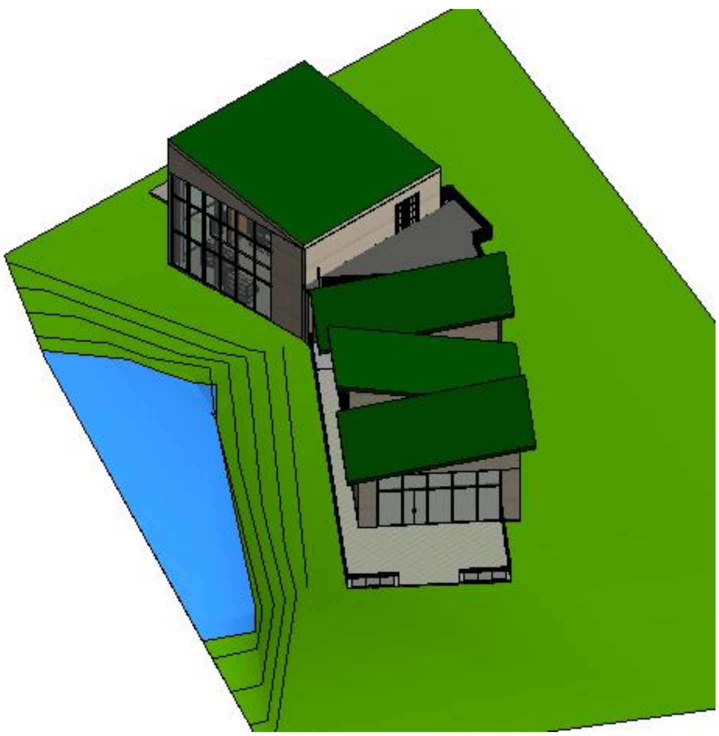


Figure 3: 3D Exterior View - Back



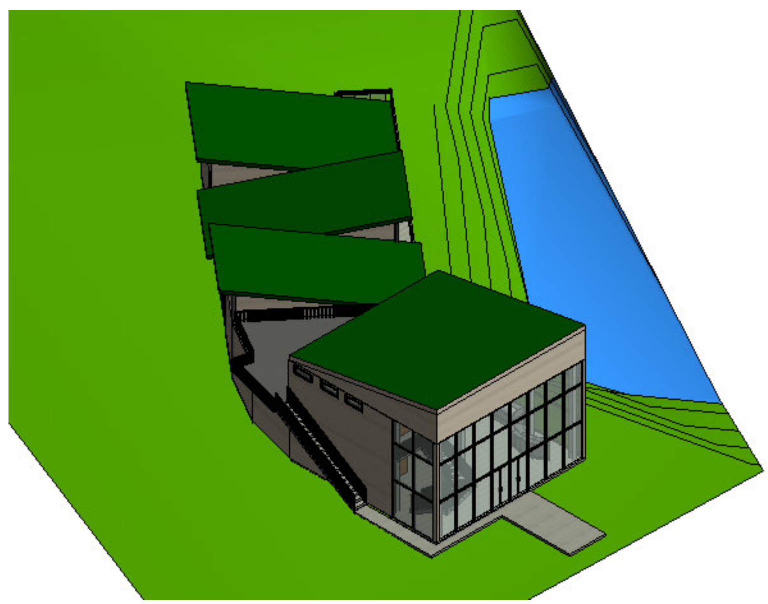
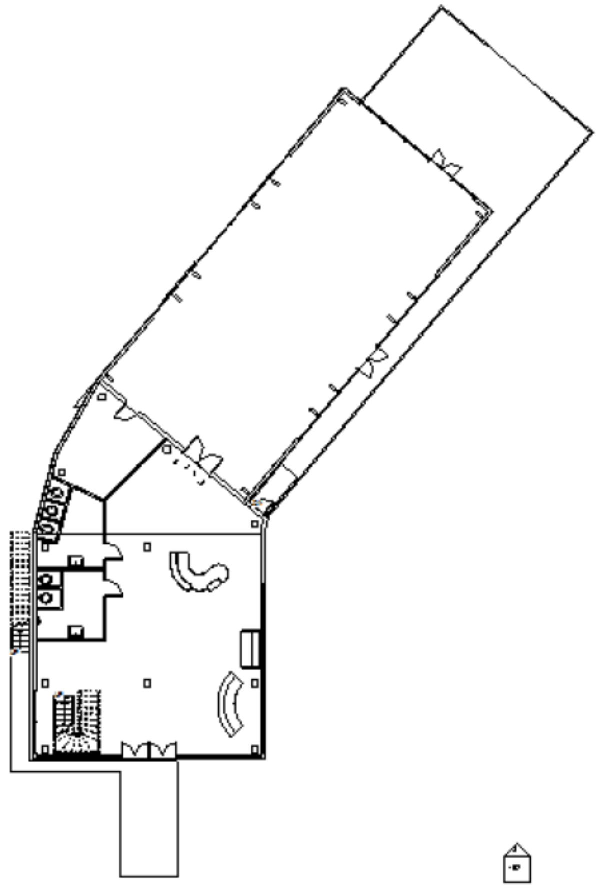


Figure 4: 3D Exterior View - Back-Side

Figure 5: 3D Exterior View - Front-Side 2



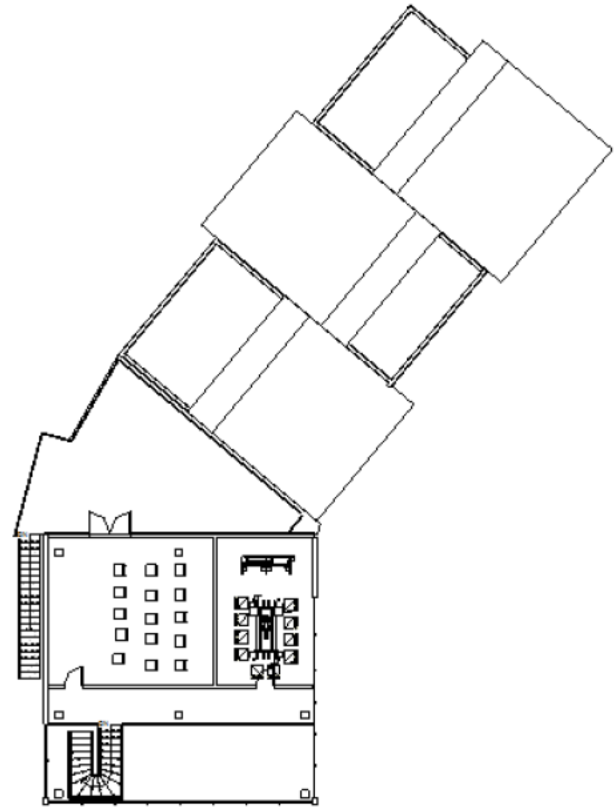


Figure 6: 1st Floor Plan View

Figure 7: 2nd Floor Plan View

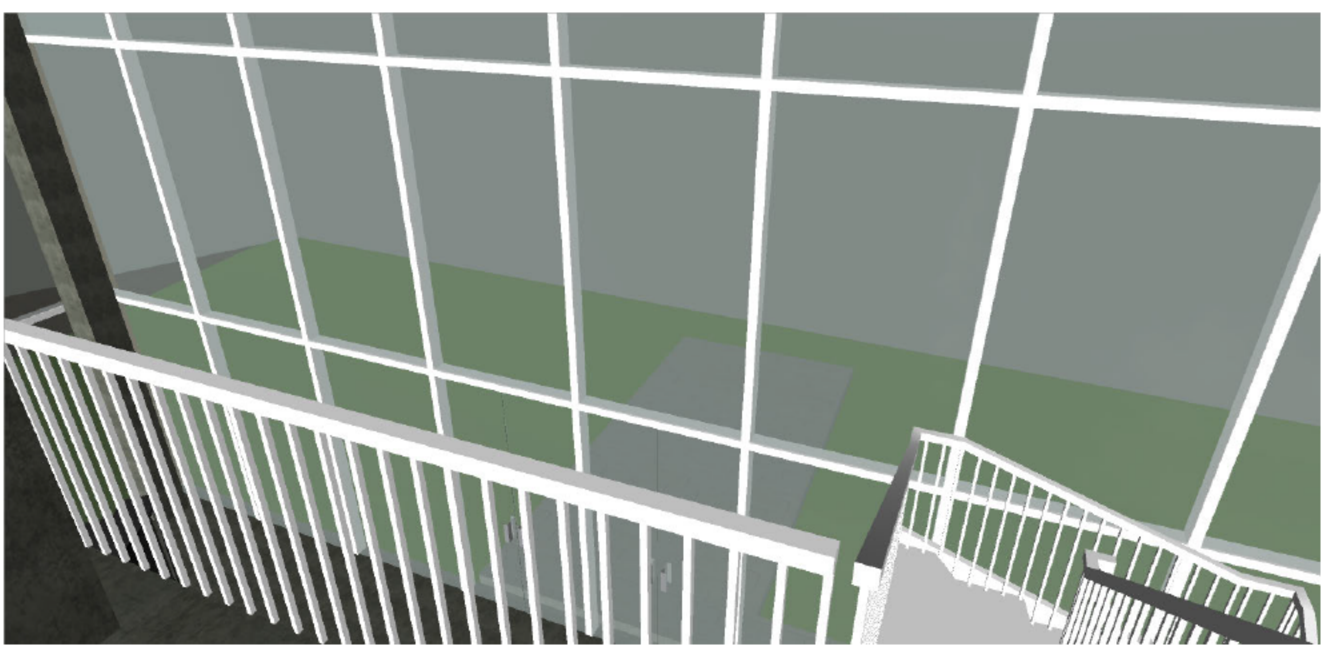


Figure 8: Interior View - Mezzanine Floor - Looking into Atrium Below

Figure 9: Interior View - Mezzanine Floor Learning Space

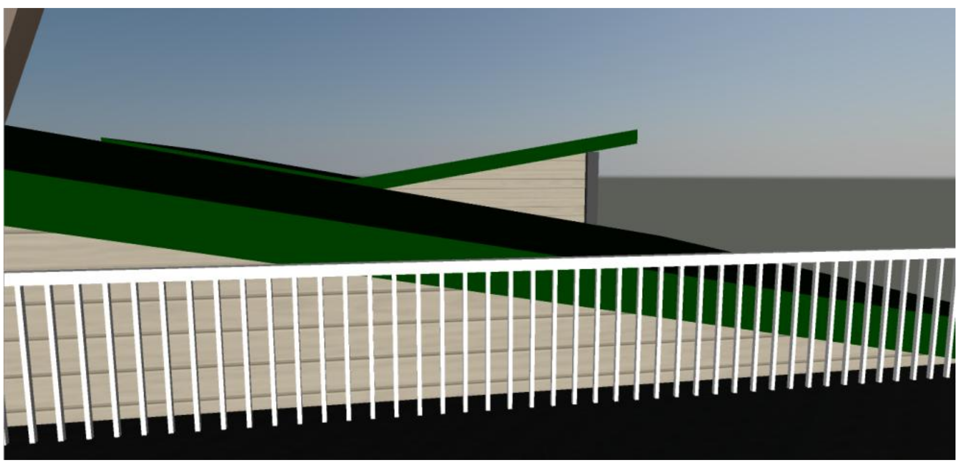


Figure 10: Interior View - 2nd Floor Balcony

Figure 11: Interior View - Event Space- Looking at entrance from Atrium

Figure 12: Interior View - Event Space - Looking out of Floor to Ceiling windows

As visitors enter the Multipurpose Building there is an open atrium with a mezzanine floor that incorporates washrooms, the learning space and a boardroom. To the rear end of the building there is an event space that opens up to uncovered patios to enjoy the vast views of the plush gardens and the pond. There is also a state-of-the-art kitchen within the event space to meet the needs of any organization renting the event space. The building makes use of floor to ceiling windows to ensure sufficient natural light enters the structure and at the same time gives the building users a natural feel as the garden is visible from the interior.

2.3 Concept For The Additional Parking Capacity

As part of the Multipurpose Building in the North Garden, additional parking capacity must be provided to accommodate more visitors, especially during events such as Apple Festival and private functions.

According to interviews with UBCBG representatives, during large events, full capacity of the existing asphalt parking lot on the south side of SW Marine drive is easily reached, and additional visitors are forced to use the West Parkade. A shuttle bus is then employed to transport people to and from their vehicles. This proves to be inconvenient to visitors, especially in inclement weather conditions. Taking into account the financial situation of UBCBG, G4 consulting investigated and proposed solutions which would provide the optimal balance between costs, environmental impacts and parking capacity. Two concepts, which can be built independently if budget constraints are an issue, will be presented below. Environmental consideration will be discussed later in the environmental section of this report.

2.3.1 Rearrangement of the Existing Parking Lot

The existing parking lot on the south side of the garden can approximately accommodate 80 motor vehicles, laid out perpendicular to the aisles. The possibility of rearranging parking stalls at an angle of 45 degrees to the aisles while maintaining their current size of 2.7m by 6.0m was investigated to increase capacity. The footprint of the parking lot itself will not be increased, and the green median will be reduced to give way to pervious pavers and more space for parking. Currently, this lot has only two aisles and a fairly sized green median between them. A possibility for the lot utilizing two smaller bio-swales and permeable pavers in the stalls is presented in the arrangement seen in Figure 13. As can be seen in the overlaid figure, if overall footprint of the parking lot is not increased, only 75 stalls can be accommodated.

Figure 13 - Conceptual Layout for Existing Parking Lot

Seeing that this rearrangement will not increase capacity in a significant manner, G4 Consulting recommends this new layout be implemented once the existing parking lot asphalt surface has reached the end of its service life.

2.3.2 Street Side Parking along SW Marine Drive

The portion of South West Marine Drive from Agronomy Rd to West 16th Ave could be repainted with new alignments to make way for street parking. This change would have to be discussed with the BC's Ministry of Transportation. However, during guest presentations, UBCBG is keen to the idea of UBC taking over this road, as it almost exclusively serves the university community (Grigg, 2014). Driving lane widths, road edges and medians will be kept constant, therefore only grinding and new line painting will be required in most areas. New shoulders may be built to ensure proper subgrade and compaction to handle sustained loads from stationary vehicles.

It is possible to have the Southbound portion of SW Marine Drive remain one lane wide until West 16th Ave. The elimination of one driving lane will give way to a bicycle lane and parking spaces. The same approach is applied on the Northbound portion of SW Marine Drive; here only a small portion (~50m length) of a bike lane is eliminated in order to conserve all existing driving lanes, but there is capability for additional parking on the existing shoulder space. Parking spaces are designed to be three metres by five and a half metres [City Vancouver, 2009]. The plan figure and cross section below illustrate the proposed changes.

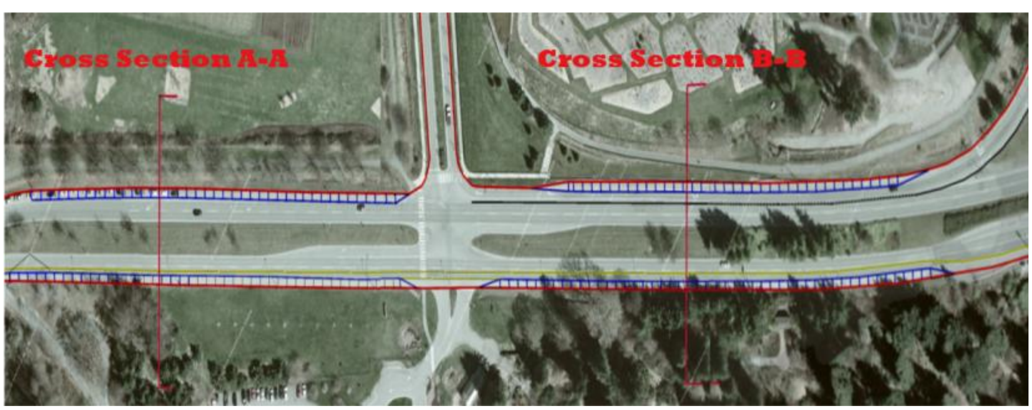


Figure 14: Plan View of New Road Arrangement

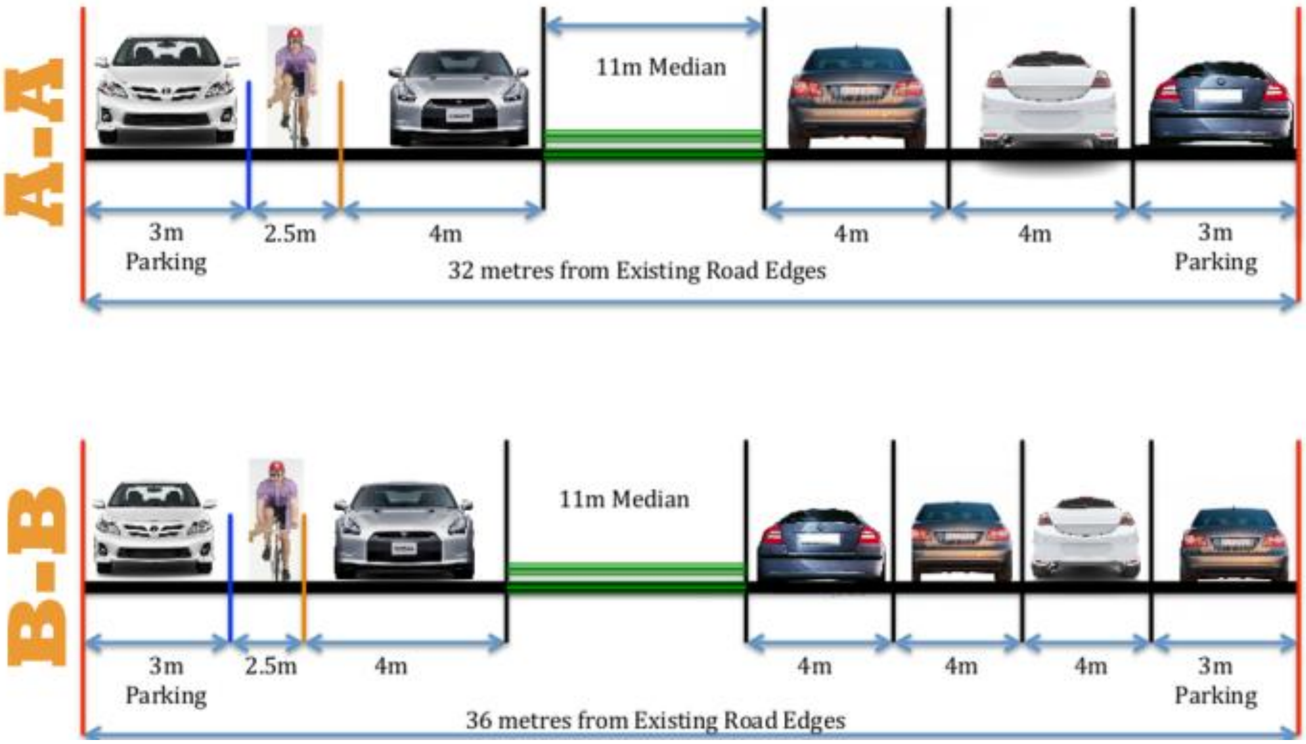


Figure 15: Proposed Road Cross-Sections

This proposed repainting of the road would allow additional capacity of about 140 parking spaces. These spaces should be metered and have maximum parking limits of about 3-4 hours with no overnight parking. While driving lanes are kept the same width, the addition of parking on the road edges may result in a more constricted driving experience. Given the general location, this stretch of road could be reduced from a 60-80km per hour zone to a 40km per hour zone.

2.4 Potential Benefits to the Client and Society

The proposed multipurpose building serves the botanical garden and the society in several ways. These services are described below:

- Educational facilities;
  - This area will be a versatile and stand-alone facility that provides information to groups of visitors through the use of models, samples, videos and displays. This area will be set up in such a way to

allow for a more dynamic interaction, such as presentations and hands-on demonstrations with plants for school field trips, university student tutorials and private groups.

  - The Boardroom on the mezzanine floor will allow UBC executive members, and those alike, to rent the space for meetings. The learning centre/classroom beside the Boardroom will also be rentable to students for learning and research purposes.

- Event areas;
  - The modern event space will provide views and access to The Great Lawn through a wrap around deck. This space will be flexible allowing events during the summer to centre more heavily on the outdoor portion of the gardens, while providing a warm and intimate setting for events during the winter months.
  - It will have an administrative area and a kitchen, which could be used for events such as Apple festivals or private functions such as weddings.
- Second entrance point to the Garden;
  - This allows visitors to enter and exit directly through the North Garden. Along with this entrance, visitor-greeting facilities such as a ticket booth, small café and gift shop will also be included in the building’s atrium.
  - A second entrance eliminates the need for a pedestrian bridge as visitors do not have to cross SW Marine Drive to enter into the garden.

Offsite development to deal with the increase of volume of vehicles includes a re-arrangement of the existing parking lot to maximize parking capacity and restructuring of the SW Marine Drive around Stadium Road to provide additional parking, which reduces parking congestion around the garden as well as ease traffic flow.

3 Design Component - Structural

The succeeding sections will describe the general structural layout and highlight the materials used within different elements of the structure. A detailed calculation has been carried out for a typical glulam column where the gravity load demand and resistance have been identified. Typical column connections have also been provided and discussed.

3.1 General Description

A multipurpose building was designed for the UBC Botanical Gardens to provide the following features:

- Welcome centre and entrance
- Dedicated learning space
- Flexible meeting space
- Event space
- Rooftop and ground level patio

The building is a composite structure composed of structural wood and concrete elements. These materials were chosen for a number of reasons:

- Wood members are aesthetically pleasing
- Wood is a sustainable building material
- Concrete is a relatively inexpensive material in the Vancouver area and is easily shaped
- Concrete and wood are durable products
- Common materials used by contractors in the region

A summary of the materials used for different elements of the building is shown in the table on the next page.

Building Element	Materials Used
Roof	Glulam rafters with tongue and grove decking
Framework	Glulam beams and columns (main event space & atrium), concrete beams and columns (Mezzanine floor & rooftop patio)
Exterior walls	Curtain wall with large glass panels and metal frame, exposed concrete
Interior Walls	Standard wood framed stud walls
Mezzanine Floor	Reinforced suspended concrete slab, beams and columns
Ground Floor	Reinforced concrete slab on grade and foundation
Ground level patio	2’X2’ pavers
Wrap around deck	Pressure treated drip deck with cedar decking

Table 1: Construction Materials Used in Structural Design

General assumptions for the detailed design include:

- Standard load duration
- Dry service conditions
- Untreated wood
- Normal importance factor

3.2 Structural Demand

The gravity load demand is calculated for a typical column in the main event space and can been seen in Figure 16 below. It should be noted that lateral forces have not been considered in the loading demand for the column. A lateral load resisting system may be required which could be in the form of bracing or shear walls.

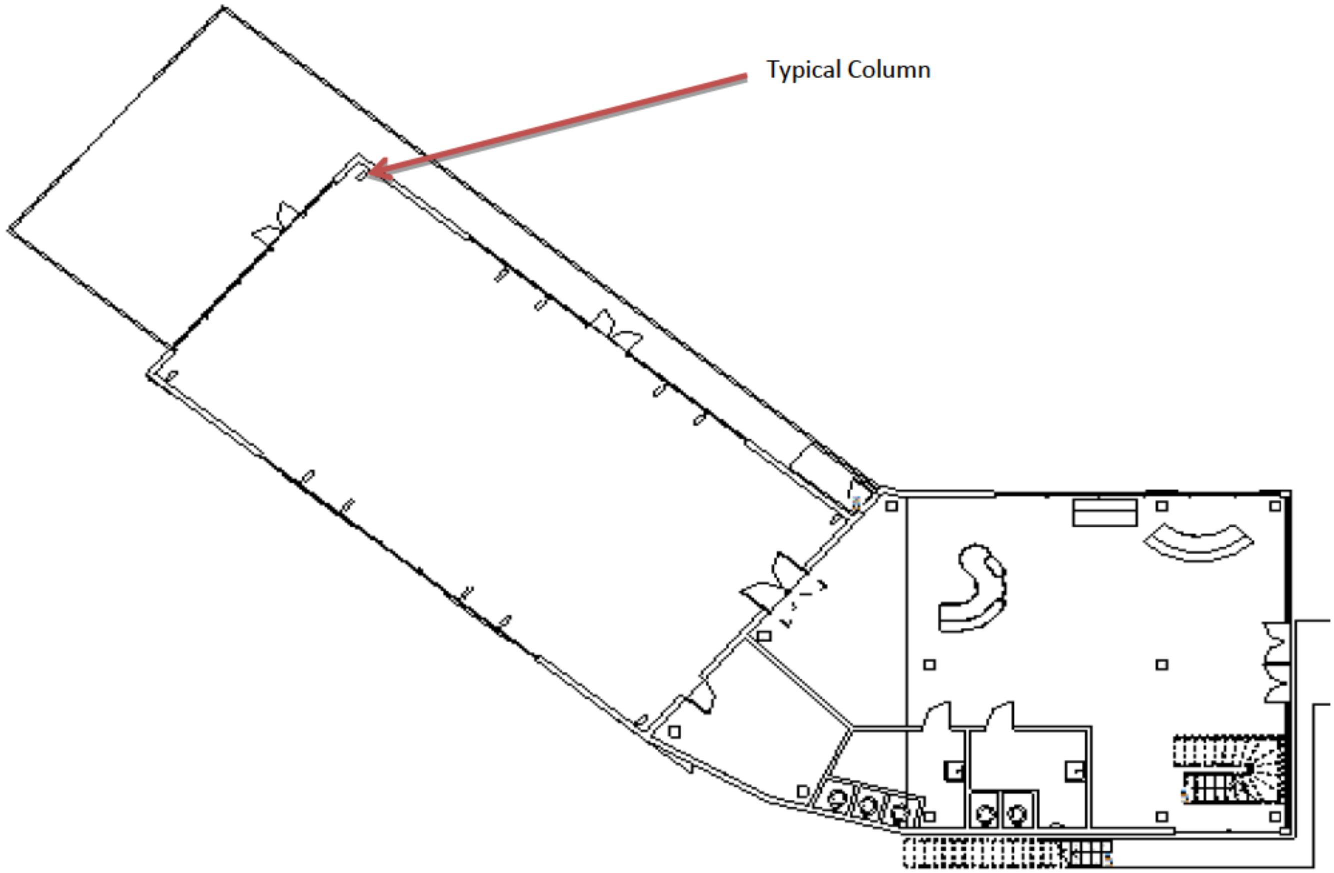


Figure 16: Location of Typical Column

A summary of the calculated gravity loads is provided in Table: 2. The snow load was calculated using a ground snow load (S_s) of 1.9 kPa and associated rain load (S_r) of 0.3 kPa (UBC Technical Guidelines, 2014). Using these values the total snow load was calculated to be 1.72 kPa. A live load of 1.0 kPa was used for the roof (Wood Design Manual, 2010). A dead load of 2.48kPa was calculated for the entire roof structure. The dead load calculation takes into account many materials of the roof including the green roof growing media (saturated weight), decking, rafters, beams and others elements. The values used for the material loads were taken from the Wood Design Manual (WDM), 2010. These values have also been adjusted to account for the slope of the roof using simple trigonometry.

Structural Design Loading - Gravity Loads

Snow Load	S = Is [Ss(Cb*Cw*Cs*Ca) + Sr] where:				
	Ss= Ground snow		1.9 kPa		
	Cb= Basic roof snow load factor		0.8		
	Cw= Wind exposure factor		1.0		
	Cs= Slope factor (all slopes < 15 deg.)		1.0		
	Ca= Shape factor		1.0		
	Sr= Associated rain load		0.3 kPa		
	S= 1.0 [1.8(0.8 * 1.0 * 1.0 * 1.0) + 0.2] =			**1.72**	**kPa**
Live load for roof				**1.0**	**kPa**
Dead loads	Roof structure	Growing media-6" saturated	1458 Pa		
		Membrane	20 Pa		
		Insulation	31 Pa		
		Sprinklers	31 Pa		
		Other fixtures	31 Pa		
		Glulam Rafters	269 Pa		
		T & G Decking	465 Pa		
		Glulam Beam	178 Pa		
		Total		**2482**	**Pa**
				2.48	**kPa**

Table 2: Gravity Load Calculations

After calculating the dead, live and snow load, standard load combinations were calculated to find the governing case. Case 3 was found to be the governing case with a total factored load of 6.18kPa. A summary of the load combinations is shown in Table 3 below.

Load Combinations

Case	Principal loads	Companion loads		
1	1.4 D		3.47	kPa
2	(1.25D or 0.9 D) + 1.5L	0.5S or 0.4W	5.46	kPa
3	(1.25D or 0.9 D) + 1.5S	0.5L or 0.4W	**6.18**	**kPa**
4	(1.25D or 0.9 D) + 1.4W	0.5L or 0.5S	3.96	kPa
5	1.0D + 1.0E	0.5L or 0.25S	2.98	kPa

Case 3 governs

Table 3: Load Combinations

3.3 Detailed Design on the Column

The roof section has an area of 74.1m^3 and the tributary area supported by the column is 18.7m^3. Using the factored load and tributary area, the factored column load was found to be 116 kN.

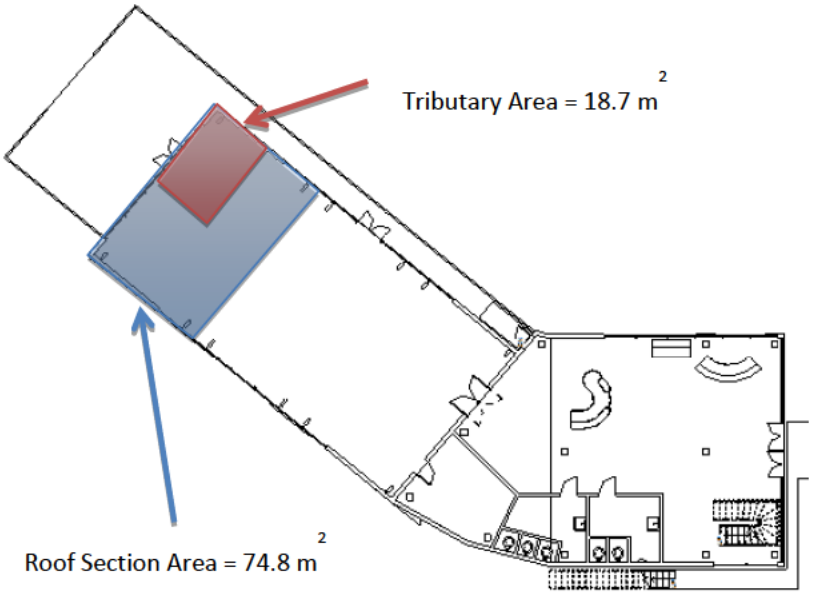


Figure 17: Tributary Area for a Typical Column

It was assumed that the column is effectively pinned at both ends. A column length of 4.5m was used because it is the longer of the two column heights in the event space and therefore the critical case. The column satisfied the WDM checklist for standard column therefore the column selection tables could be used. Below is a summary of the checklist:

1.	Is load duration "standard"?	✓
2.	Is the service condition "dry"?	✓
3.	Is the material free of strength reducing chemicals?	✓
4.	Is the effective length factor k_e equal to 1.0?	✓
5.	Is the column concentrically loaded?	✓

Table 4: Column Checklist

Using the WDM column selection tables a 175mm x 152mm 12c-E Spruce Glulam column was selected. The P_{rx}, P_{ry} values for the selected column were greater than the P_f demand load, therefore the column is deemed to be acceptable. Other columns may satisfy the demand load but this is the most efficient glulam column for the loads identified. It is recommended to use the same size column throughout the building to improve constructability.

Column Design

Given values and Assumptions
>>unbraced length = 4.5m (higher side)
>>Column effectivly pinned at both ends
>>Column supports beam above

Calculation

Tribuatry area	T.A.= (6.76m/2)*(11.06m/2) =	18.7	m^2
Total Factored load	Pf= 6.18kPa * 18.7m^2=	116	kN
Effective length	KeLx= KeLy = 1.0 * 4.5m =	4.5	m

Standard checklist satisfied in WDM section 3.3

From Beam selection tables try 175mm x 152mm 12c-E Spruce Glulam	
For KeL = 4.5m	
Prx= 161kN>116kN	acceptable
Pry= 209kN>116kN	acceptable

Use 175mm x 152mm 12c-E Spruce Glulam

Table 5: Column Design Calcualtions

3.4 Column Connections

A detailed design of the beam-column and column-base connection was not conducted as part of this report but a typical beam-column and column-base connection detail has been provided in Figure 18. Both of these connection details have been selected from the Wood Design Manual, 2010. These connections have the capacity to resist some lateral forces and uplift forces.

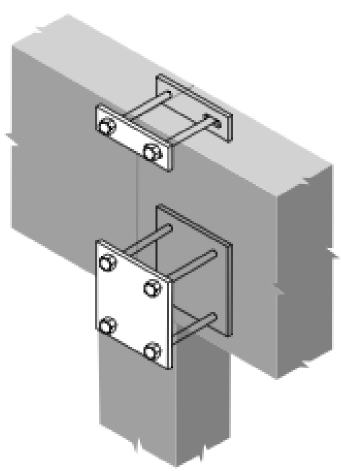
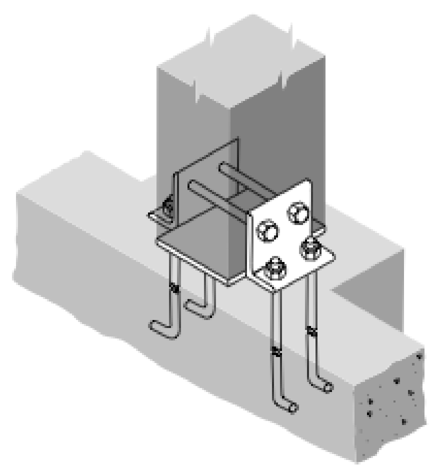
	
Beam-Column Connection	Column-Base Connection

Figure 18: Typical Connection Details (Wood Design Manual, 2010)

4 Design Component - Geotechnical

The following section will address contributions of the geotechnical engineering discipline to the Multipurpose Building and the additional overflow parking concept, focussing on the foundation design of the Multipurpose Building.

4.1 Site Investigation

A site investigation will be carried out prior to construction to characterize the in-situ geologic conditions of the site and to verify the accuracy of assumed design values. The results of the site investigation will be compared to similar investigations on the UBC campus for cross-referencing purposes. This site investigation will confirm the expected ground profile as having an upper layer of dense silty sand and till material underlain with dense sandy gravel.

The site investigation will be carried out over one week and will involve a mud rotary drill crew drilling three boreholes at specified locations as shown in Figure 19. The boreholes will be drilled to 15m depths to ensure any potentially hazardous conditions are located. During the drilling process, Standard Penetration Testing (SPT) will be carried out at two metre depth intervals to characterize soil strength parameters. In addition, Cone Penetration Testing (CPT) will be carried out adjacent to the three boreholes to further define soil behaviour and characteristics. The site investigation is expected to cost $7500.00.

Figure 19 Site Investigation Borehole Locations, denoted by White Xs

4.2 Excavation

After the site investigation has been carried out and results have been analyzed, the site will be prepared for construction. The top soil will be stripped and the 400m^2 site footprint will be excavated to a depth of 2.5m. This depth has been chosen in order to completely remove the upper silty sand unit ensuring the structure is supported on a homogenous foundation material that will experience minimal differential settlement effects. Based on analyses of previous site investigations in the area, the silty sand unit extends down from depths anywhere from one to five metres, therefore an average depth of 2.5m has been assumed for design and will be confirmed by the site investigation. The excavation side walls will be sloped at a maximum 2H:1V to minimize sloughing potential and ensure site safety standards in accordance with WorkSafe BC OHS Regulation, clause 20.81. A total of 1000m^3 of material will be excavated and disposed of off-site at a cost of approximately $150,000. It is expected that a single excavator crew will complete all excavation works at an average production rate of eight cubic metres per hour over the course of twenty work days (Methvin.org).

Special care may be required while removing material adjacent to the garden pond to ensure water does not seep into the excavation area. The observational method will be used to monitor pond behaviour, and if necessary the pond will be temporarily drained. For design purposes it has been assumed that the water table is located sufficiently beneath the bottom of excavation to avoid groundwater seepage issues, and will be confirmed by the site investigation. In addition a sump will be constructed within the excavation and a pump will be kept on hand should any water seep into the excavated area during construction.

4.3 Fill To Grade

Upon completion, the excavation will be visually inspected by a certified geotechnical engineer to verify competent soil has been reached. Following acceptance of the sub-grade, two types of structural fill material will be used to fill the excavation and provide adequate foundational support to the structure. From a depth of 2.5m to 1.5m a structural gravel fill will be placed, levelled and compacted using a static roller. This gravel fill will be classified as blast rock and supplied at a cost of $6000; it will be placed in five lifts of 200mm to ensure adequate compaction throughout the material. This material has been chosen due to its relatively non-expensive unit cost ($10.00 per cubic metre) in addition to its ability to quickly dissipate excess pore pressures. Furthermore, it can be reasonably assumed that such a material will have negligible settlement effects in the short or long term if placed and compacted adequately.

At a depth of 1.5m a geotextile fabric will be installed to ensure fine particulate cannot settle within the gravel layer, upon which a structural sand fill designated as 0-40mm crush sand will be placed in 150mm lifts to the top of the excavation, supplied at a cost of $6000. The sand will be placed and compacted at optimum moisture content to ensure a rigid, uniform, and strong foundation for the structure. It has been assumed that the sand fill has an effective friction angle, φ', of 32 degrees and a unit weight of 20 kN/m^3, as per Table B4.5 on Page 451 of *Earth Retaining Structures* (Budhu). It is anticipated that material placement and compaction will cost approximately $1500 (Methvin.org) .

4.4 Foundation Design

The primary foundation system for the Multipurpose Building consists of reinforced concrete spread footings constructed beneath structural columns, connected around the structure perimeter by reinforced concrete strip footings with an on-grade reinforced concrete mat foundation over the site footprint. The foundation system has been designed assuming a structural load of 115 kN per spread footing and 15kN per metre of strip footing. A detailed commentary on the calculations can be found in Appendix A

A bearing capacity of the sand fill has been carried out using the following equation:

$$q_u=(\gamma)(D_f)(N_q-1)(S_q)(d_q)(r_q)(w_q)+0.5(\gamma)B(N_\gamma)(S_\gamma)(d_\gamma)(r_\gamma)(w_\gamma)$$

Using the assumed design values above, an ultimate bearing capacity of 1545 kPa has been calculated. For Factored Load and Resistance design (FLRD) analysis a resistance factor φ_r of 0.45 has been chosen as per design guidelines for a semi-empirical procedure using SPT data in Table 21.2, "AASHTO Resistance Factors for Bearing Capacity of Shallow Foundations" (American Society of State Highway and Transportation Officials, inc.). By applying this resistance factor, an allowable bearing capacity of 700 kPa has been calculated.

Figure 20 shows a schematic of the proposed foundation design. Based on bearing capacity analysis a 700mm by 700mm spread footing will impart a pressure of 300kPa on the foundation material, well within tolerable limits. Therefore, a spread footing with 700mm by 700mm dimensions has been selected for design. The bottom of the footing will be located at 1m below grade, allowing 500mm of sand fill to underlie the footing. The footing itself will be 500mm deep with a 500mm pedestal ascending up to connect with the structural columns. It can be reasonably assumed that a sand thickness of 500mm which has been properly placed and compacted will have negligible settlement effects and subsequent calculations have been omitted.

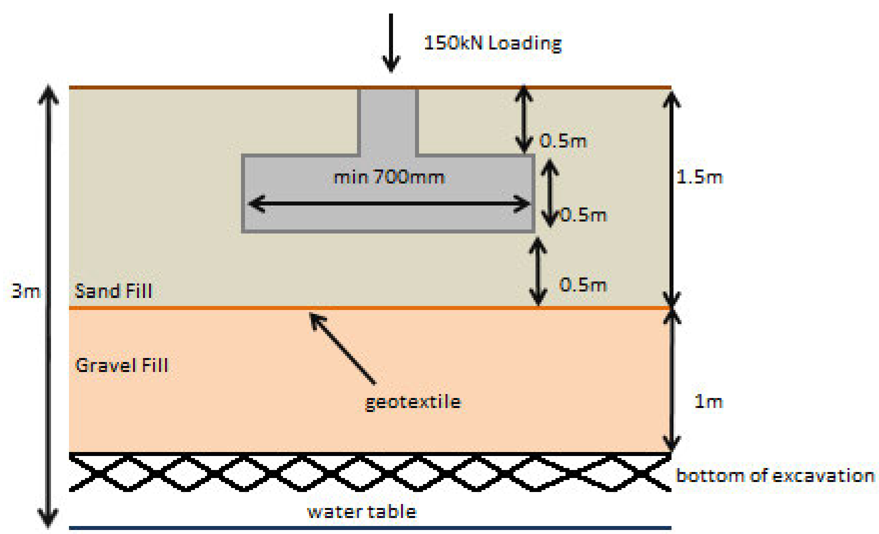


Figure 20 Proposed Foundation Design

5 Design Component - Environmental

5.1 Scope of Environmental Engineering

Environmental engineering works closely with facility managers and other professionals in the assessment, design, and planning of site operations to perform air, water and soil pollution investigations and control of potential source contamination from this project. The importance of environmental engineering in this project is to preserve and improve the environmental quality of the UBC Botanical Garden. This is primarily done by managing stormwater effectively.

5.2 Stormwater Management

Rainwater becomes runoff when it contacts impervious surface such as roofs and roads. Two major issues related to runoff are erosion and contaminant migration. The G4 team defines storm water management as retaining, reusing and infiltrating rain water with the goal of reducing the amount of water reaching the storm sewers. Reducing the amount of roof runoff entering into the storm drain system means less negative impacts to the local aquatic ecosystem and the Botanical Garden itself. This is done by use of an innovative storm water management design which includes, a green roof to attenuate peak runoff, bio-swales to contain contaminants and porous pavements to reduce runoff.

5.3 Hydrologic Analysis

The DFO (Department of Fisheries and Oceans) source control guideline addresses volume reduction by holding 6-month, 24-hour event volume which is also equivalent to 72% of the 2-year rainfall. The average annual rainfall in Vancouver is 1457mm with wet winters and dry summers. Stormwater effectiveness is measured in two ways: runoff volume reduction and runoff peak flow attenuation. Based on regional rain gauges location and the use of Intensity Duration Frequency curve (IDF), rainfall capture target for West

Vancouver is approximately 81 mm. G4's green roof design aims to have a capacity to hold 85% of the targeted rainfall capture.

5.4 Green Roof Systems

5.4.1 Green Roof

A green roof system will be installed on the Multipurpose Building with the purpose of retaining and attenuating peak runoff while providing a natural aesthetic feature to the structure which fuses with the surrounding environment. The layers that make up the green roof are the plant layer, an engineered growing medium, filter cloth (to contain the roots and soil), specialized drainage area, waterproofing membrane and insulation (Peck & Kuhn, n.d). The green roof also protects the roof membrane from UV radiation, thermal gradients and wind pressure. The figure below shows the typical cross section of our proposed green roof system.

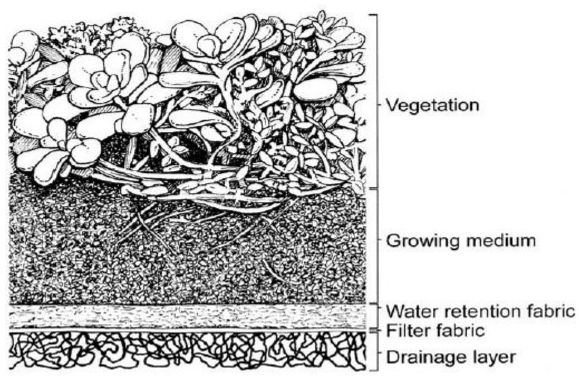


Figure 21 (VanWoert et al., 2005)

5.4.2 Green Roof Design Concern

The followings are green roof design concerns and considerations:

- Depth of soil: Depth of soil affects volume runoffs and the peak attenuation. Soil depth must be sized adequately to meets its operation criteria.

- Growing media: Different soil types have different infiltration rates and capacities. For example, clay has a high field capacity (ability to retain water) but low infiltration rate. Refer to the diagram below.

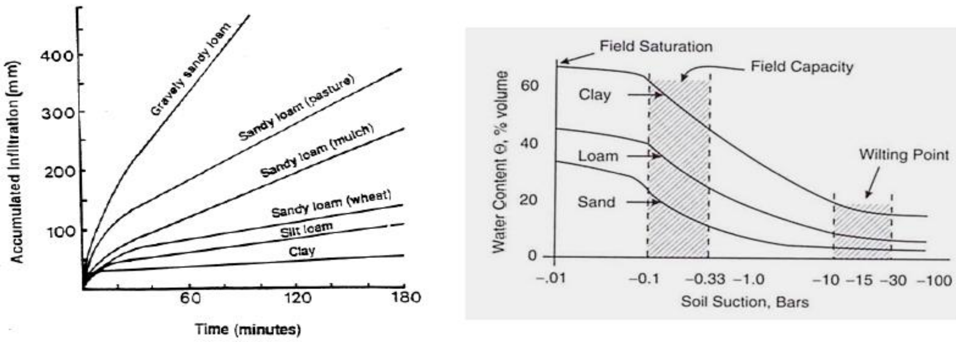


Figure 22 Soil Characteristics on Infiltration and Water Content Properties (Bedient et al., 2013)

- Vegetation type: Vegetation type is important in order to prevent soil erosion and to avoid roof degradation. The vegetation used has to be able to withstand harsh weather conditions.
- Dead load: Dead load of green roof must be designed considering the fully saturated condition.
- Slope of roof: The slope of the roof affects the allowable depth of the soil and the retention time of rain water.
- Slope stability: The infiltrated water that saturates the growing medium may reduce the stability of this slope. The steel support post keeps the growing media in place.
- Regulations: Meets stormwater criteria.
- Operation and Maintenance: Typically, two visits a year are necessary to perform weeding of invasive species, safety and membrane inspection (Peck & Kuhn, n.d)

5.4.3 Green Roof Proposed Design

G4 Consulting Ltd. has proposed an extensive green roof system for the Multipurpose Building. Extensive green roof systems offer a low weight, low capital cost, and minimal maintenance system (Peck & Kuhn, n.d). Having researched various alternatives, it was concluded that for a building of this scale it would be more economical and feasible to order a pre-engineered solution.

The pre-engineered product, “LiveRoof", offers a soil depth of 5.5 inches and can be installed on the 10% sloped roofs. The sloped roof assists in self-drainage and prevents the growing medium to be continuously saturated. It has a saturated loading weight of 1.45kPa and will sustain ground cover plants and water conserving plants. Plants used for this shallow green roof will be grass, mosses, and drought tolerant succulents such as Sedum.

Sedum has the ability to limit transpiration and store excess water (Rowe, Getter, & Durhman, 2012). A depth of 5.5 inches for growing media was chosen because deeper media depths promote greater survival and coverage of the vegetation (Rowe et al., 2012). Growing media composition affects water holding capacity which in turn influences water retention on the decks. Sedum and meadow green roofs have an effective retention time of six months (Graceson, Hare, Monaghan, & Hall, 2013). The inorganic substrate of fine crushed till proved to increase the water holding capacity. G4 uses a layer of light weight substrate consisting of sand, pumice, and compost with a total density of 822 kg/m^3. This green roof system will be placed on sloping roofs using welded posts to hold sections in place. The figure below illustrates the details.

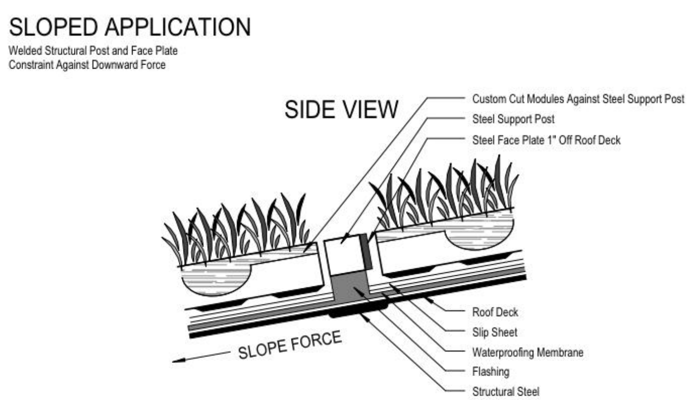


Figure 23: Sloped Green Roof Anchoring Scheme – [Live Roof, 2014]

Slope	10%
Vegetation type	mosses, grass and sedum
Growing media substrate	sand, pumice, compost and crushed tiles
Growing media depth	5.5 inches
Saturated weight	1.45 kPa
Green area	231 m^2
Total dead load	**334.95** kN

Table 6: Green Roof Design Summary

This green roof design is expected to hold approximately 70 mm of rain when conditions are assumed to be dry.

5.4.4 Limitation and Constraints

The high precipitation and low evapotranspiration during the winter months reduces the effectiveness of the decks for water retention by 50 percent (Graceson et al., 2013; Uhl & Schiedt, 2008). The extensive green roof system limits the choice of plants. Plant and waterproofing membrane maintenance are required at least twice a year with an approximately cost of $15 per square meter (Peck & Kuhn, n.d). Operating cost is expected to increase by $20 per square meter after three years. The 10% slope is not an optimal configuration to fully retain stormwater. Once media has reached its water holding capacity, additional rainfall will leave the roof as runoff regardless of media depth (VanWoert et al., 2005).

5.5 Overflow Parking Environmental Mitigation Strategies

Normal asphalt parking lots are impermeable and rain water that falls on it becomes immediate runoff. Soil erosion and migration of leaked vehicle petroleum to the sensitive garden are the negative impact of such runoff. Mitigation strategies such as permeable pavers, porous asphalt and bio-swales drainage were developed and are intended to offset known impacts to the existing botanical garden.

5.5.1 Permeable Pavers and Porous Asphalt

The use of pervious pavers in parking stalls will greatly reduce surface runoff from the lot. The existing parking lot material can also be removed and grinded to serve as filter material installed under the new pervious pavement, which is to be utilized for the parking lot driving aisles. This combination of pervious pavement and pavers will allow for the infiltration of water into the ground under the parking lot. The figures below illustrates the typical cross section of the pervious pavers. The parking lot will be graded in such a manner that the permeable asphalt driving sections will naturally drain into the drains placed under car stalls with concrete pavers and subsequently into the bio-swales in the medians. The use of concrete pavers and the base material between it and the drain will filter out contaminants, such as oil and lead.

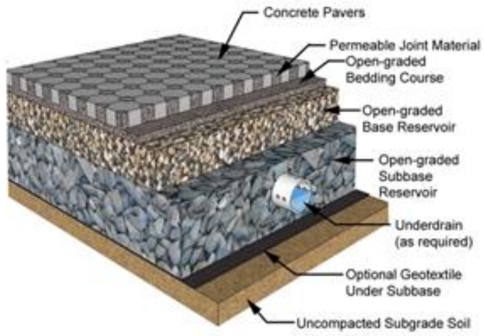


Figure 24: Typical Section of Concrete Pavers and Drainage System – [ICPI, 2014]

5.5.2 Bio-Swale Drainage

Bio-swales are landscaping elements that can effectively remove silts and contaminants from stormwater runoff. Well designed bio-swales detain 80% of runoff water and allow water to infiltrate and consequently reduce runoff volume. Bio-swales are vegetated channels similar to storm drain channels, but with a slope of less than six percent. G4 designs a bio-swale with a meandering path to maximize water retention time. Pollutants of concern are removed through a series of physical and biological processes. While the exact amount varies depending on configuration, type of vegetation, substrate and numerous other variables they are comparable to dry swales which "remove up to 91% of total suspended solids, at least 67% of phosphorus, 92% of nitrogen, and between 80 to 90% of metals" (Loechl, 2003). The bio-swales are to be installed alongside SW Marine Drive in the existing drainage ditches as well as within the medians of the new parking lot structure slated to be built once the existing one has reached the end of its useful life. The figure below shows the typical arrangement of geotextile, compacted subgrade and planting area found in a bio-swale.

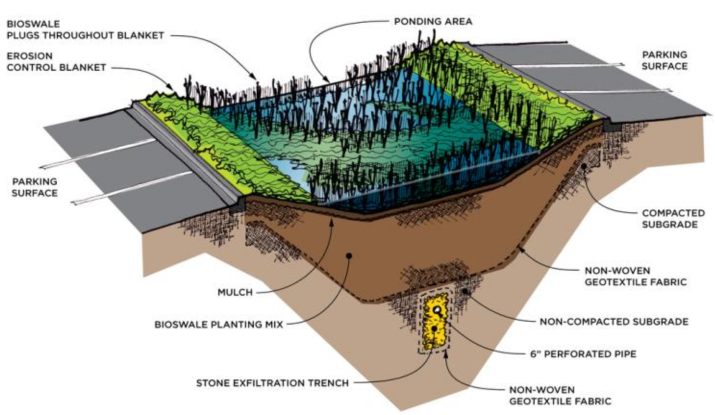


Figure 25 - Typical Bioswale Cross Section – (Gartz, 2014)

6 Schedule/Proposed Implementation Plan

G4 consulting recommends a phased construction approach and to make use of the existing maintenance yard as a site laydown area during construction. The project is estimated to take eight months to complete and it is recommended to begin construction during the fall months. A more in depth discussion of the site plan, phased construction approach, project activities and project schedule is addressed in the succeeding sections. A detailed discussion of the safety and environmental concerns with respect to construction are not discussed but will be addressed by the general contractor prior to construction.

6.1 Site Plan

A site layout is provided in Figure 1 which highlights the area of work and the proposed location of the laydown area. The laydown area will include: equipment storage, site office/trailer, first aid room and material storage. The site will be enclosed with a construction fence to ensure public safety and clear signage will be used for any notices.

6.2 Phased Construction Approach

A phased construction approach is recommended for the implementation of the Multipurpose Building and coinciding parking expansion. Firstly, street side parking will be implemented along SW Marine Dr. to address the limited number of parking spaces currently at the garden. Afterwards, the Multipurpose Building will be implemented over the course of the fall & winter. Rearrangement of the existing parking lot is not recommended until the driving surface needs to be replaced because of the large capital costs and minimal benefits. A phased approach will also be used during the construction of the Multipurpose Building. Three areas have been proposed for the phased approach: the main event space, mezzanine area and entrance atrium. This approach will allow different activities to work in parallel and reduce the overall project duration.

6.3 Construction Activities

General construction activities are included in table 7 below. The durations listed are rough estimates of the major construction activities. In the detailed schedule these activities would be broken down into sub-activities and the durations would be calculated using crew productivity rates. In general, activity durations are calculated from the known productivity rate of a work crew and the quantity of work to be completed. The activities are in order of sequence and some will be able to be done concurrently.

Activity	Estimated Duration (weeks)
Mobilization	2
Site prep and foundation work	4
Structural Work (Timber & Concrete)	6
Roofing	3
Exterior Enclosure	4
Interior Finishes	9
Landscaping	3
Site Clean and Demobilization	2

Table 7: Construction Activities

6.4 Project Schedule and Duration

The total project duration is estimated at 8 months. This value is based off the EDC building, which is located at UBC and used similar materials and methods during construction. The EDC is approximately four times the size of the Multipurpose Building and took roughly 12 months to complete. The duration estimated is not simply one-quarter of the area because of the time to mobilize to site and the difference in the number of storeys between the two structures. The duration is conservative and includes some contingency time to account for the green roof installation and any delays due to weather.

Construction is recommended to begin in the fall months as to not interrupt the garden during the peak visitation season. One area of concern regarding construction during the fall season is the gardens annual Apple Fest event. Our team believes that the garden will still be able to host the event with some slight changes and cooperation from the general contractor. Having construction during a large event such as Apple Fest could actually be a promotion for the new building. Below is a Gantt chart of the key construction activities previously discussed.

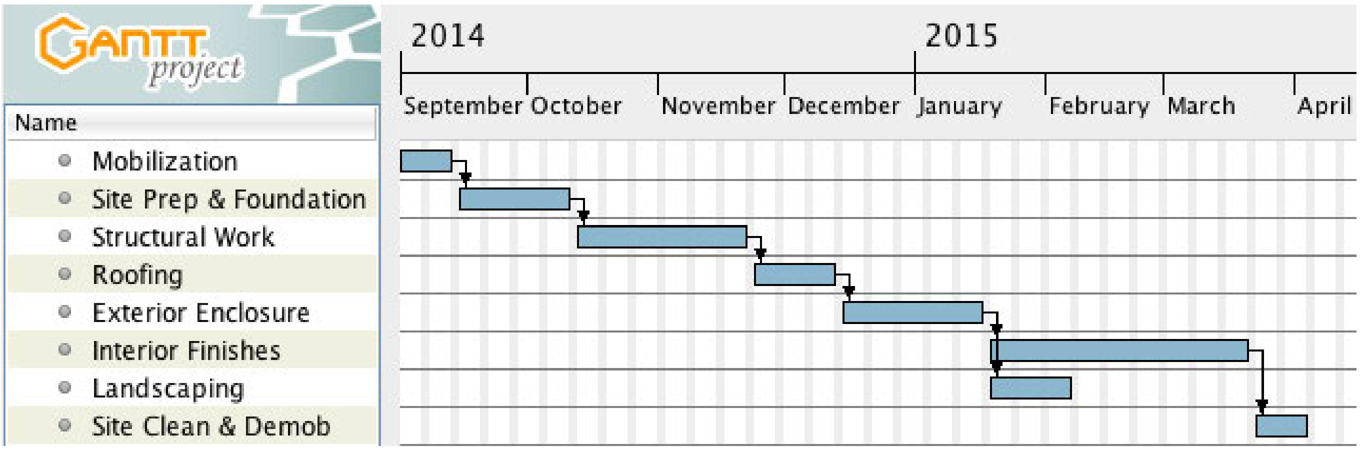


Figure 26: Gantt chart

7 Overall Cost Estimate

The Multipurpose Building has a total floor area of 6300 square feet, determined using Autodesk Revit software. Using the Square Foot (SF) Cost estimating technique, incorporating RS Means data from the Engineering-News Record database with a base unit cost of $242 for Colleges - Science Lab, accounting for inflation, and incorporating an average cost for removal of existing and placement of new asphalt/pavers, a total cost of $2,823,137.09 was determined for this project. This cost also allows for a 10% fee for building on UBC property, and allows a 10% contingency to compensate for any necessary site investigations and geotechnical requirements due to the incompetent material underlying the structure's footprint.

Cost Estimate - Multipurpose Building and Overflow Parking					
Multipurpose Building					
				Unit Cost	Total Cost
1	**Base Cost (2010)**	6300	ft²	$ 242.00	$ 1,524,600.00
2	**Cost (2010 - Size Adjusted)**				
	Proposed Building Area	6300	ft²		
	Typical Size	45600	ft²		
	Area Conversion Scale	0.14			
	Cost Modifier	1.1		$ 266.20	$ 1,677,060.00
3	**Cost (2010-Vancouver)**				
	Location Index Vancouver	106.6			
	Location Index US	100		$ 283.77	$ 1,787,745.96
4	**Cost (2014-Vancouver)**				
	Index 2014	5336			
	Index 2010	4811		$ 314.74	$ 1,982,833.60
5	**Cost (2015-Vancouver)**				
	Inflation(Assumed)	1.5%			
	Cost = $C(1+i)^n$			$ 321.84	$ 2,027,614.24
Overflow Parking					
6	*Asphalt and Pavers*	25000	ft²	$ 12.00	$ 300,000.00
7	*Drainage Swale*	(lump sum)			$ 25,000.00
Sub Total Cost					$ 2,352,614.24
UBC Properties Trust Fee (10%)					$ 235,261.42
Contingency (10%)					$ 235,261.42
Total Cost					**$ 2,823,137.09**

Table 8: Overall Cost Estimate for the Multipurpose Building and Overflow Parking

8 Conclusion

In conclusion our team believes the Multipurpose Building and additional parking improvements add value to the UBC Botanical Gardens. The Multipurpose Building will be an anchor in the north garden providing attractive functions such as a learning space, alternative entrance and event space. Through the addition of street side parking and rearrangement of the existing parking lot more parking spaces will be made available for visitors attending large events and everyday users. G4 consulting undertook design in three disciplines of engineering: structural, geotechnical and environmental. Also, a preliminary construction plan and cost estimate were completed.

The scope of the structural design included creating a 3D model, calculating the gravity load demand, selecting an acceptable glulam column and proposing potential column connections. A detailed model of the Multipurpose Building was created using Autodesk Revit 3D. The snow, dead and live loads were calculated and the governing load case was found to have a total factored load of 6.18 kPa. Using the Wood Design Manual 2010 a 175mm x 152mm 12c-E Spruce Glulam column was selected. Lastly, typical bolted column-base and column-beam connections have been identified.

A four-phase plan has been established to address the geotechnical engineering discipline, focusing on the Multipurpose Building. Phase one will consist of a site investigation to verify in-situ conditions and establish soil strength parameters. Phase two will consist of a site excavation to remove the upper silty sand unit and provide a level foundation for the Multipurpose Building. Phase three will consist of backfilling the excavation to grade with two varieties of engineered backfill material to provide adequate bearing capacity. Finally, phase four will consist of three concrete footing elements (spread, strip, mat) to safely transfer structural loads into the foundation material.

An environmental assessment was done for the proposed overflow parking and multipurpose building. G4 took into account the impacts of the proposed projects and subsequently planned mitigation strategies to minimize environmental impact mainly through stormwater management. The green roof, with a design life of 40 years, captures 85% of targeted retained water as specified by the DFO stormwater management guidelines. Engineered bio-swales trap leaked vehicle petroleum from nearby parking lots and protect the UBC botanical garden from any potential source of contaminants.

The overall duration is estimated at 8 months and construction is recommended to start in the Fall months. The G4 Consulting has determined that the final cost for the Multipurpose Building and overflow parking will be **$2,823,137.09** and incorporates a 10% contingency as well as a 10% fee for the UBC Properties Trust.

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10 Appendix A

Detailed Design Analysis of Shallow Footing

ϕ_r	=	0.45	
ULS	=	450	kPa
SLS	=	300	kPa
Load	=	115	KN

Bearing (ULS)

$q_u=(\gamma)(D_f)(N_q-1)(S_q)(d_q)(r_q)(w_q)+0.5(\gamma)B(N_\gamma)(S_\gamma)(d_\gamma)(r_\gamma)(w_\gamma)$

γ	=	23.0		23.00	KN/m3
D_f	=	1.5	=	1.50	m
N_q	=	$e^{\pi\tan(\phi')}\tan^2(45+\phi'/2)$	=	23.18	
S_q	=	$1+(B/L)\tan(\phi')$	=	1.62	
d_q	=	$1+2\tan(\phi')(1-\sin(\phi'))^2$	=	1.28	
r_q	=	1	=	1.00	
w_q	=	1	=	1.00	
N_γ	=	$(N_q-1)\tan(1.4\phi')$	=	22.02	
S_γ	=	$1-0.4(B/L)$	=	0.60	
d_γ	=	1	=	1.00	
r_γ	=	1	=	1.00	
w_γ	=	1	=	1.00	
B=	=	0.7	=	0.70	m
L	=	0.7	=	0.70	m
ϕ'	=	32	=	32.00	degrees

Q_{load}	=	234.6938776	kPa
q_u	=	1692.874964	kPa
q_a	=	761.7937337	kPa

$Q_{load} < q_a$ therefore adequate bearing capacity