UBC Social Ecological Economic Development Studies (SEEDS) Student Report

RELAXING AND LEARNING: Detailed Design Report for UBC Botanical Garden Revitalization

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RELAXING AND LEARNING

Detailed Design Report for UBC Botanical Garden Revitalization

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Executive Summary

The Relaxing and Learning renovation of the University of British Columbia Botanical Garden will be a staged development incorporating a conservatory, a second entrance serving the north side of the garden incorporating a café and improved educational pathways throughout the garden.

The three components were chosen to best meet the garden's needs of improved community engagement and visibility and enhancing visitor experiences.

This design proposal explores the qualitative social, economic and environmental effects of each renovation component and their benefits to the garden and the surrounding community. Further focus is devoted to the design of the structural frame, foundation and construction planning of the café; with specific details and calculations provided for a sample glulam column and its spread footing. A construction schedule and detailed cost estimate is provided with general economic analysis.

At a project cost of $1.9M and estimated present value of $1.5M, it is recommended that a five to eight year construction timeline be considered to secure funding and reduce present worth, with a break-even horizon expected in ten to fifteen years after project completion.

Relaxing and Learning

Detailed Design Report for UBC Botanical Garden Revitalization

Introduction

The University of British Columbia Botanical Garden (UBCBG) is a haven of tranquility hidden on the south side of the University of British Columbia (UBC) Point Grey Campus. In addition to being a valuable academic resource, it serves the surrounding community. However, it faces a number of challenges. This project aims to address a number of them, chiefly the underutilization and narrow demographic appeal of the garden within the community. Currently, the primary visitors to the garden are retirees (Justice, 2013).

The relaxing and learning renovation of the UBCBG aims to address this concern by enhancing the recreational appeal, as well as the educational capacity and spaces for learning (both academic and life-long) with the development of key infrastructure.

The intent of this report is to provide an exemplar of the design and administration services Group 12 Consulting would provide to the client should we be contracted to complete this renovation.

Design Components

The objectives of this renovation are to increase the community engagement of the garden through a targeted renovation and expansion of garden facilities. The relaxing and learning renovation of the botanical garden consists of the development of educational pathways, a café serving as a second entrance to the northern section of the garden and a conservatory. These three components were chosen to best meet the objectives of enhanced visitor experience, value to the garden collection, cost and potential for value added. Proposed locations for the components are shown in Figure 1.

FIGURE 1: PROPOSED COMPONENT LOCATIONS

Educational Pathways

The UBC Botanical Gardens can provide their patrons with a more interactive experience using a system they already have in place. They have wide paved trails and several quick response (QR) codes set up throughout their plant collections to provide further information to those carrying smart phones using a specialized barcode application. This can effectively allow participation from younger and more technology-savvy patrons as they walk through the various collections. With several upgrades this system can be maximized to allow for a more unique and memorable experience.

For ideal accessibility, the education loops will consist of the existing paved pathways through the North and South Garden. The upgrade will bring the addition of directional signage including distance estimates, allowing wandering patrons to find their desired routes. Select locations will have a full map installed to ensure that no one has lost their way through the network of trails. The upgrade will also consist of a major expansion of the existing QR code system to be more thorough and consistent along the loops. More information will be added to the system with direction from the Botanical Garden staff. The system can also include creative components like interesting info-graphics and games like scavenger hunts. To permit more visitors access to this system, it is recommended that the garden extend its current Wi-Fi range to cover the loop area to facilitate access by users with limited data accessibility on their phones. For visitors who do not possess compatible phones, paper copies of the information can be provided at the garden entrance.

Café/Second Entrance

Currently the North Garden can only be accessed through the tunnel which connects it to the South Garden. It is proposed that a café should be added on the North Garden to serve as both a second entrance point and as another scenic anchor point for the garden. The café will contribute to making the garden a more visited destination on campus. Visitors can use it as a meeting and study space, which will draw people all year round, independent of weather conditions. The café will also be located directly across the street from a bus stop and will also include covered bicycle parking, for better access.

FIGURE 2: RENDERING OF CAFE CONCEPT DEVELOPED BY GROUP 9

The café is meant to promote the sustainable values of the garden by serving organic coffee and using fresh produce to create its menu items. There will be opportunities to showcase examples of sustainable growing through informative displays, free promotional food samples and cooking demonstrations. A waste sorting program will be in place to remind patrons of the recycling and composting opportunities that are available to them. In addition, the leaf shaped roof will also be lined with custom gutters to collect rainwater, allowing to garden to work towards using less potable water for the irrigation of its collections.

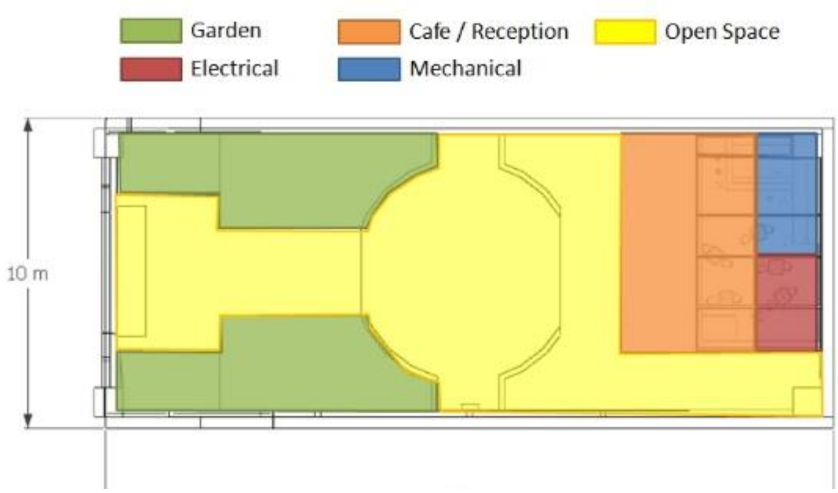

FIGURE 3: CAFE FLOOR PLAN AND EXPECTED USAGE

Conservatory

To diversify the garden's attractions, a conservatory is proposed for the North Garden. The conservatory will serve as a living laboratory for sustainability, increasing the biodiversity found in the garden and providing another anchor point for the garden, regardless of weather. There is potential to use this space as a bird and butterfly sanctuary in addition to housing plant species that would be better suited for indoor conditions. Weddings and other special events may be suitable for this attractive setting as well.

FIGURE 4: RENDERING OF CONSERVATORY CONCEPT PRESENTED BY GROUP 7

Due to UBC building regulations and the Province of British Columbia's 2006 provision, any institutional building larger than 600 square metres will need to achieve a minimum of gold standard as per the LEED 2009 standards system, designed by the Canada Green Building Council. The building design will meet the given criteria in the categories including site development, water efficiency, energy efficiency, material selection, indoor environmental quality, innovative design, and regional priority.

Project Implementation

In order to maintain the operational capacity of the garden during the renovation it is not feasible to undertake the construction of these three components simultaneously. Rather, a staged implementation of the renovation project is preferred. In order to determine the most beneficial order of component construction, Group Twelve Consulting undertook an analytical hierarchy process (AHP) analysis to determine the relative benefits of each component.

AHP involves the structuring of a decision into goal & sub-goal objectives, to establish an overall weighting system used to select the best decision from a list of alternatives. This process involves a pair-wise comparison between each Objective Function and each Sub-Objective Function to assign weighted averages. The process then goes one step further with a pair-wise comparison of each alternative, for all of the Sub-Objective Functions, resulting in a final weighted percentage for each alternative. The results of the AHP are summarized in Figure 5.

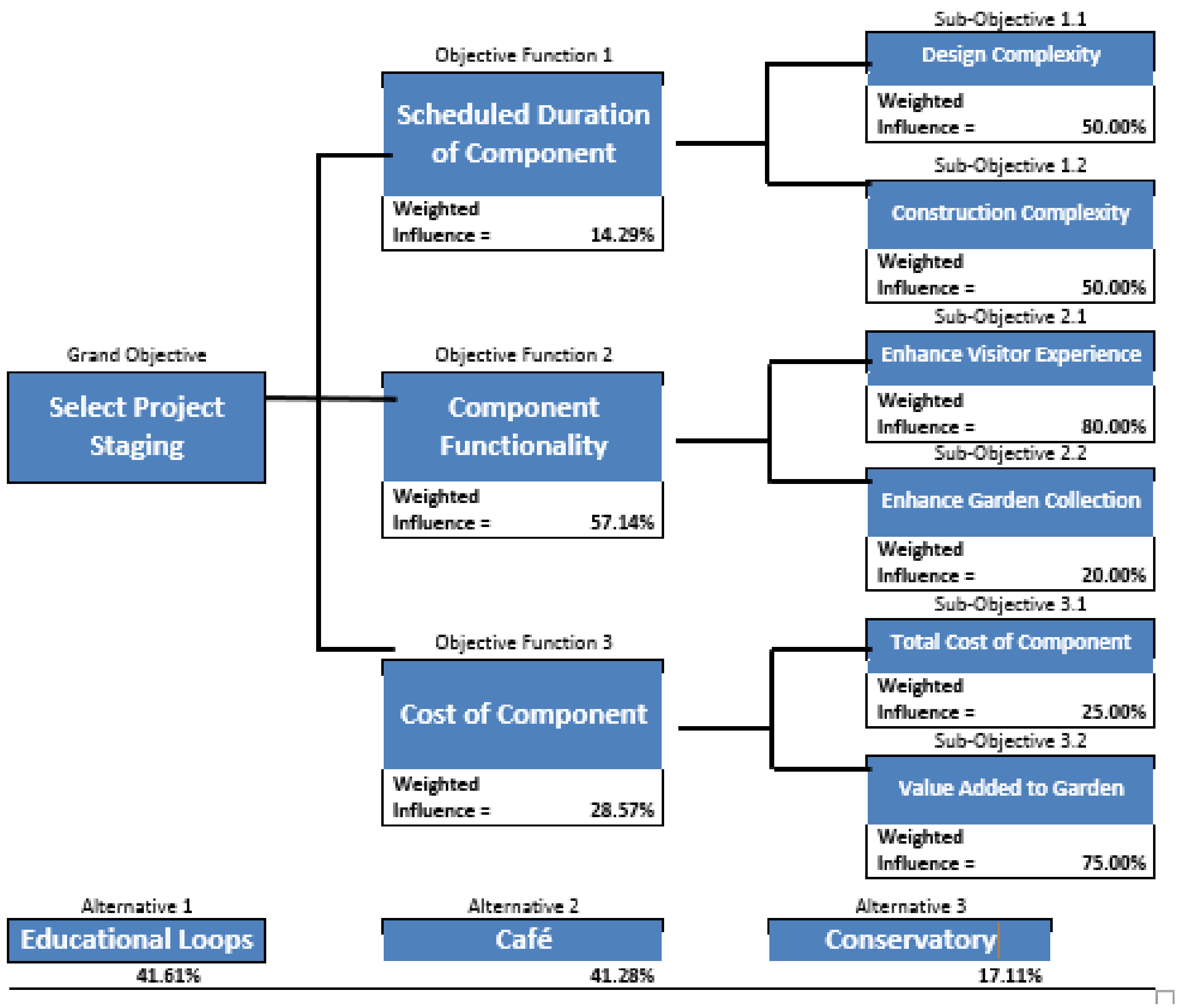

FIGURE 5: SUMMARY OF AHP OBJECTIVES AND CONCLUSIONS

Based on this analysis, it was concluded that development should begin with the educational loops, followed by the café, and end with the conservatory. Although the educational loops provide only marginally more benefit in this analysis, they are a sensible first step, in that they require substantially less cost commitment. Additional details of the calculations used in the AHP analysis are included in Appendix D.

Second Entrance Café: Sample Details

The remainder of this report will focus sample design details for the second entrance café, providing an exemplar of the quality of work and type of design and construction administration services Group Twelve Consulting would provide if hired to complete this renovation.

Structural

The café is a one-story building architecturally designed by Group 9. Its framing consists of wooden columns and beams with a leaf shaped roof structure. A glulam frame was chosen for its obvious advantages of aesthetics, but also its structural integrity, its environmental purposes, and its economic benefits. The glulam frame will be moment connected with different types of steel bolt plate connections and mounted on concrete foundations.

Group 12 Consulting's structural design will include but not be limited to the detailed design of a typical glulam column in the café's frame structure. The structural elements of the café will consist of columns, beams, slabs, foundations, connections and a roof structure. Each structural component will meet corresponding concrete, steel, and wood CSA standards. Once Group 12 Consulting is awarded the design contract we will provide a design for each structural component. The following process outlines a detailed design for a glulam column.

Estimation of Structural Loads

The first step in designing the structural members of the café was to determine typical loading on buildings in Vancouver. Using the National Building Code of Canada (NBCC) and limit states design the following load combinations seen in Table 1 are to be considered.

	Load Cases
1	1.4D
2	1.25D + 1.5L
3	1.25D +1.5S
4	1.25D + 1.4W
5	1.0D + 1.0E

TABLE 1: STRUCTURAL LOAD COMBINATIONS FOR LIMIT STATES DESIGN, VARIABLES AS DEFINED IN THE NBCC (NATIONAL RESEARCH COUNCIL OF CANADA, 2010)

These load cases give typical combinations of factored loading. Using these combinations enables the identification of worst case loading scenarios for each structural member. Seismic analysis and earthquake loading will be completed upon contract procurement.

The dead load of the building includes self-weight of all members and permanent material and equipment integrated into the building such as partition walls as stated in clause 4.1.4 of the NBCC. As the functionality and layout of café is not yet finalized, assumptions were made to calculate the dead load of the building. Including the weight of all the structural members and an appropriate scaling factor, it is estimated that the dead load is 190 kN (National Research Council of Canada, 2010).

Live loading considers temporary and moving loads as well as the use of the building as described in clause 4.1.5. The NBCC gives minimum live loading values for different types of building use. 'Dining Area' was used for the function of our building as it shared similar characteristics to a café. The corresponding minimum value of 4.8 kPa was used for live loading (National Research Council of Canada, 2010).

Snow and rain load is calculated using the formula:

$$S = I_S[S_S(C_b C_W C_S C_a) + S_r]$$

Wind load is calculated using the formula:

$$P = I_w q C_e C_g C_p$$

Snow and wind load formulas can be found in the NBCC and their factors are described in clauses 4.1.6 and 4.1.7 respectively (National Research Council of Canada, 2010).

Using assumptions for the different factors and finding the 1/50 year snow and rain loading for Vancouver in the NBCC resulted in values of 2.0 kPa for snow loading and 2 kPa for wind loading. The typical Vancouver building loads calculated are summarized in the table below.

	NBCC Loading
Wind	2 kPa
Snow + Rain	0.4 kPa
Live	4.8 kPa
Dead	190 kN

TABLE 2: CAFE STRUCTURAL LOADS

SAP Modelling of Structural Frame

A SAP2000 model of the structural frame of the café was developed using Group 9's café architectural design. Additional columns were required to make the frame structurally stable but the shape of the building was kept consistent with Group 9's design. An image of the SAP2000 model can be seen in the figure below.

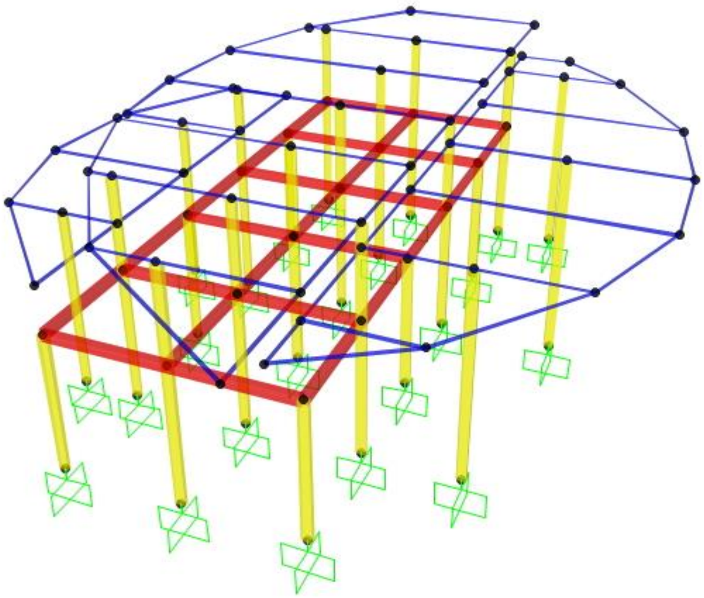

FIGURE 6: SAP2000 MODEL OF CAFE FRAME

Typical Vancouver loads were found using the NBCC were applied in the model. The dead, live and snow loads were applied in the vertical direction of the building, while rain load in the horizontal direction. The wind load was applied against the long face of the building as this yielded larger reaction and internal forces on structural members. Once the loads and their combinations have been applied SAP2000 is able to determine worst case scenarios for internal forces in the structural members as seen in Figure 7. These values were then used to calculate the design capacities required to complete a detailed design of the glulam columns.

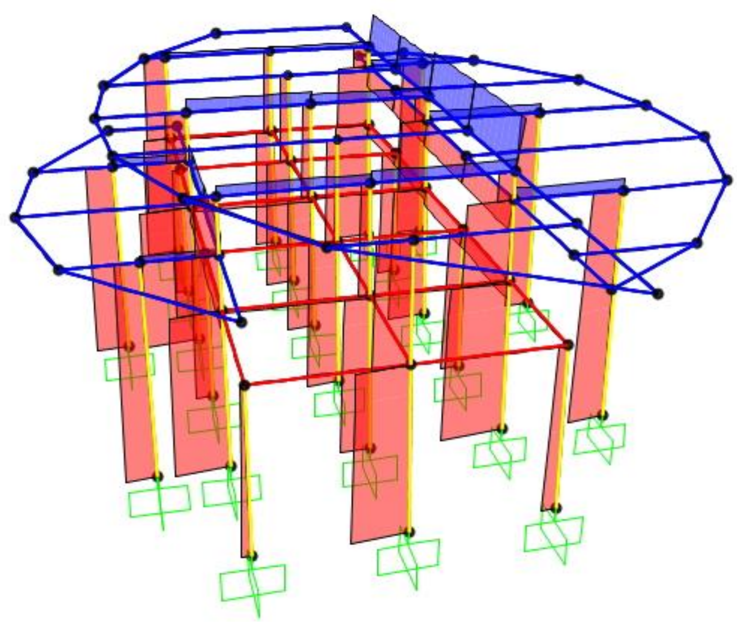

FIGURE 7: SAP2000 MODEL CAFE INTERNAL FORCES

Reactions and internal loads were calculated in the columns, beams and roof of the structure using SAP2000. Worst case axial, moment, and shear stresses and their corresponding load cases are summarized in Table 3 below.

	Axial	Moment	Shear
Column	77 kN (Case 3)	76 kN (Case 4)	25 kN (Case 4)
Beam	48 kN (Case 4)	54 kN (Case 4)	23 kN (Case 4)
Roof	37 kN (Case 3)	47 kN (Case 3)	25 kN (Case 3)

TABLE 3: CAFE INTERNAL MEMBER FORCES

These factored internal forces are then used in the detail design of each member. Specifically, the remainder of this section will focus on the detailed design and specifications for a sample column.

Wood Design

Structural specifications of wood members are to adhere and be designed in guidance with the 2010 Wood Design Manual (WDM) to satisfy CSA O86 standards. The WDM gives methodology to calculate the capacity in axial, bending and shear for wooden members.

The WDM allowed the structural team to size and specify the type glulam columns necessary for the café's structural frame. Sizing the glulam columns required a trial and error approach. After checking the capacity of numerous cross-sectional geometries the chosen specifications for the glulam columns are seen in the following table.

Size of Column	**130mm x 418mm**
Type of Glulam	20f – E Spruce Pine

TABLE 4: COLUMN SPECIFICATIONS

The glulam column's axial resistance is calculated using the following formula:

$$P_r = \varphi F_C A K_{zcg} K_c$$

The glulam column's shear resistance is calculated using the following formula:

$$V_r = {}^{2}/_{3}\, \varphi F_v A_g K_n$$

The moment capacity of the column is calculated by:

$$M_r = \varphi F_b S K_{zbg} K_x$$

The moment, shear and axial factors and equations can be found in clauses 6.5.6, 6.5.7 and 6.5.8

respectively (Canadian Wood Council, 2010). When a member is subjected to combined axial and bending loads it must also be checked for strength interaction in accordance with clause 6.5.12 and must satisfy the equation:

$$\left[\frac{P_f}{P_r}\right]^2 + \frac{M_f}{M_r}\left[\frac{1}{1-\frac{P_f}{P_e}}\right] < 1$$

Using the WDM to determine each factor and calculate the resistance of the glulam column it was found that the capacity of the 130x448 20f –E Spruce Pine glulam satisfies the factored load values determined from SAP2000 (Canadian Wood Council, 2010). Detailed calculations of the design capacity for the glulam column can be found in Appendix A. The following table compares the design capacity with the loading requirements of the column.

	Shear	**Moment**	**Axial**
Factored Loading	25 KN (Case 4)	76 KN (Case 4)	77 KN (Case 3)
Design Capacity	77 KN	111 KN	667 KN

TABLE 5: COMPARISON OF CAFE EXPECTED LOADING AND DESIGN CAPACITY

Geotechnical

The scope of the geotechnical design was to size a reinforced concrete spread footing for the column designed by the structural team (described in the previous section). The key goals of the foundation design are to ensure sufficient soil bearing capacity to support the column, assess total and differential ground settlements, as well as evaluating the potential for liquefaction under seismic loading.

The design of the column foundation was initiated through a thorough review of available geotechnical information. Due to the lack of existing information for the exact location of the development site, information from various locations proximal to UBC Botanical Garden were used; these included the geotechnical reports for Orchard Commons and Pharmaceutical Sciences building developments, and a borehole log from the BC Ministry of Environment Wells Database. The location of these information sources relative to the café development site is presented in Figure 8.

1 – Geotechnical Investigation Report, Orchard Commons
2 – Geotechnical Report, UBC Faculty of Pharmaceutical Science and Centre for Drug Research and Development Building
3 – Well Tag 92801, BC Ministry of Environment, Ground Water Wells and Aquifer Database

FIGURE 8: LOCATIONS OF EXISTING GEOTECHNICAL DATA

The available sources geotechnical information was of reasonable proximity to the development site, and showed consistency in stratigraphy and material descriptions. Thus it is assumed that the development site will have similar conditions even though previous site specific investigation is lacking. Under this assumption, a soil model for the site was developed based on the available information and is presented in Table 6.

Depth (m)		Soil Description	γ (kN/m^3)	ϕ'_p
From	To			
0	1.2	Variable Fill or Top Soil	-	-
1.2	3.5	Silty Sand, Dense to Very Dense (Till)	20 - 21	27 - 35
3.5	>12	Sand and Gravel, Dense to Very Dense	20 - 21	38 - 45
Depth to water table = 2.3m				

TABLE 6: SOIL MODEL FOR CAFE SITE

The soil conditions at the UBC Botanical Garden site is anticipated to be topsoil/variable fill overlying till, with a large thickness of compact sand and gravel underlying the till. The high density of the layers below 1.2m depth is favourable for high bearing capacities and low settlements for the shallow spread footing. With reference to the Canadian Foundation Engineering Manual, the preliminary design bearing pressure for till can be presumed to be 300-600KPa, and 200-600KPa for compact sand. While these presumed values indicate that the expected bearing demand can likely be met with relatively small footing area, a more detailed bearing capacity estimate was carried out. This assessment was made using effective stress analysis assuming drained conditions; an assumption based on the material being predominately sand and the water management issues caused by seepage as reported by representatives of the UBC Botanical Garden.

In addition to a detailed bearing capacity analysis, an assessment of settlement magnitude was also carried out. However, since the foundation soil layers are primarily coarse grained and assumed to be drained, it is not anticipated that significant long term settlements will be an issue. Settlement analysis was carried out using the Burland and Burbridge Method (Budhu, 2008), and the result are estimates of immediate settlement due to construction.

The detailed calculations for foundation bearing capacity and settlement were carried out using appropriate values of required geotechnical parameters, selected based on the descriptions of soil material and density as reported by the available information sources. These detailed calculations are presented in Appendix B, and the results indicating foundation performance are presented in Table 7 below.

Net Bearing Capacity	660 - 1940kPa
Factored Bearing Capacity (ϕ = 0.5)	330 - 970kPa
Construction Settlement	1 - 2mm

TABLE 7: SUMMARY OF FOUNDATION CAPACITY AND EXPECTED CONSTRUCTION SETTLEMENT

From the results of the detailed analyses, it was found that the factored bearing capacity is sufficient for the anticipated worst case loading of 143kPa, consisting of a 77kPa column load, a 56kPa first floor load, and a 10kPa footing self-weight. The anticipated immediate settlements are relatively low and can be accounted for during construction.

With respect to liquefaction, there is a lack of quantitative data that can be used for a detail assessment. However, it is not anticipated that the sand units are susceptible to seismic induced liquefaction. As the coarse grained layers are dense to very dense, it is not expected that they will exhibit the contractive behaviour necessary to generate the excessive pore water pressures for liquefaction.

Spread Footing Design Specifications

Based on the detailed analysis of anticipated site conditions and foundation requirements, a detailed design for the column spread footings was completed by Group 12 Consulting. A detailed drawing of the design is presented in Figure 9.

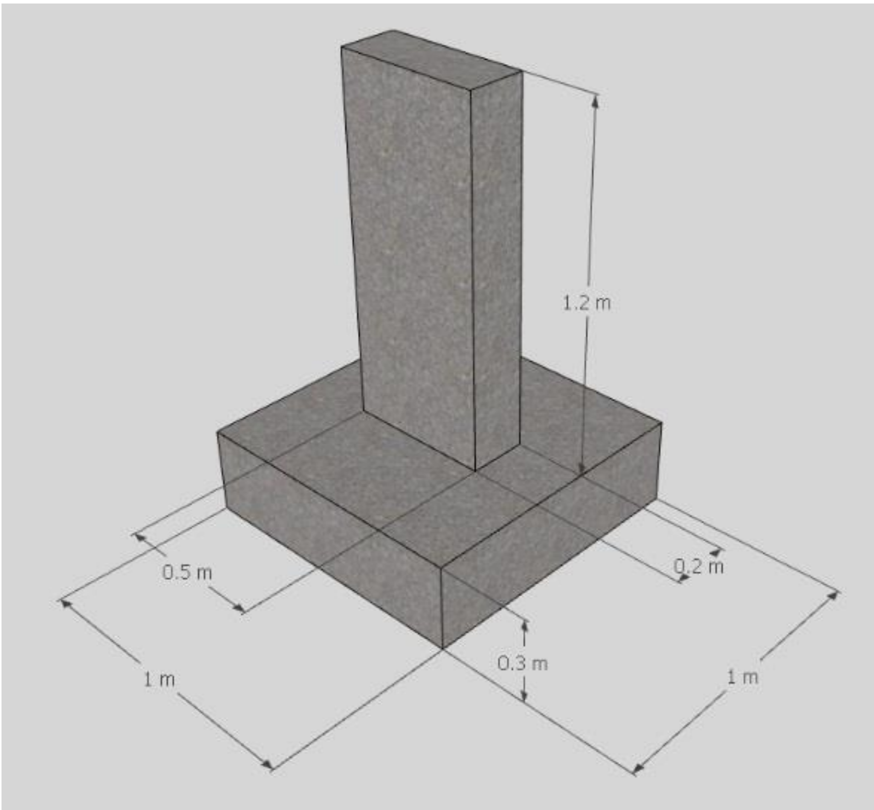

FIGURE 9: COLUMN FOOTING DETAIL

The base of the concrete spread footings is to be placed at 1.2m depth, resting on the surface of the dense and competent till layer. Foundation placement at this depth would require the excavation of any variable fill or topsoils which would likely compromise the performance of the design. It is anticipated that the footing would be well above the ground water table. The footprint of the spread footing is to be 1m x 1m with a slab thickness of 0.3m. The selection of the specified footprint area is based on satisfying bearing capacity requirements and ease of construction. While the slab thickness was selected to conform to minimum cover requirements for reinforcing steel (Canadian Standards Association, 2004).

Construction Management

Using information attained from the Structure & Geotechnical groups of the design team, in conjunction with assumptions made off an outside party's preliminary designs, a semi-detailed estimate of construction costs (including materials & labour) and durations was constructed for the key components of the Café design. The RS-Mean 2002 Construction Cost Data Handbook was used in the unit-cost/duration estimating process associated with the café. Assumptions were made in order to determine the extent of excavation required, and details related to the glazing/sub-structure/super-structure of the design component. These assumptions were necessary, as a detailed design for these elements has yet to be completed and is outside the current scope of this report. The results obtained from the unit-cost estimate are summarized below in Table 8, details of the estimating process and calculations are included in Appendix C.

Café Unit Cost Summary	
Site Preparation	$52,469.90
Footings	$20,123.27
Slab	$49,347.94
Glulam Frame	$128,080.32
Skylights & Glazing	$452,607.47
Total	$702,628.91

TABLE 8: CAFE UNIT COST SUMMARY

The data acquired from unit-cost estimating procedure, namely the durations for each event, were used as the primary data to create a preliminary schedule for the construction of the Café using Microsoft Project Professional 2013. Additionally, knowledge of industry best practices and task sequencing were incorporated. Buffers have been included to account for schedule fluctuations due to the enhanced need for environmental protection of the garden collections. The resulting Gant Chart can be seen below in Figure 10.

Due to the similarity between the Café and Conservatory components, and the fact that detailed design of the Conservatory has yet to be completed, it was assumed that construction duration of the this component would be approximately equal to that of the Café. This information was necessary to have duration estimates in order to determine the phasing of the project and provide a semi-detailed economic analysis of the project, in entirety.

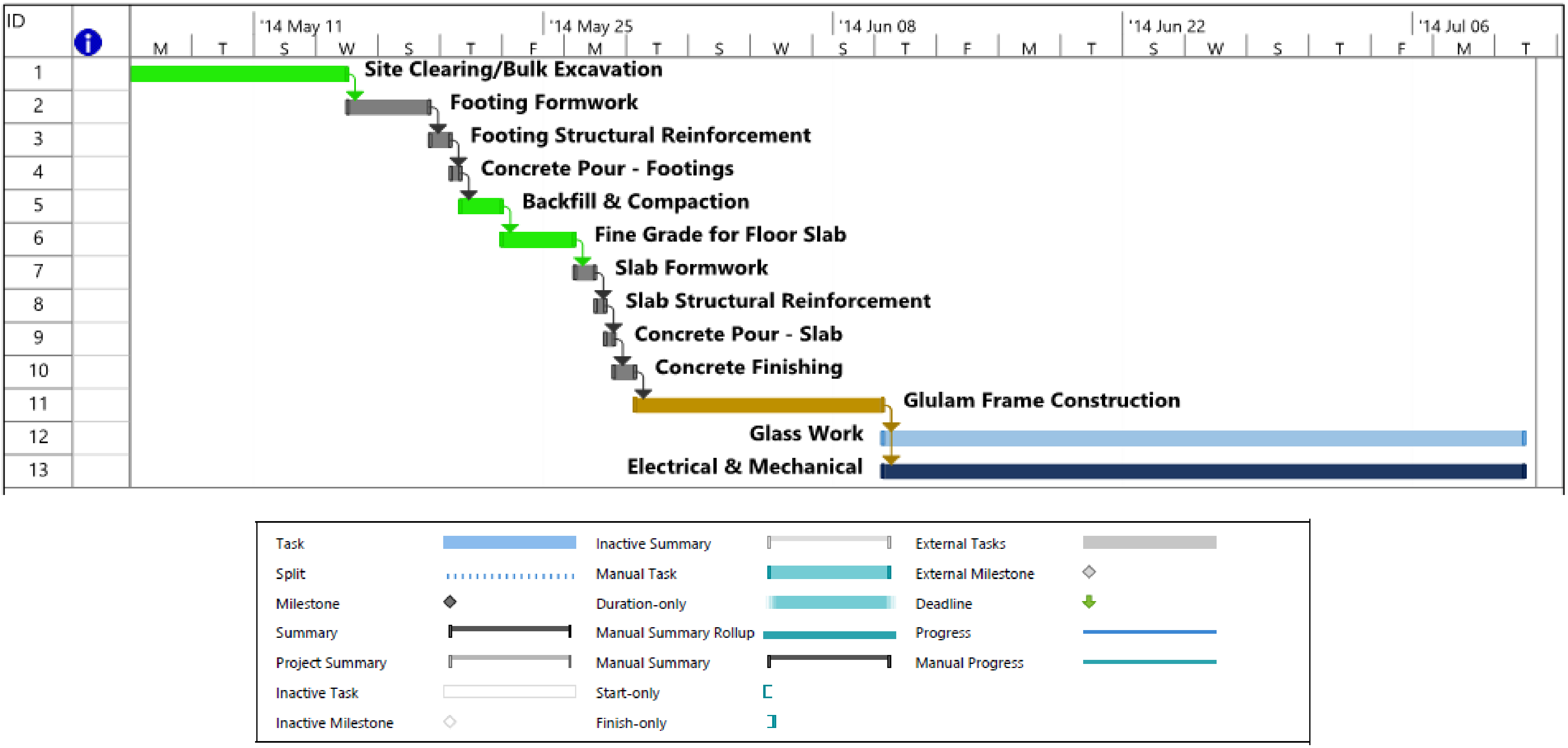

FIGURE 10: CAFE CONSTRUCTION SCHEDULE

Project Costs and Economic Analysis

In order to get a sense of the overall costs of the project, square-meter building cost data from the RS-Mean 2002 Construction Cost Data Handbook was used to prepare cost estimates for the café, and the conservatory. A cost estimate for the pathways was based on preliminary layout of paths with the existing path infrastructure and determination of typical industry costs for this type of work. Additional details of the square-cost estimating procedure are included in Appendix C.

Square Metre Costs	
Educational Pathways – Project Total Costs	$205,590.00
Café - Project Total Costs	$759,411.40
Conservatory - Project Total Costs	$935,594.84
Total	~ $1.9 M

FIGURE 11: PROJECT COSTS - SQUARE METRE COSTING METHOD

Assuming an industry standard minimum acceptable rate of return (MARR) (Isaacson, 2014) and that the components are built one-per-year over a three year period, the present worth of the project is approximately $1.5 million.

Performing a break-even analysis (Isaacson, 2014) assuming a five year horizon after the completion of project construction, it is necessary for the renovation to generate $400 000 in annual savings to recover costs.

Conclusions and Recommendations

Group 12 Consulting believes that the Relaxing and Learning Renovation at the UBC Botanical Garden will address the concerns of limited community engagement and demographic appeal facing the garden at this time through the development of three key components: enhanced educational pathways, a second entrance combined with a café and a conservatory. A staged implementation is presented here to protect the collections housed at the garden and facilitate continued garden operations and public access.

It is proposed that the café be constructed with a spruce-pine glulam frame on concrete footings to match the aesthetics of the garden, as well as facilitate sustainable design practices in accordance with UBC’s sustainable development goals. Construction of the café is expected to take three months.

The total project costs will be $1.9M, with a present worth of $1.5M if constructed over three years. However, due to the unrealistic annual savings required to break even, a five to eight year construction horizon with a ten to fifteen year to break even is recommended.

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Appendix A: Structural Calculations

Reaction Forces at Base of Columns

TABLE: Joint Reactions						
Joint	**F1**	**F2**	**F3**	**M1**	**M2**	**M3**
Text	KN	KN	KN	KN-m	KN-m	KN-m
1	0.085	0.103	5.47	-0.2011	0.1479	0.0069
2	0.006037	0.074	10.547	-0.1512	-0.0083	0.0058
3	-0.127	0.122	5.646	-0.2539	-0.2741	0.0061
4	-0.099	-0.022	10.672	0.0326	-0.2346	0.0025
5	-0.123	0.024	7.335	-0.0588	-0.2753	-0.00007675
6	-0.114	-0.032	10.101	0.0519	-0.2614	0.0024
7	-0.13	0.046	7.538	-0.1041	-0.2962	0.0059
8	-0.117	-0.129	8.458	0.2434	-0.2949	0.0087
9	-0.057	-0.108	9.765	0.2105	-0.1745	0.0063
10	0.04	-0.095	8.16	0.1928	0.0186	0.008
11	0.076	0.013	7.488	-0.0229	0.1139	0.0059
12	0.06	-0.0005134	10.207	0.0045	0.0856	0.0024
13	0.083	-0.002213	7.254	0.0083	0.1363	0.0002795
14	0.067	-0.012	10.243	0.0273	0.0956	0.0027
15	-0.026	-0.011	11.656	0.0179	-0.0891	0.0032
16	-0.035	0.009185	11.67	-0.0227	-0.0997	0.0017
17	-0.041	-0.003022	11.488	0.0015	-0.1165	0.0031
18	-0.04	0.025	11.919	-0.0544	-0.1176	0.0055
20	-0.162	-0.001083	4.486	0.0121	-0.483	0.0008232
21	-0.205	0.003405	4.558	0.0503	-0.5742	0.0018
22	0.2	-0.001889	5.08	-0.1056	0.5627	0.0014
24	0.332	0.003048	5.159	0.0042	0.996	0.000008562
25	0.328	-0.005202	5.269	-0.194	0.9383	0.0044
SUM			190.169			

Column Design Spreadsheet

Column Property

Member Size	=	175x418		
20f-E Spruce Pine				
E	=		10300	Mpa
E05	=		8961	Mpa
b	=		175	mm
d	=		418	mm
L	=		6000	mm
Vf	=		25	KN
Mf	=		76	KN*m
Pf	=		77	KN

Bending 6.5.6

Mr	=	Lesser of Mr1 or Mr2			
Mr1	=	ΦFbSKxKzbg	=	??	
Mr2	=	ΦFbSKxKl	=	??	
Φ	=		=	0.9	
Fb	=	fb(KdKhKsbKt)	=	??	Mpa
fb	=		=	25.6	Mpa
Kd	=		=	1	
Kh	=		=	1	
Kg	=		=	1	
Ksb	=		=	1	
Kt	=		=	1	
Fb	=	fb(KdKhKsbKt)	=	25.6	Mpa
S	=	bd^2/6	=	5096117	mm^3
Kx	=	1-2000(t/R)^2	=	1	
Kzbdg	=	1.03(BL)^(-.18)	=	1.65	
Cb	=		=	12.54	
Ck	=		=	19.76	
Kl	=	1-1/3*(Cb/Ck)^4	=	0.95	
Mr1	=	ΦFbSKxKzbg	=	193.64	KN*m
Mr2	=	ΦFbSKxKl	=	111.06	KN*m
Mr	=	Mr2	=	111.06	KN*m
Efficiency	=	Mr/Mf	=	1.46	

Shear 6.5.7

Vr	=	ΦFv2/3AgKn	=	??	
Φ	=		=	0.9	
Fv	=	fvKdKhKsvKt	=	??	
fv	=		=	1.75	Mpa
Kd	=		=	1	
Kh	=		=	1	
Ksv	=		=	1	
Kt	=		=	1	
Fv	=	fvKdKhKsvKt	=	1.75	Mpa
Ag	=	bd	=	73150	mm^2
Kn	=		=	1	
Cv	=		=	1	
Z	=	bdL	=	438900000	mm^3
Vr	=	ΦFv2Ag/3Kn	=	76.81	KN
Efficiency	=	Vr/Vf	=	3.0723	

Compressive Resistance 6.5.8

Pr	=	ΦFcAKzcgKc	=	??	
Cc	=	KeL/b	=	22.29	
Φ	=		=	0.8	
Fc	=	fcKdKhKscKt	=	??	
fc	=		=	25.2	Mpa
Kd	=		=	1	
Kh	=		=	1	
Ksc	=		=	1	
Kt	=		=	1	
Fc	=	fcKdKhKscKt	=	25.2	Mpa
Ag	=	bd	=	73150	mm^2
Z	=	bdL	=	0.439	m^3
Kzcg	=	0.68*(Z)^-.13	=	0.757	
Kc	=	(1+FcKzcgCc^3/(35E05KseKt))^-1	=	0.598	
Pr	=	ΦFcAKzcgKc	=	667	KN
Efficiency	=	Pr/Pf	=	8.66	

Combined Loading

Check	=	(Pf/PR)^2+Mf/Mr(1/(1-Pf/Pe))<1	=	??	
I	=	bd^3/3	=	4.26	m^4

Pe	=	Pi^2*E05*I/(Ke*L)^2	=	24771	
Check	=	(Pf/PR)^2+Mf/Mr(1/(1-Pf/Pe))<1	=	0.70	**OKAY**

Summary Table

Loads

Dead Load (D)	190	kN	(from model)
Live Load (L)	4.8	kPa	(from code)
Wind Load (W)	2	kPa	(from code)
Snow Load (S)	0.45	kPa	(from code)

Load Cases

1	1.4D
2	1.25D+1.5L
3	1.25D+1.5S
4	1.25D+1.4W
5	1.0D+1.0E

Downward Loading

	Area (m^2)	Type	Factor	Load (kN)	Nodes	Load per Node on SAP (kN)
Roof	681	S	0.5	153	53	5.78
Base	250	L	1.5	1800	18	66.67
Side	150	W	1.4	420	6	50.00
Structure		D	1.25	238		

Estimated Force on Slab

	Number of slabs	Total Downward Force	Loading on Slab	
Slab	23	2038	88.59	kN

Reactions from SAP Model

	Axial (kN)	Moment (kNm)	Shear (kN)
Column	Case 3 **77**	Case 4 **76**	Case 4 **25**
Beam	Case 4 **48**	Case 4 **54**	Case 4 **23**

Roof	Case 3 **37**	Case 3 **47**	Case 3 **25**

Maximum Loading on Slab from SAP

	Loading (kN)
Slab	**133**

Size and Quantity

	Type	Width (mm)	Depth (mm)	Length (m)	Volume (m3)
Column	Glulam	175	418	211	15
Beam	Glulam	315	380	135	16
Roof	Glulam	80	80	333	2
Total					**34**

Appendix B: Geotechnical and Foundations Calculations

Soil Model and Selected Geotechnical Parameter Values

Depth (m)		Soil Description	γ (kN/m^3)	ϕ'_p	SPT-N
From	To				
0	1.2	Fill or Top Soil	-	-	-
1.2	3.5	Silty Sand, Dense to Very Dense (Till)	20 - 21	27 - 35	30-50
3.5	>12	Sand and Gravel, Dense to Very Dense	20 - 21	38 - 45	30-50

Depth to Ground Water = 2.3m

* Geotechnical Parameters γ, ϕ'_p and SPT-N selected based on available descriptions of soil material and density, from Budhu 2008, from Table B4.5 and Table B5.2

Effective Stress Analysis of Bearing Capacity

*Analysis assumes drained conditions, calculations as outlined in Budhu 2008. Bearing surface at top of till.

*Davis and Booker (1971) equation for rough foundation used for $N\gamma$

* Geotechnical resistance factor ϕ=0.5 from NBCC 2005

ϕ'_p (degrees)	27.0	35.0
B (m)	1.0	1.0
L (m)	1.0	1.0
D_f	1.2	1.2
N_q	13.2	33.3
N_γ	9.7	37.1
W_q	1.0	1.0
$W\gamma$	1.0	1.0
S_q	1.5	1.7
S_γ	0.6	0.6

d_q	1.4	1.3
d_γ	1.0	1.0
r_q	1.0	1.0
r_γ	1.0	1.0
Net Bearing Capacity	661.4	1943.3
Factored Bearing Capacity (ϕ=0.5)	330.7	971.6

<u>Analysis of Immediate Settlement</u>

* Analysis based on Burland and Burbridge Method (Budhu, 2008)

B (m)	1	1
L (m)	1	1
Ho (m)	2.3	2.3
N	50	30
qa (kPa)	145	145
z1 (m)	1	1
Ic	0.007152	0.014623
fs	1	1
Settlement (mm)	1.037065	2.120286

Appendix C: Unit Costs & Duration Estimates

Site Preparation	Length (m)	Width (m)	Depth (m)	Quantity	UOM	Cost Code	Description	Crew Code	Daily Output (per U.O.M)	Duration (days)	Crew Daily Cost Incl. O&P	Total Labour Cost	Material Costs	Total Costs
Site Clearing	30.0	30.0	0.3	270	m3	02230-880-0020	Stripping Topsoil, and stockpiling, sandy loam, 149 kW Dozer, ideal conditions	B-10B	1759	0.15	$2,595.76	$398.44	-	$398.44
Excavating	30.0	30	0.9	810	m3	02315-410-2240	Excavating, Bulk Dozer open site, 56kW, 45m haul, clay	B-10L	95.57	8.48	$1,478.08	$12,527.41	-	$12,527.41
Backfill	30.0	30	0.9	810	m3	02315-100-1300	Dozer backfilling, bulk, up to 90m haul, no compaction	B-10B	918	0.88	$2,595.76	$2,290.38	-	$2,290.38
Compaction	30.0	30	0.9	810	m3	02315-100-1600	Compacting backfill, 150mm to 300mm lifts, vibrating roller	B-10C	612	1.32	$2,962.36	$3,920.77	$10,392.30	$14,313.07
Fine Grade	30.0	30	-	900	m2	02310-440-1150	Fine Grade for slab on grade, hand grading	B-18	585	1.54	$1,596.32	$2,455.88	-	$2,455.88
									Total Duration (days)	12			Total Cost:	$31,985.18

Reinforcing Ratio (kg/m3) 25

CIP Foundations	Length (m)	Width (m)	Depth (m)	Total Qnty (UOM)	UOM	Cost Code	Description	Crew Code	Daily Output (per U.O.M)	Duration (days)	Crew Daily Cost Incl. O&P	Total Labour Cost	Material Costs (per U.O.M.)	Total Material Costs	Total Costs
Formwork	1.0	1.0	0.3	50.6	m2CA	03110-430-5000	Spread footings, plywood, 1 use	C-1	28.33	2	$2,320.40	$4,144.45	$18.40	$931.04	$5,075.49
Formwork	-	-	-	23.0	Ea	03110-430-6050	Supports for dowels, plinths or templates, 1200mm x 1200mm footing	C-1	25	1	$2,320.40	$2,134.77	$6.90	$158.70	$2,293.47
Concrete Reinforcing in Place	1.0	1	0.3	0.173	Met. Ton	03210-600-0500	Footings, #10M to #25M	4 Rodmen	1.91	0.09	$1,096.00	$98.98	$585.00	$100.91	$199.90
Placing Concrete	1.0	1	0.3	6.9	m3	03310-700-2650	Footings, Spread, Under 0.75m3, pumped	C-20	49.7	0.14	$5,695.64	$790.74	$144.00	$993.60	$1,784.34
									Total Duration (days)	3				Total Costs	$9,353.20

Reinforcing Ratio (kg/m3)	25

CIP Slab on Grade	Length (m)	Width (m)	Depth (m)	Total Qnty (UOM)	UOM	Cost Code	Description	Crew Code	Daily Output (per U.O.M)	Duration (days)	Crew Daily Cost Incl. O&P	Total Labour Cost	Material Costs (per U.O.M.)	Total Material Costs	Total Costs
Formwork	25.0	10.0	0.3	271.0	m2CA	03110-445-3000	Edge forms, wood, 4 use, on grade, to 175mm 300mm high	C-1	183	1	$2,320.40	$3,436.22	$9.45	$2,560.95	$5,997.17
Concrete Reinforcing in Place	25.0	10	0.3	1.9	Met. Ton	03210-600-0600	Slab on Grade, #10M to #25M	4 Rodmen	2.09	0.90	$1,096.00	$983.25	$585.00	$1,096.88	$2,080.13
Placing Concrete	25.0	10	0.3	75.0	m3	03310-700-4650	Slab on grade, over 150mm thick, pumped	C-20	141	0.53	$5,695.64	$3,029.60	$144.00	$10,800.00	$13,829.60
Concrete Finishing	25.0	10	0.3	250.0	m2	03350-300-0200	Screed, float and hand trowel	4 Ce Fi	222.96	1.12	$918.40	$1,029.78	-	-	$1,029.78
									Total Duration (days)	4				Total Costs	$22,936.68

Glulam Frame Construction	Lengths - Total (m)	Width (m)	Depth (m)	Quantity (UOM)	UOM	Cost Code	Description	Crew Code	Daily Output (per U.O.M)	Duration (days)	Crew Daily Cost Incl. O&P	Total Labour Cost	Material Costs (per U.O.M.)	Total Material Costs	Total Costs
Columns	210.5	0.418	0.175	15.4	m3	06180-400-4400	Column, including hardware	F-3	4.72	3	$4,380.40	$14,290.20	$980.00	$15,090.11	$29,380.31
Beams	135.0	0.315	0.38	250.0	m2 Flr	06180-400-0200	Straight roof beams, 6.1m clear span, beams 2400mm O.C.	F-3	238	1	$4,380.40	$4,601.26	$15.50	$3,875.00	$8,476.26
Roof Joists	332.6	0.08	0.08	681.3	m2 Flr	06180-400-0200	Straight roof beams, 6.1m clear span, beams 2400mm O.C.	F-3	238	3	$4,380.40	$12,538.43	$15.50	$10,559.38	$23,097.81
									Total Duration (days)	7				Total Costs	$60,954.38

Skylights & Glazing	Quantity (UOM)	UOM	Cost Code	Description	Crew Code	Daily Output (per UOM)	Duration (days)	Crew Daily Cost Incl. O&P	Total Labour Cost	Material Costs (per UOM)	Total Material Costs	Total Costs
Skyroof	681.3	m2	08950-100-0010	Translucent panels 68mm thick, over 460m2	G-3	43.2	16	$2,386.40	$37,632.75	$195.00	$132,843.75	$170,476.50
Glazing	200.0	m2	08810-250-0010	Faceted Colour tinted glass, 19mm thick, minimum	6 Glaz	26.49	8	$4,011.84	$30,289.47	$305.00	$61,000.00	$91,289.47
						Total Duration (days)	23				**Total Costs**	$261,765.97

Unit Cost Estimates Summary Table

UBC-BG Café
Unit Cost Summary

Components	Total Costs	Location Adjustment	Time Adjustment	UBC Premium
		Seattle to Vancouver	Jan.2002 to Jan 2014	
Site Preparation	$31,985.18	$29,069.64	$45,626.00	$52,469.90
Footings	$9,353.20	$11,148.80	$17,498.50	$20,123.27
Slab	$22,936.68	$27,339.99	$42,911.25	$49,347.94
Glulam Frame	$60,954.38	$70,959.70	$111,374.20	$128,080.32
Skylights & Glazing	$261,765.97	$250,755.84	$393,571.71	$452,607.47
			Total	$702,628.91

Square Meter Cost Estimates Summary Table

Café	Area (m2)	Description	UOM	Unit Costs (3/4)	Total Costs	Adjust for Size	Adjust for Time	UBC Premium
Project Total Costs	250	Restaurants	m2	1625	$406,250.00	$438,750.00	$660,357.74	$759,411.40

Conservatory	Area (m2)	Description	UOM	Unit Costs (3/4)	Total Costs	Adjust for Size	Adjust for Time	UBC Premium
Project Total Costs	756	Offices Low - Rise (1-4 story)	m2	650	$491,400.00	$540,540.00	$813,560.73	$935,594.84

Appendix D: Analytical Hierarchy Process – Calculation Table

Pairwise comparisons for objective functions and sub-objectives

Levels of influence between the objective functions

	vs	
Scheduled Duration of Component	vs	Component Functionality
0.25		4
Scheduled Duration of Component	vs	Cost of Component
0.5		2
Component Functionality	vs	Cost of Component
2		0.5

Levels of influence between the sub-objectives

	vs	
Design Complexity	vs	Construction Complexity
1		1
Enhance Visitor Experience	vs	Enhance Garden Collection
4		0.25
Total Cost of Component	vs	Value Added to Garden
0.333333333		3

Grand Objective

	Scheduled Duration of Component	Component Functionality	Cost of Component	(a*b*c)^(1/3)	Influence
Scheduled Duration of Component	1	0.25	0.5	0.500	14.29%
Component Functionality	4	1	2	2.000	57.14%
Cost of Component	2	0.5	1	1.000	28.57%

Objective Function 1

	Design Complexity	Construction Complexity	(a*b)^(1/2)	Influence
Design Complexity	1	1	1.000	50.00%
Construction Complexity	1	1	1.000	50.00%

Objective Function 2

	Enhance Visitor Experience	Enhance Garden Collection	(a*b)^(1/2)	Influence
Enhance Visitor Experience	1	4	2.000	80.00%
Enhance Garden Collection	0.25	1	0.500	20.00%

Objective Function 3

	Total Cost of Component	Value Added to Garden	(a*b)^(1/2)	Influence
Total Cost of Component	1	0.333333333	0.577	25.00%
Value Added to Garden	3	1	1.732	75.00%

Pairwise comparison for alternatives and sub-objectives

Design Complexity

Educational Loops	vs	Café
9		0.111111111
Educational Loops	vs	Conservatory
9		0.111111111
Café	vs	Conservatory
2		0.5

Construction Complexity

Educational Loops	vs	Café
9		0.111111111
Educational Loops	vs	Conservatory
9		0.111111111
Café	vs	Conservatory
0.333333333		3

Enhance Visitor Experience

Educational Loops	vs	Café
0.5		2
Educational Loops	vs	Conservatory
7		0.142857143
Café	vs	Conservatory
4		0.25

Enhance Garden Collection

Educational Loops	vs	Café
5		0.2
Educational Loops	vs	Conservatory
0.25		4
Café	vs	Conservatory
0.2		5

Total Cost of Component

Educational Loops	vs	Café
9		0.111111111

Educational Loops	vs	Conservatory
9		0.111111111

Café	vs	Conservatory
0.5		2

Value Added to Garden

Educational Loops	vs	Café
0.2		5

Educational Loops	vs	Conservatory
1		1

Café	vs	Conservatory
4		0.25

Design Complexity

	Educational Loops	Café	Conservatory	(a*b*c)^(1/3)	Influence
Educational Loops	1	9	9	4.327	81.42%
Café	0.111111111	1	2	0.606	11.40%
Conservatory	0.111111111	0.5	1	0.382	7.18%

Construction Complexity

	Educational Loops	Café	Conservatory	(a*b*c)^(1/3)	Influence
Educational Loops	1	9	9	4.327	80.82%
Café	0.111111111	1	0.333333333	0.333	6.23%
Conservatory	0.111111111	3	1	0.693	12.95%

Enhance Visitor Experience

	Educational Loops	Café	Conservatory	(a*b*c)^(1/3)	Influence
Educational Loops	1	0.5	7	1.518	39.46%
Café	2	1	4	2.000	51.98%
Conservatory	0.142857143	0.25	1	0.329	8.56%

Enhance Garden Collection

	Educational Loops	Café	Conservatory	(a*b*c)^(1/3)	Influence
Educational Loops	1	5	0.25	1.077	26.06%
Café	0.2	1	0.2	0.342	8.27%
Conservatory	4	5	1	2.714	65.67%

Total Cost of Component

	Educational Loops	Café	Conservatory	(a*b*c)^(1/3)	Influence
Educational Loops	1	9	9	4.327	81.42%
Café	0.111111111	1	0.5	0.382	7.18%
Conservatory	0.111111111	2	1	0.606	11.40%

Value Added to Garden

	Educational Loops	Café	Conservatory	(a*b*c)^(1/3)	Influence
Educational Loops	1	0.2	1	0.585	14.88%
Café	5	1	4	2.714	69.08%
Conservatory	1	0.25	1	0.630	16.03%

Calculation of best alternative

Grand objective:	Select Project Staging					
Educational Loops	41.61%					
Café	41.28%					
Conservatory	17.11%					
Objective functions:	**Scheduled Duration of Component**		**Component Functionality**		**Cost of Component**	
Educational Loops	81.12%		36.78%		31.52%	
Café	8.81%		43.24%		53.61%	
Conservatory	10.07%		19.98%		14.87%	
Sub-objectives:	**SO 1.1**	**SO 1.2**	**SO 2.1**	**SO 2.2**	**SO 3.1**	**SO 3.2**
Educational Loops	81.42%	80.82%	39.46%	26.06%	81.42%	14.88%
Café	11.40%	6.23%	51.98%	8.27%	7.18%	69.08%
Conservatory	7.18%	12.95%	8.56%	65.67%	11.40%	16.03%

Appendix E: Sample Economic Calculations

	Costs	n (years)	MARR	P/F, I, N	PW of Costs	Assumed Annual Savings	P/A, I, N	PW of Savings stream	PW
Café	$759,411.40	2	12%	$0.80	$605,398.12	$170,000.00	$3.60	$612,811.95	$7,413.84
Conservatory	$935,594.84	3		$0.71	$665,937.93	$185,000.00	$3.60	$666,883.60	$945.67
Paths	$205,590.00	1		$0.89	$183,562.50	$50,000.00	$3.60	$180,238.81	-$3,323.69
Total	$1,900,596.24				$1,454,898.55	$405,000.00		$1,459,934.36	$5,035.82