UBC Social Ecological Economic Development Studies (SEEDS) Student Report

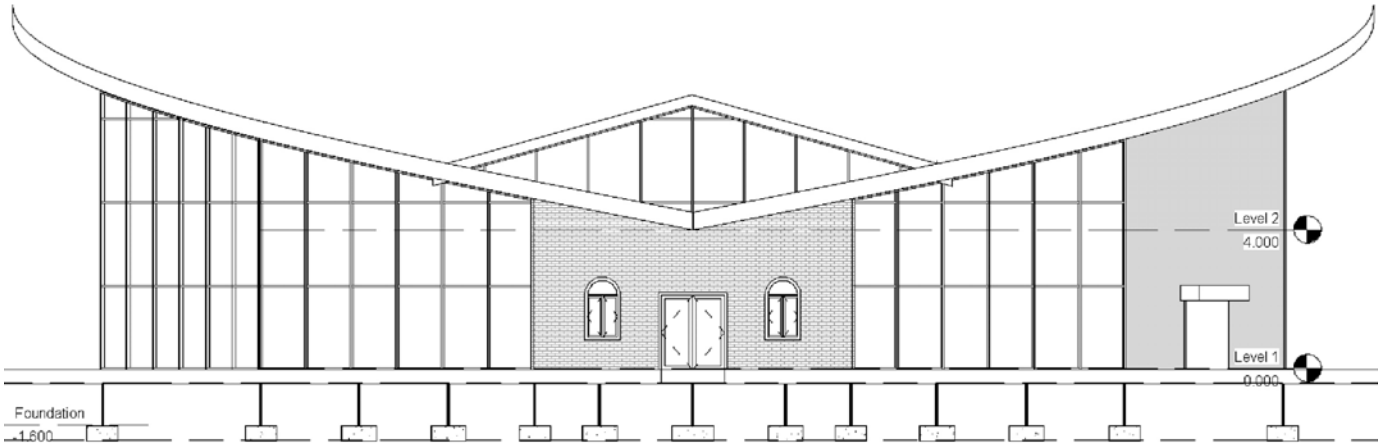
UBC BOTANICAL GARDEN RENEWAL

David Chen, Della Anggabrata, Emma Brown, Haney Wang, Rocky Zhang, Zachary Bailey

University of British Columbia

CIVL 446

April 30, 2014



UBC BOTANICAL GARDEN RENEWAL

CIVL 446 (2014) - Group 6:

Emma Brown	( )	David Chen	( )
Haney Wang	( )	Zachary Bailey	( )
Della Anggabrata	( )	Rocky Zhang	( )

EXECUTIVE SUMMARY

PROJECT HIGHLIGHTS AND SCOPE

The Group 6 UBC Botanical Garden (UBCBG) Renewal Project intends to deliver a project that will help UBCBG achieve its full potential by educating and connecting the community with the beautiful and rare collection at the Garden. The scope of our project will include a detailed design of a greenhouse café and conceptual designs of the remaining three components. The three engineering disciplines selected for this project are project management, structural, and geotechnical. Since project management is typically an area that is imperative for the success of a project, we have chosen it as the lead discipline.

BENEFITS TO THE GARDEN

The design goals that were targeted in the scope of our projects guided the design decision. As a result, the project proposed delivers a series of benefits to the garden including increased revenue, increased learning opportunities, as well as enhanced capacity for research.

PROJECT DESIGN COMPONENTS

The project management is the primary discipline of this project. The following designs are delivered in this report:

- A phased conceptual design vision for UBCBG
- A site logistics plan and construction timeline constructed on MS Project
- The cost estimation of the Greenhouse Café generated using the RS Means Data
- A resource allocation plan for the construction of the Greenhouse Café
- A 3D Building Integrated Model (BIM) constructed in Revit
- A 4D model assembled for presentation purposes

The structural system of the building will be a combination of steel and wood. The following designs are delivered in this report:

- An analysis of the gravity loads from the roof and steel truss system in RISA 2D
- The structural gravity design system for the Greenhouse Café
- The environmental study on the green roof and corresponding green roof design

The geotechnical study is integrated into the design of the project. The following designs are delivered in this report:

- A site stratigraphy and soil classification analysis
- A design of a foundation system as well as a typical footing detail
- An analysis on the serviceability under static and seismic conditions

PROJECT IMPLEMENTATION

A proposed implementation plan is detailed in the report including a site logistics plan. The scheduling of the completion of Phase 1 of the Garden has been estimated to be 103 working days based on an accelerated construction schedule. The submission of this report signifies the first step towards the implementation plan for our vision of the UBC Botanical Garden.

Emma Brown
Project Manager
April 4, 2014

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This report outlines a four-phase Relaxing and Learning project encompassing project management, structural and geotechnical disciplines to benefit the University of British Columbia's Botanical Garden (UBCBG or Garden). The main focus of the project is the design of the Greenhouse Café, which embodies the natural surrounding environment; the café will be self-sustaining and generate vital revenue for the Garden's operations.

1.1 Purpose

The UBCBG, dating back to 1916, is a world-class garden and center for plant research that curates a collection of over 1,200 plants and aims to "assemble, curate and maintain a documented collection of temperate plants for the purposes of research, conservation, education, community outreach and public display" (UBC Botanical Garden, 2014). Visiting the Garden is a beautiful, invigorating, and educational experience; however, in recent years it has had low admissions and has not been able to generate an adequate amount of revenue. Some of the major obstacles of the UBCBG include outdated facilities, poor signage, lack of attractions, and inadequate path circulation. Although many different solutions could be used to improve the Garden, the available funding limits feasible options. Due to limited funding, a solution involving incremental improvements that enhance visitor experience while generating revenue will maximize benefits for the Garden. The purpose of this report is to present the Relaxing and Learning project that will address the obstacles that the UBCBG is facing, in order to allow the Garden to reach its full potential.

1.2 Project Description

The garden revitalization project has four main components; the Greenhouse Café, adventure/educational loops, a pedestrian walkway over Marine Drive, and renovation or expansion of the current conservatory. This report primarily focuses on the detailed design of the Greenhouse Café, but also includes a conceptual plan for all four components.

The Greenhouse Café infrastructure has been designed to complement the natural environment of the Garden while simultaneously attracting more visitors to the Botanical Garden. The design uses a natural timber and green roof aesthetic to integrate the Café into its surrounding and will become a renowned destination for tourists to dine at while visiting Vancouver.

The VanDusen Garden Café has set the standard with a similar restaurant which has seen approximately a 25% increase in visitors, revenue and memberships after one year (City of Vancouver, 2014). Such an increase at the UBCBG will ensure that the operations and maintenance will be self-supported and allow for expenditures for other developmental projects.

The Greenhouse Café will be constructed in a sustainable manner in order to be energy and carbon neutral by employing green resource allocation and an efficient construction-phasing schedule. The Greenhouse Café will be self-sustained with water and will produce as much energy as it uses by applying ecological technology such as catch basins, photovoltaic cells, natural light, geothermal heating, and grey water treatment and recycling. Such technology will guarantee lower operating costs, and qualify the Café for money-saving incentives, like tax rebates and zoning allowances.

This Café will undoubtedly enhance the profile of the Garden in its diversity while being inviting for younger guests. Such a development will become a landmark for environmental enthusiasts and fine diners of all demographics.

The adventure/educational loops will make the visitors' experience more interactive. Then the overhead pedestrian walkway will make the Garden more accessible and visible. Finally, the renovation or expansion of the conservatory will create more growing space and attract more plant researchers.

1.3 Scope

Three engineering disciplines are addressed in this report; project management, structural, and geotechnical. Project management is crucial in ensuring the success of a project that is delivered on time, on budget, and with exceptional quality; therefore, project management has been chosen as the lead engineering discipline for this project. For project management a conceptual phasing has been done for all four project components, which are the Greenhouse Café, conservatory renovation/expansion, overhead walkway and adventure loops. For the Greenhouse Café, more detailed project management practices have been outlined, in addition to the design of one structural element and one geotechnical element.

2 PROJECT MANAGEMENT

Project management is an important component of any project, and has been planned in detail for this project. Included in this report is the method of project delivery, conceptual phasing for all four project component, detail construction sequencing for the Greenhouse Café, and discussion of resource allocation.

2.1 Integrated Project Delivery (IPD)

An integrated project delivery (IPD) method will be used for this project. This method eliminates many problems that are inherent in traditional delivery methods, such as an inability to fully coordinate the project, the owner being at risk to the contract for design errors, and the assumption that cheaper is beneficial. IPD aligns project objectives with interests of key participants, and relies on participation, transparency, and continuing dialog of all trades and consultants. A significant advantage of IPD is that all parties to be involved in the project are assembled as early as possible in order to provide collective expertise to the project even before designing begins. IPD also incorporates a 4D building model, which further enhances the quality of the project design and implementation. The graphic below depicts the organizational breakdown of this project.

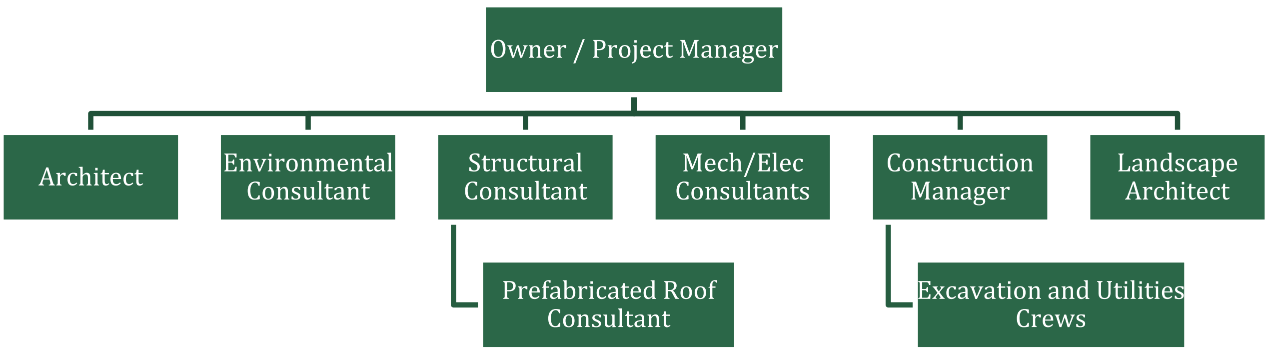


Figure 1: Organizational Chart

2.2 Project Conceptual Phasing

The project development at the UBCBC proposed by our team consists of a staged development that will cater to the growing needs of the Garden through incremental change. The construction of the Greenhouse Café in Stage 1 of the development is expected to be followed by an increase in usage and thus may lead to potential expansions and upgrades. Our design team has proposed a 4-stage development for the future of the Garden in order to optimize the visitor experience and Garden revenue. The main initiative of this conceptual phasing is to create a complete experience for the general public and attract visitors.

2.2.1 Stage 1: Create a Destination

The construction of the Greenhouse Café is the primary component of this design report. The driving motivation is to create a welcoming destination capable of increasing revenues while providing indoor space for Garden use. This stage consists of the site works, design, and construction of the Greenhouse Café.

2.2.2 Stage 2: Create an Experience

The existing visitor map of the Garden consists of the general layout and the names of the individual gardens. There is a lack of direction and information given in the brochure. The design team proposes to implement a system of educational adventure loops. This is a low cost addition to the Garden that will help drive interest and a sense of exploration in visitors. The educational adventure loops consist of a series of marks trails and tours through the Garden targeted at seasons, themes, rare flora, and visitors' interests. These loops allow the curators of the Garden to educate the public with minimal labor and staffing commitment. The loops also provide visitors with a reason to return to the Garden and explore different areas.

2.2.3 Stage 3: Improve Access

With the construction of the Greenhouse Café, there will be a necessity to improve access to the East side of the Garden. Once visitors have entered the Garden, it is not convenient to cross SW Marine Drive by foot. Stage 3 proposes to construct an ecologically considerate overhead walkway spanning over SW Marine Drive. This walkway will be constructed to enhance signage, which will attract more patrons to the Garden, while simultaneously improving access. Improvements to Stadium Road are also proposed to create a destination for the UBCBG.

2.2.4 Stage 4: Upgrade Existing Infrastructure

With the expected increase in revenue generated from the Stage 1 to Stage 3 improvements, existing infrastructure upgrades will be made to complete the facelift of the Garden. A Conservatory expansion is proposed in order to renovate the existing facility to accommodate more space for plants and attract researchers to the facility.

2.3 Site Logistics Plan

Figure 2: Site Logistics Layout

The proposed Greenhouse Café will be located adjacent to the existing amphitheater on land that is currently used as a maintenance yard for UBC operations, which has existing access off of Stadium Road. The area is moderately graded with the main obstructions being trees that surround the existing yard. The main entrance and exit of the site will continue to be the paved driveway currently south of Stadium Road. During construction, the proposed site redevelopment area will be fenced off. Since the Greenhouse Café footprint is much smaller than the area of land being redeveloped, temporary site offices and equipment can be stored on site, which will minimize delays to traffic using Stadium Road and the residents of the neighboring communities. The site plan in Figure 2 illustrates the building location and the redevelopment area. Details of the construction are outlined in the construction scheduling Gantt Chart in the following section of this report. Section 2.4.1 presents a summary of the construction timeline.

2.4 Detailed Design Implementation Plan

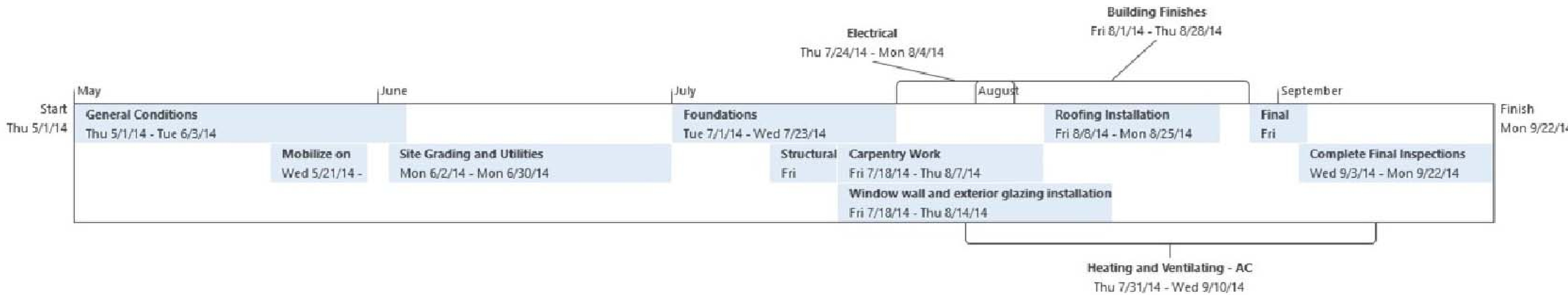
The implementation plan of the Greenhouse Café consists of several stages from permitting, to site works, to building construction and finishing. The accelerated construction schedule be completed within 103 working days of breaking ground. The anticipated start of construction is May 1st 2014 with the earliest finish date on September 22nd 2014. The proposed construction schedule (Section 2.4.1) and includes primary actions: Site Mobilization, Site Grading and Utilities, Foundations, Column Erection, Electrical and Mechanical, Heating and Ventilating, Roofing, Glazing, Finishing, and Landscaping. Certain assumptions were made in order to simplify construction and thus minimizing construction time, cost, and complications. Table 1 summarizes some of the considerations in the scheduling of the labor hours.

Table 1 Construction Considerations

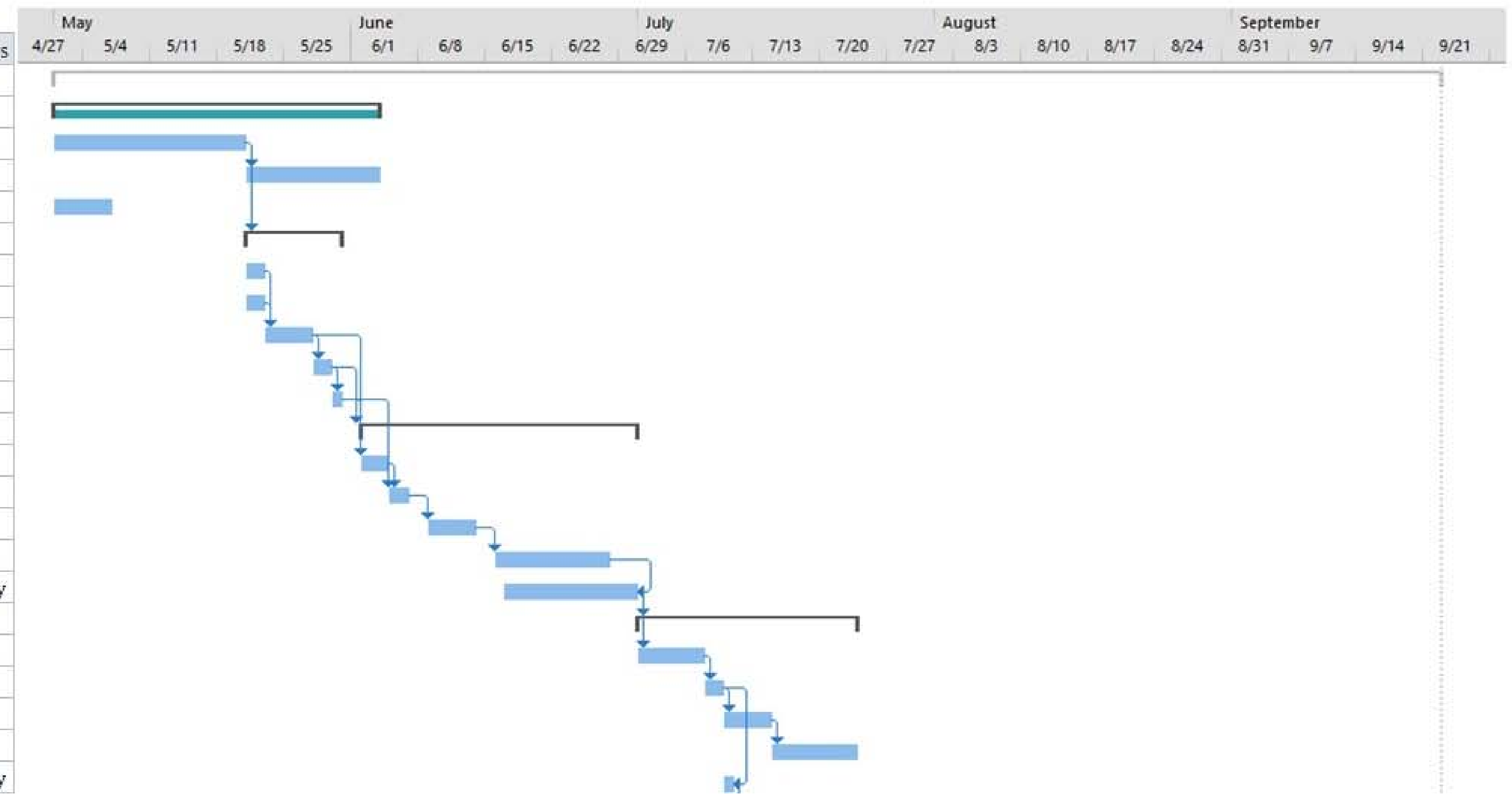
CATEGORY	ASSUMPTION
SITE WORKS	Anticipation of soil contamination as a result from repurposing of an old maintenance yard will result in longer site works due to the necessity of removing contaminated soil from the site.
UTILITIES	The Greenhouse Café is assumed to be connected to the utilities previously available at the maintenance yard.
FOUNDATIONS	Due to the small footprint of the building and simple foundation plan with basic reinforcing, it is not anticipated that foundation construction will require longer hours than standard practice.
COLUMN ERECTION	Simple beam to column connections in a modular system allow for simpler erection of structural members.
ROOF INSTALLATION	Installation of a prefabricated roofing system will result in a shorter installation time than conventional roof installation. Along with sufficient site storage area, the prefabricated sections can be moved to site well in advance of the installation.

.

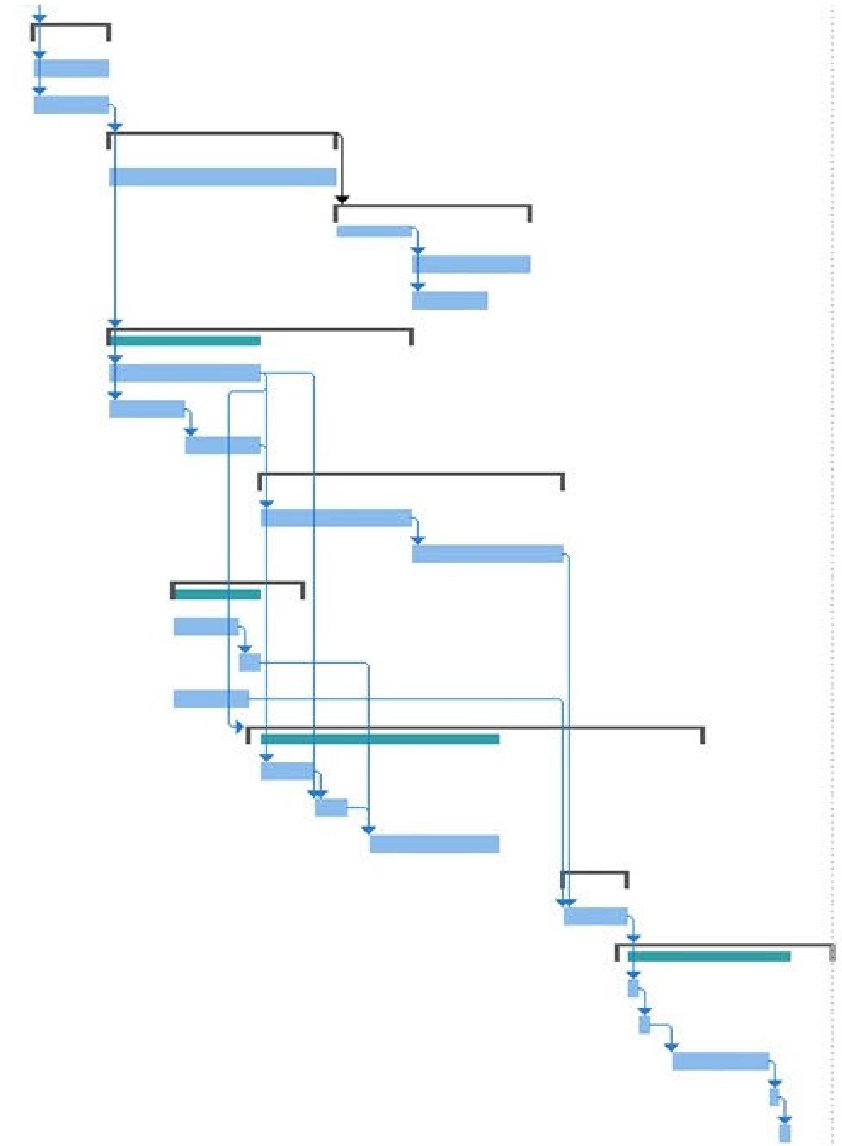
2.4.1 Construction Timeline and Ganntt Chart



Task Name	Duration	Start	Finish	Predecessors
Commercial Construction	**103 days**	**Thu 5/1/14**	**Mon 9/22/14**	
General Conditions	**24 days**	**Thu 5/1/14**	**Tue 6/3/14**	
Obtain building permits and road use permits	14 days	Thu 5/1/14	Tue 5/20/14	
Preliminary coordination	2 wks	Wed 5/21/14	Tue 6/3/14	2
Coordination and QA of construction materials	4 days	Thu 5/1/14	Tue 5/6/14	
Mobilize on Site	**8 days**	**Wed 5/21/14**	**Fri 5/30/14**	**2**
Install temporary power	2 days	Wed 5/21/14	Thu 5/22/14	
Install temporary water service	2 days	Wed 5/21/14	Thu 5/22/14	
Set up site office	3 days	Fri 5/23/14	Tue 5/27/14	6,7
Set line and grade benchmarks	2 days	Wed 5/28/14	Thu 5/29/14	8
Prepare site - lay down yard and temporary fencing	1 day	Fri 5/30/14	Fri 5/30/14	9
Site Grading and Utilities	**21 days**	**Mon 6/2/14**	**Mon 6/30/14**	**9**
Clear and grub site	3 days	Mon 6/2/14	Wed 6/4/14	8,10
Construct site access and temporary storage	2 days	Thu 6/5/14	Fri 6/6/14	12,10
Rough grade site (cut and fill)	1 wk	Mon 6/9/14	Fri 6/13/14	13
Connect ot UBC Utilities, install storm drainage	2 wks	Mon 6/16/14	Fri 6/27/14	14
Perform final site grading	2 wks	Tue 6/17/14	Mon 6/30/14	15FF+1 day
Foundations	**17 days**	**Tue 7/1/14**	**Wed 7/23/14**	**16**
Excavate foundations	1 wk	Tue 7/1/14	Mon 7/7/14	16
Form pad footings and spread foundations	2 days	Tue 7/8/14	Wed 7/9/14	18
Pour foundations	3 days	Thu 7/10/14	Mon 7/14/14	19
Cure foundations	7 days	Tue 7/15/14	Wed 7/23/14	20
Strip forms	1 day	Thu 7/10/14	Thu 7/10/14	19FF+1 day



Structural Framing	**5 days**	**Fri 7/11/14**	**Thu 7/17/14**	**22**
Erect steel columns, beams and joists	1 wk	Fri 7/11/14	Thu 7/17/14	22
Erect timber columns, beams and joist	1 wk	Fri 7/11/14	Thu 7/17/14	22
Carpentry Work	**15 days**	**Fri 7/18/14**	**Thu 8/7/14**	**25**
Install exterior sheathing and metal studs	3 wks	Fri 7/18/14	Thu 8/7/14	
Roofing Installation	**12 days**	**Fri 8/8/14**	**Mon 8/25/14**	**26**
Install pre fabricated roof	5 days	Fri 8/8/14	Thu 8/14/14	
Install Green Roof	7 days	Fri 8/15/14	Mon 8/25/14	29
Set rooftop equipment	1 wk	Fri 8/15/14	Thu 8/21/14	29
Window wall and exterior glazing installation	**20 days**	**Fri 7/18/14**	**Thu 8/14/14**	**25**
Install window wall aluminum and glass	2 wks	Fri 7/18/14	Thu 7/31/14	25
Install interior stud walls and drywall	1 wk	Fri 7/18/14	Thu 7/24/14	25
Install interior doors and hardware	1 wk	Fri 7/25/14	Thu 7/31/14	34
Building Finishes	**20 days**	**Fri 8/1/14**	**Thu 8/28/14**	
Paint walls and woodwork	2 wks	Fri 8/1/14	Thu 8/14/14	35
Complete interior and exterior sod and plantings	2 wks	Fri 8/15/14	Thu 8/28/14	37
Electrical	**8 days**	Thu 7/24/14	**Mon 8/4/14**	
Pull wire in conduit and set area transformers	4 days	Thu 7/24/14	Tue 7/29/14	
Make electrical terminations for HVAC equipment	2 days	Wed 7/30/14	Thu 7/31/14	40
Install light fixtures - test and clean	1 wk	Thu 7/24/14	Wed 7/30/14	
Heating and Ventilating - AC	**30 days**	Thu 7/31/14	**Wed 9/10/14**	**33**
Set equipment in mechanical room	3 days	Fri 8/1/14	Tue 8/5/14	33
Install duct in building chase	3 days	Wed 8/6/14	Fri 8/8/14	44,33
Set HVAC trim and test and balance system	2 wks	Mon 8/11/14	Fri 8/22/14	45,41
Final Clean-up	**4 days**	**Fri 8/29/14**	**Wed 9/3/14**	
Remove debris from building and do final clean-up	4 days	Fri 8/29/14	Wed 9/3/14	38,42
Complete Final Inspections	**14 days**	**Wed 9/3/14**	**Mon 9/22/14**	**48**
Perform architect's inspection	1 day	Thu 9/4/14	Thu 9/4/14	48
Perform local building agency inspection	1 day	Fri 9/5/14	Fri 9/5/14	50
Obtain Certificate of occupancy	7 days	Mon 9/8/14	Tue 9/16/14	51
Issue final completion documents	1 day	Wed 9/17/14	Wed 9/17/14	52
Perform Fire Marshal's inspection	1 day	Thu 9/18/14	Thu 9/18/14	53



2.5 Resource Allocation

The majority of the construction resources for the Greenhouse Café will be sourced locally. Several manufacturers around British Columbia have been located who produce glulam beams and architecturally finished products from pine beetle wood. Utilizing these products will help minimalize the wasted wood from British Columbia's pine beetle natural disaster that has been occurring over the last decade. The large glazed walls of the restaurant and greenhouse will use double glazed panes filled with monatomic gases to increase the insulation properties of the large beautiful greenhouse walls. In compliance with LEED outlines our building's concrete in the foundation and shear walls will contain roughly 40% of supplementary cementitious material and use recycled, crushed concrete as aggregate (BC Ready-Mixed Concrete Association, 2013).

3 GREENHOUSE CAFÉ DESIGN

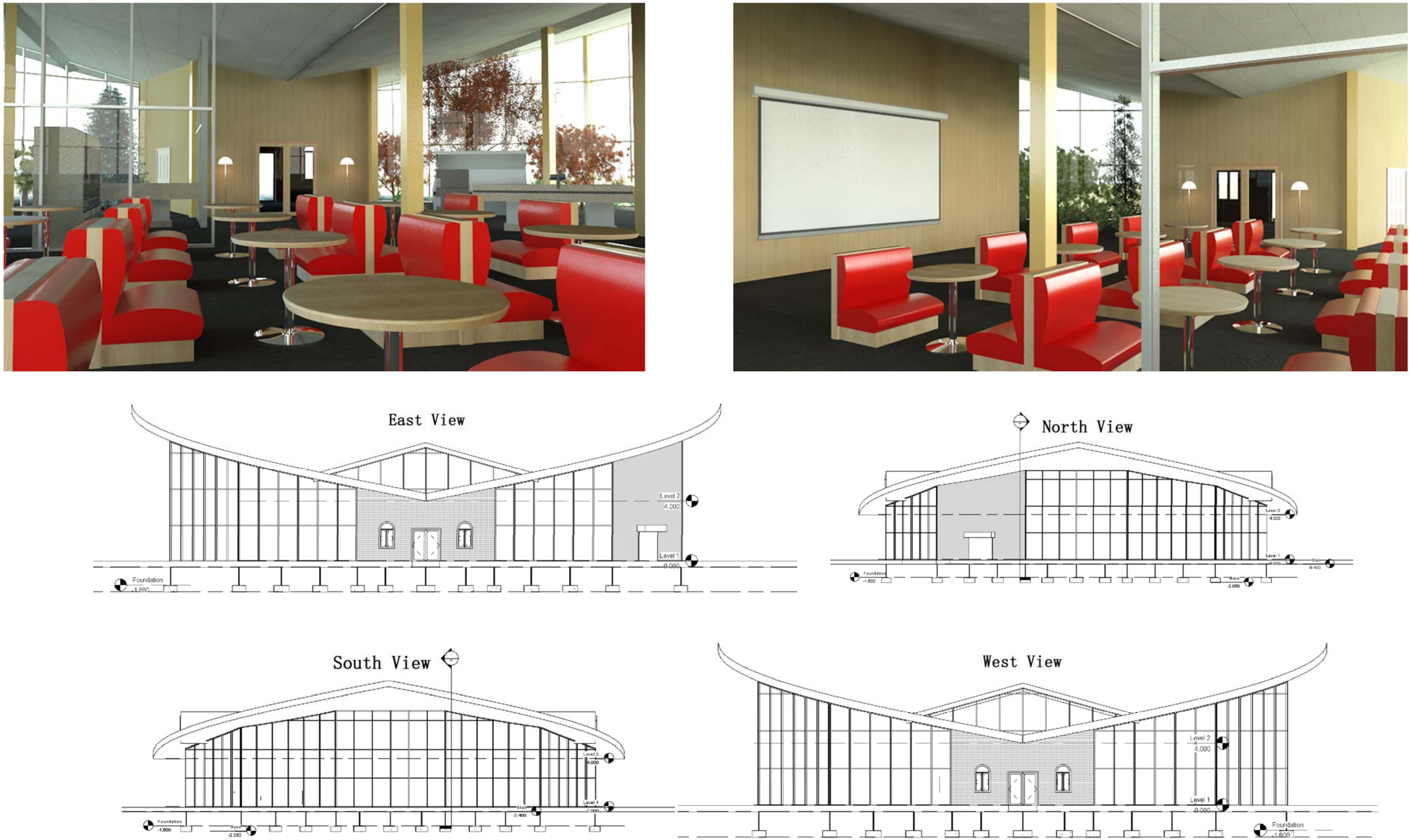
Figure 3: Greenhouse Cafe Exterior Rendering

The Greenhouse Café is the initial improvement to the Garden, aiming to attract more visitors and increase revenue. The Greenhouse Café will have a café at the centre of the building, a greenhouse at the perimeter of the building, and a green roof. A 4D model of the building was created to improve the design process. This section also includes a detailed design of one structural and one geotechnical element of the building.

3.1 Architectural Inspiration

The main objectives of the Greenhouse Café design are to develop in-house attractions, while considering environmental sustainability. The core philosophy of the design is to make the building more passive and efficient through natural lighting, while incorporating interesting architecture. Much like a sculpture, the building started out as a simple cylindrical shape and was further molded by the needs of the Botanical Garden. Early on the project design was guided by the purpose of the project until certain restraints, such as the available area was contemplated. Once the functionality of the structure was considered, the design was revised to incorporate a greenhouse around the perimeter of the structure, surrounding the Café in the centre of the building. Digital rendering, as shown in Figure 4 on the following page, allowed the final elements to be fine-tuned to complement the primary structure. The model of the building effectively turned the creative design process into an iterative procedure until all of our functional targets were met. Vague idealizations began to give way to material selections, interior design, and room layouts, which resulted in a more sophisticated 3D model rather than a traditional architectural plan. The building will showcase both innovative sustainable technologies and modern multi-cultural architecture to the community and tourism industry.

Figure 4: Greenhouse Cafe Rendering and Elevation Views



3.1.1 Enclosure System

The glass curtain wall system of the Greenhouse Café consists of two layers of glazing separated by a spacer. The spacers create an air cavity between the panes, which mitigate heat loss and provides a highly insulating building envelope. The glass is sealed together with a vapour barrier gasket to make the enclosure completely waterproof.

3.1.2 Interior System

The heating and ventilation system of the Café area is largely passive. Vents are located in the bottom and top of the structure. Hot air rising throughout the structure and being vented at the top creates a negative pressure that draws cooler air in at the bottom. In the winter months, sunlight shining through the glazing will store thermal mass in the concrete floors. At night and in the evening, this heat will be released and circulate through the structure. The sloped roof allows the air to flow evenly without collecting in the center of the building, promoting natural ventilation. The central Café area will have a number of removable interior partition walls so that they can be shifted if necessary, providing space for special events.

3.2 Structural Design

Structural design of the Greenhouse Café was made in close collaboration with the architectural and geotechnical design. The building elements are selected and designed to accommodate the architectural concept and resolve geotechnical constraints.

3.2.1 Structural Loads

The structural loads considered in our design include specified snow load, specified dead load, and specified live load. Lateral load analysis is not part of the design, therefore, the wind load and earthquake loads are not considered. The specified snow load, S, is determined to be 1.64 kPa for Vancouver; the specified dead load, D, above deck is calculated to be 0.8 kPa; and the specified live load, L, is 1.0 kPa as detailed in the National Building Code of Canada, NBCC (National Research Council of Canada, 2010).

3.2.2 Design Weight Bearing Components

The structural calculations were completed using stained Douglas Fir; however, the construction will ideally use pine-beetle lumber, which is not specified in the current revision of the NBCC. The green roof will be supported by steel decking, which transfers load to the foundation through a load path within wooden truss, girder, and column.

To design and size the structural elements, the governing load was selected from the worst (highest) load combination of cases outlined in Table 4.1.3.2.A of NBCC (National Research Council of Canada, 2010). The wind load was considered negligible on the factored load. The multiple columns provide a redundant design, which facilitates large bearing capacity and ensures a large factor of safety. While calculating the factored load, it is observed that the snow load is greater than the live load, therefore the governing equation is:

$$\boldsymbol{Factored\ load = 1.25D + 1.5S + 0.5L}$$

Deck Design

The steel deck is supported by the wooden truss, which evenly spreads the load across the span of the Café. The truss layout demands a minimum deck span of 3.3 m, which will provide sufficient load bearing capacity. The calculated factored load demand on the deck is 4.0 kPa, which is satisfied by steel deck P2436 type 22 with bearing capacity of 4.8 kPa and unit weight of 2.88 lb/sf (Canam Group, 2013). Under service conditions, deflection of the steel deck is within the allowable maximum deflection of L/360 (National Research Council of Canada, 2010). Therefore, the steel deck P2436 type 22 is acceptable.

Truss Design

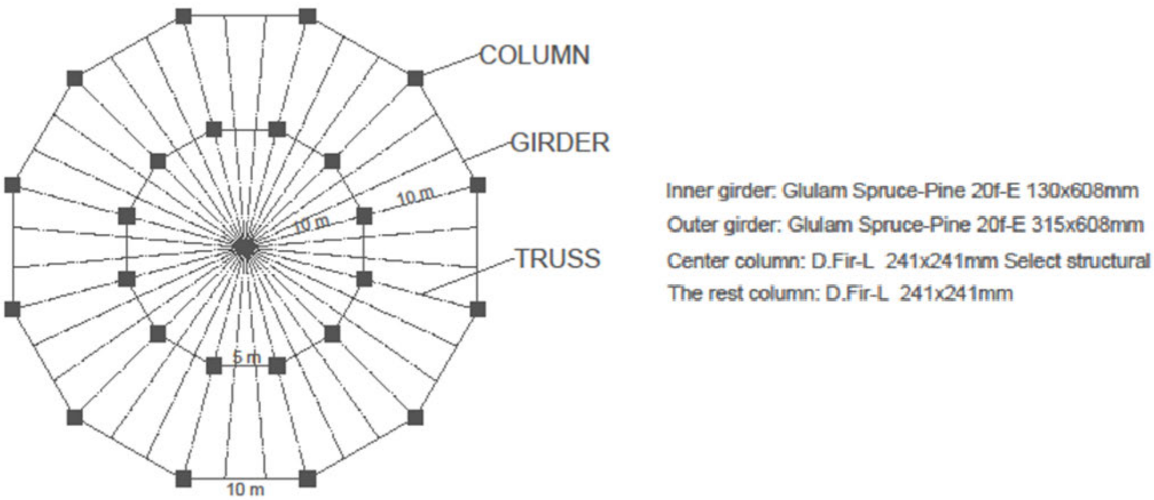


Figure 5: Truss Layout Plan

The green roof of the Greenhouse Café is a symmetrically sloped surface supported by a system of truss bays which are triangles and projected from the center of structure. Each truss carries loads from its corresponding tributary areas. The factored load demand on truss is 4.33 kPa.

For truss modeling, the point load at each joint was also calculated by tributary areas. By a RISA 2D model (see Appendix A), member forces were calculated. The member specification then was determined from the Stud Wall Selection Tables (National Wood Council, 2010).

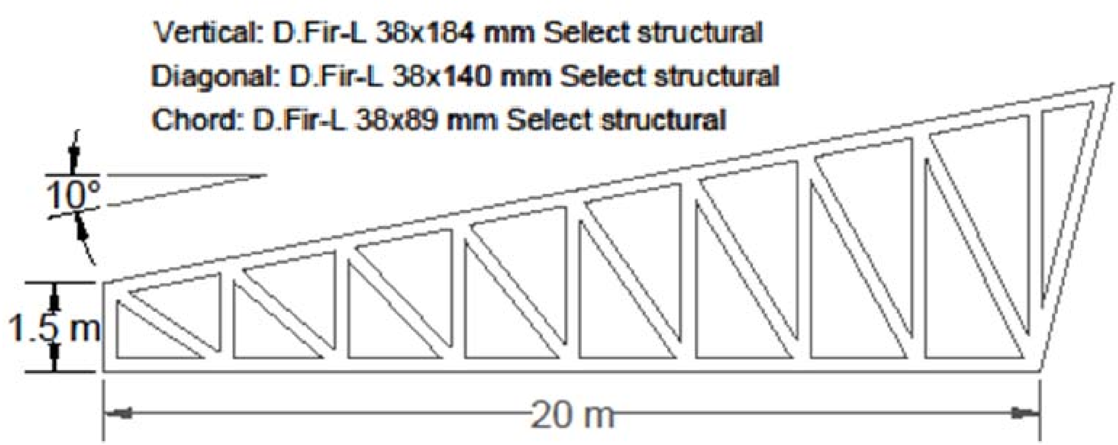


Figure 6: Typical Truss

Girder Design

The point loads applied on girders were determined by calculating factored load from the truss as shown in the RISA model (see Appendix A). The point loads are 10 kN, 81 kN, and 59 kN in central column, interior and exterior girders, respectively while considering the truss self-weight.

Glulam is commonly used for intermediate and long-span bending applications. This is due to the wide range of sizes, lengths and shapes available (National Wood Council, 2010). Our design features long girders spanning 5 m and 10 m. Therefore, glulam is our primary bending member consideration.

From the Beam Selection Table of Wood Design Manual, the lightest members with satisfying moment and shear resistance were sought. Glulam Spruce-Pine 20f-E 130x608mm was selected for interior girder and Glulam Spruce-Pine 20f-E 315x608 selected for exterior girder (National Wood Council, 2010). By deflection check, all girder materials selected are satisfactory.

Column Design

The factored load from the green roof, deck, truss and girder applied to column was calculated to be 4.34 kPa. The column load bearing was then calculated by tributary area method, followed by material selection as summarized in Table 2.

Table 2 Column Selection Details

COLUMN LOCATION	FACTORED LOAD	EFFECTIVE LENGTH	COLUMN	LOAD RESISTANCE
CENTRAL	326 kN	4 m	D.Fir-L Select Structural 241x241mm	545 kN
INTERIOR	217 kN	4 m	S-P-F No.1 241x241mm	343 kN
EXTERIOR	190 kN	4 m	S-P-F No.2 241x241mm	226 kN

3.3 Geotechnical Design

A geotechnical analysis was conducted to design effective foundations to support the UBCBG Greenhouse Café while complying with the applicable standards, including the International Building Code, Canadian Foundation Engineering Manual, and UBC's personal Standards. The structural loads calculated in the preceding section are essential inputs for the foundation design.

3.3.1 Soil Stratigraphy

Soil stratigraphy was determined using data from a set of test holes taken at Agronomy Road and West Mall, which is 900 m away from UBCBG. The soil within UBC area would have undergone similar geological experience; therefore, the soil stratigraphy is expected to not vary significantly over this distance so that the provided borehole logs should give relevant information. The eight borehole depths vary between 9 m and 12 m with ground elevation at approximately 80 m above sea level. The water table is 2 m below surface (GeoPacific Consultants, 2013). The overview of estimated soil stratigraphy is shown in Figure 7.

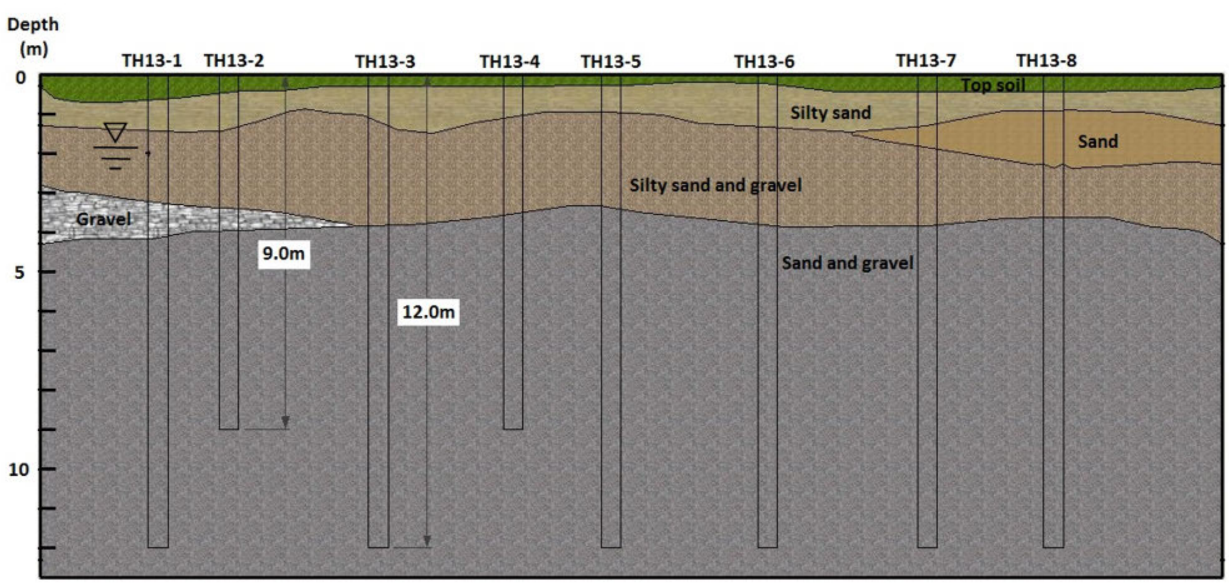


Figure 7: Soil Stratigraphy at Proposed Site

The geotechnical analysis is based on a simplified soil stratigraphy model shown in Figure 8 with typical values of soil properties (Budhu, 2007). The silty sand layer is assumed to be fairly dense and have elasticity modulus of 20 MPa (Geotechdata, 2013).

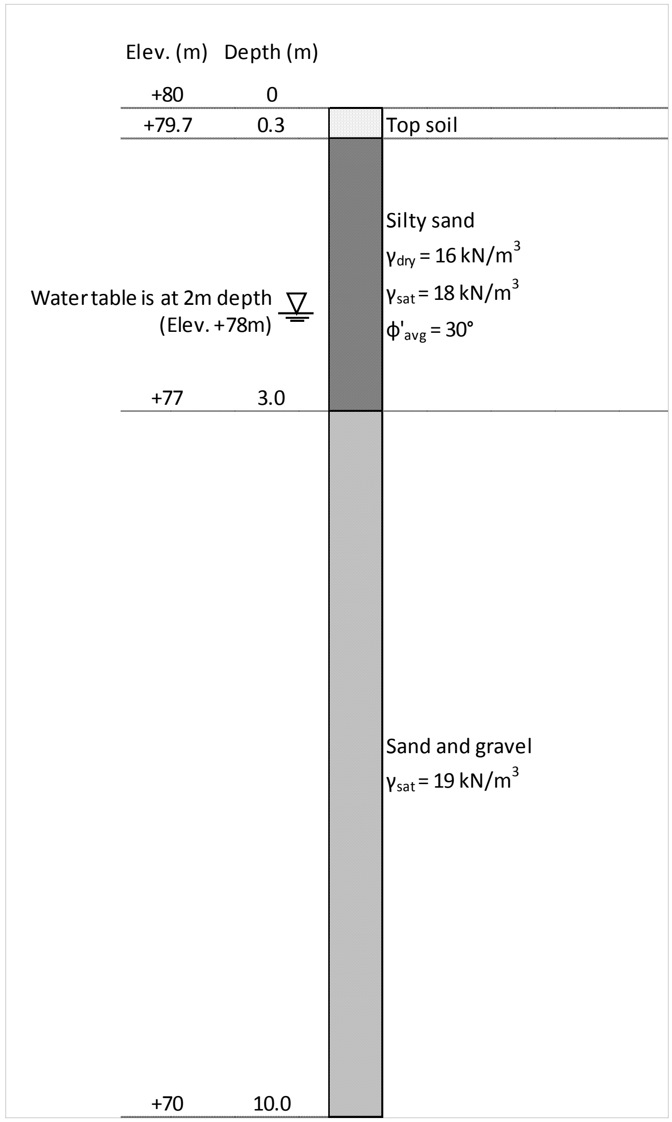


Figure 8: Simplified Soil Stratigraphy

3.3.2 Shallow Foundation Design

As the Greenhouse Café is a typical one-storey building that will be constructed on compacted silty sand (Glacial Till), a simple square footing of 1.0x1.0 m placed underneath each column will be adequate for most loads. However, as the central footing sustains the greatest load demands, its base area is increased to 1.2x1.2 m. All footing bases are 0.35 m thick at a depth of 1.2 m to satisfy the local frost line boundary located at 0.20 m depth as well as the water table located at 2.0 m depth (Easkes, 2014). The bearing capacity calculation is based on Allowable Stress Design (ASD) using a safety factor of 3.0 and Load and Resistance Factor Design (LRFD) with resistance factor of 0.5. The specification of reinforced square footing is shown in Figure 9 with results summarized in Table 3.

.

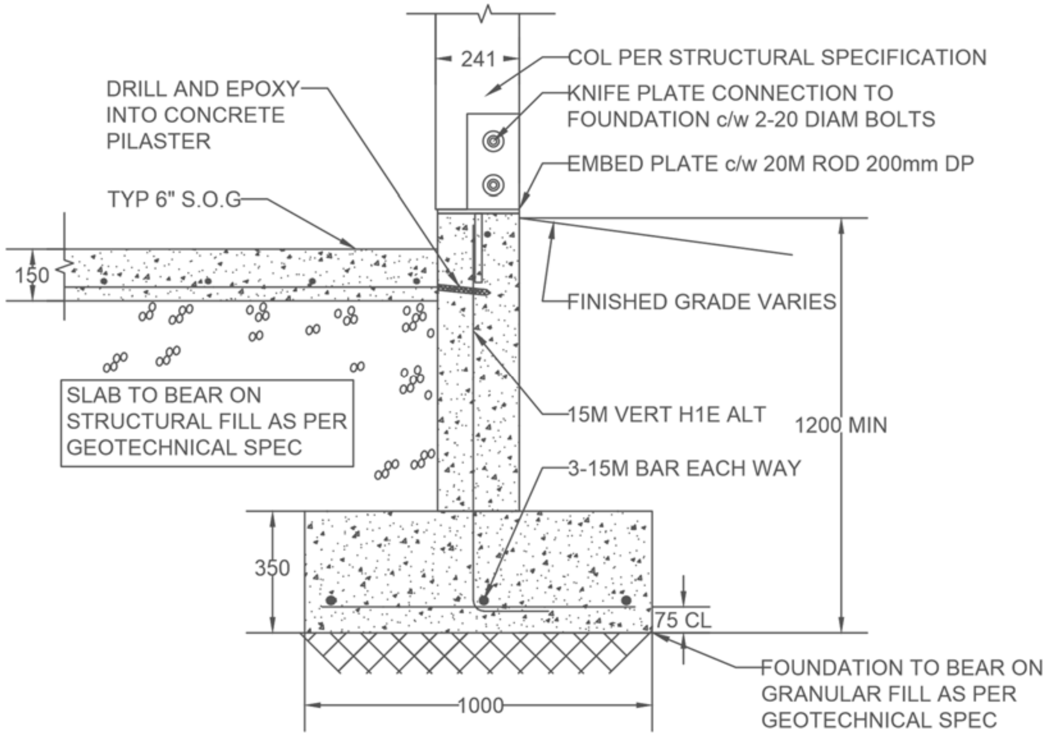


Figure 9: Typical Footing Detail

Table 3 Summary of Shallow Foundation Design

	CENTRAL FOOTING	INTERIOR FOOTINGS	EXTERIOR FOOTINGS
DIMENSION (MM X MM)	1200x1200	1000 x 1000	1000 x 1000
FACTORED DEMAND (KPA)*	234	221	191
ASD BEARING CAPACITY (KPA)	276	243	243
LRFD BEARING CAPACITY (KPA)	288	248	248
DISTORTION SETTLEMENT (MM)	4	3	3
DIFFERENTIAL SETTLEMENT	41/100000	2/3125	7/25000

** Calculated as per column load demand specified in section 3.2 Structural Design*

3.3.3 Foundation Plan

Each square footing is placed beneath each column to support the loads of the structure and green roof as specified in Figure 10.

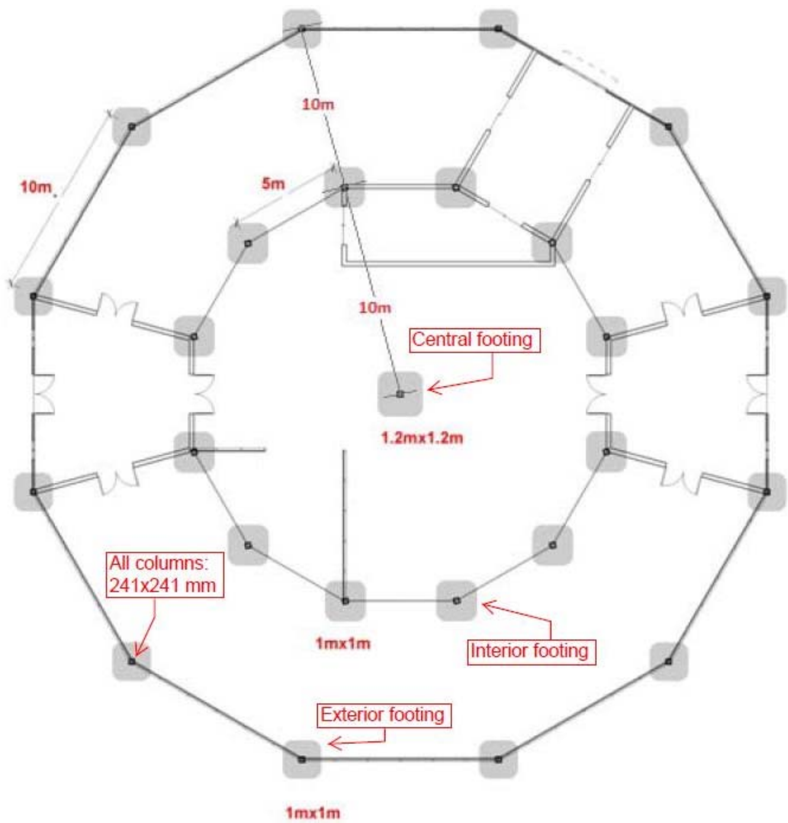


Figure 10: Shallow Foundation Plan

3.3.4 Liquefaction Assessment

Due to at least four glaciations during Pleistocene, silty sand including silty sand and gravel (Glacial Till) layer at depth up to 3 m has undergone extremely high geological pressure and thus is very compact, stiff, and has high bearing capacity (Ministry of Environment, 2014). The sand and gravel layer, located at greater than 3.0 m depth, has also undergone the same extreme geological experience as the upper layers; therefore it is also very compact and stiff. Based on this analysis, liquefaction is not expected to occur in the proposed site even though the sand layer is saturated and may have low fines content.

3.3.5 Design Standards

Below is the outline of applicable standard requirements along with the design compliance.

UBC - In order to comply with the UBC Construction Standards, all earthworks including the site classification factor for the soils shall be determined by a qualified Geotechnical Engineer for further on-site investigation (University of British Columbia, 2014).

European Committee for Standardization and Canadian Foundation Engineering Manual - The expected settlement for serviceability is 3-4 mm which satisfies the limiting value of 25 mm (European Committee for Standardization, 1994). The worst expected differential (angular) settlement of design is 2/3125 which is less than the allowable maximum δ/L ratio of 1/250 for open steel and reinforced concrete frames structure (Budhu, 2007).

International Building Code - The applicable geotechnical design requirements prescribed in the International Building Code as well as the compliance of actual design are outlined in Table 4 below (International Code Council, 2012).

Table 4 Design Compliance (International Code Council, 2012)

CODE	REQUIREMENTS	COMPLIANCE
1809.2	Shallow foundations shall be built on undisturbed soil, compacted fill material or controlled low-strength material.	Footings are placed within compacted silty sand layer that has high bearing capacity.
1809.4	The minimum depth of footings below the undisturbed ground surface shall be 12 in. (305 mm). The minimum width of footings shall be 12 in. (305 mm).	Depth of footing is 1200 mm. Width of smallest footing is 1000 mm.
1809.5	Foundations and other permanent supports of buildings and structures shall be protected from frost by one or	The footings are placed below the local frost line at 200 mm depth.

	more of the following methods: 1. Extending below the frost line; 2. Accordance with ASCE 32; or 3. Erecting on solid rock.	
1809.6	Footings on granular soil located such that the lower edges of adjoining footings shall not have a differential slope steeper than 30°with the horizontal, unless the material supporting the higher footing is braced or retained or otherwise laterally supported in an *approved* manner or a greater slope has been properly established by engineering analysis.	The footings are constructed to be at same elevation, within silty sand (Glacial Till) layer. Due to its high bearing capacity, differential settlement of footings is expected to be insignificant and less than 30°.
1809.7	One-storey building: minimum footing width of 12 in. (300 mm) and thickness of footing is 6 in. (150 mm).	The smallest designed footing is 1000 mm wide and 350 mm thick.

3.4 Environmental Consideration

The Greenhouse Café is utilizing the most advanced resources in sustainable engineering practices. This design decision gives the Café an operational advantage because of lowered hydroelectric and water management bills.

Additionally, the Café will make practice of the recent market of timber products from the Pine Beetle disaster in BC’s forests. This will help minimize the cleanup this natural disaster has ensued on the province. The pine-beetle timber as a construction material additionally stores carbon when harvested, furthermore many of these rising manufacturers invest part of their profit to reforestation projects to ensure the longevity of our local pine forests and the production industry it generates.

Many of the materials were sourced locally, which helps the economy in British Columbia and decreases transportation costs while simultaneously lowering the impact of such transport on the environment.

The first green roof in human history was built in 7th century B.C. in Babylon (Iraq) by the king of Babylon for his wife. In ancient times, green roofs were mainly for aesthetic purpose and better insulation. They were not associated with environment benefits until 1977 when Germany started formally studying green roof technology. Since then the technology has being gaining popularity in Europe and throughout the world (Rodriguez, 2006).

The concept of environmental protection has been increasingly integrated into building design and construction. To minimize the negative impacts to the environment, cities around the world are promoting sustainable building practices to achieve harmony with natural environments, not only aesthetically. As a result, building structures and interfaces are being configured to be more natural. Complementarily, green roofs make concrete building less destructive to the environment.

4 COST ANALYSIS

In order to generate an accurate cost estimate of the Greenhouse Café a square foot method estimate was compiled using the RS Means Online program and database. Our estimate took into consideration location, green construction materials, time of construction, and use of the building as a restaurant, size, and general frame type of the building.

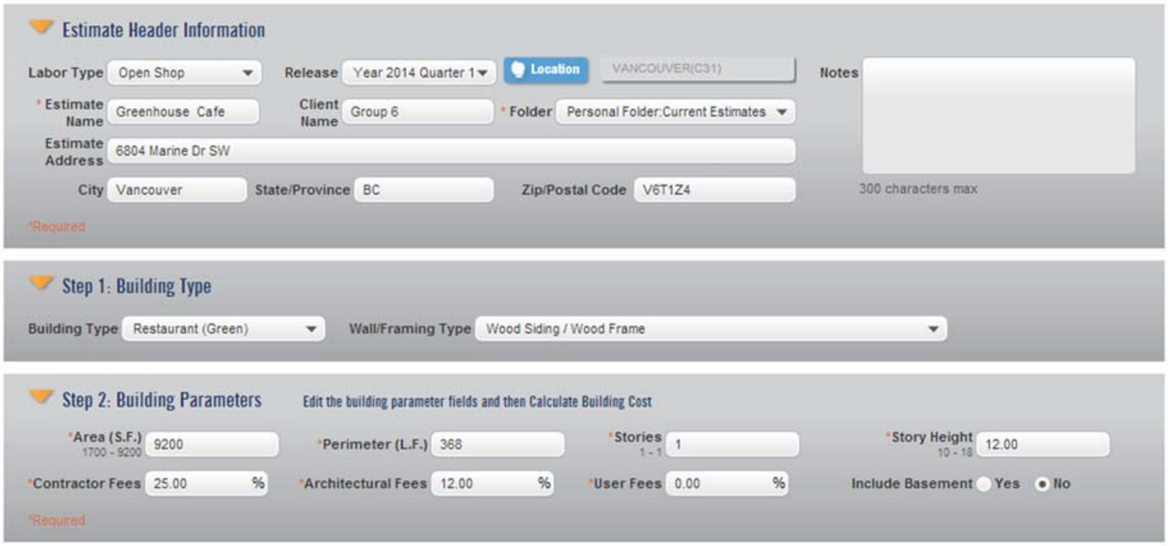


Figure 11: Square Foot Estimate Parameters

The estimate also included reserves for standard restaurant equipment (range, freezers, bar, seating and tables, etc.), green roof, water recycling equipment, heat exchangers, contractor fees, and a higher than usual architectural fee due to the intricate design. Architectural service fees are usually around 10% (The Royal Architecture Institute of Canada, 2009).

Figure 12: Square Foot Estimate

Taking all of the resources into consideration, the square foot method generated a total cost of $2,345,000.00. This cost does not take into account the extent of glazing, costly pine beetle timber or the interior greenhouse in our design. We estimate that this will add roughly $1.2M to the total cost for a total of around $3.6M for the total greenhouse and café space.

5 CONCLUSION

The cost of the Greenhouse Café was estimated at $3.6M using the RS means online database.

Construction Management:

Integrated project delivery method allows the design team to collaborate with one another early in the design process minimizing design conflicts and delays. The project management considered a conceptual phased development for the Garden in the long term as well as a site logistics plan and a construction schedule for the Greenhouse Café. The result is a construction schedule of 103 working days. A 4D BIM model aided this process and allowed for the iterative design approach. Local resource allocation makes such a fast-tracked schedule feasible.

Structural:

The structural design for this project focuses on gravity system determination without considering lateral loads and seismic loads. All calculations and analysis were conducted under the idealized loading condition. However, even with fewer factors to consider, the multi-edged footprint, the extraordinary-shaped green roof and environmental soundness still provides design excitement and challenges for structural analysis. Accordingly, truss network was set in radially to accommodate roof shape; wood was used for all load bearing components except the deck. Overall, the structure is aesthetically pleasant, functional and environmentally sounds.

Geotechnical

Based on the analysis of the soil stratigraphy, from the closest geotechnical conditions accessible, our design team determined that square shallow foundations beneath the columns were the optimized design. The footings are sized to be 1.2x1.2 m at the centre and 1.0x1.0 m elsewhere with a thickness of 0.35 m below each column. The foundations are placed at 1.2 m below the surface. The conservative footing design complies with the UBC's Standards, Canadian Foundation Engineering Manual, and International Building Code.

BIBLIOGRAPHY

BC Ready-Mixed Concrete Association. (2013). *Concrete and LEED Canada*. Retrieved from BCRMCA: http://www.bcrmca.ca/sustainable_construction/concrete_&_leed/

Budhu. (2007). *Soil Mechanics and Foundations.* Mississauga: John Wiley & Sons Canada.

Canadian Foundation Engineering Manual. (2012). *Soils & Foundations*. Retrieved March 14, 2014, from 2012 International Building Code: http://publicecodes.cyberregs.com/icod/ibc/2012/icod_ibc_2012_18_par106.htm

Canadian Standards Association. (2010). *Engineering Design in Wood.* Mississauga.

Canam Group. (2013). *Steel deck*. Retrieved from Canam: http://www.canam-construction.com

City of Vancouver. (2014). *VanDusen*. Retrieved from City of Vancouver: http://vancouver.ca/vandusen-visitor-centre-marks-one-year-anniversary.aspx

Easkes, J. (2014, March 17). *Soil & the Spring Thaw*. Retrieved from Ask Jon Easkes: http://joneakes.com/jons-fixit-database/2149-Overview-Soil-and-the-Spring-Thaw

European Committee for Standardization. (1994). *Applied Geomechanics.* Retrieved from New Mexico Tech: http://infohost.nmt.edu

GeoPacific Consultants. (2013). *Geotechnical Investigation Report, Orchard Commons, Agronomy Road & West Mall.* Vancouver.

Geotechdata. (2013, September 17). *Soil elastic Young's modulus*. Retrieved from Geotechdata.info: http://www.geotechdata.info/parameter/soil-young's-modulus.html

International Code Council. (2012). *Geotechnical investigations*. Retrieved from International Building Code: http://publicecodes.cyberregs.com/icod/ibc/2012/icod_ibc_2012_18_sec001.htm

Ministry of Environment. (2014, 03 20). *Geology, Landforms And Surficial Materials*. Retrieved from British Columbia Government: http://www.env.gov.bc.ca/soils/landscape/1.3geology.html

National Research Council of Canada. (2010). *National Building Code of Canada.* Ottawa.

National Wood Council. (2010). *Wood Design Manual.* Ottawa.

The Royal Architecture Institute of Canada. (2009). *Guide to Determining Appropriate Fees for the Services of an Architect.* Retrieved from http://drr.lib.athabascau.ca/files/arch/655/guide_architectservicefees_e.pdf

UBC Botanical Garden. (2014). *Mission*. Retrieved from UBC Botanical Garden: http://www.botanicalgarden.ubc.ca/mission

University of British Columbia. (2014). *Building, Structural & Snow Load Design*. Retrieved March 14, 2014, from UBC Technical Guideline: http://www.technicalguidelines.ubc.ca/technical/structural_design_snow_loads.html#e

APPENDIX A – STRUCTURAL DESIGN CALCULATION

Snow Load

Snow Load, S, was calculated based on Article 4.1.6.2 of the NBCC 2010.

$$S = I_S[S_S(C_b C_w C_s C_a) + S_r]$$

$$\therefore S = 1.0 * [1.8(0.8 * 1.0 * 1.0 * 1.0) + 0.2] = 1.64\ kPa$$

Calculate Dead Load & Live Load

Component	Material	Thickness	Unit Weight (psf)
Plants	Sedum Album	4”	6
Growing Medium	Organic and mineral Additives	2”	8 (WC30-40%)
Root barrier filter	60% recycled compound	0.3”	1
Drainage & retaining layer	Plastic drain mat with cone	1.5”	0.8
Moisture protection layer	Recycled polypropylene	0.3”	0.2
Separation barrier	Plastic sheet	0.2”	0.3
Thermal insulation	Extruded polystyrene foam	4”	0.6
Total dead load above deck			16.9
Structural deck	Canam Steel deck P-2436	0.036”	2.43
Uniformly distributed live load (NBCC 4.1.5.3)			1 kPa

$\boldsymbol{Factored\ load = 1.25D + 1.5S + 0.5L}$ (Table 4.1.3.2.A of NBCC 2010)

Deck design

The truss layout requires deck with a maximum single span of 3.3m with satisfying load bearing capacity. $The\ factored\ load\ on\ deck = 1.25 * 0.8 + 1.5 * 1.64 + 0.5 * 1.0 = 4kPa$

From Canam steel deck catalogue, use the lightest option P2436 type 22:

- ➔ Deck unit weight = 2.88 psf

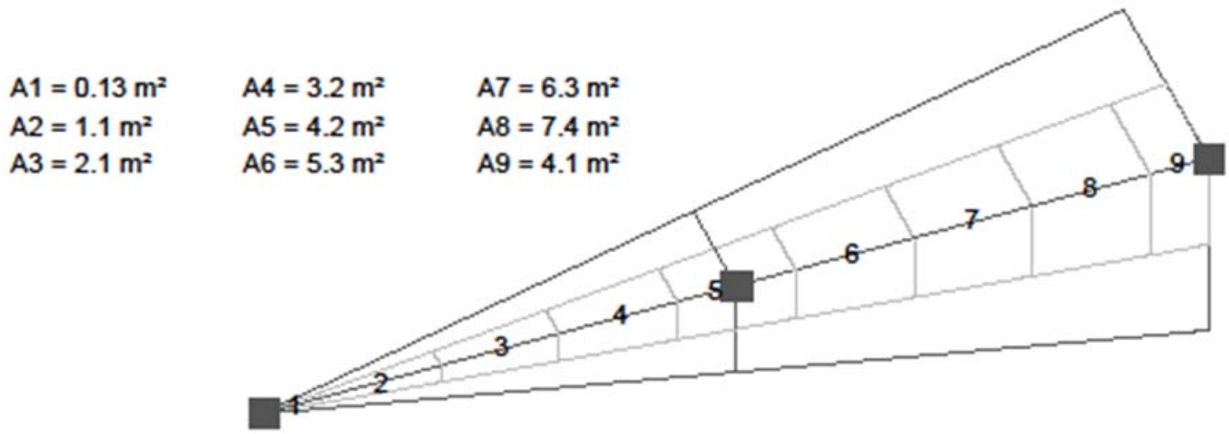
Truss Design

Each truss takes load from above by respective tributary areas. The factored load taken by each truss is 4.33 kPa including the green roof, deck and ceiling weight:

$$The\ factored\ load\ on\ truss = 1.25 * 1.1 + 1.5 * 1.64 + 0.5 * 1.0 = 4.33\ kPa$$

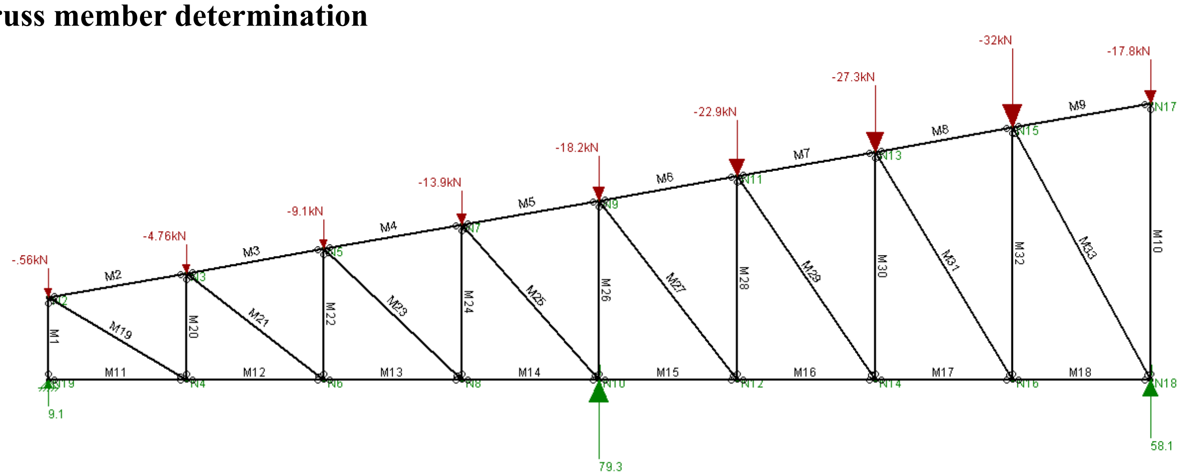
Point loads on joints:

In our truss design, the truss takes the roof load at each joint connecting with the deck. For truss modeling, the point load each joint takes are calculated by tributary areas.



Joint	1	2	3	4	5	6	7	8	9
Force (kN)	0.56	4.76	9.1	13.9	18.2	22.9	27.3	32	17.8

Truss member determination



From modeling result, members are selected Wood Design Manual 2010 (WDN), Stud Wall Selection Tables based on factors that governs:

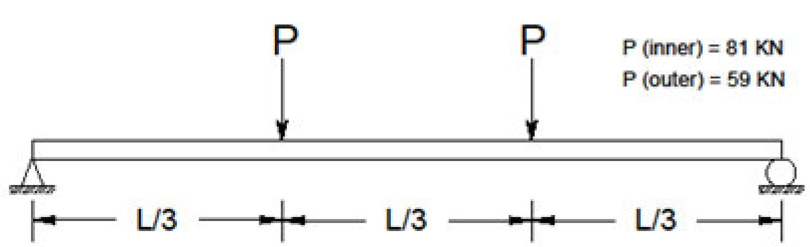
Final Member

Section	Controlling Member	Shape	Length (m)	Weight (kN)
Chords	M17	D.Fir-L 38x89mm SS	40	0.7
Verticals	M26	D.Fir-L 38x184mm SS	29	1.1
Diagonals	M27	D.Fir-L 38x140mm SS	32	0.88
Total				2.65

Girder Design

Loads

The point load on central column is 9.1 kN and 79.3 kN



POINT LOADS ON GIRDER

on interior girder and 58.1 kN on exterior girder. Plus truss self- weight taken by three points in proportion of its tributary areas. The point loads are as follows:

- Central column: 9.1 + 2.65 x (12/83) = 9.5 kN
- Interior girder: 79.3 + 2.65 x (40/83) = 81 kN
- Exterior girder: 58.1 + 2.65 x (31/83) = 59 kN

Bending moment

- Interior girder: M = Pa = 81 x 5/3 = 135 kNm
- Exterior girder M= Pa = 59 x 10/3 = 197 kNm

Bending moment resistance

From the Beam Selection Table of WDN, select the lightest members with greater moment resistance and shear resistance.

- Interior girder: Glulam Spruce-Pine 20f-E 130 x 608 mm
- Exterior girder: Glulam Spruce-Pine 20f-E 315 x 608 mm

Check deflection $\Delta max = \frac{Pa*(3L^2-4a^2)}{24EI}$ CAN/CSA O86 limits L/180 deflection

- Interior girder: Δmax = 14 mm < allowable (acceptable)
- Exterior girder: Δmax = 30 mm < allowable (acceptable)

Column Design

Factored load for column is:

$$1.25D + 1.5S + 0.5L = 1.25 * 1.1022 + 1.5 * 1.64 + 0.5 * 1.0 = 4.34\ kPa$$

Factored compressive load

- P (central) = 4.34 x 6.25 x 12 = 325.5 kN
- P (interior) = 4.34 x 50 = 217 kN
- P (exterior) = 4.34 x 43.8 = 190 kN

Select column

From the column selection table of WDM, the lightest wood columns are selected as follows:

- Central column: D.Fir-L Select Structural 241x241mm Pr = 545 kN @ L = 4 m
- Interior column: S-P-F No.1 241x241mm Pr = 343 kN @ L = 4 m
- Exterior column: S-P-F No.2 241x241mm Pr = 226 kN @ L = 4 m

APPENDIX B – GEOTECHNICAL DESIGN CALCULATION

GEOTECHNICAL ENGINEERING DESIGN CALCULATION SHEET		
	Course	**CIVL 446 Engineering Design and Analysis II**
	Subject	Foundation Design of the Greenhouse Café at the UBC Botanical Garden
	Title	Calculation of 1.2x1.2m Footing at the Centre of Cafe

INPUT						
Gamma Sat	gams	=		=	18.00	kN/m3
Gamma Dry	gamd	=		=	16.00	kN/m3
Friction Angle	phi	=		=	30.00	degrees
GWT Location	z	=		=	2.00	m
Depth of Footing	df	=		=	1.20	m
Length	l	=		=	1.20	m
Base	b	=		=	1.20	m
Thickness	t	=		=	0.35	m
Shortest distance between footings	L	=		=	10.00	m
Friction Angle Radians	phir	=		=	0.52	rad
Factor of Safety	Fs	=		=	3.00	
Resistance Factor	Fr	=		=	0.50	
Modulus of Elasticity	E	=		=	20,000	kPa
Poissons Ratio	pois	=		=	0.45	
Influence factor	I_ε	=		=	0.20	
Design Lifetime	time	=		=	50	years
Factored Applied Load	p	=		=	322	kN
Factored Weight of Footing	w	=	l*b*t*24*1.25	=	15.12	kN
Factored Applied Stress	Qapplied	=	(p+w)/(b*l)	=	234.11	kPa
Calculation of Bearing Capacity						
Case	case	=	if(z>b+df,"Case 1",if(z<df,"Case 3","Case 2"))	=	Case 2	
sq	sq	=	1+((b/l)*TAN(phir))	=	1.58	
dq	dq	=	IF(df/b>1,1+((2*tan(phir))*((1-sin(phir))^2)*(tan(df/b)^-1)),1+((2*tan(phir))*((1-sin(phir))^2)*(df/b)))	=	1.29	
Nq	Nq	=	exp(PI()*TAN(phir))*(tan((45*PI()/180)+(phir/2))^2)	=	18.40	
wq	wq	=	if(case="Case 3",(z/df)+((gams-9.8)/gams)*(1-(z/df)),1)	=	1.00	
Ngamma	Ngamma	=	0.1054*exp(9.6*phir)	=	16.06	
sgamma	sgamma	=	1-(.4*(b/l))	=	0.60	
dgamma	dgamma	=	1.00	=	1.00	
wgamma	wgamma	=	if(case="Case 3",((gams-9.8)/gams),if(case="Case 2",(z-df)/b+((gams-9.8)/gams)*(1+(df/b)-(z/b)),1))	=	0.82	
sc	sc	=	1+0.2*(b/l)	=	1.20	
dc	dc	=	IF(df/b>1,1+(0.33*(tan(df/b)^-1)),1+(0.33*(df/b)))	=	1.33	
Check: Shallow Foundation Criterion	chk_sf	=	IF (df/b < 2.5, OK, Not OK)	=	**OK**	
Ultimate Bearing Capacity of Footing	Quc	=	gamd*df*(Nq-1)*sq*dq*wq+(0.5*gams*b*Ngamma*sgamma*dgamma*wgamma)	=	764.33	kPa
ASD Calculation						
Allowable Bearing Capacity Sand	Qas	=	(Qus/Fs)+gams*df	=	276.38	kPa
Check Allowable Stress Design	chk_asd	=	IF(Qac>Qapplied,"OK","NOT OK")	=	**OK**	
LFRD Calculation						
Ultimate Gross Bearing Capacity Sand	Qults	=	Qus*Fr+gams*df	=	288.21	kPa
Check LFRD	chk_lfrd	=	IF(Qults>Qapplied,"OK","NOT OK")	=	**OK**	
Calculation of Settlement						
Eff. Vertical Stress at footing level	σ'_{zd}	=	df*gamd	=	19.20	kPa
Correction factor for depth	C1	=	1-(0.5 σ'_{zd} / (Qapplied- σ'_{zd}))	=	0.96	
Correction factor for secondary creep	C2	=	1+0.2 log (time/0.1)	=	1.54	
Correction factor for foundation shape	C3	=	1.03 - 0.03 l/b > 0.73	=	1.00	
Settlement due to Distortion in Sand Calculation						
Settlement	S	=	(Qapplied*b*I_ε/E) *C1*C2*C3	=	4.1	mm
Check Allowable Settlement	chk_settle	=	IF(S<25,"OK","NOT OK")	=	**OK**	
Differential Settlement Calculation						
Differential Settlement	S_dif	=	S/L	=	0.0004	
Check Allowable Differential Settlement	chk_setdif	=	IF(S_dif<0.0040,"OK","NOT OK")	=	**OK**	

Date:	March 19, 2014	Designed by:	DA
Group:	Team 6	Reviewed by:	HW

GEOTECHNICAL ENGINEERING DESIGN CALCULATION SHEET		
	Course	**CIVL 446 Engineering Design and Analysis II**
	Subject	Foundation Design of the Greenhouse Café at the UBC Botanical Garden
	Title	Calculation of 1.0x1.0m Interior Footing

INPUT						
Gamma Sat	gams	=		=	18.00	kN/m3
Gamma Dry	gamd	=		=	16.00	kN/m3
Friction Angle	phi	=		=	30.00	degrees
GWT Location	z	=		=	2.00	m
Depth of Footing	df	=		=	1.20	m
Length	l	=		=	1.00	m
Base	b	=		=	1.00	m
Thickness	t	=		=	0.35	m
Shortest distance between footings	L	=		=	5.00	m
Friction Angle Radians	phir	=		=	0.52	rad
Factor of Safety	Fs	=		=	3.00	
Resistance Factor	Fr	=		=	0.50	
Modulus of Elasticity	E	=		=	20,000	kPa
Poissons Ratio	pois	=		=	0.45	
Influence factor	I_ε	=		=	0.20	
Design Lifetime	time	=		=	50	years
Factored Applied Load	p	=		=	210	kN
Factored Weight of Footing	w	=	l*b*t*24*1.25	=	10.50	kN
Factored Applied Stress	Qapplied	=	(p+w)/(b*l)	=	220.50	kPa
Calculation of Bearing Capacity						
Case	case	=	if(z>b+df,"Case 1",if(z<df,"Case 3","Case 2"))	=	Case 2	
sq	sq	=	1+((b/l)*TAN(phir))	=	1.58	
dq	dq	=	IF(df/b>1,1+((2*tan(phir))*((1-sin(phir))^2)*(tan(df/b)^-1)),1+((2*tan(phir))*((1-sin(phir))^2)*(df/b)))	=	1.11	
Nq	Nq	=	exp(PI()*TAN(phir))*(tan((45*PI()/180)+(phir/2))^2)	=	18.40	
wq	wq	=	if(case="Case 3",(z/df)+((gams-9.8)/gams)*(1-(z/df)),1)	=	1.00	
Ngamma	Ngamma	=	0.1054*exp(9.6*phir)	=	16.06	
sgamma	sgamma	=	1-(.4*(b/l))	=	0.60	
dgamma	dgamma	=	1.00	=	1.00	
wgamma	wgamma	=	if(case="Case 3",((gams-9.8)/gams),if(case="Case 2",(z-df)/b+((gams-9.8)/gams)*(1+(df/b)-(z/b)),1))	=	0.89	
sc	sc	=	1+0.2*(b/l)	=	1.20	
dc	dc	=	IF(df/b>1,1+(0.33*(tan(df/b)^-1)),1+(0.33*(df/b)))	=	1.13	
Check: Shallow Foundation Criterion	chk_sf	=	IF (df/b < 2.5, OK, Not OK)	=	**OK**	
Ultimate Bearing Capacity of Footing	Quc	=	gamd*df*(Nq-1)*sq*dq*wq+(0.5*gams*b*Ngamma*sgamma*dgamma*wgamma)	=	663.44	kPa
ASD Calculation						
Allowable Bearing Capacity Sand	Qas	=	(Qus/Fs)+gams*df	=	242.75	kPa
Check Allowable Stress Design	chk_asd	=	IF(Qac>Qapplied,"OK","NOT OK")	=	**OK**	
LFRD Calculation						
Ultimate Gross Bearing Capacity Sand	Qults	=	Qus*Fr+gams*df	=	247.78	kPa
Check LFRD	chk_lfrd	=	IF(Qults>Qapplied,"OK","NOT OK")	=	**OK**	
Calculation of Settlement						
Eff. Vertical Stress at footing level	σ'_{zd}	=	df*gamd	=	19.20	kPa
Correction factor for depth	C1	=	1-(0.5 σ'_{zd} / (Qapplied- σ'_{zd}))	=	0.95	
Correction factor for secondary creep	C2	=	1+0.2 log (time/0.1)	=	1.54	
Correction factor for foundation shape	C3	=	1.03 - 0.03 l/b > 0.73	=	1.00	
Settlement due to Distortion in Sand Calculation						
Settlement	S	=	(Qapplied*b*I_ε/E) *C1*C2*C3	=	3.2	mm
Check Allowable Settlement	chk_settle	=	IF(S<25,"OK","NOT OK")	=	**OK**	
Differential Settlement Calculation						
Differential Settlement	S_dif	=	S/L	=	0.0006	
Check Allowable Differential Settlement	chk_setdif	=	IF(S_dif<0.0040,"OK","NOT OK")	=	**OK**	

Date:	March 19, 2014	Designed by:	DA
Group:	Team 6	Reviewed by:	HW

GEOTECHNICAL ENGINEERING DESIGN CALCULATION SHEET		
	Course	**CIVL 446 Engineering Design and Analysis II**
	Subject	Foundation Design of the Greenhouse Café at the UBC Botanical Garden
	Title	Calculation of 1.0x1.0m Exterior Footing

INPUT							
	Gamma Sat	gams	=		=	18.00	kN/m3
	Gamma Dry	gamd	=		=	16.00	kN/m3
	Friction Angle	phi	=		=	30.00	degrees
	GWT Location	z	=		=	2.00	m
	Depth of Footing	df	=		=	1.20	m
	Length	l	=		=	1.00	m
	Base	b	=		=	1.00	m
	Thickness	t	=		=	0.35	m
	Shortest distance between footings	L	=		=	10.00	m
	Friction Angle Radians	phir	=		=	0.52	rad
	Factor of Safety	Fs	=		=	3.00	
	Resistance Factor	Fr	=		=	0.50	
	Modulus of Elasticity	E	=		=	20,000	kPa
	Poissons Ratio	pois	=		=	0.45	
	Influence factor	I_ε	=		=	0.20	
	Design Lifetime	time	=		=	50	years
	Factored Applied Load	p	=		=	180	kN
	Factored Weight of Footing	w	=	l*b*t*24*1.25	=	10.50	kN
	Factored Applied Stress	Qapplied	=	(p+w)/(b*l)	=	190.50	kPa
Calculation of Bearing Capacity							
	Case	case	=	if(z>b+df,"Case 1",if(z<df,"Case 3","Case 2"))	=	Case 2	
	sq	sq	=	1+((b/l)*TAN(phir))	=	1.58	
	dq	dq	=	IF(df/b>1,1+((2*tan(phir))*((1-sin(phir))^2)*(tan(df/b)^-1)),1+((2*tan(phir))*((1-sin(phir))^2)*(df/b)))	=	1.11	
	Nq	Nq	=	exp(PI()*TAN(phir))*(tan((45*PI()/180)+(phir/2))^2)	=	18.40	
	wq	wq	=	if(case="Case 3",(z/df)+((gams-9.8)/gams)*(1-(z/df)),1)	=	1.00	
	Ngamma	Ngamma	=	0.1054*exp(9.6*phir)	=	16.06	
	sgamma	sgamma	=	1-(0.4*(b/l))	=	0.60	
	dgamma	dgamma	=	1.00	=	1.00	
	wgamma	wgamma	=	if(case="Case 3",((gams-9.8)/gams),if(case="Case 2",(z-df)/b+((gams-9.8)/gams)*(1+(df/b)-(z/b)),1))	=	0.89	
	sc	sc	=	1+0.2*(b/l)	=	1.20	
	dc	dc	=	IF(df/b>1,1+(0.33*(tan(df/b)^-1)),1+(0.33*(df/b)))	=	1.13	
	Check: Shallow Foundation Criterion	chk_sf	=	IF (df/b < 2.5, OK, Not OK)	=	**OK**	
	Ultimate Bearing Capacity of Footing	Quc	=	gamd*df*(Nq-1)*sq*dq*wq+(0.5*gams*b*Ngamma*sgamma*dgamma*wgamma)	=	663.44	kPa
	ASD Calculation						
	Allowable Bearing Capacity Sand	Qas	=	(Qus/Fs)+gams*df	=	242.75	kPa
	Check Allowable Stress Design	chk_asd	=	IF(Qac>Qapplied,"OK","NOT OK")	=	**OK**	
	LFRD Calculation						
	Ultimate Gross Bearing Capacity Sand	Qults	=	Qus*Fr+gams*df	=	247.78	kPa
	Check LFRD	chk_lfrd	=	IF(Qults>Qapplied,"OK","NOT OK")	=	**OK**	
Calculation of Settlement							
	Eff. Vertical Stress at footing level	σ'_{zd}	=	df*gamd	=	19.20	kPa
	Correction factor for depth	C1	=	1-(0.5 σ'_{zd} / (Qapplied- σ'_{zd}))	=	0.94	
	Correction factor for secondary creep	C2	=	1+0.2 log (time/0.1)	=	1.54	
	Correction factor for foundation shape	C3	=	1.03 - 0.03 l/b > 0.73	=	1.00	
	Settlement due to Distortion in Sand Calculation						
	Settlement	S	=	(Qapplied*b*I_ε/E) *C1*C2*C3	=	2.8	mm
	Check Allowable Settlement	chk_settle	=	IF(S<25,"OK","NOT OK")	=	**OK**	
	Differential Settlement Calculation						
	Differential Settlement	S_dif	=	S/L	=	0.0003	
	Check Allowable Differential Settlement	chk_setdif	=	IF(S_dif<0.0040,"OK","NOT OK")	=	**OK**	

Date:	March 19, 2014	Designed by:	DA
Group:	Team 6	Reviewed by:	HW

APPENDIX C – SQUARE FOOT ESTIMATE DATA

The following figures are the cost tables associated with the additional features chosen for a "Green Restaurant" setting. Most of these costs are due to kitchen equipment but also include features such as green roofs, heat exchangers and bar seating.

Step 3: Building Additives (optional)

Description	Cost	Unit	Quantity	Total
Bar, Front Bar	$493.36	L.F.	20.00	$9,867.20
Back bar	$393.44	L.F.		
Booth, Upholstered, custom straight, min	$294.76	L.F.		
max	$543.32	L.F.	120.0(	$65,198.40
"L" or "U" shaped, min	$304.76	L.F.		
max	$518.34	L.F.		
Fireplace, brick, excl. chimney or foundation, 30"x29" opening	$2,656.50	Each		
Chimney, standard brick, single flue, 16" x 20"	$118.46	V.L.F.		
2 Flue, 20" x 24"	$173.99	V.L.F.		
Kitchen Equipment				

Step 3: Building Additives (optional)

Description	Cost	Unit	Quantity	Total
Kitchen Equipment				
Broiler	$4,964.78	Each	1.00	$4,964.78
Coffee urn, twin 6 gallon	$3,622.10	Each	1.00	$3,622.10
Cooler, 6 ft. long	$5,089.68	Each	1.00	$5,089.68
Dishwasher, 10-12 racks per hr.	$5,183.35	Each	1.00	$5,183.35
Food warmer, counter, 1.2 KW	$905.53	Each	1.00	$905.53
Freezer, 44 C.F., reach-in	$6,307.45	Each	1.00	$6,307.45
Ice cube maker, 50 lb. per day	$2,404.33	Each	1.00	$2,404.33
Range with 1 oven	$3,715.78	Each	1.00	$3,715.78
Refrigerators, prefabricated, walk-in, 7'-6" high, 6' x 6'	$239.81	S.F.		

Step 3: Building Additives (optional)

Description	Cost	Unit	Quantity	Total
Refrigerators, prefabricated, walk-in, 7'-6" high, 6' x 6'	$239.81	S.F.		
10' x 10'	$189.85	S.F.		
12' x 14'	$168.62	S.F.	30.00	$5,058.60
12' x 20'	$147.38	S.F.		
Commissioning Fees, sustainable commercial construction, min	$0.26	S.F.	9780.(	$2,542.80
max	$3.31	S.F.		
Energy Modelling Fees, commercial buildings to 10,000 SF	$11,968.00	Each	1.00	$11,968.00
Greater than 10,000 SF add	$0.04	S.F.		
Green Bldg Cert Fees for comm construction project reg	$979.20	Project		
Photovoltaic Pwr Sys, grid connected, 20 kW (~2400 SF), roof	$258,393.20	Each	1.00	$258,393.20

Step 3: Building Additives (optional)

Description	Cost	Unit	Quantity	Total
max	$3.31	S.F.		
Energy Modelling Fees, commercial buildings to 10,000 SF	$11,968.00	Each	1.00	$11,968.00
Greater than 10,000 SF add	$0.04	S.F.		
Green Bldg Cert Fees for comm construction project reg	$979.20	Project		
Photovoltaic Pwr Sys, grid connected, 20 kW (~2400 SF), roof	$258,393.20	Each	1.00	$258,393.20
Green Roofs, 6" soil depth, w/ treated wd edging & sedum mats	$11.99	S.F.		
10" Soil depth, with treated wood edging & sedum mats	$13.66	S.F.	10000	$136,600.00
Solar Domestic HW, closed loop, add-on sys, ext heat exchanger	$9,367.35	Each	1.00	$9,367.35
Drainback, hot water system, 120 gal tank	$12,386.78	Each	1.00	$12,386.78
Draindown, hot water system, 120 gal tank	$12,767.18	Each		