UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC Botanical Gardens
Revitalization Project
MULTIPURPOSE BUILDING PROPOSAL

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University of British Columbia

CIVL 446

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:: CIVL 446 CAPSTONE PROJECT :: DETAILED DESIGN REPORT ::

UBC Botanical Gardens
Revitalization Project

MULTIPURPOSE BUILDING PROPOSAL

APRIL 4, 2014

PREPARED BY:

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PREPARED FOR:

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EXECUTIVE SUMMARY

Group 16 has been retained by the University of British Columbia Botanical Gardens (Client) to develop the detailed design of a multi-purpose facility in response to the needs identified by the Client and its stakeholders. The proposed design will be a two-storey facility that will not only provide a landmark entrance feature for the botanical gardens, but will also serve as an invaluable space for visitors to better interact and experience the garden. The enclosed design report summarizes the detailed design components included in the scope of the three chosen disciplines: structural, geotechnical, and building science. For each of the disciplines, the scope has been limited to a typical cross-section taken from the west exterior wall. The structural discipline focuses on the design of key structural components including the foundation, wall, slab, and beam. Constructability, structural integrity and efficiency were key factors in the selection of layouts, member sizing and detailing. Geotechnical considerations involved the assessment of risk with regard to site conditions and provides essential site-specific input critical to the other disciplines. Building science aspects covered within the scope include the design of the green roof, wall unit assembly, and perimeter drainage. Air circulation, heat flow, system efficiency and user compatibility were some issues evaluated.

The disciplines are tied together by the common goals we seek to achieve through the Botanical Gardens Revitalization project. Social aspects, such as function versatility and user experience, economical aspects, such as cost and time efficiency, and finally environmental aspects, including sustainability of material choices and building type, are discussed within the report.

The proposed design is expected to be completed over a duration of 7 months for an estimated total cost of **$1,364,168.**

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1 INTRODUCTION

1.1 PROJECT SCOPE

Group 16 has been selected to submit a detailed engineering design report for a multi-purpose building and integrated parking facility, in response to the top proposed projects identified in the Civil 445 conceptual design phase. The main design element ─ the west exterior wall of the building, is analyzed and designed with respect to the following three engineering disciplines: structural, geotechnical, and building science. Due to the rigid time frame of the Civil 446 course, limitations had to be made to the scope of the project. Specific limitations relevant to each discipline are discussed in greater detail in the respective sections. The scope of this design report includes the detailed design and the associated analyses, computations, sketches and drawings. Additionally, the schedule and cost estimate for implementation of the design is provided.

1.2 PROPOSED BUILDING DESCRIPTION

The proposed multi-purpose building, located on the southeast corner of Southwest Marine Drive and Stadium Road, will provide an iconic space to the university and the botanical garden community. Additionally, the building will act as an alternate entrance to the North Gardens, completing the circuitous loop of the garden.

Figure 1: Extent of Proposed Development

The two-storey multi-purpose building, with a 5000 square feet footprint, will include office and event space, classrooms, and a gift shop, all enclosed underneath two distinct green roof sections. Figure 2**Error! Reference source not found.** below illustrates the exterior view of the building.

Figure 2: Multi-Purpose Building - Exterior View

Pedestrian paths will be developed to complete the connections to Stadium Road and Southwest Marine Drive. In addition, temporary pick-up and drop off zones will be designated to handle additional traffic, though the primary parking facility would still be the lot adjacent to the existing entrance.

1.3 DESIGN SYNTHESIS

The three disciplines (structural, geotechnical, and building science) complement each other and are well integrated. The structural design provides a structurally feasible preliminary building layout encompassing roof spans, storey heights, and other details to the building science design, while the building science aspect uses the layout to select an appropriate green roof and wall assembly, thereby allowing the structural design to use unit weights for detailed component design. The geotechnical design provides soil characteristics for the structural design, as well as rainwater and soil seepage conditions for the building science design of the foundation layout. The geotechnical design is dependent on the drainage requirements for site conditions, as well as design loads for the design of the footings. The final design was selected with construction efficiency in mind for all three disciplines. For example, green roof designs and wall envelopes were those that have been used widely in the local industry, so contractors would likely have experience working with the materials and configurations provided.

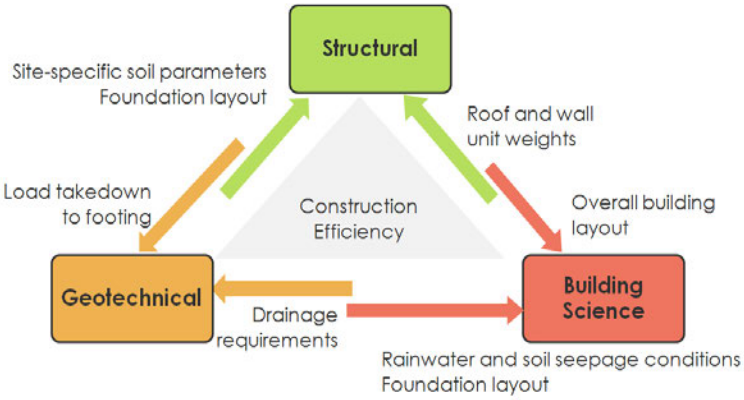


Figure 3: Discipline Integration Diagram

2 STRUCTURAL ENGINEERING

2.1 DESIGN ASSUMPTIONS

The scope of the structural design comprises of a unit strip 1 meter long of the typical cross section taken from the west exterior wall. Five components will be considered for detailed design: 1) strip footing, 2) bearing wall, 3) basement wall, 4) slab, and 5) beam. Geotechnical requirements, minimum structural requirements and code capacity calculations were considered in the development of the detailed drawings. The scope has been limited to exclude any seismic design aspects as well as the detailed design of the green roof component.

2.1.1 DESIGN CODE AND GUIDELINES

The structural loading is in compliance with the National Building Code of Canada (NBCC 2010) and the capacity design per Design of Concrete Structures (CSA A23.3). *Reinforced Concrete Design – A Practical Approach* (Brzev & Pao, 2009) was also used as a reference guide in conjunction with CSA A23.3.

2.1.2 DESIGN PARAMETERS

The following parameters were assumed in the design:

Table 1: Structural Design Parameters

Concrete compressive strength	f'c = 30MPa
Concrete Weight Factor	Lambda = 1 (normal-weight)
Yield Strength of Steel Reinforcement	fy = 400MPa
Soil Friction Angle	phi = 30 degrees
Unit Weight of Soil	gammas = 18 kN/m3

2.1.3 LOADING

Only gravity (dead and live) and environmental loading (snow and wind) have been considered for the purposes of design, with loads and their accompanying load factors taken from NBCC 2010, Table 4.1.3.2.A. All components are cast-in-place concrete and any secondary cladding is assumed to have negligible effects on loading. The green roof is an extensive green roof system as described in detail in Section 4.2.

2.2 DESIGN PROCEDURES

2.2.1 WALL AND FOUNDATION STRIP FOOTING

The bearing wall component was checked to comply with all three requirements listed in A23.3 Clause 2.2 and thus is designed per Clauses 14.1.2 to 14.4.6. A minimum thickness of 150mm is recommended by the code, but at least 200 mm is assumed to ensure constructability including sufficient flow of concrete around the concrete mat. Wall reinforcement is required to run in vertical and horizontal directions with minimum requirements provided to control temperature and shrinkage cracks. The simplified bearing capacity given in A23.3 Cl. 14.2.2.1 is applicable since it meets requirements of Cl. 14.2.2.2. Because all the factored loads are distributed uniformly along the length of the wall, it is not necessary to check the bearing capacity of the concrete at any concentrated location. The basement portion of the wall has been checked for flexure and shear capacities to satisfy the lateral pressures exerted by the confining soil.

The strip footing has been designed to satisfy geotechnical stability for a uniform bearing of 300kPa. Resulting shear demands were calculated assuming an effective distance "d" away from the base of the wall based on an assumed crack angle of 45 degrees. Flexural demands were taken at the base of the wall. As recommended by Brzev and Pao (2009), the overhanging portion is treated as a cantilever with a uniform load with shear and moment determined accordingly. The footing was then checked for minimum requirements (A23.3 Cl. 7), one-way shear (A23.3 Cl. 11.3) and flexural capacity (A23.3 Cl. 10.1). In this case, minimum requirements and practical layout considerations governed as depicted in Figure 4 below.

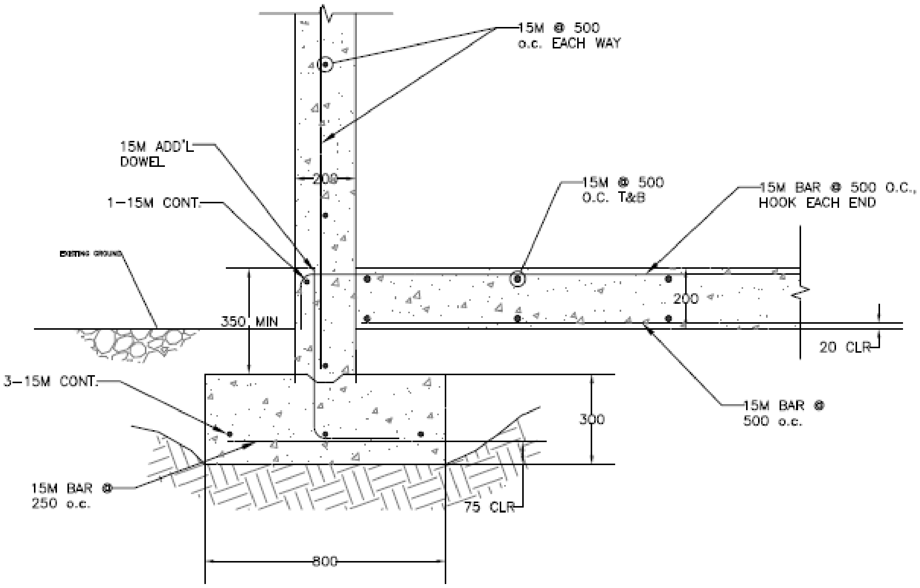


Figure 4: Wall and Wall Foundation Reinforcement Layout

2.2.2 SLAB AND BEAM

The slab was designed using fundamental flexural design principles of reinforced concrete, assuming a unit length of slab (A23.3 Cl. 10.1). Three beams spaced approximately 3m apart run along the short direction to carry load efficiently to the wall. The slab was checked for shear and flexure and was found to be adequate given minimum reinforcement requirements. The beam was designed as a T-beam based on the tributary loading width of 3m and the specified effective flange widths (A23.3 Cl. 10.3.3). A summary of the design of the slab and beam sections are given in Figure 5 and Figure 6 below.

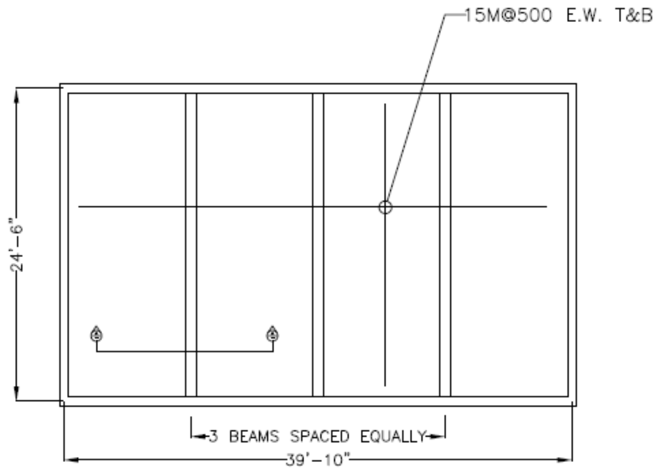


Figure 5: Typical Slab Reinforcement Layout – Northwest Wing of Structure

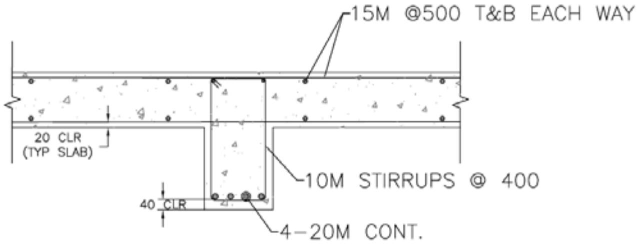


Figure 6: Section A-A: Typical Beam Reinforcement

2.2.3 CONNECTION DETAILING

Transfer of forces at the interfaces between structural components is achieved by ensuring that adequate development length has been provided on each side of the joint (A23.3 Cl. 12.2).

2.3 COST ANALYSIS

The cost of structural components is an agglomerated value which considers the associated labor, materials and equipment costs based on the International Construction Survey 2012 conducted by Turner & Townsend. The total structural cost is $873,272 with material costs comprising 20% and labor comprising 80%. A breakdown of costs is found in Appendix B.

2.4 BENEFITS & INTEGRATION

2.4.1 SOCIAL ASPECTS

The layout of the structure has been developed versatility and modularity in mind, given the diversity in visitorship expected at the multi-purpose facility. The rooms integrate ample natural lighting, open space floor plans, and sufficient partitioned rooms to provide this flexible and inviting environment.

2.4.2 ECONOMICAL ASPECTS

To maximize efficiency of work flow and minimize the high labor costs, many conventional construction practices were incorporated. Good constructability depends on having as many members with typical dimensions as possible, consistent bar sizing, industry standard connection detailing, and adequate minimum recommended member dimensions for concrete pours.

2.4.3 ENVIRONMENTAL

Structural components have been sized to ensure that minimal waste occurs and each member is as efficient as possible without sacrificing constructability or capacity. Further sustainability aspects associated with structural layout are covered under Section 4.5.3.

3 GEOTECHNICAL ENGINEERING

3.1 SITE DESCRIPTION

The proposed development site is located on the southeast corner of Stadium Road and Southwest Marine Drive. The site is bounded by Southwest Marine Drive to the west, Stadium Road to the north, the garden works yard access to the east, and the existing Carolinian Forest region of the North Gardens to the south. The site area is triangular, with an approximate area of 2000 square metres. The site slopes down from the southeast to the northwest with an elevation differential of about 1.0 m.

3.2 GEOTECHNICAL INVESTIGATION

The following geotechnical reports have been referenced to attain an understanding of the subsurface conditions of the proposed site:

- *Block F, Acadia and University Blvd., UBC Preliminary Geotechnical Report* – exp Services Inc. (2013)
- *Geotechnical Investigation Report, Orchard Commons, Agronomy Road & West Mall* – Geo Pacific Consultants Ltd. (2013)
- *Geotechnical Investigation Report - Proposed Wayne and William White Engineering Design Centre (EDC), East Mall at Engineering Lane* – GeoPacific Consultants Ltd. (2009)

In addition, the *Surficial Geology Map 1486A* from the *Geological Survey of Canada (1994)*, and *GeoMap Vancouver (1998)* have been referenced to confirm the conditions identified in the relevant reports.

3.3 CHARACTERIZATION – SUBSURFACE CONDITIONS

3.3.1 SOIL CONDITIONS

The general surficial geology of the sites discussed in the referenced reports consistently describe Vashon Glacial deposits overlying interglacial sand deposits of Pleistocene age. The deposits are characterized as glacial drift, a silty sand and gravel, underlying the site at depth. A general description of the potential soils encountered at the site is given below:

- **Top Soil and Variable Fill**

  The natural soil profile is covered by top soil and variable fill materials comprising of sand and gravel or silty sand.

- **Silty Sand to Silty Sand and Gravel (Till-like)**

The fill materials are underlain by glacial till comprised of soft to firm post-glacial soils - silty sand with varying amounts of gravel. Some cobbles and occasional boulders are expected within this layer. Across the sites analyzed in referenced reports, the glacial till-like soils varied in thickness from 1 to 10m

- **Sand and Gravel**

  The glacial till is underlain by sand and gravel with occasional to trace silt. Based on the drilling resistance listed in the relevant reports, this deposit is estimated to be dense. The amount of silt can vary greatly within this deposit and across the site.

3.4 DESIGN AND CONSTRUCTION CONSIDERATIONS

As noted, the proposed development is to consist of a two-storey multi-purpose building. Based on the described soil characteristics, the soils at founding level would consist of unweathered dense silty sand, which would be appropriate for the support of the building on conventional concrete strip and pad foundations. The *Canadian Foundation Engineering Manual* (CFEM) was referenced for design procedures.

3.4.1 SHALLOW FOUNDATIONS

The structure is expected to be constructed of heavily reinforced concrete. Foundation loads are expected to be heavy with wall service loads of 232 kN/m (LRFD). Based on our investigation, we expect that the new structure could be founded on conventional continuous footings.

The footing dimensions were determined using Limit States Design, based off the factored load listed above, and a load resistance factor of 0.5. As the section view in Figure 7 illustrates, the optimal dimensions were determined to be 800 mm wide by 300 mm.

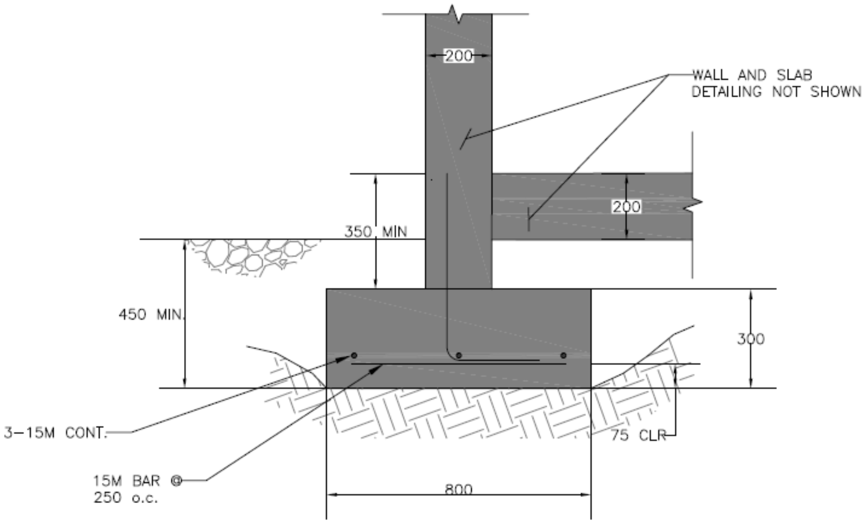


Figure 7: Section View of Strip Footing

The ultimate net bearing capacity of the strip footing was determined to be 654 kPa. Post construction settlement of foundations designed as recommended should be less than 25 mm total with a differential of less than 20 mm over a 10m span. Given that consolidation occurs quickly in coarse-grained soils such as sands and gravels, due to their high permeability, settlement is not expected to be an issue.

3.4.2 SEISMIC DESIGN OF FOUNDATION

The seismic design of the proposed buildings is to incorporate the 2010 National Building Code of Canada (NBCC 2010). The design earthquake is based on a 2% probability of exceedance in 50 years. Based on the subsurface profile described above, the average properties of the top 30m are consistent with dense soils, which are considered to be generally non-liquefiable during the design earthquake events. For building design in compliance with the 2010 NBCC, the site may be classified as Site Class C, in accordance with Table 4.1.8.4.A. This site classification may be used to determine the applicable seismic design parameters as per Table 4.1.8.4 B and C:

- appropriate spectral response acceleration values Sa(T) for period T
- acceleration and velocity based site coefficients, Fa (for short period structures) and Fv (for long period structures)
- peak ground acceleration (PGA based on Appendix C of the 2010 NBCC.

Based on these assumptions and the high level conceptual design that was completed, confirmation of geotechnical conditions is necessary for the implementation of the detailed design. To assess the feasibility of the proposed foundation, and to confirm geotechnical conditions, geotechnical investigation will be required. Ground improvements or alternative structural foundations may be necessary if the assumed conditions from borehole records deviate from what is observed in the field.

3.5 COST ANALYSIS

Geotechnical cost includes costs of excavation, foundation concrete work, and foundation reinforcing steel. Foundation cost with footing is $ 147,685 and the material cost is $88,492. When the two of them are added up, the total geotechnical cost is $236,177. (See Appendix B)

4 BUILDING SCIENCE ENGINEERING

4.1 WALL ASSEMBLY

The following section provides a detailed design summary of the proposed wall assembly, with a focus on exploring the Building Science portion of our scope. The goal of the design has been to optimize the water management, thermal retention, and lighting components of the building. The purpose and reasoning of each element and its contribution to the overall efficiency of the assembly is also described here. Designs for the detailed wall assembly have been based off of recommendations provided in the CMCH Study of Poured-In-Place Concrete Wall Assemblies.

4.1.1 DETAILED DESIGN

Wall assemblies consist of a multitude of layers, each contributing a specific benefit to the design. Various methods are available, each of which have unique benefits and downfalls. Wall assemblies consist of several components which deal with heat, air and moisture flows (both vapour and rain). These components can be installed in different sequences, with a multitude of material options. Figure 8 below, annotated by Table 2, illustrate the proposed sequencing and material choices for the new Multi-Purpose building at UBC Botanical Garden. Described further are the specific characteristics of each of the chosen elements.

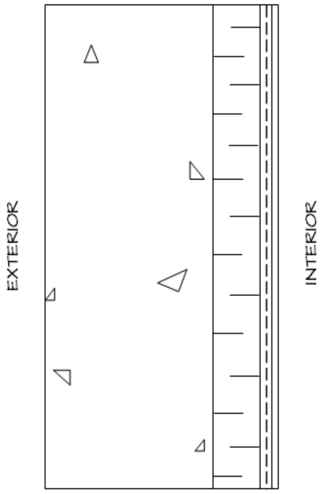


Figure 8: Schematic of Wall Assembly

Table 2: Material Breakdown of Wall Assembly

Item	Layer	Thickness (mm)
Concrete	Exterior	150
Extruded Polystyrene (XPS)		50
Polyethylene film		0.15
Gypsum wall board		13
	Interior	

Concrete has been chosen for the outer component of the wall envelope due its rain penetration benefits, ease of construction, and modern design finishing. Additionally, it offers high overall strength and stability and the capacity to support a large green roof.

In areas such as Vancouver, where rain is a common occurrence, rain penetration should be considered a priority performance criterion of any wall assembly. (CMHC) Concrete successfully achieves a resistance to water penetration through employing the *Mass Absorption Approach.* This approach relies on the absorptive capacity of the elements in the system to resist total water penetration. Water which is not shed from the surface is absorbed by the material, and released slowly and evaporated before it manages to reach the inner surface as a liquid. Coatings applied after placement of the concrete offer additional rain penetration, particularly in areas or cracking and where joints meet.

Adequate thermal performance of the assembly is provided primarily by the insulation, chosen here to be Extruded Polystyrene. Polystyrene has the benefits of being readily available, is low cost and still has a reasonable R-value of 5.0. For these reasons, polystyrene is felt to have the most benefits overall, taking into account the mild weather in Vancouver and the added ease of construction it offers (Johnson, 2014). Walls not included in the detailed drawings will be primarily composed of glass curtain walls. It is proposed that these windows be double glazed, with a 12 mm air cavity present between sheets. This system will mitigate heat losses and provide added thermal resistance. Polyethylene Film acts as a vapour retarder to limit the inward migration of moisture so that mold growth on the gypsum wall board next to the occupied space is less likely to occur. An additional component of the wall assembly is Gypsum Wall Board, which simply acts as an interior finish to the inside face of the building.

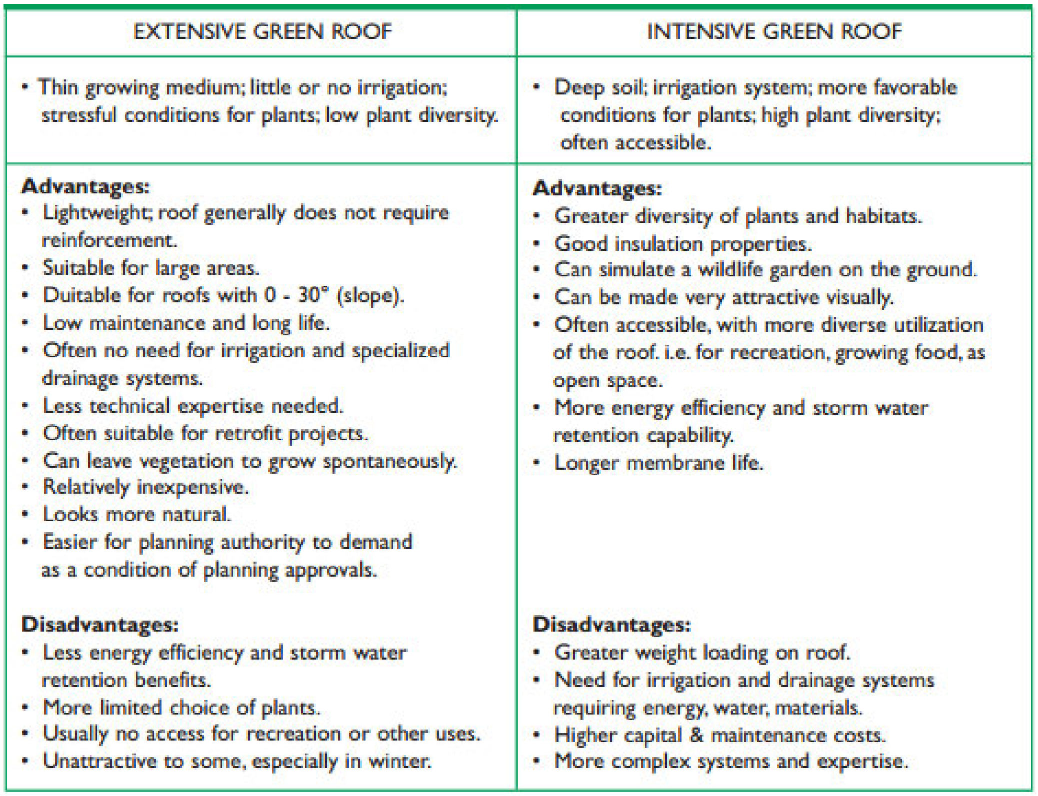
4.2 GREEN ROOF ASSEMBLY

A green roof has been designed as a part of the new Multi-Purpose Building which not only provides LEED Certification points to a structure, but provides numerous amounts of benefits with regard to thermal properties and water management of an assembly. Additionally, it offers visual appeal and offers the garden an added resource for displaying plant life. The following section details all layers that contribute to the proposed green roof, including a description of each and of their functionalities. The final section details the benefits of a Green Roof to the overall building profile.

4.2.1 DESIGN BACKGROUND

Due to the fact that the building roof will be on a slant, the chosen design is based off that of an "Extensive Green Roof." Table 3 below, provided by CMHC, outlines the key differences between the two alternative green roof options, and the benefits that each provide. Although extensive green roofs offer less water retention abilities, they are lighter in weight, easier to maintain, and have a more "natural" look to them, fitting more intuitively with the garden's layout.

Table 3: Comparison of Extensive and Intensive Green Roof Systems



EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
• Thin growing medium; little or no irrigation; stressful conditions for plants; low plant diversity.	• Deep soil; irrigation system; more favorable conditions for plants; high plant diversity; often accessible.
Advantages: • Lightweight; roof generally does not require reinforcement. • Suitable for large areas. • Duitable for roofs with 0 - 30° (slope). • Low maintenance and long life. • Often no need for irrigation and specialized drainage systems. • Less technical expertise needed. • Often suitable for retrofit projects. • Can leave vegetation to grow spontaneously. • Relatively inexpensive. • Looks more natural. • Easier for planning authority to demand as a condition of planning approvals.	**Advantages:** • Greater diversity of plants and habitats. • Good insulation properties. • Can simulate a wildlife garden on the ground. • Can be made very attractive visually. • Often accessible, with more diverse utilization of the roof. i.e. for recreation, growing food, as open space. • More energy efficiency and storm water retention capability. • Longer membrane life.
Disadvantages: • Less energy efficiency and storm water retention benefits. • More limited choice of plants. • Usually no access for recreation or other uses. • Unattractive to some, especially in winter.	**Disadvantages:** • Greater weight loading on roof. • Need for irrigation and drainage systems requiring energy, water, materials. • Higher capital & maintenance costs. • More complex systems and expertise.

Source: adapted from: "Greenbacks from Green Roofs: Forging a New Industry In Canada," CMHC. 1998.

Justifications for the chosen materials for this system are based primarily on industry best practices. Reference has been provided by CMHC Standards as well as various other sources listed below. Case studies, such as the green roof installation at the Vancouver Convention Centre, were also looked into as they relate directly to the climate and plant life viable for a green roof at UBC.

4.2.2 DETAILED DESIGN AND JUSTIFICATION

Green roof assemblies generally consist of five fundamental layers. As listed in Table 4 below, these include a root barrier of some sort, water proofing membrane, drainage layer, filter sheet, and growing medium. Each provides a unique purpose to the overall function of the green roof. Optional to green roof designs are stabilization mats. Although these do not add to the effectiveness of the green roof's environmental benefits, they provide added stability to the system in place. Components of the structural roof itself are also included in Table 4 namely, gypsum roof board and plywood. As noted below, these components also offer a root barrier system to the assembly.

Table 4: Detailed of Layers for Green Roof Assembly

Item	Details
Plants	Grasses, ferns, herbs
Growing Medium	Engineered material (special lightweight mix)
Stabilization Mat	Structural plastic mesh
Filter Sheet	Synthetic filter fabric
Drainage Layer	Perforated plastic sheets
Waterproofing membrane	Bitumen
Root Barrier/Roof Component	Gypsum Roof Board
Roof Component	Plywood

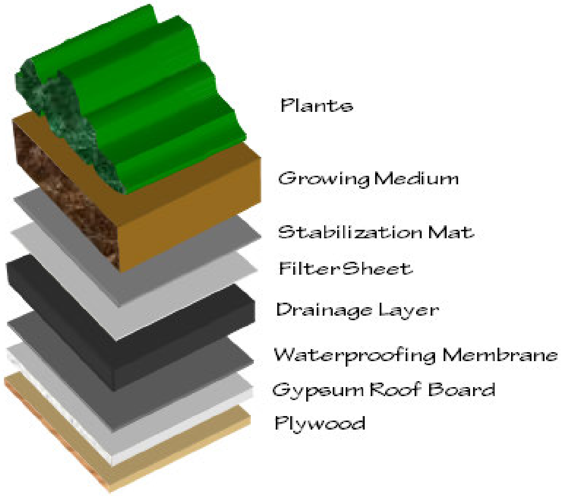


Figure 9: Cross-section of Green Roof Assembly

Beginning from the bottom and working up, the assembly starts with a root barrier system, gypsum roof board in this case. Root barriers prevent roots from penetrating the building and its structural components, which could in turn lead to structural failures as well as air and water ingress. Placed on top of the root barrier is a waterproofing membrane, which ensures components below do not get exposed to any water; this could lead to degradation and future complicated maintenance requirements. Bitumen has been chosen due to its availability and strong water resistance qualities.

The drainage layer is composed of a perforated, dimpled plastic sheet. This layer allows heavy rain to run off to a perimeter drain, while still retaining moisture during dry periods. The dimpled portions hold water that can diffuse upward in the form of vapour when the growing medium dries. The honeycomb structure allows storm water to drain and provides aeration for roots, in addition to preliminary root barrier protection from layers below. A filter sheet is utilized to stop fine particles from clogging the drainage layer. This layer is made up of synthetic filter fabric that prevents small particles from passing, while still resisting clogging from fine soil particles such as silts and clays. This is to ensure that proper flow of water can still pass through the system; else strenuous maintenance of the roof would be required.

The growing medium of the green roof is an engineered material that is capable of providing nutrients for the plants above. It is not ordinary soil; conversely it is light in weight, has good water storage characteristics, has a low organics content, suitable chemical properties (for nutrients), and contains a good distribution of particle sizes. Atop the growing medium is the plant life. Appropriate plants for green roof systems are generally ones that can survive extreme environments, namely hot and dry. Proposed for this system are low maintenance plants, such as grasses, ferns, and herbs.

4.3 PERIMETER DRAINAGE

4.3.1 DESIGN BACKGROUND

This section provides a summary of the detailed design for the proposed drainage system, the goal of which is to provide a sustainable stormwater management system for the multi-purpose building. The drainage system design is based off of Metro Vancouver and Canadian building practices, using stormwater utility maps from UBC records and short duration rainfall IDF information from Environment Canada.

4.3.2 DETAILED DESIGN

Hydrologic analysis was performed on the structure using the Rational Method to determine total flow delivered; the method is applicable to watersheds that are smaller than 200 acres; approximately 81 hectares. The total catchment area of the UBCBG is about 57.4 ha; therefore this method of analysis is appropriate (Shen & Wong, 2013). The capacity of the drainage pipe was found using the Manning Equation. The ratio of stormwater delivered to pipe capacity was found to be in an acceptable range.

With regards to the structure itself, the main concern was being able to drain rainfall in an environmentally friendly and efficient manner. The proposed design has a building footprint of 5000 square feet, approximately 0.005 hectares. Storm water utility maps of the proposed building location were obtained from UBC Infrastructure Development Records to determine to which extent drainage lines needed to be to connect to any existing lines. After calculating peak discharge, Manning's equation is then used to determine the size of the conveyance system.

4.3.3 ASSUMPTIONS

Certain assumptions were required to perform the hydrologic analysis for the structure given the amount of resources that were available. Parameters that involved the physical characteristics of the watersheds and existing utilities, to the performance of the designed green roof system and conveyance system required careful consideration and engineering judgment.

4.3.4 RATIONAL METHOD

In the rational method, key parameters that affect the peak flow Q_p are the rainfall intensity i and the runoff coefficient C. Typical design storm return periods involving stormwater fall between 2 to 5 years, using 5 minute storm durations from GVRD rainfall data. Additionally, the runoff coefficient, which indicates the presence of infiltration and storage mechanisms, depends on the imperviousness and different land uses of the watershed (Bedient, Huber, & Vieux, 2013).

4.3.5 MANNING’S EQUATION

In Manning’s equation, important parameters that influence calculations are the roughness coefficient n, the hydraulic radius R_h (a function of the cross-sectional area A and the wetted perimeter P), and the slope S. The roughness coefficient will change depending on the material and reference used. Ultimately, a roughness coefficient of 0.019 for plastic pipe was chosen as most appropriate. To find the maximum allowable flow, it was assumed the conduit operated at full capacity. For roof drains and foundations, the recommended minimum pipe diameter is 150 mm, or 6 inches, which was the pipe size taken. The pipe slope was taken as 0.015. Metro Vancouver guidelines recommend a minimum slope of 0.01 for the given pipe size.

4.3.6 DESIGN CALCULATIONS

The Rational Method is used to determine peak discharge flows that the proposed structure will experience during design rainfall events. A conversion coefficient k_c is included into the equation to convert between metric and imperial units.

$$Q_p = k_c C i A$$

Analysis of site conditions and selection of a design storm event resulted in the following input parameters: Runoff coefficient $C = 0.95$ is assumed due to the implementation and relatively inefficient performance of a green roof, for a worst case scenario of extremely minimal detention. Rainfall intensity $i = 72.0\ \mathrm{mm/hr}$ correlates to a design return period of 5 years and design storm duration of 5 minutes.

The resulting peak flow that must be discharged from the structure is then $Q_p = 0.312\ \text{ft}^3/\text{sec}$. This flow is then used in the continuity and Manning equation to determine the size of the conveyance system:

$$Q = \frac{1.49}{n} A R_h^{2/3}\, S^{1/2}$$

Assuming that the circular pipe operates at maximum capacity, the combined continuity and Manning's equation simplifies to the following expression:

$$Q = \frac{1.49}{n} A \left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

Including the assumed site and material properties stated previously, where the roughness coefficient $n = 0.019$, assuming that the drainage system being used will be plastic pipe, the pipe slope $S = 0.015$. These result in a design diameter $D = 6$ inches, providing a capacity of $0.471\ \text{ft}^3/\text{sec}$, or a flow velocity of $0.73\ \text{m}/\text{sec}$, which is an acceptable minimum value for capacity according to Metro Vancouver code. Comparing peak flow to capacity, the drainage pipe will flow at 66% capacity, within an acceptable range.

4.3.7 IMPLEMENTED DESIGN

A stormwater line (NW-SE) passes directly by the proposed building. Given the drainage system's slope and starting point at the foundation level, it is below the hydraulic gradeline of the main stormwater line. Since the mainline slope is nearly twice as steep, extending the drainage line 50 metres in the direction of the main line would allow for a tie-in, however this would require excessive excavation and disturbance to the garden. An optimal solution is to install a ChemFlow 4-4" pump onsite, to pump the stormwater directly into the stormwater line. See Appendix B for the detailed cost-benefit analysis.

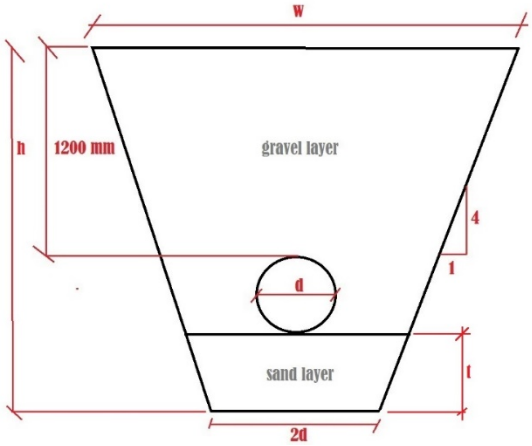


Figure 10: Cross-section of Building Drainage

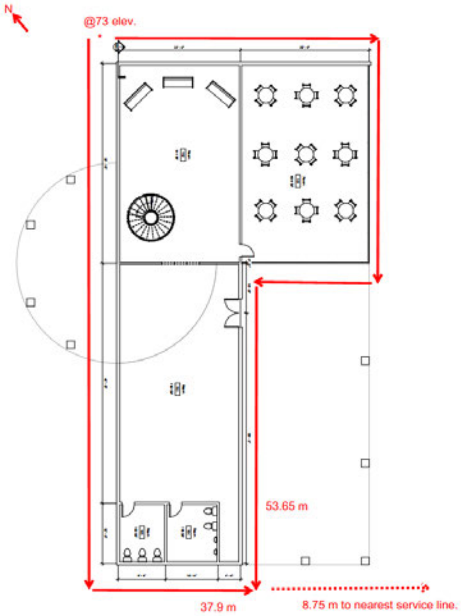


Figure 11: Plan View of Perimeter Drainage

Using standard pipe sizes, the HDPE drainage system will have a diameter of 6 inches. The drainage line will run 103 m around the building from the highest elevation at 73 m above sea level (starting in the north corner). From the south corner of the building, a ChemFlo 4-4” pump will deliver the stormwater 8.75 m to the existing stormwater branch line. Total excavation and backfill is 105 cubic metres.

4.4 COST ANALYSIS

The total cost of all building science components is $209,069 and includes the green roof, wall, and drainage pipe. The green roof assembly costs are estimated at $205/m2 based on research by Kerr Wood Leidal Associates, for a total cost of $21,935. The material cost of the wall is $20,745. The labor costs associated with wall and green roof construction is $154,294. Total construction cost of drainage pipe is $12,093. (See Appendix B)

4.5 INTEGRATION & BENEFITS

4.5.1 SOCIAL

A building envelope that effectively controls heat, air and moisture flows, while also creating a visually appealing space, allows guests to comfortably spend time in a welcome, open space. The large windowed areas, in conjunction with the variegated coloring of flowers, grasses, and wild herbs of the green roof, create an anchor that compliments the beautiful and varied landscape of the UBC Botanical Gardens.

4.5.2 ECONOMIC

The wall assembly and drainage systems can be constructed using readily available materials and ones that can be constructed or recycled with ease. All materials used for the wall assembly (concrete, XPS, polyethylene, gypsum wall board) are easily accessible on the market and will therefore require no added costs in shipment. The drainage materials (HDPE pipe, pump, backfill) are also easily accessible. These materials conform to typical design standards and are therefore easily placed and assembled, requiring no added labour/machine costs.

Although the structural, waterproofing, and drainage requirements of green roofs result in them being more expensive than bare roofs, green roofs offer significant long-term economic and environmental advantages that more than justify the higher initial cost. (Green Roof Manual). As well, the added cost of drainage is offset by the benefits of erosion control and added soil stability, leading to a decrease in chance of foundation settlement, and overall health of the turf.

4.5.3 ENVIRONMENTAL

The wall assembly system, green roof, and drainage system in conjunction with each other, offer a tremendous amount of environmental benefits. The chosen wall assembly provides strong thermal resistance, thus reducing heating and cooling requirements of the enclosure. With respect to materials, concrete and gypsum wall board are easily recyclable at the end of a building’s lifetime, adding to a positive overall life cycle of the structure. Polystyrene, although made from material not easily recyclable, is still considered by many as a “green” building material due to its ability to save substantial amounts of energy as a result of its high thermal resistance (US Department of Energy, 2011).

The green roof, as well, is remarkably energy-efficient, as is typical of green roofs. In the summer they are cool, effectively acting as white roofs and subsequently reducing the urban heat island effect. In fact, green roofs have been shown to show 50-90% reductions in cooling costs (Suzuki, 2014). Additionally, the thermal mass of the soil reduces heat gain and loss by averaging temperature extremes, making them effective insulators in the cold winter months. Green roofs also significantly reduce storm water runoff. They have been shown to typically retain half to three-quarters of annual rainfall and effectively delay the runoff of most of the remainder (Green Roof Handbook, 2005). As a result, building envelopes are less adversely affected by excessive rainfall and drainage systems can more adequately manage sever storm events.

Green roofs also act as a carbon sink, removing harmful carbon emissions from the air and replacing it with oxygen. By shielding the waterproofing membrane of the roof from the sun and reducing temperature swings, synthetic membranes can last fifty years or more.

5 CONSTRUCTION IMPLEMENTATION

5.1 IMPLEMENTATION AND SCHEDULE

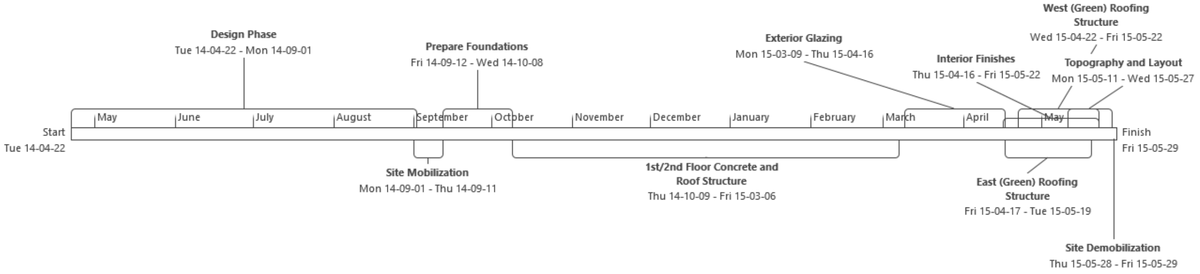


Figure 12: Schedule of Activities

The detailed project schedule and gantt chart is found in Appendix B, and is summarized above in Figure 12. The schedule comprises of ten sections as outlined in Table 5. The total during of the design phase is approximately 4 months, and construction phase is 9 months with contingency for potential construction delays such as: rework, failed inspections, and lost time due to injury.

Table 5: Schedule Phasing

Section	Party Responsible	Description of Work
Design Phase	Client/Owner	Completion and tender of detailed design documents
Site Mobilization	General Contractor	Site trailer set up, crane mobilization and demolition of Previous Site.
Prepare Foundations	Excavating subcontractor	Excavation of new site, construction of footings and foundation walls.
1st/2nd Floor Concrete Structure	General contractor/ concrete subcontractor	All concrete work: construction of forms, rebar, pouring concrete, strip forms, curing period.
Exterior Glazing	Glazing subcontractor	Construction of two exterior glazing walls on model (South and East) breaking up the installation of curtain wall mullions and curtain wall glazing panels.
Interior Finishes	General Contractor / Interior Finish Subcontractor	Interior finishes: Drywall, Flooring, Painting, Mechanical, Plumbing, Electrical and Sprinkler. (Separate tender, if necessary for the numerous specialized interior finishing subcontractors)
East/West Roofing Structure	Roofing Subcontractor	Construction of both green roofs. This section does not include the concrete base of the roofing structure as it is under the 1st/2nd floor concrete structure.
Topography and Layout	General Contractor	This section includes the construction of site elements such as concrete pathways, site accessories (benches, bike racks, etc) and site topography.
Site Demobilization	General Contractor	Includes crane disassembly and removal of site trailer. All site deficiencies should be complete at this point.

5.2 ESTIMATED PROJECT COST

The final project costs all three disciplines are broken into labour & equipment cost, material cost, and trade & engineering cost. Labor costs shown on

Table 7 are calculated based on an expected project duration of 7 months. Trade & engineering cost includes all of construction cost of the building with a green roof and wall and drainage pipe. The total costs of the components are summarized in Table 6.

Table 6: Project Cost Summary

Item	Cost ($)
Labour and equipment	478,800
Material	180,052
Trades and engineering	705,316
Total	**$1,364,168**

Table 7: Detailed Cost of Labour

Item	Unit Cost ($)	Duration (hrs)	Total Cost ($)
Site foreman	60	1680	100800
Group 2 tradesman – e.g. carpenter, bricklayer	55	1680	92400
Group 3 tradesman – e.g. carpet layer, tiler, plasterer	50	1680	84000
General labourer	45	1680	75600
Site foreman	75	1680	126000
		Total Cost	**478,800**

6 FINAL RECOMMENDATIONS

Following a thorough conceptual design phase completed in CIVL445, Group 16 was able to evaluate the unique needs and design requirements and present to its client, the UBC Botanical Gardens, several potential improvement projects. After careful consideration by the client, several design concepts were selected and carried forward to CIVL446 for detailed design. In response, Group 16 developed a detailed design of a multi-purpose building for consideration by the client. This building was designed to foster an active learning environment, and create an exciting attraction to hopefully draw new visitors to the garden. CIVL 446 has given Group 16 the opportunity to evaluate the feasibility of construction at the Botanical Gardens and their findings have been presented in this report.

The key design concept behind this project was to synergize the three major design aspects of civil engineering, ***structural***, ***geotechnical*** and ***building science***, to create a cohesive and beneficial end product. As part of essential construction management practices, cost estimates and project schedules were developed to assist the client in evaluation and prioritization of the project scope. The design developed for the typical wall section has been designed to industry standards and Canadian structural codes for all three engineering disciplines considered. If this project were to be approved for construction by the Botanical Gardens, the remainder of the building design would be carried out in the same manner.

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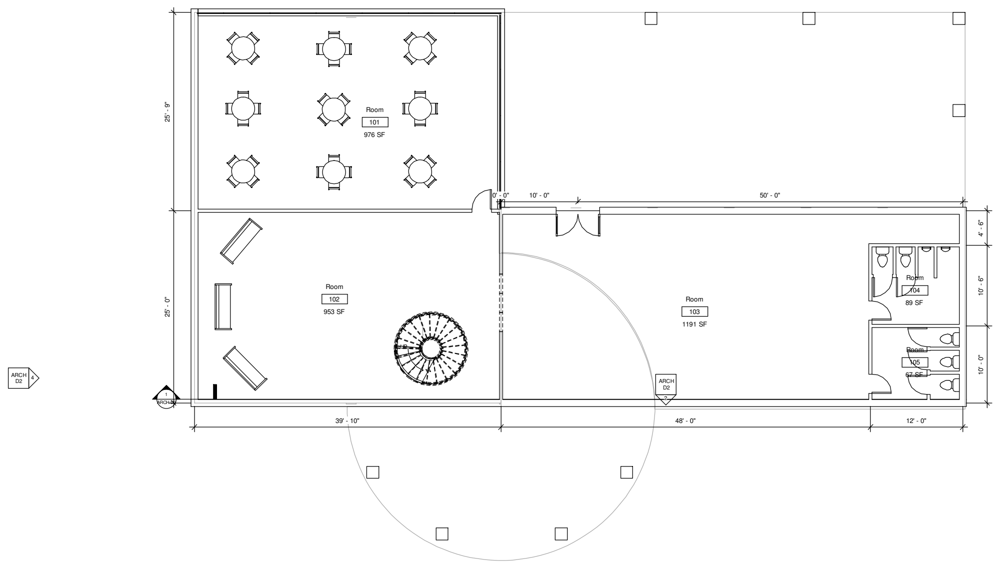
APPENDIX A – DESIGN DRAWINGS



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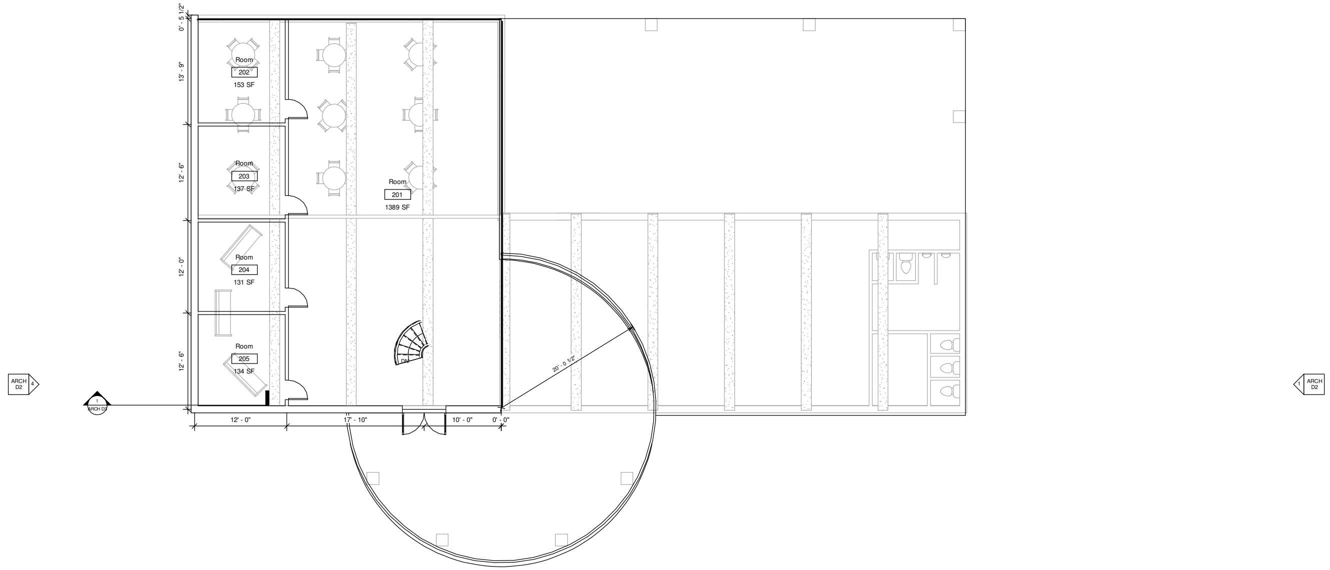

2 Level 2
3/16" = 1'-0"

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No.	Description	Date

Group 16

B. Garden

Floor Plan - Level 1&2

Project number 0001
Date April 4, 2014
Drawn by Group 16
Checked by Cayley Van Hemmen

ARCH D1

Scale 3/16" = 1'-0"

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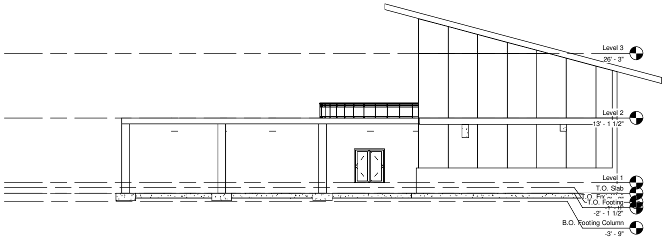

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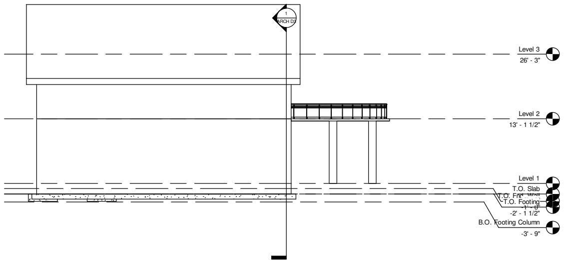

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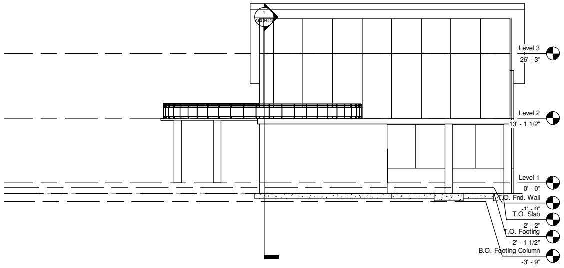

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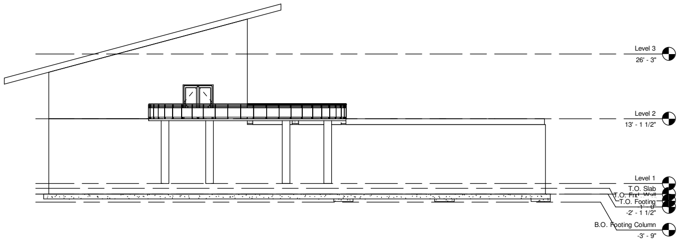

③ South
1 : 100

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No.	Description	Date

Group 16

B. Garden

Elevations

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Date	April 4, 2014
Drawn by	Author
Checked by	Checker

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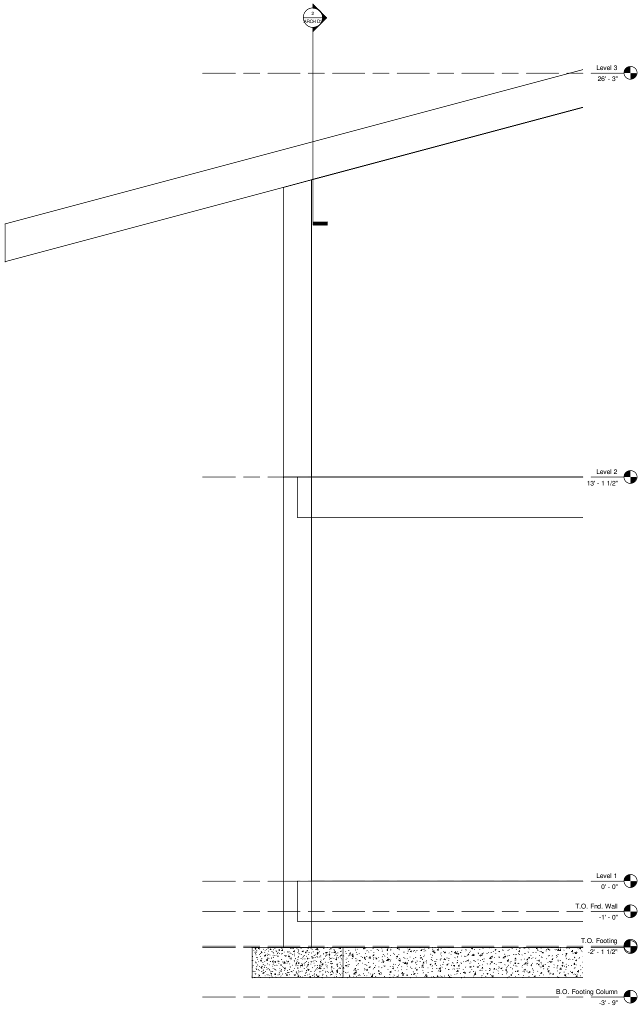

① Details - Section A
3/4" = 1'-0"

② Section 2
3" = 1'-0"

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No.	Description	Date

Group 16

B. Garden

Details

Project number	0001
Date	April 4, 2014
Drawn by	Author
Checked by	Checker

ARCH D3

Scale	As indicated

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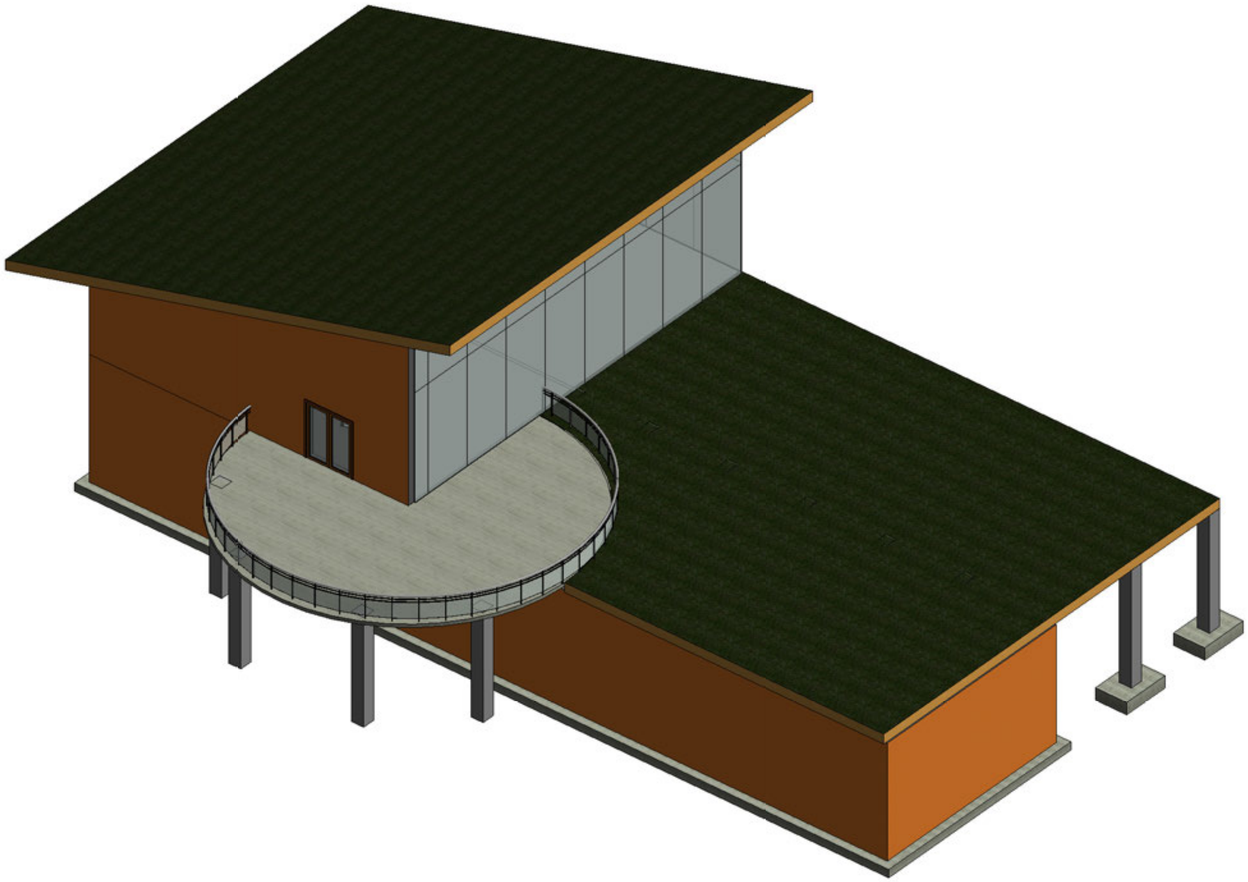

① 3D View

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No.	Description	Date

Group 16

B. Garden

3D View

Project number	0001
Date	April 4, 2014
Drawn by	Author
Checked by	Checker

ARCH D4

Scale

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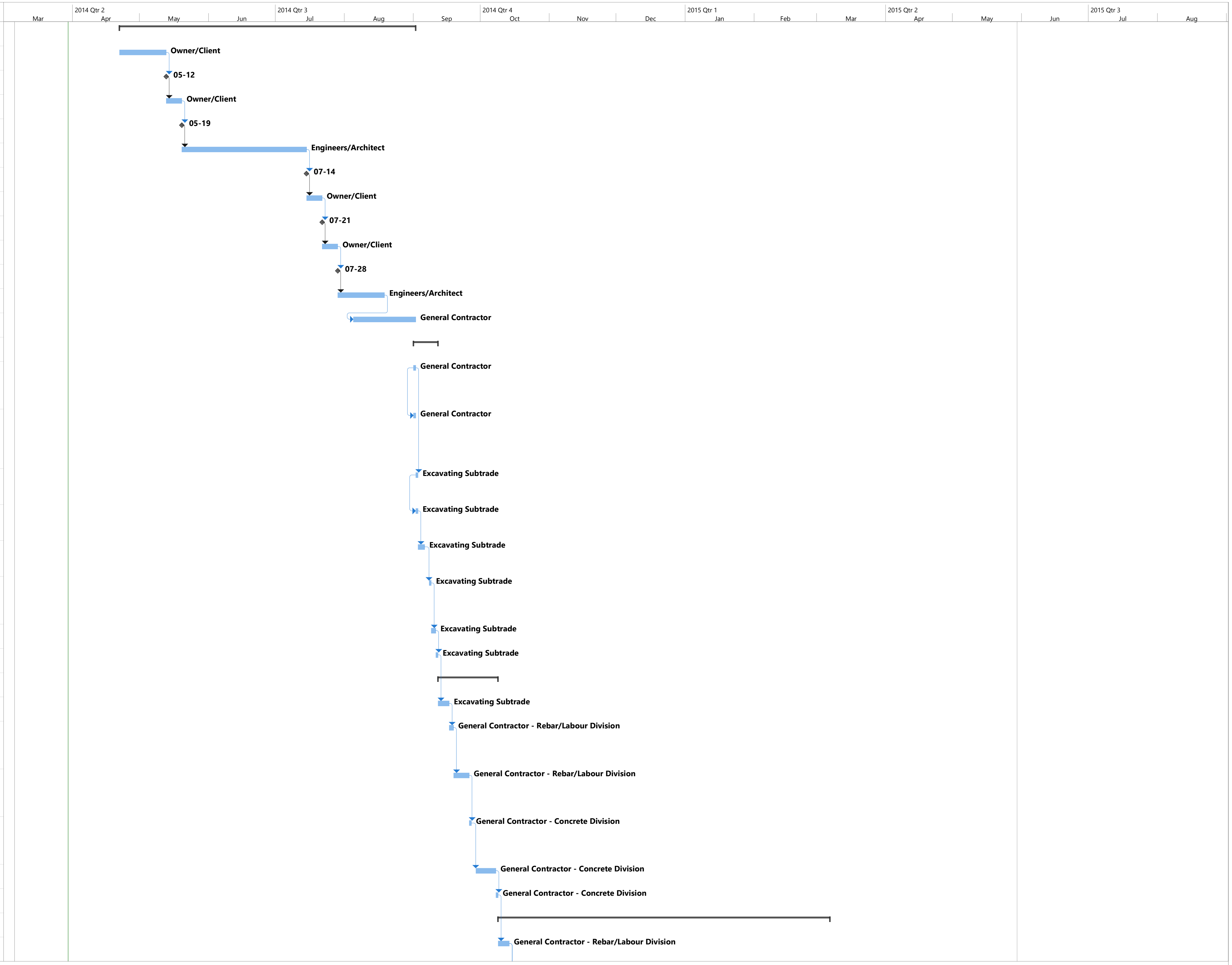
APPENDIX B – SCHEDULE AND COST

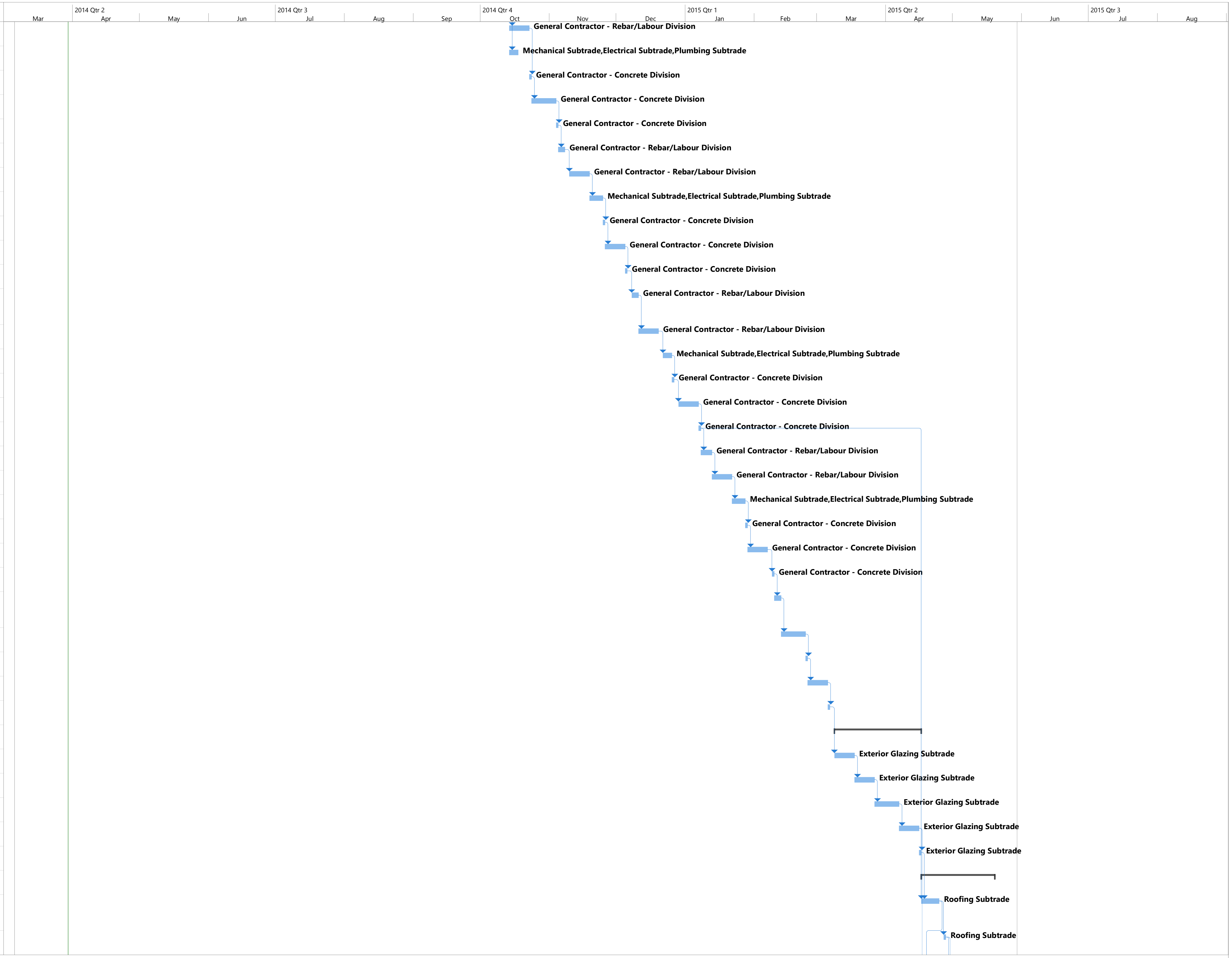
ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**Design Phase**	**95 days**	**Tue 14-04-22**	**Mon 14-09-01**	
2			Project Design Out For Bid	3 wks	Tue 14-04-22	Mon 14-05-12	
3			Bid Submissions Due	0 days	Mon 14-05-12	Mon 14-05-12	2
4			Design Bid Review Process	1 wk	Tue 14-05-13	Mon 14-05-19	3
5			Design Contractor Chosen	0 days	Mon 14-05-19	Mon 14-05-19	4
6			Detailed Design Process	2 mons	Tue 14-05-20	Mon 14-07-14	5
7			Tender Construction Drawing	0 days	Mon 14-07-14	Mon 14-07-14	6
8			Construction Documents Out	1 wk	Tue 14-07-15	Mon 14-07-21	7
9			Construction Bid Submissions	0 days	Mon 14-07-21	Mon 14-07-21	8
10			General Contractor Bid Revie	1 wk	Tue 14-07-22	Mon 14-07-28	9
11			General Contractor Chosen	0 days	Mon 14-07-28	Mon 14-07-28	10
12			Submittal Review Process	3 wks	Tue 14-07-29	Mon 14-08-18	11
13			Long Lead Items Ordered	20 days	Tue 14-08-05	Mon 14-09-01	12FS-10 days
14			**Site Mobilization**	**9 days**	**Mon 14-09-01**	**Thu 14-09-11**	
15			Set up site trailer and establish temporary site parking lot.	1 day	Mon 14-09-01	Mon 14-09-01	
16			Designate Areas on Site for Materials Storage and Garbage Disposal	1 day	Mon 14-09-01	Mon 14-09-01	15SS
17			Clear Previous Site Shrubbery/Landscape	1 day	Tue 14-09-02	Tue 14-09-02	15
18			Clear/Demolish Any Existing Road Paving	1 day	Tue 14-09-02	Tue 14-09-02	17SS
19			Demolish Existing Visitor's Center Structure	3 days	Wed 14-09-03	Fri 14-09-05	18
20			Remove Demolished Structure's Waste Materials	1 day	Mon 14-09-08	Mon 14-09-08	19
21			Excavate Site For Designed Grading	2 days	Tue 14-09-09	Wed 14-09-10	20
22			Site Layout (By Surveyors)	1 day	Thu 14-09-11	Thu 14-09-11	21
23			**Prepare Foundations**	**19 days**	**Fri 14-09-12**	**Wed 14-10-08**	
24			Excavate For Foundations (Approx 5000 sf)	3 days	Fri 14-09-12	Tue 14-09-16	22
25			Install Concrete Forms for Strip Footings and Column Foundations (NE and S Columns)	2 days	Wed 14-09-17	Thu 14-09-18	24
26			Install Rebar For Strip Footings and Column Foundations (NE and S Columns)	5 days	Fri 14-09-19	Thu 14-09-25	25
27			Pour Concrete For Strip Footings and Column Foundations (NE and S Columns)	1 day	Fri 14-09-26	Fri 14-09-26	26
28			Allow Concrete to Cure Before Loading	7 days	Mon 14-09-29	Tue 14-10-07	27
29			Strip Forms From Foundations	1 day	Wed 14-10-08	Wed 14-10-08	28
30			**1st/2nd Floor Concrete and Roof Structure**	**107 days**	**Thu 14-10-09**	**Fri 15-03-06**	
31			Prepare 1st Floor Slab Concrete Forms	3 days	Thu 14-10-09	Mon 14-10-13	29



Project: CIVL 446 - Capstone
Project - Schedule
Group 16

Task	▬	Milestone	◆	Project Summary	⎴	Inactive Milestone	◇	Manual Task	▬
Split	⋯	Summary	⎴	Inactive Task	▭	Inactive Summary	⎴	Duration-only	▬
Manual Summary Rollup	▬	Start-only	[	External Tasks	▬	Deadline	↓	Manual Progress	▬
Manual Summary	⎴	Finish-only	]	External Milestone	◇	Progress	▬		

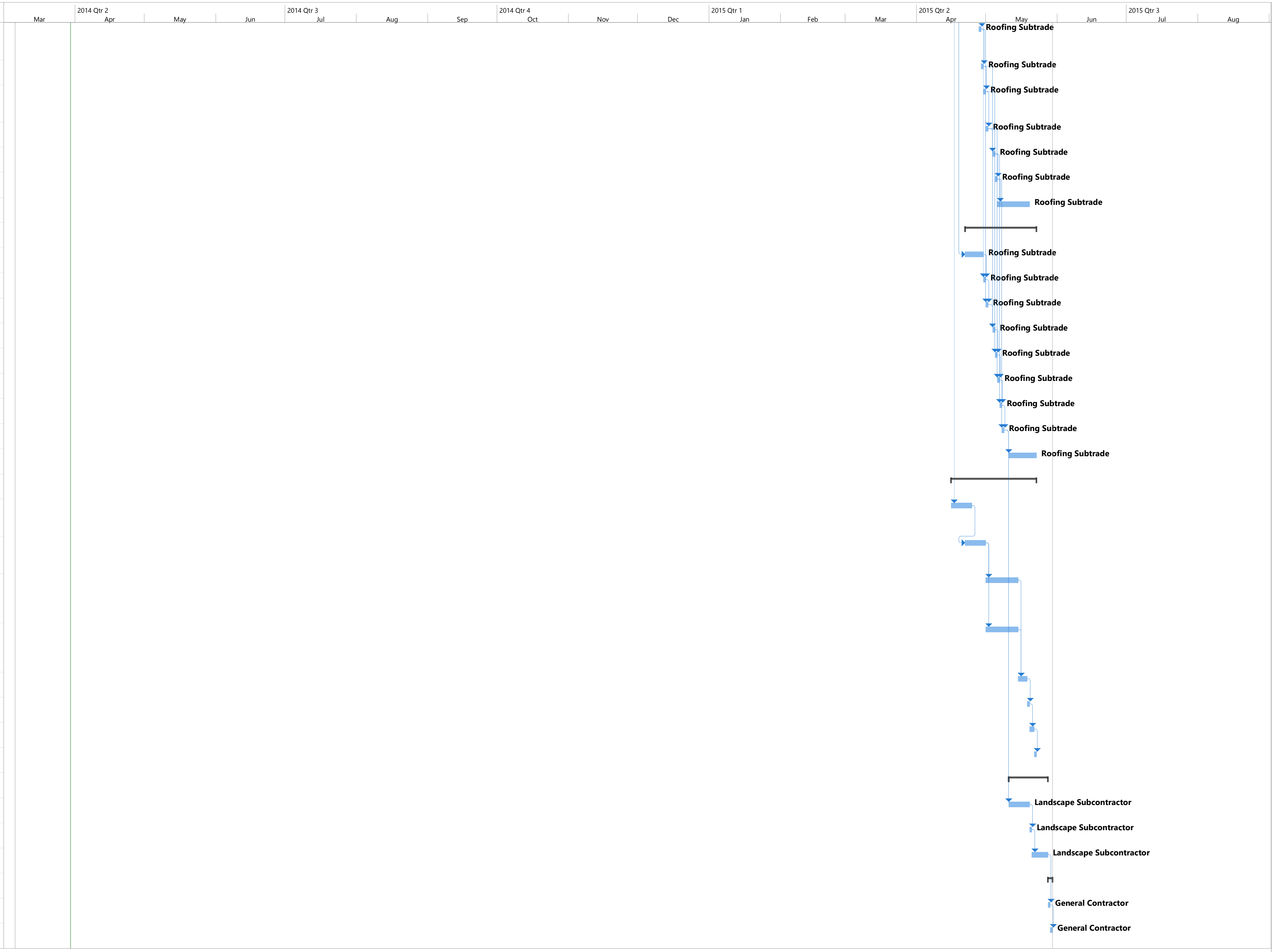
ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
32			Install Rebar For 1st Floor Slab	7 days	Tue 14-10-14	Wed 14-10-22	31
33			Install MEP Rough-In and Conduit	4 days	Tue 14-10-14	Fri 14-10-17	31
34			Pour Concrete For 1st Floor Slab	1 day	Thu 14-10-23	Thu 14-10-23	32
35			Concrete Curing Period	7 days	Fri 14-10-24	Mon 14-11-03	34
36			Strip Concrete Forms	1 day	Tue 14-11-04	Tue 14-11-04	35
37			Prepare Forms For 1st Floor Exterior Walls	3 days	Wed 14-11-05	Fri 14-11-07	36
38			Install Rebar For 1st Floor Exterior Walls	7 days	Mon 14-11-10	Tue 14-11-18	37
39			Install MEP Rough-In and Conduit	4 days	Wed 14-11-19	Mon 14-11-24	38
40			Pour Concrete For 1st Floor Exterior Walls	1 day	Tue 14-11-25	Tue 14-11-25	39
41			Concrete Curing Period	7 days	Wed 14-11-26	Thu 14-12-04	40
42			Strip Concrete Forms	1 day	Fri 14-12-05	Fri 14-12-05	41
43			Prepare Second Floor Slab Concrete Forms And Balcony Forms	3 days	Mon 14-12-08	Wed 14-12-10	42
44			Install Rebar for Second Floor Slab and Balcony	7 days	Thu 14-12-11	Fri 14-12-19	43
45			Install MEP Rough-In and Conduit	4 days	Mon 14-12-22	Thu 14-12-25	44
46			Pour Concrete For Second Floor Slab and Balcony	1 day	Fri 14-12-26	Fri 14-12-26	45
47			Concrete Curing Period	7 days	Mon 14-12-29	Tue 15-01-06	46
48			Strip Concrete Forms	1 day	Wed 15-01-07	Wed 15-01-07	47
49			Prepare Forms For 2nd Floor Exterior Walls	3 days	Thu 15-01-08	Mon 15-01-12	48
50			Install Rebar For 2nd Floor Exterior Walls	7 days	Tue 15-01-13	Wed 15-01-21	49
51			Install MEP Rough-In and Conduit	4 days	Thu 15-01-22	Tue 15-01-27	50
52			Pour Concrete For 2nd Floor Exterior Walls	1 day	Wed 15-01-28	Wed 15-01-28	51
53			Concrete Curing Period	7 days	Thu 15-01-29	Fri 15-02-06	52
54			Strip Concrete Forms	1 day	Mon 15-02-09	Mon 15-02-09	53
55			Prepare Forms For Concrete Portion of Roofing Structure	3 days	Tue 15-02-10	Thu 15-02-12	54
56			Install Rebar for Roofing Structure	7 days	Fri 15-02-13	Mon 15-02-23	55
57			Pour Concrete For Roofing Structure	1 day	Tue 15-02-24	Tue 15-02-24	56
58			Allow Concrete to Cure	7 days	Wed 15-02-25	Thu 15-03-05	57
59			Strip Concrete Forms	1 day	Fri 15-03-06	Fri 15-03-06	58
60			**Exterior Glazing**	**29 days**	**Mon 15-03-09**	**Thu 15-04-16**	
61			Install 1st Floor Steel Curtain Wall Mullions	7 days	Mon 15-03-09	Tue 15-03-17	59
62			Install 2nd Floor Steel Curtain Wall Mullions	7 days	Wed 15-03-18	Thu 15-03-26	61
63			Install 1st Floor Double Pane Glazing Panels	7 days	Fri 15-03-27	Mon 15-04-06	62
64			Install 2nd Floor Double Pane Glazing Panels	7 days	Tue 15-04-07	Wed 15-04-15	63
65			Check Connections and Stability Of Glazing	1 day	Thu 15-04-16	Thu 15-04-16	64
66			**East (Green) Roofing Structure**	**23 days**	**Fri 15-04-17**	**Tue 15-05-19**	
67			Install Roof Deck (Plywood and Lightwood Framing Structure)	6 days	Fri 15-04-17	Fri 15-04-24	48,65
68			Install Protection Board (Sheathing)	1 day	Mon 15-04-27	Mon 15-04-27	67



Project: CIVL 446 - Capstone2
Project - Schedule
Group 16

Task
Split
Milestone ◆
Summary
Project Summary
Inactive Task
Inactive Milestone ◇
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only [
Finish-only]
External Tasks
External Milestone ◆
Deadline ⬇
Progress
Manual Progress

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
69			Install Waterproof Membrane (Hot Asphalt Placement Installation)	1 day	Tue 15-04-28	Tue 15-04-28	68
70			Install Insulation	1 day	Wed 15-04-29	Wed 15-04-29	69
71			Install Drainage/Storage Layer to Ensure Permeable Membrane	1 day	Thu 15-04-30	Thu 15-04-30	70
72			Lay Filter Fabric	1 day	Fri 15-05-01	Fri 15-05-01	71
73			Lay Topsoil / Growing Medium	1 day	Mon 15-05-04	Mon 15-05-04	72
74			Plant Native Species of Plants On Green Roof	1 day	Tue 15-05-05	Tue 15-05-05	73
75			Maintain As Necessary Until Construction Complete	2 wks	Wed 15-05-06	Tue 15-05-19	74
76			**West (Green) Roofing Structure**	**23 days**	**Wed 15-04-22**	**Fri 15-05-22**	
77			Install Roof Deck (Plywood a	6 days	Wed 15-04-22	Wed 15-04-29	67FS-3 days
78			Install Protection Board (She	1 day	Thu 15-04-30	Thu 15-04-30	68,77
79			Install Waterproof Membran	1 day	Fri 15-05-01	Fri 15-05-01	69,78
80			Install Insulation	1 day	Mon 15-05-04	Mon 15-05-04	70,79
81			Install Drainage/Storage Laye	1 day	Tue 15-05-05	Tue 15-05-05	71,80
82			Lay Filter Fabric	1 day	Wed 15-05-06	Wed 15-05-06	81,72
83			Lay Topsoil / Growing Mediu	1 day	Thu 15-05-07	Thu 15-05-07	73,82
84			Plant Native Species of Plant	1 day	Fri 15-05-08	Fri 15-05-08	74,83
85			Maintain As Necessary Until	2 wks	Mon 15-05-11	Fri 15-05-22	84
86			**Interior Finishes**	**27 days**	**Thu 15-04-16**	**Fri 15-05-22**	
87			Install 1st Floor Interior Paritions (Including Rough-In Of MEP)	7 days	Thu 15-04-16	Fri 15-04-24	64
88			Install 2nd Floor Interior Paritions (Including Rough-In Of MEP)	7 days	Wed 15-04-22	Thu 15-04-30	87FS-3 days
89			Install Overhead Lighting and Electrical Wall Outlets/Data Ports (Floor 1/2)	10 days	Fri 15-05-01	Thu 15-05-14	88
90			Intall Mechanical and Plumbing Fixtures (Includes Toilets, Sinks, HVAC, etc.)	10 days	Fri 15-05-01	Thu 15-05-14	88
91			Install Interior Floor Finishes	2 days	Fri 15-05-15	Mon 15-05-18	89,90
92			Install Interior and Exterior Doors	1 day	Tue 15-05-19	Tue 15-05-19	91
93			Paint All Walls (3 Coats, Both Floors)	2 days	Wed 15-05-20	Thu 15-05-21	92
94			Final Clean	1 day	Fri 15-05-22	Fri 15-05-22	93
95			**Topography and Layout**	**13 days**	**Mon 15-05-11**	**Wed 15-05-27**	
96			Install Concrete Walkway	7 days	Mon 15-05-11	Tue 15-05-19	84
97			Install Site Accessories (Bench	1 day	Wed 15-05-20	Wed 15-05-20	96
98			Clean Up Topography, Landsc	5 days	Thu 15-05-21	Wed 15-05-27	97
99			**Site Demobilization**	**2 days**	**Thu 15-05-28**	**Fri 15-05-29**	
100			Remove On Site Garbage and	1 day	Thu 15-05-28	Thu 15-05-28	98
101			Demobilize Site Trailer	1 day	Fri 15-05-29	Fri 15-05-29	100



Project: CIVL 446 - Capstone Project - Schedule
Group 16

Task	Milestone ◆	Project Summary	Inactive Milestone ◇	Manual Task	Manual Summary Rollup	Start-only [	External Tasks	Deadline	Manual Progress
Split	Summary	Inactive Task	Inactive Summary	Duration-only	Manual Summary	Finish-only]	External Milestone ◇	Progress	

APPENDIX B: COST BREAKDOWN

Material Cost of Structural Components

Item	Unit Cost ($)	Amount	Unit	Total Cost ($)
Concrete 30 MPa	$ 165	553.37	m3	$ 91,306
Reinforcement bar 16 mm	$ 1,350	0.39	tonne	$ 524
Concrete block (400 x 200) per 1000	$ 725	0.30	1000 unit	$ 221
Standard Brick per 1,000	$ 900	0.30	1000 unit	$ 274
Structural steel beams	$ 2,100	0.39	tonne	$ 815
Glass pane	$ 165	107.00	m2	$ 17,655
Softwood timber for framing 100m x 50mm	$ 25	60.92	m	$ 1,523
Plasterboard 13 mm	$ 10	107.00	m2	$ 1,070
Emulsion paint	$ 10	6518.48	litre	$ 65,185
Copper pipe 15 mm	$ 10	60.92	m	$ 609
Copper cable	$ 7	60.92	m	$ 426
Extruded Polystyrene (XPS)	$ 4	5.38	m3	$ 24
Polyethylene film (vapour barrier)	$ 750	0.11	tonne	$ 80
Gypsum wall board	$ 3,000	0.11	tonne	$ 338
Total cost				**$ 180,051**

Trade Cost of Structural Components

Item	Unit Cost ($)	Amount	Unit	Total Cost ($)
Excavate basement	$ 15	15.54	m3	$ 233
Excavate footings	$ 20	0.60	m	$ 12
Concrete in slab	$ 190	500.44	m3	$ 95,083
Reinforcement in beams	$ 1,900	0.39	tonne	$ 737
Formwork to soffit of slab	$ 140	320.36	m2	$ 44,851
Blockwork in wall	$ 120	107.00	m2	$ 12,840
Structural steel beams	$ 3,250	0.39	tonne	$ 1,261
Pre-cast concrete wall	$ 325	107.00	m2	$ 34,775
Curtain wall glazing	$ 925	107.00	m2	$ 98,975
Plasterboard 13mm thick to stud wall	$ 25	107.00	m2	$ 2,675
Single solid core door	$ 1,600	5.00	unit	$ 8,000
Painting to walls primer + 2 coats	$ 10	107.00	m2	$ 1,070
Ceramic tiling	$ 85	640.72	m2	$ 54,462
Vinyl flooring to wet areas	$ 65	640.72	m2	$ 41,647
Carpet medium tufted	$ 55	320.36	m2	$ 17,620
Lighting installation	$ 50	640.72	m2	$ 32,036
Copper pipe 15mm to wall	$ 65	60.92	m	$ 3,960
Fire sprinklers	$ 35	640.72	m2	$ 22,425
Air conditioning incl. main plant	$ 310	640.72	m2	$ 198,624
Plants	$ 21	107.00	m2	$ 2,247
Drains/Fabrics/Membrane	$ 162	107.00	m2	$ 17,334
Growing medium	$ 22	107.00	m2	$ 2,354
Total Cost				**$ 693,221**

Cost Breakdown of Geotechnical Components

Item	Unit Cost ($)	Amount	Unit	Total Cost ($)
Excavate basement	$ 15	515.972	m3	$ 7,740
Excavate footings	$ 20	0.597	m	$ 12
Concrete in slab	$ 190	500.437	m3	$ 95,083
Formwork to soffit of slab	$ 140	320.362	m2	$ 44,851

Material	Unit Cost ($)	Amount	Unit	Total Cost ($)
Concrete 30 MPa	$ 165	515.972	m3	$ 85,135
Reinforcement bar 16mm	$ 1,350	0.388	tonne	$ 524
Concrete block (400 x 200)	$ 725	0.304602	unit	$ 221
Standard Brick per 1,000	$ 900	0.304602	unit	$ 274
Structural steel beams	$ 2,100	0.388	tonne	$ 815
Softwood timber for framing 100m :	$ 25	60.92	m	$ 1,523
Total Cost				**$ 236,177**

Construction Cost of Green Roof and Wall Assemblies

Item	Unit Cost ($)	Amount	Unit	Total Cost ($)
Plants	$ 21	107	m2	$ 2,247
Drains/Fabrics/Membrane	$ 162	107	m2	$ 17,334
Growing Medium	$ 22	107	m2	$ 2,354
Blockwork in wall	$ 120	107	m2	$ 12,840
Pre-cast concrete wall	$ 325	107	m2	$ 34,775
Curtain wall glazing incl. support system	$ 925	107	m2	$ 98,975
Plasterboard 13mm thick to stud wall	$ 25	107	m2	$ 2,675
Painting to walls primer + 2 coats	$ 10	107	m2	$ 1,070
Copper pipe 15mm to wall	$ 65	60.9204	m	$ 3,960

Material	Unit Cost ($)	Amount	Unit	Total Cost ($)
Concrete	$ 165	16.05	m3	$ 2,648
Extruded Polystyrene (XPS)	$ 4	5.38	m3	$ 24
Polyethylene film (vapour barrier)	$ 750	0.11	tonne	$ 80
Gypsum wall board	$ 3,000	0.11	tonne	$ 338
Glass (double glazing, 12mm space)	$ 165	107.00	m2	$ 17,655
Total Cost				**$ 196,975**

Construction Cost of Perimeter Drainage

Item	Amount	Unit	Convers.	Unit Cost ($)	Unit	Total Cost ($)
Piping, subdrainage, perforated PVC, 6" dia.	103.3	m	1	$ 29.69	/m	$ 3,067
Backfill, sand bedding trenches, front-end loader, 1.5 CY	5.23	cm	1.308	$ 35.90	/CY	$ 246
Backfill, spread dumped gravel/fill, dozer, 12" layers (4' layers assumed)	97.53	cm	8.829	$ 1.69	/SF	$ 1,455
Excavation by Small Backhoe or Bobcat	104.591	cm	1.308	$ 1.98	/CY	$ 271
Pump - ChemFlow 4-4	1	ea.	1	$ 970.00	ea.	$ 970
Manhole	1	ea.	1	$ 2,000.00	ea.	$ 2,000
Modifiers			See unit cost sheet			1.51
Total Cost						**$ 12,093**

APPENDIX C – SUPPORTING CALCULATIONS

	PROJECT:	UBC BOTANICAL GARDEN REVITALIZATION PROJECT	DESIGN CODE	CAN/CSA A23.3
	CLIENT:	UBC BOTANICAL GARDENS	COMPONENT:	STRIP FOOTING
	DESIGNER:	FW	DATE:	April 4, 2014

FOUNDATION DESIGN

INPUT

Unit Length of Footing (unit)	bw	=		1000	mm	
Width of Footing	l	=		800	mm	
Thickness of Slab	t	=		300	mm	
Area of Unit Length	Ag	= bw*t	=	300000	mm2	
Cover (Interior unexposed component)	cover	=		75	mm	[A23.1 6.6.6.2.3]
Length of Flange Overhang	cant	= (l-t)/2	=	250	mm	
Diameter of Bar	db	=		15	mm	
Area of Bar	Ab	=		200	mm2	
Number of Bars per unit length	num	=		4		
Total Area of Bar	As	= Ab*num	=	800	mm2	
Approx Spacing of Bars	sp	= bw/num	=	250	mm	
Diameter of Bar	dbt	=		15	mm	
Area of Bar	Abt	=		200	mm2	
Number of Bars per unit length	numt	=		3		
Total Area of Bar	Ast	= Abt*numt	=	600	mm2	
Approx Spacing of Bars	spt	= (l-2*cover)/(numt-1)	=	325	mm	
Effective Depth	d	= t-cover-1/2*db	=	217.5	mm	
Effective Shear Depth	dv	= max(0.9*d,0.72*t)	=	216	mm	
Resistance Factor of Concrete	phic	=		0.65		
Modification for Lightweight Concrete	lambda	=		1		
Factor	alpha1	= 0.85-0.0015*fc	=	0.805		
Factor	beta1	= 0.97-0.0025*fc	=	0.895		
Compressive Strength of Concrete	fc	=		30	Mpa	
Square Roof of Fc (tensile Strength)	sqrtfc	= sqrt(fc)	=	5.477225575	Mpa	
Resistance Factor of Steel	phis	=		0.9		
Yield Strength of Steel	fy	=		400	Mpa	
Factored Bearing Load Per Unit Length	qf	=		297	kPa	[From geotech]
Factored One-Way Shear Demand	Vf	= qf*bw*((l-t)/2-d) /1000^2	=	9.6525	kN	
Factored Flexural Demand on Flange	Mf	= qf*cant^2/2*bw /1000^3	=	9.28125	kNm	

MINIMUM REQUIREMENTS

Primary Tension Reinforcement Requirements (Longitudinal Direction)

Ratio of Tension Bars/Concrete Area (longitu	rho	= As/Ag	=	0.003		
Minimum Reinforcement Requirement	rhomin	=	0.002 =	0.002		[7.8.1]
Check Minimum Ratio	CH_rhomin	= if(rho>=rhomin,"OK","NG")	=	OK		
Maximum Spacing of Reinforcement	sp_max	= min(3*t,500)	=	500.000	mm	[7.4.1.2]
Check Spacing	CH_spmax	= if(sp<=sp_max,"OK","NG")	=	OK		

Shrinkage and Temperature Requirements (Transverse Direction)

Ratio of Tension Bars/Concrete Area (transv	rhot	= Ast/Ag	=	0.002		
Minimum Reinforcement Requirement	rhomint	=	0.002 =	0.002		[7.8.1, 7.8.3]
Check Minimum Ratio	CH_rhomint	= if(rhot>=rhomint,"OK","NG")	=	OK		
Maximum Spacing of Reinforcement	spt_max	= min(5*t,500)	=	500	mm	[7.4.1.2]
Check Spacing	CH_sptmax	= if(spt<=spt_max,"OK","NG")	=	OK		

SHEAR REQUIREMENTS

One Way Shear

(design to ensure that no shear reinforcement is required, ie. Vf<Vc)

Can beta =0.21 be used?	betaval	= if(cant<3*dv,"YES","NO")	=	YES		[11.3.6.2]
Factor for Shear Resistance with Cracks in C	beta	=	0.21 =	0.21		[11.3.6.2]
Shear Resistance of Concrete	Vc	= phic*lambda*beta*sqrtfc*bw*dv /1000	=	161.4905189	kN	[11.3.4]
D/C Ratio for One-Way Shear	DC_V	= Vf/Vc	=	6%		
Check D/C ratio	CH_V	= if(DC_V<1,"OK","NG")	=	OK		

Two Way Shear (Punching Shear)

Punching shear is not applicable to strip footings.

FLEXURAL RESISTANCE

Tension Force in Reinforcement	Tr	= phis*fy*As/1000	=	288	kN
Depth of Rectangular Stress Block	a	= Tr*1000/(alpha1*phic*fc*bw)	=	18.34687052	mm
Factored Moment Resistance	Mr	= Tr*(d-a/2)/1000	=	59.99805065	kNm
Demand/Capacity Ratio	DC_Mr	= Mf/Mr	=	15.5%	
Check Resistance	CH_Mr	= if(DC_Mr<1,"OK","NG")	=	OK	
Depth from Extreme edge to neutral axis	c	= a/beta1	=	20.49929667	
C/d ratio	cd	= c/d	=	0.09424964	
C/d ratio limit for balance condition	cd_lim	= 700/(700+fy)	=	0.636363636	
Check C/D limit	CH_cd	= if(cd<cd_lim,"OK","NG")	=	OK	

	PROJECT:	UBC BOTANICAL GARDEN REVITALIZATION PROJECT	DESIGN CODE	CAN/CSA A23.3
	CLIENT:	UBC BOTANICAL GARDENS	COMPONENT:	BASEMENT WALL
	DESIGNER:	FW	DATE:	April 4, 2014

BASEMENT WALL

INPUT

Height of Wall	hw	=			1000	mm
Unit Width (unit)	bw	=			1000	mm
Thickness	t	=			200	mm
Cross Sectional Area of Concrete	Ag	=	bw*t	=	200000	mm2
Cover (inside face of basement wall)	cover	=			20	mm
Diameter of Longitudinal Bar	db	=			15	mm
Area of Longitudinal Bar	Ab	=			200	mm2
Spacing of Bars	sp	=			500	mm
Total Area of Bar	As	=	Ab*bw/sp	=	400	mm2
Resistance Factor of Concrete	phic	=			0.65	
Modification for Lightweight Concrete	lambda	=			1	
Factor	alpha1	=	0.85-0.0015*fc	=	0.805	
Factor	beta1	=	0.97-0.0025*fc	=	0.895	
Compressive Strength of Concrete	fc	=			30	Mpa
Square Roof of Fc (tensile Strength)	sqrtfc	=	sqrt(fc)	=	5.477225575	Mpa
Resistance Factor of Steel	phis	=			0.9	
Yield Strength of Steel	fy	=			400	Mpa
Soil Friction Value	phi	=			30	deg
At-Rest Earth Pressure	Ko	=	1-sin(radians(phi))	=	0.5	
Unit Weight of Soil	gammas	=			18	kN/m3
Equivalet Soil Unit Weight	gammao	=	Ko*gammas	=	9	kN/m3
Soil Pressure at Base of Wall	po	=	hw*gammao/1000	=	9	kPa
Average Soil Pressure at Midheight	pavg	=	po/2	=	4.5	kPa
Maximum Axial Force on Wall	Pf	=			226	kN
Maximum Flexural Force in Wall	Mf	=	pavg*hw^2/8 /1000^2	=	0.5625	kNm
Maximum Shear Force in Wall (at base)	Vf	=	po*hw/3 /1000	=	3	kN

MINIMUM REQUIREMENTS

Wall Thickness

Minimum Thickness of Bearing Wall	t_min	=	max(hw/25,150)	=	150	mm	[14.3.6.1]
Check Minimum	CH_tmin	=	if(t>=t_min,"OK","NG")	=	OK		
							Compare to Table A.4
Ratio of Tension Bars/Concrete Area	rho	=	As/Ag	=	0.002		
Maximum Tension Reinforcement	rhomax	=					[Table A.4]
Check Maximum Ratio	CH_rhomax	=	if(rho<=rhomax,"OK","NG")	=	NG		
Minimum Reinforcement Requirement	rhomin	=	0.002	=	0.002		[14.1.8.5]
Check Minimum Ratio	CH_rhomin	=	if(rho>=rhomin,"OK","NG")	=	OK		
Maximum Spacing of Reinforcement	sp_max	=	min(3*t,500)	=	500	mm	[14.1.8.4]
Check Spacing	CH_spmax	=	if(sp<=sp_max,"OK","NG")	=	OK		

FLEXURAL REQUIREMENTS

Per Brzev and Pao, since compressive forces tend to improve the flexural resistance it is conservative to design for pure flexure without considering axial contributions.

Effective Depth	d	=	t-cover-1/2*db	=	172.5	mm
Tension Force in Reinforcement	Tr	=	phis*fy*As/1000	=	144	kN
Depth of Rectangular Stres Block	a	=	Tr*1000/(alpha1*phic*fc*bw)	=	9.17343526	mm
Factored Moment Resistance	Mr	=	Tr*(d-a/2)/1000	=	24.17951266	kNm
Demand/Capacity Ratio	DC_Mr	=	Mf/Mr	=	2%	
Check Resistance	CH_Mr	=	if(DC_Mr<1,"OK","NG")	=	OK	

Check that section is tension controlled:

Depth from Extreme edge to neutral axis	c	=	a/beta1	=	10.24964834
C/d ratio	cd	=	c/d	=	0.059418251
C/d ratio limit for balance condition	cd_lim	=	700/(700+fy)	=	0.636363636
Check C/D limit	CH_cd	=	if(cd<cd_lim,"OK","NG")	=	OK

SHEAR RESISTANCE

Design such that shear reinforcement is not required. (ie. Vc > Vf)

Effective Shear Depth	dv	=	max(0.9*d,0.72*t)	=	155.25	mm
Factor for Shear Resistance with Cracks in (	beta	=	230/(1000+dv)	=	0.199091106	
Shear Capacity of Concrete	Vc	=	phic*lambda*beta*sqrtfc*bw*dv/1000	=	110.0417407	kN
Shear Reinforcement Required?	vreinf	=	if(Vf<Vc,"NO","YES")	=	NO	

Even if shear reinforcement is not required, provide the minimum horizontal reinforcement per A23.3

PROJECT:	UBC BOTANICAL GARDEN REVITALIZATION PROJECT	DESIGN CODE	CAN/CSA A23.3
CLIENT:	UBC BOTANICAL GARDENS	COMPONENT:	BEARING WALL
DESIGNER:	FW	DATE:	April 4, 2014

BEARING WALL

INPUT

Consider a typical wall section between Floor 1 and Floor 2 (between lateral suppports)

Wall Height	hu	=		4000	mm	
Length Between Supports	lw	=		5000	mm	
Thickness of Wall	t	=		200	mm	
Unit Length	unit	=		1000	mm	
Cross Sectional Area of Wall Unit	Ag	= unit*t	=	200000	mm2	
Nominal Diameter of Distributed Reinf.	db	=		15	mm	
Norminal Area of Bar	Ab	=		200	mm2	
Number of Bars per unit Wall	bars	=		2	bars	
Spacing of Bars	sp	= unit/bars	=	500	mm	
Area of Vertical Steel	As	= Ab*bars	=	400	mm2	
Nominal Diameter of Distributed Reinf.	dbt	=		15	mm	
Norminal Area of Bar	Abt	=		200	mm2	
Number of Ties per unit Wall	barst	=		2	bars	
Spacing of Bars	spt	= unit/bars	=	500	mm	
Area of Vertical Steel	Ast	= Abt*barst	=	400	mm2	
Maximum Factored Axial Load	Pf	=		226	kN	
Maximum Factored Lateral Load	Vf	=		2.85	kN	
Maximum Factored Flexural Load	Mf	=			kNm	

MINIMUM REQUIREMENTS

Wall Thickness

Minimum Thickness of Bearing Wall	t_min	= max(min(lw/25,hu/25),150)	=	160	mm	
Check Minimum	CH_tmin	= if(t>=t_min,"OK","NG")	=	OK		

Distributed Reinforcement

Maximum Diameter of Distributed Reinforcement	db_max	= t/10	=	20	mm	[14.1.8.2]
Check Maximum	CH_dbmax	= if(db<=db_max,"OK","NG")	=	OK		
Layers of Reinforcement Required	layer	= if(t>=210,"2","1")	=	1	layer	[14.1.8.3]
Minimum Distance from Concrete Edge to Bar Centre	placement	= t/3	=	66.66666667	mm	[14.1.8.3]
Spacing of Reinforcement, Vertical and Horizontal	sp_max	= min(3*t,500)	=	500	mm	[14.1.8.4]
Minimum Area of Vertical Reinforcement Required	Avert_min	= 0.0015*Ag	=	300	mm2	
	CH_Avert	= if(As>=Avert_min,"OK","NG")	=	OK		
Minimum Area of Horizontal Reinforcement Required	Ahoriz_min	= 0.002*Ag	=	400	mm2	
Check Minimum Bar Area	CH_Ahoriz	= if(Ast>=Ahoriz_min,"OK","NG")	=	OK		

Ties for Compression Members

Ties Required for Vertical Reinforcement?	ties	= if(and(db<=20,As<0.005*Ag),"NO","YES")	=	NO		[14.1.8.7]
Maximum Spacing	spt_max	= min(16*db,48*dbt,t)	=	200	mm	[7.6.5.2]

Location: ensure it is located not more than 1/2 of a tie spacing above slab/footing [7.6.5.3]

EMPIRICAL STRUCTURAL DESIGN FOR BEARING WALLS

This design method only applies if the requirements of Clause 14.2.2.2 are met.
It has been determined that the wall being design meets these requirements.

Effective Length Factor	k	=		1		[14.2.2.3]
Compressive Strength of Concrete	fc	=		30	Mpa	
Ratio of Avg Stress in Rectangular Compression Block to Specified Concrete Strength	alpha1	= 0.85-0.0015*fc	=	0.805		[10.1.7]
Resistance Factor for Concrete	phic	=		0.65		[8.4.3]
Axial Capacity of Wall	Pr	= (2/3)*alpha1*phic*fc*Ag*(1-(k*hu/32/t)^2)/1000	=	1275.421875	kN	
Demand/Capacity Ratio: Axial Resistance	DC_Pr	= Pf/Pr	=	18%		
Check Capacity	CH_Pr	= if(DC_Pr<1,"OK","NG")	=	OK		

PROJECT:	UBC BOTANICAL GARDEN REVITALIZATION PROJECT	DESIGN CODE	CAN/CSA A23.3
CLIENT:	UBC BOTANICAL GARDENS	COMPONENT:	SLAB
DESIGNER:	FW	DATE:	April 4, 2014

SLAB DESIGN

INPUT

Unit Width (unit)	bw	=		1000	mm	
Thickness of Slab	t	=		200	mm	
Cross Sectional Area of Concrete	Ag	= bw*t	=	200000	mm2	
Cover (Interior unexposed component)	cover	=		20	mm	[A23.1 6.6.6.2.3]
Diameter of Longitudinal Bar	db	=		15	mm	
Area of Longitudinal Bar	Ab	=		200	mm2	
Spacing of Bars	sp	=		500	mm	
Total Area of Bar	As	= Ab*bw/sp	=	400	mm2	
Diameter of Longitudinal Bar, transv	dbt	=		15	mm	
Area of Longitudinal Bar, transv	Abt	=		200	mm2	
Spacing of Bars, transv	spt	=		500	mm	
Total Area of Bar, transv	Ast	= Abt*bw/spt	=	400	mm2	
Resistance Factor of Concrete	phic	=		0.65		
Modification for Lightweight Concrete	lambda	=		1		
Factor	alpha1	= 0.85-0.0015*fc	=	0.805		
Factor	beta1	= 0.97-0.0025*fc	=	0.895		
Compressive Strength of Concrete	fc	=		30	Mpa	
Square Roof of Fc (tensile Strength)	sqrtfc	= sqrt(fc)	=	5.477225575	Mpa	
Resistance Factor of Steel	phis	=		0.9		
Yield Strength of Steel	fy	=		400	Mpa	
Span Length	L	=		3	m	
Recommended Slab Thickness	trec	= L*1000/20	=	150	mm	
Uniformly Distributed Load per meter strip	w	= 1.25*3.6+1.5*4.8	=	11.7	kN/m	
Maximum Flexural Force in Wall	Mf	= w*L^2/9	=	11.7	kNm	[neg moment]
Maximum Shear Force in Wall (at base)	Vf	= w*L/2	=	17.55	kN	

MINIMUM REQUIREMENTS

Primary Tension Reinforcement Requirements (Longitudinal Direction)

Ratio of Tension Bars/Concrete Area (longituc	rho	= As/Ag	=	0.002		
Minimum Reinforcement Requirement	rhomin	=	0.002 =	0.002		[7.8.1]
Check Minimum Ratio	CH_rhomin	= if(rho>=rhomin,"OK","NG")	=	OK		
Maximum Spacing of Reinforcement	sp_max	= min(3*t,500)	=	500.000	mm	[7.4.1.2]
Check Spacing	CH_spmax	= if(sp<=sp_max,"OK","NG")	=	OK		

Shrinkage and Temperature Requirements (Transverse Direction)

Ratio of Tension Bars/Concrete Area (transve	rhot	= Ast/Ag	=	0.002		
Minimum Reinforcement Requirement	rhomint	=	0.002 =	0.002		[7.8.1, 7.8.3]
Check Minimum Ratio	CH_rhomint	= if(rhot>=rhomint,"OK","NG")	=	OK		
Maximum Spacing of Reinforcement	spt_max	= min(5*t,500)	=	500	mm	[7.4.1.2]
Check Spacing	CH_sptmax	= if(spt<=spt_max,"OK","NG")	=	OK		

FLEXURAL REQUIREMENTS

Effective Depth	d	= t-cover-1/2*db	=	172.5	mm
Tension Force in Reinforcement	Tr	= phis*fy*As/1000	=	144	kN
Depth of Rectangular Stress Block	a	= Tr*1000/(alpha1*phic*fc*bw)	=	9.17343526	mm
Factored Moment Resistance	Mr	= Tr*(d-a/2)/1000	=	24.17951266	kNm
Demand/Capacity Ratio	DC_Mr	= Mf/Mr	=	48.4%	
Check Resistance	CH_Mr	= if(DC_Mr<1,"OK","NG")	=	OK	

Check that section is tension controlled:

Depth from Extreme edge to neutral axis	c	= a/beta1	=	10.24964834
C/d ratio	cd	= c/d	=	0.059418251
C/d ratio limit for balance condition	cd_lim	= 700/(700+fy)	=	0.636363636
Check C/D limit	CH_cd	= if(cd<cd_lim,"OK","NG")	=	OK

SHEAR RESISTANCE

Design such that shear reinforcement is not required. (ie. Vc > Vf)

Effective Shear Depth	dv	= max(0.9*d,0.72*t)	=	155.25	mm
Factor for Shear Resistance with Cracks in Cc	beta	= 230/(1000+dv)	=	0.199091106	
Shear Capacity of Concrete	Vc	= phic*lambda*beta*sqrtfc*bw*dv/1000	=	110.0417407	kN
Shear Reinforcement Required?	vreinf	= if(Vf<Vc,"NO","YES")	=	NO	
Demand/Capacity Ratio	DC_Vc	= Vf/Vc	=	15.9%	
Check Resistance	CH_Vc	= if(DC_Vc<1,"OK","NG")	=	OK	

Even if shear reinforcement is not required, provide the minimum horizontal reinforcement per A23.3

DEVELOPMENT LENGTH

Basic Developmment Length, Hooked bar in t	lhb	= 0.24*db*fy/sqrtfc	=	262.9068276	mm	
Modification Factor	MF	= rhomint/rhot	=	1		[12.5.3]
Development Length, Hooked bar in tension	ldh	= max(8*db,150,lhb*MF)	=	262.9068276	mm	

PROJECT:	UBC BOTANICAL GARDEN REVITALIZATION PROJECT	DESIGN CODE	CAN/CSA A23.3
CLIENT:	UBC BOTANICAL GARDENS	COMPONENT:	BEAM
DESIGNER:	FW	DATE:	April 4, 2014

BEAM DESIGN

INPUT

Beam Height (incl slab)	h	=			500	mm	
Beam Width	bw	=			250	mm	
Slab Thickness	hf	=			200	mm	
Clear Span of Beam	ln	=	24.5/3.28*1000	=	7469.512195	mm	
Clear Distance Between T-Beam webs	lw	=	3000-bw	=	2750	mm	
Overhanging flange width	bT	=	min(ln/5, 12*hf, lw/2)	=	1375	mm	
Effective Flange Width	bf	=	bw+2*bT	=	3000	mm	
Diameter of Longitudinal Bar	db	=			20	mm	
Area of Longitudinal Bar	Ab	=			500	mm2	
Number of Bars	num	=			4	bars	
Spacing of Bars	sp	=	(bw-2*cover)/(num-1)	=	56.66666667	mm	
Total Area of Bar	As	=	Ab*num	=	2000	mm2	
Cover	cover	=			40	mm	
Resistance Factor of Concrete	phic	=			0.65		
Modification for Lightweight Concrete	lambda	=			1		
Factor	alpha1	=	0.85-0.0015*fc	=	0.805		
Factor	beta1	=	0.97-0.0025*fc	=	0.895		
Compressive Strength of Concrete	fc	=			30	Mpa	
Square Roof of Fc (tensile Strength)	sqrtfc	=	sqrt(fc)	=	5.477225575	Mpa	
Resistance Factor of Steel	phis	=			0.9		
Yield Strength of Steel	fy	=			400	Mpa	
Tributary Width	trib	=			3	m	
Uniformly Distributed Load	w	=	(1.25*3.6+1.5*4.8)*trib	=	35.1	kN/m	[along beam]
Flexural Design Load	Mf	=	w*ln^2/8 / 1000^2	=	244.7944746	kNm	
Shear Design Load	Vf	=	w*ln/2 /1000	=	131.089939	kN	

MINIMUM REQUIREMENTS

Aggregrate Size	agg	=			20	mm	
Minimum Spacing of Bars	spmin	=	max(1.4*db,1.4*agg, 30)	=	30.000	mm	
Check	CH_sp	=	if(sp>=spmin,"OK","NG")	=	OK		

FLEXURAL REQUIREMENTS

Effective Depth	d	=	h-cover-1/2*db	=	450	mm	
Tension Force in Reinforcement	Tr	=	phis*fy*As/1000	=	720	kN	
Depth of Rectangular Stress Block	a	=	Tr*1000/(alpha1*phic*fc*bf)	=	15.28905877	mm	
Check that "a" is within the flange	CH_a	=	if(a<hf,"rectangular stress block", "t-shaped stress block")	=	rectangular stress block		[OK]
Factored Moment Resistance	Mr	=	Tr*(d-a/2)/1000	=	318.4959388	kNm	
Demand/Capacity Ratio	DC_Mr	=	Mf/Mr	=	76.9%		
Check Resistance	CH_Mr	=	if(DC_Mr<1,"OK","NG")	=	OK		
Depth from Extreme edge to neutral axis	c	=	a/beta1	=	17.08274723		
C/d ratio	cd	=	c/d	=	0.037961661		
C/d ratio limit for balance condition	cd_lim	=	700/(700+fy)	=	0.636363636		
Check C/D limit	CH_cd	=	if(cd<cd_lim,"OK","NG")	=	OK		
Check minimum Steel							
Width of beam on its tension side	bt	=	bw	=	250	mm	[for t-beams, pos]
Minimum Steel	Asmin	=	0.2*sqrtfc/fy* bt*h	=	342.3265984	mm2	
Check minimum Steel	CH_Asmin	=	if(As>=Asmin,"OK","NG")	=	OK		