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Kingston, ON, K7L 3N9

March 26th, 2021

Nathan Splinter, David Gerrish
Physical Plant Services
Queen's University, Rideau Building (2nd Floor)
Kingston, ON, K7L 3N6

Re: Queen's University Green Roof Options for Campus Buildings (Final Report)

Dear Mr. Splinter and Mr. Gerrish,

The attached report is a detailed analysis of the completed work conducted for the "Green Roof Options for Campus Buildings" project. This project was conducted by Greengenuity for Queen's Physical Plant Services (PPS) on behalf of the Queen's Civil Engineering department as a capstone course project. PPS requested a standard document for green roof implementation, which will be added into the existing Queen's University Building Code.

The report highlights background information found both through an investigation of existing green roofs at Queen's University, and through research of existing standards implemented both in Southern Ontario and internationally with regards to green roof construction and maintenance. Technical aspects of green roof design, such as insulation, roof sloping, plant coverage, and drainage are described in detail. The report also acknowledges the benefits of considering the inclusion of recreational space added to new green roofs on campus. Finally, cost and benefit analyses as well as an auditing plan are included in this report for PPS to refer to when considering options for future green roof designs.

Thank you for taking the time to read this report, the team enjoyed working with you throughout the year, and we look forward to receiving feedback from you soon. Should you have any questions or concerns, do not hesitate to contact our team liaison Mackenzie Moreau at her email mackenzie.moreau@queensu.ca.

Sincerely,

Mackenzie Moreau and the team at Greengenuity
Team Liaison
CIVL 460 Capstone Project

Final Report

Green Roof Options for Campus Buildings

Greengenuity: Mackenzie Moreau, Ruizhe Yi, Shannen Krost, Thomas Sevigny

March 26th, 2021

My signature below attests that this submission is my original work. Following professional engineering practice, I bear the burden of proof for original work. I have read the Policy on Academic Integrity posted on the Civil Engineering departmental web site and confirm that this work is in accordance with the Policy.

		Ruizhe	SKrost
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Executive Summary

This final report summarizes the design process and subsequent standard requirements created by Greengenuity throughout the semester to compose the green roof standard for Queen's Physical Plant Services (PPS). Greengenuity is a capstone design team composed of four fourth year civil engineering students at Queen's University. The team was chosen by PPS to create a green roof standard for Queen's University. The final document will be used by PPS to create a standard green roof practice that will be added into the existing Queen's University Building Code to ensure the proper process is being followed on campus in terms of implementation and maintenance of green roofs. The standard will be provided to PPS as a final deliverable and should be reviewed by professional engineers before using the standard for construction purposes. The final standard document is to be submitted alongside this final report for reference.

Queen's University has implemented green roofs in the past, five of which were investigated by Greengenuity on November 13th, 2020 alongside Mr. Splinter and Mr. Gerrish from PPS. The client described an optimal green roof design for PPS as an easily maintainable design with a long life span that would not require major or frequent replacement. It was noted that many existing green roofs at Queen's University are extensive designs (i.e., green roofs that are not able to support live loads) which require little to no maintenance. While this will be acknowledged as a preferred green roof design for PPS in the final standard as well as in this report, Greengenuity will also include intensive roof designs (ie. green roofs that can be made accessible to the public/can support live loads) to highlight the additional benefits they can provide on the Queen's University campus.

The engineering design process was followed throughout the course of the project by referencing local and international green roof standards and later determining which elements of these were to be used in the Queen's requirements. Constraints focusing on environmental, structural and financial elements were specified when considering design elements that may be unique to the Queen's University campus. As requested by the client, specific requirements for green roof size and design type were created based on campus locations. Campus zones were determined based on the building density, amount of accessible green space, and the frequency of student and staff use that each location experiences.

Technical considerations for each of the green roof design components are highlighted within this report. Each layer of the green roof design is introduced, and the technical requirements that must be

met for each are explained in detail. Structural considerations are discussed in regard to loading combinations experienced in different scenarios. The possibility of using green roofs as recreational space is also highlighted. Lastly, the heat transfer and the reduction of the urban heat island effect through green roof installation is presented. Innovative usages of green roof designs are discussed, focusing on research performed in the Green Roof Innovation Testing lab (GRIT). Their research on increasing growing medium depth and the benefits of combining green roofs with photovoltaics are insights into ways that PPS can obtain additional benefits from designs. In addition to technical considerations, an auditing plan is proposed focusing on periodical monitoring of the green roof designs. Professional software and building energy monitoring as laid out in the Queen's Building Standards will examine several aspects including energy performance (eQUEST, DesignBuilder, etc.), stormwater management (SWMM 5.0), and the potential for carbon sequestration.

To ensure PPS is provided with a well-rounded knowledge of green roof designs, green roof benefit and cost analyses, as well as the risks associated with such designs are described in this report. There are many environmental benefits, and there are also proven social and mental benefits associated with implementing additional green space. This could provide major benefits for students and staff at Queen's University. Green roofs can also provide economic benefits such as reducing a building's energy costs. As well, there are a lot of incentive policies supporting environmental sustainability programs. In terms of risks associated with the project, the standard is currently being composed without oversight by a professional engineer. This causes risk for PPS, as they plan to incorporate the final standard into the Queen's University Building Code. This work should be reviewed by a qualified professional before use. As well, common construction, health, and safety issues are associated with the installation and use of green roof designs.

Looking forward to the final steps of this capstone project, communication will continue between the client and the Greengenuity team to finalize the standard document based on feedback provided by PPS. Additionally, a final presentation of the work completed over the course of the project will be presented to the capstone professors and teaching assistants, as well as to the PPS construction team, per the client's request.

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Disclaimer: Greengenuity is a team of undergraduate civil engineering students. This document, and all information contained within, has therefore not been created or approved by a professional engineer. Should Queen's Physical Plant Services and Queen's University choose to implement a green roof standard into the Queen's University Building Code, all information within this report must be analyzed and approved by a team of professionals in the field before being put into practice.

1.0 Introduction

Greengenuity is a capstone design and consulting team composed of 4th year civil engineering students at Queen's University. Professor Sean Watt and Erin Butt are the professor and team TA respectively and have provided feedback throughout the project. Mackenzie Moreau is the team liaison, Thomas Sévigny is the team lead, Shannen Krost is the editing lead, and Ruizhe Yi is the documentation lead. To learn more about specific team member's qualifications, and details on their team role, please contact Mackenzie Moreau at Mackenzie.moreau@queensu.ca .

1.1 Problem Statement

Physical Plant Services (PPS) expressed the need for standardizing and facilitating green roof infrastructure at Queen's University. The main objective of this initiative is to draft a new section of the Queen's University Building Code (Physical Plant Services 2021). Greengenuity was tasked with creating a standard focused on the implementation and maintenance of green roofs for new construction projects on the Queen's University main and west campuses. The standard will also outline the requirements that an existing building would need to satisfy for a green roof to be installed. The top priorities for the green roofs as stated by PPS is that the designs are easily maintainable, and that they have long enough life spans that the system will not need frequent replacing.

Queen's has implemented green roof designs on campus in the past, dating back around 40 years. Such designs can be found on Jeffery Hall, Biosciences, the New Medical Building, Botterell, and as shown in Figure 1, Goodes Hall. Implementing a standard into the Queen's University Building Code will help regulate the installation and maintenance practices followed for future green roof designs.

Figure 1: Existing green roof on Goodes Hall (Queen's University Sustainability Office, n.d.).

1.2 Scope

PPS is looking to adopt a standard practice for green roof implementation on the Queen's University campuses. As the topic of green roofs has been explored over the course of the project, the scope has expanded in certain areas. In earlier reports, the focus for PPS was to introduce a guideline for installing green roof designs, which focused on the structural, recreational, and technical requirements of implementing such designs on new builds.

While the main focus of the project still remains on the creation of a standard which provides regulatory guidelines for green roof implementation on new builds, PPS has requested that this notion is expanded to include the possibility of constructing green roof designs on existing campus buildings. Furthermore, there is a larger focus in this report on benefit and cost analyses, as well as opportunities for innovative green roof design features and auditing processes. These areas of research will not be included in the final standard document; however, it has been requested by the client that they are discussed within this final report. To summarize, the scope of the project has included:

- Analyzing current green roofs on campus, and examining their functionality,
- Understanding the technical aspects of green roof design, construction, and maintenance, and applying this knowledge to create a detailed standard document,
- Researching existing building standards and applying appropriate requirements and codes to the final deliverable,
- Considering the addition of recreational and educational enhancements to provide multiple social benefits,
- Creating benefit and cost analyses regarding the implementation of green roofs on campus,
- Creating a proposed auditing plan to evaluate the performance of installed designs,
- Providing a formal standard for PPS at the end of the project timeline that can be implemented into the existing Queen's University Building Design Standards document (Physical Plant Services 2021).

1.3 Goals and Objectives

The main goal of the project is to create a new standard for green roof construction on future projects at Queen's University. This standard will be added to the current Queen's University Building Code (Physical Plant Services 2021). The following objectives will be completed at the end of this project:

- Summary of optimal green roof designs for future implementation on Queen's campus buildings.
    - includes benefit/risk analyses, cost estimations, and design standards based on the location and size of new and existing buildings.
- The structural, irrigation and drainage standards corresponding to the designs,
- Recommendations for potential usages of green roof designs for recreational or educational purposes, and
- Establishing audit metrics to validate the feasibility of green roof designs on Queen's Campus buildings.

1.4 Constraints and Stakeholders

There are three main areas of constraint regarding the design, implementation, and maintenance of green roofs. Environmental constraints focus on the climate in which a green roof is installed in, as well as the predicted effects that climate change may have on such a design. Structural constraints focus on the building which the green roof system is proposed to be constructed on, in regard to loading requirements, and the constraints that roof slope will have on green roof design. Finally, financial constraints are also a factor for any construction project and are examined. The main stakeholders are those who will finance the green roof construction, and those who will benefit from it after implementation.

1.4.1 Environmental Constraints

Since Kingston has a climate that changes drastically throughout the year, there are many environmental constraints involved when implementing green roof designs with the goal of installing a system that is easily maintainable and has a long service life.

1.4.1.1 Plant Type

While sedum is a popular plant to use on green roofs due to its low maintenance requirements and easy installation, a study conducted by the University of Toronto suggests that it may not be the most beneficial choice for green roofs installed in locations that experience colder climates (Hall 2013). Sedum has a high drought tolerance, and although it retains high amounts of moisture, it does not evapotranspire (Hall 2013). This reduces the benefits that the sedum has on insulation (Hall 2013). Therefore, it is suggested that locations that experience harsh winters, such as Kingston or Toronto, should consider planting evergreen plants, or meadow grasses that are native to the area (Bass 2005). Evergreens would require a deeper soil layer to be installed on the roof, however, the roof would be easier to maintain for a long span of time, since native plants have a lower chance of dying in the winter (Bass 2005). More information on plants available for use on green roof designs is included in **Error! Reference source not found.** in *Appendix A: Vegetation Recommendations.*

1.4.1.2 Local Climate

Kingston is located in a region of Canada that experiences large variations in climate over the course of the year. This is a constraint on the project, as it affects the choice of vegetation that will have a long lifespan.

Many species of plants require certain amounts of direct, or indirect sunlight to grow properly. If the chosen vegetation does not receive enough sunlight through the year, PPS will be required to replant on a regular basis. This must be considered when determining the optimal green roof standard. Figure *2* records the average hours of sunlight Kingston experiences per month, as reported by the Meteorological Service of Canada (Weather Atlas 2020).

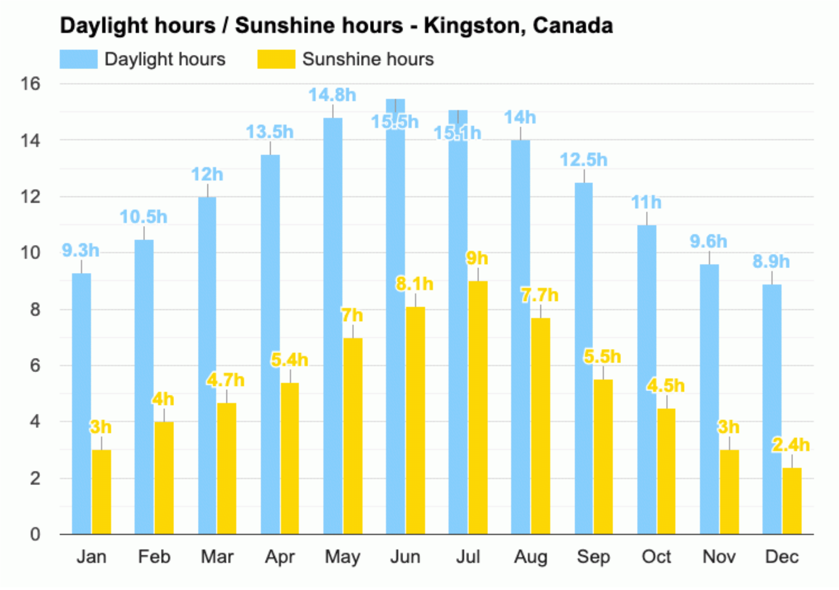


Figure 2: Average hours of sunlight per month in Kingston (Weather Atlas 2020).

As well, excess amounts of rain or snow could cause drainage issues on the roofs. A plot of average rainfall experienced per month in Kingston is shown in Figure *3*, with August experiencing the largest amount at 93.7mm (Weather Atlas 2020). Kingston also experiences large amounts of snowfall from December to March, with the highest average amount of 395mm in January, shown in Figure *4* (Weather Atlas 2020). Tables recording an average of days per month experiencing rain and snowfall in Kingston can be found in *Appendix B: Average Days of Rainfall and Snowfall per Month.* Should large storm events occur during the year, the green roofs on campus must be able to properly drain the excess water to ensure the building does not experiences major water damage.

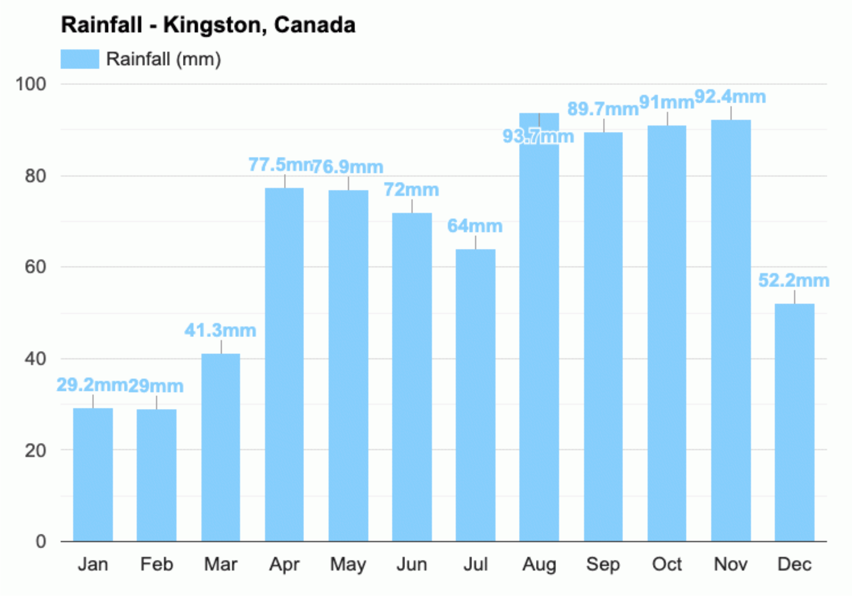


Figure 3: Average rainfall per month in Kingston (Weather Atlas 2020).

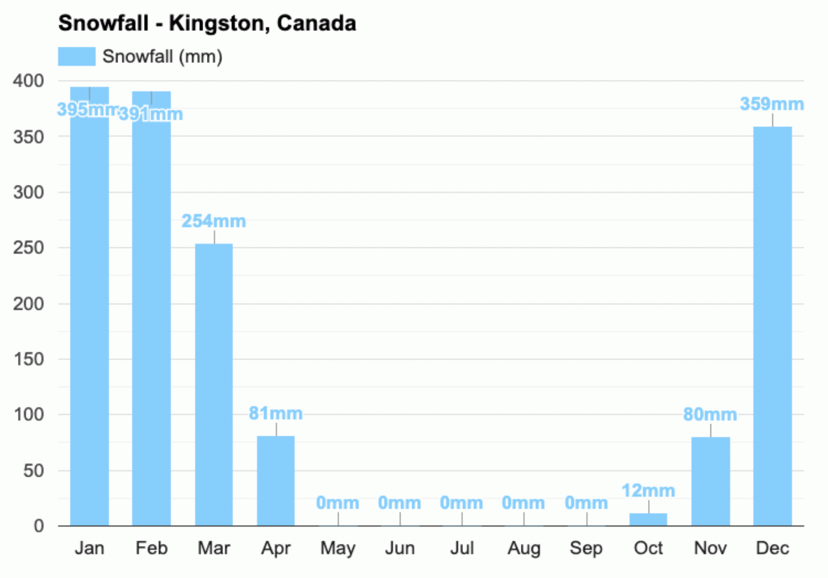


Figure 4: Average snowfall per month in Kingston (Weather Atlas 2020).

Based on the Kingston Airport weather statistics, average wind speeds in Kingston per month range from 9 mph to 11 mph, as shown in Figure 5 (Kingston Airport 2021). This must be taken into account, to ensure the plants will not be damaged by wind. Further information on the effects of wind on roofs can be found in section *4.3.2.3 Wind Pressure* of this report.

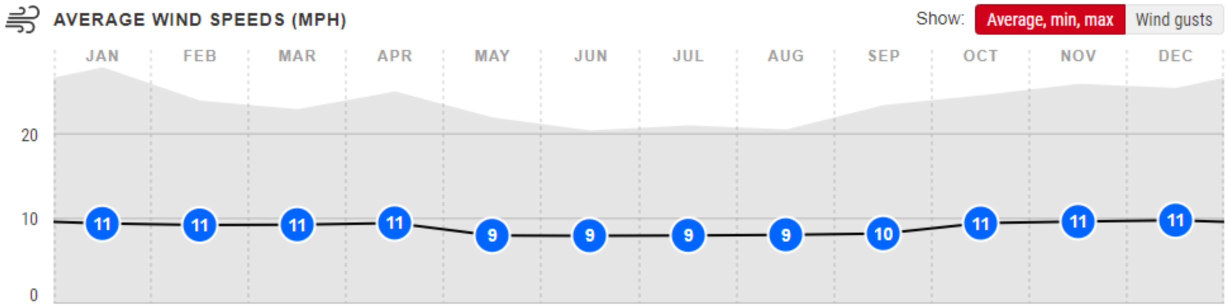
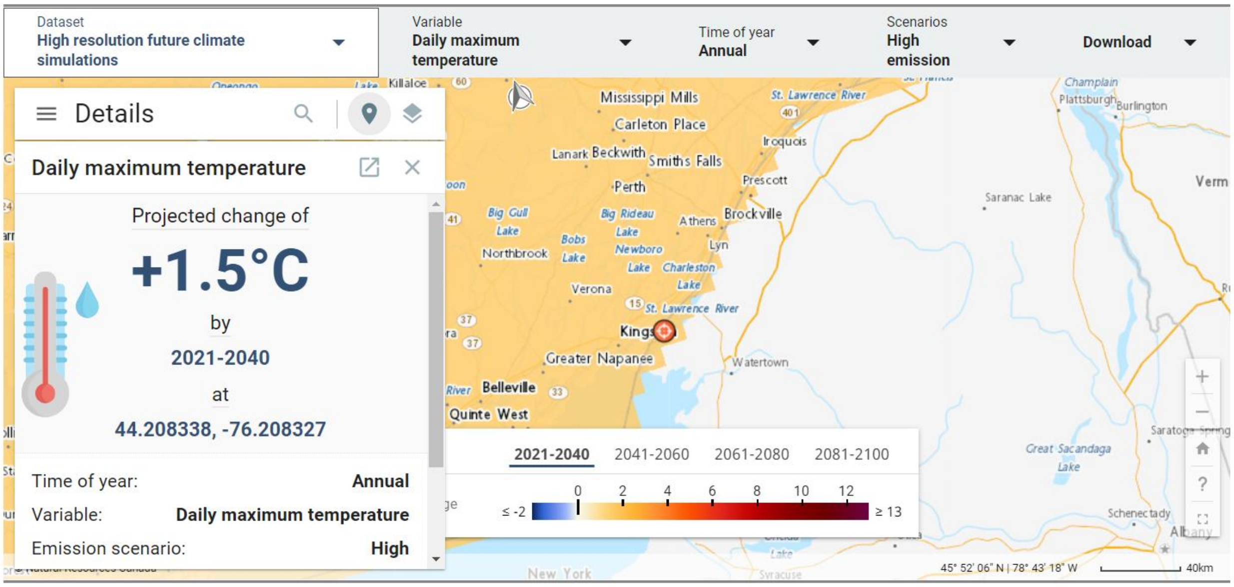


Figure 5: Average wind speeds per month in Kingston (Kingston Airport 2021).

It should be noted that while the above plots are helpful for understanding the performance of green roof designs in the near future, climate change is likely to impact these datasets within the lifespan of new green roof systems implemented on the Queen's University campuses. The Government of Canada's *Climate Data Reviewer* software on their website predicts an increase of 1.5°C by 2040 in Kingston as shown in Figure *6* (Meterological Service of Canada 2020). The data predicted by the government uses global climate models to estimate projected annual changes in temperature based on the reference period of 1986-2005 (Government of Canada 2020). More information about this modelling system can be found on the government website (Government of Canada 2020). This change in temperature, and the projected continual increase thereafter, must be accounted for when basing design decisions on environmental constraints.

Finally, it is important to consider the microclimate that the green roof will be exposed to. The microclimate of an environment varies in size and scope. In this case, green roofs should account for changes in wind speed and temperature based on each building's characteristics such as height, size, and its proximity to larger buildings (which may act as a shield from sun and wind). Therefore, when choosing soil and plant type based on environmental constraints, conservative decisions must be made to ensure that slight changes in predicted climate will not harm the vegetation and soil selected.



Dataset: High resolution future climate simulations
Variable: Daily maximum temperature
Time of year: Annual
Scenarios: High emission

Details

Daily maximum temperature

Projected change of
+1.5°C
by
2021-2040
at
44.208338, -76.208327

Time of year: Annual
Variable: Daily maximum temperature
Emission scenario: High

Figure 6: Projected increase in annual temperature between 2021-2040 (Meterological Service of Canada 2020).

1.4.1.3 Health and Safety Constraints

Finally, due to the Kingston climate, construction of the green roof systems must occur in months that are warm enough for the plants to survive the installation. This is a constraint as not only must the soil not freeze during construction, but large rainfall events would slow construction greatly due to the soil becoming muddy. Based on the data above, it would be recommended that construction of green roofs occurs between April and July once the weather is warm enough to allow for successful planting of the chosen vegetation (Weather Atlas 2020).

As well, there are health and safety risks associated with green roofs due to weather conditions. Namely for intensive roofs, which allow students and staff to access the space, there is the risk of surfaces becoming wet or iced over. This could lead to injuries should the roof be accessible at these times. Signage warning of slippery surfaces, as well as closing these spaces during the winter months, could help prevent such risks. Safety procedures followed currently within the existing Queen’s University Building Code should continue to be followed when constructing green roofs (Physical Plant Services 2021).

1.4.2 Structural Constraints

Regarding structural requirements, green roofs can add significant loading to a structure in comparison to typical roof loading. The roof structure’s bearing capacity must be sufficient to support the determined weight, stability, and moisture retention characteristics of the proposed system (CVC and

TRCA 2011). The live loads associated with maintenance access on the roof must also be taken into consideration. General standards for load and effects can be found on Section 4.1.2.1 of Ontario Building Code to be further researched at a later stage. Special consideration must also be taken for other forms of anticipated loading such as loading from maintenance equipment, the weight of fully grown vegetation, and additional snow loading due to drifting (City of Toronto 2009). Part 2.1 in the Toronto Green Roof Construction Standard outlines the gravity load considerations in accordance with the Ontario Building Code (OBC) Division B, Part 4.1 Structural Loads and Procedures (City of Toronto 2009).

Roof sloping is another important structural component in the feasibility of green roof implementation. The Toronto Green Roof Construction Standard provides best practices for the minimum and maximum slopes under green roof loading. A minimum of 4% sloping is suggested to drains under a green roof with a maximum pipe size of 3 inches, greater than the code minimum of 2% based on OBC section 7.4.8.1. This must be done as green roofs conceal the roof membrane, restricting drying. FM Global Property Loss Prevention Data Sheet 1-35 Section 2.2.10.2 limits roof slopes supporting green roofs to 17% for systems not including anti-shear preventative measures (City of Toronto 2009). It is also recommended that green roofs are not implemented on slopes above 40%. Section 2.2 of the Toronto Green Roof Construction Standard provides more extensive practices on the slope stability relating to the feasibility of green roofs (City of Toronto 2009).

1.4.3 Financial Constraints

During the preliminary meeting with PPS, it was mentioned that there would be no need to consider a particular budget when choosing the optimal green roof design, but Greengenuity has provided a cost analysis of the green roof designs in section *8.0 Cost Analysis and Funding Considerations* as a guideline for PPS.

The cost is varied between different types of green roofs. Usually, extensive green roofs are the least expensive due to their low maintenance requirements and fewer structural constraints, whereas intensive green roofs require regular maintenance and are most structurally demanding. Since most of the green roofs on Queen’s campuses are extensive, there is a comparatively low whole-life cost. Extra costs must also be considered when placing a green roof design onto an existing building to ensure the roof adheres to all structural requirements.

1.4.4 Stakeholders

The main stakeholders of the project are Queen's University and, more specifically, Queen's Physical Plant services. These stakeholders require constructed designs to be feasible in terms of maintenance and longevity but are not highly concerned about cost. The project will also affect future students, as well as members of the Kingston community. Future construction may alter normal routines for these stakeholders, but they will also benefit from the environmentally responsible and aesthetically pleasing designs. The City of Kingston is also a stakeholder and will benefit from the use of green roofs in its community, both environmentally and socially. Finally, the Queen's faculty of Civil Engineering is a stakeholder in this project. The capstone projects in civil engineering rely heavily on clients volunteering to work with students to provide them with projects to work on in their final year. The team is proud to be able to represent the Civil Engineering faculty and will strive to do so in a professional and enthusiastic manner.

2.0 Background Information

2.1 Informing the Need and Potential for Green Roofs

Sustainability-minded green construction has been increasingly implemented at universities across Canada (Quacquarelli Symonds n.d.). At Queen's University, green roofs have already been installed on several buildings including Goodes Hall, Jeffery Hall, BioSciences, Botterell Hall, and the New Medical Building. This is part of the Campus Master Plan initiative, establishing a framework to guide change among the Queen's Campus to accommodate evolving programs and activities visioned over the next 10 to 15 years. Within this framework are six guiding principles to provide direction for the evolution of the Queen's physical campus. The guiding principle number 4, pertaining to the implementation of green technologies is to "foster a more sustainable campus" (Queen's University 2014). This principle aims to lessen the university's environmental impact, with the practice of "promoting green building technologies in new and renewed development"(Queen's University 2014).

Chapter 7 of the Campus Master Plan outlines the Building Design Guidelines, providing general direction for all campus development. Clause 7.1.5 Provides the sustainability framework within the Building Design Guidelines (Queen's University 2014b). These guidelines as quoted by the Campus Master Plan are:

- New buildings should be designed to minimize their environmental impacts and contribute to the overall sustainability of the campus. To this end, the University will consider applying high standards for sustainability, such as LEED™, to new development proposals.
- Buildings should be designed for flexibility, adaptability and longevity to ensure they continue to support the University's evolving mission.
- Significant new buildings should be designed to support sustainable roofs, such as 'green' or 'white' roofs. Roofs can also be designed to accommodate small-scale green energy infrastructure, such as photovoltaic or solar hot water, where appropriate.
- Wherever possible, HVAC systems should be integrated with the campus energy distribution system and central energy plant.
- New buildings should be designed to reduce stormwater impacts, and could incorporate rainwater capture and/or contribute to reuse systems (Queen's University 2014b).

Chapter 5 of the Campus Master Plan outlines the Main Campus Master Plan. Section 5.4 of the plan provides direction for the open space network evolution on Main Campus. These initiatives include proposed landscaped projects, new development, and infrastructure renewal projects. Recommendation 3 for this framework mentions to promote biodiversity, new plantings on the Queen's University campus should be a variety of native and non-invasive species. Considerations into climate changes during different time of year must be made when selecting plants (Queen's University 2014c p. 5). This recommendation can be applied when assessing and improving the current green roofs implemented at Queen's with consideration to future projects. Recommendation 7 mentions the incorporation of plantings into the design of buildings, such as green roofs or living walls, should be encouraged in all new development (Queen's University 2014c p. 5). Thus, there is the potential for a design standard to be made and introduced into the Campus Master Plan to solidify the concept of sustainable infrastructure and meet Queens' sustainability goals.

2.2 Current Green Roofs at Queen's University

There is currently no standard for green roof implementation or maintenance within the Queen's University Building Code. However, there are green roofs existing on campus. To investigate these designs further, Greengenuity conducted a site investigation led by the PPS clients. Four green roofs were visited by the team, including designs found at Botterell Hall, New Medical Building, Biosciences, and Goodes Hall. Designs ranged from extensive to intensive designs.

A goal for PPS is to replace ground surface green space with green roof systems when constructing new buildings on campus. There are noticeable places on campus that are largely covered in concrete and man-made materials. For example, as shown in Figure *7*, Nicol Hall and surrounding buildings are next to larger amounts of green space that include large trees and grass areas. However, Mitchell Hall on the other side of Union Street is surrounded by large slabs of concrete. Such urbanized areas create harmful environmental impacts. Excess surface runoff due to a less permeable surface such as concrete may cause overflowing in local bodies of water, and as a result can increase flooding during both major and minor storm events. By introducing green roofs into exceptionally urbanized areas, effects due to excess runoff can decrease. Therefore, it is important that PPS implements a required standard into the Queen's University Building Code.

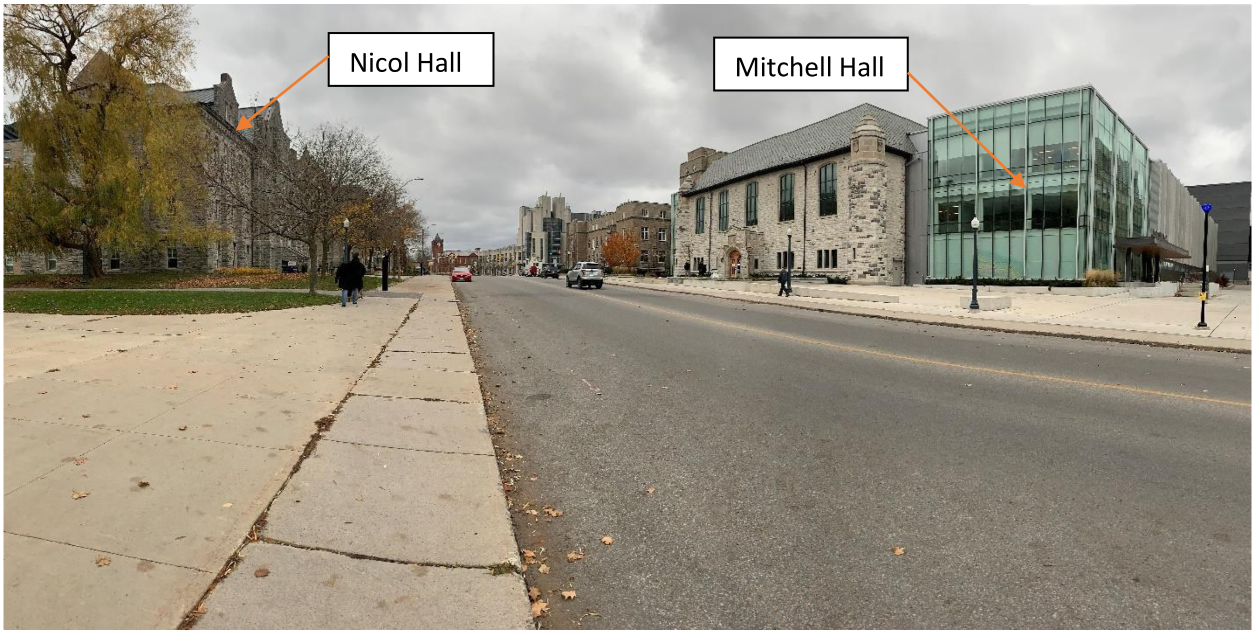


Figure 7*:* Difference between green space near Nicol Hall and green space near Mitchell Hall; image taken by Greengenuity (11/13/2020).

2.2.1 Self-Sustaining Green Roofs: Botterell, New Medical, Goodes Entry

The green roof shown in **Error! Reference source not found.** is located next to Botterell Hall. The roof covers the steam autoclave system for the building, which is used for sterilizing lab equipment. There is no regular maintenance provided for this roof, due to the choice of plants. The perennials used on the roof are self-sufficient and do not need manual watering. Aesthetically, this green roof could perform better should proper grooming occur on a regular basis. However, this is not deemed necessary by PPS due to its hidden location (the roof is not situated at a spot on campus with regular foot traffic). Even though the plants on the Botterell green roof are dormant, environmental benefits can still be obtained. Further analysis of dormant plant life will be explored in section *6.0 Benefit Analysis Considerations.*

Figure 8: Botterell Hall green roof; image taken by Greengenuity (11/13/2020).

Figure 9: Goodes Hall entrance green roof; image taken by Greengenuity (11/13/2020).

Error! Reference source not found. shows the green roof located on the top of the main entryway into Goodes Hall. Once again, the roof is inaccessible, and therefore the plants have been chosen based on the requirement of needing no maintenance. The roof is sloped and leads to a draining system to prevent flooding the roof. The exact slope of this roof is unknown; however, it is assumed that the slope meets the minimum requirements laid out in the Ontario Building Code Requirements (Ontario Building Code | Slope 2020).

The New Medical Building is also home to a small green roof. This roof is inaccessible and therefore is not maintained. However, a tree and other larger plants growing on the roof are visible from the sidewalk, suggesting that the plants perform well without the need for maintenance.

This self-sustainable design is very popular on Queen’s University campus, as it does not require PPS employees to schedule the time and effort for extra maintenance and upkeep. However, while it is beneficial to install green roofs that require little to no attention, this prevents more innovative and interactive green roofs from being built on campus. Furthermore, the mental benefits of the green roof in the long term will be minimized since it is hard for the community to access the self-sustainable green roof.

2.2.2 Green Roofs Requiring Maintenance: Biosciences and Goodes Hall

The green roof on top of a lecture hall in the Biosciences building is the first intensive green roof design that Greengenuity investigated on campus. Shown in **Error! Reference source not found.** it is a simple grassed space that can support live loads (ie. people are able to walk on the roof). The roof includes a series of drains to prevent flooding, shown in **Error! Reference source not found.** by the red oval, and is located one flight of stairs (approximately 160cm) above ground level. PPS cuts the grass on a regular basis. This process is not time consuming or difficult. While this green roof has the potential to be used as a common space for students and staff between classes, it is noted that the green roof is not a popularly used spot on campus. Members of the Greengenuity team infer that the addition of items such as picnic tables or benches, and the installation of more aesthetically pleasing plants would make the space more inviting. Once again, the client has mentioned that this has not been considered because of the complications it would create for the maintenance team. This space is a great example of a green roof that could be used in more innovative ways on campus.

Figure 10: Biosciences green roof; image taken by Greengenuity (11/13/2020).

Figure 11: Drainage system on Biosciences green roof; image taken by Greengenuity (11/13/2020).

The green roof installed on top of Goodes Hall is the best example of a green roof system on campus that combines the financial and environmental benefits of a green roof with the social benefits of an outdoor meeting space within a work environment. Shown in Figure *12*, it incorporates benches and a patio as well as perennial gardens and a drainage system. The roof is surrounded by offices and gives staff an aesthetically pleasing space to look out over. It is easy to maintain due to the choice in plants.

This is the type of design that Greengenuity strives to aim for. Green roofs should be feasible to maintain but should also incorporate design elements that spark interest in people who interact with them. While it is beneficial to allow green roofs to be used as a social space, it is important that enough vegetation remains on the roof that the environmental and economic benefits of the green roof are still noticeably present.

Table 11 indicated later in the report illustrates the guidelines that have been put in place by the City of Toronto to inform the percentage of green roof coverage based on available roof space.

Figure 12: Goodes Hall intensive green roof; image taken by Greengenuity (11/13/2020).

2.3 Design Options

Green roofs have become very popular in Europe and are becoming increasingly so in North America. Not only are they aesthetically pleasing, but they are also an excellent way of combating the effects of urbanization. There are many different green roof designs that can be implemented, but designs fall mainly into the three categories of intensive, extensive, and semi-intensive models.

2.3.1 Types of Green Roofs

Extensive green roofs are the simplest form of green roof technology. They are typically developed to accommodate low-rise plants such as shrubs, sedums, and herbs, growing in mediums less than 15 cm deep (Lee n.d.). Since the plants are low level, they are more self sustaining and require less maintenance. However, plants should be chosen to withstand harsh weather conditions. Extensive green roofs are especially ideal for stormwater management and have relatively low capital costs (Dinsdale, Shaina et al. 2006).

Intensive green roofs are often designed as recreational spaces and offer great potential for aesthetic expansion. The growing medium is deeper, which allows larger plants to grow (Lee n.d.). This form of green roof adds much more structural loading and requires more frequent maintenance. Thus, intensive roofs tend to be more costly due to their need for more frequent irrigation and attention (Dinsdale, Shaina et al. 2006).

Semi-intensive green roofs combine both aspects from extensive and intensive green roof technologies. With a growing medium between 11 cm and 19 cm, the substrate layer provides allowance for a greater variety of vegetation. Thus, this type of green roof falls in between the previous two with regards to costs for construction and maintenance (Lee n.d.). The types of green roofs can be compared using distinguishable characteristics as seen below in Table 1.

Table 1: Characteristic comparison between three main green roof types.

CHARACTERISTICS	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
PURPOSE	Mainly stormwater management, thermal insulation	Varies	Functional, accessible recreational space, aesthetics
DEPTH OF GROWING MEDIUM	15cm or less	25% above 15cm or below 15cm	Above 15cm
ACCESSIBILITY	Mainly inaccessible	May be partially accessible	Accessible
FULLY SATURATED WEIGHT (kg/m^3)	72.6-169.4	Varies	290-967.7
PLANT DIVERSITY	Low	Varies	High
COST	Lowest	Varies	Highest
MAINTENANCE	Low	Varies	Highest

At a first glance, the most desirable green roof for PPS is an extensive design, due to the lack of maintenance required, and the thermal insulation that the design can provide for buildings. However, other design factors are extremely limited by the usage of solely extensive green roofs on campus. The opportunity for growing more diverse plants, or to use a green roof as a recreational space is not available when implementing an extensive design. Since PPS has mentioned in meetings that green roofs are to replace surface vegetation when a new building is constructed, it should be considered that some of these designs are accessible for students and staff members to use the space as they may have used the original green space before construction. Greengenuity will therefore not limit the standard to a specific type of green roof design. Instead, the focus of the standard will be to create requirements that ensure proper implementation of multiple types of designs.

3.0 Designing the Standard

The following section outlines the design process that went into the formation of the standard. To obtain a degree of engineering rigor and practice, some common design tools were used throughout the project. Communicating with the client every step of the way helped keep the project in the right direction and validated the process that Greengenuity undertook. This section also covers how all of the research outlined in the report was used in the standard. That is, how the technical content translates into a policy-based format. The standard complies with two main regulatory codes: the Queen's Building Standard and the Ontario Building Code.

3.1 Design Tools

3.1.1 Engineering Design Process

All engineering work can effectively be evaluated by the engineering design process. The engineering design process is a series of steps that engineers use to guide design work. The steps are listed below:

- Identify the needs and constraints
- Research the problem
- Imagine possible solutions
- Plan by selecting a promising solution
- Create a prototype
- Test and evaluate the prototype
- Improve and redesign as needed

These steps were used to organize the fabrication of the standard. Although there exist many ways to design it, many limits ease the choice of possible solutions. The design is to be implemented into the current Queen's Buildings Standard, and so the content and format must flow with the rest of the regulations. The content is also regulated by other codes and iterations of green roof design standards. Many of which, however, do not include regulations based on the type of green roof being designed. Thus, to include discrete standards between extensive and intensive green roofs, multiple formatting styles could apply. The team opted not to separate the standard into two parts consisting of the regulations to follow if the design is either intensive or extensive. Rather, clauses were made clear when necessary if separate values or further design was required for intensive solutions.

3.1.3 Understanding Existing Standards and How They Apply

Before working on the standard for the client, existing green roof design protocols were studied. This was to get familiarized with what content needed to be included and how it was presented. Two bodies of work played a major role in defining the standard for Queen's University. The first one being the green roof design standard for the city of Toronto (Toronto Green Roof Construction Standard Supplementary Guidelines 2009). This code is cited many times throughout this report due to its relevance to our project. Toronto has a similar climate to Kingston and follows the Ontario Building Code. The second standard that is often referenced in this report is the FLL-Guideline for the Planning, Execution and Upkeep of Green Roof Sites (FLL 2018). This standard is the most in depth report in how to design green roof infrastructure. It dates back to 1975 and has since helped standardized infrastructure in Germany. It gained traction in North America at the turn of the century and has since been a quintessential reference.

3.1.4 Studying the Current Green Roofs at Queen's University

As detailed in section *2.2 Current Green Roofs at Queen's University*, the existing green roofs on campus were viewed by Greengenuity on a site visit conducted by the client. Majority of the existing roofs on campus do not require regular maintenance. As well, there is no regulated auditing process in place for evaluating the performance of the green roof in terms of building energy savings, or surface runoff prevention. This was noted by Greengenuity, and it was determined that a proposed auditing process should be suggested to the client. This would ensure that future green roofs are both being properly maintained, and that they are providing the expected environmental and energy benefits.

It was also observed that even in regard to existing intensive green roof designs that are accessible to the Queen's community, they are frequently disregarded and are not used to their full potential. It is a goal for Greengenuity that future intensive green roofs implemented on the Queen's University campuses are usable outdoor spaces that give students and staff the option of working or meeting up socially in commonly frequented areas of campus where this may not currently be available.

3.2 Materializing the Client's Concept

As mentioned earlier in the report, the scope of the project has evolved over the course of the year based on new information and ideas being provided to the client. This section further details the process undertaken between Greengenuity and PPS to create the standard document.

3.2.1 Communication

Communication between the client and Greengenuity occurred on a regular, bi-weekly basis in the form of meetings over Microsoft Teams. These meetings were a chance for the representatives of PPS, Nathan Splinter and David Gerrish to understand the progress being made in different areas of research and decision making. It is important to note that many team members of Greengenuity, as well as the client, had little to no background knowledge on the different types of green roofs available for installation. Because of this, as research on intensive and extensive designs was conducted, the scope of the project evolved. For example, PPS entered the project emphasizing the need for low maintenance designs as the most important factor for green roof designs, alongside the need for long-lasting green roofs. As the client was introduced to the benefits that more complex designs could provide, intensive designs requiring more maintenance became an item of interest.

3.2.2 Expectations

3.2.2.1 Content

It is expected by the client that Greengenuity will create a concise standard for green roof design, implementation, and maintenance based on thorough research and good engineering judgement tools. PPS is aware that the final standard created by Greengenuity, as well as all information contained within this or any deliverable provided by Greengenuity for PPS cannot be used in practice and cannot be included within the Queen’s University Building Code unless reviewed and approved by professionals within the field of structural and green roof design and engineering.

3.2.2.2 Formatting

The format of the final standard document should match that of the existing Queen’s University Building Code (Physical Plant Services 2021).

3.2.3 Feedback

Feedback from the client has been provided throughout the course of the project. The final standard must be submitted to the client no later than April 9th, 2021. To account for any comments or concerns the client may have with the created standard, the standard document will be sent to the client for review and comment at least twice before the final submission. The first submission of the standard to PPS was March 17th, 2021. Once feedback is obtained by Greengenuity, client comments will be addressed, and the standard will be sent once again. This will provide PPS a final opportunity to have their comments addressed by Greengenuity before final submission.

3.3 Regulatory Bodies

3.3.1 Queen's Building Standards

Queen's University has prepared a comprehensive set of standards that aims to guide in the design, construction, maintenance, or renovation of new projects. These standards are written as a guidance or preference but are not considered the sole solution or relieve any professional responsibility. These standards act in conjunction with codes and regulations applicable to the project. The green roof guideline will act in accordance with these standards with the same aim and objectives.

3.3.2 Ontario Building Code

The Ontario Building Code (OBC) is a regulation under the Building Code Act of 1992 that sets out detailed minimum standards for building construction. Any construction, renovation, or demolition is regulated by the OBC and all inspections must adhere to this building code. Any standard developed must not contradict this code but act in accordance.

3.3.3 Others

The green roof standard must act within all regulatory bodies for their area of implementation. This includes the OBC and any Bylaws set by the City of Kingston. Consistent monitoring of such Bylaws must be undertaken to ensure the standard falls within any future Bylaws as well.

3.4 Content Selection

3.4.1 Disclaimers

This section states the standard is a design project for Group J in class CIVL460, not for any purpose of professional use.

3.4.1.1 Preface

This section will introduce how the standard is created and the referenced documents. It is stated that the standard is not sufficient for a designer as a guideline. All real designs and operations should be based on in-depth research and in consultation with experts in the field.

3.4.1.2 Definitions

This section introduces and explains professional or technical terms that occurred in the standard.

3.4.2 Site Conditions

3.4.2.1 Campus zoning

As requested by the client, both the main and west Queen's University campuses will be sectioned into zones to define specific green roof design requirements. Zones were created qualitatively, and were based on:

- Building density
- Accessible green space
- Student and staff use

As detailed in section *4.2.1 Campus Zoning and Roof Coverage* of this report. A quantitative approach such as conducting surveys of the Queen's University community to gain knowledge on the statistical frequency of use locations on campus experience was out of the scope of this report. Should PPS determine that the campus zones must be created based on more technically specific data, such studies could be implemented in the future.

3.4.2.1 Selection of a green roof

As illustrated in Section *4.2.1 Campus Zoning and Roof Coverage* and the attached standard, three different zones are created based on different field conditions. Each zone will have a certain limit on either one of the green roof types.

The percent of green roof coverage will increase in proportion to the total available roof area, ranging from 500 to over 20,000 m^2. As well, the building's location also affects the green roof coverage. Since the intensive green roof is accessible, it will be applied at a minimum coverage of 50% for highly frequented campus locations. The percentage of extensive design will depend on the accessibility and purpose of the building as well as how frequented it is.

3.4.3 Green Roof Components

The correct selection in components is crucial for green roof operation. General components of a green roof include vegetation, growing media, moisture retention and drainage layer. The selection criteria of each layer should consider local condition, functions and longevity. Periodical maintenance is required for full functionality of the green roof. Section 5 in the standard will illustrate the requirements of each component.

3.4.4 Technical Considerations

To simplify and categorize this project, section *Those people using* the green roof must follow the safety and health codes. The standard covers protocols related to fire safety, fall prevention, material displacement, the handling/storage of equipment, foot-traffic restrictions, environmental risk prevention, roof slope, and the consideration of persons with disabilities. Furthermore, the periodical maintenance must also be kept in order to reach the longest longevity of the green roof and prevent any potential safety risks.

4.0 Technical Consideration will divide the design into green roof components, site conditions, structural considerations and insulations. Each section will then be subcategorized based on properties and functions.

Each section in the technical consideration will research on the feasibility of the green roof design. As well, the technical consideration also intends to provide an in-depth rationale regarding each section in the standard.

3.4.5 Vegetation Performance

As stated, the correct selection of each layer is crucial for a green roof's operation. The satisfied performance should follow each specific code in section 5 of the attached standard. The green roof designer should install each layer correctly and follow the guideline. Innovations such as recreation and solar energy can be applied to the green roof as extra functions.

3.4.6 Safety and Maintenance

Those people using the green roof must follow the safety and health codes. The standard covers protocols related to fire safety, fall prevention, material displacement, the handling/storage of equipment, foot-traffic restrictions, environmental risk prevention, roof slope, and the consideration of persons with disabilities. Furthermore, the periodical maintenance must also be kept in order to reach the longest longevity of the green roof and prevent any potential safety risks.

4.0 Technical Consideration

It is crucial to determine the scope of work prior to green roof design and consideration. The individual project goals must be established along with a plan for implementation, and all constraints recognized. The primary function of the roof will help determine the specific elements that will compose the green roof design. Structural load capacity, environmental considerations, and accessibility are all components that will aid in the feasibility and design for green roof implementation (Tolderlund 2010).

4.1 Green Roof Components

4.1.1 Vegetation

A study done by (Vinson and Zheng 2013) at the University of Guelph aimed to recommend plant species suitable for green roofs in the Southern Canadian Climate. The study was conducted using green roof trials on roof tops in Toronto and Guelph, Ontario to assess current green roofs in those locations. Variability in these locations as well as the applicability of these results to Kingston climates will be addressed. The five study site conditions are summarized in Table 2 below.

Table 2: Site conditions studied for Plant Recommendations for Green Roofs Under Northern Climate Survey (Vinson and Zheng 2013).

	Site 1	Site 2	Site 3	Site 4	Site 5
Location	Toronto, ON	Toronto, ON	Toronto, ON	Toronto, ON	Guelph, ON
Installation	1998	2010	2010	2009	2008
Size (m^2)	10,000	35,000	7,500	5,231	19,000
Green roof type	Extensive	Mixture of extensive and semi-intensive	Mostly extensive (butterfly/medicinal green roof garden) and partly semi-intensive (wetland green roof garden)	Semi-intensive	Semi-intensive
Media depth	4”	4¼“ and 6”	4” and 6”	6”	6”
System	Mat system (Sopranature System by Soprema)[1]	Module system (LiveRoof© Ontario Inc.)[2]	Monolithic system[3]	Monolithic system	Mat System (Nedlaw Living Roofs)
Rooftop height	3-3.5 stories	3 stories	2 stories	5 stories	4 and 5 stories
Lighting	Mix of full sun and partial shade	Mix of full sun and partial shade	Mostly full sun, partial shade on wetland	Mix of full sun and partial shade	Mostly full sun, lower half receives partial shade
Irrigation	Sprinklers induced by rain sensor	Sprinklers as needed to aid plant establishment in first 2 years, after only irrigation during extreme droughts	As needed via hand-held garden hose and/or oscillating sprinkler	Automatic sprinklers 3 hours/night from April-October	Not irrigated
Maintenance	4 times a year	During spring	Weeding as needed	Weeding as needed	Tall grasses cut back once a year

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[1] Pre-grown ‘mats’ of vegetation rolled-up and transported to the location as a formed system.

[2] Soil elevators filled with engineered soil where plants are grown to maturity and installed for an instantly mature green roof (“Module Options | LiveRoof Hybrid Green Roofs” n.d.).

[3] Constructed directly at final destination.

The plant species under the conditions indicated above were assessed by a performance rating between zero and ten. A zero indicated that the plant species has died, five indicated a mediocre performance/appearance, and ten indicated exceptional performance/appearance (Vinson and Zheng 2013). Thus, a list was formed based on the plant species that received scores of five or higher. Species receiving scores below five or having displayed overly aggressive vast weedy growth were not recommended (Vinson and Zheng 2013). The list of recommended and non-recommended plant species is indicated in **Error! Reference source not found.** in ***Error! Reference source not found.***. It must be noted that these recommendations are specific to the types of green roofs indicated in **Error! Reference source not found.** and are subject to change under different circumstances. The recommended species have been considered noninvasive to the northern location, indicating the combination of plants will be compatible. In an 88-day investigation done for the water irrigation regime on a typical sedum green roof, it was identified that the roof with a 2 cm media depth must be watered at least once every 2 weeks (VanWoert et al. 2005). It was also identified that with higher media depths, the green roof could go up to 28 days without watering (VanWoert et al. 2005).

The validity of these recommendations also depends on the Kingston, Ontario climate in comparison to the Toronto and Guelph, Ontario climates under which the study took place. The highest influencing factors on vegetation growth are temperature, precipitation, and light. Temperature is a crucial factor in plant biological activity and growth as it occurs in a range of 0°C to 50°C (Manske 2006). Below 0°C, plants become physiologically "hardened" due to the unavailability from water freezing. Biological reactions such as photosynthesis become limited and energy becomes inadequate (Manske 2006). Thus, the growing season is limited by low temperatures. Table *3* indicates the average temperatures for the three Ontario cities under review. Due to the slight deviation in temperate between the sites of study and the current site of consideration, the recommendations should hold true under most circumstances. The Northern climates fluctuation in air temperature in daytime and nighttime is beneficial to plant growth as the warm temperatures increase photosynthesis and the cooler temperatures at night reduce plant respiration rate (Manske 2006).

Table 3: Average temperatures for Guelph, Toronto, and Kingston, Ontario (Weather Atlas n.d.).

	Highest Average High Temperature		Lowest Average High Temperature		Highest Average Low Temperature		Lowest Average Low Temperature	
	Month	°C	Month	°C	Month	°C	Month	°C
Guelph	July	24.8	January	-3.8	July	15	January	-9.4
Toronto	July	24.8	January	-2.3	July	18.4	January	-7
Kingston	July	24.1	January	-3.2	July	17.7	January	-8.4

Precipitation is crucial to all life, it is necessary for plants to perform all necessary biochemical reactions and is essential for plant tissue rigidity and growth (Manske 2006). Insufficient water could lead to water stress in plants as balance must be maintained between rainfall and precipitation evaporation for vegetation to thrive (Manske 2006). Table *4* indicates the average rainfall for all three Ontario cities under study. Kingston also sees the highest amount of rainfall out of the three cities, indicating that irrigation procedures shown in the study may differ for Kingston green roofs due to the higher precipitation levels.

Table 4*:* Average rainfall for Guelph, Toronto, and Kingston, Ontario (Weather Atlas n.d.).

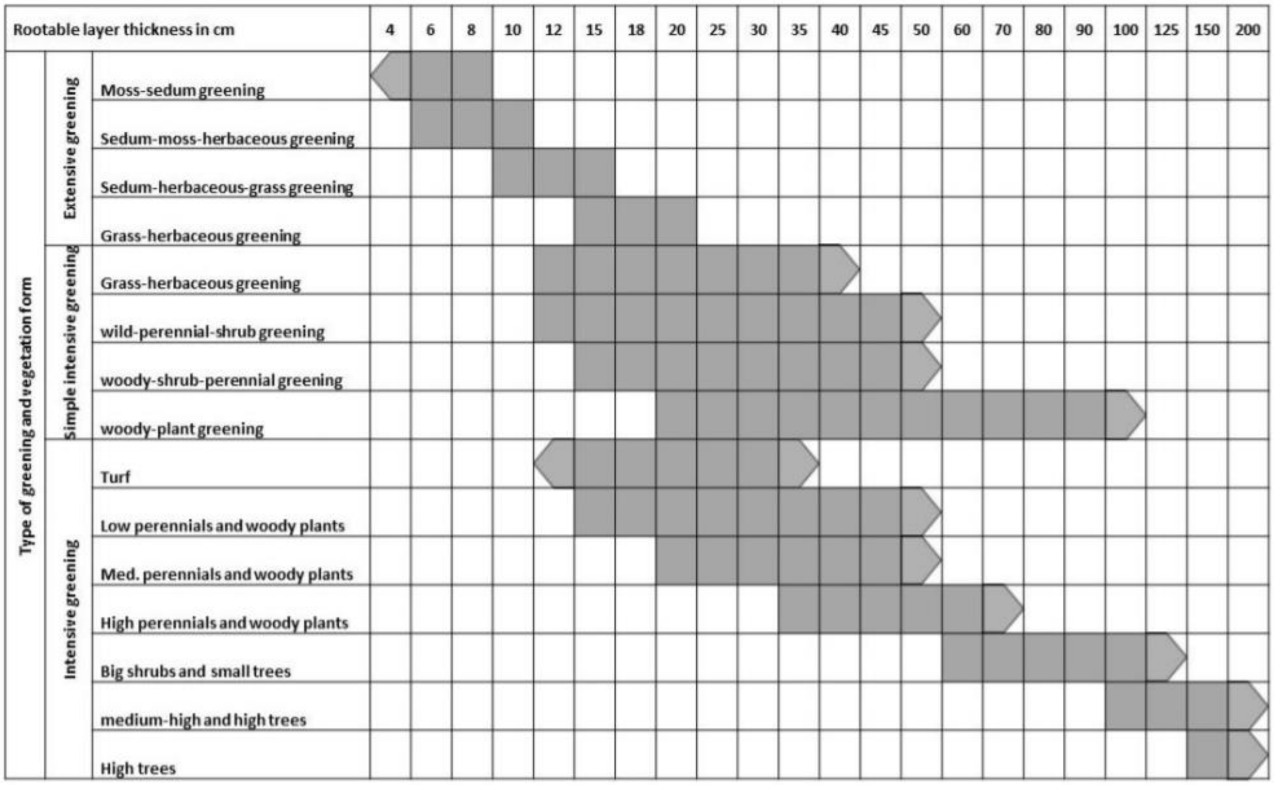
	Highest Average Rainfall		Lowest Average Rainfall	
	Month	mm	Month	mm
Guelph	May	75	September	41
Toronto	July	53	February	19
Kingston	October	92	September	53

Plants source energy from light as it is necessary for photosynthesis to occur. The rate of photosynthesis depends on factors such as the duration of sunlight within a region. Kingston and Guelph see the same average sun percentage per year of 42% with Toronto seeing a slightly higher amount of 44% (Canada 2011). Thus, photosynthesis rates will have little variability among the three cities based on sunlight duration.

Kingston has the highest average amount of snowfall of 395 mm in January (Weather Atlas n.d.). While Guelph has the highest annual snowfall during January and December of 386 mm (Weather Atlas n.d.) and Toronto has a lowest of the highest average snowfalls of 372 mm occurring in January (Weather Atlas n.d.). Therefore, due to the increase in precipitation, snowfall, and slightly harsher weather conditions, a closer consideration must be placed on the saturated weight and maintenance needs when implementing certain plant species. The increased precipitation rates in spring as well as snowfall melt in winter may require drainage systems with greater drainage capacity. It is recommended that the conditions of the currently implemented green roofs at Queen’s University and the City of Kingston be assessed against the study results mentioned above. This should be done to assess the validity of plant conditions under the Kingston climate.

4.1.2 Growing Media

Under the Toronto Municipal Code Chapter 492 Green Roofs, to support plant survivability, growing media must be at least 10 cm deep whenever structurally possible (City of Toronto 2017). Growing media must have the correct balance between organic matter, soil, sand, and gravel. It must maintain proper fertilization, approximately every two to three weeks to maintain nutrients, without damaging vegetation and releasing leached nutrients into stormwater runoff (CVC and TRCA 2011; Masabni n.d.). The thickness of the growing medium must be able to account for the rooting of the planted vegetation. The root-able layer thickness for variable plant types is shown in Figure 13. Growing medium fully saturated loading can amount to 80-170 kg/m^2 when fully saturated and must be accounted for in structural loading analysis (CVC and TRCA 2011).



Rootable layer thickness in cm			4	6	8	10	12	15	18	20	25	30	35	40	45	50	60	70	80	90	100	125	150	200
Type of greening and vegetation form	Extensive greening	Moss-sedum greening	◀	▨	▨																			
		Sedum-moss-herbaceous greening		▨	▨	▨																		
		Sedum-herbaceous-grass greening				▨	▨	▨																
		Grass-herbaceous greening						▨	▨	▨														
	Simple intensive greening	Grass-herbaceous greening					▨	▨	▨	▨	▨	▨	▨	▶										
		wild-perennial-shrub greening					▨	▨	▨	▨	▨	▨	▨	▨	▨	▶								
		woody-shrub-perennial greening						▨	▨	▨	▨	▨	▨	▨	▨	▶								
		woody-plant greening								▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▶			
	Intensive greening	Turf					◀	▨	▨	▨	▨	▨	▶											
		Low perennials and woody plants						▨	▨	▨	▨	▨	▨	▨	▨	▶								
		Med. perennials and woody plants								▨	▨	▨	▨	▨	▨	▶								
		High perennials and woody plants											▨	▨	▨	▨	▨	▶						
		Big shrubs and small trees															▨	▨	▨	▨	▨	▶		
		medium-high and high trees																			▨	▨	▨	▶
		High trees																					▨	▶

Figure 13: Thickness of different greening and vegetation types (FLL 2018).

4.1.3 Moisture Retention

Green roofs act to reduce stormwater runoff by retaining rainwater, thus delaying or eliminating the discharge of excess water. Maximum water capacity is defined as the amount of water held by a saturated substance (FLL 2018). The maximum water capacity that the vegetation may retain is dependent on the type of vegetation and the growing medium.

To dimension roof drainage, the rainwater runoff must be determined based of the amount of water retained by the vegetation. The calculation of rainwater runoff is quantified by the runoff coefficient C_s of the flow (FLL 2018). This coefficient must be assessed for different storm events upon green roof design. To calculate the percent retention, the difference between the amount of rainfall precipitation and the amount of water drained annually must be determined (FLL 2018). This depends on the thickness of the structural layers and their storage capacity based on permeability. Table 5 indicates the typical values for percentage of water retention for extensive and intensive green roofs relating to the structural layer thickness.

Table 5: Reference values for percentage annual water retention and annual runoff coefficients for green roofs.

Type of greenery	Structural thickness (cm)	Annual average water retention (%)	Runoff Coefficient (C_s)
Extensive	2-4	40	0.60
	>4-6	45	0.55
	>6-10	50	0.50
	>10-15	55	0.45
	>15-20	60	0.40
Intensive	15-25	60	0.40
	>25-50	70	0.30
	>50	>90	<0.10

To ensure proper discharge of excess water, there must be sufficient unsaturated space in the bulk materials. The water storage ability of the growing media must be parametrized to avoid waterlogging and to not exceed a 65% saturation volume (FLL 2018). These parameter limits can be seen in Table 6 in terms of type of green roof vegetation with or without grass turf.

Table 6: Water capacity of growing media (FLL 2018).

INTENSIVE GREENERY				**EXTENSIVE GREENERY WITHOUT TURF**	
Without turf		With turf			
Single layer	Multi-layer	Single layer	Multi-layer	Single layer	Multi-layer
>30% vol <65% vol	>45% vol <65% vol	>30% vol <65% vol	>35% vol <65% vol	>20% vol <65% vol	>35% vol <65% vol

4.1.4 Drainage

Having proper drainage on a green roof is critical. If the system is not able to drain properly it can negatively impact the vegetation due to oversaturation of the soil. As the soil takes on excessive amounts of water it continues to add weight to the roofing structure potentially compromising the structural integrity of the roof. Adequate flow structure must be implemented (Lake Superior Streams n.d.) .

The drainage system should direct rainwater to planted areas where the roots can intercept water and slow runoff. Excess stormwater should be directed to a water collection- storage facility for later use in irrigation of green roof or other permissible uses.

Roof drain enclosures are used to direct water out of the roof. Extensive green roofs have a shallower soil depth; therefore, the roof drain enclosure height is typically 30 cm or less.

The graphic in Figure 14 indicates a typical layering scheme layout for green roof drainage system.

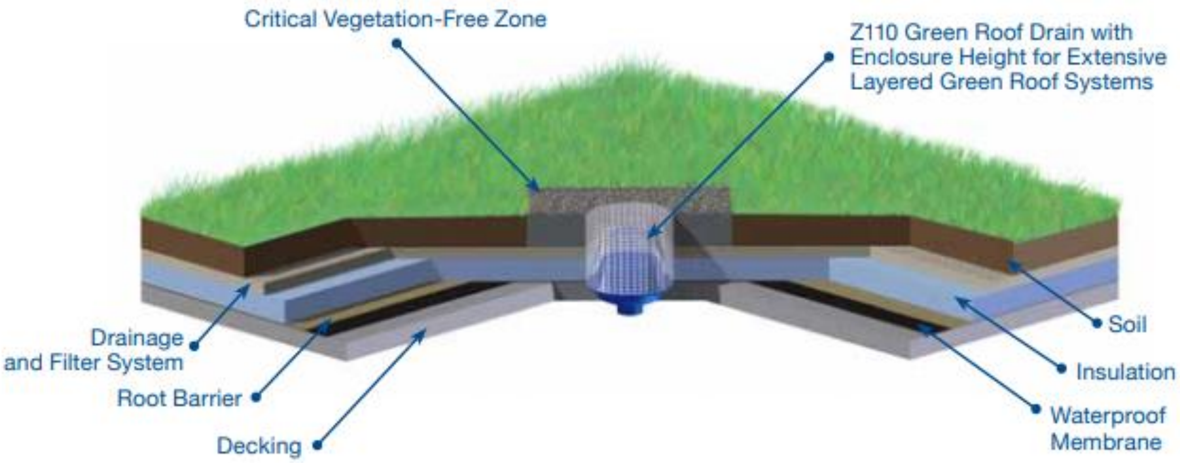


Figure 14: Extensive layered green roof drainage and filter system (Zurn Industries Limited n.d.)

More detailed models exist that account for growing layer attributes, plant types and their respective characteristics.

The drainage layer must have high permeability to allow the rapid release of excess water into the roof drain to avoid oversaturation. The drainage layer performance can be calculated using **Error! Reference source not found.** (FLL 2018).

$$q' = \frac{A \times C_S \times q}{b} \quad (1)$$

*Where, q' = volume discharge in the drainage course ($l/s \times m$), A = surface area to be drained (m^2), C_s= peak runoff coefficient (**Error! Reference source not found.**), q = design rainfall ($l/s \times m^2$), and b = drain width (m)*

When visiting the green roofs on the Queen's University campus, similar drainage measures were observed. Figure 15 is a photograph of one of the green roofs on Goodes Hall, in which all of the proper drainage requirements can be seen.

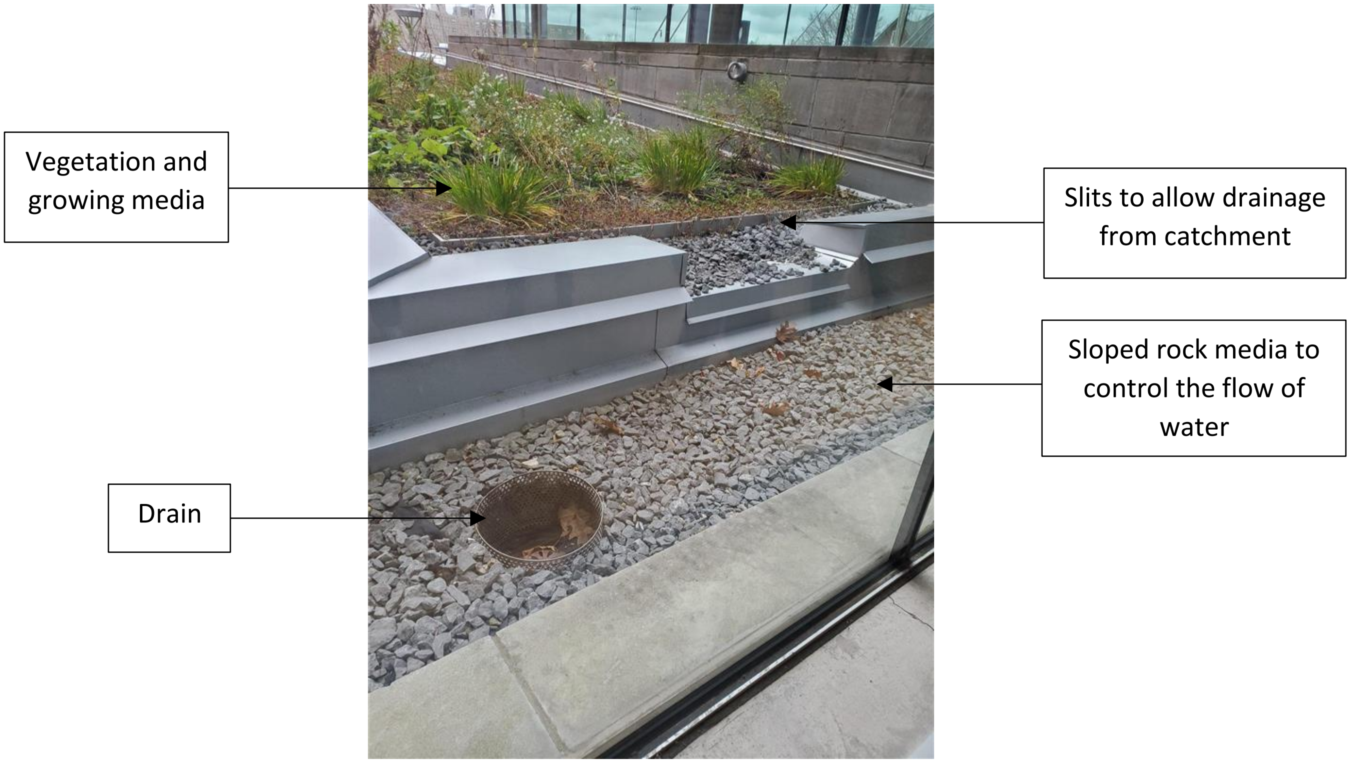


Figure 15: Goodes Hall green roof drainage system. Photograph taken 13/11/20.

4.2 Site Condition Considerations

Queen's University Main Campus is nearing land-space capacity. Thus, considerations must be made towards the goals and objectives for the future development of the Main and West campuses (Queen's University 2014a). With the advancing of technologies in green infrastructure and the need for immediate action towards protecting the environment, this plan must be assessed, and standards must be put into place to reach the climate change goals outlined in the Queen's University Climate Action Plan (Queen's University 2016).

Outlined in Chapter 2 of the Queen's University Master Plan is the development capacity of sites on Main Campus and West Campus as of 2014 (Queen's University 2014a). The following figures were based on considerations such as land utilization, building conditions, and historic significance. The site calculations and conditions are outlined in Table 7.

Table 7: Development Capacity of the Queen's University Campus as of 2014 (Queen's University 2014a).

		Main Campus Capacity	West Campus Capacity
Large Vacant Sites	Less-constrained sites that can be considered for more immediate redevelopment. Places that can accommodate modern academic buildings.	46,000 m² (495,140 ft²)	60,000m² (645,834 ft²)
Large Sites with Considerable Constraints	Clusters of buildings and vacant land with financial or logistical constraints such as demolition, phasing, or historic buildings to be retained and incorporated into new design.	12,000m² (129,166 ft²)	29,000m² (312,153 ft²)
Small Sites with Considerable Constraints	Smaller clusters of buildings and vacant lands with similar financial or logistical constraints.	22,000m² (236,806 ft²)	0m² (0 ft²)
TOTAL		80,000m² (855,112 ft²)	89,000m² (967,987 ft²)

Figure 16 displays the location of the available development sites on Queen's Main Campus, while Figure 17 represents site development locations on Queen's West Campus. Blue areas indicate large vacant sites, orange areas indicate large sites with considerable constraints, and yellows represents small sites with considerable constraints (Queen's University 2014a).

Figure 16: Development capacity locations on Queen's University Main Campus as of 2014 (Queen's University 2014a).

Figure 17: Development capacity locations on Queen's University West Campus as of 2014 (Queen’s University 2014a).

Figure 18 shows the long-term vision for Queen’s Campus Lands, where buildings in white illustrate the potential new buildings (Queen’s University 2014a).

The long-term vision illustrates the full-range of development and open space opportunities described in this plan. Buildings in white illustrate potential new buildings, while existing buildings and those under construction are illustrated in yellow.

Figure 18: Long-term vision of Queen's University Campus Lands (Queen’s University 2014a).

In Section 3.2.1 of Chapter 3, the vision for Queen’s Main Campus is introduced. Here it is envisioned that the Main Campus landscapes be integrated into its surrounding buildings, seamlessly transitioning from campus grounds to surrounding communities (Queen’s University 2014a). While many landscaping projects are outlined in Chapter 5, few green roof recommendations are made. Thus, when undertaking new building projects, it is crucial that green space removed is counteracted by sustainable infrastructure. Not only does green space create environmental benefits, but green roofs can also aid in the reduction of Greenhouse gas (GHG) emissions as outlined in Section 6.1. These positive impacts will be further explored as a green roof benefit analysis is performed in consultation with the Queen’s University Climate Action Plan (Queen’s University 2016). New building projects should be designed under the Greengenuity informed standard to support green roofs, thus minimizing the environmental impact.

For example, North of Union Main Campus Precinct Plan outlined two large development opportunities which have been completed as of 2020 and several new development projects (Queen's University 2014d). An outline for these developments can be seen in Figure 19.

Figure 19: Queen's University Main Campus Precinct 1 (North of Union) (Queen's University 2014b).

The current site conditions as seen in Figure 20, indicate that much of the area planned for development is residential. Thus, if development were to take place, new landscaping and green space would need to be implemented to make up for the environmental losses. Green roofs are a space efficient way to reintroduce green space into an area that has been developed. A standard clause must be developed to inform the percent removal for development to the green space added post-development.

Figure 20: Current site conditions of North of Union Precinct Area (Google Earth, 2019).

4.2.1 Campus Zoning and Roof Coverage

The client specified that the final standard should include green roof recommendations specific to different locations on campus. This specification allows the reader of the standard to identify the type and size of green roof that is recommended to be installed for each future building constructed on campus.

To satisfy this request, campus "zones" were created, based on building density, accessible surrounding green space, and student and staff usage. Building density referred to how many buildings were already present in a specific location on campus, and how many new builds are expected to occur in that area based on the Campus Master Plan. Accessible surrounding green space looked at the amount of naturally occurring green space in each campus location, and whether this area is used by the Queen's University community, or if it is often left unoccupied. Finally, zones were also created based on how often students or staff frequent the specified area of campus.

These zoning requirements were qualitatively determined (ie. no numerical system was used to determine what creates a red zone versus a yellow zone) and are shown in Table *8*. Areas of campus that may fall into more than one category based on the criteria in Table *8* are placed in the more restrictive zone (ie. if a location on campus could be placed in either a yellow or green zone, the location is determined to be a yellow zone).

Table 8*:* Campus zoning guidelines based on qualitative criteria.

ZONE COLOUR	BUILDING DENSITY	ACCESSIBLE GREEN SPACE	STUDENT/STAFF USE	EXAMPLES
Red Zone	Building density is almost at maximum, or predicted to become so based on Campus Master Plan	Little to no accessible green space available, green space available is frequented on a regular basis	Highly frequented locations on campus, green spaces used for athletics or other recreational purposes (the loss of this space with no replacement would be detrimental)	Residence-dense areas, sports fields, etc.
Yellow Zone	Building density high, but there is room for additional build, predicted that construction will occur based on Campus Master Plan	Little to no amount of green space, green space available is occasionally frequented	Highly to moderately frequented locations on campus, green spaces used on occasion for recreational purposes (loss of this space would be unfortunate, may require relocation of activities)	Green spaces used for activities such as frosh week, frequented areas of campus that could benefit from more green space, etc.
Green Zone	Less building density, predicted to have few to no buildings constructed based on Campus Master Plan	Large amount of green space, green space available rarely frequented, or predicted that most accessible green space will remain	Less frequented areas of campus, green space rarely used for recreational purposes	Green space without specified use (often empty), areas of campus less frequented, etc.

Should the client prefer to create zones with more specific, quantitative values associated to each criterion, surveys could be provided to Queen's community members, and more specific values could be considered such as the total surface area of buildings per a specified area.

Using AutoCAD images of the Queen's University main and west campuses, zones were illustrated as shown in Appendix I: Campus Zoning Maps of the final standard document. Based on each zone, requirements for the type of green roofs installed and the size of green roof designs were created. As a base requirement for all zones, any existing green space that is permanently removed from a site due to construction must be entirely replaced as a green roof design. The total available roof area is determined for a building by subtracting any essential area on the roof used for electrical, HVAC, or maintenance purposes from the total roof surface area. Should the total available roof area be smaller than the area of green space removed during construction, the green roof should span the entire available roof area to replace as much green space as possible.

Roof areas on campus range from around 500 m^2 to over 30 000 m^2 according to information provided by PPS. By dividing these areas into four categories, percent roof coverage could be determined. These values will be implemented into designs should the total available roof area be larger than the amount of existing green space removed on the construction site (i.e. a green roof larger than the previous green space could be installed on the building).

The Toronto Green Roof Bylaw includes a similar regulation for determining the required size of a building's green roof (City of Toronto 2017). Larger roof areas require a higher percentage of green roof space to maximize the environmental benefits, including the mitigation of urban heat island effects and excess surface runoff on the Queen's University campuses.

3.3.1.1 Red Zones

Buildings constructed in a campus Red Zone must replace 80% of the removed existing green space as an intensive design. This is due to the extreme lack of existing accessible green space in these locations on campus. The remainder of the design may be extensive if desired. As shown in section *2.0 Campus Zones and Roof Coverage* of the supplementary standard document, Red Zone buildings must install a minimum percent roof coverage of 40-70% depending on the total available roof area.

3.3.1.2 Yellow Zones

Buildings constructed in a campus Yellow Zone must replace 50% of the removed existing green space as an intensive design. This is due to the fact that these locations on campus either lack accessible green space, or the existing green space was frequently used and therefore should be partially replaced by usable outdoor space. The remainder of the design may be extensive if desired. As shown in section *2.0 Campus Zones and Roof Coverage* of the supplementary standard document, Yellow Zone buildings must install a minimum percent roof coverage of 30-60% depending on the total available roof area.

3.3.1.3 Green Zones

Finally, buildings constructed in a campus Green Zone must replace all of the removed existing green space as an extensive design. This is because these areas of campus are either less frequented by members of the Queen's community, or the area is surrounded by existing accessible green space and the removal of a portion of it will not be significantly noticeable. As shown in section *2.0 Campus Zones and Roof Coverage* of the supplementary standard document*,* Green Zone buildings must install a minimum percent roof coverage of 20-50% depending on the total available roof area.

4.3 Structural Considerations

4.3.1 Dead Loading

Standards for dead and live load design must be consulted for load combinations including wind and snow. Dead and live loads must be calculated in accordance with the Ontario Building Code Division B Section 4. A detailed load analysis must be performed for the predicted combined loading of the green roof and the bearing capacity of the structure. Loading must account for rain, wind, and snow conditions relating specifically to the area of implementation. Load combinations for ultimate states must be considered for the type of roof system being built upon. The load combinations can be calculated in consultation with the OBC, as seen in Table 9.

Green roof dead loading can be done in consultation with the ASTM E2397.05 “Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems”. This guidance provides testing methods and procedures for calculating the dead and live load of green roofs at critical points. The green roof loading must be assessed under two critical conditions: (1) When water is retained or captured under drained conditions after new water additions (such as rain or irrigation) have ended, and (2) When water additions is actively contributing, and the drainage layer is completely saturated. The difference between conditions (1) and (2) indicates the approximate live load due to weight of transient water loading. However, this procedure does not include live loading associated with wind and snow. The dead load analysis must account for all loads associated with the green roof system. Green roof components may include but are not limited to membranes, waterproofing sheet components, fabrics, geocomposite layers, synthetic reinforcing layers, insulation, growing media, granular drainage media, and intensive/extensive plant materials or supplementary components. The unit weight sum of dead loading by these components can provide an estimation of the total green roof dead loading on a structure. The saturated growing media density can be estimated using testing methods outlined in ASTM E2399.05, “Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems” or as provided by manufacturers of green roof materials.

Table 9: Ultimate limit state load combination for structural steel (OBC).

CASE	**LOAD COMBINATION**	
	Principle loads	*Companion loads*
1	1.4D	-
2	(1.25D or 0.9D) + 1.5L	1.0s or 0.4W
3	(1.25D or 0.9D) + 1.5S	1.0L or 0.4W
4	(1.25D or 0.9D) + 1.4W	0.5L or 0.5S
5	1.0D + 1.0E	0.5L or 0.25S

Where D = dead loads, L = live loads, S = snow loads, W = wind loads, and E = earthquake loading.

If vegetation loading is not provided by the supplier, Appendix A of the FLL green roof guidelines indicates load assumptions for associated green roof components. Table *10* indicates load assumptions for different vegetation forms.

Table 10*: Loading estimation per vegetation type (FLL).*

VEGETATION FORM	**LOAD ASSUMPTION**	
	kN/m^2	Kg/m^2
Extensive greening		
Moss-sedum greening	0.10	10
Sedum-moss-herb greening	0.10	10
Sedum-herb-grass greening	0.10	10
Grass-herb greening	0.10	10
Semi-intensive greening		
Grass-herb greening (grass roof, poor grassland)	0.15	15
Wild perennial-tree/shrub greening	0.10	10
Trees/shrubs-perennials greening	0.15	15
Tree/shrub greening (to 150 cm high)	0.20	20
Intensive greening		
Turf	0.05	5
Low perennials and trees/shrubs	0.10	10
Perennials and bushes to 150 cm height	0.20	20
Bushes to 3 m height	0.30	30
Large bushes to 6 m height	0.40	40
Small trees to 10 m height	0.60	60
Trees to 15 m height	1.50	150

The Toronto Green Roof Bylaw requires the construction of green roofs in new developments in the City with few exceptions (City of Toronto 2017). The size of these green roofs will depend on the available roof space in relation to the size of the building. The available roof space is calculated by subtracting designated amenity space from the total roof space (City of Toronto 2017). The following guidelines produced by the Toronto Green Roof Bylaw is as follows, indicated in Table 11.

Table 11: Required size of green roof based on available roof space (City of Toronto 2017).

GROSS FLOOR AREA (SIZE OF BUILDING)	**COVERAGE OF AVAILABLE ROOF SPACE (SIZE OF GREEN ROOF)**
2,000 - 4,999 m^2	20%
5,000 - 9,999 m^2	30%
10,000 - 14,999 m^2	40%
15,000 - 19,999 m^2	50%
20,000 m^2 <	60%

4.3.2 Live Loading

4.3.2.1 Recreational Foot Traffic

The intended use of a green roof must be established to determine the live loads based on the type of green roof as defined in Table 1. Extensive roofs will not see foot traffic whereas intensive roofs will.

The usability of the green roof should be limited to provided footpaths. The growing media should be resilient against trampling if necessary. The vegetated areas must be protected from foot traffic in order to minimize damage.

A minimum roof live loading of 1.0 kPa uniformly distributed load or 1.3 kN concentrated load must be taken as per OBC Section 4.1.5.3. Outlined in FM Global Property Loss Prevention Data Sheets 1-35 Section 2.2.5.2. is a minimum additional 0.58 kPa uniformly distributed load for extensive green roofs. If a green roof were to allow public access (i.e. intensive green roofs), the Ontario building code's standard for live loads on green roofs is a minimum uniformly distributed load of 4.8 kPa (Ontario Building Code | Full and Partial Loading 2020). The entire green roof assembly, including plants and the water required to saturate the growth media, is considered part of the dead load of the structure. Water in excess of that which saturates the growth media, snow and people visiting the green roof are all considered part of the live load of the structure (Velazquez 2010). Saturated weight data should be available from the manufacturers of the intended green roof components.

Adequate and standardized safety measures and systems must also be implemented on a case-by-case basis of the green roof type, structural, and recreational components. The safety types to consider are fire safety, falling hazards, slipping hazards, accessibility, entryways, maintenance components, and the prevention of displaced vegetation.

4.3.2.2 Maintenance

A maintenance plan is important to ensure that the green roof components perform their required functions and have an optimal service life. Maintenance plans will address the requirements for the specific growing media and vegetation: such as irrigation, pH, and environmentally dependent factors. They also address the potential need to re-plant, how to handle the green roof components without compromising the system, and to monitor growth.

A typical green roof maintenance plan will require watering the system regularly until the plants properly sink into the substrate (2-3 weeks) (Sempergreen n.d.). Inspections should be carried out at least 5 times a year to remove debris and assess the health of the vegetation. For the plants to prosper, organic fertilizers can be used to stimulate growth without compromising biodiversity (Sempergreen n.d.). A broad set of potential maintenance tasks are presented below. The frequency and intensity of maintenance tasks will vary case by case based on climate and vegetation type.

- Pruning
- Scarfing
- Mowing
- Aerating
- Fertilizing
- Watering
- Removal of unwanted vegetation

Additionally, the technical facilities have to be maintained (FLL 2018). Tasks to consider include:

- Inspecting the drainage and irrigation systems
- Inspecting weather dependent measures such as anti-slip
- Assessing structural elements, balustrades, and planter boxes.

4.3.2.3 Wind Pressure

Roofs are often susceptible to intense winds, increasing with height and geometry of the occupying structure. Uplift caused by wind pressures on a roof often vary over the area of the roof. Generally, pressures are lower in the center and higher around the perimeter and edges (Gibbons et al. n.d.). Green roofs become challenging with wind uplift due to their porosity and low level of rigidity to wind resistance (Gibbons et al. n.d.). However, they also may be used as a tool to protect susceptible areas of the roofing system due to their additional loading. Design guidance exists to work in consultation with the OBC Division B Section 4.1.7.1. wind pressure calculations to account for wind uplift of green roofs. As recommended by FM Global Property Loss Prevention Data Sheets 1-35 Section 2.2.3.2.2., if the green roof is used as the primary wind lift prevention for loose laid waterproofing membranes of the roof, a minimum safety factor of 1.7 must be applied to wind uplift calculations, or an additional 200 mm growing medium depth increase. If the green roof is used as a secondary lift prevention measure to ballast for components above the waterproofing membrane, a minimum safety factor of 0.85 should be applied to wind uplift calculations (FM 1-35 Section 2.2.3.2.4). Finally, if anchored pre-cultivated vegetated mats are used as primary lift prevention and achieve sufficient growth media attachment to resist wind uplift, a safety factor of 1.0 may be used in wind uplift calculations (FM 1-35 Section 2.2.3.2.5).

The FM Global Property Loss Prevention Data Sheets also recommend protective barrier, also known as parapets, as well as vegetation free zones to ensure safety against wind uplift. For roof elevations below 46 m, a parapet height above the growth media should have a minimum 150 mm height and 0.5 m wide vegetation free border zone (FM 1-25 Section 2.2.14.3.2). For roof elevations above 46 m, a parapet height above the growth media should have a minimum 760 mm height and 0.9 m wide vegetation free border zone as higher roofs are susceptible to greater wind uplift (FM 1-25 Section 2.2.14.3.3.).

4.3.3 Recreation

There are many ways in which green roof designs can provide a multi-faceted environment that people can interact with and benefit from. These additional live loads would require an intensive or semi-intensive green roof installation. The additional structural requirements needed to implement publicly accessible design on campus will be added into the standard provided for PPS. Below are examples of ways that green roofs can be used to creatively add more benefits to the green roofs built on the Queen’s University campus.

4.3.3.1 Social Space/Study Center

A simple example of using a green roof design to its full potential is the addition of furniture such as picnic tables or benches. By providing walkways around the gardens and installing seating and tables, students and staff alike would be able to enjoy the green roof in the warmer months of the year. The standard created for PPS will include the addition of benches or picnic tables as a minimum for intensive recreational green roof designs to encourage the Queen’s community to utilize the outdoor space. As would be required for all recreationally focused green roof designs, safety codes and structural requirements would need to be carefully adhered to.

4.3.3.2 Growing Crops

While growing vegetables requires much more maintenance than a regular green roof, growing food on green roofs is not only very feasible, it also would help Queen’s University to become a more sustainable institution. A great example of this creative addition on green roofs in use is the “urban farm” located on Ryerson University campus, shown in Figure 21.

Ryerson's green roof was initially installed to reduce energy costs, and to decrease the urban heat island effects on campus. However, the rooftop has been transformed into a garden which grows over 40 different types of crops on a four-year cycle ("Ryerson Urban Farm" n.d.). This green roof is the beginning of creating a closed circuit of food production and consumption for Ryerson ("Ryerson Urban Farm" n.d.). It has also been used for educational purposes by many faculties at the university ("Ryerson Urban Farm" n.d.). The urban farm has become so successful that the university constructed its second urban farm green roof on the Daphne Cockwell Complex in 2019 (Toye 2019). This is "the first purpose-built rooftop farm" that has been built under the City of Toronto's green roof by-law for food production ("Ryerson Urban Farm" n.d.).

This innovative design option does require more maintenance than a typical intensive design; however, it is an example of expanding the benefits that can be provided through the installation of a less simple green roof design. Considering that Ryerson University experiences a similar climate throughout the year as Queen's University, the implementation of a similar garden system is feasible to implement on future construction projects. However, it must be noted that Ryerson University is located in downtown Toronto, meaning the green roofs are partially protected from harsh weather conditions by large surrounding buildings. This would not be the case at Queen's University, which must be taken into account when considering the constraints of this design option.

Figure 21: Ryerson University urban farm green roof (Ryerson Urban Farm n.d.).

4.3.3.3 Beekeeping on Green Roofs

There has been a noticeable decline in the population of many species of pollinators globally (Potts et al. 2010). Bees are key to the environment, and play a large role in both environmental and economic wellbeing (Cameron and et al. 2011). Green roofs are one way to increase pollination by installing manmade beehives on the green roof designs. Ryerson University also uses its urban farm green roof as a beekeeping facility (Smyth 2019). Three beehives are installed on the original urban farming roof. The bees are used to pollinate the crops on the roof (Smyth 2019). Frequent checks are performed on the hives during the warm months of the year, then honey is extracted from the hives before winter, leaving enough for the bees to “overwinter” (Smyth 2019). The implementation of these hives is beneficial both for the plants on the roof, and the university, as it received around 66 lbs of honey from the hives yearly (Ryerson University Urban Farm n.d.).

Wasps are also a good option for green roofs, as they control pest populations (MacIvor 2016). However, the more aggressive nature of wasps may negatively affect the usage of more intensive designs by students or staff. From GRIT lab research, it has been reported that the best building height to implement beekeeping measures (using “trap nests” that allow for a greater level of hive control than a natural hive implementation) are mid-height to low-height buildings (MacIvor 2016). More specifically, buildings with five stories or less are optimal for beekeeping measures (MacIvor 2016). Therefore, if PPS chooses to implement beekeeping practices on green roofs at Queen’s University, these installations should occur on buildings that are five or less stories in height (MacIvor 2016). As well, beekeeping systems such as trap nests should be kept away from footpaths and other recreational installations on green roof designs, to prevent disturbance.

4.3.4 Slope Stability

Slope stability is crucial to the drainage and load bearing of the green roof. Roof slopes should be withing the slope limits outlined in Table 9.26.3.1 of the Ontario Building Code. Green roofs may occupy these existing roof slopes should they fall within the allowable green roof limits to follow and maintain proper material composition. Roofs supporting green roofs by structural concrete decks shall provide a minimum slope of 2%, all other structural systems must provide a minimum slope of 3% (FM 1-35 Section 2.2.10.1). However, green roofs being occupied at a slope greater than 17% should incorporate anti-shear measures (City of Toronto 2009). Best practice slope measures have been outlined in Table 12**.** These values indicate measures taken under certain circumstantial conditions. If no extraordinary conditions are present, a minimum slope can be taken as 2-3% and maximum of 40% including anti-shear measures (City of Toronto 2009).

Table 12: Best practice slope limits for green roof implementation (City of Toronto 2009).

Practice	Minimum Slope	Maximum Slope
Green roof restricts drying of roof membrane	4%	
Supported by structural concrete	2%	
All other structural support systems	3%	
Not including anti-shear measures		17%
Do not install green roof		>40%

4.4 Insulation

4.4.1 Heat Transfer

The most important characteristics that influence heat transfer in a green roof are plant height, leaf area index (LAI), albedo, and stomatal resistance (Berardi et al. 2014). The LAI is a representation of the plan-form area coverage of the leaves. The albedo is the reflectivity of the surface to the incident solar energy over the vegetation layer (Berardi et al. 2014). Lastly, the stomatal resistance is a biophysical parameter that governs the rate at which the plant transpires moisture.

Many different planting schemes exist for green roofs. Getter and Rowe recently offered a complete review of common plants (Getter and Rowe 2008). A study by Schweitzer and Erell argues that despite the confirmed benefits of green roofs in temperate regions, they are not as effective in hot and dry regions (Schweitzer and Erell 2014).

Green roofs reflect between 20% and 30% of solar radiation and absorb up to 60% of it through photosynthesis (Weng et al. 2004a). Liu and Minor reported the energy effectiveness of green roofs with a heat flow reduction in a range of 70–90% in summer and 10–30% in winter (Liu and Minor 2005). The thermal influence of green roof was enhanced (by 3% in the summer) once the depth of growing medium was increased.

Another impact on the effectiveness of a green roof is related to the thermal resistance of the layer it sits upon. When a green roof is above a well-insulated roof, it will have an impact mainly on the urban environment. Contrarily, if the green roof is above a less-insulated roof, then its energy balance significantly affects the building (Berardi et al. 2014). When analyzing, green roofs can equate to an additional insulation layer. In this regard, importance lies in understanding the different heat fluxes. The main heat transfer phenomena happening in a green roof are namely conductive, convective, radiative heat, and evapotranspiration heat exchanges (Cox 2010).

$$Q_{cond} = K\,\frac{(Ts - Tc)}{L} \quad (2)$$

$$Q_{conv} = h * (T\infty - Ts) \quad (3)$$

$$Q_{evap} = m * h_{fg} * Ts \quad (4)$$

Where, K = total thermal conductivity, Ts = temperature of green roof surface, Tc = temperature of cold surface, L = depth of green roof, h = effective heat transfer coefficient (convection + radiation), T∞ = ambient temperature, m =evaporation flow rate, h_{fg} *= latent heat of evaporation*

More detailed models exist that account for growing layer attributes, plant types and their respective characteristics.

5.0 Innovation in Green Roof Design

The concept of green roof design is not new, as historically green roofs date back to the Babylonian Hanging Gardens of 500 B.C (Kaluvakolanu 2006). However, green roof technology has expanded greatly within the past few decades, and there are many opportunities to expand upon the benefits provided by green roof design. This section describes different ways green roofs at Queen’s University may be able to implement new green roof research discoveries into future campus installations.

5.1 GRIT Lab Soil Research

The GRIT (Green Roof Innovation Testing) lab at the University of Toronto has dedicated itself to testing green roof designs by evaluating four main design parameters: stormwater retention, evaporative cooling, biodiversity, and life cycle cost (Javadi n.d.). This research is conducted through the observation of 33 “test beds” which are compared against each other. Parameters including growing media type, soil depth, vegetation type, and the type of irrigation are altered between the beds, and differences in green roof performance based on these parameters has been reported.

Most notably, it has been discovered through the research performed at the GRIT lab that growing mediums containing higher concentrations of organic matter (OM) were able to retain over three times the water (by volume) than those which contained less OM (Hill et al. 2016).This additional water retention can prevent plants from dying due to drought and can improve the “evaporative cooling” that green roofs provide, consequently improving their impact on the urban heat island effect (Hill et al. 2016). The use of a growing medium with a higher OM content on Queen’s campus would not only create a more effective design in terms of environmental benefits, but it may also allow for a wider variety of plants to be installed without a large increase in maintenance needs.

5.2 Photovoltaic Efficiency

Another topic being researched at the GRIT labs is the use of green roofs combined with photovoltaics (solar panels) (Javadi n.d.). It has been discovered that solar panels become less effective when the ambient temperature surrounding them increases. This is a common occurrence due to the solar radiation that the panels attract. However, the evaporative cooling of green roof designs has been shown to increase the energy efficiency of photovoltaic arrays (Helow et al. 2017).

6.0 Benefit Analysis Considerations

6.1 Environmental Benefits

Green Roofs come with many environmental benefits. For the sake of concision, all the benefits are gathered in Table 13 with a short description and available resources that support the claims.

Table 13: Environmental benefits of green roofs.

Environmental Benefit	**Description**	**Resource**
Energy consumption reduction (Decreasing cooling and heating loads)	With lower insulated systems, Green roofs are highly efficient in reducing the variation of indoor temperature and decreasing the level of building energy consumption both in warm and cold climates	(Lanham n.d.), (Sailor 2008),
Decrease of the urban heat island effect	Various studies discussed the possible influence of green roofs in urban sustainability reducing the UHI effect	(Weng et al. 2004a), (Chen 2013)
Reduction of carbon footprints	Even with potentially higher embodied carbon to maintain green roofs, insulation and mitigation benefits reduce emissions from typical bituminous systems	(Chen 2013), (Weng et al. 2004b)
Mitigation of air pollution	Trees are the most influential plants for reducing air pollution. growing plants on rooftops partially substitutes the vegetation demolished during construction.	(Tojo 2007), (Bianchini and Hewage 2012)
Stormwater management	Coupled with drainage systems, green roofs decrease surface runoff through absorption and provide a higher quality runoff filtered through organic matter	(Chen 2013)

Sound absorption	Referring to the transmission loss (TL) as the extent of sound level decrease through media, an empirical analysis concluded that green roofs increase TL from 5 to 13 dB at low and mid frequencies, and from 2 dB to 8 dB at high frequencies	(Van Renterghem and Botteldooren 2011), (Yang et al. 2012)
Ecological preservation	Various studies have focused on the impact of green roofs towards enhancing the biodiversity and reduction of habitat losses. They also raise the potential for urban agriculture	(Chen 2013), (Dunnett 2008)

6.2 Operational Benefits

Green Roofs come with many operational benefits as well. Some of which have been mentioned in the environmental benefit section such as energy consumption and stormwater management. Green roofs serve an excellent purpose in the optimization of these operations as well. Table *14* tabulates a set of operational benefits associated with the use of green roofs.

Table 14: Operational benefits of green roofs.

Operational Benefit	**Description**	**Resource**
Repurposing stormwater	Excess stormwater could be directed to a water collection- storage facility for later use in irrigation of the green roof or other permissible uses.	(“Stormwater Management - Green Roofs” n.d.)
Alleviate sewer systems	Based on a study of 50 green roofs completed between 2009 and 2016 in Toronto, approximately 10.5 million litres of stormwater was diverted from sewers annually (min cost saving of $100 000 based on history Toronto rain events)	(Lee 2017)
Lowered stormwater management fees	Other than direct monetary inducements, indirect financial incentive policies come in many forms, such as stormwater utility fees, tax abatements, density bonusing	(Carter & Fowler, 2008)
Energy Savings	Based on a study of 50 green roofs completed between 2009 and 2016 in Toronto, an average of 221,055 kwh/year in energy savings due to reduction of air conditioning ($134,462 saved per year based on Toronto Hydro rates - 12.75 cents/kwh.	(Lee 2017)
Alleviate temperature control systems	Cooler roof temperatures produced by a green roof help boost the efficiency of rooftop mechanical equipment by making the air on the roof cooler. When in cooling mode, HVAC equipment must pre–cool outside air to get it to the required temperature. If the air on the roof is	(MacIvor et al. 2016)

	made cooler by a green roof, this process is easier and uses less energy. Therefore, lower air temperatures on the roof improve the efficiency of heat–rejecting rooftop HVAC equipment because it is operating at a lower ambient temperature.	
Reduction of road traffic noise exposure	The previously mentioned attenuation physics from the use of green roofs allow for the improvement of building operations because there is less sound pollution from outdoor sources.	(Van Renterghem and Botteldooren 2011)

6.3 Social Benefits

There are many benefits to providing green spaces for people to visit in a working environment (Kellert et al. 2008). Biophilia is the human need to interact with the natural environment, and there are many proven benefits to interacting with nature, especially when it comes to wellness and productivity (Kellert et al. 2008).

6.3.1 Health and Wellness

Studies have shown that people who live close to nature are less likely to experience health related issues, both physical and social (Kellert et al. 2008). As well, patients of hospitals that incorporate green spaces such as gardens or green roofs tend to require less medication during the healing process than those without such resources (Liveroof n.d.). Most relevant to Queen's University students and staff, it is noted that stress levels tend to decrease when an individual has access to a natural environment (Kellert et al. 2008). Queen's University strives to implement a multitude of mental wellness measures to ensure students do not struggle with stress or more serious mental issues. The implementation of accessible green roofs has the potential to promote mental wellbeing on campus.

6.3.2 Productivity

Natural spaces also have a large impact on workplace performance. It has been observed that workplace settings that include natural light, or outdoor spaces report that employees are more productive and motivated (Kellert et al. 2008). Studies have also shown that cognitive abilities related to concentration as well as memorization can improve when individuals experience regular contact with nature (Kellert et al. 2008). These benefits would have positive effects on both students and staff at Queen's University.

7.0 Auditing Considerations

7.1 Energy Performance of Green Roofs

7.1.1 Cooling Effect (Summer) and Thermal Insulation (Winter)

Green roof work as insulators for indoor environments. By working as a temperature buffer and decreasing surface temperature of roof, studies have shown that green roofs are successful energy savers. A monitoring technique was explored by researchers in Utrecht, Netherlands, to determine the extent and variables of the cooling effect by several green roof compositions on a one-story building (Solcerova et al. 2017). A baseline case using conventional white gravel was conducted for comparison. For the five-year monitoring period, a meteorological station was installed including air temperature sensors, solar radiation, wind speed, and rainfall (Solcerova et al. 2017). Two temperature sensors were placed, one above the ground in the center of each green roof and one 2 cm below the substrate layer. The study concluded that the sedum covered green roofs did have a heat regulating effect (Solcerova et al. 2017). The green roofs showed a slight warming effect in the daytime with a slightly weaker cool down of the immediate environment at night. The research concluded that water availability in substrate plays an important role in the cooling abilities of the roof system (Solcerova et al. 2017). It was also concluded that greater cooling effect can be reached by plant choice with higher moisture retention abilities (Solcerova et al. 2017).

To assess the performance of new green roof implementation, analysis of energy modelling must occur as per Queen’s University Building Code Section 1.8.4. To gain closer accuracy of performance, energy must be monitored for a period before green roof implementation on the different energy types used in the building system. Upon green roof implementation these consumptions must be monitored and recorded to compare to the building’s initial consumption. It is also important to consider the energy distribution among the building when performing the energy analysis.

Another performance analysis option for new and existing buildings is through the use of 3D energy modelling such as eQUEST, DesignBuilder, TRACE 700 and many more. If sufficient data is collected and building composition parameters are known (or sufficient assumptions are made), a 3D energy model can be produced of the system. Buildings may be designed with green roofs in mind using such software. For existing buildings, matching energy consumption reports to an energy model with little margin of error can be used to predict the energy performance of the building under different loading (i.e., green roofs).

7.1.2 Reducing Heat Island Effect Performance

Green roof performance is largely dependent on the vegetation and substrate layer of the system. Researchers have found that extensive green roof combinations that offer the highest performance against surface temperatures in the summer are those that have greater plant heights, leaf area index values, and leaf reflectivity (Cascone et al. 2019). Green roof vegetation shades buildings and increases evapotranspiration, thus shifting a roof's energy balance. Factors of energy balance include latent and sensible heat exchange, short and longwave radiation, heat conduction, and thermal storage (US EPA 2018).

To assess green roof composition performance against the heat island effect, more extensive building energy simulation programs such as EnergyPlus can be used. EnergyPlus models energy consumption for heating, cooling ventilation and lighting and has many modelling capabilities including heat balance based solutions, combined heat and mass transfer, standard summary and detailed output reports, and many more ("EnergyPlus" n.d.).

Another option is to use the Green Roof Energy Calculator developed by the University of Toronto and Portland State University. This easy-to-use calculator provides simple estimates to compare annual energy performance with a green roof installed compared to a generic roof system. Thus, quick estimates can be made based on the resulting effects of the green roof on the building's energy use (US EPA 2018).

7.2 Stormwater Management Performance

In a study done by the National Research Council of Canada (NRC), a performance analysis was undertaken to provide technical data on green roof performance in the City of Toronto. Two extensive green roofs were implemented on a community centre, containing 75-100 mm deep lightweight growing medium and a variety of vegetation (Liu and Minor 2005). Stormwater runoff was monitored by diverting drainage pipes under the roof deck to an mechanical room in which magnetic induction instrument flow meters (MAGmeters) were installed (Liu and Minor 2005). The flow volumes for runoff flow rate of green roof occupancy as compared to a control roof saw an annual reduction of 57% (Liu and Minor 2005).

Green roofs are often used as LID stormwater management techniques. Instead of water flowing off roofs due to low imperviousness, the water is absorbed by soil and plants and released in the form of evapotranspiration. The Green Roof Energy calculator can also be used in preliminary design to assess the retention of stormwater in the green roof as compared to a conventional roof during wet weather (US EPA 2018). More complex software such as SWMM 5.0 can be used to model storm water management tools including green roofs by indicating both storm and study location parameters. These programs can provide insight into the amount of runoff being produced at the roof location for both a conventional roof with low imperviousness and a green roof with higher imperviousness.

7.3 Carbon Sequestration

Queen's university has created a Climate Action Plan (CAP) in coordination with the pledge signed by Principal Woolf to commit Queen's in reducing greenhouse gas (GHG) emissions (Queen's University 2016). Green roofs not only aid in improving energy performance subsequently reducing Queen's energy needs, but they also have the potential to sequester carbon itself. In a study done by Dalhousie University in Halifax, Nova Scotia, the viability of carbon sequestration by extensive green roofs was analyzed. The goal methodology of the investigation involved collecting building surface area (m^2) and the carbon sequestration potential of plants (kg CO_2/m_2) to identify the total amount of carbon (kg CO_2)(Shafique et al. 2020). Data regarding surface area of available green space were found using the geographic information system research tool ArcGIS having given data on building carbon footprints (Shafique et al. 2020). Calculations were performed for different scenarios regarding a best-case scenario of 100% usable roof coverage and a worst-case scenario of 50% usable roof coverage. Literature identified two possible values for the specific sequestration rate of sedum as used as the vegetation material. The results of these carbon sequestering calculations can be seen in Table *15*.

Table 15: Carbon sequestration scenario calculations (Shafique et al. 2020).

Specific Sequestration Rate (kg/m^2)	Roof Coverage	Total Roof Surface Area (m^2)	Total Carbon (C) Sequestered (kg C)	Total Carbon Dioxide (CO_2) Sequestered (kg CO_2)
5.87	100%	63,164	370,773	13,585,348.56
	50%	31,582	185,386	679,265.05
0.375	100%	63,164	23,687	86,790.54
	50%	31,582	11,843	43,393.44

The median of these results amounts to approximately 6,814,371 kg of carbon dioxide sequestered (Shafique et al. 2020). Based on the estimated 97,393,000 tons of greenhouse gases emitted by Dalhousie University in the 2013-1014 academic school year, approximately 0.00008% of carbon dioxide can be sequestered by green roofs (Shafique et al. 2020). This amount is variable to green roof properties and variability of sequestration rates in literature. While this sequestration amount is small, it does aid in reducing global warming impact by universities.

8.0 Cost Analysis and Funding Considerations

In a policy analysis done by Queen's University Master's student Joanne Lee on the feasibility of green roof implementation in Toronto, cost was identified as a main barrier (Lee 2017). Stakeholders within the investigation also brought up concerns of the implications due to increased loadings on existing buildings having an effect on capital cost, mainly due to retrofit projects (Lee 2017). A cost benefit analysis is necessary to understand the economic benefits of green roof implementation pertaining to energy savings (Lee 2017). Energy savings are very sensitive and depend on individualized factors, reliant on the green roof composition and the residing structure. In a 2006 study done on the feasibility for green roof application on Queen's University Campus, reasonable estimates of a range for capital investments and savings were made using some basic assumptions (Dinsdale et al. 2006). The authors based their assumptions on a predicted similar Soprema green roof in Toronto, Ontario. The team found a minimum cost of \$160/m^2 with a negligible cost of maintenance in comparison to the capital investment (Dinsdale et al. 2006). However, these predictions assume the likelihood of an extensive green roof being implemented on the Queen's Campus. Since the team will be researching into further options for different types of green roof implementation, it is likely the capital cost could be higher with regard to higher material density and non-negligible maintenance costs.

8.1 Cost Comparison – Green Roofs (extensive and intensive) versus Conventional Roofs

Baltimore, Maryland–based Green Roof Technology, a company that specializes in the specification and design of green roofs, notes that increases in costs can depend on growing media depth, desired water storage, and plant material (Green Roof Technology 2020). However, they point out that green roofs can be considerably less expensive, up to 50% cheaper, when they cover more than 10,000 square feet because of economies of scale. Compared to a black roof, a 3-inch to 6-inch green roof covering 10,000 feet has a net present value of \$2.70 per square foot per year, payback of 6.2 years and an internal rate of return of 5.2% nationally (GSA 2018).

The University of Michigan, for instance, compared the expected costs of conventional roofs with the cost of a 21,000-square-foot green roof and all of its benefits, such as stormwater management and improved public health from the absorption of nitrogen oxides National Park Service 2021). The university found that the green roof would cost $464,000 to install versus $335,000 for a conventional roof in 2006 dollars. Over its lifetime, though, the green roof would save about $200,000. Nearly two-thirds of the savings come from reduced energy needs for the building below it.

Factors like increased loading, location, quality of the roofing membrane, roof accessibility, structural load capacity, growing media depth, and ease of material conveyance can also play a role in the overall cost of green roofs (Lee 2017).

A study by General Services Administration evaluated and summarized perhaps the most interesting numbers (GSA 2018)

- The installed cost premium for multi-course extensive green roofs ranges from $10.30 to $12.50 per square foot more and keeps increasing for intensive projects.
- Annual maintenance for a green roof is typically higher than for a black roof, by $0.21 to $0.31 per square foot. Over their lifetime, high savings are what make up for the premium.
- Extensive roofs can cost about $10 to $50 per square foot, while intensive roofs can cost from $20 to $200+ per square foot.

8.2 Incentive programs

Direct financial incentive policies financially support developers and property owners with short and long-term subsidies or grants to address budgetary barriers associated with green roof implementation. In this regard, the Eco-Roof Incentive Program is primarily intended to motivate developers and property owners to voluntarily install their own green roofs, particularly retrofitting roofs ("Eco-Roof Incentive Program" 2017). The Program provides grants of $100 per square meter for eligible green roof projects that are not subject to the requirements of the Bylaw, including: 1) Existing residential, industrial, commercial, and institutional buildings; 2) All new buildings with a gross floor area of less than of 2,000 square meters; 3) All new Toronto Public and Separate School Board Buildings of any size; and 4) All new construction projects by organizations incorporated as not-for profit corporations (Lee 2017).

Incremental costs for an extensive green roof built in Toronto is approximately $182 per square meter as of October 2016, while the average cost of green roofs was 371 per square meter based on six case studies of retrofit projects developed in Toronto.

Another amendment to the Program is the provision of Structural Assessment Grant (SAG) to address a significant barrier associated with structural assessment costs for retrofit projects. Green roof costs are generally higher for existing buildings than new developments due to structural modifications. “As one of the first steps in determining whether to install a green roof”, a structural analysis is necessary to determine an existing building’s structural load-bearing capacity and check for any damage associated with the additional load of green roof (“Eco-Roof Incentive Program” 2017). The completion of structural assessment by a professional engineer typically costs up to $3,000. In response to this, the RiverSmart Rooftops Rebate Program in Washington, D.C., which offers a maximum grant of $250 (approximately $330 CAD) for a structural analysis, motivated the Eco-Roof Incentive Program to establish the SAG (Department of Energy, 2016). As a result, the additional funding up to $1,000 for structural assessments, enforced since 2016, is likely to offset approximately a third of a typical structural assessment cost.

8.3 Indirect Financial Incentives

Other than direct monetary inducements, indirect financial incentive policies come in many forms, such as stormwater utility fees, tax abatements, density bonusing (Carter & Fowler, 2008). Many U.S. municipalities have various types of incentives to offer financial rewards to developers and property owners in requital of installing and maintaining their green roofs, while none of these policies are included in Toronto’s green roof policy (Magill et al. 2011). Developers and property owners in Toronto shoulder the entire costs of their green roofs in compliance with the Bylaw without any compensation. In contrast, the Clean River Rewards Stormwater Discount Program in Portland, Oregon offered up to a 100% discount on the on-site stormwater management charges to property owners, while property owners in the City of New York received a one-year property tax abatement of $4.50 (USD) per square foot (“Stormwater Discount Program | The City of Portland, Oregon” n.d.). The need for the indirect incentives for green roof projects, especially stormwater fee discount based on decreases in impervious surfaces, in Toronto was reflected by (Saxe, 2015). She mentioned the cases of three municipalities in Ontario which are Kitchener, Waterloo, and Mississauga. Although these municipalities do not have any regulations associated with green roofs, they offer financial incentives to property owners in compensation of stormwater management benefits. In Kitchener and Waterloo, the 30 Stormwater Utility and Credit Program provides property owners with stormwater credit up to 45% of stormwater utility fee portion for their properties in compensation of reducing the amount of stormwater runoff. Additionally, the City of Mississauga adopted its stormwater charge based on impervious surfaces for residential, multi-residential, and non-residential properties in effect since January 2016. A Floor Area Ratio (FAR) bonus in the building code of Portland, Oregon encourages developers to earn a bonus ranging from 1 to 3 square feet of additional floor area based on the amount of their green roof coverage, while Chicago, Illinois offers a FAR bonus for developments including a green roof that covers 50% or 2,000ft2 of the roof area (Carter & Fowler, 2008).

9.0 Risks

9.1 Disclaimer

It is important to note that Greengenuity is a team of students working for PPS on this project. The members of Greengenuity are not yet professional engineers, and therefore, are unable to sign off on a final product confirming that all information is correct. PPS may find the final standard document useful as a guide, however, PPS must accept the risk that not all information in the final deliverable may be accurate. Areas within the standard for constructing green roofs may not include all necessary information. PPS must adhere to local and provincial building practices and legislature when installing green roofs on Queen's University campus. Should PPS desire to implement Greengenuity's standard document into the Queen's University Building Code, it is strongly recommended that the document is reviewed and signed by a professional engineer.

9.2 Health and Safety Risks

As mentioned in other sections and covered in the standard, there are risks to human health associated with the construction and use of green roofs.

In terms of construction, it is important that construction workers adhere to company policies on health and safety, as well as the health and safety guidelines provided by the Ontario Ministry of Labour, Training and Skills Development (Government of Ontario Ministry of Labour, Training and Skills Development 2020). All employees accessing the roofs during construction should be trained in working at heights, and at least one person who is certified in first aid should be present.

In terms of safety risks once the green roofs have been constructed, there is the risk of injury due to wet surfaces on the green roof should it be accessible for maintenance staff, students and staff, or both. To mitigate this risk, the green roofs should be closed to the public in the winter months when they are the most likely to be wet or iced over. Signs warning of wet surfaces and the risk of injury should be present either on the green roof or at the entrance to the green roof. Furthermore, since the design is built on the top of the building, proper safe railings must be installed on the green roof to prevent potential fall hazards. Only approved workers with safety equipment are allowed to access those buildings that required repair.

10.0 Final Steps

Thus far, significant progress has been made to arrive at a desirable solution for the task at hand: designing a green roof construction standard to be implemented to the Queen's Building Standards.

This section will briefly outline the major tasks that still need to be undertaken before project completion in April of 2021. Greengenuity's goals and deliverable are also laid out in the GANTT charts seen in Figure 24 and Figure 25, and the Work Breakdown Structure seen in Figure 28 of Appendices. The timelines for the fall and winter semesters can be seen in Figure 26 and Figure 27 respectively.

10.1 Finalizing the Standard

Greengenuity will continue to consult the client about the standard that has been drafted. The last moments of the attributed timeline for this project will be dedicated to gaining feedback and reiterating drafts of the standard to obtain a final product.

10.2 Present the Research and the Standard

The team has been asked to present the work undertaken throughout this project. A presentation will be given for the academic team and student body involved in CIVL 460. Another presentation is set, in order to provide the department of PPS insight into the final product. Both these events will stimulate great feedback.

10.3 Looking Forward

As the members of Greengenuity look to complete the coursework for CIVL 460 and go on to graduate, the future of the green roof design standard is attributed to the client. Possible next steps include refining the details, implementing the standard into the Queen's Building Standard, and setting the design protocol into motion with theoretical and practical applications.

11.0 Conclusions

This report summarizes the process undergone to create a standard document for Queen's University Physical Plant Services in regard to the implementation and maintenance of green roof designs on new and existing buildings on Queen's campus.

Within the report, the engineering design process that was undertaken throughout the project to determine the requirements that would be include in the final standard was specified. Technical considerations are provided for the most important aspects of green roof design, such as types of vegetation, drainage, insulation, and structural considerations for dead and live loads. The possibility of using the green roofs as recreational space is also discussed.

In addition to technical elements of the report that were implemented into the final standard, Greengenuity also included benefit analyses and cost analyses, as well as an auditing process that could be implemented by the client should they see fit. These elements were included as additional information that the client may use in tandem with the requirements laid out in the standard to develop a complete understanding of how a green roof system can benefit the Queen's University campuses.

Looking forward, Greengenuity will continue to meet with the client to edit and submit the final green roof standard document by the deadline of April 23rd, 2021. As well, the team looks forward to presenting the information to the construction team at PPS virtually later in April.

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Appendices

Appendix A: Vegetation Recommendations

The following table, Table 16, indicates the recommended and non-recommended types of vegetation for green roofs in the Northern Climate.

Table 16: North American green roof plant recommendation for various green roof conditions (Vinson & Zheng, 2013).

	Recommended Plant Species	Non-Recommended Plant Species
Site 1	Allium schoenoprasum (Wild Chives) Aster ericoides (Heath Aster) Aster laevis (Smooth Aster) Aster ptarmicoides (Upland White Aster) Aster sp. (other Aster species) Campanula carpatica (Carpathian Bellflower) Echinacea purpurea (Purple Coneflower) Festuca spp. (Fescue species) Fragaria sp. (Strawberry species) Hypericum perforatum (St. John's-wort) Lupinus perennis (Lupine) Monarda sp. (Bergamot species) Rosa sp. (Rose species) Rudbeckia hirta (Black-Eyed Susan) Solidago sp. (Goldenrod species)	Medicago lupulina (Black medick) Trifolium sp. (Clover species) Vicia cracca (Tufted vetch)
Site 2	Achillea millefolium 'Terra Cotta' (Terra Cotta Yarrow) Achillea tomentosum (Wooly Yarrow) Allium cernuum (Nodding Onion) Allium schoenoprasum 'Forescate' (Chives) Allium senescens var. glaucum (Ornamental Onion / Curly Onion) Amsonia hubrichtii (Arkansas Blue Star) – perform better in partial shade than in full sun Calamagrostis 'Karl Foerster' (Karl Foerster Feather Reed Grass) Campanula rotundifolia (Bluebell Bellflower / Harebell) Echinacea pallida (Pale Purple Coneflower) - perform better in partial shade than in full sun Echinacea paradoxa (Bush's Purple Coneflower / Yellow Coneflower) - perform better in partial shade than in full sun Echinacea purpurea (Eastern Purple Coneflower) - perform better in partial shade than in full sun	Aster laevis (Smooth Aster) Deschampsia flexuosa (Wavy Hair Grass) Vicia cracca (Tufted Vetch)

	Euphorbia myrsinites (Donkey Tail Spurge) Gaillardia 'Oranges and Lemons' (Oranges and Lemons Blanket Flower) Geum triflorum (Prairie Smoke) Helictotrichon sempervirens (Blue Oat Grass) Liatris spicata 'Kobold' (Blazing Star / Gay Feather) Monarda fistulosa (Bergamot) Nepeta xfaassenii 'Walkers Low' (Walker's Low Catmint) Panicum virgatum 'Heavy Metal' (Heavy Metal Switch Grass) - perform better in partial shade than in full sun Penstemon digitalis (Foxglove Beardtongue) Perovskia atriplicifolia 'Little Spire' (Little Spire Russian Sage) Rudbeckia fulgida fulgida (Orange Coneflower) Scabiosa columbaria (Pincushion Flower) Schizachyrium scoparium (Little Bluestem) Sesleria autumnalis (Autumn Moor Grass) Solidago rugosa 'Fireworks' (Fireworks Goldenrod) Solidago sp. (Other Goldenrod species) Sporobolus heterolepis (Prairie Dropseed) Stachys byzantina (Lamb's-ears)	
Site 3	*Wetland green roof garden:* Aster spp. (Aster species) Carex spp. (Sedge species) Eupatorium maculatum (Joe-Pye Weed) Rosa acicularis (Prickly Wild Rose) Verbena stricta (Hoary Vervain) *Butterfly/medicinal green roof garden:* Allium cernuum (Nodding Onion) Aster sp. (Aster species) Baptisia australis (False Indigo) Campanula rotundifolia (Harebell) Coreopsis lanceolata (Sand Coreopsis) Fragaria virginiana (Wild Strawberry) Monarda fistulosa (Bergamot) Oenothera biennis (Evening Primrose) Schizachyrium scoparium (Little Bluestem) Solidago sp. (Goldenrod species)	Wetland and butterfly/medicinal green roof gardens: Trifolium sp. (Clover species)

	Sporobolus heterolepis (Prairie Dropseed) Verbena stricta (Hoary Vervain)	
Site 4	Achillea millefolium (Common Yarrow) Allium cernuum (Nodding Onion) Allium schoenoprasum (Wild Chives) Allium tuberosum (Garlic Chives) Bouteloua curtipendula (Side-Oats Grama) Coreopsis lanceolata (Sand Coreopsis) Gaillardia sp. (Blanket Flower) Liatris squarrosa (Ontario Blazing Star / Scaly Blazing Star) Nepeta xfaassenii 'Walker's Low' (Walker's Low Catmint) Penstemon hirsutus (Hairy Beardtongue) Phlox subulata (Creeping Phlox) Rudbeckia sp. (R. hirta or R. triloba), (Black-Eyed Susan or Brown-Eyed Susan) Schizachyrium scoparium (Little Bluestem) Solidago ptarmicoides (Upland White Aster / Upland White Goldenrod)	
Site 5	Bouteloua curtipendula (Side-Oats Grama) Coreopsis sp. (Coreopsis species) Erigeron annuus (Daisy Fleabane) Potentilla simplex (Common Cinquefoil) Rudbeckia hirta (Black-Eyed Susan)	

Appendix B: Average Days of Rainfall and Snowfall per Month

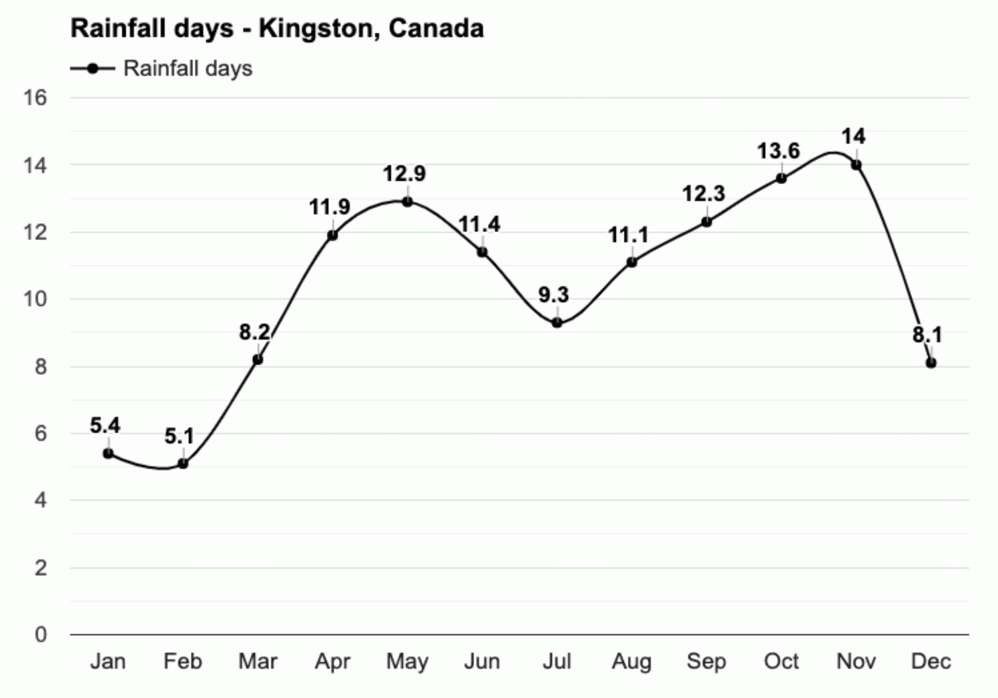


Figure 22: Average rainfall days per month in Kingston (Weather Atlas 2020).

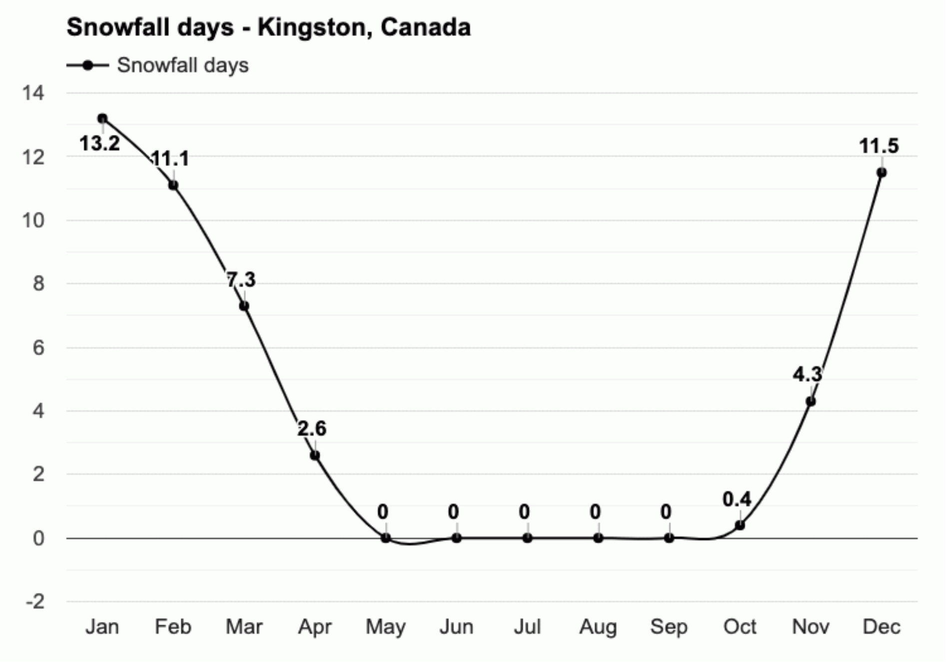
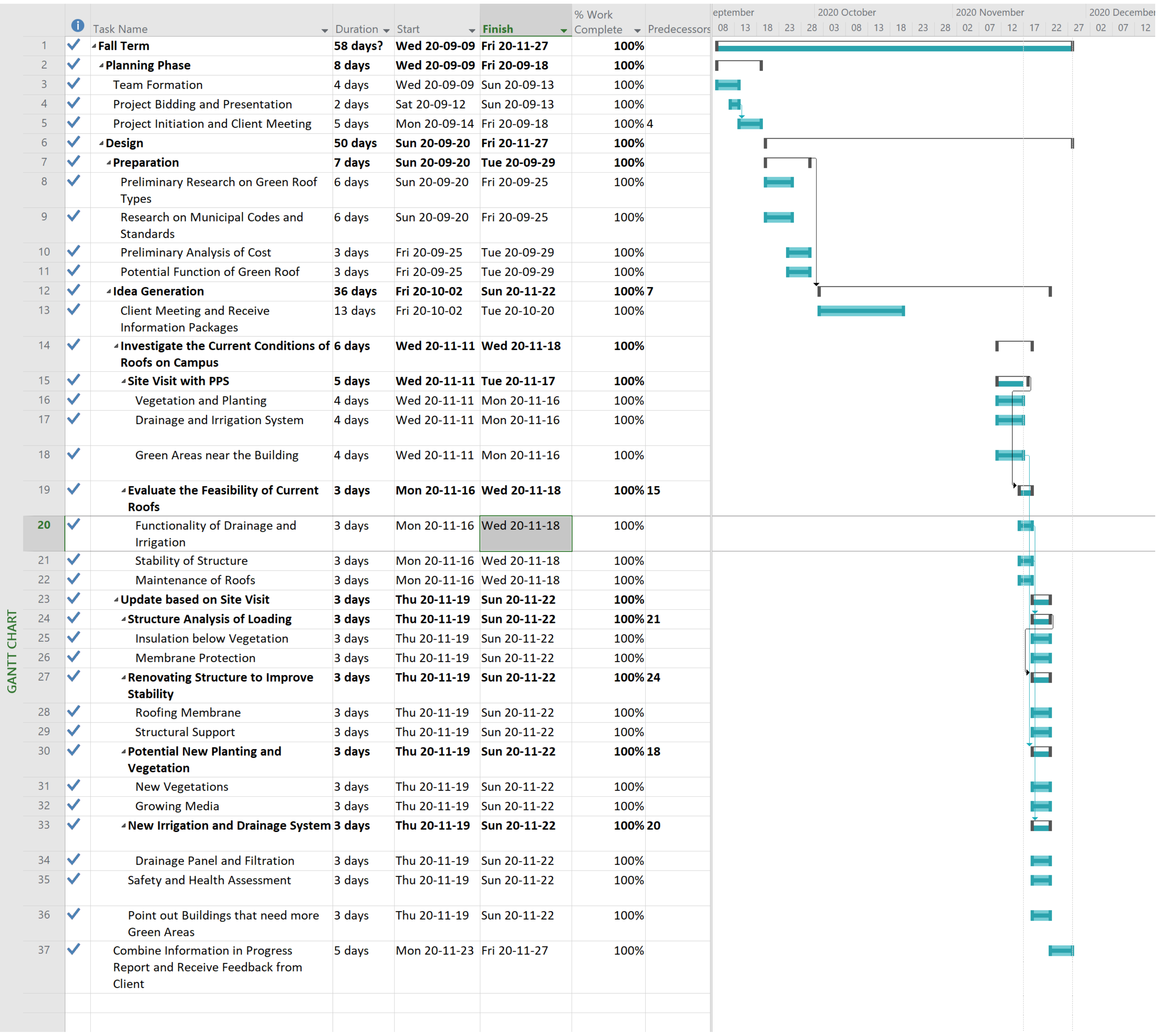


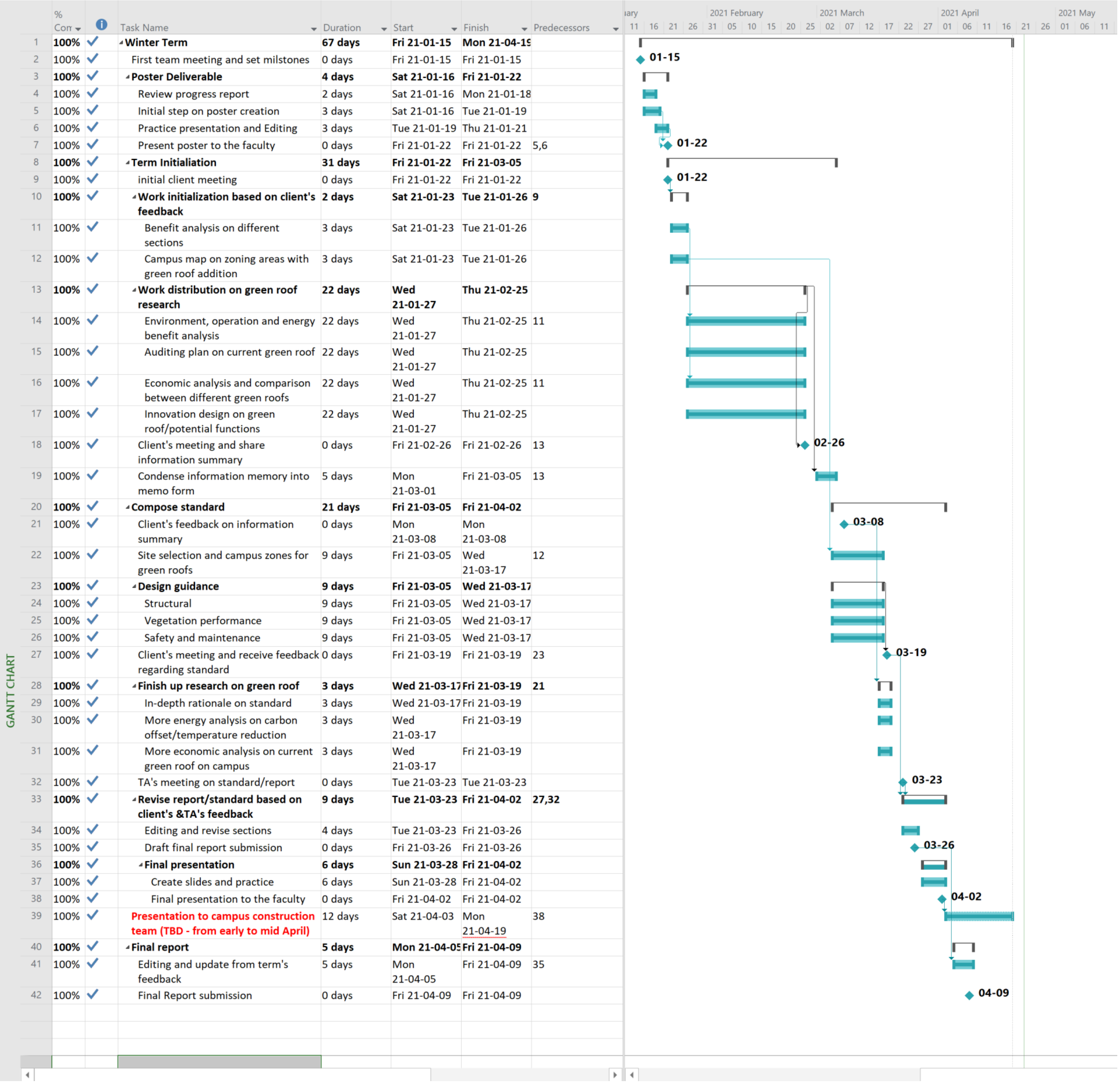
Figure 23: Average snowfall days per month in Kingston (Weather Atlas 2020).

Appendix C: Timeline, Gantt Chart and WBS Chart



		Task Name	Duration	Start	Finish	% Work Complete	Predecessors
1	✓	**Fall Term**	**58 days?**	**Wed 20-09-09**	**Fri 20-11-27**	**100%**	
2	✓	**Planning Phase**	**8 days**	**Wed 20-09-09**	**Fri 20-09-18**	**100%**	
3	✓	Team Formation	4 days	Wed 20-09-09	Sun 20-09-13	100%	
4	✓	Project Bidding and Presentation	2 days	Sat 20-09-12	Sun 20-09-13	100%	
5	✓	Project Initiation and Client Meeting	5 days	Mon 20-09-14	Fri 20-09-18	100%	4
6	✓	**Design**	**50 days**	**Sun 20-09-20**	**Fri 20-11-27**	**100%**	
7	✓	**Preparation**	**7 days**	**Sun 20-09-20**	**Tue 20-09-29**	**100%**	
8	✓	Preliminary Research on Green Roof Types	6 days	Sun 20-09-20	Fri 20-09-25	100%	
9	✓	Research on Municipal Codes and Standards	6 days	Sun 20-09-20	Fri 20-09-25	100%	
10	✓	Preliminary Analysis of Cost	3 days	Fri 20-09-25	Tue 20-09-29	100%	
11	✓	Potential Function of Green Roof	3 days	Fri 20-09-25	Tue 20-09-29	100%	
12	✓	**Idea Generation**	**36 days**	**Fri 20-10-02**	**Sun 20-11-22**	**100%**	**7**
13	✓	Client Meeting and Receive Information Packages	13 days	Fri 20-10-02	Tue 20-10-20	100%	
14	✓	**Investigate the Current Conditions of Roofs on Campus**	**6 days**	**Wed 20-11-11**	**Wed 20-11-18**	**100%**	
15	✓	**Site Visit with PPS**	**5 days**	**Wed 20-11-11**	**Tue 20-11-17**	**100%**	
16	✓	Vegetation and Planting	4 days	Wed 20-11-11	Mon 20-11-16	100%	
17	✓	Drainage and Irrigation System	4 days	Wed 20-11-11	Mon 20-11-16	100%	
18	✓	Green Areas near the Building	4 days	Wed 20-11-11	Mon 20-11-16	100%	
19	✓	**Evaluate the Feasibility of Current Roofs**	**3 days**	**Mon 20-11-16**	**Wed 20-11-18**	**100%**	**15**
20	✓	Functionality of Drainage and Irrigation	3 days	Mon 20-11-16	Wed 20-11-18	100%	
21	✓	Stability of Structure	3 days	Mon 20-11-16	Wed 20-11-18	100%	
22	✓	Maintenance of Roofs	3 days	Mon 20-11-16	Wed 20-11-18	100%	
23	✓	**Update based on Site Visit**	**3 days**	**Thu 20-11-19**	**Sun 20-11-22**	**100%**	
24	✓	**Structure Analysis of Loading**	**3 days**	**Thu 20-11-19**	**Sun 20-11-22**	**100%**	**21**
25	✓	Insulation below Vegetation	3 days	Thu 20-11-19	Sun 20-11-22	100%	
26	✓	Membrane Protection	3 days	Thu 20-11-19	Sun 20-11-22	100%	
27	✓	**Renovating Structure to Improve Stability**	**3 days**	**Thu 20-11-19**	**Sun 20-11-22**	**100%**	**24**
28	✓	Roofing Membrane	3 days	Thu 20-11-19	Sun 20-11-22	100%	
29	✓	Structural Support	3 days	Thu 20-11-19	Sun 20-11-22	100%	
30	✓	**Potential New Planting and Vegetation**	**3 days**	**Thu 20-11-19**	**Sun 20-11-22**	**100%**	**18**
31	✓	New Vegetations	3 days	Thu 20-11-19	Sun 20-11-22	100%	
32	✓	Growing Media	3 days	Thu 20-11-19	Sun 20-11-22	100%	
33	✓	**New Irrigation and Drainage System**	**3 days**	**Thu 20-11-19**	**Sun 20-11-22**	**100%**	**20**
34	✓	Drainage Panel and Filtration	3 days	Thu 20-11-19	Sun 20-11-22	100%	
35	✓	Safety and Health Assessment	3 days	Thu 20-11-19	Sun 20-11-22	100%	
36	✓	Point out Buildings that need more Green Areas	3 days	Thu 20-11-19	Sun 20-11-22	100%	
37	✓	Combine Information in Progress Report and Receive Feedback from Client	5 days	Mon 20-11-23	Fri 20-11-27	100%	

Figure 24: Fall Gantt Chart.



	% Con	ℹ	Task Name	Duration	Start	Finish	Predecessors
1	**100%**	✓	**Winter Term**	**67 days**	**Fri 21-01-15**	**Mon 21-04-19**	
2	100%	✓	First team meeting and set milstones	0 days	Fri 21-01-15	Fri 21-01-15	
3	**100%**	✓	**Poster Deliverable**	**4 days**	**Sat 21-01-16**	**Fri 21-01-22**	
4	100%	✓	Review progress report	2 days	Sat 21-01-16	Mon 21-01-18	
5	100%	✓	Initial step on poster creation	3 days	Sat 21-01-16	Tue 21-01-19	
6	100%	✓	Practice presentation and Editing	3 days	Tue 21-01-19	Thu 21-01-21	
7	100%	✓	Present poster to the faculty	0 days	Fri 21-01-22	Fri 21-01-22	5,6
8	**100%**	✓	**Term Initialiation**	**31 days**	**Fri 21-01-22**	**Fri 21-03-05**	
9	100%	✓	initial client meeting	0 days	Fri 21-01-22	Fri 21-01-22	
10	**100%**	✓	**Work initialization based on client's feedback**	**2 days**	**Sat 21-01-23**	**Tue 21-01-26**	**9**
11	100%	✓	Benefit analysis on different sections	3 days	Sat 21-01-23	Tue 21-01-26	
12	100%	✓	Campus map on zoning areas with green roof addition	3 days	Sat 21-01-23	Tue 21-01-26	
13	**100%**	✓	**Work distribution on green roof research**	**22 days**	**Wed 21-01-27**	**Thu 21-02-25**	
14	100%	✓	Environment, operation and energy benefit analysis	22 days	Wed 21-01-27	Thu 21-02-25	11
15	100%	✓	Auditing plan on current green roof	22 days	Wed 21-01-27	Thu 21-02-25	
16	100%	✓	Economic analysis and comparison between different green roofs	22 days	Wed 21-01-27	Thu 21-02-25	11
17	100%	✓	Innovation design on green roof/potential functions	22 days	Wed 21-01-27	Thu 21-02-25	
18	100%	✓	Client's meeting and share information summary	0 days	Fri 21-02-26	Fri 21-02-26	13
19	100%	✓	Condense information memory into memo form	5 days	Mon 21-03-01	Fri 21-03-05	13
20	**100%**	✓	**Compose standard**	**21 days**	**Fri 21-03-05**	**Fri 21-04-02**	
21	100%	✓	Client's feedback on information summary	0 days	Mon 21-03-08	Mon 21-03-08	
22	100%	✓	Site selection and campus zones for green roofs	9 days	Fri 21-03-05	Wed 21-03-17	12
23	**100%**	✓	**Design guidance**	**9 days**	**Fri 21-03-05**	**Wed 21-03-17**	
24	100%	✓	Structural	9 days	Fri 21-03-05	Wed 21-03-17	
25	100%	✓	Vegetation performance	9 days	Fri 21-03-05	Wed 21-03-17	
26	100%	✓	Safety and maintenance	9 days	Fri 21-03-05	Wed 21-03-17	
27	100%	✓	Client's meeting and receive feedback regarding standard	0 days	Fri 21-03-19	Fri 21-03-19	23
28	**100%**	✓	**Finish up research on green roof**	**3 days**	**Wed 21-03-17**	**Fri 21-03-19**	**21**
29	100%	✓	In-depth rationale on standard	3 days	Wed 21-03-17	Fri 21-03-19	
30	100%	✓	More energy analysis on carbon offset/temperature reduction	3 days	Wed 21-03-17	Fri 21-03-19	
31	100%	✓	More economic analysis on current green roof on campus	3 days	Wed 21-03-17	Fri 21-03-19	
32	100%	✓	TA's meeting on standard/report	0 days	Tue 21-03-23	Tue 21-03-23	
33	**100%**	✓	**Revise report/standard based on client's &TA's feedback**	**9 days**	**Tue 21-03-23**	**Fri 21-04-02**	**27,32**
34	100%	✓	Editing and revise sections	4 days	Tue 21-03-23	Fri 21-03-26	
35	100%	✓	Draft final report submission	0 days	Fri 21-03-26	Fri 21-03-26	
36	**100%**	✓	**Final presentation**	**6 days**	**Sun 21-03-28**	**Fri 21-04-02**	
37	100%	✓	Create slides and practice	6 days	Sun 21-03-28	Fri 21-04-02	
38	100%	✓	Final presentation to the faculty	0 days	Fri 21-04-02	Fri 21-04-02	
39	100%	✓	**Presentation to campus construction team (TBD - from early to mid April)**	12 days	Sat 21-04-03	Mon 21-04-19	38
40	**100%**	✓	**Final report**	**5 days**	**Mon 21-04-05**	**Fri 21-04-09**	
41	100%	✓	Editing and update from term's feedback	5 days	Mon 21-04-05	Fri 21-04-09	35
42	100%	✓	Final Report submission	0 days	Fri 21-04-09	Fri 21-04-09	

Figure 25: Winter Gantt Chart.

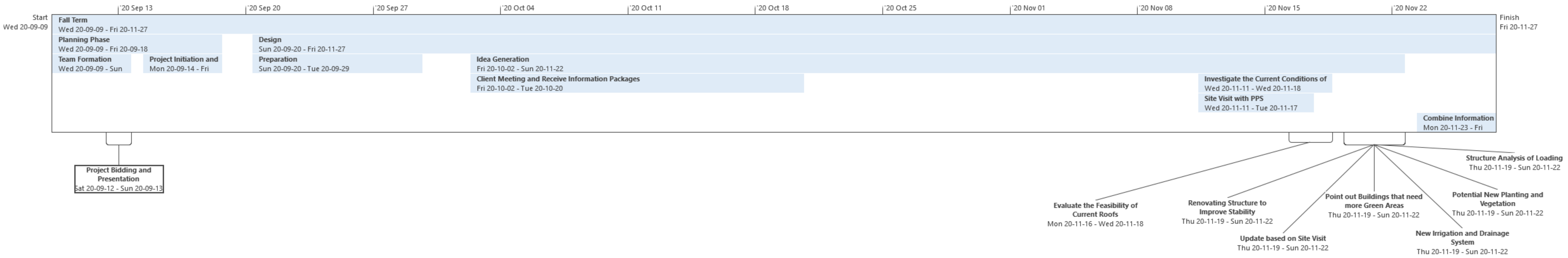


Figure 26: Fall semester timeline.

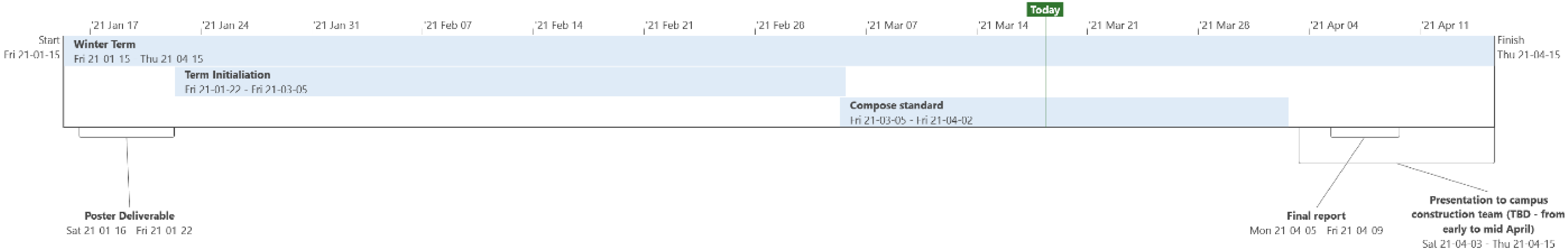


Figure 27: Winter semester timeline.

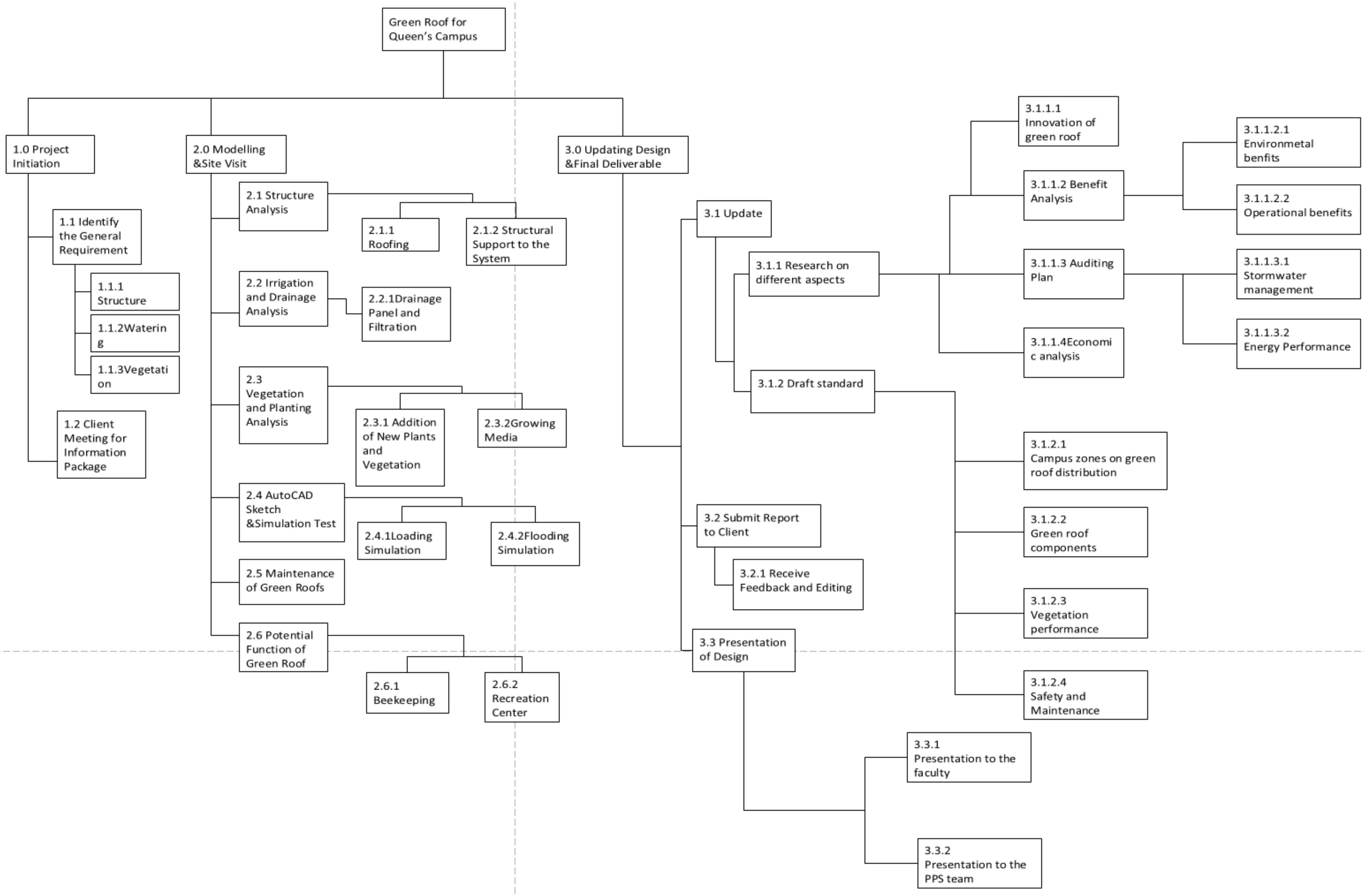


Figure 28: Work breakdown structure.

Appendix D: Meeting Logbook (Date to 2021/04/23)

Introductory Client Meeting 2020/09/18 (F)

Scope of the project

Expectation from the client (requirement of the project)

The main goal of this project for the client is to create a new section for the current Queen's University building standard focused on the implementation of green roofs on new construction projects. Our team will conduct research on different types of green roofs, and applicable standards and codes, to create the most optimal building standard for future buildings on Queen's campus. Cost will also be considered but will not be the focus of the report. The top priorities for the final design will be that the roofs are easy to maintain and have a long lifespan.

Resources

The client will be able to provide many helpful resources to assist in the initial researching process. This includes the Queen's Building Standards, and any information on existing buildings that may be able to have green roofs installed as a renovation.

https://www.queensu.ca/pps/sites/webpublish.queensu.ca.ppswww/files/files/Queen's%20Building%20Standards.pdf

Alongside current Queen's building standards, our team will research building standards that already include green roof designs. These standards may be from other universities, or cities such as Toronto that have already added these standards to their building codes. Our client also mentioned a report created by students in the environmental science faculty which focused on the impact of green roofs in Kingston. Our team will also look into this report as it will help create a more local context.

Focus Areas

The team will be focusing on the structural integrity of current roofs at Queen's and their ability to withstand implemented green roofs. The types of green roofs and their feasibility within the Queen's campus will also be assessed in comparison to the current green roofs on campus and the possibilities for expansion or improvement. Both Watson and McArthur Hall have the ability to support a new green roof addition.

Requirements

The team will focus on different areas, such as structural and environmental protection. The client also mentions the maintenance and biodiversity needs of the roof ecosystem. There are several existing green roofs on campus, and campus buildings that have the potential for green roof implementation, such as Watson Hall and McArthur Hall. The existing roofs are inverted roofs. Most of them have lasted for 30 to 40 years. The team will take into account the need for green space differing between buildings depending on their surrounding landscape.

For more information introducing the current green roofs on campus, the team will visit:

https://www.queensu.ca/sustainability/campus-initiatives/buildings/green-roofs

Communication

Our team is committed to providing our client with a weekly work summary outlining which tasks were completed each week. As well, a regularly scheduled meeting time slot will be created to update the client as well as ask any questions in person. Microsoft Teams will be the primary resource for meetings. Our team will be flexible to accommodate extra meetings should the need for them arise.

Bi-weekly Client Meeting 2020/10/02 (F)

Updates on Past Two Weeks

- Created work plan report; highlights goals, deliverables, and work breakdown structure
- Shannen: preliminary research; extensive/intensive designs, Queen's building codes, specific designs located on other university campuses, etc.
- Will send work plan to client by Friday evening for overview

Upcoming Plan (next two weeks)

- Working towards progress report; due November 27th
- Research into extensive and intensive designs, which design is more suitable for Queen's buildings?
- Present research to client at next meeting, receive feedback

Clarification from Client

- Main deliverable must be a standard to place directly into current building code
- Could create highlighted areas on campus map that must install certain green roof designs on new builds
- Design options for future buildings must consider
    - Location of building (if the building is located in a heavily urbanized area, should implement a larger green roof)
    - Requirements for green roof implementation
    - When to use intensive vs extensive designs

Bi-Weekly Client Meeting 2020/10/20 (F)

Summary of Past Two Weeks

- Preliminary research; document shared in Microsoft Teams chat and explained by Shannen Krost
  - Master Plan: outdated; reference this in recommendations
- Clarifications on zoning: the standard should provide regulations for the MINIMUM design that must be implemented
  - Create recommendation about improving access to green space within certain zones, etc.
  - Different types of green roofs (ie. intensive vs extensive) can be used in the same zones; this should be further explained in standard

Next Steps

- Research into standards, use documents provided by client to get better understanding of current green roofs on campus
  - Understand the effectiveness of the current green roofs (age, how well plants are growing, any issues, etc.)
  - Site visit possible; will be scheduled soon with client
- Progress Report will begin (due late November)

Site Visit and In-person Client Meeting 2020/11/13 (F)

Summary from the past two weeks

- Prepare for Progress Report and work distribution: update the project plan based on the work plan feedback. Information research for next steps
    - Green roof construction and precaution
    - Background research of current green roofs on campus
    - Read through the information package from PPS

Site Visit

- New Medical Building
    - Not authorized, but watched from outside
    - Small area of the green roof, which is lack of maintenance
- Botterell Hall
    - On the ground floor with less foot traffic
    - Covers with the autoclave system of building
    - Overgrown plants
- Bioscience Complex
    - Nine drainage wells on site. Some of them are not maintained properly and buried with overgrown plants
    - The PPS team cut the grass on a regular schedule
- Goodes Hall
    - Two green roofs in the building: one is inaccessible and designed for self-sustainability. The other one is at the housetop of the building, and the office area surrounds it.
- Green space is not enough near Mitchell Hall and its surrounding area

Next steps

- Sum up the observation from the site visit and Update the information according to the observation
- Compile the research and observed information, finish the first draft of progress report by November 20th.

Bi-weekly Client Meeting 2020/11/27 (F)

Summary of Past Two Weeks

- Sum up the information obtained in site visit and conduct further research into the technical aspect of green roof design. Compile the research and obtained information and write draft progress report.
- Edit the progress report according to TA’s feedback

Next Steps

- Use client’s feedback on progress report to renovate the design and conduct research into:
- Design an optimum green roof
- Finalize a structure
- Benefit analysis
- Analyze the effectiveness of the potential functions
- Schedule a future work plan; set up new client meeting time in winter

Client Meeting 2021/01/22 (W)

1. **Progress Report –** questions, comments
2. **Poster Presentation –** short run-through
3. **Comments and Recommendations**
    - Use areas of campus as indication for what to implement in the standard
    - Benefit analysis (performance in different seasons, environmental benefits, social and mental benefits of intensive green roofs)
    - Explore cost difference between extensive and intensive designs
    - **Presentation for construction team to be scheduled**

Client Meeting 2021/02/26 (W)

1. Research Document: short run-through

- Presented a summary of the research document created regarding benefit analysis, innovative options, project auditing, and cost analysis/incentives

Client feedback: Create a condensed version of this research to send, approx. 1 page in length

2. Next Steps

- Condense the current research document into a short memo and send to PPS by Friday, March 5th
- Begin creating “rough draft” of final standard document

Client Meeting 2021/03/05 (W)

Summary Research Report: A summary of research conducted since the previous progress report; the client is encouraged to read the document and share the information with other stakeholders. Any questions or concerns can be brought up in a future meeting or can be emailed to Mackenzie.moreau@queensu.ca

Looking Ahead:

- **Final Report/Standard Document:** will be organized amongst the team this weekend and work will begin next week. Client meetings are anticipated to be more frequent in nature to receive feedback on work and to keep everyone updated.
- **Presentation for PPS:** The presentation for PPS will be a summary of the benefits, financial analysis, and technical standard recommendations that the team has determined feasible for Queen’s University. The presentation is tentatively scheduled for early April.

Client Meeting 2021/03/12 (W)

Summary from previous week

- Draft standard/Campus zone drawing on green roof distribution
- Introduction/explanation of zoning system to the client (Mackenzie)

Client's feedback

Current green roof

- percentage of each zone (minimum requirement for each zone)
- heritage building to be considered (building roof condition – cannot change much)
- Team preference on which building to choose/rationale (which type of roof should be used more, social space, activity area, the cost is not considered)
- Increase/decrease in certain area's green roof

Present the zoning rationale in table

The ratio should be greater for larger roof/ depends on the size of the building

Loading capacity of existing roofs should be explored

- Lowest weight capacity of the roof required to support new green roof installation
- Watson hall (designed to carry higher load/expected load)

Looking ahead

- Initial standard
- Final report

Client Meeting 2021/03/19 (W)

Client's expectation

Embodied carbon emission of the building

- The PPS used to consider only carbon emission generated in the operation
- Expect the team to provide an embodied carbon emission and rationale
    - Will add-in material affect the carbon emission? (i.e., steel, concrete)
    - Reality: the actual performance is varied among buildings

Looking ahead

Final report

Presentation to Physical Plant Services team 2021/04/19 (W)

Meeting Summary

- Presentation to introduce the client and Queen’s building team the general information of the project; QA sessions to answer the questions from the building team
  - Insurance measures
  - Water retention function
  - Prospects of green roof and green areas on Queen’s campus in the future
- Watch another presentation by QMIND team on recycle system application

Looking ahead

Final report and standard editing

Appendix E: Hour Table (Date to 2021/03/26)

Fall Term

Week	Member and Hours					Individual Task	Group Work
1 **Sep. 6-Sep. 13**	Mackenzie Moreau	5				Team Initiation and project bidding	Initial Team Meeting Project Bidding **(9/11)**
	Ruizhe Yi		4				
	Shannen Krost			5			
	Thomas Sevigny				3.75		
2 **Sep. 14-Sep. 20**	Mackenzie Moreau	4				Client Meeting Summary	Introductory Client Meeting **(9/18)** Teams Charter **(9/18)**
	Ruizhe Yi		4				
	Shannen Krost			4		Team Charter	
	Thomas Sevigny				4		
3 **Sep. 21–Sep. 27**	Mackenzie Moreau	4				Project constraints, Project stakeholder	Weekly TA meeting, Draft Work Plan Research on general information
	Ruizhe Yi		4			Gantt Charts, WBS tables and graph	
	Shannen Krost			7		Initial Preliminary research, Conclusion, Report editing	
	Thomas Sevigny				5	Introduction, Project background,	
4 **Sep. 28-Oct. 4**	Mackenzie Moreau	7				Email client and schedule meeting time, Revise the WBS table based on TA's feedback	Weekly TA meeting Receive feedback from draft Client Meeting Receive information package
	Ruizhe Yi		7			Revise schedule table and graphs based on TA's feedback	
	Shannen Krost			4		Generalize preliminary analysis based on TA's feedback	
	Thomas Sevigny				4	Revise background information according to TA's feedback	
5 **Oct.5-Oct. 11**	Mackenzie Moreau	3				Check the municipal building code and green roof standards	Questions to client regarding to the current green roofs on campus Work Plan Submission **(10/2)** Work Plan Submission **(10/2)**, Weekly TA meeting General Research
	Ruizhe Yi		2			Investigate the structural requirement for green roof	
	Shannen Krost			3		Preliminary analysis of green roof types, Preliminary analysis of cost	

	Thomas Sevigny				1.5	Potential usage of green roof	
6 **Oct. 12-Oct 18**	Mackenzie Moreau	1				Email client and schedule meeting time	Team Meeting Weekly TA meeting
	Ruizhe Yi		1				
	Shannen Krost			1			
	Thomas Sevigny				2.5		
7 **Oct. 18-Oct 25**	Mackenzie Moreau	4				Update information from first half of semester	Weekly TA meeting Initiation of Progress Report
	Ruizhe Yi		2				
	Shannen Krost			4			
	Thomas Sevigny				1.5		
8 **Oct.26–Nov. 1**	Mackenzie Moreau	4				Email client and schedule meeting time, Investigate the green areas near the building	Weekly TA meting Site Visit and In-person meeting with PPS
	Ruizhe Yi		5.5			Stability of structure, Revise work plan up to date	
	Shannen Krost			4		Maintenance of current green roofs	
	Thomas Sevigny				4.5	Functionality of drainage and Irrigation system	
9 **Nov. 2-Nov.8**	Mackenzie Moreau	6				Structural analysis of loading	Progress Report Weekly TA meeting Draft Progress Report **(11/20)**
	Ruizhe Yi		4			Renovate structure to improve stability	
	Shannen Krost			6		Feasibility of potential functions	
	Thomas Sevigny				9.5	Addition of new vegetation and growth media	
10 and beyond **Nov.9-Nov. 29**	Mackenzie Moreau	16				Email client and schedule meeting time, Editing Progress Report	Weekly TA meeting on draft final report Final progress report Client Meeting Peer reviewing progress reports
	Ruizhe Yi		10			Edit Progress report	
	Shannen Krost			19			
	Thomas Sevigny				8		
	Fall Total	54	43.5	57	47		

Winter Term

Week	Member and Hours					Individual Task	Group Work
19 **Jan. 11 - Jan. 17**	Mackenzie Moreau	3.5				Review progress report and last term's work	Initial group meeting and set up term milestones
	Ruizhe Yi		3.5				
	Shannen Krost			3.5			
	Thomas Sevigny				3.5		
20 **Jan. 18 - Jan. 24**	Mackenzie Moreau	6				Slides introducing project background and objectives	Create slide and practice presentation Poster presentation **(2021/1/22)** Initial client meeting and present poster Initial TA meeting
	Ruizhe Yi		5			Slides introducing progress and summary up to date	
	Shannen Krost			5		Slides introducing project background and objectives	
	Thomas Sevigny				4.5	Slides introducing following steps and future plan	
21 **Jan. 25 - Jan. 31**	Mackenzie Moreau	1				Initial research on green roof component and benefits	Research based on client's feedback
	Ruizhe Yi		0.5				
	Shannen Krost			1			
	Thomas Sevigny				0.5		
22 **Feb. 1 - Feb. 7**	Mackenzie Moreau	2				Initial research on green roof component and benefits	Weekly client meeting Work distribution and set up goals for the following weeks research
	Ruizhe Yi		0.5				
	Shannen Krost			2			
	Thomas Sevigny				2		
23 **Feb. 8 - Feb. 14**	Mackenzie Moreau	8				Campus map on green roof distribution and rationale	Research on green roof: benefit analysis, auditing plan, innovation plan
	Ruizhe Yi		5			Environmental benefits and social benefits	
	Shannen Krost			8		Auditing plan recommendations	
	Thomas Sevigny				4	Operational benefits and economic analysis	
24 **Feb. 22 - Feb. 28**	Mackenzie Moreau	10				Campus map on green roof distribution and rationale	Summary based on initial research. Weekly client meeting
	Ruizhe Yi		5			Environmental benefits and social benefits	
	Shannen Krost			10		Auditing plan recommendations	
	Thomas Sevigny				6.5	Operational benefits and economic analysis	

25 **Mar. 1 - Mar. 7**	Mackenzie Moreau	7				Campus zones and roof coverage	Compose draft standard: Green roof component, structural, vegetation performance, campus zone
	Ruizhe Yi		8			Green roof component s and guidance	
	Shannen Krost			6		Structural standard	
	Thomas Sevigny				8.5	Drainage standard and safety, maintenance codes	
26 **Mar. 8 - Mar. 14**	Mackenzie Moreau	7				Campus zones and roof coverage	Compose draft standard: Green roof component, structural, vegetation performance, campus zone
	Ruizhe Yi		7			Green roof component s and guidance	
	Shannen Krost			7		Structural standard	
	Thomas Sevigny				6	Drainage standard and safety, maintenance codes	
27 **Mar. 15 - Mar. 21**	Mackenzie Moreau	22				Campus zones and roof coverage, compose report draft	Submission of report draft and draft standard **(2021/3/19)**
	Ruizhe Yi		14			Green roof component s and guidance, compose report draft	
	Shannen Krost			20		Structural standard, compose report draft	
	Thomas Sevigny				14	Drainage standard and safety, maintenance codes, compose report draft	
28 **Mar. 22 - Mar. 28**	Mackenzie Moreau	23.5				Editing final report	Submission of final initial final report **(2021.3.26)** Weekly client meeting
	Ruizhe Yi		13				
	Shannen Krost			25			
	Thomas Sevigny				16		
29 and beyond **Mar. 28 – April 23**	Mackenzie Moreau	15				Editing final report and standard to submit to PPS	Final presentation **(2021/3/30)** PPS presentation (2021/4/19) Peer review Final edits for client submission
	Ruizhe Yi		13				
	Shannen Krost			16			
	Thomas Sevigny				10.5		
	Winter Total	104	74.5	103	80.5		
	Cumulative Total	**160**	**118**	**160.5**	**127.5**		