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Green Roof Carbon Sequestration Potential of Dalhousie's Halifax Campuses

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EXECUTIVE SUMMARY

This project aims to determine the carbon sequestration potential if extensive green roofs were installed on viable buildings on Dalhousie University's Carleton, Sexton, and Studley campuses in Halifax Regional Municipality. Reasons to undertake this project are the potential to offset Dalhousie University's carbon emissions and fulfill the university's goals regarding sustainability.

Research methodology consisted of determining which Dalhousie University buildings were considered viable in supporting green roofs, using the ArcGIS to determine roof surface areas, selecting a green roof plant species that can thrive in Nova Scotia's climate, and the carbon sequestration potential of that species.

By using roof surface area values in conjunction with carbon sequestration potential values, several scenarios for the total amount of carbon that could be sequestered were laid out. The total carbon sequestration was calculated to be 11,843 to 370,773 kg of carbon, or 43,393.44 to 13,585,348.56 kg of carbon dioxide. It was estimated that Dalhousie University's carbon emissions could be decreased by 7.00% through the implementation of green roof technology. This reduction is roughly equivalent to removing 2,166 mid-size cars from the road.

The implementation of green roofs still decreases the total greenhouse gas emissions released by Dalhousie. Although findings did not indicate a large mitigation of Dalhousie University's carbon emissions, green roofs may still be used as a method to reduce greenhouse gas emissions. For this reason, it is recommended that Dalhousie University consider the implementation of green roofs, or other sustainable techniques. This will provide opportunities for additional research while still continuously reducing environmental impacts.

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1 INTRODUCTION

Although it is wildly controversial among the public, there is substantial scientific consensus that human activity contributes to climate change (Boer, 2014). While it is difficult to predict the effects of climate change, it will likely have adverse impacts on ecosystems (Döll & Zhang, 2010) and society (Field, Barros, & Intergovernmental Panel on Climate Change, 2014). Human activity contributes to climate change because we get our energy from burning substances that emit greenhouse gases. Dalhousie University emitted 97,393,000 tonnes (CO₂ equivalent) of greenhouse gases in the academic year of 2013-2014 (Office of Sustainability, 2014). To improve their practices, Dalhousie University is taking steps to mitigate and reduce their carbon footprint (Office of Sustainability, 2014). Dalhousie has joined universities across Canada in signing a “Climate Change Statement of Action” a commitment to reducing greenhouse gas emissions (Pottle & Reagan, 2012). In light of this, our research project investigates the feasibility of a project that would offset carbon emissions. This offset would be achieved through carbon sequestration, a process by which atmospheric carbon is removed from the atmosphere and stored in another form (liquid or solid). Specifically, the project will focus on carbon sequestration by plants; through photosynthesis, plants remove carbon dioxide from the air, and store it in their tissues as sugar.

This project focuses on the campuses of Dalhousie University located in Halifax Regional Municipality, Nova Scotia, which are the Carlton, Sexton, and Studley campuses. Part of the reasoning behind this study area is that it is difficult to sequester carbon through plants on an urban campus with many roads and buildings. An innovative solution to this is the use of green roofs; a roof of a building that is covered with vegetation. Dalhousie University already has some green roofs installed such as the Mona Campbell building and the LeMarchant Place building. This project’s research explored the potential for green roofs on existing Halifax campus buildings.

This project’s research aims to determine the carbon sequestration potential of installing extensive green roofs on viable buildings pre-dating 2016 on Dalhousie University’s Halifax campuses. Extensive is defined in Section 1.1.1, and the classification of what constitutes a viable building is set out in Section 3.1. Figure 1, located below, provides a context map of the Dalhousie University buildings considered in this project.

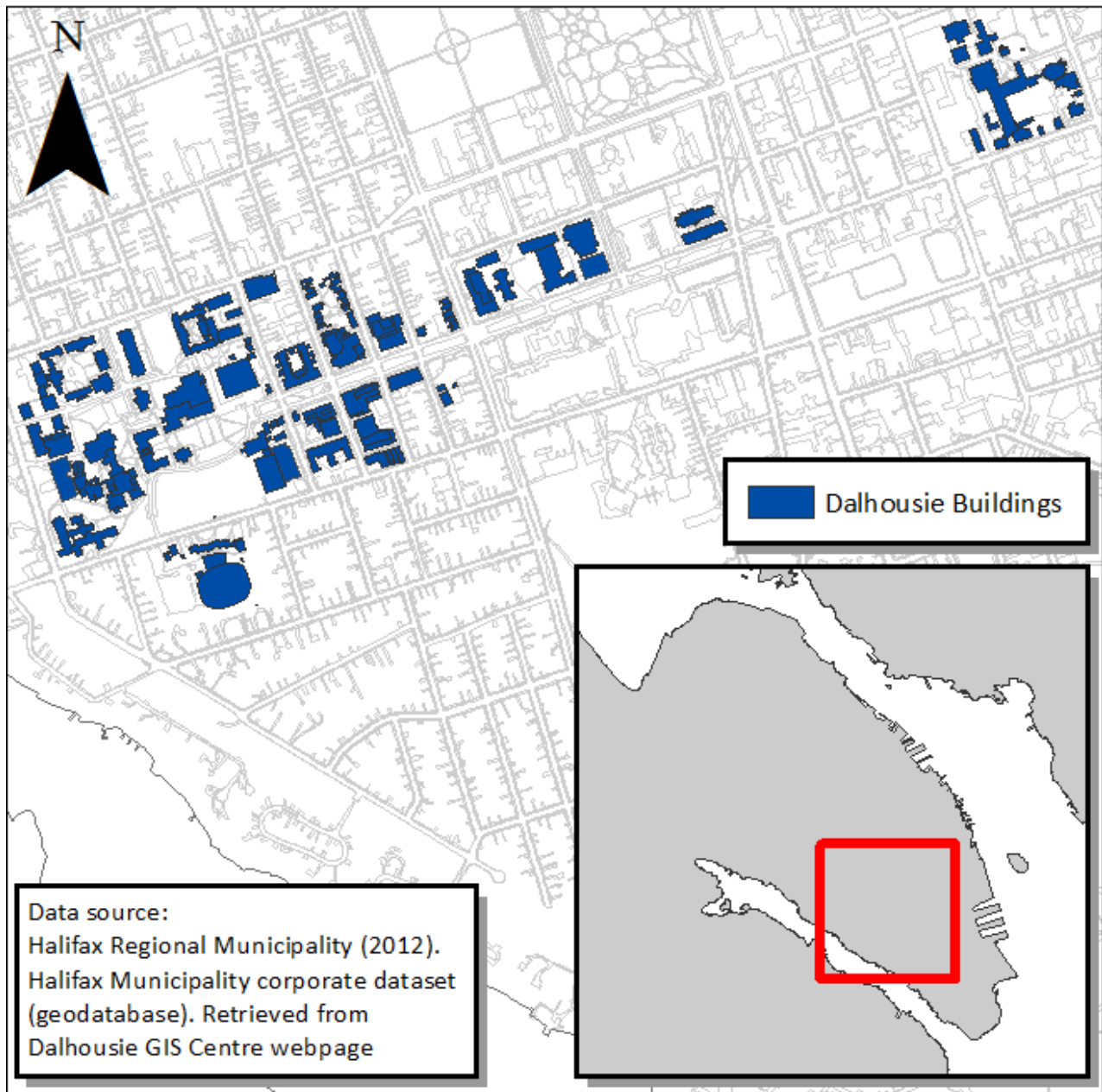


Figure 1: A context map of the Dalhousie University buildings considered in this project, located in Halifax Regional Municipality, Nova Scotia

1.1 BACKGROUND AND RATIONALE

1.1.1 Types of Green Roofs

Green roofs, also known as vegetative roofs, can be described as layers of living vegetation on top of a conventional roof (Miller, 2008). Modern green roofs can be classified as intensive or extensive systems, depending on the plant material used and the intended usage for the roof area (Getter & Rowe, 2006).

Intensive green roofs are designed to be similar to landscaping found at natural ground level, and are therefore much heavier as they host a larger diversity of plant species and deeply-rooted plants (Getter & Rowe, 2006). The weight of vegetation and deeper substrate requires costlier and more complex building design structures to support this type of roof (Credit Valley Conservation, 2008). They are often intended for public access and therefore require regular maintenance.

Extensive green roofs, on the other hand, are much smaller in depth and more lightweight than intensive green roofs. These characteristics narrow the range of plant species they can support to herbs, grasses, mosses, and sedum (Getter & Rowe, 2006). Extensive green roofs require minimal maintenance compared to intensive green roofs, as they are not intended for public access (Getter & Rowe, 2006). Rather, extensive green roofs are often used to satisfy engineering and performance goals of the building (Miller, 2008).

Due to the nature of this project's research, focus has been narrowed to solely extensive green roofs. Reasoning for this is that they are less costly and require less structural support than intensive green roofs, allowing them to be more feasibly implemented on existing buildings on Dalhousie University's Halifax campus.

1.1.2 Green Roof Benefits

Environmental

There are numerous environmental benefits that result from the implementation of a green roof. The installation of a green roof essentially offers a replacement for the vegetated footprint destroyed by the construction of the building. Benefits of this vegetation include the management of storm water runoff. Vegetation aids in decreasing the volume of storm water runoff by absorbing the precipitation and reducing infiltration into ground water, which results in a reduction of flooding and less stress on municipal sewer systems (Getter & Rowe, 2006). Green roofs may retain 70 to 90 percent (%) of precipitation during summer months, and 25 to 40% in winter months (GHRC, 2014). Additionally, the quality of storm water runoff is improved with the installation of a green roof, as impervious surfaces collect pollutants, including oil, heavy metals, salts, pesticides and animal wastes. These contaminants may wash in to streams and waterways, resulting in a negative effect on both ecosystems and human health (Getter & Rowe, 2006).

Replacing conventional roof tops with a green roof also results in mitigation of what is known as the urban heat island effect. This is the occurrence of warm temperatures in urban areas due to the large amount of built surfaces which absorb heat and radiate it back in the evening hours (Getter & Rowe, 2006). Night air temperatures therefore remain high in built-up areas. The urban heat island occurs as a result of reduced vegetation and increased impervious surfaces, combined with the heat-absorbing properties of structures, which in turn creates higher temperatures inside and outside the building (Getter & Rowe, 2006). Green roofs aid in the reduction of the urban heat island through the process of evapotranspiration, in which moisture is able to re-enter the atmosphere and therefore cool cities (GRHC, 2014).

Economic

Roofs transfer the greatest heat loss from buildings in the winter and the hottest temperatures into buildings in the summer (GRHC, 2014). Green roofs offer a solution to high energy bills by helping to maintain internal building temperatures, reducing energy consumption and CO₂ emissions (Castleton et al., 2010). Indoor temperatures have been shown to be 3-4 °C lower under a green roof when outdoor temperatures are between 25 to 30 °C, while every 0.5 degrees decrease in internal building air temperature may reduce electricity use for air conditioning up to 8 percent (Getter & Rowe, 2006). Building owners have the opportunity to save money on renovating out-dated storm water infrastructure and to power cooling and heating systems (Getter & Rowe, 2006). Additionally, green roofs have the potential to out-live conventional rooftops, which is a long-term cost saving benefit (GRHC, 2014).

1.1.3 Relevant Work Conducted

In 2006, a group of students enrolled in the course Environmental Problem Solving II (ENVS 3502) conducted an analysis to determine the feasibility of a Rainwater Collection system (RWCS) at Dalhousie University. The foremost objective of their research was to examine an alternative sustainable solution to reduce water consumption on campus. In the course of their data generation, the team chose interactive techniques such as interviews and surveys to obtain crucial information and recommendations from professionals “in the areas of water resource management, geology, engineering, plumbing, urban planning and economics” (Abdual, Arsenault, Bachiu, Garrey, MacGillivray, & Uloth, 2006). Other procedures undertaken by the team include an extensive research on the functioning of RWCS and water usage at Dalhousie University. Subsequent to the compilation of the gathered information, their analysis has indicated the area between University of King’s College and Life Sciences Centre as the most feasible location for an installation of RWCS (Abdul et al., 2006). In spite of the fact that their research study was predominantly on RWCS, their article does contain discussion that relates to green roofs. Hence, reviewing their research study could be beneficial because both RWCS and green roofs are categorized as sustainable development designs.

In 2009, a feasibility analysis of a green roof on the Life Science Center was conducted by a group of students enrolled in the same university course. They conducted a cost-benefit analysis of the economic, environmental and social impacts of green roofs. They found that though the environmental benefits of green roofs outweigh the environmental costs, economic costs can initially be high and social benefits are difficult to quantify. A limitation of their study was a lack of information regarding Life Science Center's structure and roof capacity (Block et al., 2009). Lastly, the team concluded that their project would be beneficial to anyone has similar interest to transform Dalhousie University into a more environmentally friendly campus. This report gave a lot of information on the costs and benefits of green roofs, but was restricted in scope to the Life Science Centre and was limited in the information they could obtain about the building's structure. Our study will use a variety of methods to get as much information as possible about campus building structure, so that physical feasibility of green roof installation can be established in the literature.

In 2015, another group of students conducted a study that examined green roofs as a possible strategy to mitigate the risks of storm water on Studley campus. The goal of their study was to "address the current issues with storm water management on Studley campus and apply a sustainable solution to mitigate associated environmental damages" (Cranstone, Hu, Laing, Watling & Zhang, 2015). Their report acknowledged the installation of a green roof as an affordable and highly effective way to improve storm water management and reduce the amount of water reaching sewers. Through the use of ArcGIS, the project defined the total viable surface area of buildings on Studley campus and estimated the installation cost to the University (Cranstone et al., 2015). Although this study was similar in the sense that it focused on the potential of installation of green roofs for Dalhousie's Studley campus, the project only concentrated on the effects that green roofs would have on the reduction of storm water on campus.

In contrast to these projects, our project will contribute to the information on projected benefits of green roof installation on Dalhousie University campus by adding information regarding carbon sequestration potential. In addition, our study will approximately quantify the amount of carbon sequestered through green roof installation. This will give the Office of Sustainability numbers to work with as they project their carbon footprint in the future.

1.1.4 The Dalhousie Campus

The Dalhousie institution has three major campuses located in downtown Halifax. These campuses include Sexton campus, Studley campus and Carlton campus. These three campuses combined consist of approximately 76 buildings, many of which have the potential for the development of a green roof. A university campus is a complex system due to the various processes that are required for normal operation. University campuses can be associated with a large number of carbon emissions, some of which are associated with

transportation, electricity, heating, student laboratories and pilot scale plants. In fact, campus sustainability is becoming an increasing concern due to the environmental impacts of the activities conducted at university campuses (Alshuwaikhat & Abubakar, 2008). Therefore, education institutions are beginning to integrate sustainable practices into regular operation by implementing sustainability into curriculum, and even going as far as signing international charters and declarations (Nejati, 2013). The implementation of green roofs on Dalhousie campus buildings is an opportunity to improve the sustainability of the campus.

Dalhousie has implemented green roofs on some of their buildings in an attempt to promote green building through their sustainable building policy. The buildings containing green roofs on Dalhousie Campus include the Mona Campbell, LeMarchant Place and Wallace McCain buildings. The green roofs on these buildings vary in scale, and the ultimate goal of these green roofs is not necessarily carbon sequestration. For example, while the Mona Campbell building has vegetative green roof to help filter air pollutants, some of the other objectives for implementation include reducing stormwater runoff and mitigating the urban heat island effect. The green roof of the Wallace McCain building is accessible, making it an intensive green roof available for public use. Finally, the LeMarchant Place green roof has both vegetation and solar hot water collectors to help improve the sustainability. Therefore, a green roof can improve sustainability in a number of different ways. The implementation of a full scale extensive green roof composed entirely of vegetation may prove an effective manner of improving campus sustainability through carbon sequestration.

1.1.5 Policies on Green Roofs in Halifax

The installation of green roofs across the Halifax campuses would align with Dalhousie University's Sustainability Policy. This policy indicates that Dalhousie University focuses on sustainability goals, which include supporting physical systems that enhance sustainability and decrease air emissions (Dalhousie, 2009). A green roof is a physical system that not only enhances sustainability, but has potential for decreasing air emissions through carbon sequestration. The policy also indicates that new and existing policies will be developed to achieve these sustainability goals (Dalhousie 2009). Thus, in 2011, Dalhousie University approved a sustainable building policy to reduce environmental impacts and represent leadership in sustainable building practices. The policy indicates that any new building greater than 10,000 square feet will be designed to achieve Leadership in Energy and Environmental Design (LEED) gold certification, at a minimum. The policy also indicates that any smaller renovations and retrofits will be considered for sustainable building, and the concept of LEED for existing buildings will be explored (Dalhousie, 2011). The LEED Green Building Rating System is designed to benchmark high performance green buildings.

Although green roofs are not mandatory for LEED certification, there are several rating points that can be obtained from benefits associated with green roofs. The LEED Gold certification requires qualification for

at least 60 of the 110 available rating points, and the implementation of green roofs can help achieve this goal (Canada Green Building Council, 2009). Because of this, our project assumes that most buildings constructed on Dalhousie University Halifax campuses in the future will have green roofs. Thus, our project explores the somewhat neglected possibility of green roofs on existing Dalhousie University Halifax campus buildings.

Although green roofs provide unique opportunities for sustainable building, there are currently no regulations or by-laws that require their implementation within Halifax. However, it is worth noting that this may not be the case in the future. In fact, Toronto implemented a green roof by-law in 2009 which required the installation of green roofs for large institutional and industrial buildings (City of Toronto, 2013). Installation of green roofs may help compliance with any future policy or regulation amendments in Halifax Regional Municipality.

2 RESEARCH METHODS

To determine which buildings were viable, a literature review of past student projects on the subject of green roofs at Dalhousie University was conducted. Literature review was also conducted to determine the carbon sequestration potential of green roofs: First by identifying plant species native to Nova Scotia that could thrive on green roofs, then by discovering the quantitative carbon sequestration potential of these native plants. While these literature reviews took place, the surface area of viable buildings was identified using ArcGIS. With the quantities of carbon sequestration and roof surface area, calculations were done to determine the potential for carbon sequestration on Dalhousie University's Halifax campuses.

2.1 METHODS OVERVIEW

The research performed was deductive and quantitative in nature. The literature research performed in the background study indicates that an extensive green roof is able to sequester carbon from the atmosphere. This means it is reasonable to expect that the Dalhousie University Halifax campuses would be able to sequester carbon if extensive green roofs were installed. The quantitative data collected allowed for the estimation of the amount of carbon sequestration possible, if extensive green roofs were installed.

The purpose of the research was to determine the carbon sequestration potential from installing extensive green roofs on viable buildings (as defined in Section 3.1) in the Dalhousie University Halifax campuses. Therefore, there was quantitative data collected based on Dalhousie University building information and carbon sequestration potentials of extensive green roofs. The major goal was to collect building surface area (measured in metres squared {m²}), and carbon sequestration potential of plants (measured in kilograms of carbon dioxide per square metre {kg CO₂/m²}) to determine the total amount of carbon (measured in kilograms of carbon dioxide {kg CO₂}) that could be sequestered. The types of data being collected and the methods of collection have been briefly summarized in Table 1.

Building information was collected by first determining the number of Dalhousie University buildings which are capable of supporting an extensive green roof. Criteria for valid roofs were to be relatively flat and to appear capable of supporting a green roof. These viable buildings were then used to determine the total surface area available for extensive green roof installation. Carbon sequestration potential information was collected based on existing extensive green roofs and varying vegetation species. Vegetation species focused on vegetation that is able to acclimate to the Halifax climate. The methods of data collection included ArcGIS analysis, and literature review. Interviews were to be conducted only if the literatures review and geographic information system (GIS) analysis were unable to provide sufficient information; however this was

unnecessary as the information was readily available. The majority of the data collection was associated with literature research.

Table 1: Summary of Data Collection Methods

Information	Data to be Collected	Method of Collection
Building Information	Buildings capable of supporting a green roof within Halifax	Literature Review
	Campuses	
	Total surface area of viable green roof space	ArcGIS Software
Carbon Sequestration Potential	Determination of optimal plant species for green roofs at Dalhousie University, Halifax Nova Scotia	Literature Review
	Carbon sequestration potential of specific plant species	Literature Review
	Total carbon sequestration potential of Halifax Campuses	Data Analysis

2.2 DATA COLLECTION

2.2.1 Literature Review

The research project did not involve any form of sampling, and therefore a literature search was one of the chosen methods for data collection. It was determined that this would be the most reliable and efficient method to collect data. This is because the majority of relevant carbon sequestration information was readily available in literature. This also minimized the time associated with research by avoiding the scheduling and development of interviews.

Firstly, a list of all buildings on Dalhousie’s Halifax campuses was obtained from their website (Dalhousie University, n.d.). To find out which buildings were viable for a green roof, literature review was conducted analyzing previous studies performed on green roofs. The first task was reviewing previous projects conducted at Dalhousie University that are associated with green roofs. This information was obtained from Dalhousie online libraries and previous ENVS 3502 projects. These studies were able to provide some information on buildings capable of supporting a green roof. However, the information of building suitability was insufficient, and further analysis was performed using other sources. These sources included municipality by-laws related to green roofs, and best practices for green roofs. Based on this, criteria were formed to assess a building’s ability to hold a green roof: the slope of the roof is less than 10°, and the roof is not on a small residential-style building. If a building fit these criteria, it was considered viable. Dalhousie University infrastructure information was analyzed using ArcGIS.

Finally, literature review was performed to determine potential plant species for implementation on the green roof. This involved researching characteristics of different plants including topics on native location,

carbon content, carbon sequestration potential, etc. Different species are able to sequester different quantities of carbon, based on their growing capacity. This section of the literature review first determined species that were able to acclimate to Halifax’s climate. Then, the species commonly used on green roofs with this climate were found. The species with potential use for extensive green roofs in Halifax were then further analyzed for their specific carbon sequestration rates. A summary of the databases and keywords used in this literature review can be seen in Table 2.

Table 2: Summary of literature search methods

Research	Databases Searched	Key Words
Native green roof species	ProQuest	Green Roof
	Web of Science	Sedum
Sedum carbon sequestration rates	Agricola, Biological and Agricultural Index	Carbon Sequestration
	Environmental Sciences and Pollution Management	[Species Name] Carbon Content Sedum

2.2.2 ArcGIS

ArcGIS, a computer program provided by Esri with permission from Dalhousie University, was used to calculate the total surface area of viable green roof space on Dalhousie University’s Halifax campus buildings. The use of this research tool was quantitative in nature.

To use ArcGIS as a research tool, data was required. Specifically, data on building footprints (representing the space buildings take up within their lots, providing an approximate size of their roofs) within Dalhousie University’s Carlton, Sexton, and Studley campuses was needed. Data for buildings was obtained through the use of Dalhousie University GIS Centre’s in-house data, specifically the Halifax Municipality 2012 Corporate Dataset. Permission to use this data is granted to Dalhousie University faculty, staff, and students (Dalhousie University, 2015a); thus, the SUST 3502 students undertaking this project had access to these datasets. In the cases that these datasets do not provide sufficient building data, the shapefiles (a file type containing geographic data as well as other information) were created manually in ArcGIS using the same projection as the Dalhousie University GIS Centre’s dataset.

2.3 DATA ANALYSIS

2.3.1 Calculations

The carbon sequestration potential (measured in kg CO₂) of extensive green roofs on Dalhousie University campus was calculated by using the surface area simulated from ArcGIS and the values obtained from plant species literature review. The specific carbon sequestration value (measured in kg C/m²) of the plant species was multiplied by the total surface area (measured in m²) of the green roofs. However, the values found in the literature referred to the weight of only the carbon atoms themselves, so this had to be converted to kg of CO₂ through stoichiometry. The carbon sequestration potential of the sedum species was analyzed to determine both the minimum and the maximum sequestration rate found in the literature. The calculations considered minimum roof coverage of 50% and maximum roof coverage of 100%. A carbon sequestration potential was calculated for four different scenarios. The calculations performed to analyze these four different scenarios have been summarized in Table 3.

Table 3: Summary of Carbon Sequestration Potential Scenarios Analyzed

Scenario	Specific Carbon Sequestration Rate	Roof coverage
Minimum Sequestration Potential	Minimum sequestration rate	50%
Low sequestration Potential	Minimum sequestration rate	100%
High Sequestration Potential	Maximum Sequestration rate	50%
Maximum Sequestration Potential	Maximum Sequestration rate	100%

Calculations were also performed to illustrate both the quantity of carbon dioxide produced by Dalhousie University, and the carbon sequestered by extensive green roofs. The amount of carbon produced by Dalhousie University was compared to the weight of a blue whale. The amount of carbon that would be sequestered as a result of green roof installation was compared to the carbon emissions of various passenger vehicles. The amount of carbon sequestered has been related to the equivalent emission reduction that would be seen from removing the vehicles from the road. The analysis was performed for small, medium, large and hybrid cars for a varying various annual travel distances. This comparison was performed to illustrate the impacts of carbon sequestration at a level that is understandable by the general public.

2.3.2 ArcGIS

ArcGIS was used to calculate the total surface area of roof space in metres squared on Dalhousie University's three Halifax campuses. In the project's data analysis stage, this information was then used in conjunction with criteria identifying which roofs were considered viable for the installation of green roofs and

data regarding carbon sequestration potential to determine the total amount of carbon that may be sequestered. An overview process taken in ArcGIS is described below; see Appendix A for a detailed transcription of the steps taken to obtain building roof area estimates.

With the appropriate data gathered, ArcGIS was used to isolate buildings on Dalhousie University’s Carleton, Sexton, and Studley campuses. The shapefiles of those buildings were selected and exported as a separate layer. The area of each building shapefile was then calculated in that new layer’s Attribute Table and exported in a format viewable at a later time in Microsoft Excel. Roof area was estimated by calculating the area of the building footprints, which provided an approximate size of their roofs.

A major benefit of using ArcGIS as a research tool is that once the appropriate data (shapefiles) are gathered, the program can be used to almost instantly calculate required area values with only small effort exerted by the user. ArcGIS can also then be used to create maps to aid with the representations of research findings in written reports or presentations.

2.4 DELIMITATIONS AND LIMITATIONS

Several delimitations (constraints set by the researchers) and limitations (constraints beyond the researchers’ control) were present in this project. They are as follows:

Table 4: Complied Delimitations and Limitations

Delimitations	Description
Detail of roof criteria	Roof criteria were only estimations of which Dalhousie University buildings would be considered viable and may not be infallibly correct It may be possible to install green roofs on buildings not included in this project’s criteria
Estimations of roof coverage	Roof coverage was estimated with generalised scenarios, however on a case-by-case basis, buildings may support smaller areas of green roof
Cost considerations	This project did not focus on the financial implications of installing green roofs Cost may be a determining factor in whether or not green roofs were to be installed on Dalhousie University buildings
Limitations	Description
Time	This project’s focus was narrowed given the amount of time available for its completion

	Given more time, financial implications could have been considered, and more information could have been gathered on the viability of buildings to support green roofs
Literature available – Carbon sequestration potential	Only two usable resources were found to be available regarding carbon sequestration potential Given a large difference in the carbon sequestration numbers, more documentation could have potentially meant more accurate project results
Literature available – Carbon sequestration predictions	The literature available was lacking detail as to how much carbon could be sequestered beyond the first year of implementation Availability of carbon sequestration information over several years would have allowed this project’s results to give a better idea of green roof effectiveness

2.4.1 Delimitations

A delimitation in our study was the buildings we eliminated from the study based on certain criteria such as minimum roof area (a very small roof may not be worth renovating) or type of roof (buildings with flat, broad roofs will be favoured over buildings with pitched roofs). No other information could be found on the architecture of Dalhousie roofs and their ability to support a green roof in the time allotted.

2.4.2 Limitations

A limitation to this project was the detail in which the potential carbon sequestration of Halifax campus buildings was calculated. These calculations were limited according to what data is available in the literature. Data was also limited due to which green roof plant species had carbon sequestration data.

3 RESULTS

3.1 VIABLE BUILDINGS & TOTAL ROOF AREA

We identified twenty-two buildings as viable to be retrofitted with green roofs based on the criteria we adopted to assess viability. Mostly large academic buildings were deemed viable as they tended to have large, flat roofs. By and large, small residential-style structures were considered not viable as they usually featured sloped roofs. The building areas identified, retrieved from a Microsoft Excel file produced using data from Halifax Municipality 2012 Corporate Dataset, are as follows:

Table 5: Viable Halifax Campus Buildings

Building Name	Area (square metres)
A, B, C, D Building complex & Sexton Library	8853.94
Burbidge Building	704.90
Chase Building	797.30
Chemical Engineering (F Building)	1236.80
Clinical Research Centre	3049.67
Collaborative Health Education Building	1751.73
Dalhousie Arts Centre	3652.88
Dentistry Building	2848.31
G.H. Murray Building (G Building)	730.43
Gerard Hall	573.75
Goldberg Computer Science Building	191.42
Howe Hall	5504.62
Industrial Engineering (I Building)	380.56
Kenneth C. Rowe Management Building	2721.88
Killam Library	3386.56
Life Sciences Centre	8271.71
Life Sciences Research Institute	2831.74
Marion McCain Arts and Social Sciences	3567.49
O'Brien Hall (M Building)	557.21
Ralph M. Medjuck Building (H Building)	1360.67
Risley Hall	2206.43
Sir James Dunn Building	2034.04
Student Union Building (SUB)	2598.65
Tupper Building & Kellogg Library	1400.24

Weldon Law Building & Law Library	1951.63
<p><i>Note:</i> As Shapefiles of some Dalhousie University buildings were not available, the area of the Collaborative Health Education Building has been estimated by manually creating polygons in ArcGIS and calculating the areas from there.</p>	

3.2 PLANT SPECIES & CARBON SEQUESTRATION

We found that due to the shallow growing media profile of extensive green roofs that range from 6 inches or less, perennial plants such as forbs, sedum, moss, and grasses are commonly selected for cultivation (Green Roof Technology, 2016). Characteristics shared among these species are low growth height, a fibrous root system, and minimal maintenance. In addition, any plant species grown on green roofs must also be able to thrive under intense heat, cold, wind and drought. As a result, these factors posed a challenge in determining suitable vegetation type for green roofs.

Some of the appropriate plant species for Halifax Regional Municipality’s climate comprise of grasses, shrubs, and mosses. Plant species we found that grow successfully on green roofs in Halifax’s climate were Blue Fescue (*Festuca glauca*), Chives (*Allium schoenoprasum*), Hairy Goldenrod (*Solidago bicolor*), Three-toothed Cinquefoil (*Potentilla tridentata*), Crowberry (*Empetrum nigrum*), Poverty Oat Grass (*Danthonia spicata*), Wavy Hair-grass (*Deschampsia flexuosa*), Golden Root (*Rhodiola rosea*), Harebell (*Campanula rotundifolia*), and Seaside Plantain (*Plantago maritima*). Among this great variation of native plant species, several *Sedum* species such as *Sedum Ternatum*, *Sedum Xenox*, and *Sedum Matriona* have been identified to possess a remarkable capability to withhold their resilience and resistance under Halifax’s humid continental climate. Despite the different appearances which set one species from one another in the *Sedum* genus, all of them share several things in common. All *Sedum* species are classified as succulent plants (United States Department of Agriculture, n.d.), so they are able to store water in their thick leaves and require minimal supplemental water. In contrast to other green roof plant species, *Sedum* can “survive and thrive on as little as two rains per month” (Vela, 2014). In addition, past studies have also observed that “*Sedum* absorbs carbon dioxide and turns it into malic acid, which is used during the day for photosynthesis. The pores in the leaves only open at night to minimize the loss of moisture during the hot and dry day” (Maja, 2015).

The information we found for each species on carbon sequestration potential was minimal. Most searches of “carbon sequestration” and a species name had no results. About five papers were found on species that could grow in Nova Scotia, and two of them included results on several *Sedum* species. These papers also had the most appropriate information for our project, focusing specifically on green roofs in climates similar to Nova Scotia climate, and including above- and below-ground sequestration. These two papers were by Getter, Rowe, Robertson, Cregg, & Andresen (2009) and Whittinghill, Rowe, Schutzki, & Cregg (2014). Whittinghill et al.

found that after one year, many types of *Sedum* grown together sequestered 5.87 kg Carbon/m². Getter et al. found that on average the different types of *Sedum* sequestered 0.375 kg C/m². Getter et al. explained that their higher result could be due to their study using deeper substrate, irrigation, and growing the different types of *Sedum* together.

Several research studies have indicated that species richness does in fact intrinsically connect with plant productivity. For instance, it has been observed that such phenomenon contributes to an increase of efficiency in assimilation of nutrients and solar energy, which then consecutively helps to yield a greater production of biomass (University of Gotthenburg, 2011). Furthermore, some researchers have also noted that “plant species with taller height, larger diameter, and larger shoot and root biomass” are much more effective at storing carbon in plant biomass (Andresen et al., 2009). Besides, it is also advantageous to incorporate native plant species to the green roofs as they are believed to have evolved as part of the region’s ecosystem (Virginia Department of Education, 2013).

3.3 SCENARIOS

The two numbers we found for *Sedum* sequestration were very different. In addition, there was insufficient information on Dalhousie University campus roofs, so we made assumptions in relation to roof area. These assumptions could be incorrect; however we accounted for this in the results with scenario calculations. We performed calculations for four different scenarios using the two sequestration results and both a best case and worst case scenario for usable roof area. These calculations are simply a linear relationship, and therefore linear interpolation can be used to determine the carbon sequestration of any roof coverage percentage between 50% and 100%, for the respective specific sequestration rate. In the best case scenario, 100% of the roof area we approved in our building selection would be converted to green roof area. In the worst case scenario, 50% of the roof area we approved would be converted to green roof. For example, if some buildings we said could hold green roofs actually cannot, or if some buildings can’t fill 100% of their roof with vegetation, the 50% scenario would account for this. The results of the four scenario calculations are shown in Table 6.

Table 6: Scenario Calculations

Specific Sequestration Rate	Roof Coverage	Total Roof Surface Area	Total carbon (C) sequestered	Total Carbon Dioxide (CO ₂) Sequestered
5.87 kg/m²	100%	63,164 m ²	370,773 kg C	13,585,348.56 kg CO ₂
	50%	31,582 m ²	185,386 kg C	679,265.05 kg CO ₂
0.375 kg/m²	100%	63,164 m ²	23,687 kg C	86,790.54 kg CO ₂
	50%	31,582 m ²	11,843 kg C	43,393.44 kg CO ₂

4 DISCUSSION

The goal of this project was find the carbon sequestration potential of installing extensive green roofs on pre-existing buildings on Dalhousie University's Halifax campuses. According to our calculations, the answer to this is 11,843 to 370,773 kg of carbon in the first year of green roof installation. This results in a mass of 43,393.44 to 13,585,348.56 kg of carbon dioxide being removed from the atmosphere. After the first year, more carbon would be sequestered in the soil, but not quite as much as was sequestered in the first year (Whittinghill et al., 2014). This is a very wide range of results, making it difficult to interpret. The main reason the range was so large was the differing results of the literature review, suggesting that more research is needed to understand carbon sequestration of plants on green roofs.

Taking the median of our range (6,814,371 kg of carbon dioxide), installing green roofs on viable Dalhousie University buildings would sequester enough carbon to be the equivalent of taking approximately 2,166 mid-size cars off the road for one year*. The full range of calculations for different vehicles can be seen in Appendix B. It is important to note that these results only consider carbon dioxide from the combustion of fuel, not for the entire life cycle of the car. Although this result is substantial, Dalhousie University's carbon footprint is much larger, and this sequestration only represents 7.00% of the total footprint. This is also based on a generous assumption that the median sequestration rate is used. Dalhousie currently emits greenhouse gasses at a rate of around 97,393,000 kg carbon dioxide equivalents per year (Office of Sustainability, 2014). This is roughly equal to the mass of 537 blue whales, based on a blue whale mass of 181,437 kg (National Geographic, n.d.). The highest sequestration estimation would sequester carbon dioxide equivalent to the weight of approximately 75 blue whales. This shows that in order to offset Dalhousie University's large carbon footprint, many other methods of carbon reduction may need to be implemented.

This study filled a gap in existing research; there was no research done on carbon sequestration of all viable roofs on the Halifax campuses. However, this research did not consider two other things: the amount of carbon dioxide emitted when building a green roof, and the amount of carbon dioxide emissions avoided through building energy savings from green roofs. By incorporating these two values, future research could find an overall net carbon footprint of green roofs.

* Based on a mid-size car driving a distance of 12,000 miles at a fuel consumption rate of 33 miles per gallon and a carbon dioxide production rate of 8.65 kg CO₂ per gallon of fuel.

5 CONCLUSION

The feasibility analysis indicated that the assessment of the carbon sequestration potential was relatively small, sequestering only 7% of Dalhousie University's total emissions. This is a highly variable estimation due to the lack of precision associated with the specific carbon sequestration rates. However it is still clear that green roofs would be unable to outbalance the total carbon dioxide emissions, even if installed on all viable buildings on Dalhousie's University Campus. Fortunately, this is still a sufficient amount of carbon dioxide sequestration to equate removing 2,166 mid-size cars from the road. Even though the sequestration results are very small, it would still provides Dalhousie University with a smaller global warming impact. It is strongly believed that additional research is required in the hope to ensure a more sustainable and safe environment through the means of extensive green roof carbon sequestration.

Our research examined existing buildings on Dalhousie's Halifax campuses, rather than ones yet to be built. Older buildings do not have green roofs, suggesting that the option of greening old buildings has not been looked into. Based on our results, it would be worthwhile for Dalhousie to implement green roofs on older buildings in order to reduce the carbon footprint of the University.

In conclusion, green roofs are a valuable part of any initiative for improving the sustainability of buildings on campus. For this reason, it is highly recommended that Dalhousie University consider the implementation of additional green roofs or other sustainable techniques to mitigate environmental impacts and provide additional opportunities for research.

5.1 RECOMMENDATIONS

The purpose of this research project was to focus on the carbon sequestration potential of installing additional green roofs on viable buildings on Dalhousie University Halifax's campuses. We kept the scope of our research rather narrow. We only examined the carbon sequestration potential of *Sedum* plants that were cultivated on green roofs (due to its prevalent use in Nova Scotia and the availability of research), and only considered green roof implementation for relatively flat rooftops (to maximize the likelihood of implementation without delving into a large amount of detail regarding costs). The scope of our project could be broadened by exploring the effectiveness of more plant and roof types, and by including buildings beyond Dalhousie University's campuses on the Halifax peninsula.

Nevertheless, it has been illustrated that extensive green roofs can be successfully installed on uneven surface rooftops, though installment costs are estimated to be moderately higher. As such, research can be broadened by incorporating factors that were not included. In this research, green roofs are simply a

sustainable technique that may help pave the way for Dalhousie University to undertake sustainable management. Dalhousie University can also consider other environmentally friendly initiatives to enhance the health of the surrounding environment while reducing expenses from energy use.

This study focused on existing and old buildings rather than new ones. It is counter-intuitive to attempt to reduce carbon footprint by building LEED certified buildings, because unless these buildings are completely carbon-neutral, they will add to the carbon footprint of the school. Finding innovative and efficient ways to improve old buildings is crucial to reducing Dalhousie's footprint. A green roof is one strategy, but it should be accompanied by many others, such as changing old lights and plumbing fixtures, or making heating more efficient.

6 ACKNOWLEDGEMENTS

We would like to thank our wonderful course instructor Dr. Tarah Wright for helping us improve our research strategies and allowing us to do this research in her course. Thank you to Adam Cheeseman, the Teaching Assistant whose sage advice guided us through the project weekly. As well, being Dalhousie students has allowed us to access information that would otherwise be private to us, so we are grateful that Dalhousie allowed us to do this research in its full capacity.

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APPENDIX A- GIS STEPS

GIS Steps

The following are the steps taken using ArcGIS using the Halifax Municipality 2012 Corporate Dataset to calculate the total surface area of roof space in metres squared on Dalhousie University's Carleton, Sexton, and Studley campuses.

Calculating roof area from existing building shapefiles

After desired Dalhousie University buildings were selected manually using Select by Attributes, making the buildings their own shapefile by:

- Select Export Data

- Export: Selected Features

- Output feature class: "DalBuildings.shp"

Dissolving "DalBuildings.shp" so that a total area may be calculated:

- Input features: DalBuildings.shp

- Outputfeatures: DalBuildings_dissolve.shp

Calculating the area of "DalBuildings_dissolve.shp":

- Open Attribute Table

- Add Field...

- Name: Area_m²

- Type: Double

- OK

Right click the "Area_m²" column in the "DalBuildings_dissolve.shp" Attribute Table

- Calculate Geometry...

- Property: Area

- Units: Square Metres [m²]

- OK

Exporting the "DalBuildings_dissolve.shp" Attribute Table to a file format that Microsoft Excel can read:

- Export...

- Output table: DalBuildings_TotalArea.csv

- OK

Creating new Dalhousie University building polygons

Using ArcCatalog, created a new shapefile titled "New_DalBuildings.shp" with the Spatial Reference "NAD_1983_CSRS_UTM_Zone_20N" (the same coordinate system as the Halifax Regional M Data 2012).

Added it to the working ArcGIS file.

Using building lot sizes, adjacent buildings, and Google Maps (2016) as reference, building polygons were drawn.

Added a new field titled "Names" to the "New_DalBuildings.shp" Attribute Table

In Edit Toolbar, added appropriate building names to the "New_DalBuildings.shp" Attribute Table

Calculating the area of new Dalhousie University building polygons

Calculating the area of "New_DalBuildings.shp":

Open Attribute Table

Add Field...

Name: Area_m²

Type: Double

OK

Right click the "Area_m²" column in the "New_DalBuildings.shp" Attribute Table

Calculate Geometry...

Property: Area

Units: Square Metres [m²]

OK

Exporting the "New_DalBuildings.shp" Attribute Table to a file format that Microsoft Excel can read:

Export...

Output table: NewDalBuildings_Area.csv

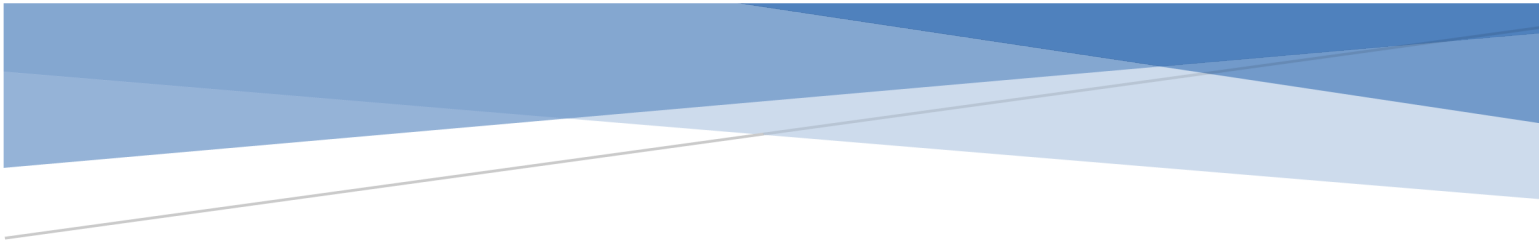
OK

APPENDIX B- CARBON SEQUESTRATION CAR EQUIVALENCY CALCULATIONS

	Miles/Gal	Average Distance Driven (miles)	Carbon Dioxide Produced (kg removed)	Cars Removed From Road (Small Sequestration)	Cars Removed from Road (Large Sequestration)	Cars Removed from Road (Median Sequestration)
Small Car	37	6000	1403.31	31	9681	4856
		9000	2104.97	21	6454	3238
		12000	2806.63	16	4841	2428
Medium Car	33	6000	1573.41	28	8635	4331
		9000	2360.12	19	5757	2888
		12000	3146.82	14	4318	2166
Large Car	24	6000	2163.44	21	6280	3150
		9000	3245.16	14	4187	2100
		12000	4326.88	11	3140	1575
Hybrid	50	6000	1038.45	42	13083	6563
		9000	1557.68	28	8722	4375
		12000	2076.90	21	6542	3282

Carbon dioxide emissions from fuel combustion were estimated from four different internet sources. It was found that emission rate was 8.019 kg CO₂/Gal (American Forests, n.d.), 8.91 kg CO₂/Gal (EIA, 2015) 8.89 kg CO₂/Gal (USEPA, n.d.) and 8.80 kg CO₂/Gal (USEPA, n.d.). An average emission rate of 8.65 kg CO₂/Gal was used to perform the calculations. It was also found that the fuel efficiency of a small car, medium car and large car could be estimated at 24 miles/Gal, 33 miles/Gal and 37 miles/Gal, respectfully (Carbon Independent, 2015).

APPENDIX C- TEAM MUIR PROPOSAL



GREEN ROOF CARBON SEQUESTRATION POTENTIAL OF DALHOUSIE'S HALIFAX CAMPUSES

Preliminary Research Proposal

Submitted to Dr. Tarah Wright and Adam Cheeseman
March 3, 2016

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1 PROJECT DEFINITION

Though it is wildly controversial among the masses, there is substantial scientific consensus that human activity creates greenhouse gas emissions that contribute to climate change (Boer, 2014). Though it is difficult to predict the effects of climate change, it will likely have adverse impacts on ecosystems (Döll & Zhang, 2010) and society (Easterling & Apps, 2005). Carbon dioxide is a major greenhouse gas of concern, which humans emit by burning fossil fuels for electricity (“Carbon Dioxide Emissions,” 2016). Dalhousie University emitted over 84,000 tonnes of carbon dioxide in the academic year of 2013-2014. To improve their practices, Dalhousie University is taking steps to mitigate and reduce their carbon footprint (Office of Sustainability, 2014). In light of the Dalhousie Office of Sustainability’s goal of carbon neutrality, our research investigates the feasibility of a project that would offset carbon emissions. This offset would be achieved through carbon sequestration, a process by which atmospheric carbon is removed from the atmosphere and stored in another form (liquid or solid). Specifically, our project will focus on carbon sequestration by plants: through photosynthesis, plants remove carbon dioxide from the air, and store it in their tissues as sugar.

There are not as many opportunities for plant carbon sequestration in the City of Halifax (where the larger Dalhousie campus is) as there are in rural areas. An innovative solution to this is a green roof; a roof of a building that is covered with vegetation. Dalhousie University already has some green roofs installed such as the Mona Campbell building and soon, the LeMarchant Place Building. Our research will find more potential for green roofs on Halifax campus (i.e. the Carlton, Sexton, and Studley campuses) buildings.

Our research will determine the carbon sequestration potential of installing extensive green roofs on viable buildings pre-dating 2016 on Dalhousie University’s Halifax campuses. Extensive is defined in part 2.1, and the determination of what constitutes a viable building is set out in section 3.

2 BACKGROUND AND RATIONALE

2.1 GREEN ROOFS

Green roofs are classified into two types, intensive and extensive. Intensive green roofs are often intended for public access and consist of greater soil depths than extensive green roofs. Intensive green roofs are able to host a larger diversity of plant species and deeply-rooted plants due to their greater soil depths. They are much heavier in weight than extensive green roofs, often requiring more costly and complex building design structures to support them (Credit Valley Conservation [CVC] & Toronto and Region Conservation Authority [TRCA], 2008). Intensive green roofs are often intended for public access and require regular maintenance.

Extensive green roofs are much smaller in depth and more lightweight than intensive green roofs. Although they can support a smaller selection of plant species, extensive green roofs require less maintenance than intensive green roofs because they are not intended to be seen by the public. Additionally, they also do not require fertilization and irrigation like intensive green roofs.

Our research focuses on extensive green roofs because, as noted above, intensive green roofs are more costly and require more structural stability. This means an extensive green roof is more feasible to be implemented on Dalhousie University Halifax campus buildings.

2.2 GREEN ROOF BENEFITS

Environmental

From an environmental perspective, one benefit is that green roofs aid in the management of storm water runoff. Storm water is stored by the substrate and later taken up by plants, where it returns to the atmosphere through transpiration and evaporation (Green Roofs for Healthy Cities [GRHC], 2014). In this way, green roofs delay the time at which runoff occurs, thus decreasing stress on sewer systems. In summer months green roofs retain 70-90% of the precipitation that falls on them, while in winter they retain between 25-40% (GRHC, 2014).

Vegetation on roof tops also reduces what is known as the 'Urban Heat Island' effect by absorbing light which would otherwise be converted into heat energy. Through the process of evapo-transpiration, moisture is able to re-enter the atmosphere and cool cities in the process (Draper, 2002). Green roofs also reduce the distribution of dust and particulate matter throughout the city, in addition to smog, which can play a role in the reduction of greenhouse gas emissions as well as adapting urban cities to a warmer climate (GRHC, 2014).

Improved air quality is another environmental benefit of green roofs. The plants on green roofs are able to capture airborne pollutants and atmospheric deposition, while also filtering noxious gases (GRHC, 2014). By moderating temperature, green roofs may also reduce demand on power plants, potentially decreasing the amount of carbon dioxide and other pollutants being released into the air (GRHC, 2014).

Economic

Roofs transfer the greatest heat loss from buildings in the winter and the hottest temperatures into buildings in the summer (GRHC, 2014). Increased insulation which green roofs provide for buildings allows for a reduced dependence on energy to moderate the temperature of the building. Indoor temperatures have been

shown to be 3-4 °C lower under a green roof when outdoor temperatures are between 25 to 30 °C, and in the winter heat loss is minimized through added insulation on the roof (Dunnett & Kingsbury, 2004, 33). Owners therefore have the opportunity to save money on the climate control of the building. Additionally, green roofs have the potential to out-live conventional rooftops, which is a long-term cost saving benefit (GRHC, 2014).

2.3 RELEVANT WORK CONDUCTED

In 2006, a group of students enrolled in the course Environmental Problem Solving II (ENVS 3502) conducted an analysis to determine the feasibility of a Rainwater Collection system (RWCS) at Dalhousie University. The foremost objective of their research was to examine an alternative sustainable solution to reduce water consumption on campus. In the course of their data generation, the team chose interactive techniques such as interviews and surveys to obtain any crucial information and recommendations from professionals “in the areas of water resource management, geology, engineering, plumbing, urban planning and economics” (Abdul et al., 2006). Other procedures undertaken by the team include an extensive research on the functioning of RWCS and water usage at Dalhousie University. Subsequent to the compilation of the gathered information, their analysis has indicated the area between University of King’s College and Life Sciences Centre as the most feasible location for an installation of RWCS (Abdul et al., 2006). In spite of the fact that their research study was predominantly on RWCS, their article does contain discussion that relates to green roofs. Hence, reviewing their research study could be beneficial because both RWCS and green roofs are categorized as sustainable development designs.

In 2009, a feasibility analysis of a green roof on the Life Science Center was conducted by a group of students enrolled in the same university course. They conducted a cost-benefit analysis of the economic, environmental and social impacts of green roofs. They found that though the environmental benefits of green roofs outweigh the environmental costs, economic costs can initially be high and social benefits are difficult to quantify. A limitation of their study was a lack of information regarding Life Science Center’s structure and roof capacity (Block et al., 2009). Lastly, the team concluded that their project would be beneficial to anyone has similar interest to transform Dalhousie University into a more environmentally friendly campus. This report gave a lot of information on the costs and benefits of green roofs, but was restricted in scope to the Life Science Centre and was limited in the information they could obtain about the building’s structure. Our study will use a variety of methods to get as much information as possible about campus building structure, so that physical feasibility of green roof installation can be established in the literature.

In 2015, another group of students also conducted a study, which examined a possible strategy that can help to mitigate the risks of storm water on Studley campus through the installation of green roofs. The goal of their study was to “address the current issues with storm water management on Studley campus and apply a sustainable solution to mitigate associated environmental damages” (Cranstone et al., 2015). Their report acknowledged the installation of a green roof as an affordable and highly effective way to improve storm water management and reduce the amount of water reaching sewers. Through the use of GIS, the project defined the total viable surface area of buildings on Studley Campus and estimated the installation cost to the University (Cranstone et al., 2015). Although this study was similar in the sense that it focused on the potential of installation of green roof for Dalhousie’s Studley campus, the project only concentrated on the effects that green roofs would have on the reduction of storm water on campus. In contrast to their project, our project will contribute to the information on projected benefits of green roof installation on Dalhousie campus by adding information regarding carbon sequestration potential.

In addition, our study will approximately quantify the amount of carbon sequestered by green roof installation. This will give the Office of Sustainability numbers to work with as they project their carbon footprint in the future.

2.3.1 Policies on Green Roofs in Halifax

The installation of green roofs across the Dalhousie Halifax campuses would align with Dalhousie's Sustainability Policy. This policy indicates that Dalhousie focuses on sustainability goals, which include supporting physical systems that enhance sustainability and decrease air emissions (Dalhousie, 2009). A green roof is a physical system that not only enhances sustainability, but has potential for decreasing air emissions through carbon sequestration. The policy also indicates that new and existing policies will be developed to achieve these sustainability goals (Dalhousie 2009). Thus, in 2011, Dalhousie University approved a sustainable building policy to reduce environmental impacts and represent leadership in sustainable building practices. The policy indicates that any new building greater than 10,000 sq. ft will be designed to achieve LEED gold certification, at a minimum. The policy also indicates that any smaller renovations and retrofits will be considered for sustainable building, and the concept of LEED for existing buildings will be explored (Dalhousie, 2011). The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is designed to benchmark high performance green buildings.

Although green roofs are not mandatory for LEED certification, there are several rating points that can be obtained from benefits associated with green roofs. The LEED Gold certification requires qualification for at least 60 of the 110 available rating points, and the implementation of green roofs can help achieve this goal (Canada Green Building Council, 2009). Because of this, our project assumes that most buildings constructed on Dalhousie Halifax campuses in the future will have green roofs. Thus, our project explores the somewhat neglected possibility of green roofs on existing Dalhousie Halifax campus buildings.

Although green roofs provide unique opportunities for sustainable building, there are currently no regulations or by-laws that require their implementation within Halifax. However, it is worth noting that this may not be the case in the future. In fact, Toronto implemented a green roof by-law in 2009 which required the installation of green roofs for large institutional and industrial buildings (City of Toronto, 2013). Installation of green roofs may help compliance with any future policy or regulation amendments in the Halifax area.

3 PROPOSED RESEARCH METHODS

To determine which buildings are viable, we will conduct a literature review of past student projects on the subject of green roofs at Dalhousie, and if necessary will conduct interviews with knowledgeable persons. To determine the carbon sequestration potential, we will conduct a literature review on plant species native to Nova Scotia that could thrive on a green roof and the carbon sequestration potential of these plants. We will attempt to quantify the amount of carbon that these plants could sequester. We will find the area of the roofs of viable buildings using Arc Geographic Information System (ArcGIS). With the quantities of carbon sequestration and roof area, we will make calculations to determine the potential for carbon sequestration on Dalhousie’s Halifax Campuses.

3.1 METHODS OVERVIEW

The research being performed is deductive and quantitative in nature. The literature research performed in the background study indicates that an extensive green roof is able to sequester carbon from the atmosphere. This means it is reasonable to expect that the Dalhousie University Halifax campuses would be able to sequester carbon if extensive green roofs were installed. The quantitative data collected will allow for the estimation of the amount of carbon sequestration possible, if extensive green roofs were installed.

The purpose of the research is to determine the carbon sequestration potential from installing extensive green roofs on viable buildings in the Dalhousie University Halifax campuses. Therefore, there will be quantitative data collected based on Dalhousie University building information and carbon sequestration potentials of extensive green roofs. The major goal is to collect building surface area (m²) and carbon sequestration potentials (g CO₂/m²) to determine the total amount of carbon (g CO₂) that could be sequestered. The types of data being collected and the methods of collection have been briefly summarized in Table 1. Building information will be collected by first determining the number of Dalhousie University buildings which are capable of supporting an extensive green roof. This information will then be used to determine the total surface area available for extensive green roof installation. Carbon sequestration potential information will be collected based on existing extensive green roofs and varying vegetation species. Vegetation species will focus on vegetation that is able to acclimate to the Halifax climate. The methods of data collection will include ArcGIS analysis, and literature review. Interviews will be conducted only if the literature review and GIS analysis is unable to provide sufficient information. The majority of the data collection will be associated with literature research.

Table 3-1: Summary of Data Collection Methods

Information	Data to be Collected	Method of Collection
Building Information	Buildings capable of supporting a green roof within Halifax Campus	Literature Review Interview
	Total surface area of viable green roof space	ArcGIS Software
Carbon Sequestration Potential	Determination of optimal plant species for green roofs at Dalhousie	Literature Review
	Carbon sequestration potential of specific plant species	Literature Review
	Total carbon sequestration potential of Halifax Campus	Data Analysis

3.2 DATA COLLECTION

3.2.1 Literature Review

The literature review will be performed by analyzing previous studies performed on green roofs. The first task will be reviewing previous projects conducted at Dalhousie University that are associated with green roofs. This will be done in the attempt to determine if there are any previous studies referring to the viability of green roofs on Dalhousie campus buildings. These studies would be able to provide the buildings capable of supporting a green roof. If this information is unavailable, then studies will be performed on Dalhousie University roof characteristics that are capable of sustaining a green roof. Dalhousie University infrastructure information will be analyzed using ArcGIS. Finally, literature review will be performed to determine potential plant species for implementation on the green roof. This will involve researching characteristics of different plants such as native location, carbon content, carbon sequestration potential, etc. Different species will be able to sequester different quantities of carbon, based on their growing capacity. The total carbon sequestration will be calculated from values used from literature, based on plant species and extensive green roof data.

An interviewing process will be considered if the desired information regarding Dalhousie University infrastructure is not available. This will involve non-probabilistic criterion sampling through the process of interviewing persons with the knowledge on green roof technology and Dalhousie University Halifax campus infrastructure. The interview will be conducted in the form of an exploratory consultation. The interview process will request information regarding which buildings are capable of supporting extensive green roofs.

3.2.2 ArcGIS

ArcGIS, a computer program provided by Esri with permission from Dalhousie University (Dalhousie University, 2015a), will be used to calculate the total surface area of viable green roof space on Dalhousie University's Halifax campus buildings. Use of this research tool will be quantitative in nature.

To use ArcGIS as a research tool, data is required. Specifically, data on building footprints (representing the space buildings take up, and thus the size of their roofs) within Dalhousie University's Carlton, Sexton, and Studley campuses is needed. Data for buildings will be obtained through the use of Dalhousie University GIS Centre's in-house data. Permission to use this data is granted to Dalhousie University faculty, staff, and students (Dalhousie University, 2015b; Dalhousie University, 2015c); thus, the SUST 3502 students undertaking this project will have access to these datasets. In the case that these datasets do not provide sufficient building data, the appropriate shapefiles will be created manually in ArcGIS using satellite imagery (included in the Dalhousie University GIS Centre's datasets) as a base reference.

3.3 DATA ANALYSIS

3.3.1 Calculations

The carbon sequestration potential of extensive green roofs on Dalhousie campus will be analyzed by using the surface area calculated from ArcGIS and the values obtained from green roof and plant species

research. The carbon sequestration potential of the various plant species will be reviewed to determine the optimum sequestration rate. The optimum value can then be multiplied by the total available surface area to determine the total carbon sequestration.

3.3.2 ArcGIS

ArcGIS will be used to calculate the total surface area of viable green roof space in metres squared (m²) on Dalhousie University's three Halifax campuses. In data analysis, this information will be used in conjunction with data regarding carbon sequestration potential and which roofs are capable of supporting green roofs to determine the total amount of carbon that may be sequestered.

Once the data identifying which buildings could support green roofs is gathered through literature review, in ArcGIS the shapefiles of those buildings will be selected and exported as a separate layer. The area of each building shapefile can then be calculated in ArcGIS in metres squared and exported in a format that may be viewed at a later time either in ArcGIS or Microsoft Excel.

In this process any major roof features (such as ventilation devices) that would not support a green roof must be acknowledged. To deal with this, shapefiles will be created for these roof features, their areas will be calculated and exported from ArcGIS, and then those areas will be subtracted from the building area data in Microsoft Excel. If this process does not work as expected, an alternative way of dealing with these roof features has been identified. Here separate building shapefiles which do not include the roof features may be created, and their areas can then be calculated and exported.

A major benefit of using ArcGIS as a research tool is that once the appropriate data (shapefiles) are gathered, the program almost instantly calculates the area values required by the project with only small effort exerted by the user. ArcGIS can also then be used to create maps to aid with the representations of research findings in written reports or presentations.

3.4 DELIMITATIONS AND LIMITATIONS

A delimitation in our study is the buildings we will eliminate from the study based on certain criteria such as minimum roof area (a very small roof may not be worth renovating) or type of roof (buildings with flat, broad roofs will be favoured over buildings with pitched roofs). More precise criteria will be established throughout the research process.

Another delimitation is an assumption of which vegetation types will be planted in order to provide carbon sequestration calculations. A standard set of plants will be selected for the calculations of carbon sequestration across each of the three campuses, rather than determining a desired set of plants for each individual building.

A limitation to this project is the detail in which the potential carbon sequestration of Dalhousie University Halifax campus buildings can be calculated. These calculations will be limited according to what data is available in the literature. Data will also be limited temporally depending on what time range the data covers, as well as in scope, depending on which green roof plant species have carbon sequestration data.

4 SCHEDULE AND BUDGET

Team Muir’s research project schedule is summarized in a Gantt chart, presented as Figure 1. Further information on the proposed tasks and who is designated to complete them is provided in Table 4-1. Our team members will procure all work. As such, funding is not required to continue with our proposed research.

Table 4-1: Tasks and Milestones with Responsibilities

Week (Dates all 2016)	Tasks and Milestones	Responsibility
Week 3 (Jan 24-30)	ENVS 3502 groups assigned	--
	Jan 26- Worksheet completed	Everyone
	Secret Facebook group set up	Hut
Jan 31- Feb 6	Weekly meeting- determination of research methods	Everyone
Feb 7- 13	Create proposal template and Google Document Folder	Nikki
	Review of potential GIS requirements and capabilities	Sam
	Review of existing/capacity of green roof species	Hut
	Consider structural and technical requirements	Cody
	Initiate literature review	Olivia and Jasmin
	Weekly meeting- research project development	Everyone
	Snow day Work Sheet	Everyone
Feb 14-20 (Study break)	Individualized Research	Jasmin, Hut, Olivia
	Finalize research question	Lead by Sam, supported by team
	Review past ENVS 3502 proposals	Everyone
	Develop methods	Sam and Cody
	Group meeting to delegate sections of proposal writing	Everyone
Feb 21- 27	Group meeting- to finalize our research question and proposal responsibilities	Everyone
	Weekly meeting- finalization of methods section	Everyone
Feb 28- March 5	Group meeting- work towards proposal	Everyone
	Research proposal due March 3rd	Everyone
March 6- 12	Review feedback on proposal	Everyone
	Determine if interviews are required	Cody and Sam
	Literature review	Olivia, Jasmin and Hut
March 13-19	Further delineate roles and responsibilities to complete our research project	Everyone
March 20-26	Brainstorming session for presentation	Everyone
March 27- Apr 2	Internal Review Pecha Kucha Slide	Everyone
	Draft research project due for internal review	Everyone
Apr 3- 9	Pecha Kucha prep and presentation	Everyone
Apr 10-16	Finalize and submit final Project	Everyone

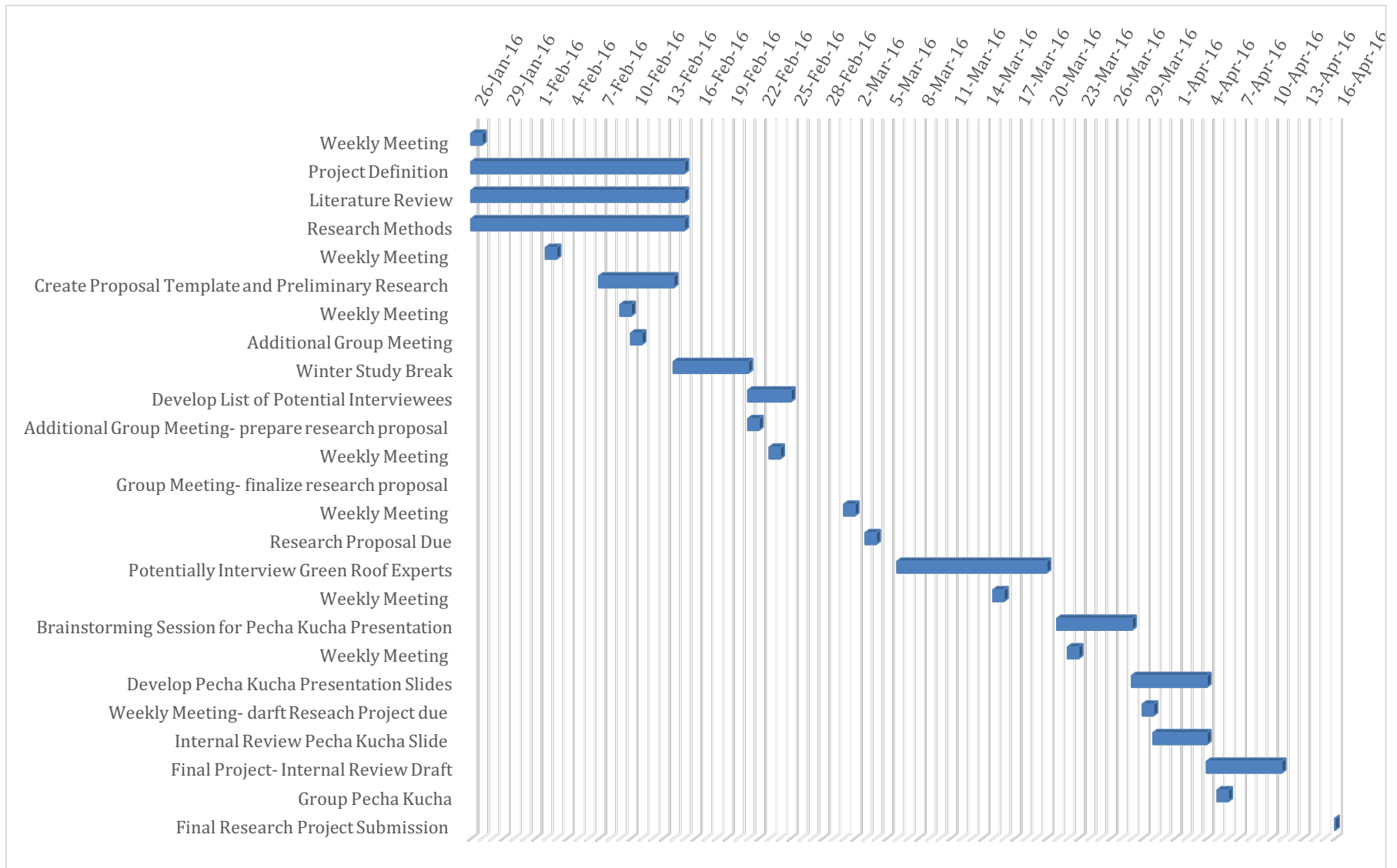


Figure 1: Team Muir's Research Project Development Schedule

5 COMMUNICATION PLAN AND DELIVERABLES

The purpose of this project is to provide an understanding of the carbon sequestration potential if green roofs were installed on viable Halifax campus buildings. We hope our project will be useful to Dalhousie University; specifically the Office of Sustainability, as they consider how to meet their goal of carbon neutrality. Our communication objective is to provide clear and defensible research that can be considered by the Office of Sustainability, our professor Dr. Tarah Wright, our mentor Adam Cheeseman, as well as current and future ENVS 3502 students.

In developing our work, our team will communicate by three main methods:

1. In-class group discussions (held weekly)
2. Sunday Research Group sessions (as required)
3. Facebook and Google Docs- ongoing discussion and sharing of information related to our research

Our major deliverable will be our final report that presents our project, outlines our methods and summarizes our findings. In addition, our group will develop a presentation to be delivered on April 5, 2016.

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Evaluation

Project Definition – 4.5/5

Background and Rationale – 4.5/5

Research Methods – 4/5

Schedule and Budget – 3.5/5

Deliverables and Communication Plan – 5/5

References and Appendices – 4/5

Organization, Specifications and Writing Style – 3.5/5

Total – 29/35 or 8.3/10

Key Next Steps – You need to consider our comments and add in some updated references especially in background and methods. No budget included. Really great proposal overall, keep up the good work!