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Nathan Splinter, Manager of Energy and Sustainability
Queen's Facilities
207 Stuart Street
Kingston, ON K7L 3N6

Carbon Connected
45 Union St
Kingston, ON

April 22, 2022

RE: Final Report for Queen's University Facilities Carbon Embodiment Project

Dear Mr. Gerrish and Mr. Splinter,

Please find attached the final report for Carbon Connected's project relating to embodied carbon in new construction at Queen's University.

This report outlines our final research which includes existing embodied carbon measurement tools, other universities' sustainability goals and low-carbon buildings, and financial considerations. It also includes our recommendations for software, benchmarks, and goals. Finally, a case study was conducted using the recommended software as a proof-of-concept.

Please note that this report was designed for Queen's Facilities and the contents shall not be used for any other purpose than the intended project. Please feel free to contact us with feedback or any questions.

Sincerely,

Spencer Robins
17sir@queensu.ca

CARBON CONNECTED

Embodied Carbon in New Construction at Queen's University

CIVL 460 – Final Report

Benjamin Anderson, Madelaine Smith, Spencer Robins

20102294, 20091230, 20099459

March 28, 2022

Our signatures below attest that this submission is our original work. This report was designed for use by Queen's Facilities and shall not be used in any other case. Further, this report is a draft and is subject to change as the project progresses. Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Civil Engineering departmental web site (www.civil.queensu.ca/undergraduate) and confirm that this work is in accordance with the Policy.

Benjamin Anderson | **Madelaine Smith** | **Spencer Robins**

Executive Summary

Queen's Facilities contracted Carbon Connected to conduct an evaluation of approaches and modelling tools for determining and lowering the embodied carbon emissions in new construction at the university. Embodied carbon is the carbon dioxide (CO_2) emissions associated with materials and construction processes throughout the whole lifecycle of a building or infrastructure. Embodied carbon accounts for 11% of annual global CO_2 emissions. Therefore, it is an urgent issue and is critical to the mitigation of the effects of climate change.

The team's goal is to develop an overview of tools and methods that exist for the measurement and reduction of embodied carbon. The final deliverable will include: a detailed report that explains the technical background and methodology; a one-page, high-level document that can be distributed and explained easily to consultants, contractors, and top Queen's officials; and an oral presentation delivered to Queen's Facilities outlining the project recommendations.

The team conducted research through information provided by the client, online sources, and expert interviews. The main topics of research were on embodied carbon, methods to calculate embodied carbon, existing tracking tools and software, The Canadian Green Building Standards, the Queen's Climate Action Plan, LEED, and investigating sustainability goals at other universities. The team used the research to develop an evaluation method for potential solutions and set meaningful targets that the final solution will aim to achieve.

Carbon Connected recommends the use of OneClick LCA as a software to measure embodied carbon and find sustainable alternatives for materials. OneClick LCA meets all of Queen's Facilities' needs and includes additional features that the clients may find helpful. The team recommends Queen's set a goal of 50% embodied carbon reduction compared to a baseline building by 2030 and aim for all new buildings to be LEED Gold certified. This puts Queen's in line with the leader in embodied carbon reduction, the University of British Columbia. The team has also determined a set of financial and innovation recommendations to support these goals. The introduction of virtual and physical interactive content will visualize Queen's sustainability progress on campus to educate students and faculty. Furthermore, Queen's Facilities should promote a sustainability funding campaign that encourages Queen's alumni to donate specifically for sustainable building design on campus.

Using the student version of OneClick LCA, a case study was conducted using data from a new residence building currently under construction by Queen's University. Using data from architectural and structural drawings, along with EPDs provided by the client, Carbon Connected was able to show how the software could be used by Queen's Facilities.

This report that clearly defines the problem and its scope, the deliverables requested by the client. Thorough background information clarifies why embodied carbon is an important topic and connects it to Queen's, the climate, and society. A set of final recommendations is determined that covers the environmental, social, financial, and innovation aspects of the project.

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List of Acronyms and Abbreviations

Building Code Act of 1992	BCA
Building Design and Construction	BD+C
Canadian Green Building Council	CaGBC
Canadian Green Building Standards	CaGBS
Carbon Dioxide	CO_2
Canadian Institute of Steel Construction	CISC
CIVL 460 Group D	Carbon Connected
Environmental Product Declaration	EPD
Greenhouse Gas	GHG
International Standards Organization	ISO
Kilograms of Carbon Dioxide Equivalent	kg CO_2e
Leadership in Energy and Environmental Design	LEED
Life Cycle Assessment	LCA
National Building Code of Canada	NBCC
Climate Action Plan	CAP
Queen's University Facilities	Facilities
United Nations	UN
United States Environmental Protection Agency	EPA
Zero Carbon Building	ZCB

1.0 Introduction

In September 2021, Queen's University Facilities ("Facilities") contracted CIVL 460 Group D ("Carbon Connected") to conduct a comprehensive evaluation of potential approaches and modelling tools for determining the embodied carbon emissions for materials used in new construction at Queen's University in Kingston, Ontario. The project includes researching metrics or targets for embodied carbon in new construction for potential integration into the Queen's Building Standards. The overall methodology is outlined in a multiphase approach and the scope is described in greater detail below. This final report outlines our research which includes existing embodied carbon measurement tools, other universities' sustainability goals and low-carbon buildings, and financial considerations. It also includes our recommendations for software, benchmarks, and goals. Finally, a case study was also conducted using the recommended software as a proof-of-concept.

2.0 Project Description

Nathan Splinter and David Gerish act as the main points of contact for the client, Queen's Facilities. Nathan Splinter is the Manager of Energy and Sustainability at Queen's whose work includes pursuing goals set by the Queen's Climate Action Plan (CAP), a blueprint developed to engage in activities aimed at reducing greenhouse gas (GHG) emissions. The plan met its 2020 GHG emissions reduction target of 35% and aims to reduce emissions by 70% from the baseline by 2030. Ultimately, the plan targets net-zero emissions by 2040 for Queen's ("Queen's to announce Climate Action Plan" 2020). David Gerish is an Energy Specialist at Queen's University whose work includes reducing utility usage and carbon emissions. Splinter and Gerish represent Queen's Facilities, which focuses on the construction, operations, and maintenance of Queen's University. Their current work includes waste diversion, central heating plant switch to low carbon, and additional lower-carbon-emission projects ("Facilities | Queen's University" n.d.).

2.1 Problem Statement

The project addresses embodied carbon which is the carbon dioxide (CO_2) emissions associated with materials and construction processes throughout the whole lifecycle of a building. This includes emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials and is responsible for a significant percentage of global emissions ("1 - Embodied Carbon 101" 2020). According to a study by Architecture 2030 on annual global CO_2 emissions, as much as 11% of global emissions come from manufacturing building materials ("Embodied Carbon Actions – Architecture 2030" n.d.). Quantifying embodied carbon uses a method known as Life Cycle Assessment (LCA) to track emissions produced from when the product is first manufactured to the end of its life. It considers the amount of GHG emissions that are released throughout the supply chain, including phases such as extraction of raw materials, transportation, manufacturing, construction, demolition, and landfill ("Embodied Carbon" 2021). This emissions data is then converted into a metric that reflects potential environmental effects ("1 - Embodied Carbon 101" 2020). These effects are imperative to consider when taking steps against climate change. The world is currently experiencing irreversible and catastrophic effects caused by climate change, due in large part to the accumulation of CO_2 in the atmosphere ("1 - Embodied Carbon 101" 2020). Therefore, targeting these emissions is an urgent issue and is critical in protecting the future health of the planet. While there is extensive documentation from Queen's on construction building codes and sustainability plans, there is currently no framework in place for reducing embodied carbon. This is a vital gap in Queen's sustainability goals that must be addressed. The embodied carbon life cycle of a material is shown in Figure 1 below.

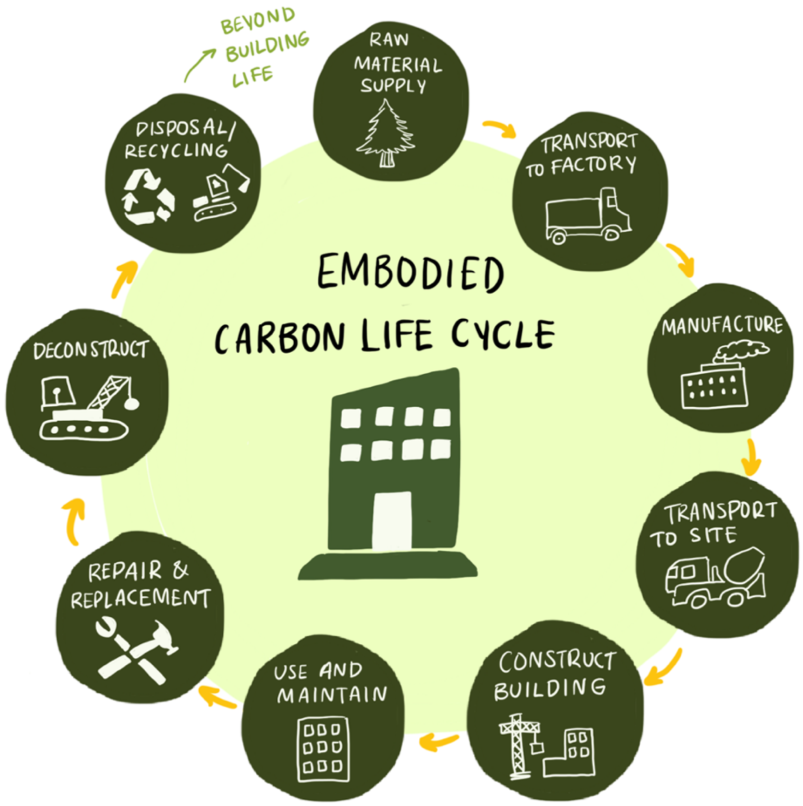

Figure 1: Circular Embodied Carbon Life Cycle Diagram

3.0 Scope

While Queen's has a well-developed general sustainability plan for the university, including net-zero operational carbon, there is a lack of embodied carbon modelling and reduction methodology. The team's goal is to develop an overview of current tools and methods used in industry for the measurement and reduction of embodied carbon. This project will be divided into seven major phases, corresponding to the Level 1 tasks in the Work Breakdown Structure shown in Figure 13 in Appendix A. The project will conclude in a final deliverable that will include: a detailed report that explains the technical background and methodology; a one-page, high-level document that can be distributed and explained easily to consultants, contractors, and top Queen's officials; and an oral presentation delivered to Queen's Facilities outlining the project recommendations.

This project's scope excludes operational carbon which refers to the GHG emissions associated with a building's energy consumption. The full life cycle of the carbon emissions is considered, however, including material extraction, transportation, manufacturing, construction, maintenance, repair, deconstruction, and disposal.

In the team's research and development, scaling existing solutions to the size and capability of Queen's construction projects/buildings is necessary. From a design perspective, the team seeks to develop a solution that is flexible and not limited to one model; a variety of digital, physical, and educational solutions are considered. This broadens the opportunity for innovation through various means.

4.0 Goals, Objectives, and Deliverables

The detailed report, one-page high-level document, and oral presentation are the major client deliverables for this project. The success of these deliverables is dependent on the client's satisfaction with the solution delivered in the report. The report will be successful in the short term if:

- The client can easily implement the solution into all new construction projects.

The report will be successful in the long term if:

- The implemented solution achieves the embodied carbon targets that it specifies.
- With the resources and time given to complete this report, it is feasible for Carbon Connected to deliver these stated goals.

By monitoring and reducing embodied carbon in new construction, Queen's will be able to lower its overall carbon emissions and therefore help reduce the impact of climate change.

5.0 Stakeholders

The main stakeholders for this project are Queen's University; Queen's Facilities, Queen's students and faculty; other Canadian universities; architects, consultants, and engineers; material manufacturers; and the construction industry at large. The team has included stakeholders in the decision-making when feasible. This includes continuous consultation with Queen's Facilities, and occasional contact with university officials, students/faculty, and industry professionals. An infographic depicting the main stakeholders is shown below in Figure 2.

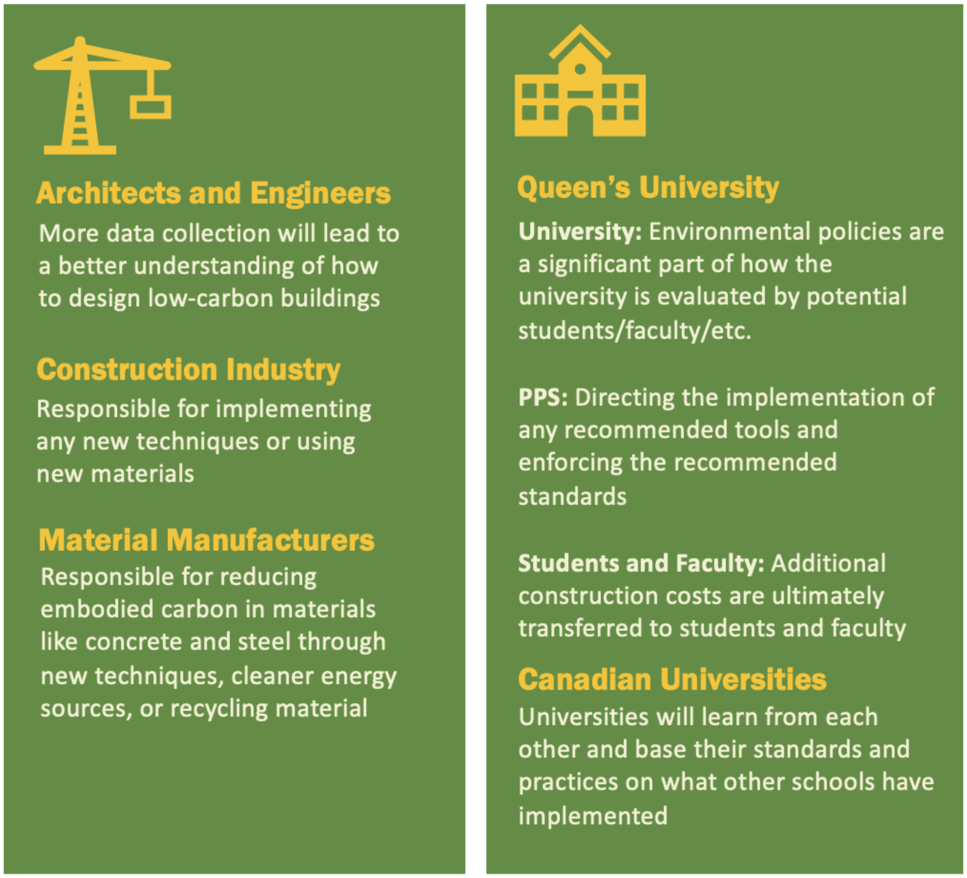

Figure 2: The primary stakeholders for the project.

6.0 Constraints and Considerations

There are a variety of constraints for the team in terms of the research and development of tools and standards. As well, constraints exist on Queen's Facilities in terms of the usability and enforcement of the recommended system.

6.1 Team Constraints

Given this project is being managed by students, it is restricted in terms of time, budget, resources, and available existing tools. The research, development, and delivery of the recommendation to the client must be completed within a 24-week time frame and will be presented to the client no later than April 15th, 2022. It must also be delivered at no cost to the clients or the university. The team lacks the expertise and resources to develop new software or tools for tracking embodied carbon, so the recommendation is limited to existing tools currently utilized in the industry.

6.2 Facilities Implementation Constraints

Any recommendations to materials or structures must comply with the Ontario Building Code and Queen's Building Codes. Additionally, Queen's codes must change to comply with any new provincial or federal embodied carbon policies that may be created in the future. The team's recommendations are also limited by what can feasibly be implemented by Queen's Facilities. There exist many materials and construction techniques that might greatly reduce embodied carbon but may be prohibitively expensive to implement. Moreover, there may be a variety of methods and tools that can precisely track and measure embodied carbon, but they could be too labour-intensive and time-consuming to use in this case. The recommendation must strike a balance between accuracy, efficacy, cost, and ease of use.

6.3 Economic Constraints

In the traditional economic cycle of construction, a linear path is followed; natural resources are gathered, transformed into building materials, and after the useful life of a building, discarded as waste. This practice, although economically efficient, does not consider the environmental aspect, and as such is not efficient from an embodied carbon standpoint.

To align with the ideas of leaders in the embodied carbon community, Carbon Connected is proposing to emphasize the principles of circular economy in new construction. The main tenet of a circular economy is to remove waste entirely. This is done by designing buildings to last longer, using high-quality materials, as well as designing for disassembly and reuse. By limiting waste, carbon is not being released back into the environment and is instead contained in construction.

The team's solution is also constrained by the budget of Queen's University. Because the recommendation is intended to be implemented in future construction projects, it must be economically feasible. The team has investigated the economics of past projects to gauge the financial commitment Queen's is willing to offer for new buildings. Further, the economics of similar low embodied carbon buildings will be analyzed to understand the cost differences between a sustainable and traditional design. A value will also be put on the reduction of embodied carbon to understand how much Queen's should be willing to pay for a given value of carbon savings.

6.4 Health and Safety Constraints

To guide the process toward an optimal solution, it is vital to recognize the importance and risk of health and safety. Accidents occur regularly in the construction industry and major risks must be addressed. As the embodied carbon project strives to implement a solution into the Queen's Building Standards, this concern is extremely relevant. Generally, major hazards that are encountered include working at heights, moving heavy objects, slips, trips, noise, hand and vibration syndrome, materials handling, asbestos, electricity, and airborne fibers and materials ("Top ten health and safety risks in construction" n.d.). These risks are essential to consider for this project's constraints and considerations. Decisions to reduce the embodied carbon of materials can greatly impact the health and safety of stakeholders. For instance, cutting back on materials with high embodied carbon may come at the cost of the safety of the building. Substituting materials for the sake of meeting targets poses many safety concerns. If the material was a lower quality than its GHG-emitting counterpart, this could result in a poorly constructed building (Jeusu and Burns n.d.).

Ensuring these risks will not be a problem is a major consideration in the project development. Currently, Queen's has specific standards to comply with regarding health and safety. The University complies with numerous policies approved by the university's Senate and/or the Board of Trustees and includes safety policies on health and safety roles and responsibilities, asbestos, guidelines for working in the heat, electrical equipment, safety of building occupants, and transportation of dangerous goods, all of which can be linked to potential embodied carbon solutions ("Policies and Standard Operating Procedures | Environmental Health and Safety" n.d.). In the Queen's Building Standards, environmental health and safety is addressed in the general requirements of the division 1 section, as well as numerous statements on safety regarding design of buildings ("Policies and Standard Operating Procedures | Environmental Health and Safety" n.d.).

Outside of Queen's existing by-laws, the Building Code Act of 1992 (BCA) and related regulations lays out the legislative framework governing the construction, renovation, demolition, and change of use of buildings in Ontario. It defines the purposes of the Building Code to include standards for public health and safety of buildings ("11. Building regulation" 2018).

Additional measures to ensure these health and safety risks will be eliminated are training manuals and risk assessments, which would both address any potential risk associated with embodied carbon reduction as well as proper training to reduce these risks. Queen's University currently has existing manuals and risk assessments. However, introducing an embodied carbon perspective would be beneficial for the reduction of health and safety concerns with any associated embodied carbon risk.

It is important to recognize a limitation of these existing codes and standards. They specifically address the safety concerns of the construction and operation of the building, but there is a lack of information on the embodied carbon-related safety concerns. Regardless of the phase in the material's life cycle, health and safety risks are continuously apparent. Beyond construction, there are risks in the extraction of materials, transportation, and demolition. This demonstrates the need to extend the goals of the project beyond the existing construction codes.

6.5 Technical Constraints

The project is constrained by technical requirements that must be met to ensure the safety, functionality, and feasibility of all new construction projects at Queen's.

While minimizing materials is an effective method to reduce embodied carbon, this cannot be done in a manner that would compromise the structure of the building. The National Building Code of Canada (NBCC) sets comprehensive guidelines on the requirements of a building based on specific factors of the design ("National Building Code of Canada 2015" 2018). For example, all partition walls in residence buildings are required to be constructed as firewalls for occupant safety ("National Building Code of Canada 2015" 2018). Further, 50% of all pedestrian entrances need to be barrier-free to accommodate people with a physical or sensory limitation ("National Building Code of Canada 2015" 2018). The solution developed in this report must not prevent new construction projects at Queen's from adhering to the NBCC. Failure to comply with this condition would result in an unsafe design.

All new construction projects at Queen's are developed to serve a function. The proposed solution must not compromise the functionality of the building. For example, the design of a residence building must consider the safety and comfort of the students living there. A design that reduces embodied carbon by lowering material usage through the elimination of non-structural partition walls would not be appropriate because students living in the building require privacy.

The solution must also be technically feasible given the capabilities of Queen's construction team. There are specific factors that dictate the technical details that can feasibly be constructed at Queen's. For example, all Queen's buildings are subject to certain height and size restrictions. Further, there is a limit to the availability of skilled workers at Queen's and the design must consider the technical abilities of the available contractors.

6.6 Societal Role as a Constraint and Consideration

Reducing embodied carbon and developing a modelling system for the University's Facilities will have a major effect on the society and culture of Queen's University, the Kingston community, Canada, and beyond. This impact is important as a consideration in the project and the question of what role do universities play in the development of civil society and social transformation should be asked. Universities play a vital role as leaders in teaching and learning, in education, research, and technology (Sharma 2015). Therefore, the development of buildings in this institution is a physical reflection of this leading responsibility. But this societal impact extends beyond the construction of a Queen's residence or dining hall building. By addressing embodied carbon and developing a solution to model and reduce it, Queen's broadcasts its values of sustainability and protecting the environment. Universities are considered to have been regarded as key institutions in processes of social change and development, and developing an embodied carbon solution fosters this sustainable change (Sharma 2015). Social impact and related goals will be communicated and serve as an insightful impact to evaluate in the final solution.

6.7 Environmental Impact as a Constraint and Consideration

The main objective of this project is to decrease the environmental impact of new construction at Queen's through the reduction of embodied carbon. Thus, it is obvious that there are environmental considerations constraining the final solution. The solution must meet sustainability targets. The development of these targets and the actions that must be taken if these targets are exceeded or failed to be met are within the scope of this project. The report will use the Queen's CAP and other resources to assess reasonable and meaningful goals for this project. The final sustainability targets will be communicated and serve as a basis to evaluate the final solution.

6.8 Cultural and Ethical Constraints

Queen's University is situated on traditional Anishinaabe and Haudenosaunee Territory ("Indigenous Land Acknowledgement | Queen's University" n.d.). As members of the Queen's community, we acknowledge this traditional territory and its long history that predates the earliest European colony. The native communities that lived on this land viewed the environment with a very different perspective than people today. Aboriginal people considered the growth, reproductive, and regeneration cycles of plants, animals, and birds. To interrupt these cycles was considered against the law of nature ("Aboriginal Perspective of Sustainable Development" n.d.). Since the colonization of this land and the development of European institutions such as Queen's University, the land has been treated as a resource. This contradicts traditional First Nations views which saw the environment as a living organism. Their knowledge and understanding of nature reflected the importance of "sustaining Mother Earth for seven generations to come" ("Aboriginal Perspective of Sustainable Development" n.d.). Today, First Nations groups embrace the concept of survival of the seventh generation and believe it is the definition of sustainability ("Six Nations Lands and Resources" n.d.). Because of the views and practices of the traditional inhabitants of this land, there is cultural pressure to use the land in a sustainable way. For this project, the team is constrained by this pressure. Finding a way to develop this land while not compromising the beliefs of its traditional inhabitants is a key consideration.

6.9 Assumptions

Several assumptions had to be made to develop a logical methodology and make recommendations to Facilities. It is assumed that Queen's Facilities will use any recommended software or methodologies as intended and outlined by Carbon Connected. Facilities will act to the best of their abilities to meet the carbon reduction goals set by Carbon Connected. To estimate the time commitment and learning difficulty of new solutions, it is assumed that Facilities employees have no experience with tracking embodied carbon. Facilities is assumed to be constructing primarily reinforced concrete structures, and they can track their material quantities with accuracy. In terms of measuring social impact, Carbon Connected assumes that Queen's students and the surrounding community want to reduce the climate impact of the university.

7.0 Research

7.1 Climate Change

Observations described in the United Nations (UN) 2021 Climate Report show that increases in GHG concentrations since around 1750 are distinctly caused by human activities. Since the start of the 21st century, the global average surface temperature has been 0.99 °C warmer than it was from 1850-1900. The changes in global temperature relative to 1850-1900 are illustrated below in Figure 3.

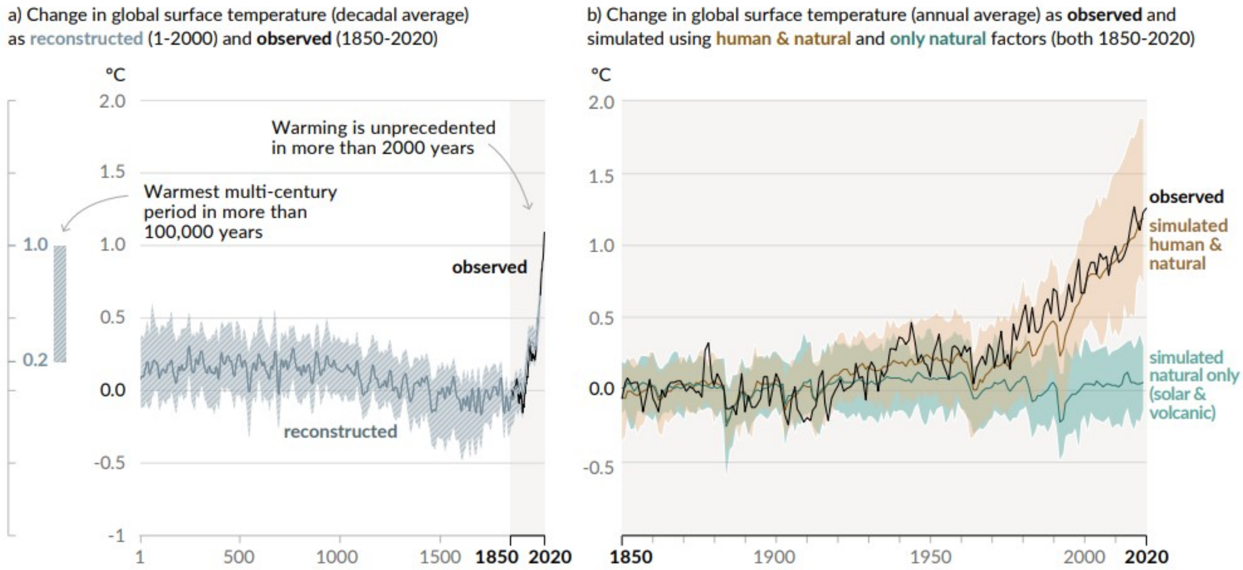

Figure 3: Changes in global surface temperature relative to 1850-1900 (Masson-Delmotte et al. 2021)

It is likely that human influence has increased global average precipitation over land since 1950 and very likely that humans are the main cause of global glacier retreat since 1990 and the decrease in arctic sea ice. The global mean sea level increased by 0.20m between 1901 and 2018 and the average rate of sea-level rise was 3.7mm/yr between 2006 and 2018 (Masson-Delmotte et al. 2021).

The UN Climate Report quantifies the global effects of climate change, but it is important to understand climate change in the context of this project. Understanding how buildings impact climate change will contextualize the importance of reducing embodied carbon in new construction projects at Queen's. It is estimated that buildings generate 39% of the world's GHG emissions (*Reporting Matters: Six years on: the state of play WBCSD 2018 Report* n.d.). Of these emissions, 28% is operational carbon, which refers to the GHG emissions associated with a building's energy consumption, and 11% is embodied carbon (*Reporting Matters: Six years on: the state of play WBCSD 2018 Report* n.d.). Further, it is estimated that 40% of raw materials consumed in North America are used for new construction (Ross 2021). To combat the built environment's effect on climate change there needs to be a shift in how the construction industry approaches new projects. The solutions outlined in this report are intended to provide options for how this can be achieved.

7.2 What is Embodied Carbon

Embodied carbon describes the GHG emissions created during the process of material extraction, manufacturing, transport, construction, maintenance, repair, refurbishment, replacement, demolition, and disposal (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). Embodied carbon emissions represent approximately 11% of all global energy-related carbon emissions (*Reporting Matters: Six years on: the state of play WBCSD 2018 Report* n.d.). The Canadian Green Building Council (CaGBC) requires that embodied carbon be reported in a unit of kilograms of carbon dioxide equivalent (kg CO_2e) as a total value (*Zero Carbon Building: Design Standard Version 2* 2021). A building's embodied carbon can be organized by identifying the three life-cycle stages of a building. Figure 4 illustrates these three stages and the elements within them that contribute to embodied carbon.

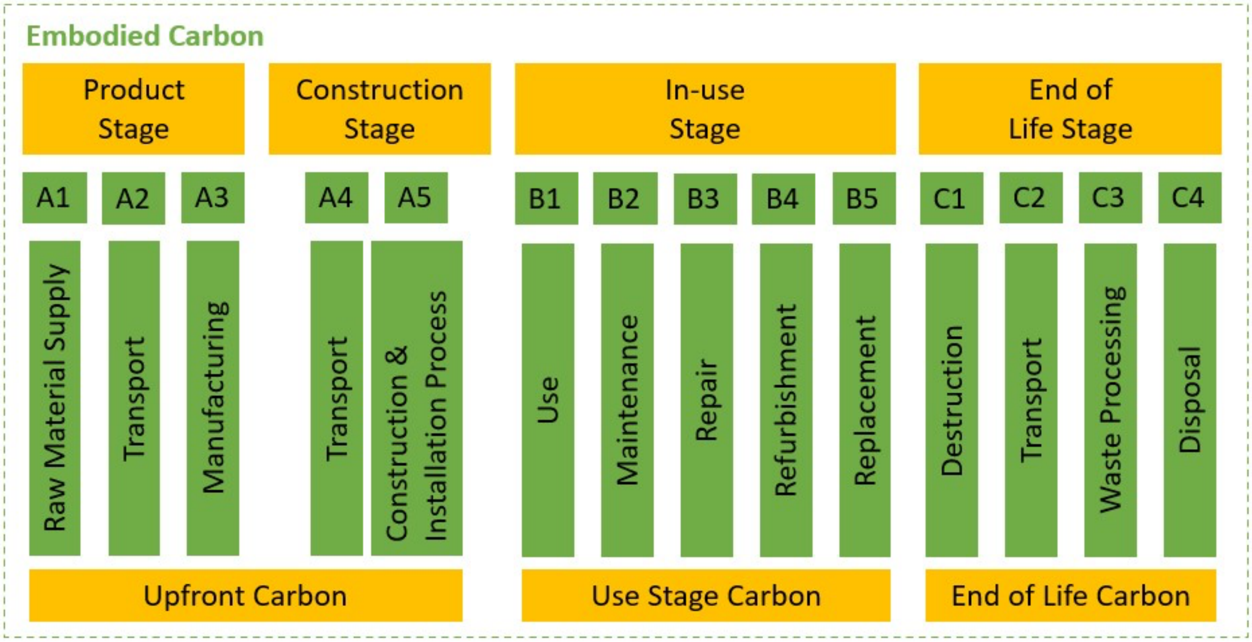

Figure 4: Embodied Carbon Life-Cycle Stages

Upfront carbon consists of the product and construction stages. The product stage considers the design aspects of the building including the production and transport of building materials. The construction stage considers the emissions produced from the building's erection including emissions from operating machinery and waste material (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). Next, use stage carbon encompasses the embodied carbon created while the building is in operation. Use, maintenance, repair, refurbishment, and replacement are the factors that contribute to embodied carbon while a building is operational. Finally, end-of-life carbon considers the embodied carbon emissions that will occur after the operational life of the building. This includes the destruction of the current structure and the transport, processing, and disposal of the resulting waste (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). Breaking down embodied carbon into the three life-cycle stages is an effective way to quantify the embodied carbon emissions caused by the creation of new building.

7.3 Methodology

To quantify carbon emissions and other environmental impacts, a multi-step procedure known as a Life Cycle Assessment (LCA) is used (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). This assessment quantifies both embodied and operational carbon, but for the scope of the project, embodied carbon calculations are the primary focus. The essential calculation of embodied carbon involves the product of the quantity of each material and a carbon factor, normally measured in kgCO_2e per kg of material ("A brief guide to calculating embodied carbon" 2020). This relationship is seen in Figure 5 below.

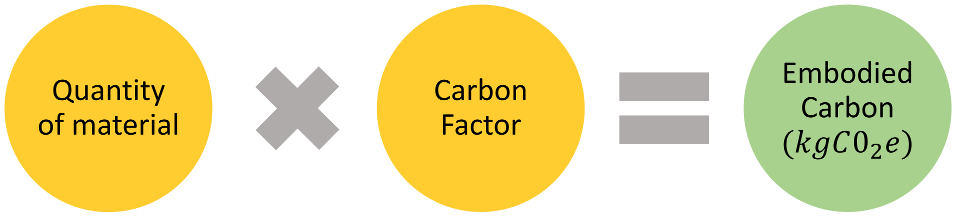

Figure 5: Embodied Carbon Equation

The quantity of each material is an estimate that improves throughout the design process and is calculated depending on the stage of design and available tools ("A brief guide to calculating embodied carbon" 2020). The carbon factors are divided based on their phase in the life cycle and improve in accuracy as more is learned about the procurement process of the project. Regardless, the simple calculation can be used as early as the concept stage, allowing design options to be compared quantitively, and therefore improving the design process. It is most important to calculate the embodied carbon at the early design stages to develop an initial scope and make changes in the selection of materials ("A brief guide to calculating embodied carbon" 2020). It should be noted that at this stage there is a limitation in accuracy, as there exists uncertainty in material quantities.

However, it is still essential to measure the embodied carbon value at every design stage to target carbon reductions through material selection, specification, efficiency, and reuse ("A brief guide to calculating embodied carbon" 2020). This whole-life carbon modelling process is necessary for the design of building projects.

The embodied carbon lifecycle stages seen in Figure 4 are essential to determine the amount of carbon released for a material. At early design stages such as A1-A3, the material quantities are estimated based on general theoretical assumptions or calculations, whereas later in the design process, structural analysis or building information models are used to determine the quantities ("A brief guide to calculating embodied carbon" 2020). When determining carbon factors, the range for each stage can be large. Therefore, more accurate factors should be requested through the supply chain.

It is also vital to obtain accurate Environmental Product Declarations (EPDs) which are independently verified and registered documents that include valuable information about the life cycle environmental impact of a product (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). In an interview conducted by the team with Sustainability Specialist Mirko Farnetani, the importance of EPDs was highly emphasized. Farnetani recommended using the information that comes from EPDs as frequently as possible since it is the most reliable source of carbon data available. This is specifically important to follow the construction phase as many of the major decisions are made by the contractor.

7.4 Existing Tools and Software

There are several tools available to aid in the assessment of the carbon footprint of a building. The most comprehensive evaluation technique is the LCA. LCAs compile and evaluate the environmental impacts of a building throughout its entire life cycle. This is an ideal evaluation technique as it supports a circular economic analysis approach. Several tools to conduct LCAs for buildings exist today. These tools vary in their LCA methodologies, data, sources, standards followed, and certifications with which they comply (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). Some of the most common programs are BEAM, One Click LCA, and eTool LCD (*LETI Embodied Carbon Primer: Supplementary guidance to Climate Emergency Design Guide* 2020). It is imperative when deciding which tool to use for calculating and conducting an LCA, to consider the accuracy of material data as well as its applicability to the type of building construction.

Carbon footprint analysis focuses on EPDs for building materials. EPDs are used by manufacturers to communicate potential human and environmental health impacts of a product. These are especially useful when considering embodied carbon, as they can be used to evaluate the carbon released in the manufacturing process as well as the recyclability of the material.

7.4.1 BEAM Estimator

BEAM is a software designed in Canada by Builder's for Climate Action; an organization committed to reducing carbon emissions in new, low-rise construction. This tool is designed for use by construction planners to be able to easily identify the carbon footprint of the materials to be used in a construction project. To do this, the dimensions of a building are inputted, and the system outputs a comparative database of materials that may be used, along with their respective carbon implications. The benefits of this software are numerous, and include ease of implementation, easily accessible carbon data, and its comparative approach to material selection. Although very useful for some applications, BEAM is designed for low-rise buildings under four stories ("BEAM Calculator" n.d.). As such, buildings with five or more stories will require that a different carbon modelling software is used. Additionally, the BEAM tool is still in the beta testing phase and as such, commercial access is not yet available. At the request of Carbon Connected, the creators of BEAM have granted beta access to determine the practicality of its use by Facilities.

7.4.2 OneClick LCA

OneClick LCA is a leading construction sector life-cycle assessment and EPD software. LCA has specific tools intended for calculating embodied carbon, generating embodied carbon reduction targets, and comparing material life-cycle impacts. OneClick LCA has a 4.6/5 rating on Capterra, a third-party website that collects reviews from users. A common criticism of One Click LCA is that it may be difficult to find a comparable material if the one being used is not already in their database ("One Click LCA Reviews 2021 - Capterra" n.d.).

7.4.3 eTool LCD

eTool is a life-cycle assessment software for buildings and infrastructure that was recommended to Carbon Connected by Mirko Faernetani, an architect and sustainability specialist who leads Hilson Moran's embodied carbon division. eTool can track equivalent CO_2 emissions, cost, energy, water and land use, ozone depletion, and more, but is not intended to track embodied carbon ("eTool - Leading LCA tool for buildings and infrastructure" n.d.). Therefore, eTool is not an appropriate tool for this application. The cost of eTool ranges from $50 USD to $500 USD based on what services are purchased and how many users are required.

7.5 Canadian Green Building Standards

The CaGBC's Zero Carbon Building Design Standard focuses on carbon emissions across the entire life cycle of a building. As such, it states that reductions in embodied carbon should be pursued as part of an approach that also considers operational carbon (*Zero Carbon Building: Design Standard Version 2* 2021). However, operational carbon is outside the scope of this project so this report will examine their recommendations on embodied carbon specifically. The design standard emphasizes upfront carbon (as described in Section 11.1) stating, "upfront carbon is emitted before a building is operational and can significantly outweigh operational carbon" (*Zero Carbon Building: Design Standard Version 2* 2021). It recommends reducing upfront carbon by sequestering carbon in building materials. Materials can lock carbon away for decades or longer and it is even possible to store more carbon than results from upfront life-cycle stages of materials (*Zero Carbon Building: Design Standard Version 2* 2021).

To achieve Zero Carbon Building (ZCB) certification, applicants must provide an embodied carbon report. Included in the report is an LCA of the building materials. The LCA must consider the following life cycle stages, illustrated in Figure 4:

- Upfront carbon (life-cycle stages A1-5)
- Use stage carbon (life-cycle stages B1-5)
- End-of-life carbon (life-cycle stages C1-4)

The LCA must include all envelope and structural elements, including footing and foundations, structural wall assemblies, structural floors and ceilings, roof assemblies, and stairs. To encourage retrofits and material reuse, the LCA should only include new materials (*Zero Carbon Building: Design Standard Version 2* 2021). Projects can choose to expand the scope of the LCA beyond structural and envelope materials to find reductions elsewhere. The LCA must assume a building service life of 60 years and report embodied carbon in a unit of kg CO_2e.

To quantify the reductions in embodied carbon the proposed building must be compared to a baseline building. The baseline building must be equivalent to the proposed building with the following kept constant between both:

- Operational energy use
- Gross floor area
- Functional use of space
- Building shape and orientation

Retrofit projects that use an existing structure for 50% or more of the final gross floor area are not required to model a baseline building (*Zero Carbon Building: Design Standard Version 2* 2021).

To meet the impact and innovation requirements the proposed building must have an embodied carbon reduction of at least 20% compared to the baseline building (*Zero Carbon Building: Design Standard Version 2* 2021).

7.6 Integration into Queen's Building Standards

Queen's CAP lays out the institution's strategies to reduce its environmental impact, specifically related to its GHG emissions, and sets reduction goals for the future ("Climate Action Plan: Building a Sustainable Future" 2016). The report primarily focuses on Scope 1 and Scope 2 emissions, which encompass direct emissions from owned or controlled sources, and indirect emissions from the generation of purchased electricity and heating/cooling (US EPA 2016). The university's reduction targets from 2008 levels are shown below in Table 1.

Table 1: Queen's University carbon reduction targets based on 2008 levels ("Climate Action Plan: Building a Sustainable Future" 2016).

Year	Target Reduction	Reduction from Baseline (tCO_2e)
2020	35%	20 200
2030	70%	40 400
2040	100%	57 716

These targets were set using the following criteria, as stated in the CAP ("Climate Action Plan: Building a Sustainable Future" 2016):

1. The UN Intergovernmental Panel on Climate Change estimates that developed countries need to reduce GHG emissions by 25-40% below 1990 levels by 2020, and 50-80% by 2050 to avoid a temperature rise of 2˚C.
2. Targets should be technically viable and should not rely on technologies that have not been commercialized and/or demonstrated as successful.
3. Targets should be set using an achievable timeline, including time for planning/approval cycles.

Embodied carbon falls under Scope 3 emissions, which is defined by the United States Environmental Protection Agency (EPA) as "emissions that are the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly impacts in its value chain" (US EPA 2016). The university's CAP states that "in the future, Queen's could consider including Scope 3 emissions in its inventory..." but does not currently lay out any specific embodied carbon reduction strategies or goals ("Climate Action Plan: Building a Sustainable Future" 2016). This is inadequate given that Scope 3 emissions often represent a majority of the GHG emissions of an organization.

It is assumed that any carbon embodiment targets that Queen's sets should follow the guidelines outlined above for Scope 1 and 2 emissions reductions. Most importantly, in this case, the guidelines state that the targets should not rely on technologies that have not been commercialized and/or demonstrated as successful. With embodied carbon becoming a more important aspect of environmental sustainability, there are various new technologies emerging that could reduce embodied carbon but have not yet been proven on a large scale. For example, mass timber structures are becoming more common as a building method and some experts say that "by 2034, the North American construction industry as a whole will store more carbon than it emits" because of this technology ("Mass Timber's Carbon Impact" 2020). But with under 500 mass timber buildings completed in Canada in the last decade, it would be premature to make this emerging field a key part of the embodied carbon reduction plan ("Mass timber report shows projects reaching new heights across Canada - constructconnect.com" 2021). Therefore, Queen's must set targets based on existing and proven technologies and construction methods. The targets that are set should be reevaluated every 5 years by Facilities to account for new carbon reduction approaches and ensure that the goals are always attainable but ambitious.

7.7 LEED

LEED (Leadership in Energy and Environmental Design) is the world's most widely used green building framework. First released in the United States in 1998, LEED was later adapted to the Canadian market by Canada Green Building Council (CAGBC) in 2004 ("Why LEED certification | U.S. Green Building Council" n.d.). LEED provides a framework for efficient, cost-effective, and sustainable buildings. It is a reputable certification that is recognized around the world. LEED certification is highly sought after among universities trying to improve the sustainability of their new buildings.

The LEED rating system is organized into 5 environmental categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality ("LEED Canada for New Construction and Major Renovations 2009" n.d.). To achieve LEED certification, points are allocated per credit based on the potential environmental impacts and human benefits of each credit with respect to a set of impact changes. A higher number of points gets you a higher LEED certification. The result is a weighted average that combines building impacts and the relative value of the impact categories.

There are 4 LEED certification levels: Certified, Silver, Gold, and Platinum each signaling a higher number of points from LEED certified credit initiatives. 2 Queens buildings have LEED certification, the School of Kinesiology building is LEED Certified, the Goodes Hall West Wing, shown in Figure 6, achieved LEED Canada-NC Gold Certification, and the JDUC project (in progress) is registered but not yet confirmed ("Design & Construction | Facilities" n.d.).

Figure 6: Goodes Hall West Wing, seen on the left side, at Queen's University.

7.7.1 LEED Embodied Carbon Credits

The materials and resources credit category incentivizes reduction in embodied carbon at multiple scales throughout the building life cycle. The requirements of this credit category rewards building reuse; life-cycle analysis and environmental product declarations (EPDs); material ingredient reporting and optimization; responsible sourcing of raw materials; and waste reduction and management ("How LEED v4.1 addresses embodied carbon | U.S. Green Building Council" n.d.). The materials and resources category requires reductions of construction and demolition waste for all new construction and major renovation projects. This is completed by recovering, reusing, and recycling materials.

Low carbon building materials can also contribute to LEED credits. Table 2, shown below, outlines nine LEED credit areas that can be achieved by using low carbon building materials ("LEED Canada for New Construction and Major Renovations 2009" n.d.).

Table 2: Low Embodied Carbon LEED Credits

Category	Credit	Points
Materials and Resources	Building Life-Cycle Impact Reduction	5
	Building Product Disclosure and Optimization - Environmental Product Declarations	2
	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
	Building Product Disclosure and Optimization - Material Ingredients	2
	Furniture and Medical Furnishings (Healthcare Only)	2
Indoor Environmental Quality	Low Emitting Materials	3
	Indoor Air Quality Assessment	2
Innovation	Innovation	5
Regional Priority	Regional Priority – MRc Building Life-Cycle Impact Reduction	1

It is important to recognize that while LEED certification encourages embodied carbon reductions through the credit category requirements, buildings do not need to meet any quantitative embodied carbon goals to be certified.

7.7.2 Using LEED to Inform Targets

Regardless of whether embodied carbon reductions are necessary to earn enough credits for LEED certification, the recommendations pertaining to embodied carbon should be understood. LEED accreditation is a well-known metric for sustainable buildings that Queen's should continue to pursue. Incorporating their embodied carbon recommendations into Queen's construction would allow the school to get the recognition from a globally known organization and meet its goal of being a leader in low embodied carbon construction.

Table 14, shown in Appendix C, illustrates in further detail the LEED credit requirements pertaining to embodied carbon reductions ("Low Carbon Building Materials and LEED v4" 2017).

7.8 Canadian University's Embodied Carbon Data

To gauge an appropriate target for embodied carbon reductions at Queen's, it is important to explore the goals of other Canadian universities. Queen's has goals to become a leader in low embodied carbon construction so looking at the climate goals of U of T, McGill, UBC, and Western helps assess their goals relative to other top Canadian schools. Figure 19-22, shown in Appendix C, organize the green building information of the listed universities.

The figures help illustrate that many universities do not have specific goals on embodied carbon reduction. Of the four schools, UBC had the most comprehensive targets on embodied carbon reduction. Their goal of a 50% reduction in embodied carbon from their baseline by 2030 is the only explicit embodied carbon reduction target of the four schools. Aligning Queen's embodied carbon goals with UBC's would be a realistic and valid first step.

7.8.1 Brock Commons Tallwood House

UBC's Brock Commons Tallwood House serves as a useful comparison to the case study conducted in Section 11. Brock Commons is also a residence building, that houses 400 students and includes additional amenity space. The highlight of this building is its hybrid structure that is composed of cross-laminated timber floor panels, parallel strand lumber columns, cast-in-place concrete foundations, ground floor and elevator core, and steel connections at the roof structure ("Brock Commons Tallwood House" 2019). The emphasis on mass timber as the main building material for this project creates several environmental benefits including ("Environmental Building Declaration for Brock Commons Tallwood House | Case Studies, Research + Resources" n.d.):

- Renewable and regional available resource
- Carbon sequestration
- Smaller carbon footprint than steel and concrete
- Lighter structure requiring a smaller foundation and therefore fewer materials
- Prefabrication capabilities, faster installation, and reduced construction waste
- De-constructability, reuse, and recycling potential

The climate and access to regionally available materials means that constructing a large-scale mass timber building at Queen's is not as viable as the Brock Commons project. However, investigating a 100-year cradle to grave life cycle assessment of the project will give us metrics to compare with new Queen's buildings.

Table 3, shown below, lists some important metrics derived from a life cycle assessment conducted by the Athena Sustainable Materials Institute (Bowick and Meil 2017). These numbers can be compared to those found in the OneClick LCA case study of Queen's new residence building.

Table 3: Brock Commons Tallwood House's Life Cycle Assessment Results

Environmental Impacts	Unit	Per-m²-year
Global warming potential	kg CO_2 eq.	1.98E+01
Depletion of the stratospheric ozone layer	kg CFC-11 eq.	7.15E-08
Acidification potential of land and water	kg SO_2 eq.	1.22E-01
Eutrophication potential	kg N eq.	2.84E-02
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq	9.93E-01
Abiotic resource depletion potential of fossil fuels	MJ Surplus	4.63E+01
Resource Use	**Unit**	**Per-m²-year**
Renewable primary energy excluding energy resources used as raw material	MJ	4.88E+02
Renewable primary energy resources used as raw material	MJ	1.72E+01
Non-renewable primary energy excluding resources used as raw material	MJ	3.08E+02
Non-renewable primary energy resources used as raw material	MJ	3.79E+00
Secondary material	kg	1.48E+00
Net use of fresh water	m^3	8.81E-01
Waste Categories	**Unit**	**Per m²-year**
Non-hazardous waste disposed	kg	3.74E+00
Output Flows Leaving the System	**Unit**	**Per m²-year**
Components for re-use	kg	6.43E-01
Materials for recycling	kg	5.35E+00
Materials for energy recovery (not being waste incineration)	kg	0.00E+00
Exported energy	MJ	0.00E+00

7.9 Financial Considerations

7.9.1 Feasibility Study

A 2020 feasibility study written by the UK Green Building Council highlights how new buildings can be designed to reach net-zero performance targets and the effect this has on cost. Through both a case study for an office and residential building, an analysis of the effect on cost across design scenarios is useful to compare to Queen's building projects. The study estimates the changes required in the financing of new net-zero buildings and focuses on changes to capital cost. Overall, it was determined that the cost increase for both intermediate building scenarios was considered feasible today given the costs will be offset by the value benefits, such as lower offsetting costs, and lower operating/lifecycle costs.

It is important to note that this case study is UK centralized. While it is strategic to prioritize Canadian-based examples, this specific study cannot be found in local reports and is necessary to provide a financial analysis of embodied carbon building design. Therefore, it is necessary to use this feasibility study as a basis for financial research and evaluation, to ultimately compare with Queen's building projects.

7.9.2 Office Feasibility Study

The first cost case study analyzes an office for a new 16 story building on an urban infill site. The effect on construction costs from developing a low carbon design for this building can be seen in the tables below, a calculation of individual building elements. The costs have been converted from British pound sterling (GBP) per square meter to Canadian dollar (CAD) per square meter for reference, and are compared between three carbon scenarios: baseline, intermediate and stretch - each increasing in carbon reduction design. Key design changes made as the cases progress in terms of carbon reduction include replacement of steel and concrete, alteration of ventilation, material choice, and change of heating infrastructure. These design fixes ultimately produced a larger reduction of embodied carbon as the cases progressed. The major increases and decreases in cost are highlighted in orange and blue respectively.

Table 4: Cost analysis of office building in case study ("Building the Case for Net-Zero" 2020)

	Baseline	Intermediate		Stretch	
	$/m²	**$/m²**	**% Change from baseline**	**$/m²**	**% Change from Baseline**
1. Substructure	$ 532.79	$ 598.36	12%	$ 263.27 - $ 304.41	-44 to 50%
2. Frame, upper floors & stairs	$ 737.70	$ 1,024.59	39%	$ 1201.17 - $ 1349.26	63% to 82%
3. Roof	$ 122.95	$ 122.95	-	$ 123.41	-
4. External walls, windows & doors	$ 811.48	$ 729.51	-10%	$ 814.50 - $ 904.99	0 to 11%
5. Internal walls & doors	$ 155.74	$ 155.74	-	$ 156.32	2%
6. Finishes & fittings	$ 385.25	$ 385.25	-	$ 386.68	1%
7. Mechanical, electrical & plumbing (MEP)	$ 1,196.72	$ 1,221.31	2%	$ 781.59 - $ 1349.26	2 to 12%
8. Lifts	$ 180.33	$ 196.72	9%	$ 213.91 - $ 230.36	17 to 27%
9. Preliminaries; overheads & profit; design & build risk	$ 1,000.00	$ 1,000.00	-	$ 1151.81 - $ 1275.22	15 to 27%
Total Shell & Core	**$ 5,122.95**	**$ 5,442.62**	**6.20%**	**$ 5,545 - $ 6,022**	**8 to 17%**

Some cost drivers include the change in the concrete substructure. The cost is lower for the baseline to remain consistent with the benchmarked single-story height, whereas the intermediate design doubles in height. The removal of the basement for carbon reduction purposes omits costs for secant piling and basement excavation, generating a saving of $312.63/m² across a reduced gross internal area (GIA) of 24,650m². Some key cost increases include the change of frame and upper floors, as the intermediate design introduces CLT slabs instead of concrete material on a metal deck. This increases the cost slightly of the floors. As well, in the stretch design, the frame and upper floors are entirely constructed from timber, creating a slightly increased price. Additional changes in the roof, external walls, and elevators show an increase in cost with associated design changes for carbon reduction purposes. While these costs reflect a slight increase, the change is considered feasible and is likely to correspond with an increase in the value of the buildings.

7.9.3 Residential Feasibility Study

The second case study reflects an 18-story residential building on an urban site. The cost breakdown for three scenarios can be seen in the table below and follows the same exchange changes.

Table 5: Cost analysis of residential building in case study ("Building the Case for Net-Zero" 2020).

	Baseline	Intermediate		Stretch	
	$/m²	**$/m²**	**% Change from baseline**	**$/m²**	**% Change from Baseline**
0. Demolition and enabling	$ 57.61	$ 57.61	-	$ 57.61	-
1. Substructure	$ 214.00	$ 214.00	-	$	-4%
2. Frame, upper floors & stairs	$ 411.53	$ 436.22	6%	$469.14	14%
3. Roof	$ 139.92	$ 139.92	-	$ 148.15	6%
4. External walls, windows & doors	$ 757.22	$ 839.52	11%	$ 781.91	3%
5. Internal walls & doors	$ 329.22	$ 329.22	-	$ 329.22	
6. Finishes & fittings	$ 559.68	$ 559.68	-	$ 576.14	3%
7. Mechanical, electrical & plumbing (MEP)	$ 954.75	$ 971.21	2%	$ 1028.83	8%
8. External works	$ 98.77	$ 98.77	-	$ 107.00	8%
Measured Works Total	**$ 3,522.70**	**$ 3,646.16**	**3.5%**	**$ 3,712.00**	**5.4%**
9. Preliminaries; overheads & profit; design & build risk	$ 946.52	$ 979.44	3%	$ 995.90	5%
Construction Total	**$ 4,469.22**	**$ 4,625.60**	**3.5%**	**$ 4,707.90**	**5.3%**

7.9.4 Feasibility Study Summary

Comparing this price increase to Queen's Universities facilities designs, it is important to recognize the difference in building type from a financial perspective. University buildings do not have the same marketability and profitability as residential or offices. For the case study, while the capital costs may be higher, it corresponds with an increase in the value of the buildings, higher rental premiums, lower tenancy void periods, and potentially lower life cycle costs. However, for universities, there is no benefit for tenants as the major income comes from student tuition, which may have limitations. Altering the building design costs would impact the Queen's facilities budget, but for the sake of environmental design, these changes may be necessary.

While the intermediate cost uplift for both building projects is considered feasible, the increased cost uplift for the stretch scenarios reflects substantially more demanding net-zero targets for 2030 and a premature marketplace, not yet prepared for delivering the associated results. This leads to a recommendation for a long-term consistent regulatory movement that will strengthen green building standards over time and provide an opportunity for the supply chain to innovate as costs come down. This reflects an overall need for a reshaping of the building marketplace, a goal that is optimistic, but out of scope for this project.

8.0 Iteration

Figure 7 below is a visual representation of our current design process. In an iterative approach, the process includes background research, idea generation, solution development, interviews, weighted evaluation, followed by iteration. In the iteration phase, optimization is essential to ensure that the design being developed is the ideal solution for the project. This step considers the evaluation matrix in the step prior and aims to improve the solution with the weighted factors considered. At this phase, the entire iterative cycle has been completed and there's been multiple iterations of the final report.

Figure 7: Team's Iteration Design Process

9.0 Solution Assessment

A weighted evaluation rubric, shown in Table 6, has been created to evaluate solutions for tracking embodied. Each solution will be judged based on a selection of seven indicators: economic, social impact, ease of implementation, accuracy, time commitment, innovation, and environmental impact. Every indicator has been assigned a weighting based on its importance to Carbon Connected. Carbon Connected has consulted with the client to revise the indicators, their scoring criteria, and their weighting to reflect the priorities of Queen's. Each of the indicators is defined in detail in Section 9.1 and their weightings are justified in Section 9.2.

9.1 Evaluation Matrix

The evaluation rubric can be found in Table 6 and completed evaluation matrices can be found for each tool in Appendix B: Evaluation Matrices. The scores for BEAM Estimator, OneClick LCA, and eTool LCD were 97, 153, and 139 respectively, out of 180.

Table 6: Weighted evaluation rubric for scoring potential embodied carbon tracking and measuring solutions.

Indicator	Exceeds Expectations 8-9	Meets Expectations 6-7	Needs Improvement 4-5	Not Demonstrated 0-3
Economic Weight: 4	The solution is available at no cost to Queen's Facilities.	The solution costs less than 0.1% of the total value of a project.	The solution costs less than 0.5% of the total value of a project.	The solution costs less than 1% of the total value of a project.
Ease of Implementation Weight: 3	Requires under 5 hours of training for basic use and instructional videos are available at no cost.	Requires under 10 hours of training for basic use and instructional videos are available for purchase.	Requires under 20 hours of training for basic use and written instructional material is available.	Requires more than 20 hours of training for basic use and instructional material is limited or nonexistent.
Accuracy Weight: 3	Measures the embodied carbon of the structure to within 5% accuracy.	Measures the embodied carbon of the structure to within 10% accuracy.	Measures the embodied carbon of the structure to within 20% accuracy.	Measures the embodied carbon of the structure to less than 20% accuracy.
Time Commitment Weight: 3	Increases the time commitment required by Facilities for a project by less than 1%	Increases the time commitment required by Facilities for a project by less than 2%	Increases the time commitment required by Facilities for a project by less than 5%	Increases the time commitment required by Facilities for a project by more than 5%
Innovation Weight: 2	Solution demonstrates abstract thinking, originality in analysis, and addresses a commonly encountered issue.	Solution demonstrates abstract thinking, thorough research, and addresses an infrequently encountered issue.	Solution demonstrates some research and addresses an infrequently encountered issue.	Solution found uses well-known design processes or proposed solution is not appropriate.
Environmental Impact Weight: 5	Predicted to exceed the carbon reduction goals.	Predicted to meets the carbon reduction goals.	Predicted to fail to meet the carbon reduction goals, but within 15%.	Predicted to fails to meet the carbon reduction goals not within 15%.

9.2 Indicator Definitions

Economic: Represents the total cost or savings of implementing the technology or method. This includes the cost of purchasing/subscribing to any relevant software, but also any material cost savings as a result. For example, if a recommended software costs $2000, but leads to the selection of a building material that saves $5000 on a project, or that lowers building operations costs by $1000 annually, then the software exceeds expectations.

Social Impact: Represents the benefits of the solution to society, independent of monetary or environmental impacts. As an example, timber construction can have positive impacts on employee and student moods ("Wood construction reduces stress and offers a healthy living environment" n.d.). After all potential solutions have been established, an anonymous survey should be distributed to a variety of stakeholders to estimate and assess the societal impact of each proposed solution.

Ease of Implementation: Represents how much training time is required for Queen's Facilities employees to gain a working knowledge of the method/technology. A solution is also easier to implement if there are training materials provided by the associated company or available from a third-party.

Accuracy of System: Represents how accurately the technology or method models the embodied carbon of the structure. This indicator must be taken from published data by the software creator or by third-party reviewers since there is no method for Queen's to measure the embodied carbon of a structure with 100% accuracy and compare the results.

Time Commitment: Represents the additional time that the Facilities staff must spend on a project to incorporate this technology/method. The method meets expectations if it increases the duration of a project by less than 2% of the baseline time to completion. For example, if the construction of a residence is expected to take 2 years, the method meets expectations if it increases the duration of the project by less than 15 days.

Innovation: Represents the novelty of the proposed solution. An innovative solution demonstrates abstract thinking, deep engineering knowledge, and includes details on how the solution would be implemented. Given the project's constraint of only utilizing existing software or methodologies, innovation also relates to the originality of how the recommended tools are implemented and advertised in the university.

Environmental Impact: Represents the predicted environmental performance of the solution relative to the goals set by Connected Carbon and Queen's Facilities. This indicator requires the Carbon Connected team to use their discretion in evaluating whether a given solution could feasibly allow Queen's Facilities to meet the carbon reduction goals. It is assumed that, given accurate embodied carbon data for new construction, Queen's Facilities will act accordingly to meet the set targets. If the selected method provides additional tools in reducing embodied carbon, such as identifying high embodied carbon items and suggesting replacements, then Queen's Facilities could exceed their targets. If a tool does not provide data, or provides inaccurate data, then the client may not be able to meet the carbon reduction goals.

9.3 Weighting Justification

Each indicator was given a weighting out of 5 to reflect Carbon Connected and the client's values.

Economic: Received a weighting of 4 since Queen's Facilities has a limited budget to design and construct their projects. They will only be able to increase each project budget marginally, if it all, to account for the implementation of low-carbon solutions. Systems should take long-term savings that could justify increased upfront costs.

Social Impact: Received a weighting of 3 to reflect Queen's University's desire to create positive social change in the Kingston community and across the world by being a leader in academic institution sustainability. Since the data for this indicator is collected through anonymous survey, the results will be based on personal experience and hence very qualitative, therefore too much weight should not be applied to this metric.

Ease of Implementation: Received a weighting of 3 to reflect the client's desire for a solution that can easily integrate into their current operations with minimal and straightforward training. The system also must be simple enough to explain to consultants and contractors. Despite the appeal of a straightforward system, the client prioritizes an effective, flexible, and useful methodology at the expense of simplicity.

Accuracy of System: Received a rating of 3 because, although the accuracy of the system is very important, it is difficult to measure. A solution is pointless if it cannot accurately measure the embodied carbon since Queen's Facilities would be basing their decisions on false data. Since Carbon Connected is unable to independently measure the accuracy of each system being considered, the accuracy measurement must be taken from third-party assertions which cannot be substantiated. Therefore, Carbon Connected has chosen not to weigh this indicator heavily, since the data used for scoring cannot be verified.

Time Commitment: Received a weighting of 3 since Queen's Facilities strives to complete projects quickly and on schedule. Time commitment is also inherently related to the economic indicator, in that any extension of the project duration adds cost. Facilities would be willing to increase the time of construction to some extent to allow for the implementation of lower-carbon solutions.

Innovation: Received a weighting of 2 as Queen's Facilities and Carbon Connected prioritize efficacy over novelty. Originality adds value to the solution in terms of advertising for Queen's and could therefore attract more funding.

Environmental Impact: Received a weighting of 5 since the primary purpose of measuring embodied carbon and setting reduction targets is to reduce the university's environmental impact. It is vital that whatever solution is selected, can feasibly help achieve the targets set in Section 8.5.

10.0 Recommendations

10.1 OneClick LCA

Based on the quantitative results of the weighted evaluation matrix and the subjective opinion of Carbon Connected, OneClick LCA is the recommended tool for Queen's Facilities. OneClick LCA is used by trusted and reputable firms such as Arup, WSP, and Foster + Partners as well as government organizations such as the Joint Research Centre European Commission and the European Bank for Reconstruction and Development. The platform complies with a variety of international standards including, but not limited to, ISO 21931-1 ISO 21929-1, ISO 21930, and LEED. The version currently being tested by Carbon Connected is the free student license, but it is recommended that Facilities subscribes to the Business License. This allows access to all the features described below, including importing data from BIM and benchmarking tools in addition to an automated LCA check for completeness and plausibility, the ability to download EPDs directly, and 1.5 hours of online training. Carbon Connected have requested a quote for the Business subscription license from OneClick LCA.

10.1.1 Embodied Carbon Measurement

In terms of measuring embodied carbon, OneClick LCA allows the user to calculate and optimize a building's carbon footprint from all life-cycle stages. The software allows design data to be entered manually or, with the Business subscription license, through importing existing designs from Revit, BIM, Excel, or other energy models. The process of modelling embodied carbon in OneClick LCA is outlined in Appendix D: OneClick LCA Figures.

10.1.2 Additional Features

OneClick LCA has a variety of additional features which Queen's Facilities may find useful. The Building Circularity tool allows the user to track, quantify, and optimize the circularity of the materials used during the life cycle and end-of-life of a building. The tool also supports the principles of Design for Disassembly and Design for Adaptability, which were discussed by Mirko Faernetani as an important aspect of sustainable design. The tool is applied during the material input process when additional information is entered regarding the percentage of recycled, renewable, or reused material. By default, materials will have a preset end-of-life practice, but this can be altered to account for more sustainable processes. For example, it can be set that reinforced concrete will have its rebar separated (2% reused) and concrete concerted to aggregate. From this data, the program creates a Building Circularity Score which can be easily compared against baseline or alternative designs.

Though not included in the scope of this project, OneClick LCA also allows the user to track operational carbon and energy consumption. By inputting electricity use, fuel type, and district heating properties, if relevant, the platform can calculate annual energy consumption and equivalent carbon.

OneClick LCA also has an embodied carbon benchmarking service called Carbon Heroes. This tool allows the user to benchmark projects' embodied carbon with thousands of buildings including different building types in a variety of regions. The data is collected from thousands of verified building projects using the OneClick LCA software. It implements ISO 21930 standards as the basis of measurement and includes life-cycle stages A1-A3, A4, B4-B5, and C1-C4. This allows the user to set reduction targets based on regional construction practices and compare material life cycle impacts.

10.2 Embodied Carbon Reduction Goals

The first step to setting an appropriate goal for embodied carbon reductions in all future construction projects is to create a baseline building. The baseline building serves as a benchmark that all future buildings will be based on. Differences in building size, purpose, and location means the baseline must be flexible and adaptable. To allow the benchmark to be applied for a variety of building designs, embodied carbon is measured in CO_2e/m^2. Embodied carbon baselines are calculated for a fixed 60-year period. They consider quantities of materials, material transportation, and material replacements. The building's end of life processing is also considered. The impacts are always calculated on per gross internal floor area (m^2) basis. Figure 8, shown below, is an example of a graded embodied carbon benchmark designed for Canadian buildings. A graded benchmark system is useful for creating and assessing a baseline building.

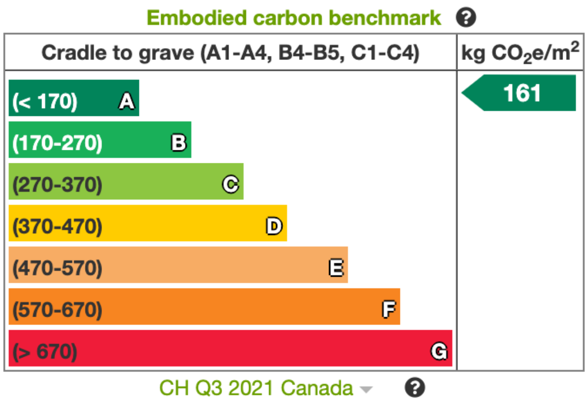

Figure 8: Embodied carbon benchmark from OneClick LCA for buildings in Canada in 2021.

When an appropriate baseline is set, metrics for embodied carbon reduction goals can be developed. Following UBC's target of a 50% reduction of the baseline by 2030 on all new construction is the recommended first target for Queen's. Additionally, Queen's should aim to achieve LEED Gold certification on all new buildings. Achieving LEED certification will help Queen's stay true to their goals. Further emphasis should be placed on the LEED embodied carbon credits outlines in section 7.7.2. Goals and targets are subject to change as new developments in technology and the climate come to light. As stated in section 7.6, it is recommended that the goals and targets be updated every 5 years.

10.3 Social Impact

Developing an embodied carbon modelling and reduction solution for Queen's University will have a major social impact. There are many social benefits to sustainable architecture and design. This includes knowledge transfer, improved environmental quality, community restoration, and reduced health risks from pollutants associated with building energy use ("The Social Benefits of Sustainable Design" n.d.). It also facilitates a growing interest in the community of sustainable design. Regarding wellbeing, sustainable design provides an enhanced health and wellbeing of those living and working in the designed environment ("Social benefits of Green buildings" 2018). Reducing the embodied carbon of Queen's building projects in a green building initiative could have a positive impact on the students, faculty, and staff. To support this, a 2016 study by the Harvard School of Public Health and the State University of New York Upstate Medical University demonstrated that those working in green-certified buildings had 26% higher cognitive function test scores than those in similarly high-performing buildings that were not green-certified ("Social benefits of Green buildings" 2018).

Embodied carbon plays a key role in this societal drive towards a sustainable future. Approaching sustainability from a perspective beyond only operational carbon allows society to rethink the process of designing buildings on a new level. Embodied carbon analysis will be used to drive new design decisions.

It is also important to note the disproportionate impact of climate change on communities. An EPA analysis conducted in the fall of 2021 proves that the most severe harms from climate change fall disproportionately upon underserved communities who are least able to prepare for, and recover from, heat waves, poor air quality, flooding, and other impacts (US EPA 2021). This societal concern cannot be overlooked and strengthens the importance of combatting climate crises by any means. Climate change is a social issue. If the planet continues to warm in the coming years, millions of citizens living in poverty face greater challenges in terms of extreme events, health effects, food security, livelihood security, migration, water security, cultural identity, and other related risks ("Social Dimensions of Climate Change" n.d.). Finding a solution to model and reduce embodied carbon for Queen's Facilities is a small yet necessary step in the greater societal fight against the warming planet. Communities like Queen's University bring unique perspectives, skills, and a wealth of knowledge to address climate change and can set priorities, influence ownership, and design and implement programs responsive to their community's needs. The embodied carbon solution for the university reflects innovation and addresses a major concern that must be addressed for the sake of society.

The social impact of reducing embodied carbon reflects the values of non-monetary advantages. This is important to consider in the development of a solution. While reducing costs and improving the environment are valuable and important benefits, they may not necessarily outweigh the value of improving the daily lives of citizens in society. This impact is vital to consider in the evaluation of potential solutions to model and reduce embodied carbon in Queen's construction and promote green building design in the overall community.

10.4 Innovation

According to Mirko Farnetani, timber construction has great potential for growth and innovation in the embodied carbon space. Farnetani addressed his concerns about the deep connection the construction industry has with concrete and steel manufacturing. He implored the team to consider cross-laminated timber, and glulam beams and columns as well as explore the concept of reusing a material as much as possible and designing it to be remounted and demounted. Among the major construction materials, wood provides the lowest life-cycle impact and can be used to lessen the environmental burdens associated with building design and construction (Green 1373382070). However, in an interview conducted by the team with embodied carbon expert Chris Magwood, major concerns with wood were addressed. Magwood explained that quantifying the carbon storage value of timber used in a building is difficult. He emphasized that there is a lack of verification for wood and ultimately has an unclear effect on the environment. Certain embodied carbon calculating tools do not include carbon storage in wood, as it is extremely difficult to verify where the material came from. However, despite these concerns, timber must be explored as an innovative tool. The limitations Magwood mentioned cannot be ignored and should be used as a catalyst to explore innovative solutions.

In addition to providing recommendations to lower embodied carbon in new construction, the team also intends to innovate the way people interact with the built environment at Queen's. This will be accomplished through the introduction of virtual and physical interactive content.

Firstly, an interactive 3D map will be created of Queen's campus, as shown below in Figure 9 and 10. This map will include all the buildings at Queen's with information about the building design accessible to users. The design information will include when it was constructed, the embodied carbon encapsulated in the building, the methods the building uses to increase its stainability, and other information relevant to the environmental impact of the building. By implementing this interactive map, users will be able to contextualize what makes a building sustainable. Further, they will be able to see the progress Queen's has made towards ensuring new buildings have lower environmental impacts.

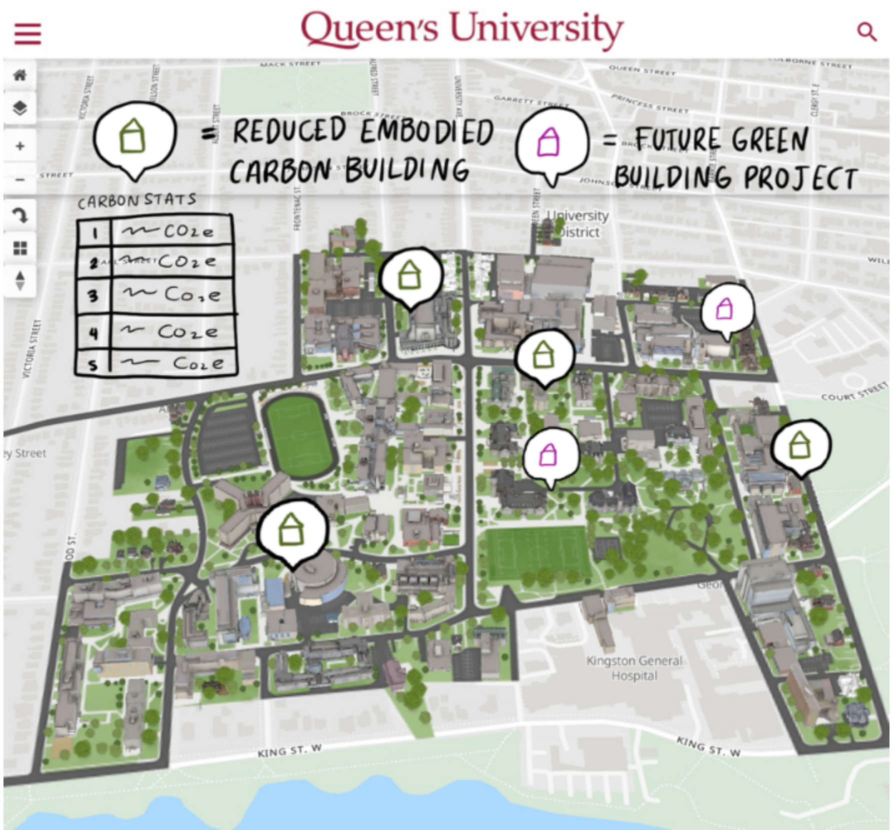

Figure 9: An interactive 3D map of Queen's campus

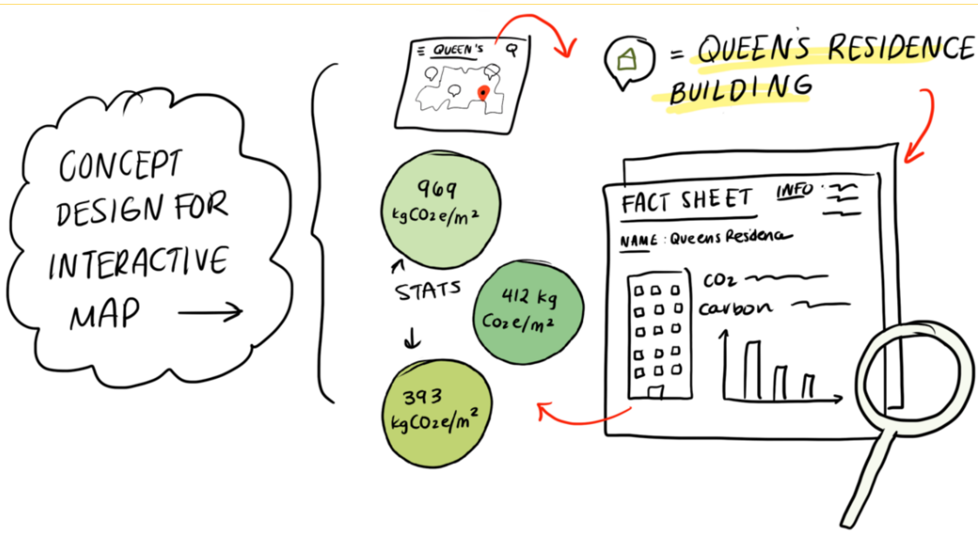

Figure 10: Interactive map information examples.

Furthermore, a physical representation of Queen’s progress towards their climate goals will be installed in a very visible part of campus, shown in Figure 11. This adaptive model will allow people to see how effectively Queen's is accomplishing its sustainability goals. If Queen's is underachieving, the model will help inspire people to act. If they are overachieving, it will encourage people to investigate the effective measures Queen's has used. Regardless, the model will serve as a physical reminder to everyone on campus that there is an active effort towards creating a more sustainable university.

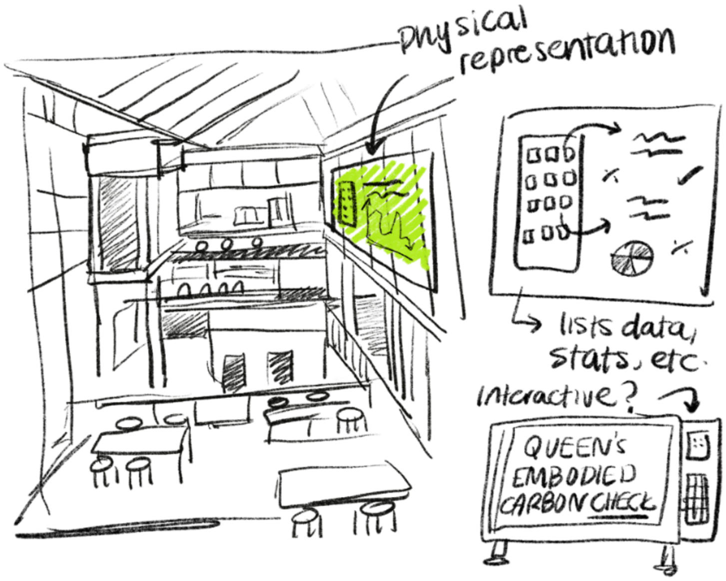

Figure 11: Architectural drawing of physical representation in engineering building

Lastly, Queen's will offer information sessions to inform people of the methods used to reduce embodied carbon in new construction. This will include virtual and in-person discussions centered around the Queen's sustainability strategy. The goal of this is to educate people on methods to minimize environmental impact in construction and engage people with the Queen's CAP.

There are cost implications to adding the described interactive content onto Queen's campus. Alternatively, Queen's could choose to not implement any of the proposed ideas and would continue as they are for no additional charge. However, the team believes that the benefits created would outweigh the financial cost. Firstly, all these ideas would help increase the community's awareness of sustainability issues, creating a positive impact on the environment. Furthermore, it would encourage intelligent and like-minded individuals to become involved with the Queen's sustainability initiatives. Lastly, it would help instill a positive reputation of Queen's as a leader in sustainability which could potentially bring in funding for more environmental projects. For these reasons, the ideas should be implemented despite their cost.

10.5 Financial Recommendations

Analyzing as an investment opportunity, lowering embodied carbon is quite commercially advisable. A UKGBC report points out that investor rating and measurement indices are beginning to include assessments of embodied carbon ("Tackling embodied carbon" n.d.). For instance, benchmarks for investors such as the Down Jones Sustainability Index (DJSI) and the FTSE4Good Index include sections in their reports regarding the lifecycle assessment of building materials and related carbon emission reductions ("Tackling embodied carbon" n.d.). It is important to note that Queen's University is publicly funded in Ontario, which can impact the intentions behind funding major facilities projects. As a publicly funded University, Queen's receives funding from cooperation between the government of Canada and the government of Ontario. Public funding of the university involves direct public funding of institutions for instruction, investment, and research combined with funding of students (Salmi and Hauptman 2006). This financial setup differs from previously discussed commercial and residential building projects. However, the increasing trend of embodied carbon design as an investment opportunity reflects the change within the construction industry and encourages modelling and design.

For additional recommendations, the team has devised a financial opportunity that promotes and funds sustainable building design while connecting Queen's University alumni with the Queen's Facilities. The proposal, as an innovative effort, recommends Queen's Facilities to promote a sustainability funding campaign that encourages Queen's alumni to donate their money specifically for sustainable building design on campus. This would enhance traditional funding efforts by creating a transparent and educational way for those who wish to fund Queen's as a University in a sustainable manner. This would include providing key information on what embodied carbon design is, and how Queen's will plan on incorporating those practices into place.

11.0 Case Study

11.1 Using OneClick LCA

To demonstrate the use of OneClick LCA, a case study was conducted using data from a new residence building currently under construction by Queen's University. The 334-bed residence is situated on Albert Street and is targeting a LEED v4 Building Design and Construction (BD+C) Gold certification. The project is expected to be complete and ready for occupancy in September 2022. A render of the residence is shown below in Figure 12.

Figure 12: New Queen's Albert St residence.

Carbon Connected was provided with the relevant architectural and structural drawings, architectural specifications, as well as EPDs for various products. To begin, a project was created in OneClick LCA and the general information was input, as shown in Table 7.

Table 7: General information input in OneClick LCA for case study.

Building type	Apartment
Gross floor area	10 407 m^3

Frame type	Concrete frame
Certifications pursued	LEED v4 BD+C Gold

Next, the material quantities had to be calculated. This was done using an online tool, ConX, to take measurements from the drawings. Then, volumes could be calculated using the footing and gravity wall schedules from the structural drawings, shown in Table 8.

Table 8: Spread footing, strip footing, and gravity wall schedule from structural drawings.

Spread Footing Schedule	Size (mm)
Footing 1	1000x1000x500
Footing 2	1200x700x500
Footing 3	1400x700x500
Footing 4	1900x650x500
Strip Footing Schedule	**Size (mm)**
Strip Footing 1	600x300
Strip Footing 2	850x500
Gravity Wall Schedule	**Size (mm)**
Wall 1	250
Wall 2	300

Using the schedules above in combination with the measurements from ConX, the concrete volumes were calculated, as shown in

Table 9.

Table 9: Concrete volume calculations using measurements from ConX and schedules provided in drawings.

	Units/Length/Area		Concrete Volume (m^3)
Basement			
Footing 1	3.0	-	1.5
Footing 2	2.0	-	0.8
Footing 3	2.0	-	1.0
Footing 4	5.0	-	3.1
Strip Footing 1	47.4	m	8.5
Strip Footing 2	155.9	m	66.3
125mm Slab-on-Grade	541.4	m^2	67.7
300mm Slab-on-Grade	15.5	m^2	4.7
Level 1			
Strip Footing 1	20.9	m	3.8
Strip Footing 2	234.4	m	99.6
Wall 1	123.5	m	98.8
125mm Slab	1188.1	m^2	148.5
250mm Slab	554.8	m^2	138.7
Level 2/3/4/5			
Wall 1	632.3	m	505.9
Wall 2	10.1	m	9.7
200mm Slab	7304.9	m^2	1461.0
Mechanical Penthouse			
Wall 1	43.4	m	34.7
200mm Slab	1073.9	m^2	214.8
300mm Slab	716.4	m^2	214.9

The volumes calculated above were increased by 5% in OneClick LCA to account for the conservative average concrete wastage for commercial projects ("HOW TO CONTROL WASTAGE OF CONCRETE AT SITE?" 2014). The architectural specifications require the concrete to be 35MPa GU Type, to contain a minimum of 25% supplementary cementing material (SCM), and a maximum of 25% recycled aggregate. An EPD was not provided by Queen's Facilities for the concrete, so a comparable product was selected from the OneClick LCA EPD (Ready-mix concrete, 34.48-41.37MPa, 30-39% fly ash). For simplicity, the rebar volume was assumed to be 1.5% of the concrete volume.

It was assumed the subgrade walls were constructed using concrete masonry units (CMU). The volume of CMU was estimated by measuring the perimeter of the basement and using the block dimensions given by the provided EDP. The amount of cement mortar for the blocks was assumed to be $0.03m^3$ per $1m^2$ of block ("How to Calculate the Quantity of Mortar for Laying Blocks - Structville" n.d.). Per the specifications, a latex-based vapour barrier is modelled for application to the subgrade walls.

Following the architectural specifications, above-grade exterior walls are covered using Fundermax Exterior panels, a Carlisle Air-Vapour barrier is attached, Huntsman Heatlok spray polyurethane foam insulation is applied, and most of the exterior is finished with Arriscraft natural stone cladding. Glazing area was measured and modelling using Alumicor Thermawall, as per specifications.

All interior framing is constructed using softwood lumber, as per the specifications. All interior walls are covered in Certainteed drywall and insulated using Rockwool Stone Wool insulation batts. It is assumed all drywall is coated in Sherwin Williams ProMar recycled interior paints. All ceilings are assumed to be constructed using Cirrus Ceiling panels. For simplicity, the floor of the residence is assumed to be 70% Interface modular carpet, and 30% Polyflor vinyl covering. Sinks and toilets are modelled as one set shared between every two rooms plus additional sets to account for shared bathrooms on each floor.

The steel frame and steel roof of the mechanical penthouse is constructed using W310x39 steel sections and cold-rolled steel sheeting. The length of steel required was measured using ConX and the mass per meter for the W310x39 section was found in the CISC Handbook of Steel Construction.

The roof of the building is modelled using a sublayer of Georgia Pacific Dens Deck per the specifications, followed by Dow Styrofoam Roofmate, and solar-reflective concrete pavers and aggregate.

Additional items such as doors, door frames, and windows were counted and an item comparable to the specifications was found in the OneClick LCA EPD database, as none were provided by the client. Some items, such as tiling and wall panels in common rooms and counters in bathrooms were excluded from this model for simplicity but could be modelled by the client. All the quantities entered into OneClick LCA are summarized below in Appendix D: OneClick LCA. The software then runs a completeness and plausibility check to confirm that the data entered falls within plausible ranges, based on data from similar buildings in the region. In this case, the model received a score of A, indicating the model is relatively complete and plausible. The results of the model can then be generated, and several sections of the results report are shown in Appendix D: OneClick LCA.

11.1 Case Study Conclusion

The case study was valuable in demonstrating the ease of use of the software and confirming that it met the needs of Facilities. Using free online resources only, the members of Carbon Connected were able to learn how to use OneClick LCA to the extent that it could be used to model a structure under construction at Queen's. With the same online resources, in addition to the virtual training by OneClick LCA provided with a subscription, Carbon Connected is confident that Facilities learn the software quickly and easily. OneClick LCA is time and cost effective and will help Facilities to better understand the carbon footprint of their construction.

12.0 Conclusion

Embodied carbon is defined as the carbon dioxide emissions associated with materials and construction processes throughout the whole lifecycle of a structure. Carbon Connected's goal is to develop an outline of tools and methods that exist for the tracking and reduction of embodied carbon in new construction at Queen's University. The team conducted research through online sources and interviews with industry experts. The main topics of research were methods to track and calculate embodied carbon, existing tracking tools and software, The CaGBS, LEED, the embodied carbon goals of other universities, and the Queen's CAP. The team used the research to develop methods that can be used to evaluate potential solutions and set meaningful carbon reduction targets. To create accurate targets for embodied carbon reduction, a baseline must be created as outlined in section 10.2. When an appropriate baseline is set, a 50% reduction of the baseline by 2030 is the recommended first target for all new buildings. Additionally, Queen's should aim to achieve LEED Gold certification on all new buildings. Emphasis should be placed on the LEED credits that focus on reductions in embodied carbon. Through the evaluation process, OneClick LCA was determined to be the optimal software to track embodied carbon. Queen's new residence building was the subject of a case study to test the validity of OneClick LCA. The version tested by Carbon Connected was the free student license, but it is recommended that Facilities subscribes to the Business License. Carbon Connected also recommends innovating the way people interact with the built environment at Queen's. This will be accomplished through the introduction of virtual and physical interactive content that will visualize Queen's sustainability progress on campus. Furthermore, Queen's Facilities should promote a sustainability funding campaign that encourages Queen's alumni to donate their money specifically for sustainable building design on campus. Carbon Connected will be moving forward into the next stages of this project by developing a one-page executive document outlining the findings of this report and presenting these findings to a group of Queen's Facilities employees.

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Appendix A

Project Management

A.1 Schedule

A.1.1 Gantt Chart

Having a preplanned and thorough work schedule is vital to keep the team on track throughout the project. Therefore, the team developed a Gantt chart to organize the various timelines for completing main and subtasks. When creating the schedule, the team considered the most logical path for completing each task and allotted additional time where possible as a contingency. The complete Gantt chart is found as an attached PDF with this submission.

A.1.2 Meetings

The team also holds weekly meetings scheduled on Wednesday at 3:30pm with Team Manager. In addition to weekly meetings, the team is committed to bi-weekly meetings with the clients to ask any questions the team may have and ensure the client remains satisfied with the progress of the project. Additionally, the team meets internally on a weekly basis with dates and times depending on schedule availability.

A.1.3 Current Progress

Currently, the team is maintaining the general timeline established in the workplan, leading up to the final deliverable to the client. There has been an effort to complete each task in the timeframe illustrated on the Gantt chart. However, time was reprioritized to different tasks as it is clear which ones are most essential to the project. For example, the research phase extended beyond what was expected due to additional interviews with leading industry professionals. Those conversations as a result provided the team with additional information that extended timeline including the use of embodied carbon modelling software such as OneClick LCA. This extension of the Gantt chart only enhanced the report deliverable, and additional time was taken. Moving forward, the team is currently preparing the final deliverables to the client including a finalized detailed report as well as a condensed high-level whitepaper to summarize the findings. These final reports will be edited in the coming days following the submission of this document.

A.2 Task Allocation

A.2.1 Work Breakdown Structure

The WBS identifies the important deliverables for this project and breaks them down into task packages. There are four tiers of tasks, the first being the large, broad steps that must be taken to complete the main objectives. The next tiers break down the task into smaller subtasks that are easily distributed to team members. Some tier-one tasks have more subtasks than others because they are more complex or can logically be separated into a great number of individual items. This system aims to create small action items that team members can work on based on their experience and skills. The WBS will be a key tool, as it illustrates how the action items ultimately fit together to successfully complete the client's deliverables. The WBS can be found in Figure 13 and Figure 14.

Figure 13: Work Breakdown Structure (WBS)

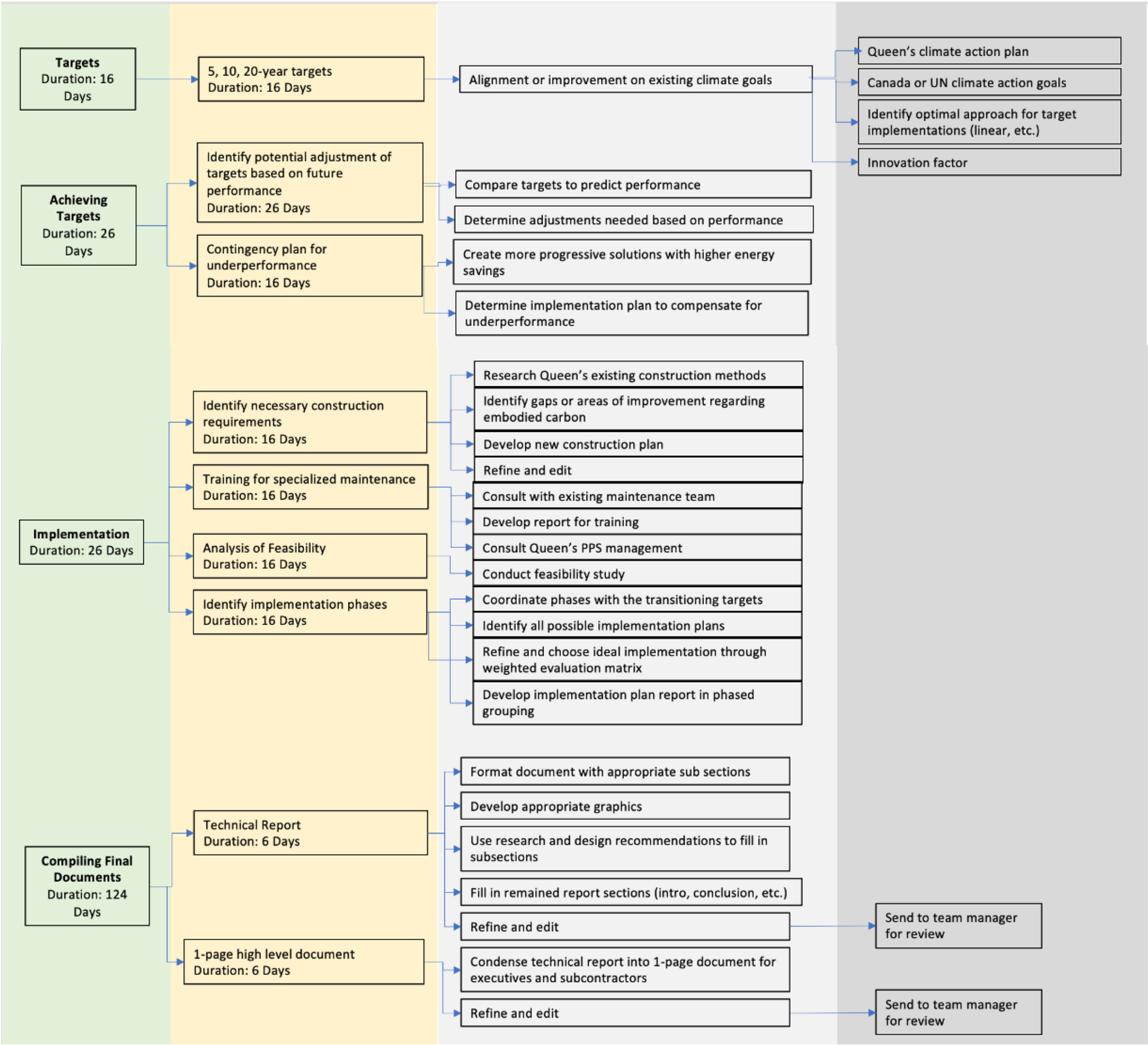
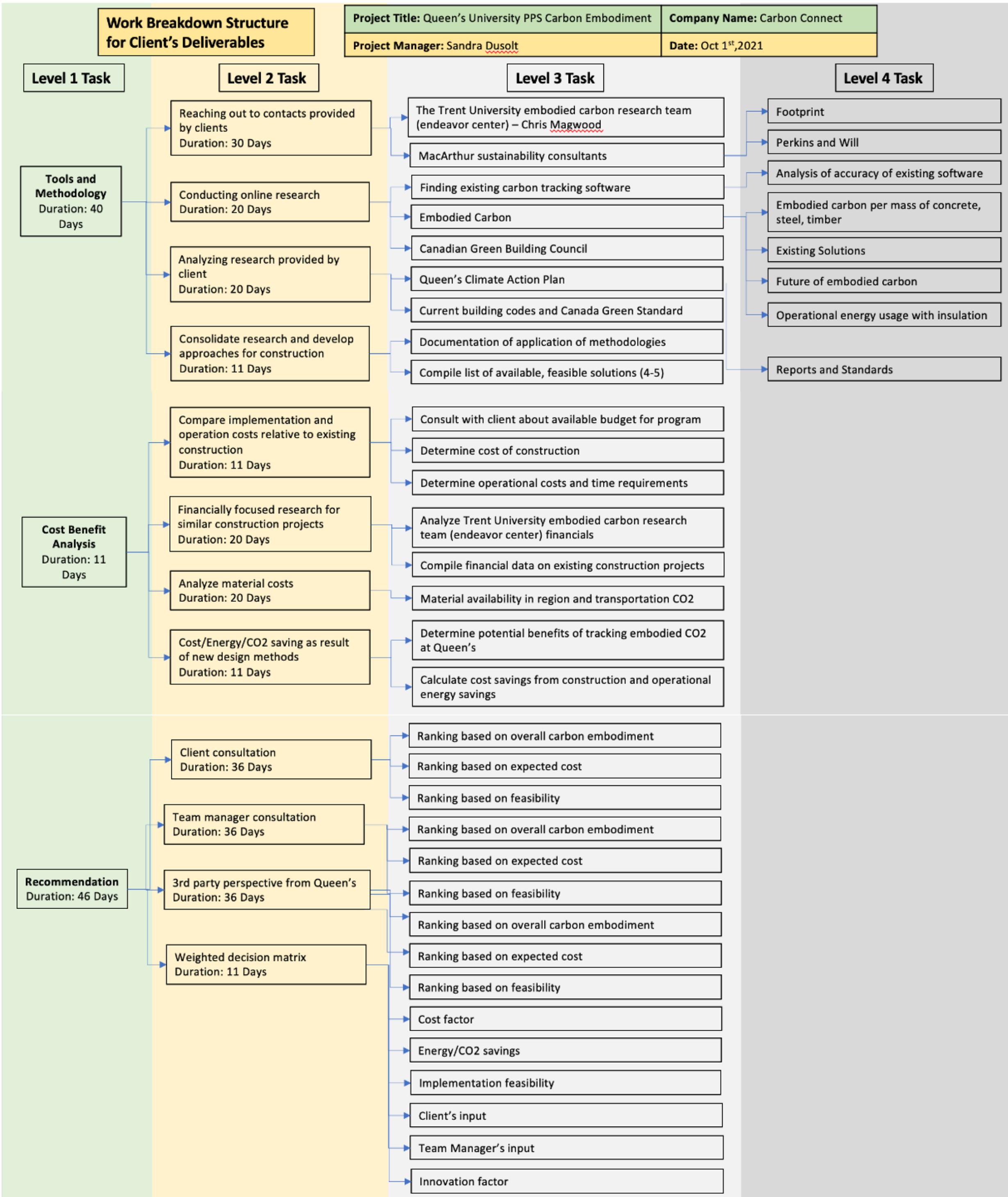


Figure 14: Work Breakdown Structure (WBS) Cont.



A.2.2 Responsibility Assignment Matrix

The Responsibility Assignment Matrix is shown in Figure 15. Each team member has been assigned various tasks as their primary responsibility. Other team members have been assigned support roles for tasks that require a greater amount of effort or time. In a support role, team members will take direction from the primary member, and contribute to that task as required, in any capacity to ensure its success. Some items are designated as team tasks and require the effort of all team members to guarantee a cohesive and high-quality result. Members assigned to edit are responsible for reading and revising the primary member's writing to ensure there are no grammar or spelling errors and enhance quality.

There have been no changes made to the Responsibility Assignment Matrix since the Work Plan was submitted. Though it is useful to have one person take the lead on certain tasks, most activities have been completed collaboratively, rather than using the Primary, Support, and Edit model that was developed. This is indicative of a strong team dynamic where all members can work together and support each other on most tasks, rather than simply dividing responsibility.

	Maddie	Ben	Spencer
Tools and Methodology			
Reaching out to contacts provided by client			
The Trent University Endevour Centre	P		
MacArthur sustability consultants			
Perkins and Will			P
Footprint			P
Conducting online research			
Finding existing emboided carbon tracking software			
Analysis of accuray of existing software	P	S	
Embodied carbon			
Embodied carbon per mass of concrete, steel, and timber	S		P
Existing solutions	T	T	T
Future of embodied carbon	S	P	
Operational energy usage with insulation	P		S
Canadian Green Building Council			
Reports and standards		S	P
Analyzing research provided by client			
Queen's Climate Action Plan	P	S	
Current building codes and Canada Green Standard		P	S
Consolidate research and develop approaches for construction			
Documentation of application of methodologies		P	S
Compile list of applicable, feasible solutions	T	T	T
Cost Benefit Analysis			
Compare implementation and operational costs relative to existing construction			
Consult with client about available budget for program		P	
Determine operational costs and time requirements for PPS			P
Financially focused research for similar construction projects			
Analyze Trent University Endeavour Centre Financials	P		S
Compare financial data on existing construction projects	S		P
Analyze material costs			
Material availability in region and transportation CO2	P	S	
Cost/energy/CO2 savings as result of new design methods			
Determine potential benefits of tracking embodied CO2 at Queens	S	E	P
Calcualte cost savings from construction and operational energy savings	E	P	S
Recommendation			
Client consulation		P	
Team manager consultation			P
Third party consultarion	P		
Weighted decision matrix	S	P	S
Targets			
5,10,20 year targets			
Compare to Queen's Climate Action Plan			P
Compare to Canada and UN Climate Action Goals	P		
Identify optimal approach for target implementation	T	T	T
Feasbility of implementation for period		S	P
Achieving Targets			
Identify potential adjustment of targets based on future performance			
Compare targets to predicted performance	S	P	
Determine adjustments needed based on performance			P
Contingency plan for underperformance			
Create more progressive solutions with higher energy savings	P	S	
Determine implementation plan to compensate for underperfomace	P		S
Implementation			
Identifiy necessary construction requirements			
Research Queen's existing construction methods	P	S	
Identify gaps or areas of improivement regarding embodied carbon		S	P
Develop new construction plan	T	T	T
Training for specialized maintenance			
Consult with PPS team		P	
Develop report for training	P		
Analysis of feasibility			
Conduct feasibility study	T	T	T
Identify implementation phases			
Cooridnate phases with transitioning targets	S	P	
Identify all possible implementation plans		P	S
Refine and choose ideal implementation through weighted evaluation matrix	P		
Develop implementation plan report in phased grouping	T	T	T
Compiling Final Documents			
Technical Report			
Format document with appropriate sub sections	S	E	P
Develop appropriate graphics	T	T	T
Use research design recommendations to fill in subsections	T	T	T
Write up missing information	T	T	T
Send to team manager for review		P	
1-Page high-level document			
Condense technical report into 1 page document for executives ad subcontractors	P	S	P
Send to team manager for review		P	
Number of Primary Responsibilities:	14	13	14
Number of Support Responsibilties:	8	9	8

P = Primary Responsibility
S = Support
E = Revise and Edit
T = Team task

Figure 15: Responsibility Assignment Matrix (RAM)

A.3 Team Member Qualifications

The figures below give an overview of each team members' experience and qualifications.

Ben's role on the Carbon Connected team is Project Coordinator and key client contact. Ben is well suited for this role based on his experience as a project coordinator for Homestead Land Holdings. In this role, he learned to manage subtrades and serve as a link between the construction management team and the subtrades working on the site. These skills will also serve him well as the key contact with the client because he is well versed in communicating through email and in site meetings.

Figure 16: Ben Anderson Qualifications

Maddie is the team's Materials and Sustainability Manager. Her experience mixing and testing concrete at Institut Građevinarstva Hrvatske in Croatia means she is well suited to manage the material aspect of this project. Additionally, her work on the Commerce and Engineering Environmental Conference gives her the credentials to take the responsibility of sustainability coordinator.

Figure 17: Maddie Smith Qualifications

Spencer is the team's Energy Systems Manager. His time working for Enwave Energy Corporation gives him experience working with sustainable energy systems. This experience will be key for the team when developing different methods of clean energy production for this project.

Figure 18: Spencer Robins Qualifications

A.4 Report Section Assignments

Table 10 below outlines which member was primarily responsible for each section of the report. All members were involved in assisting with and editing all sections.

Table 10: Member primarily responsible for each section of the report.

Section	Member Responsible
Executive Summary	Spencer
Introduction	Ben
Problem Description	Maddie
Scope	Maddie
Goals, Objectives, Deliverables	Ben
Stakeholders	Spencer
Constraints and Considerations	Maddie + Ben
Research – Climate Change, Embodied Carbon, Methodology	Ben
Research – Existing Tools	Spencer
Research – Canadian Building Standards	Ben
Research – Integrations into Queen's Building Standards	Spencer
Research – LEED, Baseline Embodied Carbon	Ben
Research – Financial	Maddie
Iteration	Maddie
Solution Assessment	Spencer
Recommendations – OneClick LCA	Spencer
Recommendations – Social Impact	Ben
Recommendations – Innovation, Financial	Maddie
Recommendations – Embodied Carbon	Ben
Case Study	Spencer
Conclusion	Ben

Appendix B

Evaluation Matrices

Table 11: Evaluation matrix for BEAM Estimator.

Indicator	Exceeds Expectations 8-9	Meets Expectations 6-7	Needs Improvement 4-5	Not Demonstrated 0-3
Economic Weight: 4	The solution is available at no cost to Queen's Facilities.	The solution costs less than 0.1% of the total value of a project.	The solution costs less than 0.5% of the total value of a project.	The solution costs less than 1% of the total value of a project.
Ease of Implementation Weight: 3	Requires under 5 hours of training for basic use and instructional videos are available at no cost.	Requires under 10 hours of training for basic use and instructional videos are available for purchase.	Requires under 20 hours of training for basic use and written instructional material is available.	Requires more than 20 hours of training for basic use and instructional material is limited or nonexistent.
Accuracy Weight: 3	Measures the embodied carbon of the structure to within 5% accuracy.	Measures the embodied carbon of the structure to within 10% accuracy.	Measures the embodied carbon of the structure to within 20% accuracy.	Measures the embodied carbon of the structure to less than 20% accuracy.
Time Commitment Weight: 3	Increases the time commitment required by Facilities for a project by less than 1%	Increases the time commitment required by Facilities for a project by less than 2%	Increases the time commitment required by Facilities for a project by less than 5%	Increases the time commitment required by Facilities for a project by more than 5%
Innovation Weight: 2	Solution demonstrates abstract thinking, originality in analysis, and addresses a commonly encountered issue.	Solution demonstrates abstract thinking, thorough research, and addresses an infrequently encountered issue.	Solution demonstrates some research and addresses an infrequently encountered issue.	Solution found uses well-known design processes or proposed solution is not appropriate.
Environmental Impact Weight: 5	Predicted to exceed the carbon reduction goals.	Predicted to meets the carbon reduction goals.	Predicted to fail to meet the carbon reduction goals, but within 15%.	Predicted to fails to meet the carbon reduction goals not within 15%.

Table 12: Evaluation matrix for OneClick LCA.

Indicator	Exceeds Expectations 8-9	Meets Expectations 6-7	Needs Improvement 4-5	Not Demonstrated 0-3
Economic Weight: 4	The solution is available at no cost to Queen's Facilities.	The solution costs less than 0.1% of the total value of a project.	The solution costs less than 0.5% of the total value of a project.	The solution costs less than 1% of the total value of a project.
Ease of Implementation Weight: 3	Requires under 5 hours of training for basic use and instructional videos are available at no cost.	Requires under 10 hours of training for basic use and instructional videos are available for purchase.	Requires under 20 hours of training for basic use and written instructional material is available.	Requires more than 20 hours of training for basic use and instructional material is limited or nonexistent.
Accuracy Weight: 3	Measures the embodied carbon of the structure to within 5% accuracy.	Measures the embodied carbon of the structure to within 10% accuracy.	Measures the embodied carbon of the structure to within 20% accuracy.	Measures the embodied carbon of the structure to less than 20% accuracy.
Time Commitment Weight: 3	Increases the time commitment required by Facilities for a project by less than 1%	Increases the time commitment required by Facilities for a project by less than 2%	Increases the time commitment required by Facilities for a project by less than 5%	Increases the time commitment required by Facilities for a project by more than 5%
Innovation Weight: 2	Solution demonstrates abstract thinking, originality in analysis, and addresses a commonly encountered issue.	Solution demonstrates abstract thinking, thorough research, and addresses an infrequently encountered issue.	Solution demonstrates some research and addresses an infrequently encountered issue.	Solution found uses well-known design processes or proposed solution is not appropriate.
Environmental Impact Weight: 5	Predicted to exceed the carbon reduction goals.	Predicted to meets the carbon reduction goals.	Predicted to fail to meet the carbon reduction goals, but within 15%.	Predicted to fails to meet the carbon reduction goals not within 15%.

Table 13: Evaluation matrix for eTool LCD.

Indicator	Exceeds Expectations 8-9	Meets Expectations 6-7	Needs Improvement 4-5	Not Demonstrated 0-3
Economic Weight: 4	The solution is available at no cost to Queen's Facilities.	The solution costs less than 0.1% of the total value of a project.	The solution costs less than 0.5% of the total value of a project.	The solution costs less than 1% of the total value of a project.
Ease of Implementation Weight: 3	Requires under 5 hours of training for basic use and instructional videos are available at no cost.	Requires under 10 hours of training for basic use and instructional videos are available for purchase.	Requires under 20 hours of training for basic use and written instructional material is available.	Requires more than 20 hours of training for basic use and instructional material is limited or nonexistent.
Accuracy Weight: 3	Measures the embodied carbon of the structure to within 5% accuracy.	Measures the embodied carbon of the structure to within 10% accuracy.	Measures the embodied carbon of the structure to within 20% accuracy.	Measures the embodied carbon of the structure to less than 20% accuracy.
Time Commitment Weight: 3	Increases the time commitment required by Facilities for a project by less than 1%	Increases the time commitment required by Facilities for a project by less than 2%	Increases the time commitment required by Facilities for a project by less than 5%	Increases the time commitment required by Facilities for a project by more than 5%
Innovation Weight: 2	Solution demonstrates abstract thinking, originality in analysis, and addresses a commonly encountered issue.	Solution demonstrates abstract thinking, thorough research, and addresses an infrequently encountered issue.	Solution demonstrates some research and addresses an infrequently encountered issue.	Solution found uses well-known design processes or proposed solution is not appropriate.
Environmental Impact Weight: 5	Predicted to exceed the carbon reduction goals.	Predicted to meets the carbon reduction goals.	Predicted to fail to meet the carbon reduction goals, but within 15%.	Predicted to fails to meet the carbon reduction goals not within 15%.

B.1 Scoring Justification for BEAM Estimator

BEAM did not receive a score for the 'Economic' indicator, because the software is not fully released yet and therefore a quote is not available. It received a eight in 'Ease of Implementation' because it is a relatively straightforward software that does not require much training. The reason it is simple to learn though is because it does not go into the same detail as the other software, and is meant for smaller buildings, and therefore is not as accurate for most of Queen's buildings. The tool received a six for innovation because although tracking embodied carbon is still somewhat innovate in the industry, the tool is not unique in its feature set. Finally, the tool received a five on 'Environmental Impact' because the results that the tool provides would not be very helpful in allowing Facilities to reach their reduction goals. Therefore, BEAM Estimator received a total score of 97/180.

B.2 Scoring Justification for OneClick LCA

OneClick LCA received a six for the 'Economic' indicator, because the software costs between $480 and $2000. A request for a quote has been submitted by Carbon Connected for a more exact cost. It received a nine in 'Ease of Implementation' because it is a straightforward software with an intuitive UI that does not require much training. Additionally, online training from experts is included with certain plan subscriptions. There is also extensive training information available on their website. The software received a nine in accuracy because it allows the user to input their own EPDs for any product while having an extensive preset database, so the model can be as accurate as possible. It received a score of seven in 'Time Commitment' based on the complexity of the software and Carbon Connected's experience using it. The tool received a six for innovation because although tracking embodied carbon is still somewhat innovate in the industry, the tool is not unique in its feature set. Finally, the tool received a nine on 'Environmental Impact' because the results that the tool provides would be very helpful in allowing Facilities to reach their reduction goals. It shows useful metrics and suggests sustainable alternatives for materials with high embodied carbon. It easily allows the user to compare different designs, allowing the selection of the lowest carbon proposal. Therefore, OneClick LCA received a total score of 153/180.

B.3 Scoring Justification for eTool LCD

BEAM received a score of seven for the 'Economic' indicator, because the software is available for between $63 and $625 per month. It received an eight in 'Ease of Implementation' because it is a relatively straightforward software and online training is included with some subscription plans. eTool LCD does not have the same extensive training on their website and their software is not as intuitive to use as OneClick LCA. The software received an eight in accuracy because it allows the user to input their own EPDs for any product, so the model can be accurate. The tool received a six for innovation because although tracking embodied carbon is still somewhat innovate in the industry, the tool is not unique in its feature set. Finally, the tool received a six on 'Environmental Impact' because the results that the tool provides would be helpful in allowing Facilities to reach their reduction goals by providing accurate data and clear results, but it does not suggest sustainable alterative to materials. Therefore, eTool LCD received a total score of 139/180.

Appendix C

Reference Figures and Tables

Table 14: Low Embodied Carbon LEED Credit Requirements

<table>
<tr><th>Category</th><th>Credit</th></tr>
<tr><td rowspan="2">Materials and Resources</td><td>Building Product Disclosure and Optimization – Material Ingredients (1-2 points)
This credit encourages the use of products and materials that reduce harmful ingredients and that provide information on product life cycle, including environmental, economic, and social impacts.
Early in design, identify products that qualify for this credit and discuss strategies with the design team</td></tr>
<tr><td>Furniture and Medical Furnishings (Healthcare only) (1-2 points)
This credit requires project teams to consider the impacts that freestanding furniture may have on environmental and human health.
This credit also includes soft medical furnishings, such as mattresses, making it imperative to consult early-on with the owner and operator. Early on in design, determine applicable furniture and discuss with team and owner. Wood and Sustainable Agriculture Network (SAN) certified products may have an advantage with this credit. Discuss what products are available and applicable to this credit early on with the design team. Wood products will have an advantage with this credit, as they often perform well in the applicable categories.</td></tr>
<tr><td rowspan="2">Indoor Environmental Quality</td><td>Low Emitting Materials (1-2 points)
This credit requires that all products on the inside of the primary and secondary air weatherproofing barriers meet low Volatile Organic Compound (VOC) requirements.
This credit also requires that products claiming to have low VOCs be tested according to certain standards. Note that furniture that is part of the scope of the project is also required to meet the applicable credit requirements.</td></tr>
<tr><td>Indoor Air Quality Assessment (1-3 points)
This credit requires a flush-out or air testing of the building after construction ends. For the air testing requirement, with the ventilation running as during occupancy, the formaldehyde concentrations must not exceed 27 ppb. Testing for other contaminants such as Particulates, Ozone, VOCs, Carbon Monoxide are also required.</td></tr>
<tr><td>Innovation</td><td>Innovation (1-5 points)
Using wood in LEED projects can help achieve Innovation points by achieving exemplary performance requirements from the Materials and Resources credits</td></tr>
</table>

	and by looking at wood as a biophilic material. Biophilic design looks at incorporating nature and natural processes into the built environment. Exposed wood, as a natural material, is considered an indirect experience of nature, and has been shown to help reduce stress levels and improve performance of building occupants. Using wood can help achieve an innovation credit through biophilic design, either through a credit of the WELL Building Standard, Feature 88 Biophilia, Qualitative or Feature 100, Biophilia, Quantitative, or the Living Building Challenge Imperative 09, Biophilic Environments.
Regional Priority	Regional Priority (1-4 points) • This credit rewards projects for achieving other credits that have been deemed to be of special regional significance, such as those that are particularly important to a specific geographical area (e.g., protection and restoration of water resources). With regards to low carbon building materials, one Regional Priority credit is applicable for all regions of B.C. Achieving MRc Building Life-Cycle Impact Reduction rewards the project with a Regional Priority point.

University of Toronto	
Green Building Goals	Green Building Project
• 37% reduction in greenhouse gas emissions by 2030 • Climate positive by 2050	University of Toronto Exam Centre  • LEED Gold Certification (“University of Toronto Exam Centre – Montgomery Sisam” n.d.)
Embodied Carbon Specifications	
• Emphasis on the environmental consequences of all aspects of products’ life cycle • Target reduction of 8325 eCO2/year by 2030 from designing to new building standards	

Figure 19: U of T Green Building Information (“Low Carbon Action Plan (2019-2024)” 2019)

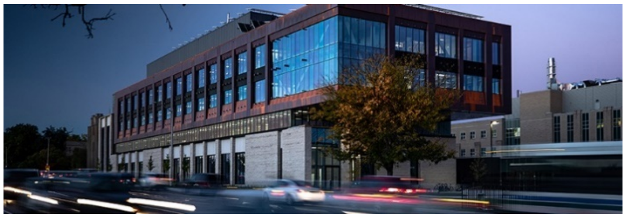
McGill University	
Green Building Goals	Green Building Project
• Goal to increase the environmental performance of buildings while reducing their carbon footprint by 2025 • All new construction and major renovation projects to be, at minimum, LEED Gold certified	McGill University's Life Sciences Complex  • LEED Gold Certification • 96.4% of construction-related waste was diverted from landfill • 30% of materials used contained recycled content • >20% of materials were locally sourced ("McGill University's Life Sciences Complex earns LEED Gold certification" 2012)
Embodied Carbon Specifications	
• Life Cycle Cost Analysis will be performed to quantify the 20-year impacts on GHG, energy costs, maintenance costs, etc. • Material Analysis Tool (MAT) website used for the selection of building products	

Figure 20: McGill Green Building Information ("McGill University Climate & Sustainability Strategy" n.d.)

University of British Columbia	
Green Building Goals	Green Building Project
• 85% reduction in campus operations emissions by 2030 • 100% reduction in operational greenhouse gas emissions by 2035 • Net-zero by 2050	Brock Commons Tallwood House  • LEED Gold Certification • Carbon sequestration through use of mass timber
Embodied Carbon Specifications	
• Establish an embodied carbon baseline and align new building and renewal designs with a 50% reduction target by 2030 • Goal to develop guidance for reducing embodied carbon in buildings to discourage, reduce or potentially	

eliminate materials with the highest embodied carbon impacts.	• De-constructability, reuse, and recycling potential (“Environmental Building Declaration for Brock Commons Tallwood House | Case Studies, Research + Resources” n.d.)

Figure 21: UBC Green Building Information (“UBC Embodied Carbon Pilot” 2020)

<table>
<tr><th colspan="2">Western University</th></tr>
<tr><td>Green Building Goals</td><td>Green Building Project</td></tr>
<tr><td>• Reduce greenhouse gas emissions by at least 45% by 2030
• Achieve net-zero emissions for campus operations by 2050</td><td rowspan="3">Amit Chakma Engineering Building

• LEED Platinum Certification
• Locally sourced Canadian Maple
• Limestone quarried from Wiarton, Ontario
• Regional steel to hold up the two-storey cantilevered section of the building
• Electrochromic windows

(“Green Buildings” n.d.)</td></tr>
<tr><td>Embodied Carbon Specifications</td></tr>
<tr><td>• Operational policy that all new building construction and retrofits will achieve a minimum LEED Silver certification
• Goals to improve waste management and diversion rates for waste generated from new builds
• Emphasis on using recycled materials in new builds</td></tr>
</table>

Figure 22: Western Green Building Information (“Western University Sustainable Design Guidelines” 2018)

Appendix D

OneClick LCA Figures

D.1 Embodied Carbon Measurement Process

Gross material consumptions (including losses) are entered by material type and divided by type of structure, as shown in Figure 23.

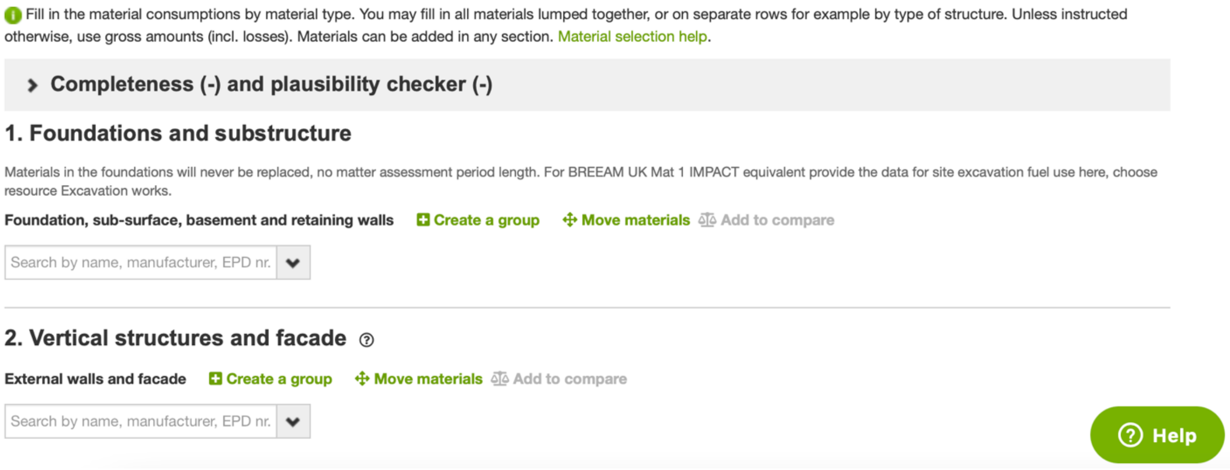


Figure 23: OneClick LCA material consumption input UI.

Materials can be created manually using EPDs provided by suppliers, as shown below in Figure 24.

Figure 24: OneClick LCA manual material input.

Alternatively, the software has the world's largest generic and EPD database, shown in Figure 25, that is updated, verified, and enhanced by OneClick LCA's quality assurance team. The database includes global generic data or manufacturer-specific, third-party verified EPDs. The platform also allows the user to request EPDs from manufacturers directly.

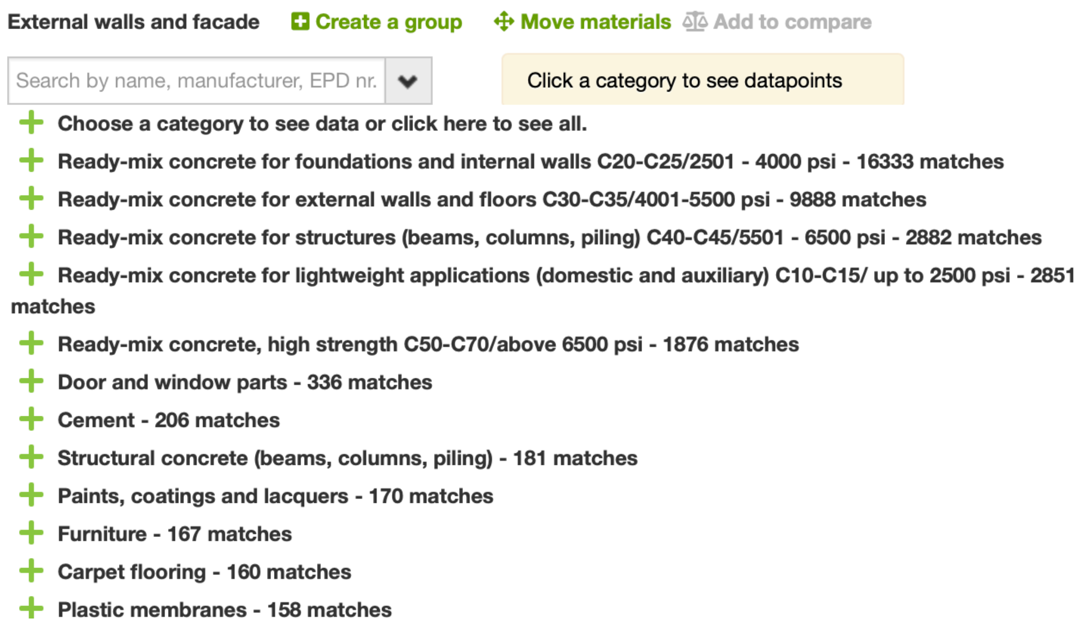


Figure 25: OneClick LCA material emissions database.

Once a material is selected, gross quantities are entered as well as information including transport type and service life can be added, as shown below in Figure 26.

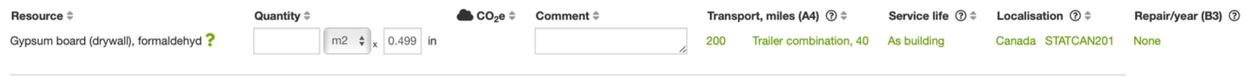


Figure 26: OneClick LCA material database additional information input UI.

OneClick LCA also allows the user to create baseline and alternative designs to easily compare the carbon footprint of each. By inputting additional information regarding material and labour costs, and using regional cost parameters preset by the system, the software can compare costs between designs. Using this design data, it can generate automated, easy to read, LCA reports which include embodied carbon, as shown below in Figure 27 and Figure 28.

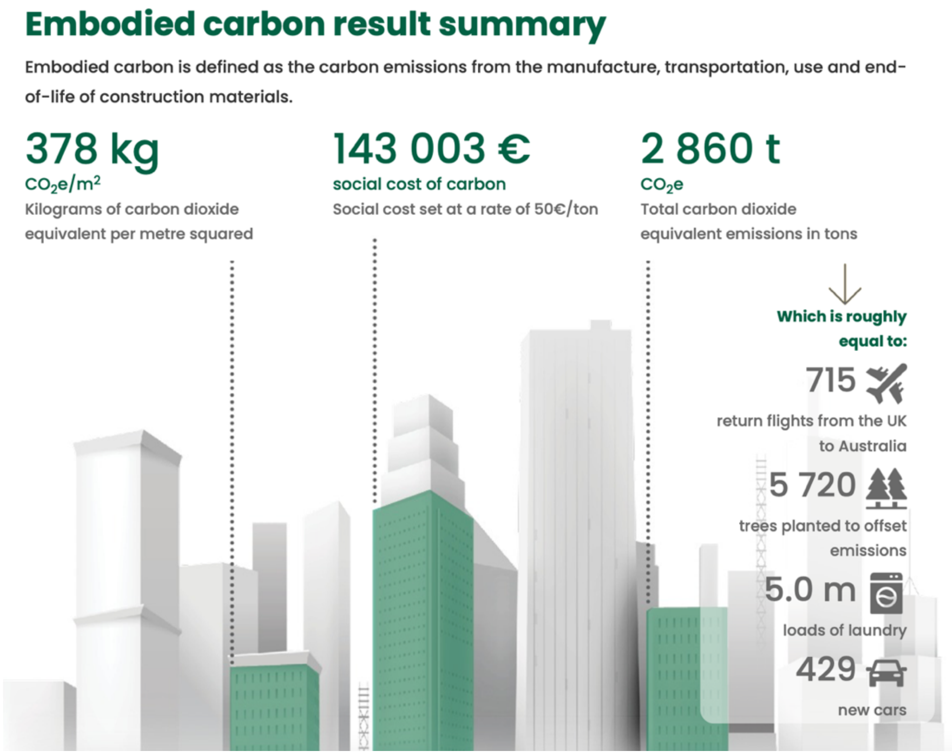
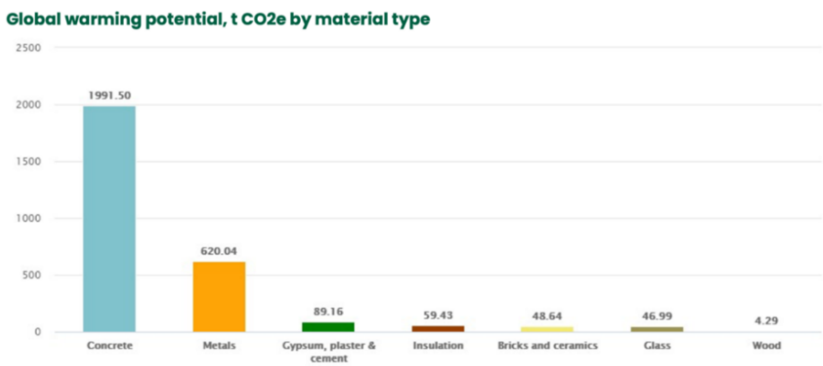


Figure 27: OneClick LCA sample report depicting embodied carbon result summary.



Most contributing materials

Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)
1. Hollow core concrete slabs, generic	1,4 tons CO_2e	48.8 %
2. Structural steel hollow sections	0,45 tons CO_2e	15.9 %
3. Hollow core concrete slabs, generic	0,36 tons CO_2e	12.7 %
4. Ready-mix concrete	0,13 tons CO_2e	4.7 %
5. Ready-mix concrete, normal-strength, generic	0,1 tons CO_2e	3.5 %

Figure 28: OneClick LCA sample report depicting global warming potential by material type and the materials contributing the most equivalent CO_2 emissions.

D.2 Case Study Data and Results

1. Foundations and substructure — 178 Tons CO_2e - 9 %

Materials in the foundations will never be replaced, no matter assessment period length. For BREEAM UK Mat 1 IMPACT equivalent provide the data for site excavation fuel use here, choose resource Excavation works.

Foundation, sub-surface, basement and retaining walls — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity		CO_2e	Comment	Transport, miles (A4)		Service life
Concrete, ready mix, 5001 - 6000 ps	208.0	m3	91t - 5%	Footings + CMU Fill	20	Concrete mixer truck	Permanent
Concrete, ready mix, 5001 - 6000 ps	76.0	m3	33t - 2%	Slab on grade	20	Concrete mixer truck	Permanent
Latex-based membrane, vapor imperme	650	m2	4.8t - 0.3%	Below-grade vapour barrier	350	Trailer combination, 40	Permanent
Concrete masonry unit (CMU), normal	123	m3	35t - 2%	Below-grade walls	200	Trailer combination, 40	Permanent
Cement mortar, 0.834 lb/ft2, 80.03	20	m3	13t - 0.7%		200	Trailer combination, 40	Permanent

2. Vertical structures and facade — 906 Tons CO_2e - 40 %

External walls and facade — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity				CO_2e	Comment	Transport, miles (A4)		Service life
Spray polyurethane foam insulation	3500	m2	x 1.5	in	3.6t - 0.2%	Huntsman Heatlok Spray	350	Trailer combination, 40	As building
Natural stone cladding, 49.67 lb	3500	m2	x 3.54	in	126t - 6%	Arriscraft Natural Stone	120	Trailer combination, 40	As building
Latex-based membrane, vapor imperme	3500	m2			35t - 2%	Carlisle Air-Vapour Barrier	350	Trailer combination, 40	30
High pressure compact laminate pane	3500	m2			246t - 11%	Fundermax Exterior Panels	900	Trailer combination, 40	15

Columns and load-bearing vertical structures — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity		CO_2e	Comment	Transport, miles (A4)		Service life	Loca
Concrete, ready mix, 5001 - 6000 ps	681.0	m3	298t - 13%	Shear walls/columns	20	Concrete mixer truck	As building	Loca

Internal walls and non-bearing structures — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity				CO_2e	Comment	Transport, miles (A4)		Service life
Gypsum board (drywall), formaldehyd	80000	m2	x 0.625	in	154t - 7%	Certainteed Drywall	200	Trailer combination, 40	As building
Stone wool insulation batt, for int	3000	m2	x 1.46	in	2.4t - 0.1%	Interior insulation	200	Trailer combination, 40	As building
Softwood lumber, kiln-dried and pla	500	m3			41t - 2%	Interior walls	560	Trailer combination, 40	As building

Floor slabs, ceilings, roofing decks, beams and roof — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity				CO_2e	Comment	Transport, miles (A4)		Service life
Concrete, ready mix, 5001 - 6000 ps	1136.0	m3			497t - 26%	Slabs	20	Concrete mixer truck	As building
Ceiling panel, mineral fiber (m2	2200	m2	x 0.75	in	2.7t - 0.1%	Cirrus Ceiling Panels	350	Trailer combination, 40	As building
Reinforcement steel (rebar), 7850 k	25.5	m3			-	Rebar (1.5% concrete volume)	580	Trailer combination, 40	As building
Gypsum board with glass mat sheathi	1800	m2			13t - 0.7%	Georgia Pacific Dens Deck	200	Trailer combination, 40	40
Concrete, interlocking paving un	831	m2	x 3	in	44t - 2%	Roof concrete pavers (2	200	Trailer combination, 40	As building
Aggregate (crushed gravel), generic	450	m2	x 2	in	0.21t - ~0%	Roof aggregate	30	Dump truck, 19 ton	As building
XPS insulation, R=1m2K/W, 0.681 kg/	1800	m2	x 0.996	in	36t - 2%	Dow Styrofoam Roofmate	350	Trailer combination, 40	As building

4. Other structures and materials — 394 Tons CO_2e - 21 %

Other structures and materials — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity		CO_2e	Comment	Transport, miles (A4)		Service life
Vitreous ceramic sanitaryware, flus	190	unit	6.1t - 0.3%	Toilets	850	Large delivery truck, 9	As building
Ceramic bathroom sink, 9.54 kg/unit	190	unit	4.2t - 0.2%	Sinks	850	Large delivery truck, 9	As building
Door exit device from steel, 4.0	20	unit	0.25t - ~0%	Allegion Door Exit Devices	800	Trailer combination, 40	As building
Structural steel profiles, generic,	12675	kg	29t - 2%	Mechanical Penthouse	580	Trailer combination, 40	As building

Windows and doors — Compare answers · Create a group · Move materials · Add to compare

Search by name, manufacturer, EPD nr.

Resource	Quantity		CO_2e	Comment	Transport, miles (A4)		Service life
Insulating Glass Unit (IGU), coated	200	m2	13t - 0.7%	Alumicor Thermawall	200	Trailer combination, 40	As building
Aluminium frame windows, 42.6 kg/un	505	unit	99t - 5%	Kawneer Aluminum Framed	650	Trailer combination, 40	As building
Galvanized steel door frames, 18.8	414	unit	22t - 1%	Door frames	800	Trailer combination, 40	As building
Galvanized steel door with honeycom	405	unit	90t - 5%	Interior doors	550	Trailer combination, 40	30
Galvanized steel door with honeycom	9	unit	2t - 0.1%	Exterior doors	550	Trailer combination, 40	30
Panel door leaf, per unit, 26.84 kg	355	unit	15t - 0.8%	Interior bathroom doors	550	Trailer combination, 40	40

Finishes and coverings — Compare answers · Create a group · Move materials · Add to compare

2,497 Tons CO_2e · 43.04 kg CO_2e / m^2 / year · 124,849 € Social cost of carbon

Carbon Heroes Benchmark

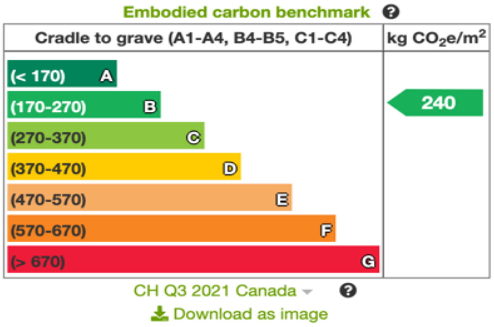


Figure 30: Results from OneClick LCA depicting total statistics and embodied carbon benchmark using Carbon Heroes service.

	Result category	Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg Ne	Ozone Depletion kg CFC11e	Formation of tropospheric ozone kg O3e	Fossil fuel primary energy MJ	Total use of primary energy ex. raw materials MJ
A1-A3	Construction Materials	2,184,102.84	8,607.55	2,949.25	0.08	174,584.96	23,064,990.54	29,453,290.83
A4	Transportation to site	70,298.6	277.18	52.88	0.02	7,109.18	1,597,391.97	1,627,583.58
B3	Repair	0	0	0	0	0	0	0
B4-B5	Material replacement and refurbishment	147,022.26	857.06	337.3	0.03	10,983.47	1,589,724.39	1,867,918.54
B6	Energy use							
C1-C4	Deconstruction	95,565.27	343.74	265.23	0.01	6,220.28	979,569.52	1,016,121.11
	Total	**2,496,988.98**	**10,085.53**	**3,604.65**	**0.15**	**198,897.89**	**27,231,676.42**	**33,964,914.06**
	Results per denominator							
	Gross Internal Floor Area (ASHRAE) 10407.0 m^2	239.93	0.97	0.35	0	19.11	2,616.67	3,263.66

Figure 31: Results from OneClick LCA depicting LCA broken down by life-cycle stage.

Most contributing materials (Global warming)

No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)	Sustainable alternatives
1.	Concrete, ready mix	1,320 tons CO_2e	60.4 %	Show sustainable alternatives
2.	Reinforcement steel (rebar)	260 tons CO_2e	11.9 %	Show sustainable alternatives
3.	Gypsum board (drywall), formaldehyde absorbing, Moundsville (WV) facilities	112 tons CO_2e	5.1 %	Show sustainable alternatives
4.	Aluminium frame windows	98 tons CO_2e	4.5 %	Show sustainable alternatives
5.	Natural stone cladding	81 tons CO_2e	3.7 %	Show sustainable alternatives

Figure 32: Results from OneClick LCA outlining materials with highest embodied carbon. Also displayed is the ability to compare sustainable alternatives directly within OneClick LCA.

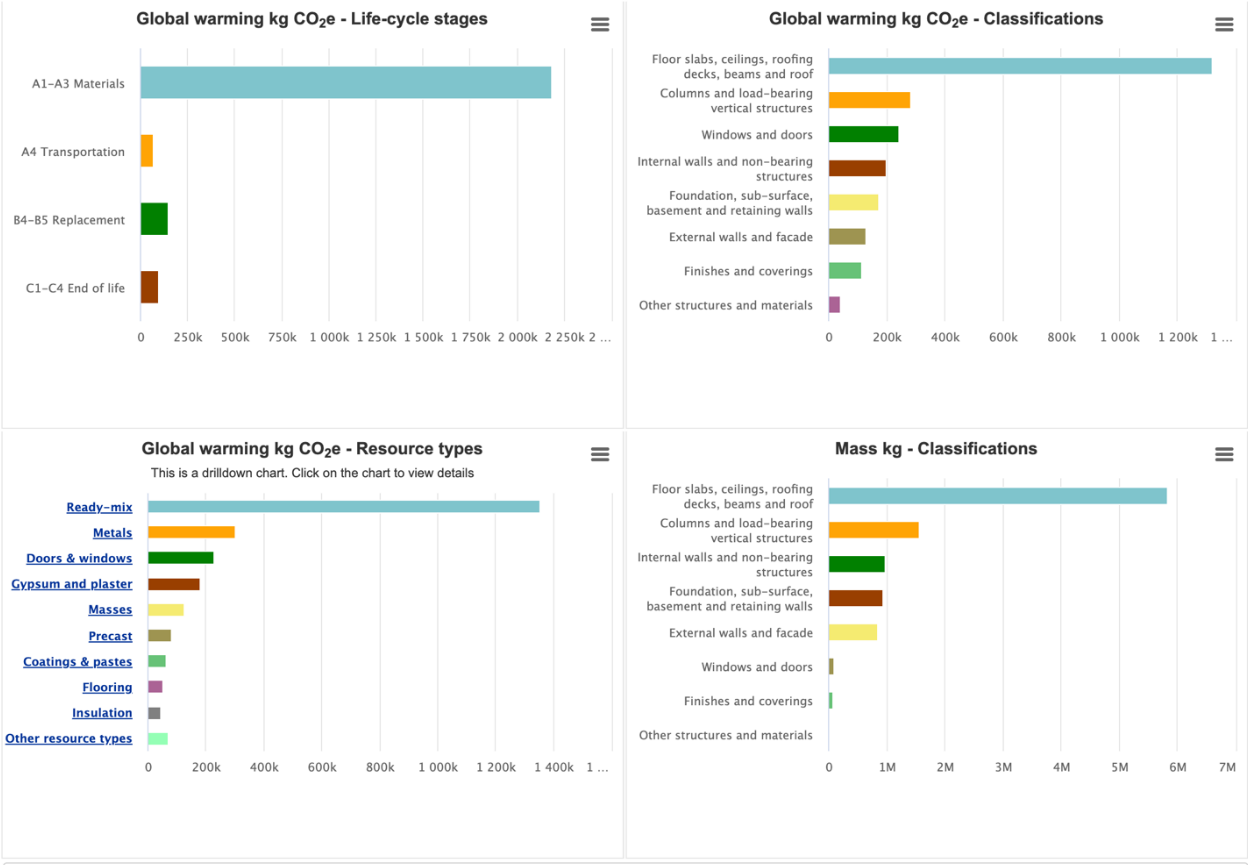


Figure 33: Several graphs produced within the results of OneCLick LCA.