EMBODIED CARBON WHITE PAPER

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SUBMITTED TO:

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EXECUTIVE SUMMARY

Introduction

The building sector accounts for about one third of GHG (greenhouse gas) emissions globally, and about 12% in Canada. This 12% figure, however, does not include the manufacturing and transportation of building materials, suggesting that the building sector accounts for a higher percentage of GHG emissions. Indeed, buildings emit GHG throughout their lifecycles, from raw material extraction and construction to operations and demolition. Given that current energy performance programs primary focus on operational emissions, these longitudinal embodied carbon emissions are missed in energy performance models.

Although focusing on operational emissions has both spurred technological advances in energy conservation measures and precipitated significant reductions in building GHG emissions, they only represent part of the sustainability equation. As pressure mounts to reduce GHG emissions, efforts to address carbon emissions have widened to include those embodied in raw material extraction, manufacturing, delivery, construction methods, and end of life disposal or recycling.

What is Embodied Carbon?

Embodied carbon is defined as the GHG emissions associated with the production of a building, including the extraction, manufacturing and transportation of construction materials, as well as construction processes. Embodied carbon also accounts for any major renovations, where materials are added to a building, and the end of life demolition of a building.

While embodied carbon emissions comprise a range of sources, the greatest contributor is construction materials, accounting for 60% to 80% of total embodied emissions. For this reason, the majority of embodied carbon emissions occur at the outset of a building's life cycle.

Purpose of this White Paper

This white paper explores the issues and urgency relating to embodied carbon, current industry trends on the topic, and the potential to influence regulations and standards to incorporate embodied carbon measures. This paper also analyzes the impact of design decisions on embodied carbon, specifically structural materials, building form, and ECMs. Where applicable, embodied carbon is compared to the operational savings associated with these design decisions.

Study Methodology

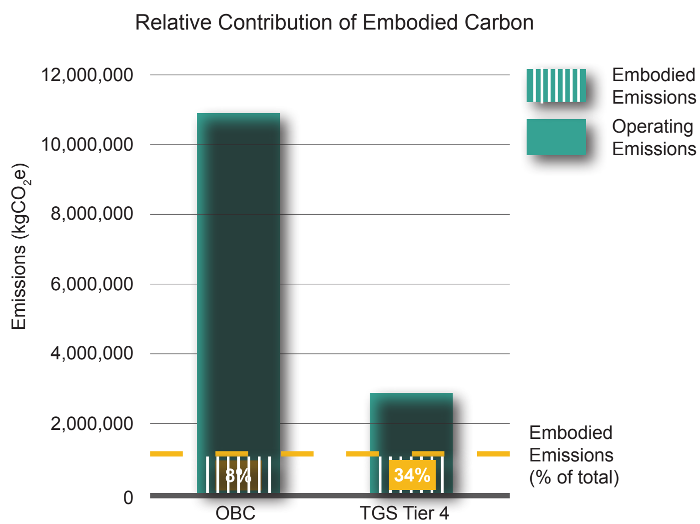
This white paper analyzes embodied carbon impacts by conducting a life cycle analysis of a typical Multi-Unit Residential Building located in Ottawa, Ontario. To conduct this analysis, the Athena Impact Estimator for Buildings program was used. This program, available online, uses a bill of materials input by the user to estimate the life cycle impacts of a building, and accounts for the building location as well as other parameters that effect the embodied emissions.

The reference building's structural components are made of concrete. Because structural components of a building represent a large quantity of material, the type of structure will have an impact on the total embodied carbon of a building. For this reason, the reference building was used to model and compare the impacts of two more common structural materials for a mid-rise building: steel and timber.

Furthermore, energy conservation measures that's effect the amount of materials used for a building also have an impact on the embodied carbon. The reference building was used to model the effects of adjusting the window to wall ratio (WWR) and increasing the thermal insulation of a building's wall assembly.

Key Findings

1. The impact of Embodied Carbon on a building's total Life Cycle emissions becomes greater with the decrease of operational energy usage resulting from energy conservation measures.



3. The Window-to-Wall Ratio (WWR) has a modest effect on the embodied carbon emissions of a building, where smaller WWRs result in less emissions and vice versa. A greater benefit is realized in the savings of operational energy.

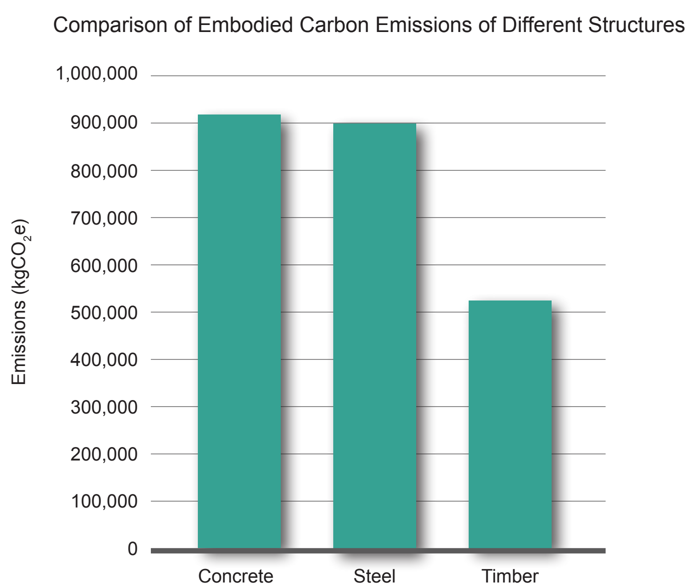
+1.27%
Change in Embodied Carbon

+1.81%
Change in Operational Carbon

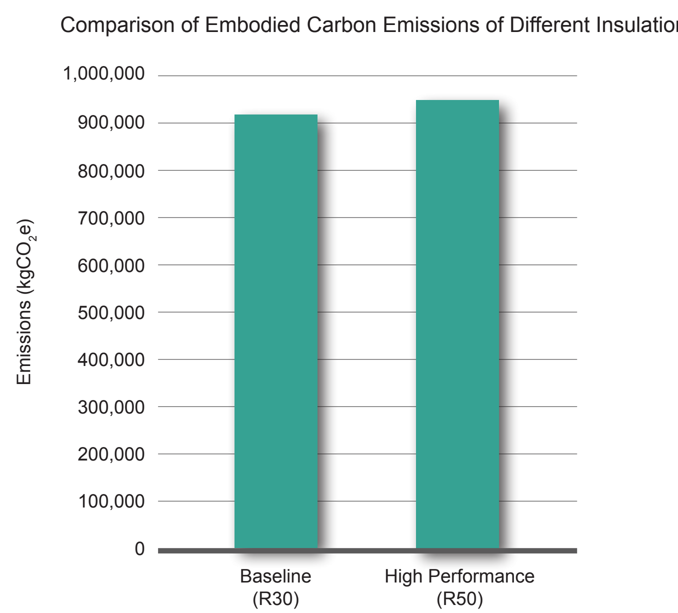
-1.04%
Change in Embodied Carbon

-1.44%
Change in Operational Carbon

2. For the same building height, composition and location, a concrete structure has the highest amount of embodied carbon, followed by steel, then timber.



4. Increasing the Thermal Insulation of a Building has a minimal impact on the embodied emissions of a building.



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Foreword

This study was undertaken by Urban Equation for Sustainable Buildings Canada to better understand the embodied carbon impact of buildings.

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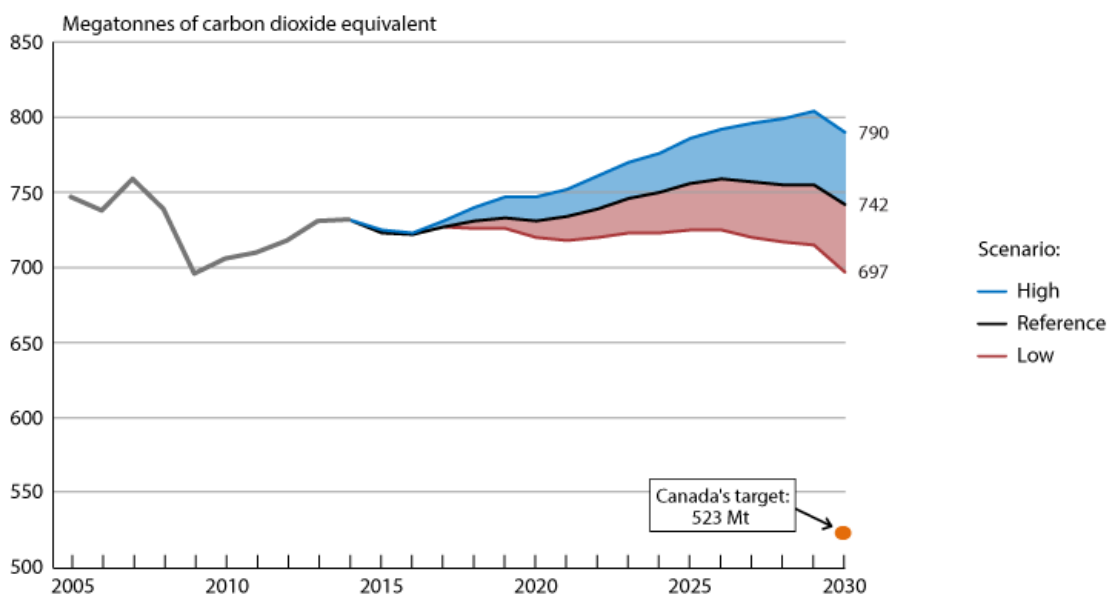
1 INTRODUCTION

Since humans first began harnessing energy to provide our most basic needs, its availability and cost can be tracked directly with human prosperity and progress. Energy is inextricably connected to our quality of life, and the health of our planet. It is a complex subject that has become a defining issue of our generation.

The Intergovernmental Panel on Climate Change (IPCC) has identified the maximum amount of carbon dioxide (CO_2) emissions that can be released to avoid the most dangerous affects of climate change. If emissions remain at the same rates they are today, we are set to exceed this amount before the end of 2045, potentially leading to a 2^{o}C temperature rise above pre-industrial era levels. The implications of reaching this level are significant, some of which we are beginning to see today, such as an increase in forest fires, global rise of sea level, and increasingly frequent storms. As a result, there is a global push to reduce greenhouse gas (GHG) emissions to mitigate the impacts of climate change.

In Canada, the Federal Government has established a medium-term target to reduce Canada's total GHG emissions by 30% in 2030, relative to 2005 emission levels, or 523 Megatons of CO_2e. With current policies and measures in place, we will not reach this goal (Figure 1).

Figure 1 Canada's Carbon Emissions Projections with Policies and Measures as of November 2016 [1]



The building sector accounts for about 33% of GHG emissions globally, and about 12% in Canada [1]. However, this excludes the manufacturing, transportation, or waste emissions associated with building materials, which would result in a much higher percentage of total GHG emissions.

Buildings emit GHGs at every stage of their lifecycle, from raw material extraction to construction, and operations to demolition. Currently, most programs for the built environment focus on energy use reduction; specifically, they put the primary focus on energy conservation measures (ECMs) that reduce the *operational* GHG emissions in buildings. The majority of operational GHG emissions in Canada stem from the use of natural gas and electricity usage, particularly during peak periods. Sustainability programs such as the Toronto Green Standard (TGS) and Leadership in Energy and Environmental Design (LEED) both encourage developers to meet energy efficiency standards, and reward them with certification depending on how much energy they are expected to save as a result of implementing ECMs. The Canada Green Building Council reports that there has been a significant increase in green building projects in Canada, with over half of Canadian industry professionals reporting that 30% of their projects are 'green' [2].

Therefore, one can conclude that reducing operational emissions has been met with success. Buildings have become more energy efficient with increased adoption of ECMs, such as increased thermal insulation and mechanical system upgrades, and the growth of renewable energy generation has provided alternative, cleaner forms of energy.

Embodied emissions represent an opportunity for Canada to work towards achieving our climate change goals.

However, as pressure mounts to reduce GHG emissions, there is an increasing focus on embodied carbon within buildings; the carbon emissions associated with a buildings materials, construction, renovations, and end of life demolition. As buildings become more energy efficient, the impact of embodied carbon has a larger relative contribution to the total life cycle emissions of a building.

The importance of reducing embodied carbon also relates to when these emissions occur. Embodied emissions are the first emissions in a building's lifecycle, and are the majority of a building's emissions for the first 15 to 20 years [3]. Because GHG emission reductions are time critical, the embodied emissions of new buildings becomes a significant factor in reaching climate change targets and commitments set by countries globally.

This white paper will explore the issues and opportunities relating to embodied carbon and current industry trends on the topic. The paper will also analyze the impact of design decisions on embodied carbon, specifically structural materials and ECMs. Where applicable, embodied carbon will be compared to the operational savings associated with these design decisions.

1.1 Embodied vs Operational Emissions

Embodied carbon is defined as the GHG emissions resulting from the energy consumed in the production of a building, including the extraction, manufacturing and transportation of construction materials, as well as construction processes. Embodied carbon also takes into account any major renovations and maintenance, where materials are added to a building, as well as the end of life demolition of a building.

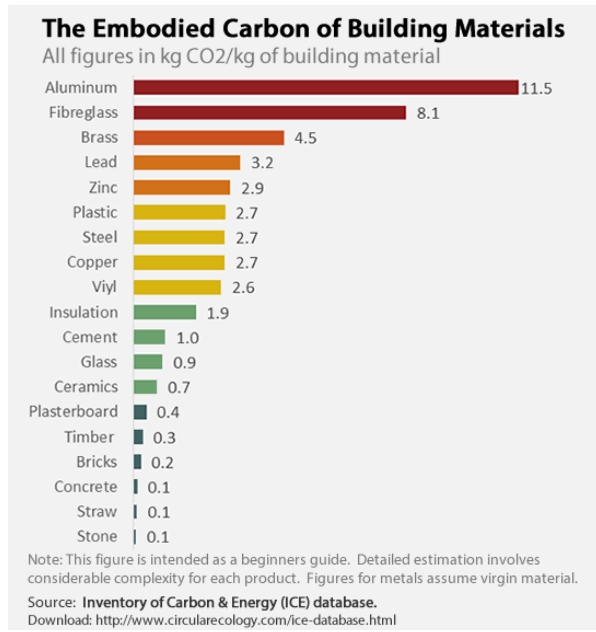
Previously, embodied carbon emissions were not prominent factors in the emissions reductions field, due to the fact that they only accounted for 10% to 20% of a building's total emissions [3].

However, as ECMs have become more effective and wide-spread, along with cleaner energy grids, the impact of embodied carbon emissions on the total life cycle emissions of buildings has become greater. For buildings with a shorter service life, the relative impact of embodied carbon versus operational is even larger.

There are many factors that contribute to embodied carbon. Far and away the largest are the materials used for construction; materials account for 60% to 80% of embodied carbon emissions [3]. Embodied carbon also differs geographically, due to energy grid make-up, manufacturing processes, building codes, and construction practices.

Despite these variables, and challenges detailing embodied carbon on a product by product basis, location by location basis, the Inventory of Carbon & Energy (ICE) has developed a database of the embodied carbon of building materials per kilogram, which can be used to see the relative emissions associated with materials compared to one another (see Figure 2). The ICE figures suggest that Aluminum has the highest embodied carbon of all building materials per unit mass, while more natural materials such as stone have lowest embodied carbon. This figure may seem to suggest that concrete releases less embodied carbon emissions than timber, but it is important to note that these figures are per one kilogram of material. As will be discussed in Part 2, for the same building, a concrete structure has a much larger mass than a timber structure, therefore resulting in higher embodied emissions.

Figure 2: ICE Database of Embodied Carbon of Building Materials



However, the sensitivity to building location in Canada, described in global warming potential, is rather small when compared across major cities (Table 1).

Table 1: Sensitivity of Embodied Carbon Across Major Canadian Cities [4]

Location	Ratio
Vancouver (Baseline)	1.0000
Calgary	1.0549
Halifax	1.0193
Montreal	0.9802
Ottawa	0.9983
Quebec City	0.9868
Toronto	0.9889
Winnipeg	1.0028

Because the majority of embodied carbon emission are generated at the beginning of a buildings life cycle, there is a significant opportunity to reduce these emissions when one takes in to account the current rate of construction projects. According to Emporis, the City of Toronto had approximately 178 buildings under construction in 2017 [5]. If embodied carbon emissions are addressed in these new builds, this could mean large reductions in carbon emissions realized in the immediate term.

1.2 Current Industry Trends

Despite the significance of embodied emissions, the majority of current climate change policies and programs do not account for them. The lack of embodied carbon frameworks can be attributed to the complexity of the subject, and lack of accurate data readily available, standardized, and simplified for use [6].

There are, however, a number of jurisdictions around the world that are establishing precedents, and best practices, in relation to embodied carbon. These include:

International:

- Many European countries have voluntary Environmental Product Declarations (EPDs), which provide life cycle environmental impact data, and are required for manufacturers wishing to make environmental marketing claims [6];
- Germany, France and the United Kingdom offer voluntary building labels and incentives for meeting embodied carbon consumption targets [6];
- The Netherlands require embodied carbon reporting for building permit applications for new buildings over 100 m^2 [6];
- In Switzerland and Germany, whole building life cycle assessments are required for new government buildings [6].

Canada:

- Vancouver requires developers applying for a rezoning application to include a report of life cycle embodied carbon emissions.
- Public Services and Procurement Canada, who manage government buildings across the country, require a life cycle analysis for new buildings.

While some certification standards have been addressing embodied carbon indirectly though strategies such as materials reuse, recycled content or regional materials, they are only just beginning to address the subject directly.

- The Living Building Challenge requires projects to account for embodied carbon impact by purchasing a one-time carbon offset. Embodied emissions are addressed indirectly through requiring sustainable materials, and for materials to be local and recycled, and requiring net positive waste;
- The Toronto Green Standard has no specific reference to embodied carbon emissions, but includes voluntary approaches, such as sourcing local construction materials, to reduce these emissions;
- LEED v4 includes a credit for whole building life cycle assessments and rewards projects for demonstrating a 10% reduction in embodied carbon impacts. Similar to

some European jurisdictions, LEED v4 also awards credits to projects that use products which have EPD's;

- Canada Green Building Council's (CaGBC) Zero Carbon Building Standard defines a net zero building as a building that is highly energy-efficient and produces onsite or procures carbon-free renewable energy in an amount sufficient to offset annual carbon emissions associated with operations [7]. While embodied emissions are not included in the amount of renewable energy required to be generated, the Standard requires that projects report the embodied emissions of the building.

In order for these embodied carbon frameworks to be effective, tools that allow the measuring of embodied carbon that are simplified and readily available are essential. The following tools are recommended by the CaGBC to achieve the reporting credit in the Zero Carbon Building Standard:

- Athena Impact Estimator for Buildings – A software available for free online that relies on input by the user to determine material quantities, or a bill of materials uploaded into the program.
- Tally – A plug-in for Autodesk Revit that calculates material quantities based on take-offs from the Revit model. Revit is currently a popular software for building design, making Tally an attractive option for new builds.

2 QUANTIFYING EMBODIED CARBON

When considering energy for a new building or development, operational carbon, through energy conservation measures, is generally the starting point when reducing emissions; rarely are the embodied carbon emissions taken into account when making these decisions.

To what effect do ECMs have on embodied carbon emissions of a building is generally not considered, nor is the collective impact of these decisions on the overall building emissions. For example, if we reduce the window to wall ratio (WWR) to achieve a better thermal performance of the building envelope, are we positively or negatively affecting the embodied carbon? Would this effect be significant? Would it offset any savings made by changes to the WWR? And what would the impact be on total life-cycle emissions?

In order to explore these unknowns, along with other parameters such as differences in structural materials, we conducted a life cycle analysis (LCA) study on a multi-unit residential building (MURB) located in Ottawa. To determine the importance that embodied emissions will have in the near future, when today's high-performance buildings become the standard, a reference building was chosen that exceeds performance compared to MURBs of similar composition. In this case the building, which has achieved LEED Platinum, uses a ground source heat pump system for heating and cooling, making its operational GHG emissions less than that of a conventional MURB that relies strictly on natural gas for heating and cooling.

Table 2: Typical MURB Building Design Summary

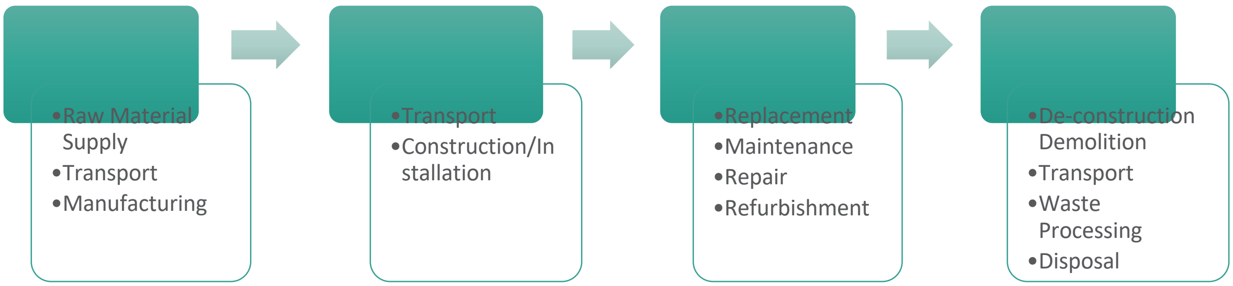
Building Type	MURB – Condominium
Year Built	2014
Location	Ottawa, Ontario
Gross Floor Area (GFA)	6163 m^2
# of Storeys	6 Storeys + 1 Underground Parking
Envelope	Steel Stud with Metal Wall Cladding (R30)
Structure	Concrete Slab on Grade, Concrete Footings, Columns and Slabs
Window to Wall Ratio (WWR)	~ 40%

2.1 Methodology

To conduct the LCA, we used the Athena Impact Estimator for Buildings (IE4B). This program uses a bill of materials input by the user to estimate the life cycle impacts of a building. The IE4B LCA includes all stages of embodied emissions, from production to end of life [Figure 3] and accounts for the location of the building, as well as building height to determine construction methods, such as crane lifting. This approach aligns with the methodology outlined in the LEED v4 pilot credit for LCA of buildings.

The outputs of the assessment are reported in terms of global warming potential (GWP) and are shown in units of kilograms of carbon dioxide equivalent (kg CO_2e). Impact Estimator calculates life cycle emissions using EPDs, life cycle impacts of products produced by manufacturers, peer reviews, and databases. Athena's Impact Estimator does not account for the operational emissions, but this data can be added in manually, if available. Mechanical systems are not currently available in the Athena Impact Estimator, and are therefore excluded from the study.

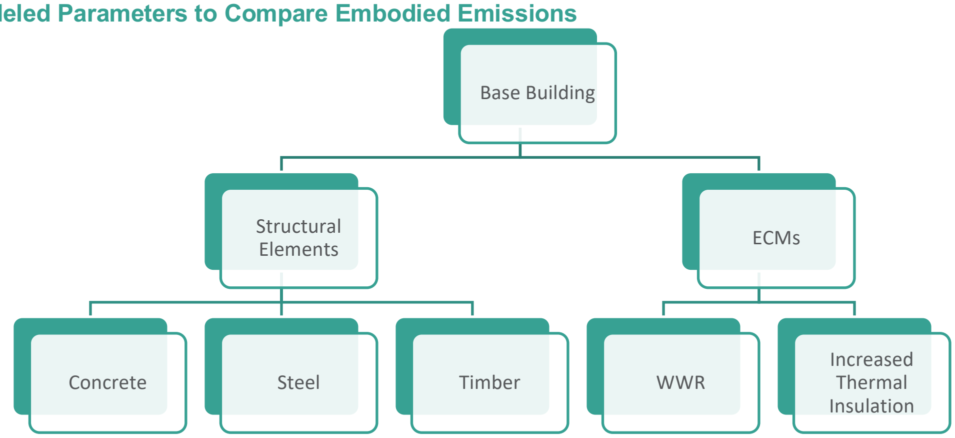
Figure 3: Embodied Emissions by Life Cycle Stages



The reference building's structural components were constructed from concrete. Because structural components of a building represent a large quantity of material, the type of structure will have a significant impact on the total embodied carbon of a building. For this reason, the reference building was used to model and compare the impacts of two more common structural materials for a mid-rise building: steel and timber.

Furthermore, to determine the possible impacts of ECMs on the embodied carbon of the building, the Toronto Green Building Standard was reviewed to identify measures that could have an effect on the embodied carbon of a building. Measures which require additional or alternative materials would result in an impact on embodied emissions, therefore the study focusses on determining the impact of adjusting the window to wall ratio (WWR) and increasing the thermal insulation of a building's wall assembly, Figure 4.

Figure 4: Modeled Parameters to Compare Embodied Emissions



2.2 Results

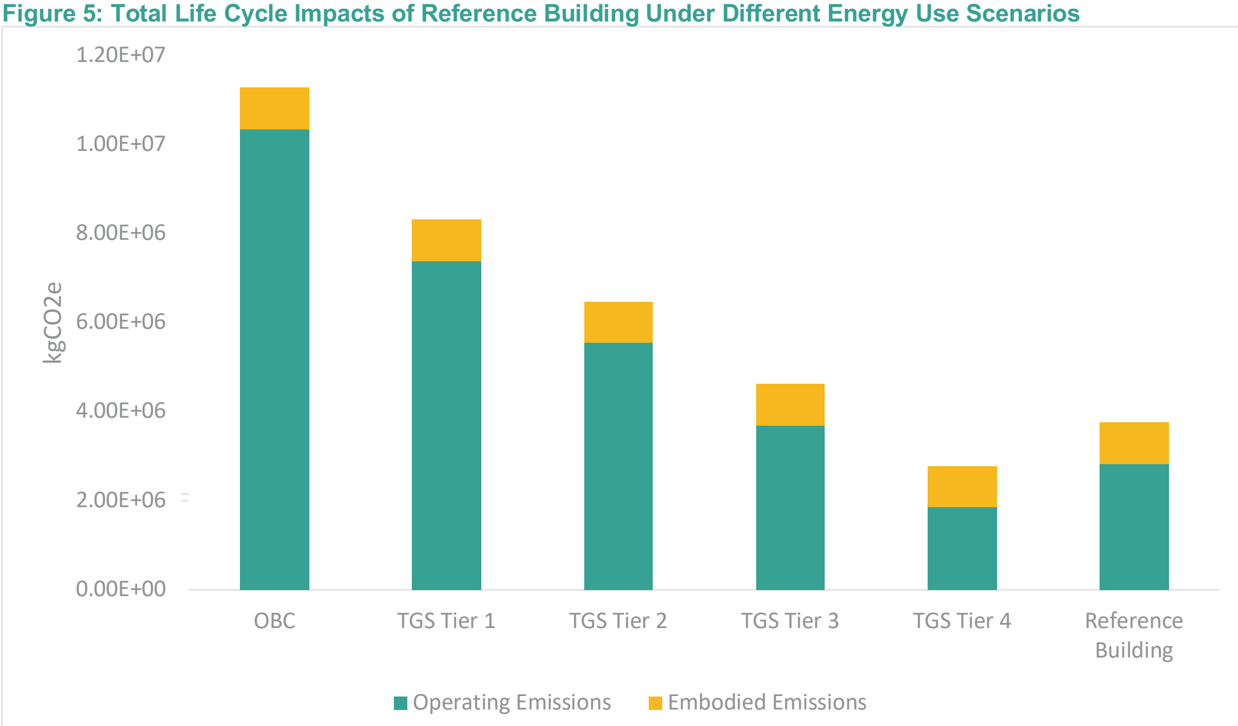
As buildings become more efficient, the impact of Embodied Carbon on a building's total life cycle emissions becomes greater.

Due to the increase of green building projects, the reference building chosen for this analysis is one that has pursued significant energy conservation measures. Specifically, the reference building uses ground sourced heat pumps, which contribute towards lowering its total operating energy usage. As a result, the building's embodied carbon emissions account for 25% of it's total life cycle emissions, where traditionally it would have accounted for 10% to 20% [3]. As buildings become more efficient, the share of carbon emissions related to embodied carbon will grow.

To understand the relative impact of ECMs further, operational emissions were estimated using various TGS compliance packages, where TGS Tier 4 represents the most rigorous level. These operational emissions were compared with the total embodied emissions of the building with the results represented in Figure 5.

The results show how the impact of embodied emissions, as a share of the total life cycle emissions of the building, increases as compliance packages become more stringent. At Tier 4, embodied carbon can account for more than 30% of a building's life cycle emissions.

Figure 5: Total Life Cycle Impacts of Reference Building Under Different Energy Use Scenarios



A concrete structure has the highest amount of embodied carbon, followed by steel, then timber.

Concrete, steel, and timber are the most common structural elements for mid-rise buildings. For the reference building used in this study, a steel structure has 3% less total embodied carbon than concrete, and a timber structure has 42% less total embodied carbon. The majority of emissions savings for timber are realized in the production phase, but benefits are evident in the construction phase and end of life as well.

Not only does the manufacturing of timber release less emissions, but the construction methods used to build a timber structure are also less energy intensive, the trees themselves sequester carbon, and the material is lighter than concrete, making it easier to transport and crane lift [8]. Figure 6 and Figure 7 represent the impact of each building material on the embodied carbon emissions, by assembly and life cycle stage.

Figure 6: Embodied Carbon Impacts of Different Structures by Building Element

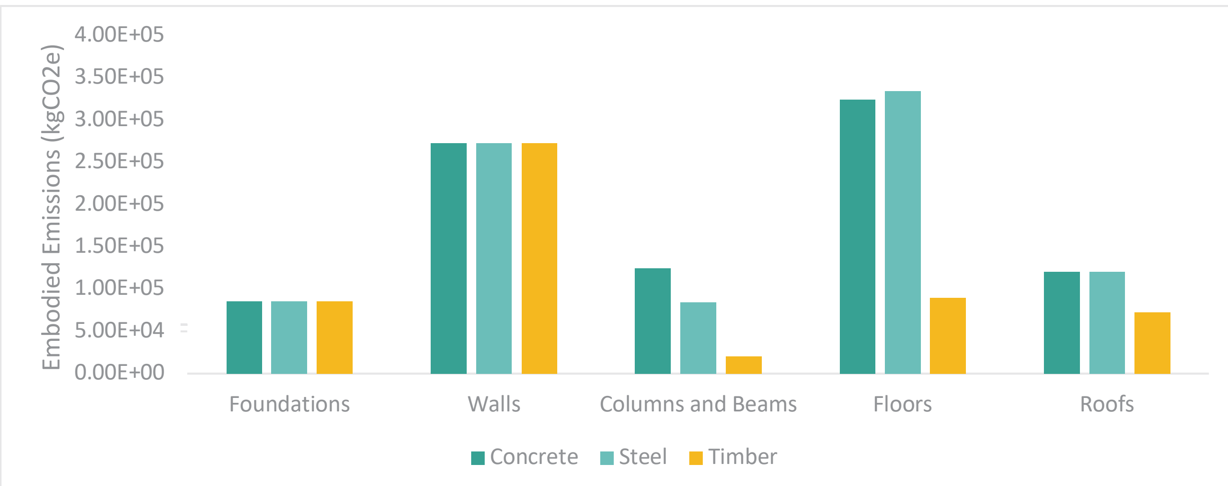
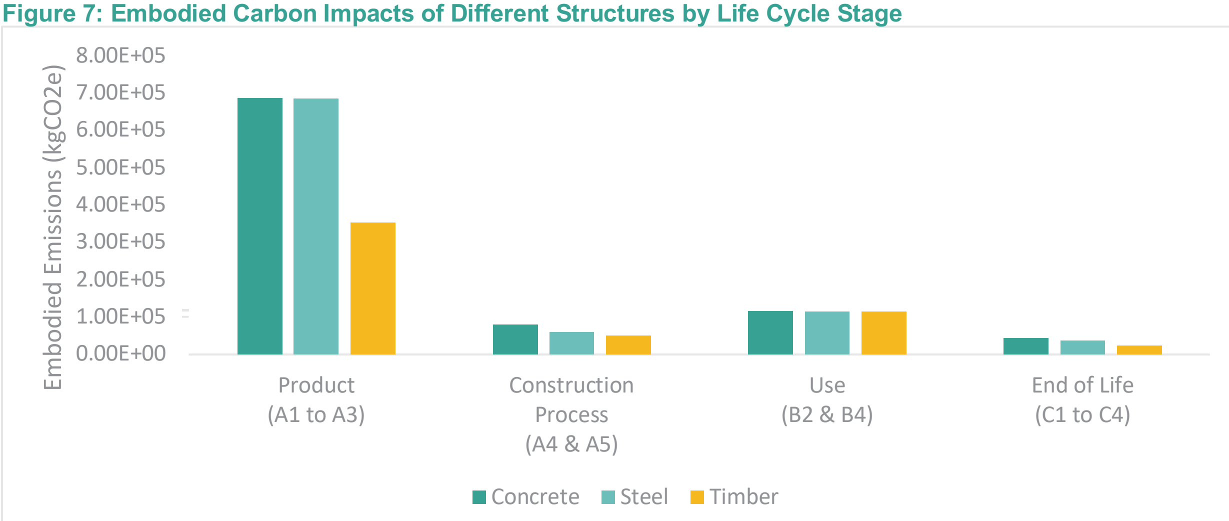


Figure 7: Embodied Carbon Impacts of Different Structures by Life Cycle Stage

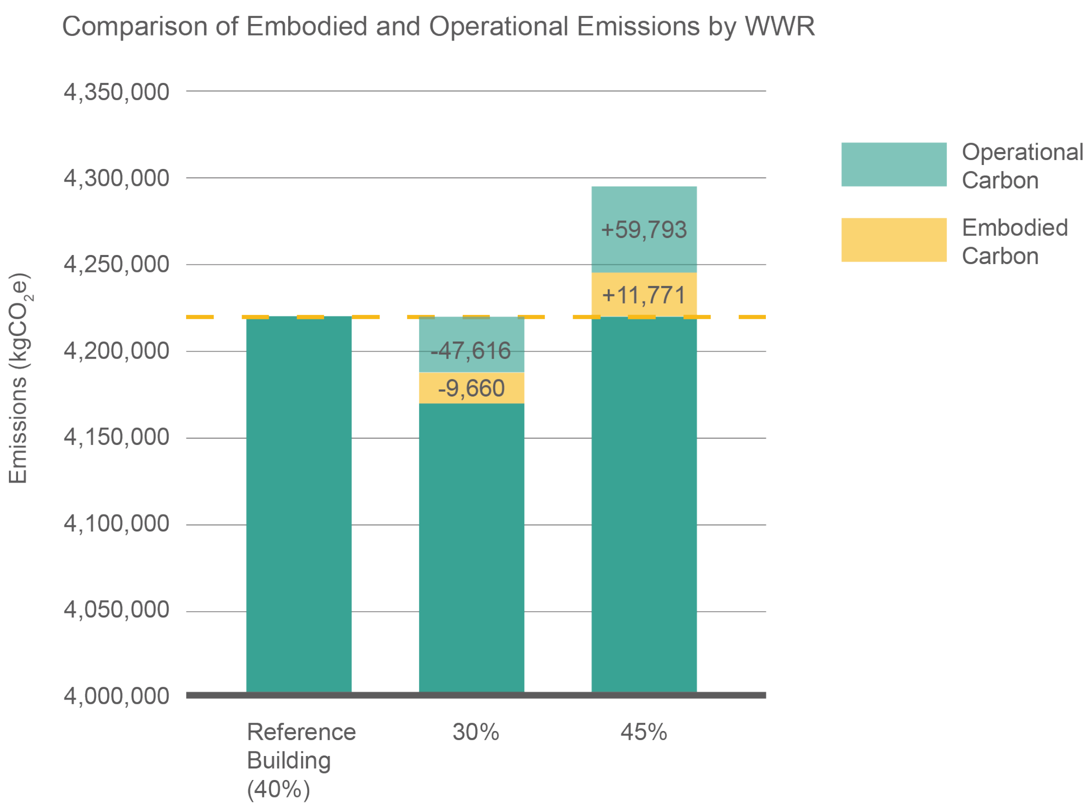


The Window-to-Wall Ratio (WWR) has a modest effect on the embodied carbon emissions of a building, where smaller WWRs result in fewer emissions and vice versa. A greater benefit is realized in the savings of operational energy.

The WWR of the reference building was approximately 40%. As different WWRs were assessed, it was observed that the sensitivity of changing the WWR ratio has a very small impact on embodied carbon emissions. Although a smaller WWR resulted in lower embodied carbon emissions than a higher WWR, it was clear that these decisions have a greater impact on operational emissions, as windows represent areas of heat loss for buildings. For the reference building, a decrease in WWR of 10% resulted in a decrease in *total* life cycle emissions of 57,276 kgCO2e, Figure 8.

Figure 2 would suggest that insulation has higher embodied emissions than glass, meaning more opaque wall assemblies would result in higher total embodied emissions for the building. But as previously discussed, Figure 2 represents embodied emissions per kg, and glass is heavier than insulation. In addition, aluminum has the highest embodied carbon per kg, and more/larger windows require more aluminum for the framing. Increasing the WWR also results in more windows to replace, as windows typically have a shorter life cycle than wall assemblies, further explaining the relationship between WWR and embodied emissions.

Figure 8: Effect of WWR on Total Life Cycle Emissions of the Reference Building

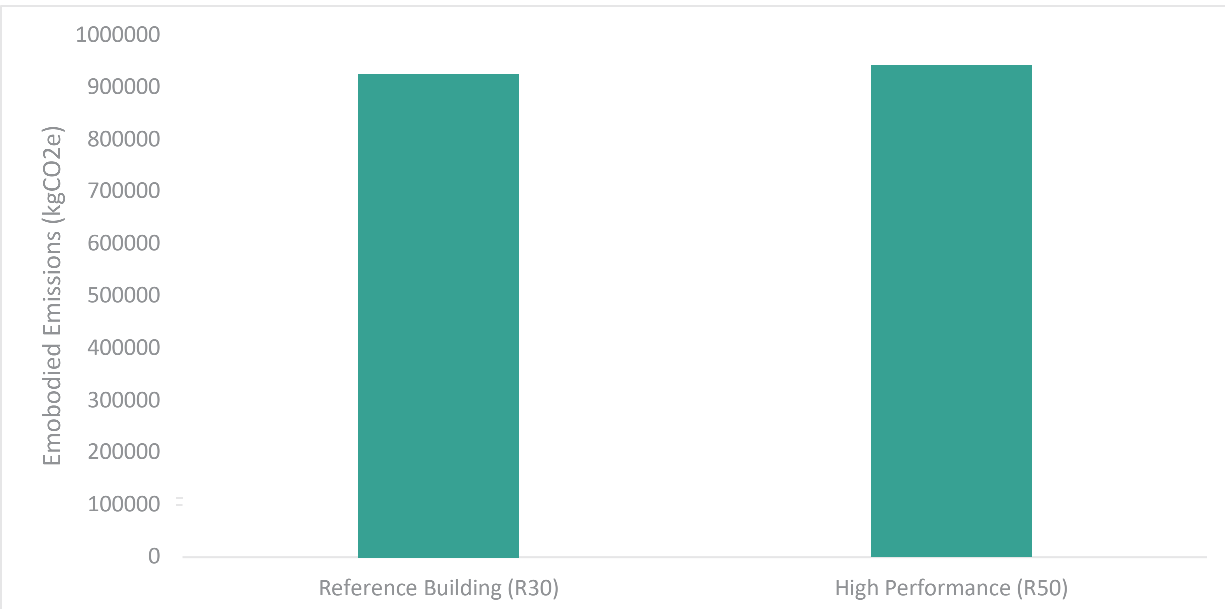


Increasing the Thermal Insulation of a Building has a minimal impact on the embodied emissions of a building.

The reference building was constructed with insulation that had an effective R value of 30. Increasing insulation is an energy conservation measure used to decrease operational energy for heating, which is particularly important for buildings in Canada where heating represents the highest source of emissions for buildings.

While increasing insulation to an R value of 50 resulted in a slight increase in embodied carbon emissions (2%), it would likely be offset by savings of operational energy required for heating [Figure 9].

Figure 9: Embodied Carbon Effects of Increasing Insulation



3 CONCLUSION

A number of conclusions can be drawn about the impacts of embodied carbon. Seemingly most important is the increased significance of embodied carbon on the total life cycle emissions of a building following the incorporation of energy conservation measures, such as those expected for a LEED Platinum, net-zero or TGS Tier 4 building. Energy conservation measures themselves did not have a significant impact on the embodied carbon emissions of a building, affirming that designers should continue to consider energy conservation measures to reduce operational energy usage.

The factor that represent the most significant impact on the embodied carbon emissions of a MURB, is the structural elements chosen for the building. A timber structure represents the lowest embodied carbon emissions. While industry continues to show interest in timber construction of MURBs, this paper demonstrates that scaling up the use of timber in mid- and high-rise structures appears to offer the sector the best opportunity to reduce overall, life-cycle building emissions.

Furthermore, while our methodology did not take into account emissions beyond building life, these too can have a large effect on the total life cycle impact of a building. When one takes into account the effects of carbon sequestration, the total embodied emissions of a building can see a significant decrease, depending on the types of materials used for construction. Carbon sequestration includes the ability of a material to store carbon dioxide, and in the case of building materials and LCA, also includes the recycling of construction materials such as steel.

When one assesses building life emissions on the reference building, we see a 4% decrease in the total life cycle embodied emissions for the concrete structure, 16% decrease for steel, and a 40% decrease for the timber structure. These decreases in total embodied emissions are a factor of the carbon sequestration and recyclability benefits of building materials. Currently, beyond building life emissions are not included in building rating systems such as LEED v4, and for that reason we eliminated them from our assessment, but these benefits further legitimize the push for timber construction for mid-rise projects in Canada.

Despite the complexity establishing embodied carbon frameworks, and the complexity of the subject, this white paper shows that material selection during the planning process has a significant, and immediate, effect on embodied carbon emissions. As a result, it should therefore be a focus of municipal green building policy, and standards organizations such as the Canada Green Building Council.

While reporting embodied emissions is important, reducing and offsetting them through more informed design decisions, and renewable energy, will help the sector reduce emissions, and bring the sector closer to net-zero as it relates to total building emissions.

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5 APPENDIX

5.1 Assumptions

Conducting a life cycle assessment is known for being a difficult task. In order to compare materials and ECMs and define their impacts on embodied carbon, assumptions were made:

- In the LCA model, as assumption was made that the foundation would the same for all the three structural materials. While the material, concrete, would be used as a foundation for these structural materials, the size and quantity of the foundation would differ. For example, a timber structure is lighter than a concrete structure, and would require less concrete for the foundation.
- For window to wall ratios, the number of windows remained the same while the areas changed to accommodate the ratio change. In reality, a different WWR may reduce or increase the numbers of windows on the building.
- The LCA methodology followed those used by green building rating tools, and therefore did not consider beyond building life emissions.
- Although mechanical equipment was not included in this study, research suggests that building services can account for 100 $kgCO_2/m^2$ for air-conditioned office building, and about 50 $kgCO_2/m^2$ for non-conditioned offices [9]. Including mechanical equipment in life cycle analysis is an important next step and area for research in the embodied carbon industry.

Despite these assumptions, the conclusions drawn about embodied carbon emissions remain important and relevant.

5.2 Guide for Builders

Now that the importance of embodied carbon emissions is understood, this section is intended to help builders and designers navigate the complex process of reducing embodied carbon emissions in real applications by providing a tool to guide decision-making. In order to help pilot the discussion, this guide assumes the project will be pursuing LEED certification.

Embodied Carbon Guide for Developers and Design Teams

This Guide is intended to support developers and design teams who are interested in reducing embodied carbon on projects. It provides a simple framework, aimed at helping designers understand where to start, and what key steps are required to reduce embodied carbon, and total project, emissions. These strategies work best when developed alongside other sustainable design strategies, such as exploring operational emissions.

Step 1: Commit to Reducing Life-Cycle Carbon Emissions

Choose a certification standard and/or define boundaries for embodied carbon. LEED and the Net-Zero Building standard have different embodied carbon requirements.

Choose a method for measuring Embodied Carbon, such as Athena Impact Estimator for Buildings, or Tally.

Step 2: Create a LCA Baseline

Create a baseline LCA by identifying a building of comparable size, function, orientation, and operating energy performance. This building can be your initial building design, or another building that fits this criteria.

Step 3: Reduce Embodied Carbon

Using the LCA tool, assess and compare materials that will reduce embodied carbon.

Consider reducing the quantity and volume of materials, compare the content of key matierials, consider the impact of recycled content, etc.

Step 4: Ensure Financial Feasibility

Consider the price differential of the various scenarios and materials. Financial feasibility should be performed at each step, in order to make appropriate decisions.

Step 5: Compare the Proposed Design with the Baseline

Complete a LCA Model using the chosent tool, and identify the reduction in embodied carbon.

Refine the proposed design until a 10% reduction in embodied impact is achieved, and the LEED requirements are met.

Step 6: Report Results

Document the baseline and proposed building designs, and reductions in embodied carbon.

Promote reductions in embodied, and total, carbon emisisons.