CANADIAN INSTITUTE OF STEEL CONSTRUCTION
INSTITUT CANADIEN DE LA CONSTRUCTION EN ACIER

rjc Engineers

# CISC Low-Rise Commercial Buildings
## Embodied Carbon Study

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# FORWARD

The Canadian Institute of Steel Construction is a national industry organization representing the structural steel, open-web steel joist and steel plate fabricating industries in Canada. Formed in 1930 and granted a Federal charter in 1942, the CISC functions as a non-profit organization promoting the efficient, economic and sustainable use of fabricated steel in construction.

The Institute has a general interest in all uses of steel in construction. The CISC supports and actively participates in the work of the Standards Council of Canada, the Canadian Standards Association, the Canadian Commission on Building and Fire Codes and numerous other organizations, in Canada and other countries, involved in research work and the preparation of codes and standards.

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# PREFACE

Sustainable development means development that meets the needs of the present without compromising the ability of future generations to meet their own needs. We at the Canadian Institute of Steel Construction are committed to this concept and are working tirelessly to supply the Canadian construction industry with the tools it needs to limit global carbon emissions. In response to municipal embodied carbon emissions targets, such as the Toronto Green Standard and Vancouver Building Bylaws, our Sustainability Committee is pleased to release the CISC Low-Rise Commercial Building – Embodied Carbon Study. This document, created in collaboration with RJC Engineers, presents an analysis of how real-world steel structures are meeting embodied carbon targets today and can continue to for years to come.  Structural steel is the choice for a sustainable future.

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# Executive Summary

As requested, RJC Engineers (RJC) has completed a study on the embodied carbon of typical low-rise steel structures in Canada. To develop this report RJC's work included: computing and reporting structural quantities for five representative projects and nonstructural quantities for four representative projects in Canada; conducting and reporting the results of whole-building life-cycle assessments (wbLCA) for the five projects; and discussing key topics of interest related to quantities and embodied carbon.

This study found that low-rise steel buildings (i.e., 1-6 storeys) should be expected to satisfy current municipal embodied carbon limits in Canada if a reasonable effort is made to source low-carbon materials. The average embodied carbon intensity was around 301 $kgCO_2e/m^2$ (based on quantities from contract documents, normalized by the built floor area) for four projects that were constructed in Canada. In the lowest carbon scenario, alternative low-carbon steel materials could reduce the total embodied carbon by approximately 15% - this reduction may allow typical low-rise steel buildings to meet the strictest embodied carbon limits that currently exist in Canada. On the other hand, it is unlikely that buildings utilizing steel solely sourced from basic oxygen furnaces will meet embodied carbon limits.

Of the total embodied carbon, approximately 90% was "upfront" embodied carbon (i.e., due to wbLCA phases A1-A5). The average nonstructural (i.e., cladding and finishings) contribution to the total embodied carbon was around 25%. The average contribution of steel to structural embodied carbon was around 50%; the average contribution of deep foundations to structural embodied carbon was around 20% while the same contribution for shallow foundations was around 10%. Of the structural steel elements, the highest contributors to structural embodied carbon were consistently hot-rolled shapes (nearly 20% of baseline structural on average) and cold-formed steel floor/roof decks (around 10% of baseline structural on average). It is expected that the NBCC 2020 seismic provisions may lead to an increase of around 7% in the buildings evaluated in this study. This is a rough estimate that could be improved through functionally equivalent buildings designed to different versions of NBCC.

For the steel buildings studied, the floor and roof systems contributed around 40% of the total baseline structural GWP on average. Approximately 11% of the structural GWP (about ¼ of the total floor GWP) was due to the concrete within the composite slab. Furthermore, there was around a 3% reduction in total building GWP when comparing a CLT floor system with a composite slab system with OWSJs. However, a greater reduction in GWP may be found if the building was designed with a mass timber structure from schematic design.

Finally, this study focused on scenarios of procuring low-carbon steels as a method to reduce embodied carbon. Additional carbon reductions can be obtained by using low-carbon concrete materials and efficient envelope systems. We also note that there are carbon implications to architectural decisions (e.g., the need for large cantilevers and transfer systems). Regardless of the strategies used to reduce carbon, comparisons should be based on wbLCA results, i.e., comparisons cannot be based solely on EPDs because the quantity and functional units of different materials need to be considered as well.

# Introduction

## Background

Carbon emissions from new construction contribute significantly to global carbon emissions, which in turn are an important driver of climate change. These emissions are often referred to as *embodied carbon*, which is a measure of the greenhouse gas emissions generated due to manufacturing, transportation, installation, maintenance, and disposal of building materials (Carbon Leadership Forum, 2025). Recognizing the importance of reducing embodied carbon, the Canadian government and municipalities are actively engaging in programs to reduce the carbon emissions from new construction. For instance, it is expected that new construction meets carbon emissions targets set out by the cities of Toronto and Vancouver (City of Toronto, 2025; City of Vancouver, 2023). Therefore, it is important to be able to identify low-carbon building solutions at an early stage in construction projects and have methods of reducing carbon impacts as projects progress from schematic design through to project completion.

Embodied carbon is typically estimated for buildings through a whole building life-cycle assessment (wbLCA) of the building's materials. The wbLCA captures the upfront carbon, the carbon emitted during the use stage (excluding operational carbon) and the end-of-life carbon as shown in **Figure 1**. The total global warming potential (GWP) is calculated by summing the contributions from the product stage (A1-A3), the construction process stage (A4 and A5), the use stage (B1-B5), and the end-of-life stage (C1-C4). This GWP is often quantified in terms of mass of equivalent carbon emissions per meter squared of building ($kgCO_2e/m^2$). Normalizing the GWP by an area metric allows for relative targets to be set that can be applied to a wide range of projects, as is done in Canadian Green Building Council's (CAGBC's) Zero Carbon Building (ZCB) standard version 4 (Canadian Green Building Council, 2024), Toronto Green Standard version 4 (City of Toronto, 2025) and the Vancouver Building Bylaw (VBBL) (City of Vancouver, 2023).

Referring to **Figure 1**, the largest contributor to GWP is from the product stage (A1-A3). The A1-A3 embodied carbon can be simplified to a basic equation:

$$\textit{GWP} = \textit{Material Quantity (units)} \times \textit{Carbon Factor} (kgCO_2e/unit) = \textit{Embodied Carbon} (kgCO_2e)$$

This simplification provides insight into the heart of the issue and opportunities for reducing embodied carbon. The material quantities are a function of the building type, occupancy and the structural systems. Therefore, it is critical to understand the impact of these systems and select the most carbon efficient option that satisfies functional requirements. Appropriately selecting the functional requirements, the structural system, the building envelope, and the amount of parking are the first opportunities to reduce embodied carbon. Reducing material use through efficient structural systems and optimal designs are well-seasoned skills of structural engineering firms such as RJC.

Next, the carbon factor represents the choice of specific materials and their production processes. For instance, in structural steel, the largest contribution is from the process of converting the raw materials (e.g., iron ore, alloying metals, recycled content) into steel. The two predominant methods are the Basic Oxygen Furnace (BOF), which utilizes coal, and the Electric-Arc Furnace (EAF), which utilizes electricity. Steel produced by EAFs have lower carbon factors than steel produced by BOFs, particularly if the electricity is generated from a low-impact source (e.g., hydro power).

Steel production and environmental considerations will be discussed in the forthcoming Canadian Institute of Steel Construction (CISC) Low Carbon Steel Design Guide that is expected to be published in 2025.

The carbon factors for materials are reported through environmental product declarations (EPDs) for the product stage of the wbLCA (A1-A3). The two primary types of EPDs are product-specific and industry average. The product specific EPDs represent the emissions for a declared unit of material generated from a specific manufacturer at an individual production site. Industry average EPDs represent the emissions for the average declared unit of material generated in a particular region or collection of processes. Organizations such as the CISC produce industry average EPDs for a variety of structural steel products used in Canada. EPDs are important because they provide the project team with the opportunity to evaluate the carbon impact of different products when sourcing materials. Selecting materials from carbon-efficient manufacturing processes is another key piece in the puzzle of reducing embodied carbon. Specific care must be taken to compare EPDs within the same class of products that follow the same Product Category Rules (PCR) as the requirements and reporting units may vary. Conducting wbLCA is the preferred way to compare a variety of products found within a building.

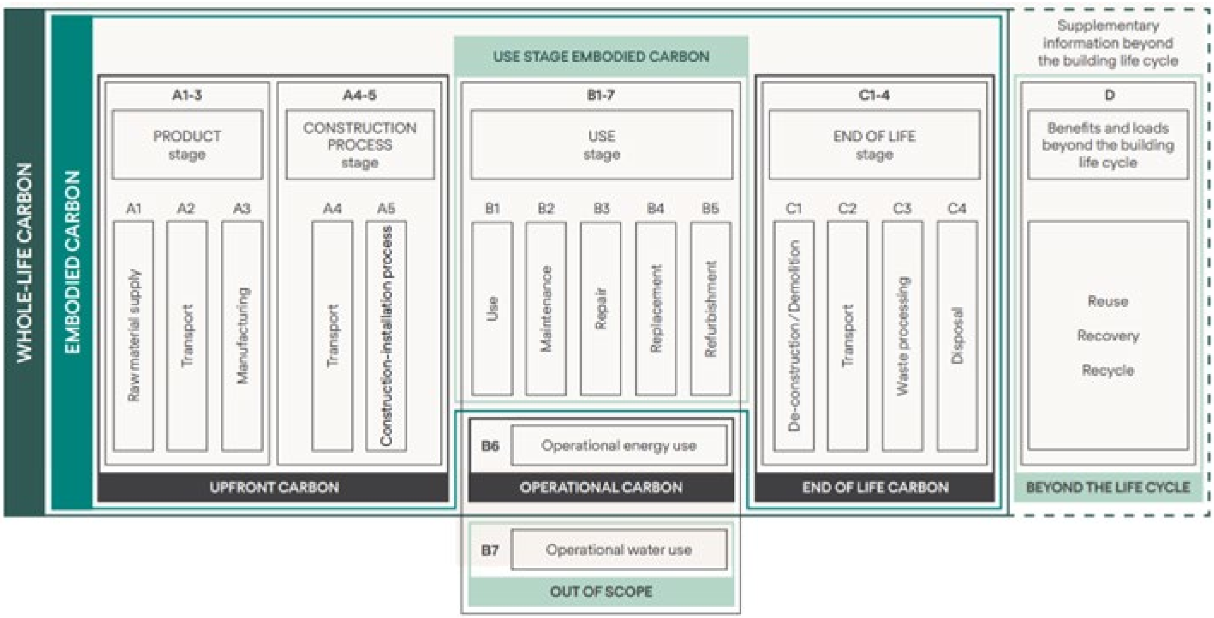



**Figure 1 – Terminology used in this report cross-referenced to terms and lifecycle stages defined in EN 15987 (European Committee for Standardization, 2011), from CAGBC (2024).**

# Study objectives

As embodied carbon is an emerging topic of critical importance, data collection is a necessary first step in better understanding how to estimate embodied carbon in buildings and develop methods to reduce embodied carbon. To further this goal, RJC, contracted by the Canadian Institute of Steel Construction (CISC), has prepared this report on the embodied carbon in low-rise commercial steel buildings in Canada.

The goals of this study are to:

- Evaluate the embodied carbon impact of five typical low-rise commercial or institutional buildings in Canada.
- Evaluate the relative contribution to the overall GWP of:
  - Structural and architectural elements.
  - Structural steel components.
  - Lateral force resisting systems.
- Evaluate the embodied carbon of selected buildings relative to Canadian embodied carbon targets.
- Evaluate the relative change in GWP using industry average EPDs versus product specific EPDs.
- Evaluate the impacts of increased seismic loading in NBCC 2020 on the GWP.
- Evaluate the use of mass timber as an alternate floor system on one of the projects.

The methods used to accomplish each of these goals are enumerated in the Methodology section. Then the results are provided collectively with minimal commentary in the following Results section. A comprehensive discussion of the results is then provided in the Discussion section, and finally, the key findings are summarized in the Conclusion section.

# Methodology

## Building selection

The criteria for selecting typical low-rise commercial steel buildings built in Canada are as follows:

1. The building is in Canada in a region of low-to-moderate seismicity.
2. The primary gravity force resisting system for the above ground portion is constructed from steel.
3. Between one to six stories above grade of commercial or institutional occupancy.
4. Designed to 2010 or 2015 National Building Code of Canada.
5. Buildings are completed or at construction level documents.
6. The buildings should preferentially cover a few different commercial sectors.

These criteria were selected to study a competitive market sector with a wide range of applicability across Canada. The above criteria resulted in a list of projects, from which five were selected in consultation with the CISC sustainability council in Q4 of 2024. A summary of the selected projects is provided in **Table 1**, while pictures and architectural renderings are provided for each building in the Results section. In short, there are three projects in Alberta and two in Ontario. They are mostly designed according to NBCC 2010, with one project to NBCC 2015, however, the seismic loading for these locations did not change appreciably from NBCC 2010 to NBCC 2015. The building usages cover healthcare, office, and post-secondary education. The approximate gross floor area (GFA) ranges from 2,500 to 56,000 m2. All buildings have either 3- or 5-stories above grade, with steel composite deck and open web steel joist (OWSJ) systems, or steel composite deck with composite beams. The lateral force resisting systems are either concrete shear walls or steel braced frames.

Table 1: Overview of projects selected for this study.

| Project Name | Usage | Location | Completion | Model Code (NBCC) | Stories Above Grade/ Below Grade | Approx. GFA ($m^2$) | Floor System | Lateral System |
|---|---|---|---|---|---|---|---|---|
| NW Health Campus | Office / Healthcare | Calgary, AB | 2022 | 2015 | 3/0 | 2,500 | OWSJ | Concrete shear wall, braced frame |
| Suburban Office | Office | Edmonton, AB | 2018 | 2010 | 3/1 | 6,000 | OWSJ | Braced frame |
| Durham College | Post-Secondary | Oshawa, ON | 2018 | 2010 | 5/0 | 7,000 | Composite beams | Concrete shear wall |
| Seneca CITE | Post-Secondary | Toronto, ON | 2018 | 2010 | 5/0 | 25,500 | Composite beams | Concrete shear wall |
| Quarry Crossing (3 Bldgs.) | Office | Calgary, AB | 100% CD(1) | 2010 | 5(2)/3 | 56,000 | OWSJ | Concrete shear wall |

(1) The construction documents were completed; however, the project is in redesign for residential use.

(2) The three 5-storey buildings are connected by two stories of below grade parking.

# Quantities and building areas

Quantities of materials used within the building are broadly categorized into structural and nonstructural elements. For this study, structural quantities refer to the material required to satisfy the construction documents as designed by RJC. For this study, the nonstructural quantities include the building envelope and finishes as described later. Other nonstructural components, such as electrical and mechanical equipment, are not included. The components included in this study align with the scope of the ZCB standard as well as TGS. Furthermore, building areas are reported along with material quantities so that normalized carbon emissions can be computed, as explained in the introduction. The following subsections explain the processes for extracting quantities in more detail.

## Structural quantities

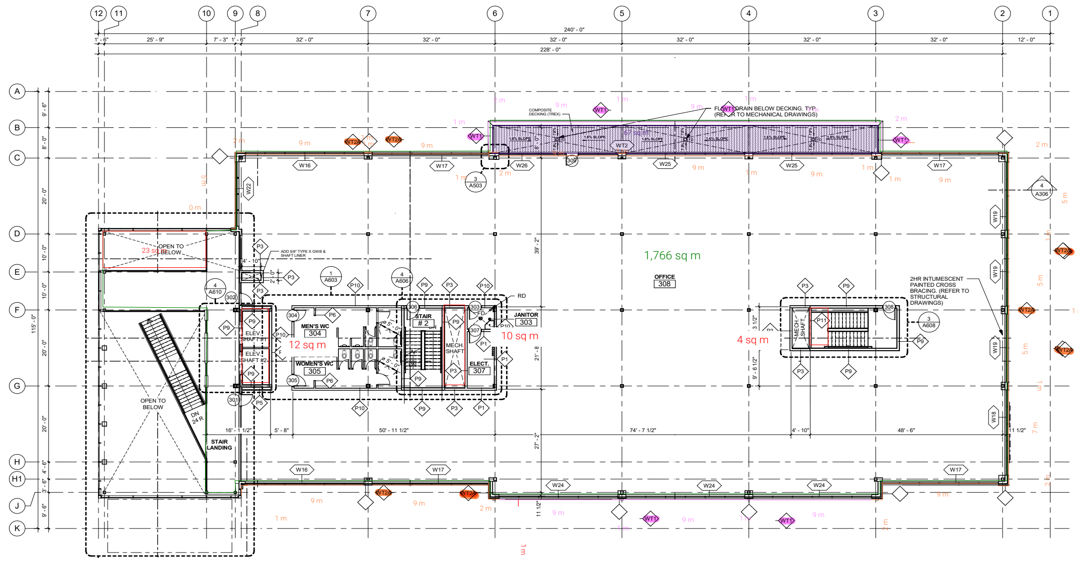
Structural quantities are reported in either volume or mass of material (i.e., volume of concrete, mass of steel), and are organized by specific material type according to their manufacturing process. Separation by material is important because different manufacturing standards are associated with different intensities of embodied carbon per unit of material.

Structural quantities are primarily extracted from the building information model (BIM) that was used to generate the structural contract documents. The software Revit 2022 (Autodesk Inc., 2022) is used for this purpose. Custom Revit plugins developed by RJC have the capability to collect and summarize the structural quantities for all the modelled elements in the project.

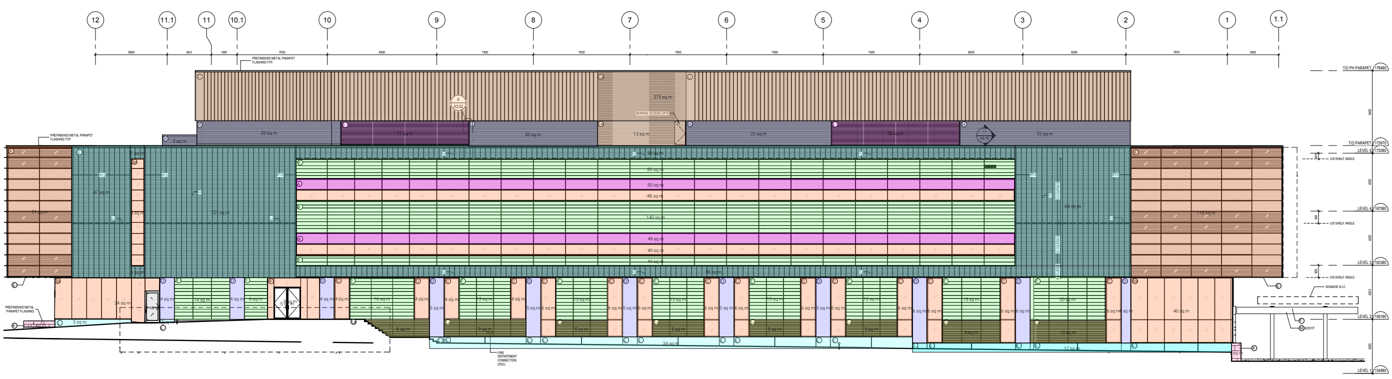
## Nonstructural quantities

Nonstructural quantities include exterior wall assemblies, foundation wall assemblies (i.e., not the structural retaining wall), floor assemblies, doors, windows and roof assemblies. The quantities of each are computed from the latest architectural drawings. There are two components to computing the nonstructural quantities: estimating the area of each type and defining an enclosure assembly for each type defined in the project. The estimated areas are computed using scaled length and height measurements of the elevations, floor plans and building sections from architectural drawings using the software Bluebeam Revu (Bluebeam Inc., 2024). The window and exterior door area and types are determined using the window and door schedules.

Once the areas for each assembly are determined, the corresponding assembly sheet from the architectural drawings is used to identify the materials and their thicknesses, material properties and thermal performance. This information is critical for assigning the correct material EPD for each component within the envelope assemblies. Finally, only the continuous materials within the envelope assemblies are considered in life cycle assessments. Envelope components such as cladding support materials (e.g. Z-girts, thermally broken clips, panel supports and fasteners) are not included. Furthermore, cold-formed steel studs within the envelope are counted as nonstructural elements.

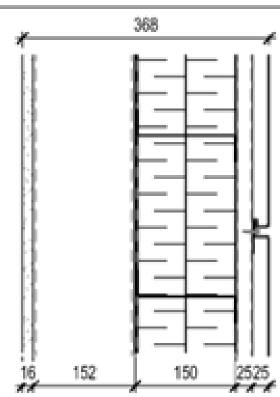



(a) Sample floor area and enclosure perimeter take-offs



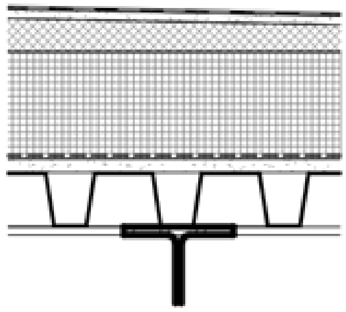
(b) Sample elevation area take-off

## EXTERIOR WALL ASSEMBLIES

| TYPE | ASSEMBLY | CONSTRUCTION |
|---|---|---|
| W1 |   | EXTERIOR WALL TYPE W1<br>ARCHITECTURAL METAL SYSTEM (MET-1) C/W<br>25mm VERTICAL SUPPORT SYSTEM<br>150mm HORIZONTAL METAL SUPPORT SYSTEM (THERMALLY BROKEN)<br>150mm SEMI-RIGID INSULATION (MINIMUM R=25)<br>22ga METAL LINER PANEL AIR/ VAPOUR/ MOISTURE BARRIER<br>152mm WIND-BEARING METAL STUD<br>16mm GYPSUM BOARD |

(c) Sample exterior wall assembly

**Figure 2 - Examples for floor area and enclosure take-offs from the architectural drawings.**

| ROOF ASSEMBLIES | | |
|---|---|---|
| TYPE | ASSEMBLY | CONSTRUCTION |
| RF1 |  | ROOF TYPE RF1<br><br>2-PLY MODIFIED BITUMEN ROOFING MEMBRANE<br>ADHERED COVER BOARD<br>SLOPED RIGID INSULATION (SEE ROOF PLAN)<br>TWO LAYERS OF 75mm (150mm TOTAL) RIGID INSULATION (R=30 MIN)<br>WITH STAGGERED JOINTS<br>FULLY ADHERED VAPOUR RETARDER MEMBRANE<br>MECHANICALLY FASTENED COVER BOARD<br>76mm STEEL DECK (SEE STRUCTURAL) |

(d) Sample roof assembly

**Figure 2 - Examples for floor area and enclosure take-offs from the architectural drawings.**

## Building areas

In this study, four area metrics are estimated for each project based on CAGBC's definition in the Zero Carbon Building standard version 4 (Canadian Green Building Council, 2024):

1. Above-grade GFA: The above-grade gross floor area (GFA) is computed in-line with CAGBC's ZCB. This is the sum of above-grade floor areas of all enclosed spaces inside the building. Measurements are taken from the exterior faces of exterior walls, and the area excludes parking, air shafts, and penthouse spaces with headroom less than 2.2 meters.
2. Below-grade GFA: The below-grade GFA is computed similarly to the above-grade GFA, but below the grade level.
3. Above-grade parking area: The sum of all above-grade enclosed parking and roof-top parking areas.
4. Below-grade parking area: The sum of all enclosed below-grade parking.

From these four base area metrics: the total GFA is the sum of above- and below-grade GFA and the total parking area is the sum of above- and below-grade parking. Then finally, the built floor area (BFA) is the total GFA + the total parking area.

Building areas are extracted from the PDFs of architectural drawings. If not directly provided, scaled area measurements are made using the software Bluebeam Revu (Bluebeam Inc., 2024) according to the definitions above for each of these metrics. See **Figure 2(a)** for an example of measurements made in this process.

# Environmental Product Declaration selection

As discussed in the introduction, Environmental Product Declarations (EPDs) are an essential part of estimating embodied carbon. The steel EPDs used in this study are summarized in **Table 3** and were current at the time of the study and does not represent an exhaustive list of available products. This table below lists the type of steel element that it applies to, the provider of the EPD and its global warming potential (GWP) per metric unit ton of steel. Although EPDs routinely contain information other than just the GWP (e.g., acidification potential, etc.), these considerations are outside the scope of this study.

Note that the list of potential steel EPDs in each category can be extensive. New EPDs are published regularly, and not all products will be feasible to implement on a given project, therefore, engaging the contractor and fabricator early in the project to review the proposed materials is imperative to the success of specifying lower carbon materials. Furthermore, steel is a global product, the CISC industry average EPDs represent steel manufactured in North America and fabricated in Canada, however, the steel being included on the project may be sourced from other regions and should be considered in the project specifications.

Two additional scenarios are evaluated for each building in addition to the baseline scenario. The Baseline EPDs in this study represent the GWP to manufacture an average unit of material in a geographical region. Meanwhile, the two additional scenarios use product specific EPDs in this study represent the GWP required to manufacture a unit of material at a specific production facility. Scenario 1 (Lowest Carbon) was selected to reflect the best-in-class structural steel EPDs currently available in North America. These EPDs were selected from EPDs available from the CISC website, OneClick LCA and the EC3 (CISC, 2025; OneClick LCA Ltd., 2025, Building Transparency, 2025) database of EPDs from major manufacturers in North America with products that were available in each category and were later reviewed with the CISC Sustainability Committee. Scenario 2 (Basic Oxygen Furnace), was chosen to highlight the impact of the production source. The three scenarios considered in this study are detailed below:

1. **Baseline scenario**:
    a. The concrete EPDs are selected from the catalogue of materials from Concrete Alberta and Concrete Ontario (Concrete Alberta, 2022; Concrete Ontario, 2022). For each region, the concrete strength is matched within the catalogue to the baseline material without air entrainment. The concrete EPDs are summarized in **Table 2**.
    b. The baseline rebar material is provided by the Concrete Reinforcing Steel Institute (Concrete Reinforcing Steel Institute, 2022).
    c. The CISC industry average EPDs are used as the baseline for steel sections, plates, and cold-formed steel (panels, decks, etc.). Note that the “Cold-formed Steel (Steel Deck, Steel Studs and Track)” category is applied to all deck and roof panels.
    d. The Steel Joist Institute industry average EPD is used as the baseline for open web steel joists (Steel Joist Institute, 2022).

2. **Scenario 1 ("lowest carbon"):** The "best-case" steel materials are used for each category.
    a. Several manufacturer EPDs were considered for each steel element type using OneClick LCA's database (OneClick LCA Ltd., 2025), the EC3 database (Building Transparency, 2025) and the CISC's sustainability page (Canadian Institute of Steel Construction, 2025).
    b. The specific EPD that has the lowest GWP of available options for each steel element type was selected.
    c. Transportation considerations were not altered from the default transportation distance.
    d. Baseline concrete EPDs are used because the focus of this study is on the embodied carbon impact of structural steel materials.
3. **Scenario 2 ("basic oxygen furnace"):**
    a. The "WORLD BOF" EPD is used for hot-rolled shapes.
    b. The EPDs selected for Scenario 1 are used for the remaining categories, i.e., for HSS, Steel Plates, CFS, OWSJ, Merchant Steel and Rebar.
    c. Again, the baseline concrete EPDs are used because the focus of this study is on the embodied carbon impact of structural steel materials.

Table 2: Overview of the baseline concrete EPDs used in this study.

| EPD Provider | Description | A1-A3 ($kgCO_2e/m^3$) |
|---|---|---|
| Concrete Ontario | 25 MPa | 254.1 |
| | 30 MPa | 264.4 |
| | 35 MPa | 295.5 |
| Concrete Alberta | 25 MPa | 306.3 |
| | 30 MPa | 334.5 |
| | 32 MPa | 313.6 |
| | 35 MPa | 328.0 |

Table 3: Overview of the steel EPDs selected for this study.

| Steel Element Type | Scenario | EPD Provider | A1-A3 ($kgCO_2e/t$) |
|---|---|---|---|
| Hot-Rolled Shapes (W, S, I) | Baseline | CISC Industry Average (CISC, 2021) | 1170 |
| | Scenario 1 | Gerdau: Petersburg, VA (Gerdau, 2022) | 680 |
| | Scenario 2 | WORLD BOF (British Steel, 2020) | 2450 |
| Hollow Structural Steel Shapes (HSS) | Baseline | CISC Industry Average (CISC, 2021) | 1860 |
| | Scenario 1,2 | ArcelorMittal Dofasco (ArcelorMittal Dofasco, 2023)Nucor – Chicago (Alliance Steel Fabrication, 2023) | 1070[1]<br>1170 |
| Steel Plate | Baseline | CISC Industry Average (CISC, 2021) | 1710 |
| | Scenario 1,2 | EVRAZ (Regina) (EVRAZ, 2023) | 950 |
| Cold-Formed Steel (Steel Deck) | Baseline | CISC Industry Average (CSSBI, 2022) | 2430 |
| | Scenario 1,2 | ArcelorMittal Dofasco Xcarb (ArcelorMittal Dofasco, 2023) | 1260 |
| Joists (OWSJ) | Baseline | SJI Industry Average (Steel Joist Institute, 2022) | 1430 |
| | Scenario 1,2 | Nucor Joists (Nucor, 2022) | 840[2] |
| Merchant Bar Quality (C, L) | Baseline | CISC Industry Average (CISC, 2021) | 1720 |
| | Scenario 1,2 | Nucor – Seattle (Nucor, 2022) | 530 |
| Rebar | Baseline | CRSI (CRSI, 2022) | 850 |
| | Scenario 1,2 | Cascade Steel Rolling Mills, Inc (Cascade Steel Rolling Mills Inc., 2022) | 440 |

(1) Indicates that this EPD was selected for Scenario 1 & 2. At the time of publication, HSS is currently being produced on a project-by-project basis using this material. HSS is also being currently manufactured by Nucor at a similar GWP.

(2) Nucor Vulcraft released a new EPD subsequent to the analysis in this report with a GWP of 757 kg $CO_2e/t$ (Vulcraft Canada, 2024).

# Whole-building life cycle assessment

## Base method

Whole-building life cycle assessments (wbLCAs) are conducted using the software OneClick LCA (OneClick LCA Ltd., 2025). The phases identified in **Figure 1** (A1-5, B1-5, C1-4) are considered in this study. Note that phase D is not considered within the scope of compliance with national standards (City of Vancouver, 2023; City of Toronto, 2025; Canadian Green Building Council, 2024). Therefore, phase D was reported only in the CLT comparison as the main aim of this study was to evaluate baseline and alternative scenarios with these compliance targets. Phase D results may be important in future studies that compare archetypes designed with different structural materials (e.g., steel and concrete structural systems) to investigate the circularity of structural materials.

The following assumptions are made in this study:

- The A4 contribution is assumed based on default values in OneClick LCA with default Canadian transportation distances. These transportation distances are assumed to remain constant for product-specific EPDs as well. This decision is made because the product-specific EPDs represent a best-case scenario where all the materials would be available for the project.
- The A5 contribution of hot-rolled steel is assumed to remain constant between Scenarios 1 and 2.
- The OneClick LCA energy localization feature was not used in this project. Enabling the energy localization changes the reported A1-A3 GWP based on national energy grid efficiency compared to where the product was manufactured. This would impact EPDs that contain any materials produced outside of Canada and may produce unrealistic results if the feature was enabled, particularly for manufacturer specific EPDs from the USA.
- Operational carbon and structural repairs are not included in this study. Therefore, the contributions of wbLCA phases B1, B2, B3, B6, B7 are all assumed to be zero.
- The remaining contributions are based on OneClick LCA default values.
- Biogenic carbon is not considered.

# Key metrics and standard limits

The keys metrics evaluated in this study are the global warming potential (GWP) and GWP intensity. The GWP intensity is the mass of equivalent CO2 emissions normalized by an area of the building, reported in $kgCO_2e/m^2$. Although each building project may not particularly fall under all these specific jurisdictions, the following standard limits are used in this study for reference:

The following assumptions are made in this study:

- **CAGBC ZCB v4 (Canadian Green Building Council, 2024):**
  - **ZCB:** The target benchmark per ZCB is 425 $kgCO_2e/m^2$ for all buildings except warehouses and distribution centers.
  - **ZCB-1:** The project can demonstrate an improvement beyond the minimum requirements by meeting a target of 350 $kgCO_2e/m^2$ for all buildings except warehouses and distribution centers.
  - **ZCB-2:** The project can demonstrate a deeper reduction in embodied carbon by meeting a target of 260 $kgCO_2e/m^2$ for all buildings except warehouses and distribution centers.
  - The GWP according to the ZCB is computed based on phases A1-5, B1-5, C1-4 and the area is defined using the built floor area (BFA), which is the floor area including underground parking spaces (area "with parking").
- **Proposed Vancouver Building Bylaw 2025** (City of Vancouver, 2022; City of Vancouver, 2023; City of Vancouver, 2024):
  - **VBBL-1** – The City of Vancouver Benchmark of 400 $kgCO_2e/m^2$ for projects from which a reduction must be achieved.
  - Under the "absolute path" compliance, the 2025 VBBL is proposed to require 10% reduction from the benchmark with 0-5% of the reduction being credited for Industry Leadership credits.
  - **VBBL-2** – The "absolute path" compliance value is 95% of 400 $kgCO_2e/m^2$ for projects that are pursuing the full 5% available for Industry Leadership Credits. Therefore, the limit per VBBL-2 is 380 $kgCO_2e/m^2$.
  - **VBBL-3** – The "absolute path" compliance value is 90% of 400 $kgCO_2e/m^2$ for projects that are not pursuing Industry Leadership Credits. Therefore, the limit per VBBL-3 is 360 $kgCO_2e/m^2$.
  - The GWP according to the VBBL is computed based on phases A1-5, B1-5, C1-4 and the area is defined using the gross floor area (area "without parking").
  - VBBL also offers a "baseline path" compliance that designates a reduction from the baseline GWP values (City of Vancouver, 2023). Reductions of 95% and 90% will be considered for comparing Scenarios 1 and 2 of this study to the baseline scenario.
- **Toronto Green Standard version 4** (TGS v4) for mid- to high-rise residential and non-residential buildings (City of Toronto, 2025):
  - Tier 1 is the mandatory performance level which currently has no GWP Intensity target in version 4, Tier 2 and Tier 3 are optional performance levels.
  - TGS version 5 is expected to be released in 2026 and typically the lowest performance tier, i.e. Tier 1, would be eliminated and effectively Tier 2 v4 ➜ Tier 1 v5 and Tier 3 v4 ➜ Tier 2 v5.
  - **TGS-2:** Residential and commercial projects pursuing TGS v4 Tier 2 must demonstrate an A1-A5 GWP intensity less than 350 $kgCO_2e/m^2$.
  - T**GS-3:** Residential and commercial projects pursuing TGS v4 Tier 3 must demonstrate an A1-A5 GWP intensity less than 250 $kgCO_2e/m^2$.
  - The GWP according to the TGS is computed based on phases A1-5 and the area is defined using the built floor area which, is the floor area including underground parking spaces (area "with parking").

# Mass timber floor design

A mass timber floor option is studied by comparing the baseline scenario embodied carbon of the NW Health Campus to an additional scenario where the majority of the floor is replaced with cross-laminated timber (CLT) panels. A preliminary floor framing system was proposed by RJC based on the existing steel floor frame. An all timber solution was not explored because this would affect existing floor-to-floor heights, mechanical layouts, etc.. The baseline scenario OWSJs are removed while the main steel beams and girders are maintained. The same column locations are maintained as well. This resulted in a 50 mm concrete topping reinforced with welded wire mesh on a 5-ply 175 mm CLT panel to meet serviceability and ultimate limit states. The estimated mass per unit area of the existing 64 mm concrete topping on 38x0.76 mm composite steel deck composite steel slab and assuming 20 kg/m2 for the OWSJ is 181 kg/m2 while the CLT option is 200 kg/m2. The increase in mass corresponds to a less than 5% increase in total factored load considering a 1.5 kPa superimposed dead load and a 3.6 kPa live load. The total height of the original steel composite slab is 102 mm plus a 102 mm joist shoe for a total thickness of 204 mm while the CLT system is 225 mm. The storey heights for the NW Health Campus are 4 and 3.5 m, respectively. Therefore, the ~25 mm increase in floor height represents a less than 1% increase in building height to maintain the same clear storey height.

Quantities of concrete and CLT materials are computed explicitly from the Revit model following the methodology in the section on Structural Quantities. The CLT concrete topping material is matched to the steel composite slab material (i.e., 25 MPa). The steel gravity system (i.e., beams, girders, columns) was not resized because the increase in self-weight of the CLT system only corresponds to less than a 5% increase in the total factored floor loading. Likewise, the envelope quantities were not adjusted because there would only be a less than 1% increase in the façade area. The increase in mass may have a minor influence on the design lateral force in highly seismic regions but this was not considered in this study. The EPD for Cross-Laminated Timber produced in British Columbia is used for this study (ASTM International, 2023). The A1-A3 GWP per unit used for CLT in this project is 100.75 $kgCO_2e/m^3$. Default software settings are used within OneClick with respect to computing the effects of wbLCA module D results.

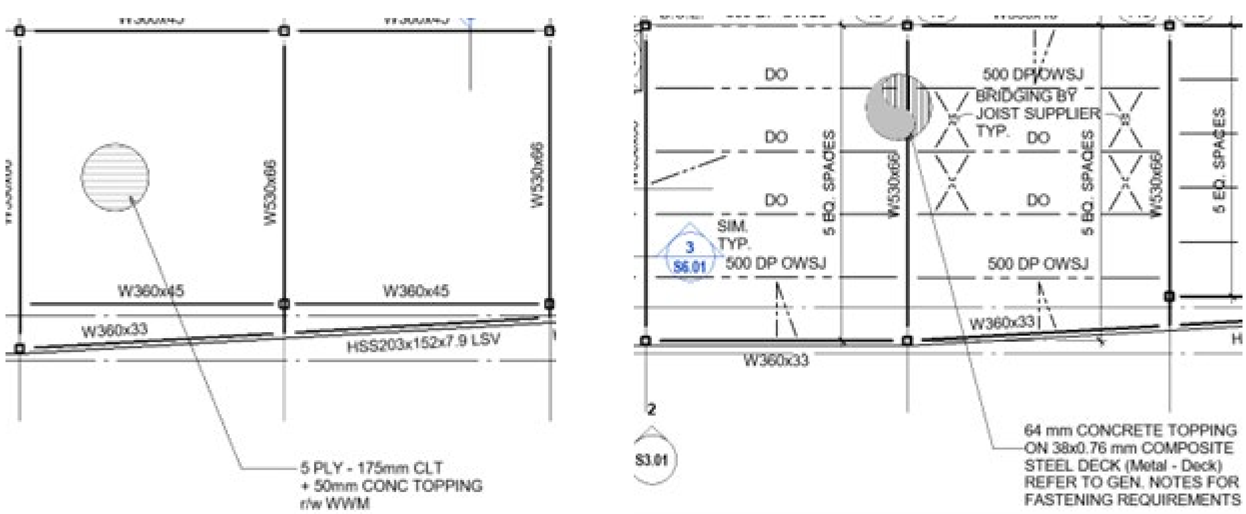



**Figure 3 – Comparison of steel and CLT floor systems for the NW Health Campus.**

# Results

## Summary of results

Summary tables that contain data from all the projects are presented in this section (note: that the results for the Quarry Crossing project include all three buildings and the underground parking in these tables).
The following assumptions are made in this study:

- **Table 4** provides the measured area take-offs for the floor areas. Recall that the built floor area (BFA) is the sum of GFA and parking areas.
- **Table 5** provides the total material quantities broken down for concrete, rebar and structural steel. The quantities are summed in each of these categories regardless of specific material. The BFA is repeated in this table for reference.
- **Table 6** provides breakdowns of the specific steel materials based on the EPD categories in **Table 3**.
- **Table 7** provides a summary of the GWP and the GWP intensities. The intensity without parking is the GWP divided by GFA, the intensity with parking is the GWP divided by the BFA. The Quarry Crossing results are excluded from the following observations because it only includes the structural embodied carbon:
  - **Baseline:** The total GWP intensities (without parking) range between 307-370 kg$CO_2$e/m$^2$, with an average of 341 kg$CO_2$e/m$^2$. The total GWP intensities (with parking) range between 255-359 kg$CO_2$e/m$^2$, with an average of 301 kg$CO_2$e/m$^2$. The structural contribution to the GWP is 72% on average.
  - **Scenario 1:** The total GWP intensities (without parking) range between 259-319 kg$CO_2$e/m$^2$, with an average of 282 kg$CO_2$e/m$^2$. The total GWP intensities (with parking) range between 220-284 kg$CO_2$e/m$^2$, with an average of 248 kg$CO_2$e/m$^2$. The structural contribution to the GWP is 67% on average.
  - **Scenario 2:** The total GWP intensities (without parking) range between 311-398 kg$CO_2$e/m$^2$, with an average of 357 kg$CO_2$e/m$^2$. The total GWP intensities (with parking) range between 240-398 kg$CO_2$e/m$^2$, with an average of 317 kg$CO_2$e/m$^2$. The structural contribution to the GWP is 73% on average.
- **Table 8** provides the portion of total GWP broken down by structural steel EPD categories.
- **Table 9** provides the portion of structural GWP for the lateral force resisting system and the foundation elements in the Baseline scenario. For the projects in this study, lateral force resisting elements are categorized as either concrete shear walls or steel vertical braces; the foundation elements are categorized as either shallow (spread/strip footings) or deep (concrete piles). The lateral systems are reported in this table for reference. For each project, the spectral accelerations at a period of 0.2 s used in design are reported along with the values from NBCC 2020. The NBCC 2020 values are based on the same site classification reported in the initial design.
- **Table 11** provides the phase D GWP contributions of structural materials for the baseline and CLT options of NW Health Campus. Each entry in this table is the phase D GWP divided by the total structural GWP.

Table 4: Summary of area take-off results.

| Project | Gross Floor Area (GFA) ($m^2$) | Parking Area ($m^2$) | Built Floor Area (BFA) ($m^2$) | Gross Floor Area / Built floor Area (GFA/BFA) |
|---|---|---|---|---|
| NW Health Campus | 2550 | - | 2550 | 1.00 |
| Suburban Office | 6020 | 2710 | 8730 | 0.69 |
| Durham College | 7060 | 1110 | 8170 | 0.86 |
| Seneca CITE | 25600 | - | 25600 | 1.00 |
| Quarry Crossing | 56400 | 39200 | 95600 | 0.59 |

Table 5: Summary of total structural material quantities.

| Project | Built Floor Area (BFA) ($m^2$ | Total Concrete Volume ($m^3$) | Total Rebar Mass (t) | Total Steel Mass (t) |
|---|---|---|---|---|
| NW Health Campus | 2550 | 580 | 45 | 125 |
| Suburban Office | 8730 | 2060 | 185 | 295 |
| Durham College | 8170 | 1810 | 100 | 650 |
| Seneca CITE | 25600 | 9460 | 810 | 2230 |
| Quarry Crossing | 95600 | 27000 | 2410 | 2830 |

Table 6: Breakdown of structural steel material quantities.

| Project | Hot-rolled (t) | HSS (t) | Plate (t) | CFS[(1)] (t) | OWSJ (t) | Merchant (t) | Rebar (t) |
|---|---|---|---|---|---|---|---|
| NW Health Campus | 67.9 | 3.4 | 10.0 | 22.3 | 19.7 | 0.6 | 44.0 |
| Suburban Office | 99.0 | 67.2 | 20.4 | 47.4 | 44.1 | 14.2 | 185.2 |
| Durham College | 444.7 | 63.2 | 48.8 | 92.2 | 0 | 0 | 98.2 |
| Seneca CITE | 1620.2 | 71.3 | 158.2 | 361.5 | 0 | 6.4 | 810.0 |
| Quarry Crossing | 1637.2 | 1.7 | 163.3 | 517.1 | 486.8 | 20.9 | 2473.2 |

(1) Cold-Formed Steel

Table 7: Summary of global warming potential (GWP) summed from all phases A-C and GWP intensity. B = baseline scenario, S1 = Scenario 1, S2 = Scenario 2.

| Project | | Structural GWP ($tCO_2e$) | Non-structural GWP ($tCO_2e$) | Structural GWP Intensity ($kgCO_2e/m^2$) | | Non-structural GWP Intensity ($kgCO_2e/m^2$) | | Total GWP Intensity ($kgCO_2e/m^2$) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **GFA** | **BFA** | GFA | BFA | GFA | BFA |
| NW Health Campus | B | 483 | 298 | 190 | 190 | 117 | 117 | **307** | **307** |
| | S1 | 374 | 298 | 147 | 147 | 117 | 117 | **264** | **264** |
| | S2 | 495 | 298 | 194 | 194 | 117 | 117 | **311** | **311** |
| Suburban Office | B | 1506 | 717 | 250 | 172 | 119 | 82 | **370** | **255** |
| | S1 | 1201 | 717 | 200 | 138 | 119 | 82 | **319** | **220** |
| | S2 | 1376 | 717 | 229 | 158 | 119 | 82 | **348** | **240** |
| Durham College | B | 1765 | 558 | 250 | 216 | 79 | 68 | **329** | **284** |
| | S1 | 1273 | 558 | 180 | 156 | 79 | 68 | **259** | **224** |
| | S2 | 2061 | 558 | 292 | 252 | 79 | 68 | **371** | **320** |
| Seneca CITE | B | 7584 | 1592 | 296 | 296 | 62 | 62 | **359** | **359** |
| | S1 | 5690 | 1592 | 222 | 222 | 62 | 62 | **284** | **284** |
| | S2 | 8586 | 1592 | 336 | 336 | 62 | 62 | **398** | **398** |
| Quarry Crossing | B | 17987 | - | 319 | 188 | - | - | - | - |
| | S1 | 14373 | - | 255 | 150 | - | - | - | - |
| | S2 | 16709 | - | 296 | 175 | - | - | - | - |

GFA: Values are normalized by the gross floor area (GFA).
BFA: Values are normalized by the built floor area (BFA).

Table 8: Relative contribution to total GWP (all phases A-C, in %) by structural steel material.

| Project | Scenario | Hot-rolled | HSS | Plate | CFS(1) | OWSJ | Merchant | Σ Structural Steel | Rebar | ΣSteel & Rebar |
|---|---|---|---|---|---|---|---|---|---|---|
| NW Health Campus | Baseline | 11.2 | 0.9 | 2.4 | 7.8 | 4.1 | 0.1 | **26.5** | 5.4 | **31.9** |
| | Scenario 1 | 7.7 | 0.6 | 1.3 | 4.8 | 2.9 | 0.1 | **17.4** | 3.4 | **20.8** |
| | Scenario 2 | 21.7 | 0.5 | 1.1 | 4.1 | 2.5 | 0.0 | **29.9** | 2.9 | **32.8** |
| Suburban Office | Baseline | 5.8 | 6.0 | 1.7 | 5.8 | 3.1 | 0.8 | **23.2** | 8.0 | **31.2** |
| | Scenario 1 | 3.9 | 4.1 | 0.9 | 3.6 | 2.1 | 0.5 | **15.1** | 5.1 | **20.2** |
| | Scenario 2 | 12.0 | 3.8 | 0.8 | 3.3 | 2.0 | 0.4 | **22.3** | 4.6 | **26.9** |
| Durham College | Baseline | 24.7 | 5.4 | 3.8 | 10.8 | 0 | 0 | **44.7** | 4.1 | **48.8** |
| | Scenario 1 | 18.6 | 4.0 | 2.3 | 7.3 | 0 | 0 | **32.2** | 2.8 | **35.0** |
| | Scenario 2 | 43.1 | 2.8 | 1.6 | 5.1 | 0 | 0 | **52.6** | 2.0 | **54.6** |
| Seneca CITE | Baseline | 22.8 | 1.5 | 3.2 | 10.8 | 0 | 0.1 | **38.4** | 8.4 | **46.8** |
| | Scenario 1 | 17.0 | 1.1 | 2.0 | 7.2 | 0 | 0.1 | **27.4** | 5.8 | **33.2** |
| | Scenario 2 | 40.4 | 0.8 | 1.6 | 5.2 | 0 | 0.0 | **48.0** | 4.1 | **52.1** |
| Quarry Crossing(2) | Baseline | 11.8 | 0.0 | 1.7 | 7.9 | 4.4 | 0.2 | **26.0** | 13.2 | **39.2** |
| | Scenario 1 | 7.2 | 0.0 | 0.9 | 5.2 | 2.4 | 0.1 | **15.8** | 8.0 | **23.8** |
| | Scenario 2 | 20.1 | 0.0 | 0.8 | 4.5 | 2.1 | 0.1 | **27.6** | 6.8 | **34.4** |

(1) Cold-Formed Steel

(2) GWP only includes structural elements.

Table 9: Seismic spectral accelerations and relative contribution of the lateral and foundation systems to structural GWP (all phases A-C) for the baseline scenario.

| Project | Lateral System | Foundation System) | Increase in Sa(T1) | Contribution of Lateral to Structural GWP (%) | Contribution of Lateral Foundations to Structural GWP (%) |
|---|---|---|---|---|---|
| NW Health Campus | Concrete shear wall, steel braced frame | Shallow | 63% (NBCC 2015) | 10 | 7 |
| Suburban Office | Steel braced frame | Deep | 24% (NBCC 2015) | 4 | 2 |
| Durham College | Concrete shear wall | Shallow | 63% (NBCC 2010) | 8 | 3 |
| Seneca CITE | Concrete shear wall | Deep | 92% (NBCC 2010) | 9 | 8 |
| Quarry Crossing | Concrete shear wall | Shallow | 108% (NBCC 2005) | 7 | 4 |

Table 10: Contribution of floor system to structural GWP for the Baseline scenario (all phases A-C, in %).

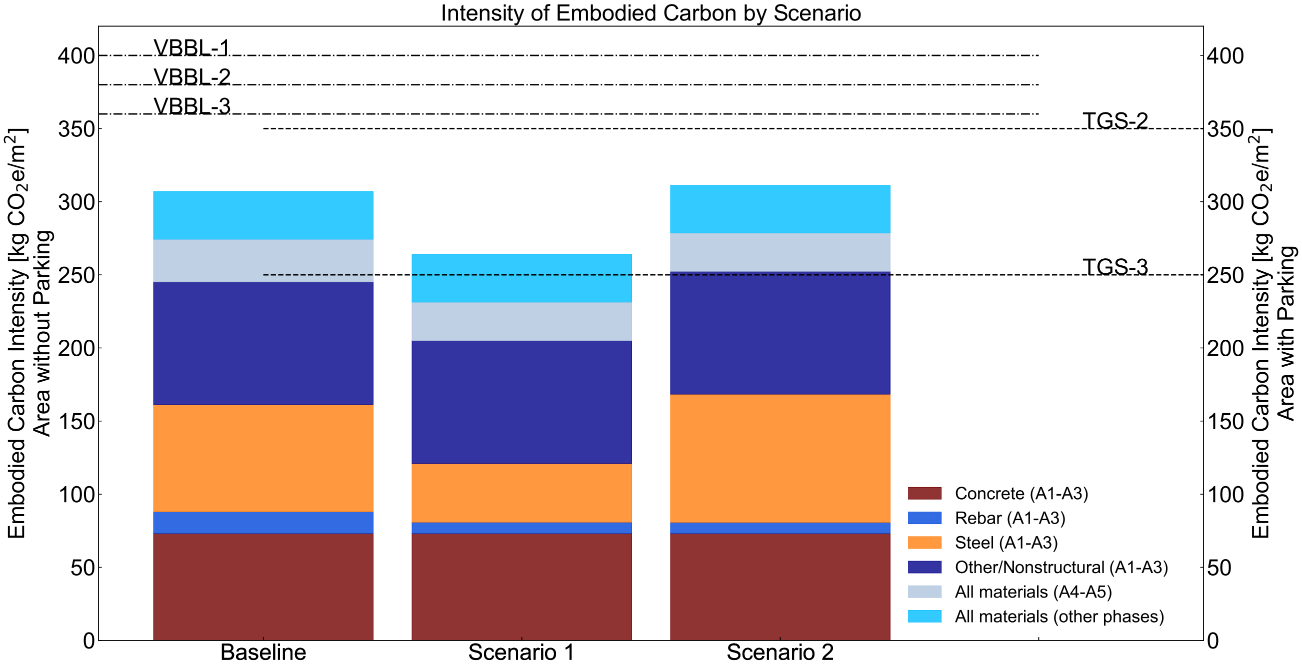
| Project | Roof Decks | Floors (deck) | Floor (concrete) | Gravity Beams | OWSJs | **Floor & Roof Σ** |
|---|---|---|---|---|---|---|
| NW Health Campus | 4.4 | 8.2 | 12.3 | 14.1 | 6.7 | **45.6** |
| Suburban Office | 3.9 | 5.2 | 10.6 | 8.3 | 4.5 | **32.6** |
| Durham College | 3.1 | 9.2 | 11.4 | 26.9 | 0 | **50.6** |
| Seneca CITE | 2.6 | 8.8 | 11.6 | 20.2 | 0 | **44.8** |
| Quarry Crossing | 1.7 | 6.1 | 9.7 | 10.3 | 4.0 | **31.8** |

Table 11: GWP ratio of phase D to other phases A-C for NW Health Campus (per structural material, values in %).

| Scenario | Concrete | Rebar | Steel | Timber | **Total Weighted Average** |
|---|---|---|---|---|---|
| Baseline | 2 | -7 | -48 | 0 | **-22** |
| CLT Option | 2 | -7 | -20 | -428 | **-60** |

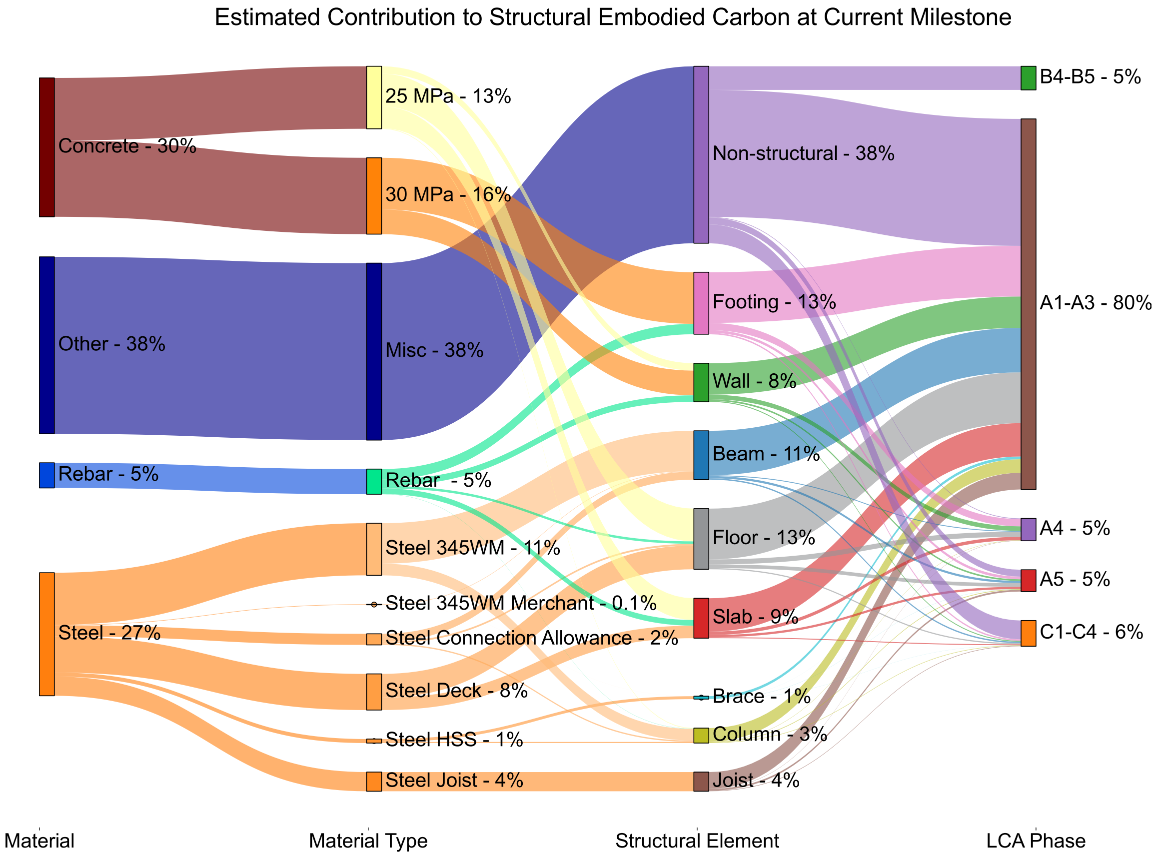
## NW Health Campus

(a) Building rendering/image




(b) GWP by scenario (GFA/BFA = 1.00)

**Figure 4 – Project results for NW Health Campus.**

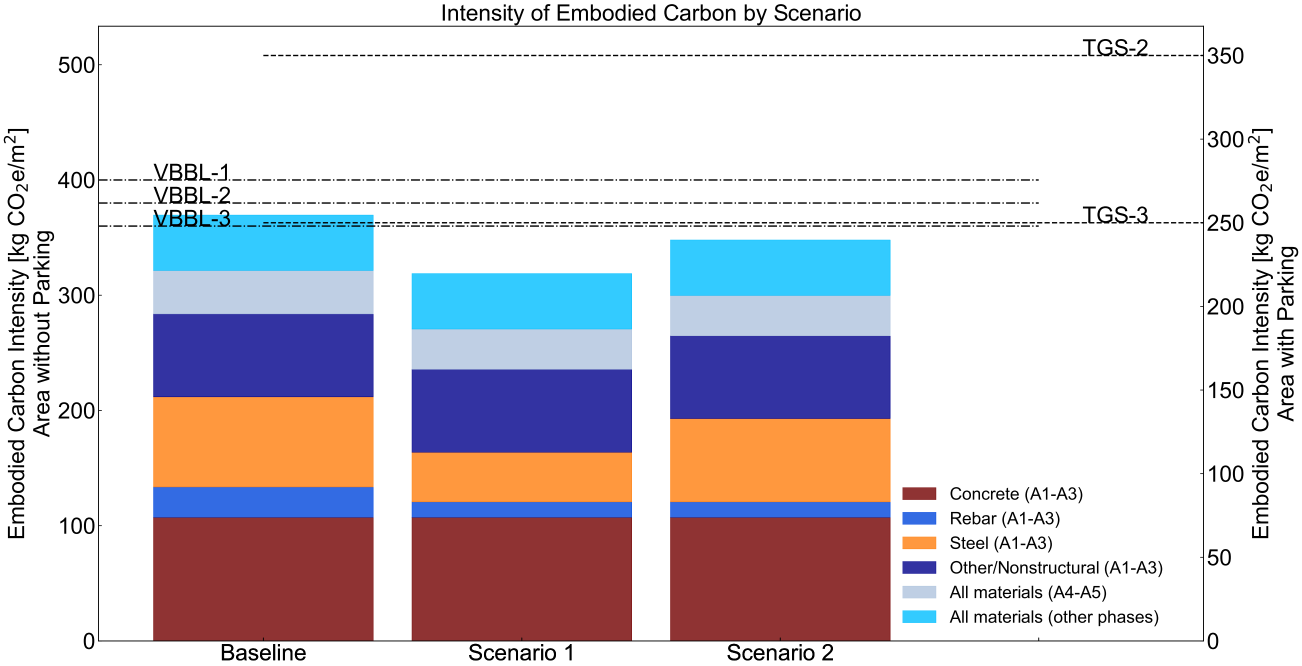



(c) Embodied carbon breakdown

**Figure 4 – Project results for NW Health Campus.**

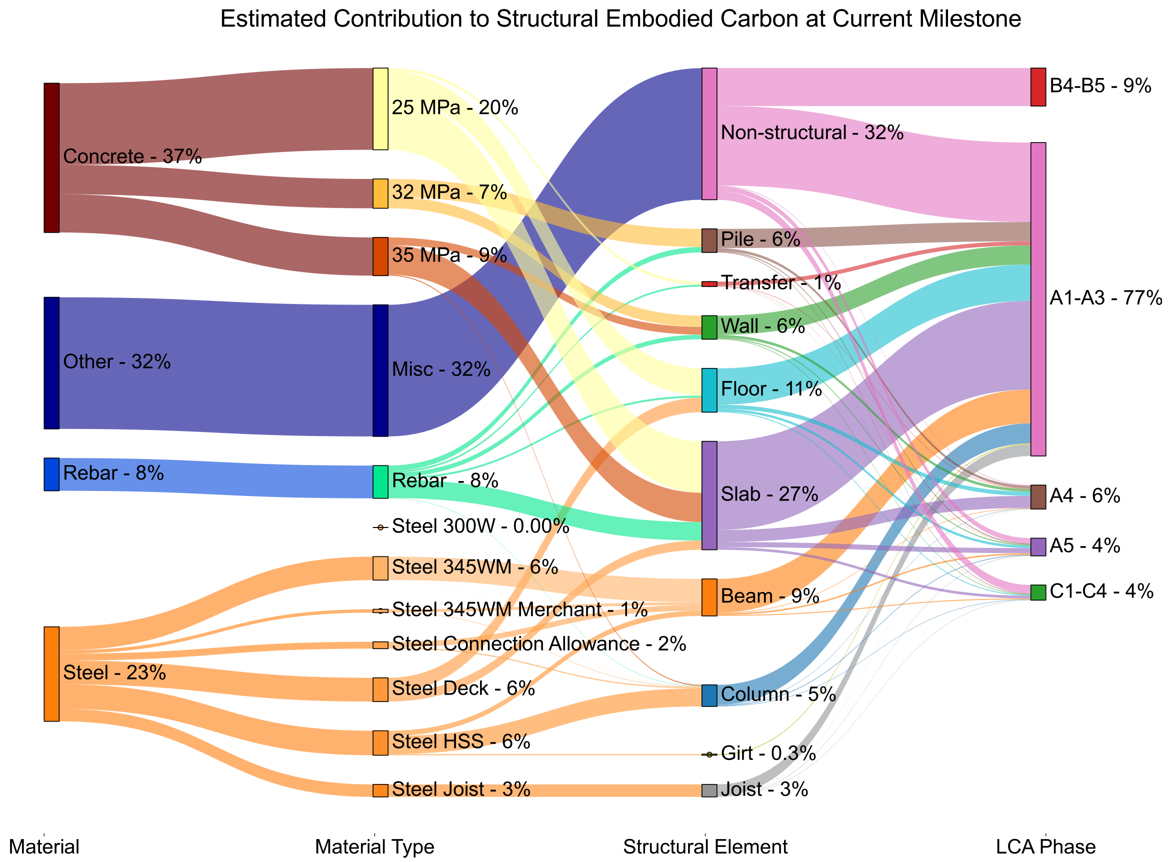
## Suburban Office

(a) Building rendering/image




(b) GWP by scenario (GFA/BFA = 0.69)

**Figure 5 – Project results for the Suburban Office.**

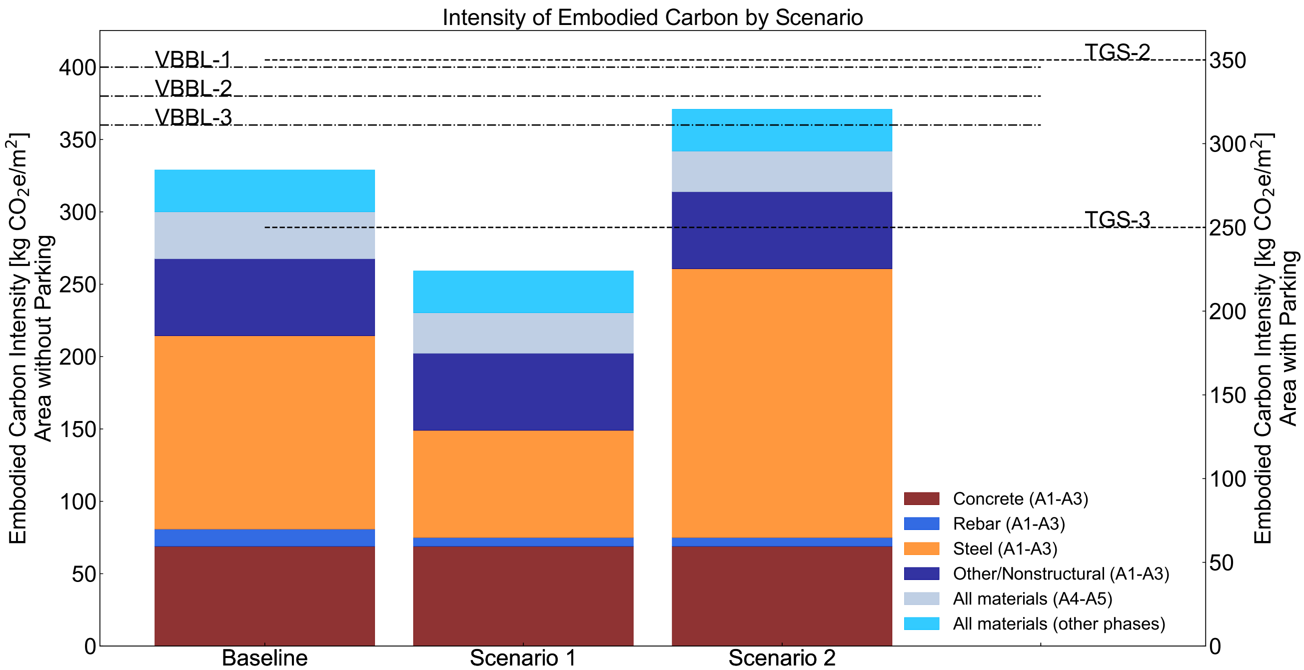



(c) Embodied carbon breakdown

**Figure 5 – Project results for the Suburban Office.**

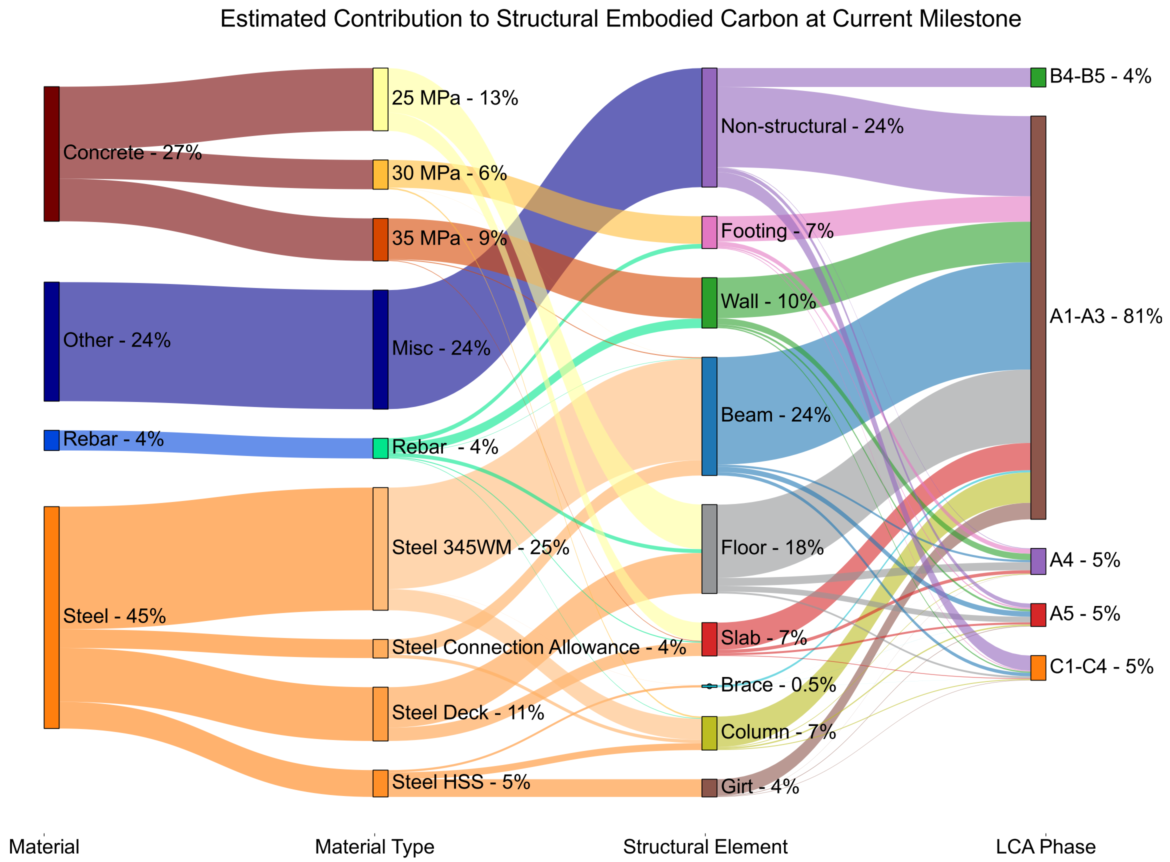
# Durham College

(a) Building rendering/image




(b) GWP by scenario (GFA/BFA = 0.86)

**Figure 6 – Project results for Durham College.**

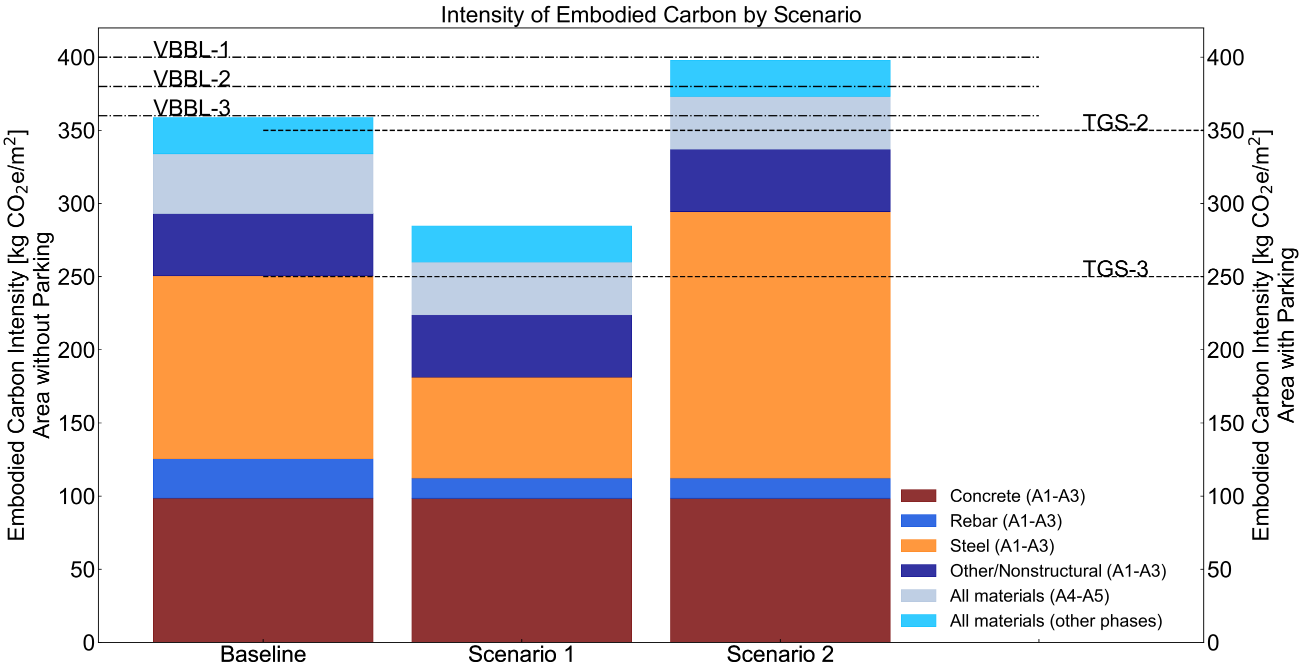



(c) Embodied carbon breakdown

**Figure 6 – Project results for Durham College.**

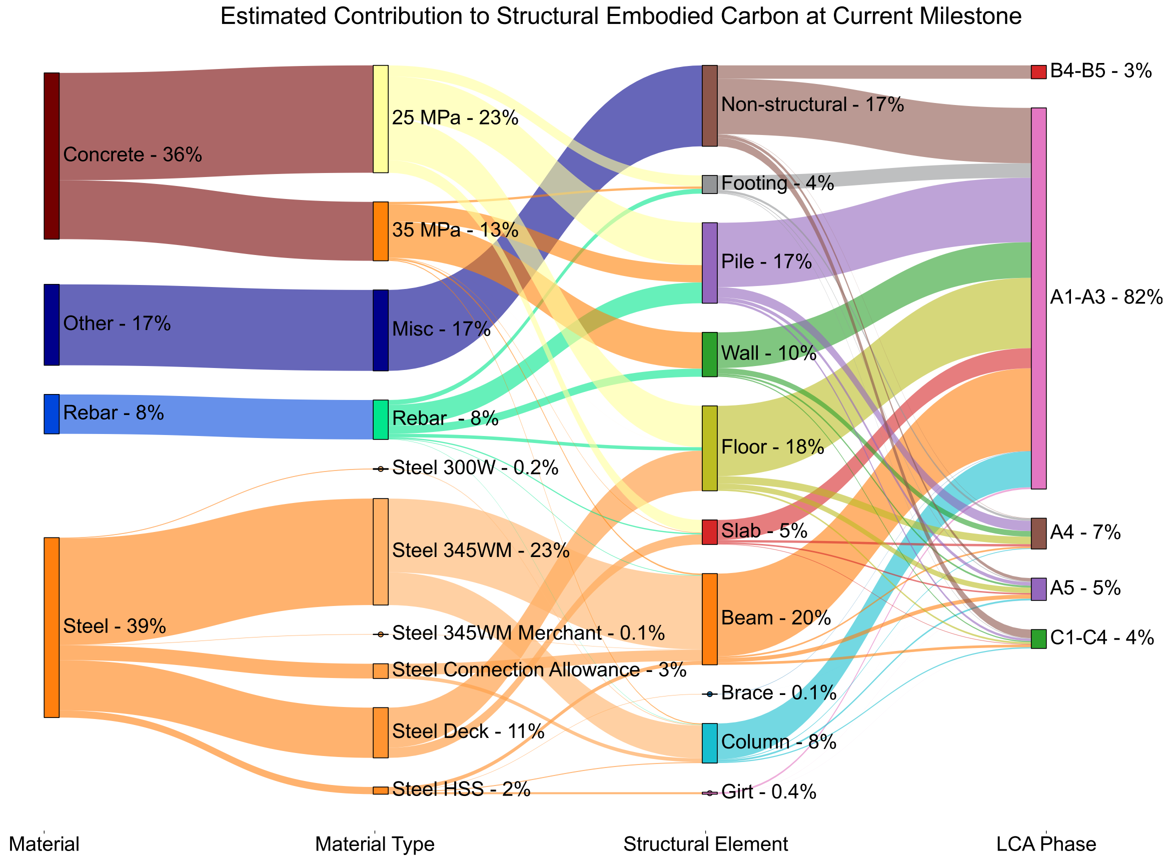
# Seneca Center for Innovation, Technology, and Entrepreneurship (CITE)

(a) Building rendering/image




(b) GWP by scenario (GFA/BFA = 1.00)

**Figure 7 – Project results for Seneca CITE.**

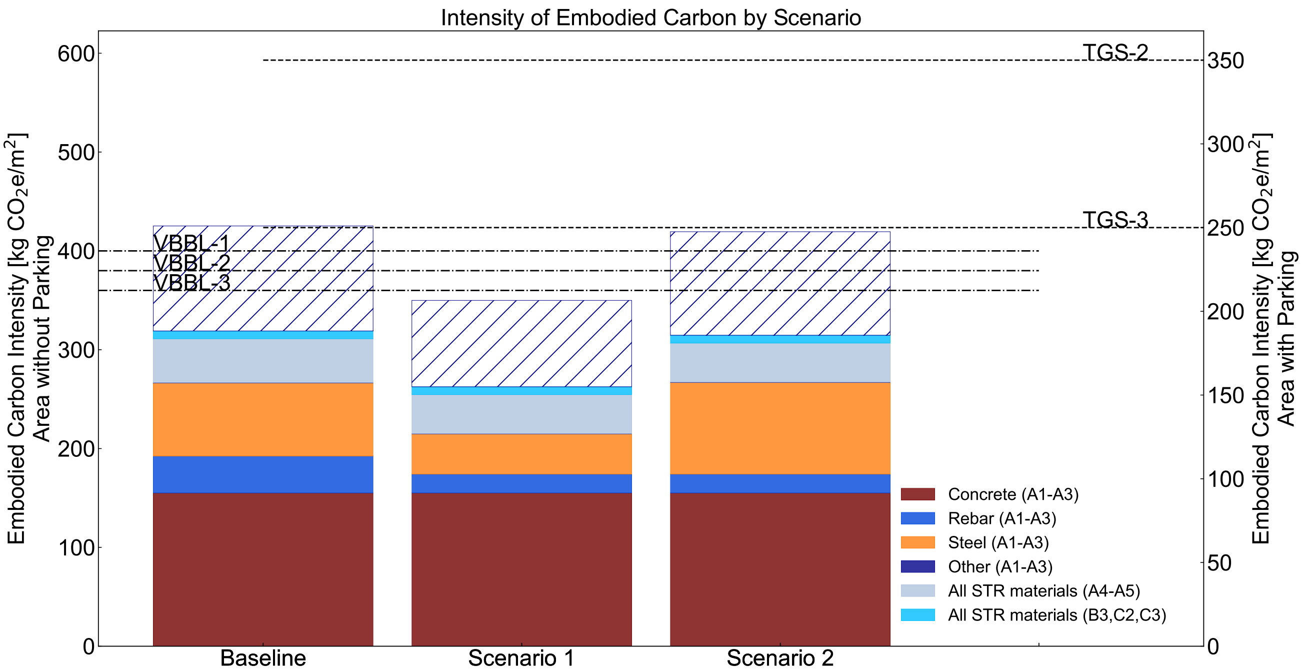



(c) Embodied carbon breakdown

**Figure 7 – Project results for Seneca CITE.**

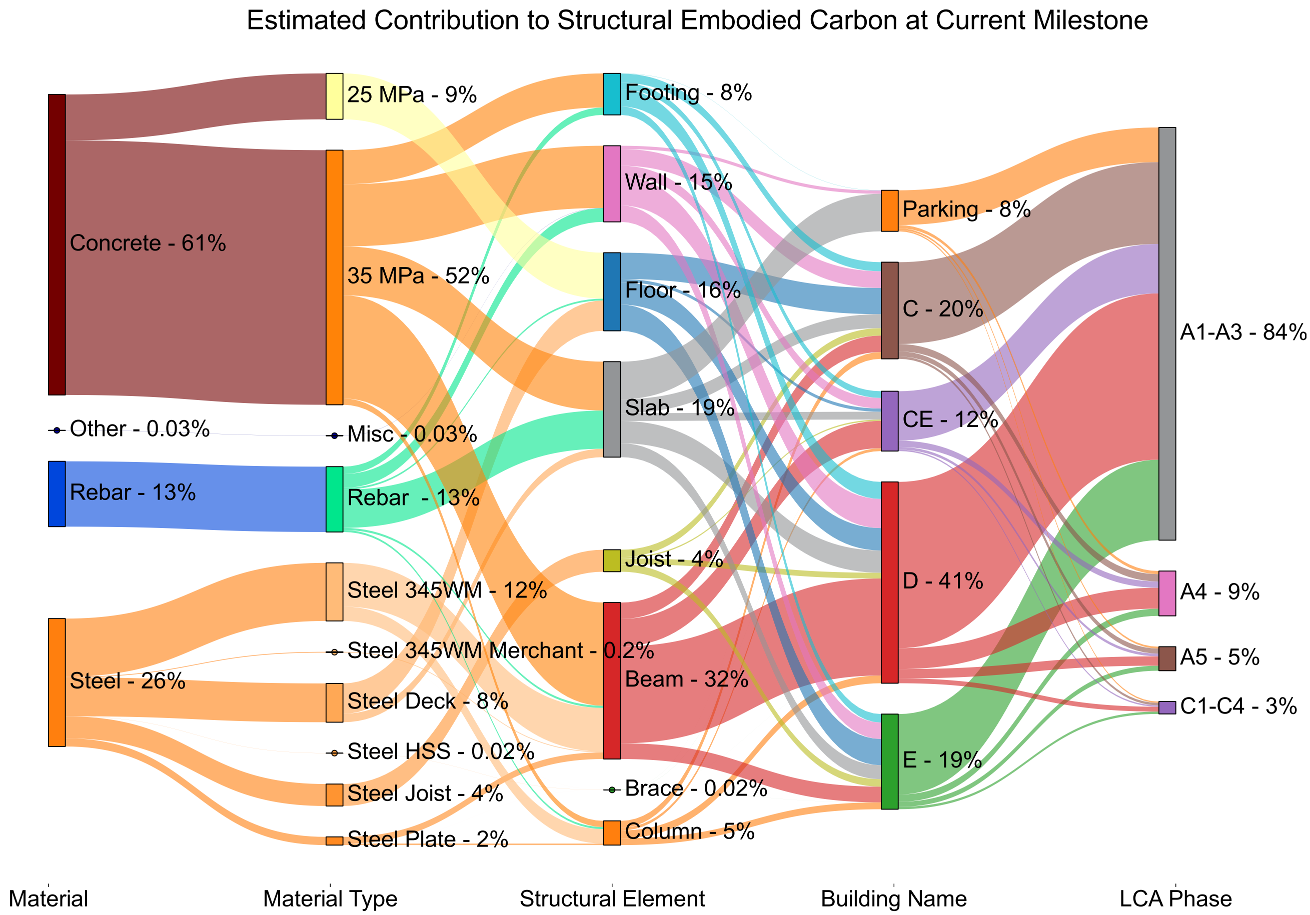
## Quarry Crossing

(a) Building rendering/image




(b) GWP by scenario (GFA/BFA = 0.59)

**Figure 8 – Project results for Quarry Crossing.**

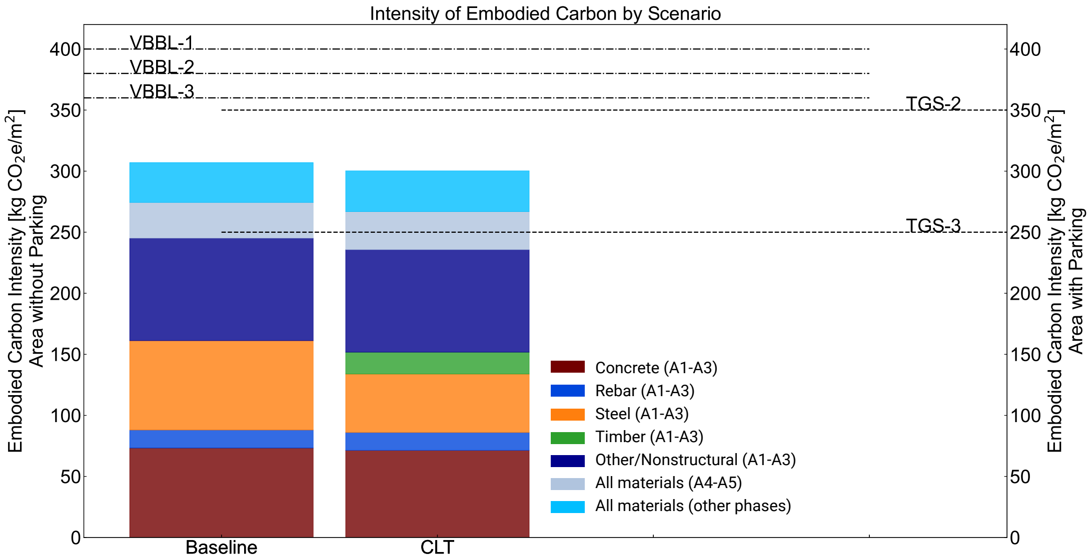



(c) Embodied carbon breakdown

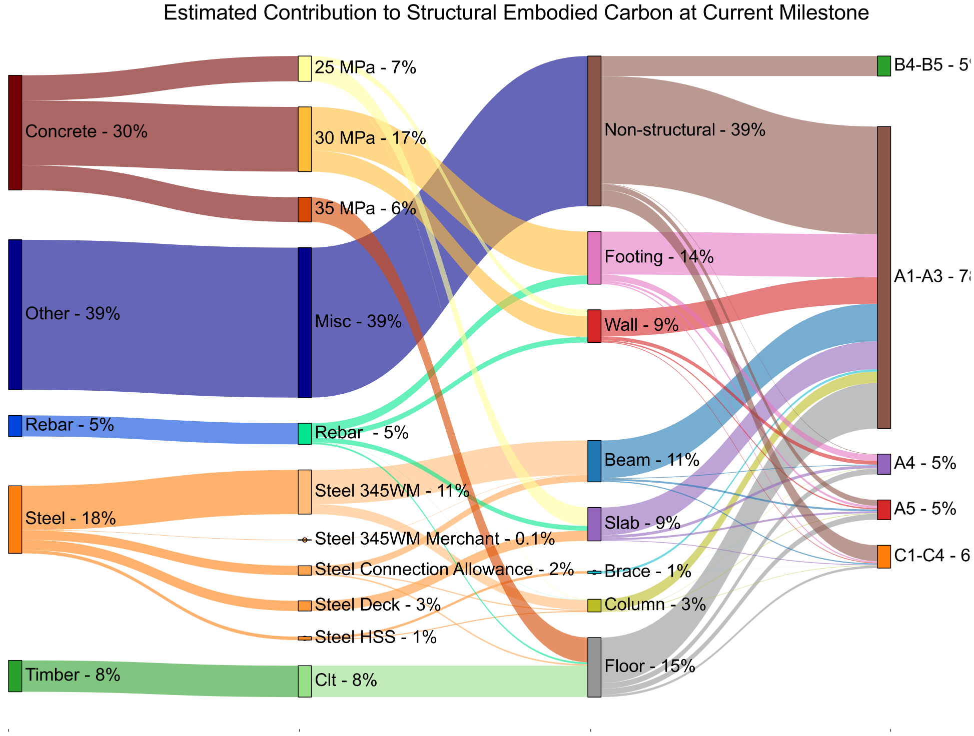
**Figure 8 – Project results for Quarry Crossing.**

# Mass timber floor option

The GWP intensity for the mass timber floor option of the NW Health Campus is 300 kg$CO_2$e/m$^2$. A comparison of the GWP intensity the baseline and CLT options for the NW Health Campus are shown in **Figure 9a**. The breakdown of GWP for the CLT option is shown in **Figure 9b**. The ratio of GWP for phase D is provided for the baseline scenario and CLT option in **Table 11**. For example, for the baseline scenario, phase D represents a 2% increase in structural GWP for concrete materials, a 7% reduction for rebar and a 48% reduction for structural steel.




(a) GWP by scenario (GFA/BFA = 1.00)




(b) Embodied carbon breakdown

**Figure 9 – Project results for the mass timber floor option**

# Results

## Baseline embodied carbon impact of typical low-rise steel buildings

Within the assumptions made in this study, typical low-rise structural steel projects in regions of low-seismicity should be expected to meet the current embodied carbon limits in Canadian municipalities if an effort is made to source low-carbon materials. Carbon reductions could be achieved, not only as explored in this study through low-carbon structural steels, but also by employing lower-carbon concrete and exploring strategies to reduce material use. The average GWP intensity of the buildings in the Baseline Scenario with parking is 301 $kgCO_2e/m^2$, which is below the ZCB-1 limit demonstrating an improvement beyond the minimum requirement in the Zero Carbon Building Standard (Canadian Green Building Council, 2024). The Toronto Green Standard relies on the upfront embodied carbon, from **Figure 10** (a), all projects but Seneca CITE meet the TGS-2 target. The average total GWP intensity (without parking) reported in **Table 7** is 341 $kgCO_2e/m^2$ for the baseline scenario. This is below the current limit of 360 $kgCO_2e/m^2$ (VBBL-2) in the Vancouver Building Bylaw (VBBL).

Large underground parking areas have a significant influence on the apparent GWP performance. For instance, in **Figure 10**, even accounting for a 25% increase in the Quarry Crossing project for missing nonstructural GWP, this is one of the best performing projects when the GWP is normalized by the built floor area (including underground parking). However, in Figure 8 (b), we can see that Quarry Crossing exceeds the 400 $kgCO_2e/m^2$ limit of the Vancouver Building Bylaw when the area is based on the gross floor area (not including underground parking). The use of different area metrics is an oft-discussed topic (Mattman, et al., 2023); and the results herein contribute to underscoring the importance of the area metric in defining embodied carbon limits for Canadian municipalities.

The upfront embodied carbon (i.e., phases A1-A5) is the main contributor to the total GWP of all the projects investigated in this study. The follow discussion excludes Quarry Crossing because it does not include the nonstructural embodied carbon. Looking at the GWP breakdown by wbLCA phase in **Figure 4** to **Figure 7**, the main contributor to GWP is the A1-A3 phase, with an average value of 80% of the total. The A4 and A5 phases add a combined average of around 10%, so the A1-A5 average is over 90% of the total GWP. Furthermore, from **Table 7**, the average structural contribution to embodied carbon is around 72% from the baseline scenario. These results reinforce the idea that, to the fullest extent possible, retrofitting existing structural systems and reusing structural materials should be preferred over new construction to reduce embodied carbon.

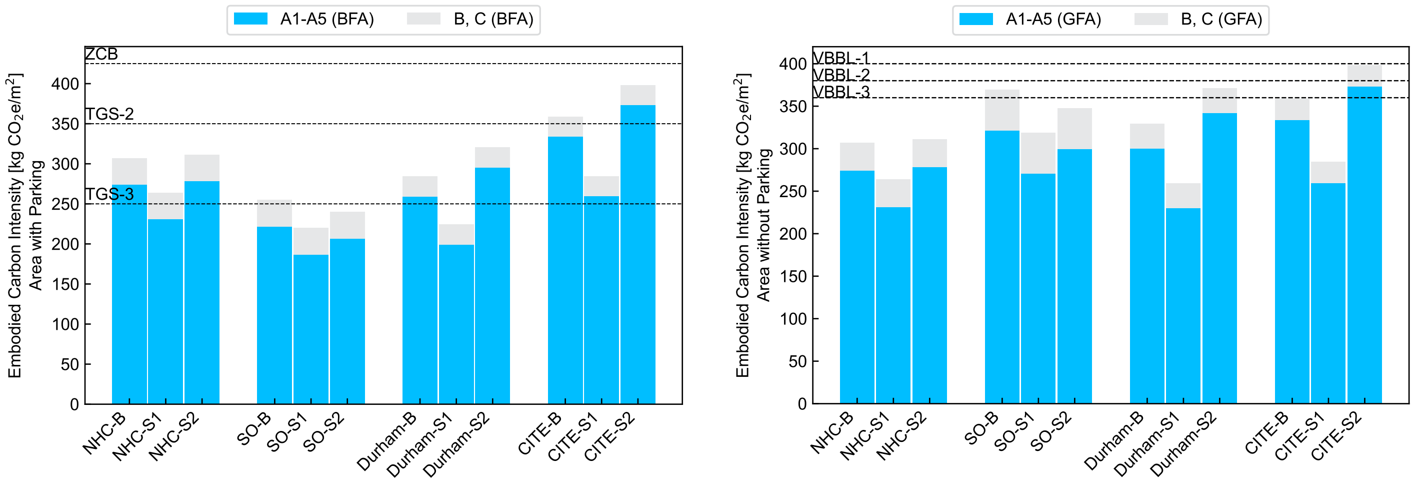
Both gravity and lateral structural systems have varying levels of relative impact on the GWP. The structural floor system appears to have a large impact on the structural steel embodied carbon contributions found in this study. From **Table 8**, the contribution of structural steel to the total embodied carbon from systems with OWSJ is around 32%, while the same contribution is around 48% for composite deck/beam systems. For example, the combination of hot-rolled members and OWSJs contributed 15% to the total GWP in the NW Health Campus project (see **Table 8**). Compare this value to the distribution shown in Figure 6 for Durham College, where the hot-rolled beams contribute a full 25% of the total GWP. These results are reinforced considering the typically lower floor and roof sums for projects with OWSJs in **Table 10**. This difference highlights the relative efficiency of joist systems and indicates that, architectural constraints notwithstanding, they may be a preferred system to reduce embodied carbon in structural steel buildings.

Soil conditions also appear to have a moderate impact on the total embodied carbon found in this study. From the baseline scenario, when the GWP intensity of the two buildings on deep foundations those with a similar structural system (OWSJs or composite beams), the buildings while the shallow foundations had a lower GWP Intensity with respect to GFA. For instance, comparing NW Health Campus and Suburban Office (both have OWSJ), the project with piles has around 30% higher structural GWP intensity based on GFA. Likewise, comparing Durham College and Seneca CITE, the project with piles has around 18% higher structural GWP intensity based on GFA. The need for deep foundations, and potentially suspended slab-on-grade systems, leads to an obvious increase in embodied carbon over shallow foundation systems.

The number of stories has a relatively minor impact on the GWP intensity within the limited range of projects included in this study. For example, comparing the 3 storey buildings to the 5 storey buildings from the baseline scenario, the proportional contribution of columns to the total GWP increases from around 3% to 7%. Likewise, the GWP contribution of the foundations is expected to increase with increasing number of stories given equivalent soil strengths. However, although the column GWP intensity nearly doubles, the overall effect is more muted because the floor system, which is independent of the number of stories, contributes so heavily to the total GWP.

## Contribution of structural steel to GWP

For the typical low-rise buildings in this project, the baseline average contribution of steel to the structural GWP is around 50%, as shown in **Figure 12**. The remaining 50% is due to concrete, primarily in the slab on deck, slab on grade, foundation walls, shear walls and foundations. **Figure 12** also confirms that projects with large underground parking spaces (e.g., Quarry Crossing) and deep foundations (e.g., Suburban Office) have relatively lower contributions of structural steel. The concrete source is also influential in meeting embodied carbon targets, e.g., buildings in Alberta may have a more difficult time achieving targets because of higher carbon intensity concretes (see **Table 2**). Of the structural steel types shown in **Figure 11** and **Figure 12**, hot-rolled steel consistently contributes the highest portion of GWP because it also contributes the highest portion of steel mass (see **Table 6**). The second highest structural steel contributor is consistently cold-formed steel, as most of the gross floor area is supported by steel composite slabs. Therefore, hot-rolled steel members and steel decks may be the two highest priority items to consider when selecting carbon efficient materials in low-rise steel buildings.




(a) Area metric with parking (built floor area)

(b) Area metric without parking (gross floor area)

**Figure 10 – Embodied carbon intensities for each scenario broken down by wbLCA phase (NHC = NW Health Campus, SO = Suburban Office, Durham = Durham College, CITE = Seneca CITE; -B = baseline, -S1 = scenario 1, -S2 = scenario 2).**

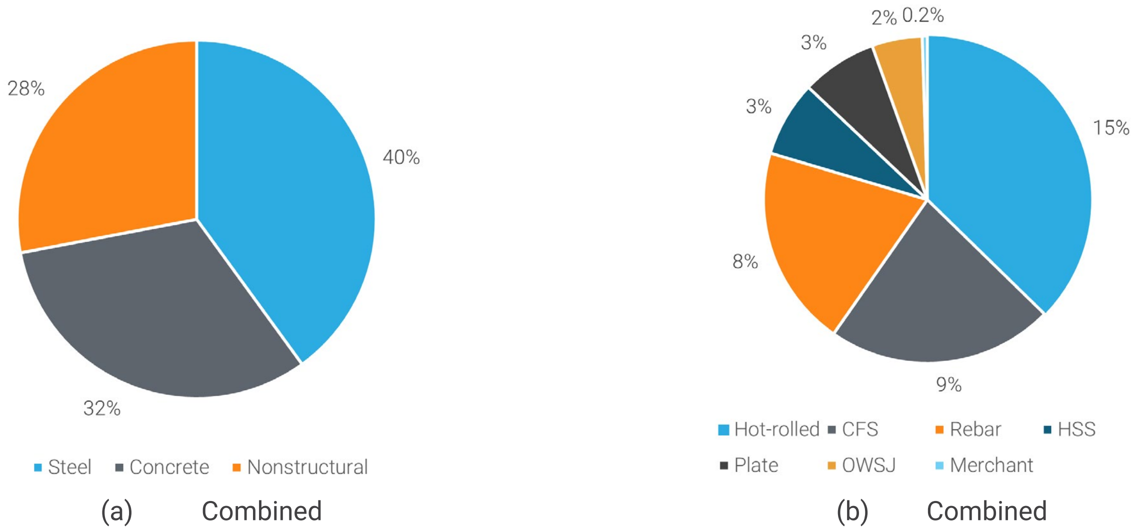
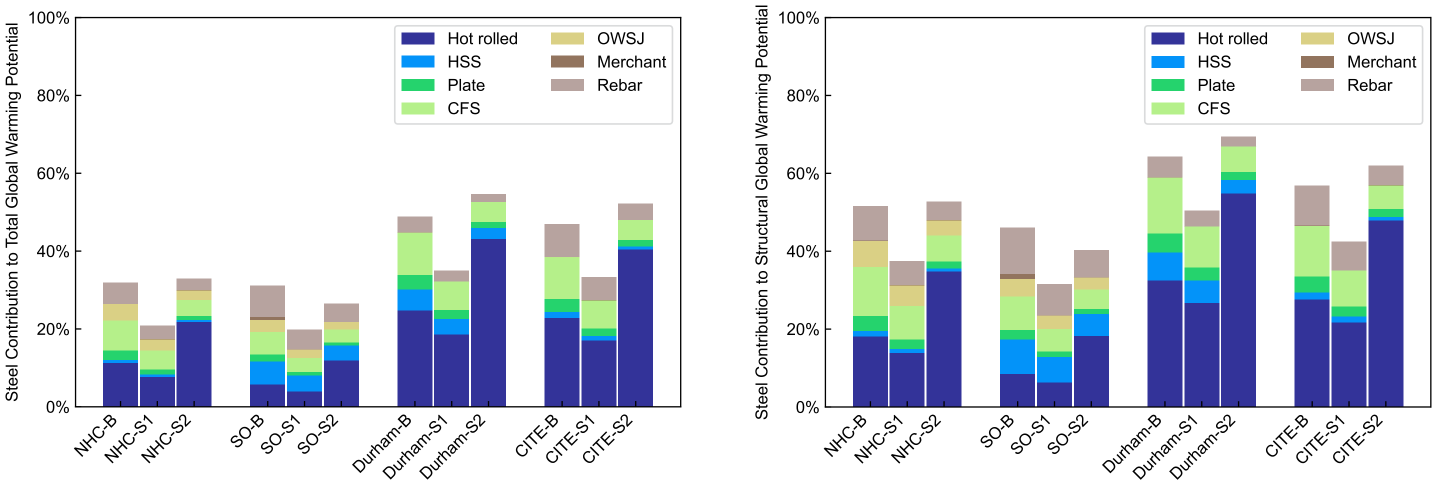



**Figure 11 – Contribution of steel elements to total GWP, average of projects other than Quarry Crossing**

In the lowest carbon scenario (Scenario 1), there is an average reduction in embodied carbon from the baseline of about 17%. This is equivalent to a reduction in steel GWP of around 32%. This represents the maximum reduction in embodied carbon that can realistically be achieved by using alternative steel products at the date of publication. Note that this scenario was evaluated under the assumption of consistent transportation carbon emissions. The A4 carbon may increase or decrease when evaluating a specific project location. While not included in this study, further reductions for utilizing lower carbon concrete, 10% below baseline EPD, could result in a further 3% +/- overall GWP reduction. In this best-case scenario, the projects, apart for NW Health Campus and Seneca CITE, meet the strictest limits on embodied carbon in Canadian municipalities. NW Health Campus appears to perform worse than the other projects due to a high contribution of nonstructural GWP, while Seneca CITE appears to perform worse than the other projects due to the contribution of deep foundations. The average 17% reduction noted above satisfies the "baseline path" compliance for the proposed VBBL (City of Vancouver, 2024). This observation is important for structures with significant demands due to site conditions or parking requirements that do not satisfy the "absolute path". A review of the projects compared to the compliance targets is shown in **Figure 10**. Altogether, low-rise steel buildings appear to be a promising structural solution to meet even the strictest embodied carbon limits currently in Canada if carbon efficient materials are sourced for the project.

Buildings that source steel through a basic oxygen furnace (BOF) process are not likely to meet the strictest embodied carbon limits in Canada. For instance, in Scenario 2, only the Suburban Office project is likely to meet the TGS-3 limit shown in **Figure 10** (a) , and the NW Health Campus to meet the VBBL-3 limit in **Figure 10** (b). This is due to the approximately 3.5x increase in the A1-A3 GWP for "hot-rolled" products from the lowest carbon scenario (see **Table 3**). Furthermore, consider that Scenario 2 is with only the hot-rolled products produced in a BOF while the all the remaining steel materials are still sourced from a "best-case" producer. Therefore, sourcing material from BOFs is likely to be a significant detriment for a low-rise steel building's ability to meet embodied carbon standards in Canada.




(a) Contribution to total GWP

(b) Contribution to structural GWP

**Figure 12 – Contribution of steel material types to the structural embodied carbon (NHC = NW Health Campus, SO = Suburban Office, Durham = Durham College, CITE = Seneca CITE; -B = baseline, -S1 = scenario 1, -S2 = scenario 2).**

## Effect of NBCC 2020 seismic changes

The spectral accelerations and contribution of the lateral-force resisting system (LFRS) to the structural GWP are shown in **Table 9**. The average contribution of the LFRS to GWP is around 8%. **Table 9** also indicates that the seismic forces increased an average of around 70% between the National Building Code of Canada used at the time of design and NBCC 2020. The increase is lowest in Edmonton that is designated as a region of low-seismicity. Note that a portion of this increase is due to how spectral accelerations are computed for site classes in NBCC 2020. Prior to NBCC 2020, Sa(T1) was computed at a mid-point value of the Vs30 range for the corresponding site class. In NBCC 2020, Sa(T1) is computed at the lower-bound value of Vs30, leading to higher apparent accelerations for the same site class. This change in definition means that the increases reported in **Table 9** may be slightly larger than expected if the Vs30 is measured, which may be standard practice for new construction projects.

The increase in seismic forces of around 70% in NBCC 2020 may increase the structural GWP of the lateral systems explored in this study by around 5-6% for the low-rise steel buildings in this study. This correlates to an expected increase in total GWP of around 4%. The GWP of foundations supporting the lateral force resisting system will also increase. The average contribution of the LFRS foundations to the structural GWP is around 5%. Therefore, it is expected that the increase in foundations required for the NBCC 2020 seismic requirements would further increase the structural GWP by around 3-4%. This correlates to an expected increase in total GWP of around 3%. Combining the LFRS and its foundations, the NBCC 2020 seismic changes may increase the total GWP of low-rise steel buildings in regions of moderate seismicity by around 7%.

# Comparison of CLT and steel floor systems

The GWP is reduced by around 3% from the baseline for the CLT option of the NW Health Campus, this comparison is shown in **Figure 9a**. Although the A1-A3 GWP per unit of CLT is significantly lower than steel decks, there is significantly more CLT required due to the thickness of the 175 mm CLT floor panel. This underscores the importance of comparing systems through a wbLCA rather than looking at the EPDs alone. Furthermore, the concrete topping required for serviceability of the CLT floor system does not lead to an appreciable reduction in concrete and reinforcing quantities. For instance, in **Figure 9**, approximately half of the floor GWP is due to CLT and half due to the concrete topping. However, note that further reductions in GWP for the CLT scenario may be realized if the structure was designed with a CLT floor system rather than a steel floor system starting from the concept design phase. This is because the optimal CLT panel layout depends on the beam/column layout. Note that this would also have a strong influence on the cost of the CLT option, although it was not studied in this project. Therefore, the carbon reduction for the CLT option in this study should be treated as the minimum reduction expected (i.e., there may be greater carbon savings with a mass timber system if it was designed from concept) . Notwithstanding, the results of this study imply that replacing a steel floor system with a mass timber floor system would not be solely sufficient to achieve relative GWP reductions specified in Canadian municipalities.

Material reuse, recovery and recycling, although outside the scope of typical wbLCA reports, may be an important consideration when comparing different material options. Phase D of the wbLCA indicates benefits and loads beyond the system boundary associated with reuse, recovery and recycling. The values reported in **Table 11** indicate that around 20% of the structural GWP is recovered in phase D for the baseline NW Health Campus. The benefit is solely due to structural steel materials. The same phase D value is around 60% for the CLT option, this increase over the baseline is because timber materials provide greater potential for benefits outside the system boundary compared to steel materials. Therefore, steel materials appear to provide greater reuse, recovery and recyclability compared to concrete materials, and timber materials appear to provide a larger benefit over steel materials. A more detailed study is required to investigate this topic in detail.

# Conclusion

RJC has undertaken a comprehensive study on the embodied carbon impact of typical low-rise steel buildings in regions of low- to -moderate seismicity within Canada. This study investigated five projects that were enumerated in **Table 1**. Structural quantities were computed for all five projects and the envelope quantities were computed for the four projects that have been constructed. Three scenarios were investigated in this study: the baseline scenario using Canadian and North American industry average environmental product declarations (EPDs); Scenario 1, a lowest carbon, or “best-case” scenario, assumed the best-in-class steel products were available for each project; and Scenario 2, a “basic oxygen furnace” scenario, assumed the hot-rolled steel sections were sourced from a producer using a basic oxygen furnace process. The quantity and embodied carbon results were presented in tables and graphs. A discussion on the key topics of interest followed.

Note that all these conclusions are in the context of the five low-rise steel buildings studied in this report. Therefore, these conclusions are based on limited data. The authors recommend that similar additional data is collected in the future. Notwithstanding, the following main conclusions are made from the results and discussion:

- Low-rise steel buildings should be expected to satisfy municipal embodied carbon limits if a reasonable effort is made to source low-carbon materials. The baseline embodied carbon met the Toronto Green Standard limit for Tier 2 (TGS-2) for all but one project. In all cases, TGS-2 could be met by using carbon-efficient steel products.
- The choice of area metric (e.g., with or without underground parking) has a significant impact on the reported results when there are large underground parking structures. All partners (e.g., structural engineers, architects, clients, etc.) involved in building projects should be aware of the different area definitions and how they apply.
- Open-web steel joist (OWSJ) systems appear to be a more carbon efficient alternative to hot-rolled steel beams when used in flooring systems. Therefore, OWSJ systems may be preferred to reduce embodied carbon, architectural constraints notwithstanding.
- The upfront embodied carbon, represented by the A1-A5 wbLCA phases, accounts for around 90% of the total embodied carbon in a project. Furthermore, the structural embodied carbon is approximately 75% of the total embodied carbon. These results reinforce the idea that, to the fullest extent possible, retrofitting existing structural systems and reusing structural materials should be preferred over new construction to reduce embodied carbon.
- On average, approximately 50% of the total baseline structural embodied carbon was due to structural steel, while the remaining 50% was due to concrete. Of the structural steel elements, hot-rolled steel sections were consistently the highest contributor to global warming potential (GWP), followed by steel decks. Therefore, hot-rolled steel members and steel decks represent the two highest priority items to consider when selecting carbon efficient materials in low-rise steel buildings.
- In a lowest carbon scenario (Scenario 1 in this study), the maximum overall reduction in GWP by selecting carbon efficient steel products is expected to be around 17%. This reduction may be even greater if carbon efficient concrete materials are selected as well. Regardless, a 17% reduction from the baseline brought most of the projects below the strictest embodied carbon limits examined in this study. Therefore, low-rise steel buildings appear to be a promising structural solution to meet the current embodied carbon limits in Canada if carbon efficient materials are sourced for the project.

- It does not appear to be likely to meet strict embodied carbon targets when sourcing steel from solely producers that utilize basic oxygen furnaces.
- Replacing a composite steel floor system with a CLT floor system for one example in this study indicated an embodied carbon reduction of around 3% from the baseline. However, greater reductions in embodied carbon may be realized if the building was designed from the schematic phase with a CLT system in mind. The GWP benefits from phase D of the wbLCA indicate that steel has greater potential for reuse, recovery and recyclability than concrete; and that mass timber products have greater potential than steel.
- The NBCC 2020 seismic provisions are likely to increase the GWP reported in this study. Since lateral force resisting elements make up a minority of the overall structural GWP, even a large increase in seismic force will have a tempered impact on the overall GWP. The increase in total GWP is estimated to be on the order of around 7% for typical low-rise steel buildings in regions of low- to moderate- seismicity in Canada.

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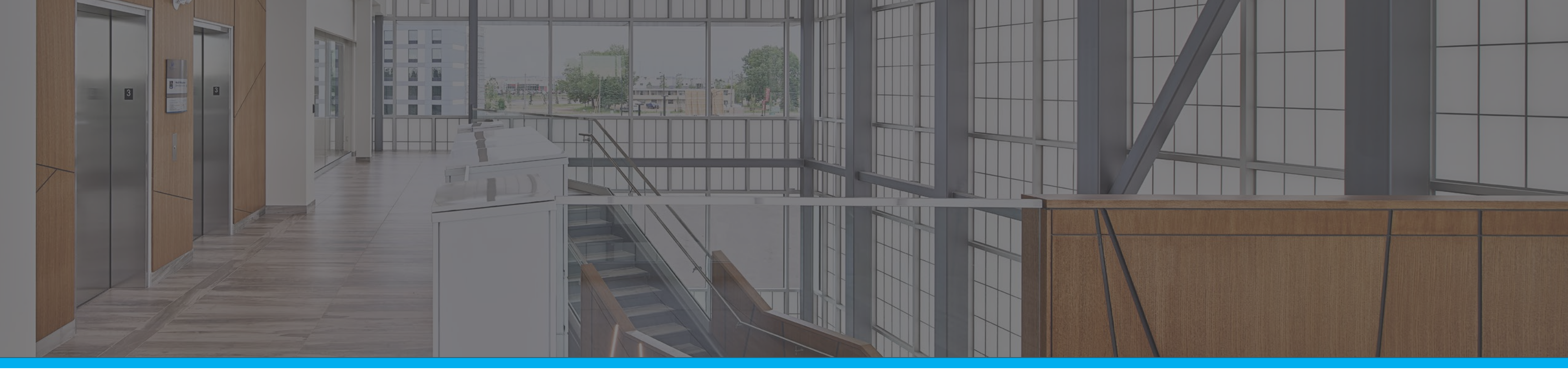


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