Net Zero Carbon Construction

Insights from the TD Future Cities Centre's Net Zero Carbon Redevelopment

Executive Summary + Technical Report
September 2020

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EVERGREEN

LOW CARBON AGENDA

Civil & Mineral Engineering
UNIVERSITY OF TORONTO

Table of Contents

Note: This report and its contents are the opinion of the project partners and in no way represent the views of the Ontario government or the Ontario Ministry of Training, Colleges and Universities.

Key Terms

Carbon offset: a reduction of greenhouse gas emissions purchased to offset emissions produced elsewhere.

Embodied carbon: the carbon associated with material harvesting, manufacture, transport, construction, maintenance and ultimate end-of-life, including recycling or landfilling of building materials and construction activities.

Environmental product declarations (EPDs): reports created by some product and material manufacturers that summarize the LCA-based environment impact of their products, including their embodied carbon. EPDs can be industry average (e.g., for “typical” Canadian concrete) or facility-specific (e.g., for a specific concrete mix from a specific facility).

LCA core materials scope: common LCA practice – including LEED and Zero Carbon Building (ZCB) Standard – to include only the building structure and envelope. This focuses effort on the materials that are typically used in the largest quantities, have the largest combined environmental impact, and are least likely to be replaced.

LCA expanded materials scope: materials used on the project that are not included in the typical core materials scope. This includes things like: non-structural walls and partitions; floor and ceiling finishes (e.g., carpets, tiles, gypsum/drywall and ceiling tiles); mechanical, plumbing and electrical systems; excavation; parking lots; and site work.

Leadership in Energy and Environmental Design (LEED): the most widely used green building rating system in the world. It sets out best practices in green building design. The newest version (v4) includes LCA.

Life cycle assessment (LCA): the accounting method used to estimate embodied carbon (among other environmental impacts). LCA typically presents carbon using the term “global warming potential” (GWP) of the greenhouse gases associated with a project. This is typically measured in units of kg (kilograms) or t (tonnes) of CO_2e (carbon dioxide equivalent).

Net zero carbon/carbon neutral: net zero carbon emissions achieved by balancing the measured amount of carbon released with an equivalent amount sequestered or offset, to make up the difference.

Operational carbon: the carbon associated with the ongoing use of a building such as heating, cooling and plug loads.

Whole-life carbon: all carbon associated with a project or activity. The sum of embodied carbon and operational carbon.

Executive Summary

When it comes to creating lower-carbon construction, does the building industry have a blind spot?

We know how much energy it takes to operate a building, but not so much about the emissions associated with all other stages of a building's life cycle such as construction material manufacture and transportation, building maintenance/rehabilitation, and end-of-life decommissioning. Most building designers have no idea how much carbon is emitted in those areas, let alone how to take actions to reduce it.

For a model of true sustainable development, consider the TD Future Cities Centre located at Evergreen Brick Works, in Toronto's Don Valley. There, the historic Kiln Building has been transformed. It has become a demonstration hub for piloting and scaling projects that push the boundaries in low-carbon city building and create vibrant community spaces. The TD Future Cities Centre demonstrates what's possible when you take a holistic view towards creating a carbon-neutral construction project.

For decades, the Ontario Building Code has included minimum energy efficiency requirements for buildings. These have become stricter with each subsequent update. Thanks to this, buildings are now designed and operated to use significantly less energy than ever.

This shift has focused on operating energy. That's the carbon[1] emitted from the energy tied to a building's day-to-day operations. The source of these emissions typically includes energy used for heating, cooling, lighting, ventilation, pumps and plug loads.

This reduction of operational energy is welcome. It must continue. But it represents only part of the energy and carbon associated with our buildings.

Think of the emissions generated from all other stages of a building's life cycle: raw material extraction, manufacture, transportation, construction activities, rehabilitation, maintenance, and end-of-life processes (such as disassembly, recycling and landfilling). All of that falls under another label: embodied carbon. And guess what? There are no embodied carbon requirements in the Ontario Building Code.

[1] Carbon is referenced throughout the report as a proxy for global warming potential (GWP), the aggregate of the various greenhouse gases (carbon dioxide, methane, nitrous oxides, etc.), as presented in tonnes of carbon dioxide equivalent (t CO_2e).

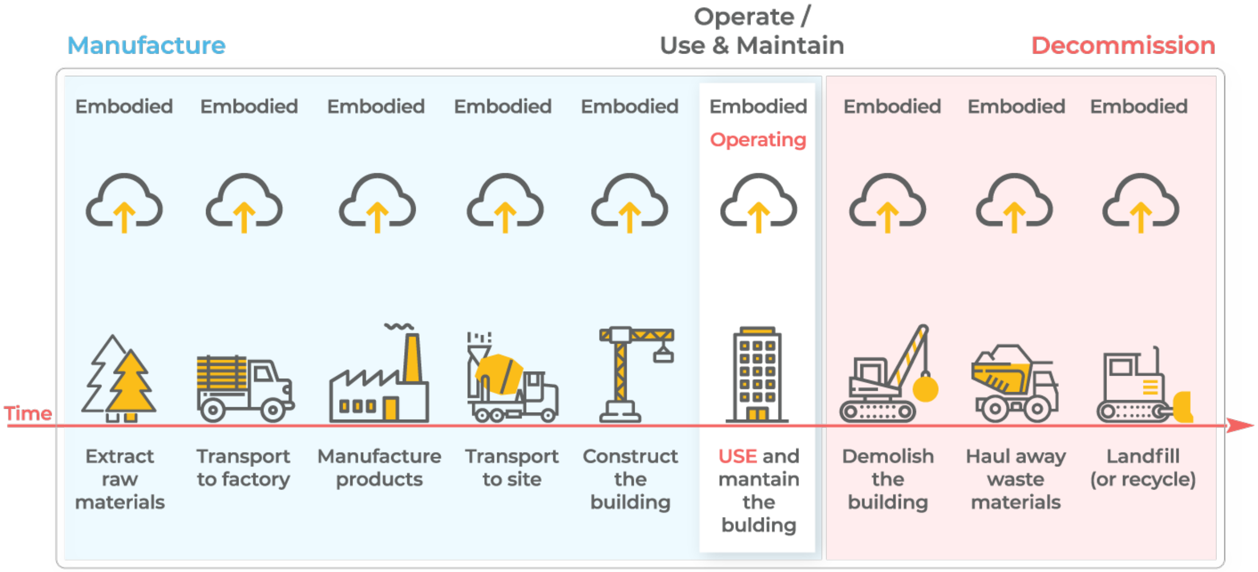

Figure 1: Building life cycle stages and associated types of carbon emissions

As operational energy use (and carbon) from new construction drops over time through increased building code energy efficiency requirements, embodied carbon is becoming an increasingly dominant source of building emissions. Yet embodied carbon remains mostly unmeasured and unmanaged. That leaves a lot of carbon "on the table".

Not at the TD Future Cities Centre.

For almost a century, the Don Valley Brick Works was Canada's foremost brickyard. After closing, the City of Toronto and the Toronto Region Conservation Authority expropriated the site for public use. Evergreen is a national not-for-profit transforming communities across Canada to be more livable, green and prosperous. In 2010, Evergreen Brick Works opened its doors to the public for the first time after a major revitalization project that transformed the 16 historic factory buildings into a year-round hub as a vibrant public space, example of leading-edge green technologies and demonstration centre to test and scale ideas that fuel low carbon cities across Canada.

The redeveloped Building 16, also known as the Kiln Building, will now serve as a hub connecting various sectors to the evolving challenges and opportunities facing cities.

Another challenge was central to the new TD Future Cities Centre: helping to uncover and share strategies to realize lower-carbon construction. Future Cities Canada's recent report, *Building Canada's Low-Carbon Approach to*

Infrastructure Investments through Prioritization, Policy and Procurement, digs into this important issue from a policy perspective. It provides the foundation for the work and analysis presented here. The insights gained on this project will lead to a better understanding of how to reduce embodied carbon in construction.

What we have learned from the TD Future Cities Centre can also serve investors who are trying to reduce the carbon footprint of their portfolio, and are investing in real estate and infrastructure. For those investing in real estate and infrastructure, focusing on energy efficiency or green building certifications (like LEED) alone is not enough. Those are no longer best practices. Construction should reuse existing buildings/materials where possible, and aim to be carbon-neutral, targeting both operational and embodied carbon.

Estimating embodied carbon

Despite the increasing importance of embodied carbon, most players in the building industry do not yet understand it well. Nor is it regulated or included in most zero-carbon frameworks.

Why? Operational carbon is easy; just look at your energy bill. With embodied carbon, you must drill deeper. A lot more players are involved, and not as much data is available.

Consider all of the elements. There is the source of raw materials and the manufacturing process. The distance and mode of transportation between those stages and the final construction site. The construction process at the project site. The amount of recycled content in each material and product. The frequency of building system maintenance and replacements, such as windows, roofing, carpet and solar panels (among many more). And the way in which materials are recycled or landfilled.

When you examine this list for each material in a building, it can easily grow to thousands of separate data points. For this reason, a building operator cannot easily calculate their embodied carbon like they can their operating carbon.

However, there is an accounting approach to do just that. It is called a life cycle assessment (LCA). An LCA typically includes an assessment of life-cycle carbon based on global warming potential (GWP) of the greenhouse gases associated with a project. In this case, the Brick Works project estimated the carbon associated with the:

- harvest, transport, and manufacture of materials;
- transportation of materials to the project site;
- on-site construction processes;
- replacement of major building systems; and
- building end-of-life (deconstruction, transport, processing, disposal).

The project also accounted for carbon savings associated with reusing existing building materials. We included more materials than a typical embodied carbon assessment, which is normally limited to structural and envelope materials only.

Carrying out this ambitious project involved five partners:

1. Evergreen, which set out to create a carbon-neutral redevelopment.
2. EllisDon, the construction team and LCA research partner.
3. The University of Toronto's Department of Civil and Mineral Engineering, which took the lead on embodied carbon/LCA research where required.
4. Mantle314 (formerly Zizzo Strategy), which served as the main embodied carbon/LCA consultant and coordinator.
5. Government of Ontario, which funded the project.

The partners hosted a full-day workshop for the building design and construction industry. It covered the importance of embodied carbon, introduced LCA and how to perform one, and presented the TD Future Cities Centre case study. The goal was to provide practical training and resources on how future construction projects can minimize their emissions including by using often overlooked or not well understood strategies, using one of Canada's most innovative examples.

To learn more, check the presentation slide deck, as well as the sessions that were recorded and uploaded to Evergreen's YouTube channel.

Cutting embodied carbon in half

The existing historic structure that was rehabilitated is a one-storey building with an area of 4,960 m^2 (53,000 sq ft), making it by far the largest building on the site. To meet the goal of carbon neutrality, Evergreen has employed the following measures:

- Roof-mounted solar thermal panels integrated with the geoexchange field, to collect, use and store heat seasonally.

- The radiant floor and two large heat pumps linked to the geo-solar system, as the primary means of heating and cooling.
- High performance glazing and natural ventilation, to minimize heating and cooling loads.
- Innovative flooring substrate to provide 20 times higher insulation than regular substrate, minimizing winter heating.
- Lower embodied carbon concrete for the flooring, resulting in a 50% reduction of concrete-related CO_2 emissions.
- A unique raised cavity floor system called Cupolex®, to minimize concrete required.
- New classroom spaces designed with low-carbon cross laminated timber (CLT), a form of mass timber.

The result? The project team found this project to result in 1,044 tonnes of carbon dioxide equivalent (t CO_2e). This value can be expressed, on a per-square metre basis, as 215 kg CO_2e/m^2.

Meanwhile, the amount of carbon avoided due to the reused historic materials was estimated at 979 t CO_2e. Put another way, the project was estimated to have cut its total embodied carbon impact in half against a baseline of demolition and rebuilding, by reusing the historic structure. The amount saved was approximately equivalent to the annual emissions of 47 single family homes in Toronto.

We need large carbon reductions in a very short timeframe

Such progress is urgently needed. Electricity grids and fuels are becoming lower carbon over time. As this shift continues, electricity efficiency will have diminishing returns on carbon reductions. Therefore, government policies should expand to require higher efficiencies in other areas, outside of electricity, such as heating fuel use and embodied carbon of construction materials.

A typical building's whole-life carbon has changed significantly over the past few decades. Numerous LCA studies[2] have shown that an average building in the past had a carbon profile, over a typical 60-year life cycle, similar to this graph on the next page:

[2] http://www.athenasmi.org/resources/publications/

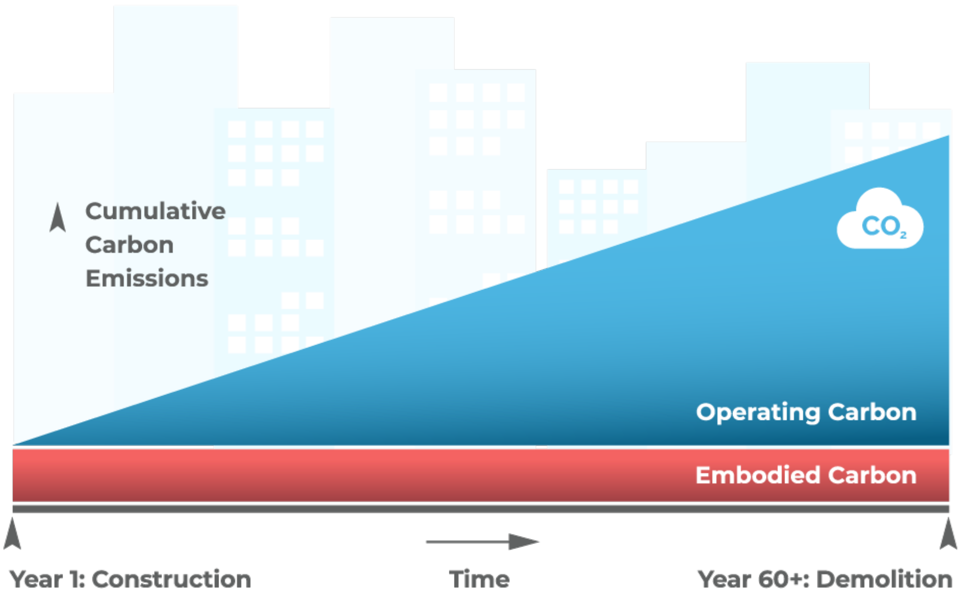

Figure 2: Whole-life carbon for a typical building in the past

In contrast, high-efficiency buildings of today have a carbon profile similar to this.

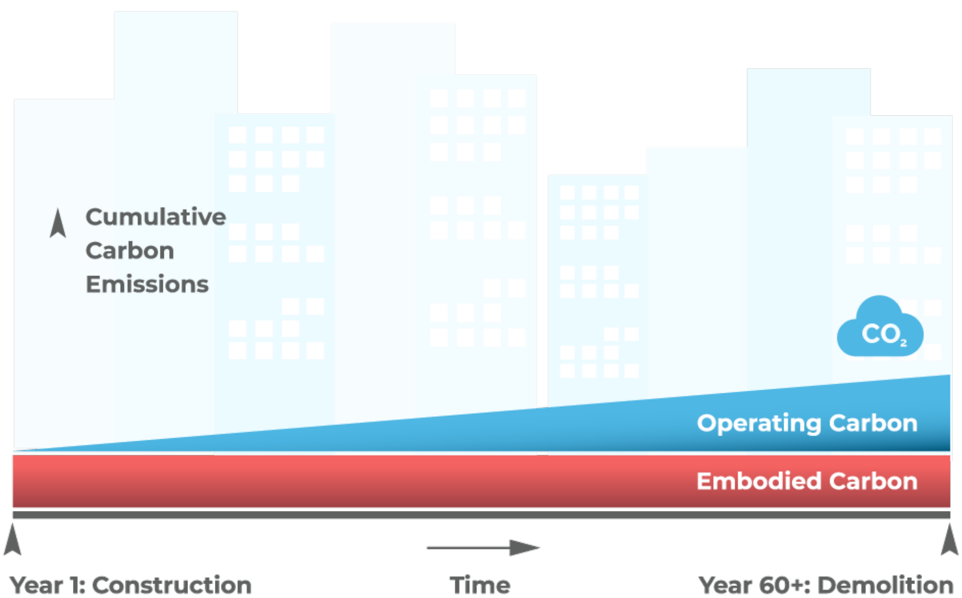

Figure 3: Whole-life carbon for a high-performance building built today

As our buildings use less operating energy, and our electricity grids decarbonize, the carbon associated with operating our new buildings has shrunk dramatically. This clearly shows why embodied carbon has been increasing in importance. However, the most startling argument for embodied carbon reductions comes when we consider shorter timeframes than the typical 60-year lifespan of a building considered in most LCA studies.

A report released by the UN[3] noted that we have roughly 12 years in which to significantly reduce our emissions before catastrophic climate change becomes unavoidable. What happens if we only consider the first 12 years?

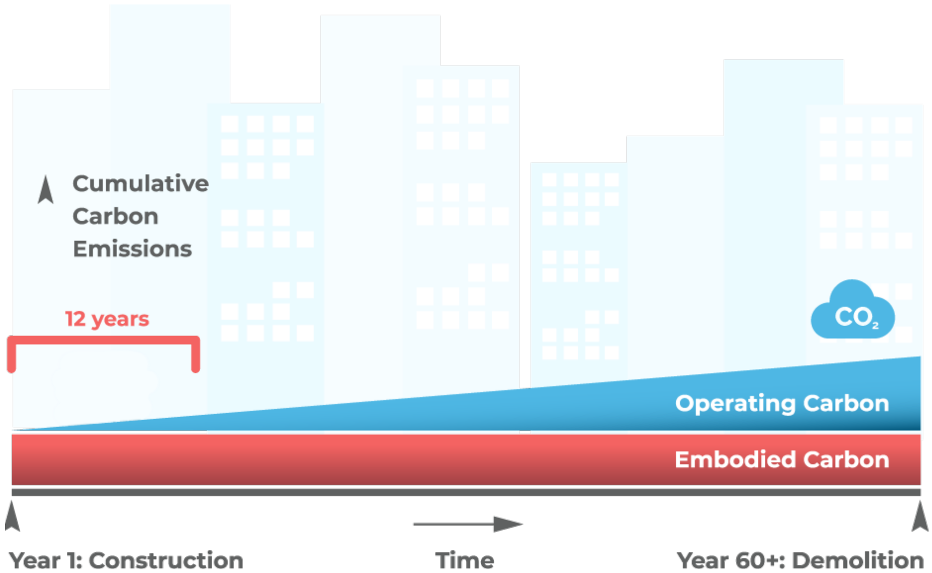

Figure 4: Whole-life carbon for a high-performance new building, highlighting a 12-year window

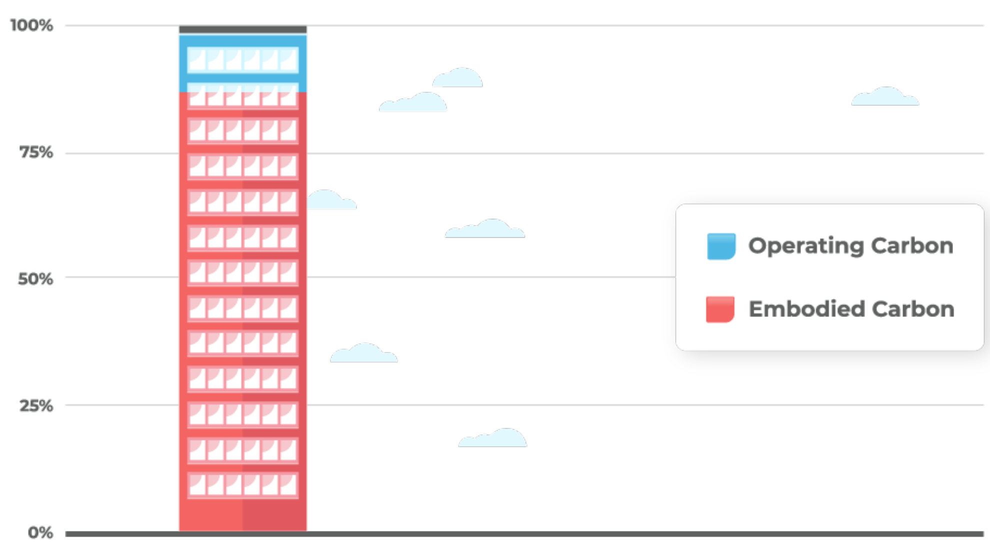

Figure 5: Cumulative carbon from new high-performance construction over 12 years

[3] https://www.ipcc.ch/report/sr15/

Over the next 12 years, most of the carbon that will be emitted from new construction will come from embodied sources. What we do in these 12 years is critical.

When we consider this shorter time-scale, significantly more carbon is emitted to *create* new buildings than to *operate* them. Yet nearly all our reduction efforts are currently focused on the latter.

Society's recent focus on driving down operating carbon through electricity efficiency, and the greening of our energy grid, must rapidly evolve and expand. We need these efforts to include embodied carbon of materials if we want to avoid catastrophic climate change.

De-carbonization efforts must include industry, and the creation, transport, install, maintenance and decommissioning of construction materials. Material manufacturers and industries that fail to evolve their business risk being left behind.

Lessons learned

The renovation of the Kiln Building and creation of the TD Future Cities Centre offer several lessons for designers and construction teams.

- **Expand the scope.** Renovation projects may wish to expand their LCA scope to include materials not typically covered by new construction LCA, such as non-structural walls and partitions, mechanical equipment, plumbing, and finishes. These materials accounted for 37% of the embodied carbon calculated in this project. They would normally be omitted when following a standard LCA practice, meaning the true carbon footprint of a project is often significantly under-represented.

Table 1: Major source of embodied carbon by construction scope

Construction scope	Most likely dominant source of embodied carbon
New construction	• Structure • Envelope
Renovation	• Envelope (if replaced) • Non-structural walls and partitions • Mechanical equipment and plumbing • Finishes

- **Focus on finding lower-carbon alternatives for a small number of high-impact materials.** That will efficiently reduce embodied carbon. Most embodied carbon are from a small number of high-impact materials. In this project, four materials/components accounted for 80% of the total embodied carbon over the life cycle: concrete, steel, solar panels, and plastic. Each of these accounted for more emissions than the transportation of all materials to the site, and the on-site energy used during construction, combined.

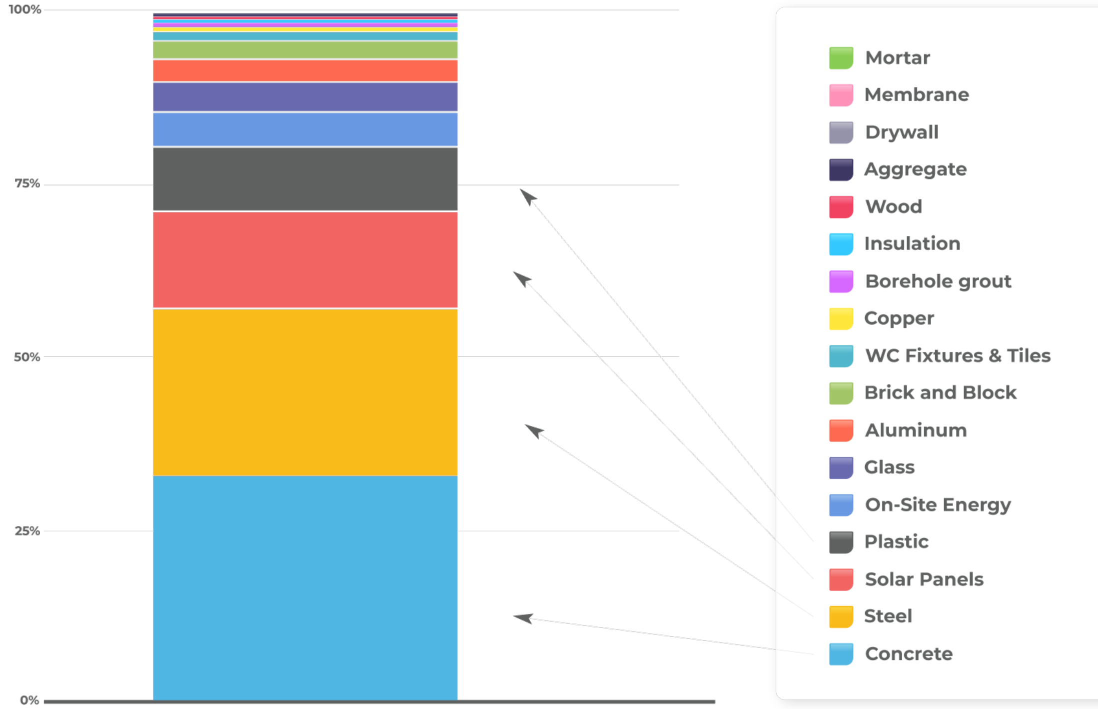

Figure 6: Relative GWP impact per material/component

- **Focus on sourcing efficiently manufactured materials rather than on local, low maintenance or low end-of-life-impact materials.** Raw material harvest and manufacture is by far the dominant source of emissions, accounting for roughly 75% of the total life cycle carbon footprint.

- **Clarify the LCA scope.** That is especially true if you're including material deliveries/transportation, construction energy and operational energy. If so, will they be tracked on-site, or estimated using LCA software or other sources? It's recommended to report operational carbon alongside embodied carbon, and not to combine the two.

- **Make requirements clear.** Include requirements for low-carbon materials in project specifications. Request environmental product declarations (EPDs) from all suppliers of major materials. That includes structural and envelope materials (e.g. concrete, steel, wood, aluminum, masonry, glass, insulation, etc.) plus major finishes (e.g. carpets, gypsum, ceiling tiles, flooring, etc.). Even if EPDs are not yet available, requesting this information will encourage the market to develop more of them by signalling demand. Push your supply chain for lower-carbon options and more disclosure of their carbon impact.

- **Follow an LCA standard.** That includes ISO 14044 or the guidance associated with the LCA approach in an established green building system, e.g. LEED v4 or the Canada Green Building Council's Zero Carbon Building Standard.

- **Establish a clear information tracking sheet.** It should outline the required information for the LCA. Share this with the project manager, who can then help determine from whom and when to obtain each piece of information. You can perform a preliminary LCA early in design using estimates that can help inform the design progression towards lower-carbon options, and update it as better information becomes available.
- **Consider establishing processes to easily track on-site carbon impacts.** That includes tracking quantity of deliveries (e.g. concrete pour records, delivery waybills for key materials like steel and masonry, etc.), and energy consumption (e.g. through centralized fuel storage and tracking, and electricity and water submetering for construction works).

- **Offset your carbon.** Consider purchasing high-quality third-party certified carbon offsets for the embodied carbon calculated for the project. This can be an important part of a carbon-neutral strategy.

By understanding, quantifying, reducing and offsetting your project's embodied carbon, we can move towards a lower-carbon – and eventually a carbon-free – built environment.

PART 1 – EMBODIED CARBON AND LIFE CYCLE ASSESSMENT

1 Introduction

1.1 What is embodied carbon?

Carbon is referenced throughout the report as a proxy for global warming potential (GWP). That is the aggregate of the various greenhouse gases (carbon dioxide, methane, nitrous oxides, etc.), as presented in tonnes of carbon dioxide equivalent (t CO_2e).

Carbon emissions associated with buildings can mostly be categorized in two ways:

1. Operational carbon emissions associated with the day-to-day operation or use of a building. The sources typically include energy used for heating, cooling, lighting, ventilation, pumps and plug loads such as appliances.

2. Embodied carbon emissions from all other stages of a building's life cycle. These stages, illustrated in Figure 7, include: raw material extraction; manufacture; transportation; construction activities; rehabilitation; maintenance; and end-of-life processes such as disassembly, recycling and landfilling.

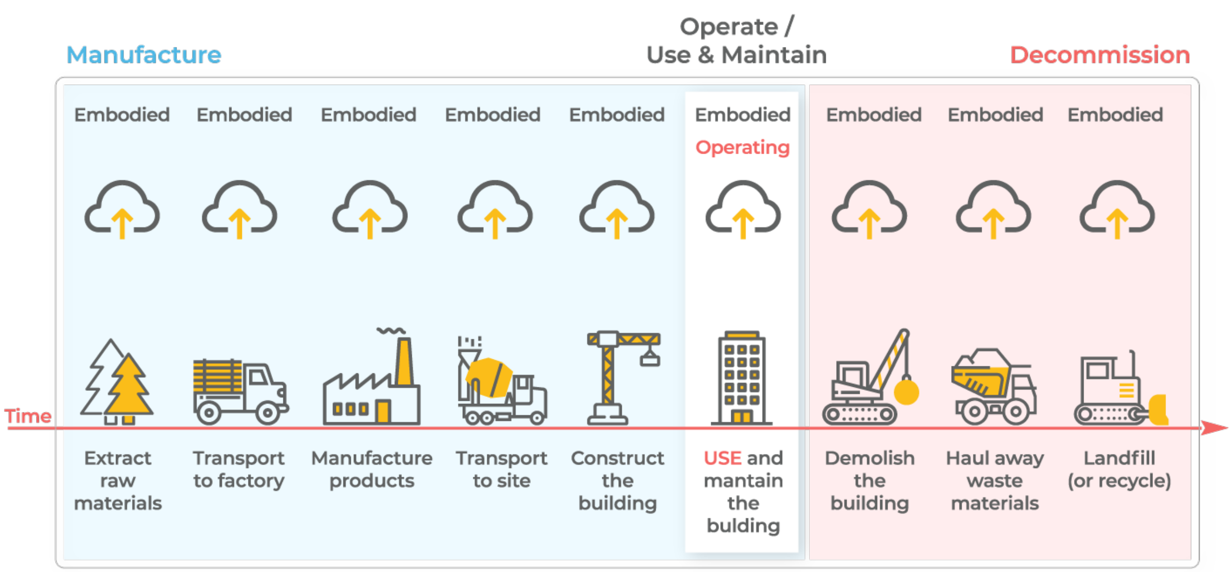

Figure 7: Illustration of the building life cycle stages and the associated types of carbon emissions

Operational carbon reductions have resulted from the increasing effort to measure, manage and minimize operating energy over the past decades. Unfortunately, embodied carbon emissions have mostly been ignored. Yet only when both categories of carbon emissions are considered do we have a true picture of the carbon associated with buildings. This is called whole-life carbon.

1.2 The growing importance of embodied carbon

Future Cities Canada's recent report, *Building Canada's Low-Carbon Approach to Infrastructure Investments through Prioritization, Policy and Procurement*, digs into this important issue from a policy perspective. It provides the foundation for the work and analysis presented here. The insights and guidance help designers and construction teams to better understand and reduce embodied carbon on new construction and renovation projects.

The focus on embodied carbon has been growing significantly over the past few years, a trend which is expected to accelerate. There are three key reasons for this.

Whole-life carbon =
operational carbon + embodied carbon

1) Buildings are becoming more energy efficient

In the past, buildings were not typically designed or operated with a strong focus on energy efficiency. However, we have increasingly recognized the importance of energy efficiency, to a point where it is now a critical issue to the building industry and governments around the world.

The Ontario Building Code began introducing energy efficiency requirements for buildings in 1993, and has made these requirements stricter with each subsequent update. Thanks to this gradual shift, buildings are now designed and operated to use significantly less energy than ever before.

However, this shift has been mostly limited to operational energy. The reduction of operational energy is welcome and must continue. However, it's only part of the energy associated with our buildings. That has left embodied energy to be largely unmeasured and unmanaged.

As operational energy use drops over time through increased efficiency, embodied energy remains essentially unaddressed. As a result, embodied carbon is becoming an increasingly dominant source of building emissions (Figure 8).

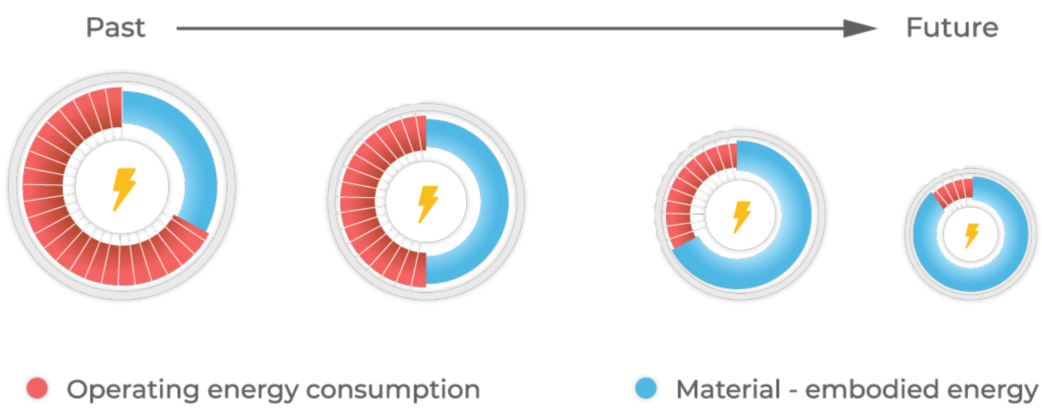

Figure 8: Operational and embodied energy relative change over time

2) Energy is becoming lower carbon

One of the main drivers for energy efficiency is to reduce greenhouse gas emissions associated with energy produced from fossil fuels, which cause pollution and climate change. Governments around the world are now moving to not only regulate and reduce energy consumption, but also directly limit carbon emissions.

As part of this shift, electricity grids and fuels (where possible) are becoming lower carbon. How? By decommissioning carbon-intensive coal-fired power plants and investing in renewable energy sources like solar panels, wind turbines, biofuels and other technologies.

This shift means a given unit of energy is typically becoming less carbon intensive over time. For example, since Ontario phased-out coal-fired power plants, its electricity is quite low-carbon compared to most regions around the world. Similarly, Quebec and British Columbia have very low-carbon grids, due to their reliance on hydro power to generate electricity.

In these regions, efforts to reduce electricity consumption – the focus of significant government policy and incentives – already have relatively little impact on reducing carbon emissions. As this shift continues, electricity efficiency will have diminishing returns on carbon reductions. Therefore, government policies should require higher efficiencies in other areas, such as heating fuel use and embodied carbon of materials.

Because of more energy-efficient buildings and lower-carbon energy, a building's whole-life carbon has changed significantly over the past few decades.

- Numerous LCA studies[4] have shown that in the past a typical building had a carbon profile – over a typical 60-year life cycle – similar to that shown in Figure 9. In contrast today's high-efficiency buildings have a carbon profile similar to the one shown in Figure 10.

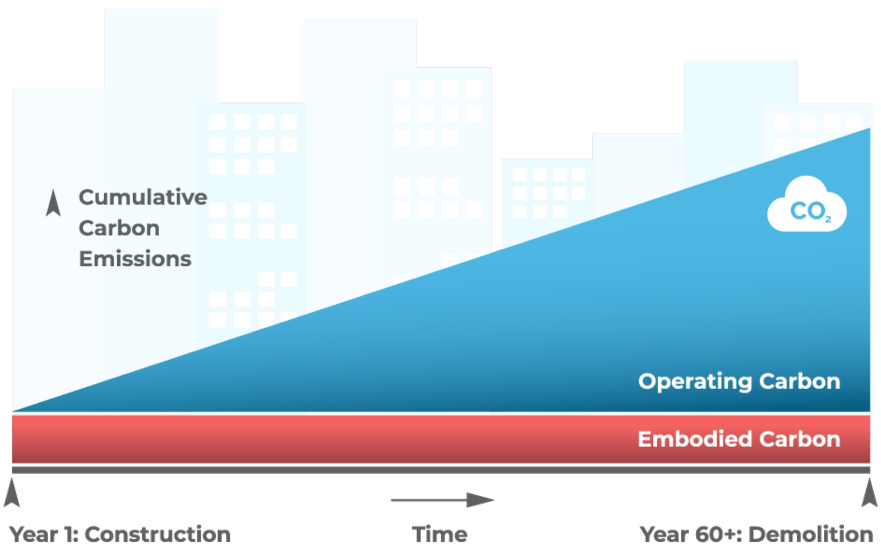

Figure 9: Whole-life carbon for a typical building in the past

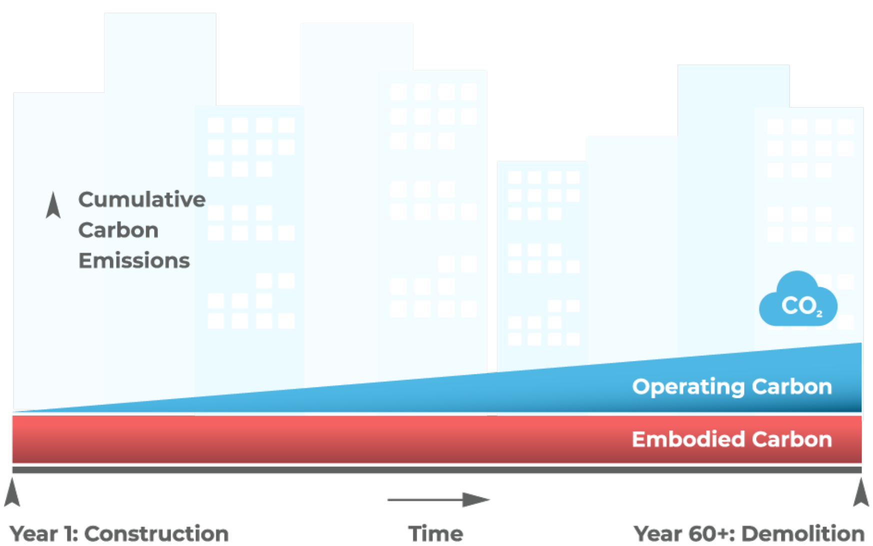

Figure 10: Whole-life carbon for a high-performance building built today

[4] http://www.athenasmi.org/resources/publications/

The comparison shows why embodied carbon has increased in importance. However, the most startling argument for embodied carbon reductions comes when we consider shorter timeframes than a building's typical 60-year lifespan.

3) Large carbon reductions are required in a very short timeframe

A recent report released by the UN[5] noted that we have roughly 12 years to significantly reduce our emissions before catastrophic climate change becomes unavoidable. What happens to Figure 10 if we only consider the first 12 years? This is shown in Figure 11 and Figure 12.

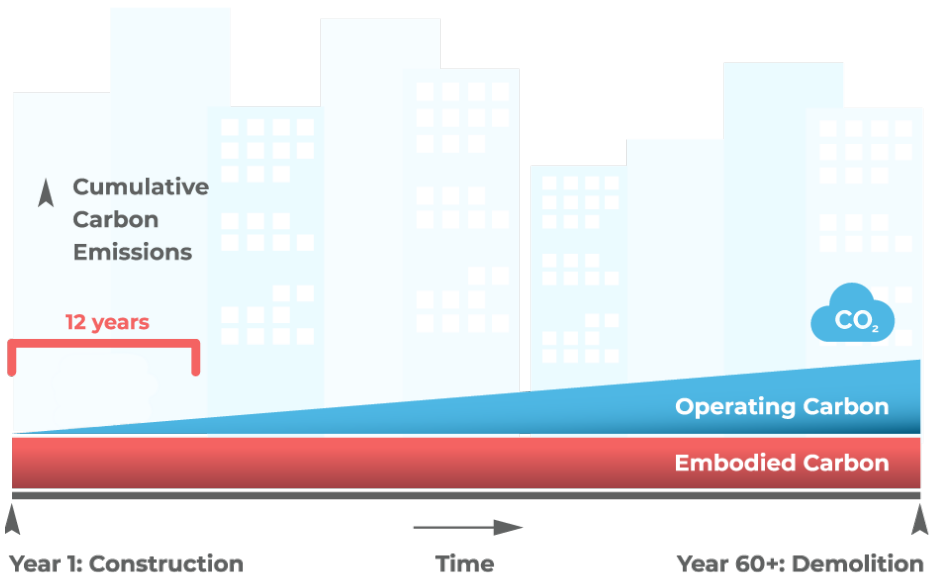

Figure 11: Whole-life carbon for a high-performance building built today – with 12-year window shown

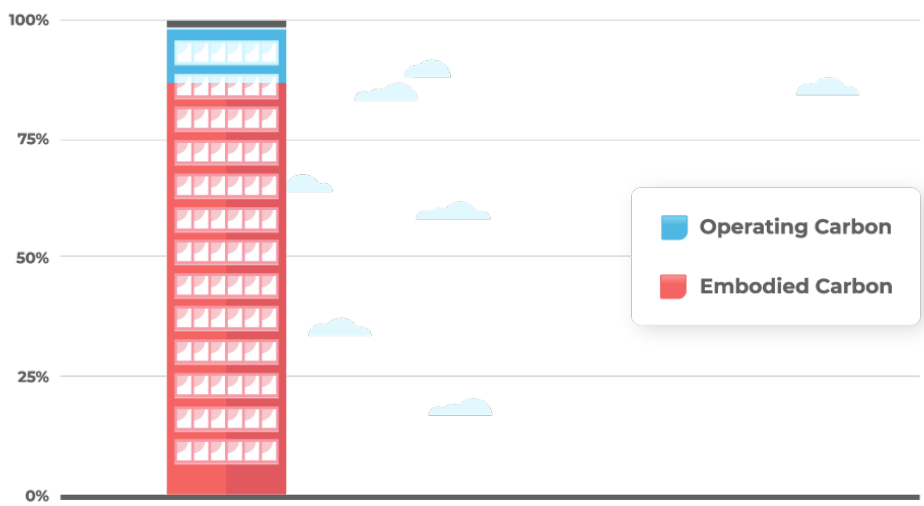

Figure 12: Cumulative carbon from new high-performance building after roughly 12 year[6]

[5] https://www.ipcc.ch/report/sr15/

[6] Architecture 2030

Figure 12 illustrates that most carbon to be emitted from new construction over the next 12 years will come from embodied sources. The carbon emitted to *create* our buildings will be far greater than the amount coming from *operating* them. Yet, most of our reduction efforts are currently aimed at operational carbon.

That's a blind spot for the building industry. We know how much energy it takes to operate a building, but not so much about the emissions associated with all other stages of a building's life cycle like material manufacture, transportation, maintenance, rehabilitation, and decommissioning. Most building designers have no idea how much carbon is emitted in those areas, let alone how to take actions to reduce it.

Society's recent focus on driving down operating carbon through electricity efficiency, and the greening of our energy grid, must rapidly evolve. We must reduce embodied carbon if we want to prevent the worst impacts of climate change.

1.3 Life Cycle Assessment (LCA)

No one system or product is responsible for a building's embodied emissions. Rather, embodied carbon is the sum of hundreds, or even thousands, of separate processes and actions:

- source of raw materials;
- distance from the material manufacturer to the distributor, and finally to the construction site;
- method, and thus carbon intensity, associated with material transportation;
- amount of recycled content in each material and product;
- frequency of building system replacements, such as windows, roofing, carpet, solar panels, and many more; and
- how materials are recycled or landfilled.

A building owner or designer cannot easily calculate their building's embodied carbon like they can operating carbon, by examining their utility bills.

However, there is an accounting approach and associated tools to help quantify embodied carbon – it's called a life cycle assessment (LCA).

Life cycle assessment (LCA) is a methodology to measure embodied carbon. Embodied carbon is all carbon emissions associated with all aspects and timelines of the building and materials, other than operational carbon from energy use.

LCA quantifies the environmental impacts of a material, product, or service over all phases of its life cycle. It considers the impacts from raw material extraction through processing, manufacture, transportation, construction, use, maintenance, refurbishment, disassembly, and ultimate end-of-life (landfill, reuse or recycle).

The building industry can use LCA to determine several different environmental impacts including global warming potential (GWP). GWP can consist of operational and/or embodied carbon, depending on the scope of the study or the project specifics.

Whole-life carbon = operational carbon + embodied carbon.

LCA is a methodology to measure embodied carbon.

2 LCA Scope, Methodology, Data & Assumptions

Projects aiming for carbon neutrality need to minimize both operational and embodied carbon. Designers and procurement teams can use LCA to quantify the embodied carbon emissions of a project, and compare and specify lower-carbon designs and materials.

When performing or interpreting an LCA, it's important to review the following considerations, including the project scope, the methodology (how the analysis is carried out), the data, and what assumptions are applied.

2.1 Life cycle phases & system boundary

LCA considers the whole life cycle of the building. That includes manufacturing, transport, use and final disposal of the resources required for delivering the building functions for the period the LCA covers.

The International Standard ISO 21930 and European Standard EN 15804 both include modular definitions for building life cycle stages (see Figure 13). That makes it easier to compare each stage in isolation with other projects. However, not all LCAs include all these phases. Some phases may not be:

- required by some standards;
- calculated by some software; or
- considered / relevant by some project owners.

Therefore, it is extremely important that any LCA include a clear statement of the system boundary and phases. Stages A1-A5, B1-B7, C1-C4 and D are depicted in Figure 13 below.

The construction material product stage information (A1-A3) is nearly always represented, as it is typically dominant. Most assessments also include the end-of-life stages (C1-C4). Depending on the LCA's purpose, and other limitations (such as software functionality and data availability), other stages are typically omitted or replaced with an estimate.

2.1.1 Operational energy (B6)

When comparing LCA impacts between projects, it is especially important to note if operational energy (B6) is included. Some standards, including LEED, exclude it from building LCAs and approach it separately; other standards require its inclusion in the LCA.[7] This is a critical consideration, since operating energy can be the largest source of carbon emissions for most buildings over their life cycle.

Operational energy use is typically measured and managed separately from the rest of the LCA scope. Requirements on operational energy use of buildings exist in many forms, including building code requirements, so it is often removed from LCA results to avoid double counting. However, that means the LCA results only show embodied carbon, not whole-life carbon.

The Canada Green Building Council (CaGBC) limits their LCA system boundary to *"…resource extraction, product manufacturing and transportation, building construction, product maintenance and replacement, and building demolition/deconstruction/disposal. It does not include the operating energy used by the* building".[8] Operating carbon is considered elsewhere, not in the LCA.

The assessment of the TD Future Cities Centres does not include operational energy (B6) or operational water (B7).

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[7] LEED has different "credits", including for operational energy and whole-building LCA. As such, operational energy is excluded from the LEED LCA scope to avoid double-counting or overlap between credits. It may be beneficial to include operational energy results as part of a non-LEED whole-building LCA, depending on project goals and what the LCA is being used to communicate.

[8] Canada Green Building Council. Zero Carbon Building Standard. Embodied Carbon.

2.1.2 Construction processes (A5)

Due to some ambiguity and inconsistency in the LEED Reference Guide, it is unclear whether construction processes (A5) must be included in LEED-compliant LCAs. Therefore, some "LEED-compliant" LCA tools were designed to include A5, while others were not.

What percentage of a rehabilitation project's carbon footprint comes from construction processes (A5)?

This is one of the primary questions investigated in this project. There is a lack of information on this topic, especially in the Ontario context. EllisDon (the construction team and sustainability consultant on this project) has been working closely with the University of Toronto Department of Civil and Mineral Engineering (UofT) over the last two years to more closely understand this topic and has also appointed an internal working group to quantify and understand the carbon footprint association with their construction processes. This project will provide one data point towards answering this question.

Figure 13 illustrates the various life cycle phases and their standardized labels [A-D]. Phases were either included or excluded for the TD Future Cities Centre as shown, depending on data availability and software functionality.

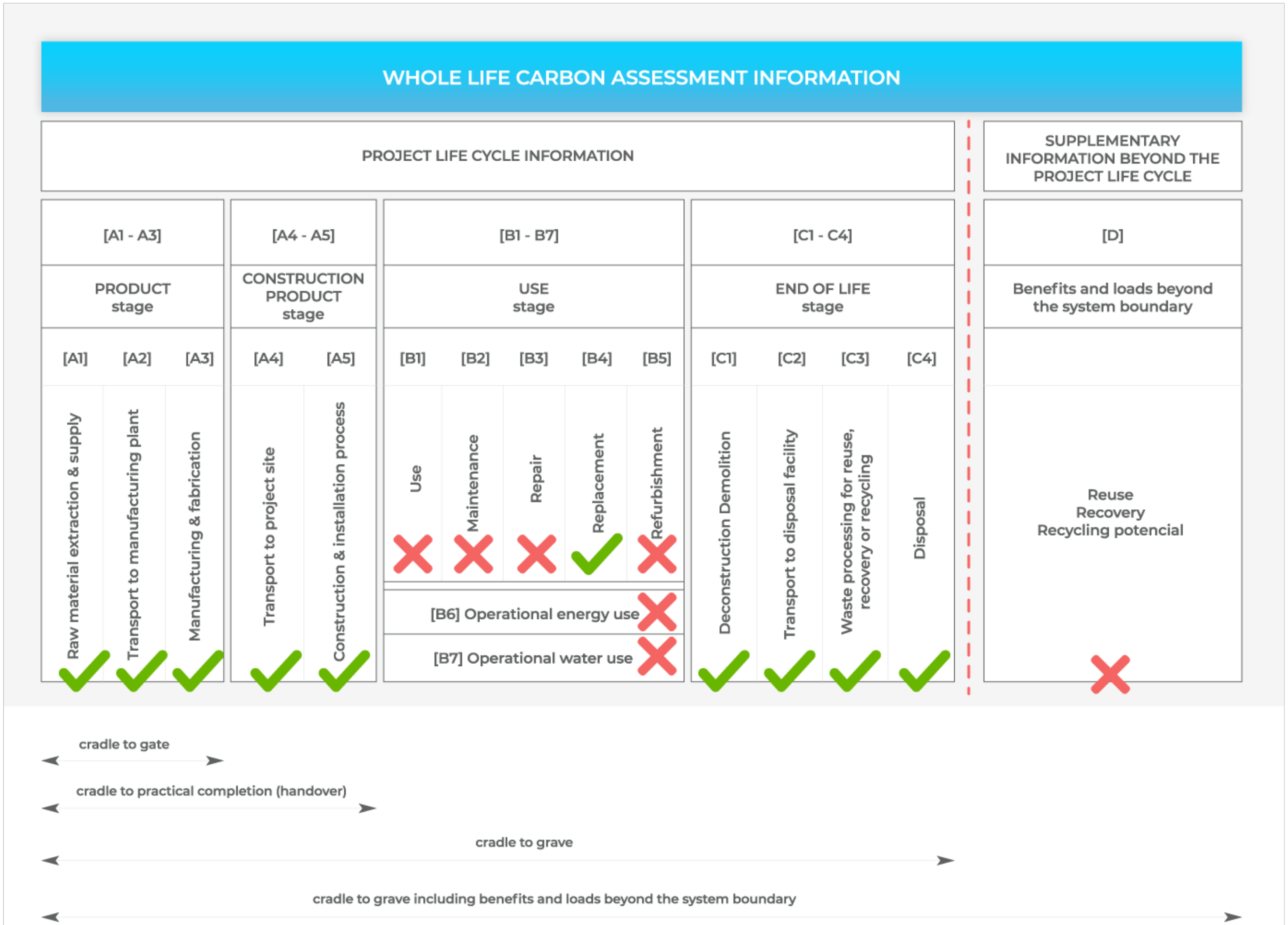

Figure 13: Building life cycle phases (from ISO 21930 and EN 15804)

2.2 LCA Building Material Core Scope

Current common LCA practices (including LEED and the CaGBC ZCB Standard) limit the scope to mainly the building structure and envelope. This focuses effort on the materials that typically are used in the largest quantities, have the largest combined environmental impact, and are least likely to be replaced in future through tenant turnover (like carpet and ceiling tile, for example).

According to CaGBC this means that project teams should include *"all envelope and structural elements (including parking structure), including footings and foundations, and complete structural wall assemblies (from cladding to interior finishes, including basement), structural floors and ceilings (not including finishes), roof assemblies, and stairs construction, but exclude excavation and other site development, partitions, building services (electrical, mechanical, fire detection, alarm systems, elevators, etc.), and parking* lots".[9]

It's clear that the above core scope excludes significant materials and activities.

What is the quantity of emissions that are excluded by focusing on this core scope while ignoring things like finishes, mechanical equipment and site works, among others?

This is another key question that the project team hoped to answer in our assessment of the TD Future Cities Centre.

[9] Canada Green Building Council. Zero Carbon Building Standard. (similar scope to LEED).

PART 2 – CASE STUDY: TD FUTURE CITIES CENTRE

3 Project Overview

3.1 Site History

From 1889 to the 1980s, the Don Valley Brick Works was Canada's foremost brickyard. After closing, the City of Toronto and Toronto Region Conservation Authority (TRCA) expropriated the site for public use, restoring its quarry into the Weston Family Quarry Garden.

Since 1991, Evergreen's focus has been revitalizing the site's 16 historic factory buildings from the early 1900s, and the industrial sheds from the 1950s. Today, Evergreen Brick Works stands as an environmental community centre, with programming that builds on the site's unique geological, industrial and natural heritage[10,11].

3.2 Project Details & Scope of Work

Located at 550 Bayview Avenue in Toronto (Figure 14), the redeveloped building has been known by numerous names including "Building 16" and "The Kiln Building". It has been rechristened the TD Future Cities Centre, to serve as a hub connecting various sectors to the evolving challenges and opportunities facing cities.

Figure 14: TD Future Cities Centre, highlighted on Evergreen Brick Works aerial photo

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[10] http://urbantoronto.ca/database/projects/evergreen-brick-works
[11] https://www.evergreen.ca/about/

Project Team

Evergreen is working in partnership with the following project team:

Table 2: TD Future Cities Centre redevelopment project team

Role	Name
Architect & Design Sustainability Consultant	LGA Architectural Partners
Heritage Consultant	ERA Architects
Structural Engineer	ARUP
Mechanical Engineer	Brookfield GIS
Electrical Engineer	Ianuzziello & Associates
Civil Engineer	SCS Consulting Group
Construction Manager & LCA Research Partner	EllisDon
Project Management	Waverley Projects
LCA Consultant	Mantle314 (formerly Zizzo Strategy)
LCA Research Lead	University of Toronto

Existing Building

The existing historic structure that has been rehabilitated is a one-storey building with an area of 4,960 m^2 (53,000 sq ft), making it by far the largest building on the site (Figure 15). The space, largely untouched since Evergreen took over the property, was an open-air structure without walls on the west elevation of the building. It contains old industrial equipment including kilns (or ovens) for brick firing.

Prior to redevelopment, this space was primarily used as a fair-weather exhibition and event venue, with a capacity of 2,000 people. Since the building was not fully enclosed, and did not include heating or cooling, it severely limited the use and thus value to Evergreen.

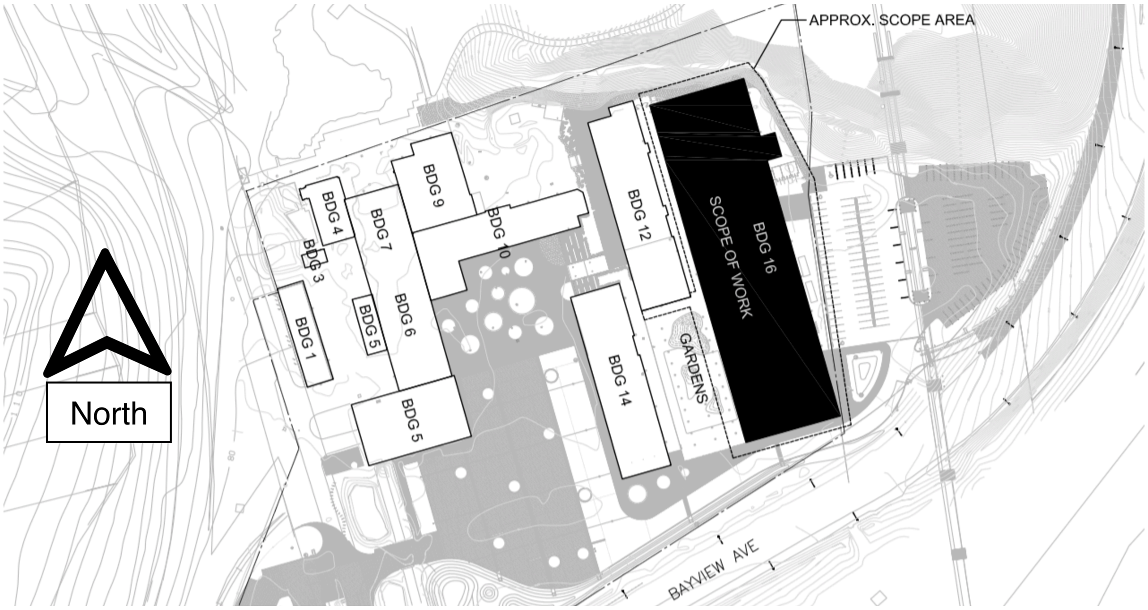

Figure 15: Site plan, highlighting Building 16 scope of work

Objective & Scope of Work

Evergreen and EllisDon set out to create a carbon-neutral building with the redevelopment. This will bring Evergreen closer to its long-term goal of operating the Brick Works as a carbon-neutral campus.

The redevelopment scope of work included:

- New raised cavity flooring system (exposed concrete) with in-floor radiant heating, covering most of the ground level.
- An operable glass wall to enclose the space from the west, allowing views to Koerner Gardens. The wall includes operable openings, allowing the space to be opened in fair weather conditions.
- Multiple new entrances.
- New roofing with operable skylights for cross-ventilation along its length. Roof to be topped with insulation and solar thermal panels.
- A geoexchange/borehole field (40 boreholes each 610 feet deep) expands out at various angles from the space on the east side of the building, between the building and east parking lot.
- Two classrooms/studios constructed out of low-carbon cross laminated timber (CLT) on steel structure with light-gauge metal stud framing, on a newly created second floor level (entirely contained within the high-ceilinged building), This is designed to appear as if they are floating above a portion of the brick kilns. This level will also include an observation area overlooking the kilns below.
- A new Dry Kiln Interpretive Gallery.

- Washroom facilities on the ground floor.
- A new mechanical room outside the building, along the northern end of the east wall, and a new mechanical room additional inside the building along the north end of the west wall.
- Event support room on the ground floor.
- Design to meet current accessibility standards and Ontario Heritage Act requirements.

To meet the goal of carbon neutrality, Evergreen has employed the following measures[12]:

- Roof-mounted solar thermal panels integrated with the geoexchange field to collect, use and store heat seasonally.
- The radiant floor and two large heat pumps linked to the geo-solar system, as the primary means of heating and cooling.
- High-performance glazing and natural ventilation, to minimize heating and cooling loads
- Innovative flooring substrate, to provide 20 times higher insulation than regular substrate, minimizing winter heating.
- Lower-embodied carbon concrete for the flooring, resulting in a 50% reduction of concrete-related CO_2 emissions.
- A unique raised cavity floor system called Cupolex®, to minimize concrete required. Cupolex will also, in combination with low-impact landscape design strategies, support flood and stormwater management, as it helps water, moisture and gases escape from beneath the floor.
- New classroom spaces designed with low-carbon cross laminated timber (CLT), a form of mass timber.

The project followed an accelerated timeline. That limited the low-carbon material analysis and selection, which could have otherwise been done during design. Additionally, material selection was limited by flooding and heritage restrictions. That precluded certain lower-carbon materials from being used, such as high-performance wood curtain wall mullions instead of the aluminum options specified.

3.3 Project Phases

The construction work was subdivided into three phases. The LCA was completed between the second and third stage. Actual measured values

[12] https://www.evergreen.ca/about/news-releases/evergreen-redevelopment-of-kiln-building-sets-carbon-neutral-target-for-bri/

were used where possible for the first and second stage. Estimates from design documents were used for the third stage.

Table 3: Project construction phases

Phase	Timeline	Description	Included in LCA?
1	2017	Creation of new raised floor, including hydronic radiant subfloor heating system. Plumbing rough-in.	As ‘completed’
2	2018	Façade work including new doors, windows and north gable. New west elevation curtain wall. Geoexchange system boreholes dug, plus new piping to new exterior and interior mechanical rooms. New event support area and unisex washroom. New ramps and walkways.	As ‘completed’
3	2019-2021	Add new roof layers over existing roof, including insulation and 260 solar thermal panels. New skylights. New classroom spaces.	As ‘planned’

3.4 Project Material Core and Expanded Scopes

To push the industry forward and to better understand a building’s full embodied impact, Evergreen decided to estimate the impact of the materials beyond the core LCA material scope identified in Section 2.2. That included an expanded scope of additional materials, with an effort to calculate the entire embodied carbon of the project.

A breakdown of the building systems that are included in each scope is described in Table 4.

Table 4: Building material scopes in LCA

Scope	Corresponding materials and systems
Core[13] **(typically included in LCAs; aligns with LEED and ZCB LCA approach)**	**Completed:** New envelope and structural elements; complete structural wall assemblies (from cladding to interior finishes); structural floors and ceilings (including some finishes). **Planned:** New roof assemblies including insulation, metal, and skylights; raised classrooms; south gable; washroom wall glass exterior. Both completed and planned core scopes include deliveries to site.
Expanded **(not typically included in LCAs;** **not required in LEED's LCA approach)**	**Completed:** Borehole digging and geoexchange tubes; finishes; building services; washroom fixtures and doors; (electrical and mechanical, including radiant floor tubing, plumbing pipes and fixtures, etc.). **Planned:** Solar thermal panels; additional mechanical, electrical and plumbing equipment. *Note: all construction and installation processes (A5) results are presented as part of the expanded model.*
Excluded	• Existing roof, foundation, walls, etc. (existing materials that will be reused are not included in the main calculation scope of this project, but were estimated as part of a preliminary model) • Parking lot (was created during earlier construction phases and is not part of current project scope) • Site landscaping • Furniture (not part of project scope, and likely to change over course of building lifecycle)

[13] Building components in the core scope were assumed to remain intact throughout the service life of the building, i.e. B4 = 0.

4 Data Collection

Data Sources

Since LCA is not yet commonly performed for buildings, it can be difficult to obtain all the information typically required for a robust calculation. Current LCA software includes default values and assumptions where specific data is not available. See the following breakdown of the mandatory vs. optional data sources for buildings.

Table 5: Mandatory and optional data sources

	Description
Mandatory for any LCA	Envelope and structure material quantity and descriptions to allow for selection of appropriate/representative materials in the LCA software tool.
Optional to increase accuracy of results	Transport vehicle type and distance from manufacturer to the construction site, so that the LCA model can be adjusted from the default distances and assumptions in the LCA software tool. Material quantity and descriptions for additional material scopes (i.e., expanded scope) beyond the mandatory core scope of envelope and structure. Energy used on-site during construction to supplement or replace the LCA tool assumptions. Specifications of raw materials and production processes from local manufacturers for materials or components used in the project, to replace generic or national average data. Details on future planned maintenance, operation, renovations and end-of-life scenarios (reuse, recycle and landfill), to replace LCA tool assumptions.

To account for all the materials listed in the core and expanded scopes listed in Table 4, the LCA practitioner reviewed various documents. That ranged from drawings and specifications created during the design phase, to photographs and delivery tickets collected during construction. The construction manager, EllisDon, was responsible for obtaining this information from the sub-trades. Additionally, the project team reached out to sub-trades via email or phone to obtain additional information and clarifications.

5 Results

Three LCAs have been performed on this project: preliminary, core and expanded.

Table 6: Comparison of LCAs performed

LCA	Performed	Information Sources	Use
Preliminary	Late 2017	Preliminary design documents including structural drawings and BIM.	To provide a high-level estimate of the embodied carbon of existing materials to be reused and new materials to be procured.
Core	Late 2018	Design documents including structural drawings and BIM, records of material deliveries to site during construction and construction equipment use logs.	To estimate the embodied carbon associated with the typical core LCA project scope, using actual material quantities being delivered.
Expanded	Same as core		To estimate the embodied carbon associated with the materials and processes that are not typically included in an LCA project scope, using material estimates from design documents.

5.1 Preliminary

A high-level whole-building LCA was performed in late 2017. The analysis – which only includes the “core” structure and envelope materials – considered the “avoided embodied emissions” associated with the reuse of much of the building’s envelope and structure using the LEED methodology. Pre-construction building material descriptions and quantities were provided by the design structural engineers (ARUP) and contractor (EllisDon). Embodied carbon estimates were calculated using the One Click LCA software.

Table 7 shows the quantities of the major materials. At the design stage time of this preliminary LCA, some key data was not available. Therefore, several assumptions were made about the new materials to be added. For example, less concrete and rebar was used in new material construction than was originally estimated and accounted for in the preliminary model. However, this did not impact the main reason for this preliminary model – to estimate the embodied carbon of the reused materials.

Reuse of existing material was estimated to avoid 979 t CO_2e of embodied carbon. This reduction is equivalent to the annual emissions from 47 single-family homes in Toronto[14].

Table 7: Preliminary LCA results

Material	Building System	Material Description	Quantity (m^3)	Embodied Carbon ($T\ CO_2\ e$)
Existing material to be reused	Roof	Structural framing, 345 MPa Steel	26	979
		Metal decking, 18 gauge	5	
	Walls	Concrete, cast-in-place, 32 MPa, 25% SCM, Portland cement, air entrainment	373	
		Brick	424	
	Columns	Brick	3	
	Floors	Concrete, cast-in-place, 25 MPa, 15% SCM, Portland cement, no air entrainment	1,456	
New material to be added	Floors	Concrete, cast-in-place, 25 MPa, 15% SCM, Portland cement, no air entrainment	415	1,630
		Rebar	50	
		Lumber	45	
		Steel gate	13	
		Metal deck	8	
		Plastic (Cupolex)	8 tonnes	
		Screed	195	
	Columns	Concrete, cast-in-place, 32 MPa, 25%, SCM, Portland cement, air entrainment	71	
		Rebar	11	
	Walls	Concrete, cast-in-place, 32 MPa, 25%, SCM, Portland cement, air entrainment	51	
		Rebar	5	
		Concrete masonry units	226	
	Various	Structural steel throughout	13	
Total Embodied Carbon Estimate:				2,609

[14] 2013 Project Neutral Annual Summary of Results http://www.projectneutral.org/assets/files/documents/p18vl8coarmq9j73c3nss7h594.pdf

5.2 Core and Expanded

A second whole-building LCA was performed in late 2018 consisting of two models: core and expanded. The scope of the core model included mostly new envelope and structural elements (see Table 4), in accordance with the LEED methodology.

The team used data collected during construction. Information requests to subcontractors and vendors were used to fill data gaps. Design documents were used to predict emissions associated with future planned construction. Embodied carbon estimates were calculated through a combination of the LCA software *One Click LCA* and manual calculations using *Microsoft Excel*, using other sources of emission factors.

The innovative zero-carbon operational energy strategy of this project has been achieved through a geoexchange system. That comprises a borehole field, radiant floor tubing and roof-mounted solar thermal panels. A whole-building LCA's core scope does not include mechanical or electrical systems. So the core model doesn't account for any of the emissions associated with the production, transportation or installation of these systems. However, the expanded scope does capture those emissions.

Due to the exclusion of the building's operational energy use phase (B6) from this assessment, the low-carbon operation of these innovative systems are not accounted for in any of the LCA scopes.

By separating the expanded model from the core model, the project team was able to determine the relative impacts of each. This helped to determine if future rehabilitation projects should consider expanding their LCA scope for a more holistic quantification of their carbon impact. Table 8 provides the resulting estimated embodied carbon for each scope.

Table 8: GWP estimates for all scopes

Scope	Embodied Carbon	
	Total (t CO_2e)	Per Area (t CO_2e/m^2)
Core	654	134
Expanded	389	80
Total	1043	215

The total estimated emissions from the core scope are 654 t CO_2e (134 kg CO_2e/m^2), roughly 63% of the total project embodied emissions. Emissions for the expanded construction scope are 389 t CO_2e (80 kg CO_2e/m^2), roughly

37% of the total project embodied emissions. The total project estimated emissions (core plus expanded) are estimated at 1043 t CO_2e (215 t CO_2e/m^2).

The absolute GWP estimates, for both core and expanded scopes, are shown in Figure 16. The relative impact of each scope (core vs. expanded) and their phase (completed vs. planned) is shown in Figure 17.

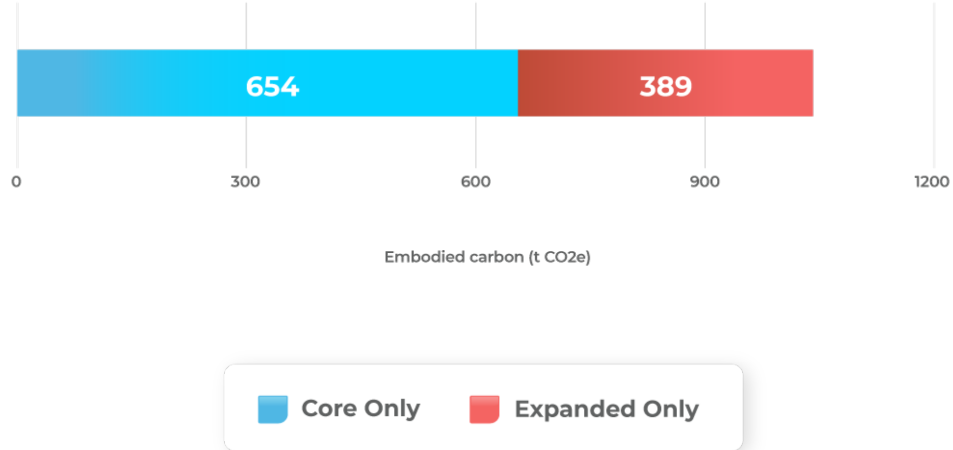

Figure 16: Core vs expanded absolute GWP

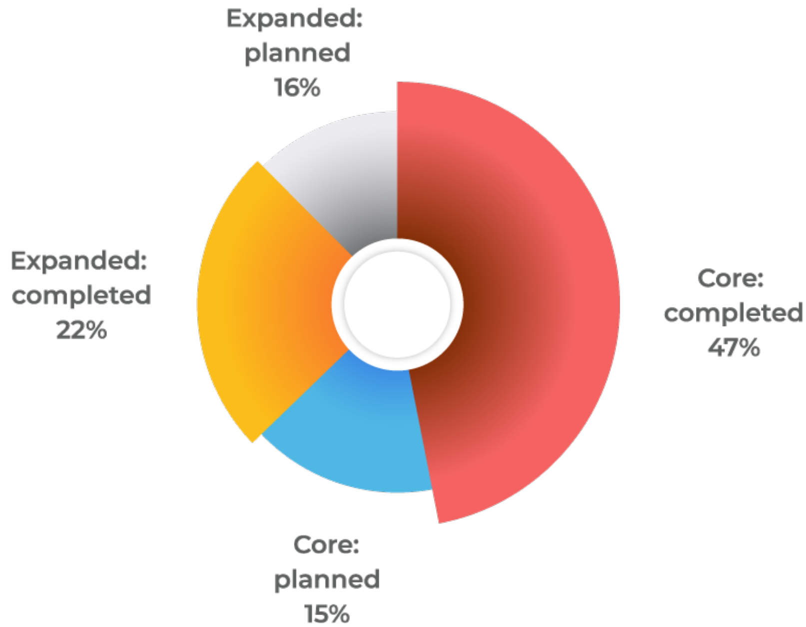

Figure 17: Relative size of emissions by scope (core vs expanded) and phase (completed vs planned)

The materials/components that contributed the most emissions to the project were concrete, steel, solar panels and plastic (mainly plastic pipes, radiant floor tubes and underfloor Cupolex system), as shown in Figure 18. Together, these top four materials account for 80% of the project's embodied carbon.

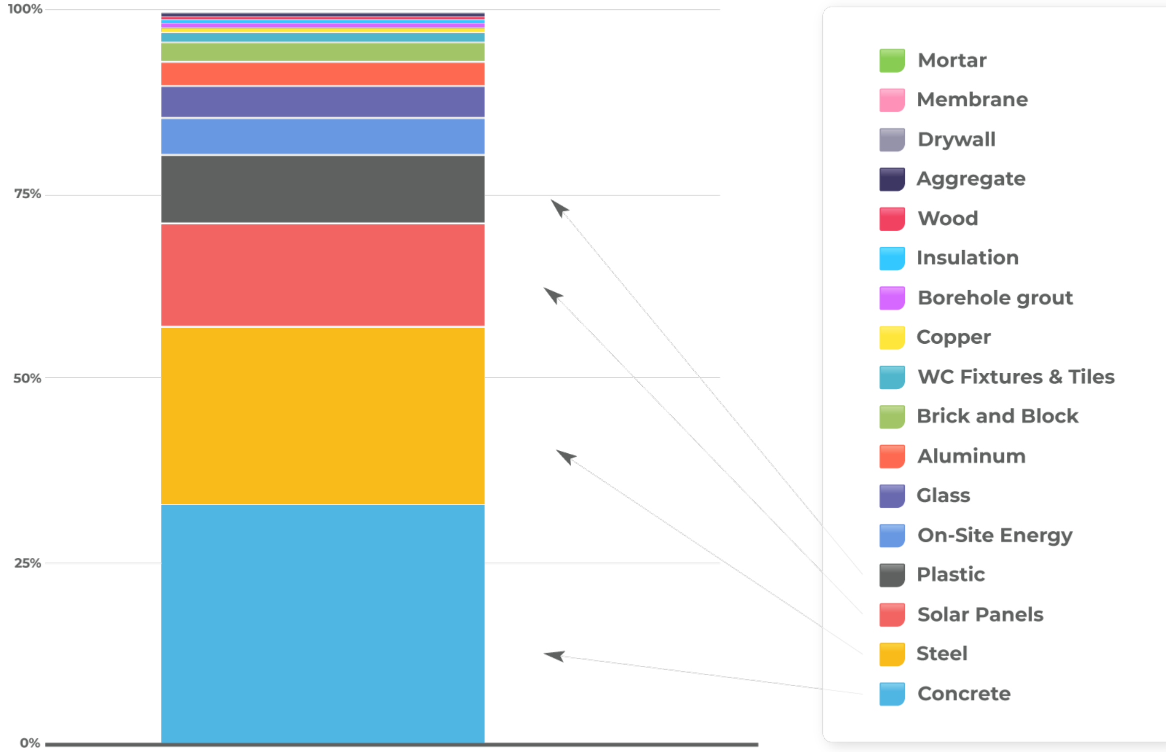

Figure 18: Relative GWP impact per material/component

The harvesting of raw materials and manufacture of the construction materials (life cycle phases A1-A3) is the dominant source of embodied emissions, accounting for approximately 75% of the total.

Figure 19 shows that material replacement and refurbishment during the use phase (B) is the second largest source of emissions. That consists mostly of the replacement of solar panels after their useful service life. Note that only B4 was calculated as part of this study. Other use phase elements, namely B1-B3 and B6-B7 were not included due to data and software limitations (see Figure 13). Those phases are assumed to have relatively small contributions, since the building is historic and is not expected to undergo major repairs or rehabilitation.

The project team spent significant effort tracking the construction-related source of emissions, mainly transportation impacts to the construction site (A4) and construction processes (A5). Together, they account for approximately 8% of the total embodied emissions. The construction process (A5) accounts for 80% of that. Roughly half the construction emissions are due to diesel for fueling equipment, and the other half is due to space heating during cold months. Electric powered equipment was found to have an insignificant contribution to the total project (less than 0.5% of total).

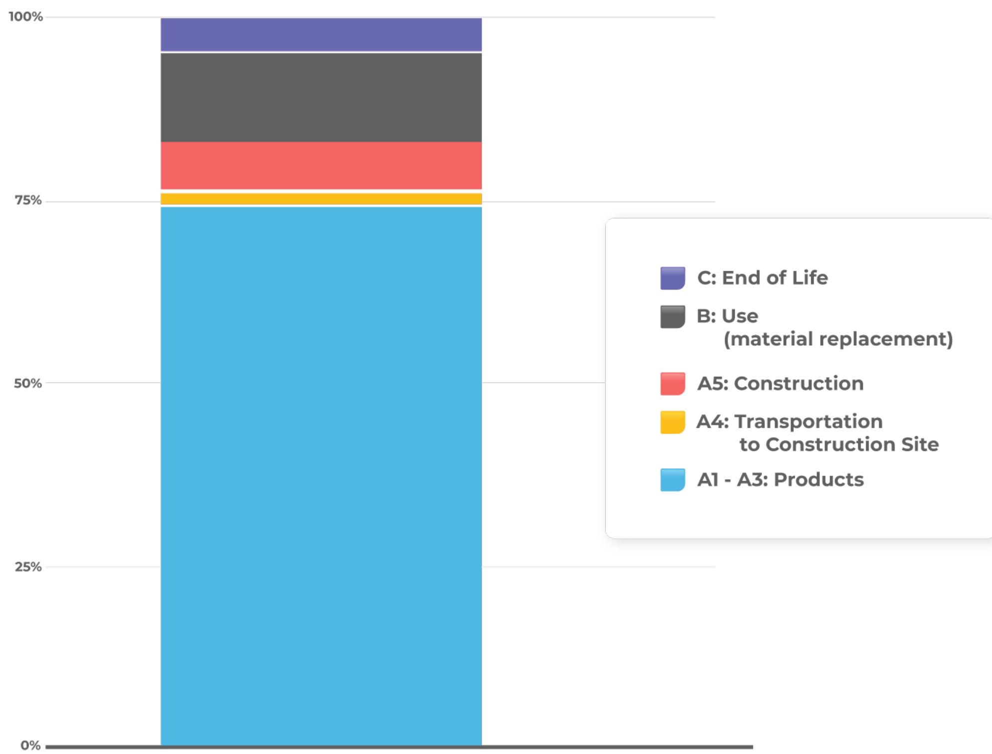

Figure 19: Relative breakdown by life cycle phase

5.3 Key findings

As this project is unique, it would not be appropriate to extrapolate the project's key findings to a typical construction project. However, some of these findings are likely applicable to other large rehabilitation projects, where the core and shell of a building is being maintained but the interior is being refurbished.

KEY FINDING 1: Renovation projects may wish to expand their LCA scope to include materials not typically covered by new construction LCA, such as non-structural walls and partitions, mechanical equipment, plumbing, and finishes.

- As a renovation project, this project included the reuse of large portions of the building structure and envelope. Therefore, the impacts from the core LCA scope was significantly smaller than would be expected for a typical construction project – one where those materials would be newly procured and included in the analysis.
- The expanded scope, not typically included in whole-building LCA, was comparatively quite large in this study. It accounted for more than one third of the total project impact. It is not clear what

percentage this expanded scope would account for in a new-build project.

KEY FINDING 2: To efficiently reduce embodied carbon, focus on finding lower-carbon alternatives for a small number of high-impact materials.

- Most embodied impacts are from a small number of materials. In this project, four materials accounted for 80% of the total embodied impacts over the life cycle: concrete, steel, solar panels, and plastic. Each of these accounted for more emissions than the transportation of all materials to the site and the on-site energy used during construction, combined.

KEY FINDING 3: Embodied carbon reduction efforts should be focused on sourcing lower-impact materials instead of on reducing maintenance or end of life-related impacts.

- Product sourcing (A1-A3) is the dominant source of this project's calculated life cycle embodied emissions, accounting for 75%, and thus should be the focus of reduction efforts.
- The use (B) and end of life (C) phases of the life cycle accounted for less than 20% of the total carbon impacts, combined.

KEY FINDING 4: On-site construction processes and the transportation of materials to site accounted for relatively small shares of total project emissions – 6.5% and 1.8% respectively.

- Smaller carbon impacts are associated with the replacement phase (B4), due to refurbishment/replacement of key items like solar panels after their useful service life. The construction phase (A4-A5) was less impactful – those emissions came mostly from on-site diesel use for construction equipment and space heating. The end-of-life phase (C) accounted for the least emissions.

6 Carbon Offset Strategy

6.1 Background on carbon offsets

Carbon offsets represent a reduction of GHG emissions, purchased to offset emissions produced elsewhere. Offsets can be produced through sustainable land use, sustainable water or forest management, resource recovery, and renewable energy generation (e.g., solar, wind, or hydroelectric). This can be a strategy to help organizations meet their climate goals. One carbon offset is typically equal to one metric tonne of carbon dioxide equivalent.

Ideally, the investment that flows into offset projects is required for the project to be viable. Offset investments should lead to carbon reductions, rather than provide money to a project that reduces carbon but would have happened without the offset purchase. This is known as "additionality".

Other criteria of high-quality carbon offsets:

- validation and verification of the project by reputable third-parties;
- steps by the project developer to ensure that each offset is only sold once (e.g. by listing the offsets on a public registry and retiring the offset after purchase); and
- systems in place to control "leakage", where creating a GHG reduction in one region causes an unintended increase in GHG emissions elsewhere (e.g. protecting a forest in one location could simply shift logging to a forested area in a new location).[15]

Standards for carbon offsets

It can be difficult for offset buyers to get clear answers to the above questions. So it's prudent to purchase offsets that have been certified to recognized standards. Just as tenants have confidence that a LEED-certified building meets industry best practice for green design, high-quality third-party carbon offset standards provide assurance that certain criteria are met. Several voluntary standards exist for carbon offsets:

- Clean Development Mechanism (CDM)
- Gold Standard (GS)
- Voluntary Carbon Standard 2007 (VCS 2007)
- VER+
- The Voluntary Offset Standard (VOS)
- Chicago Climate Exchange (CCX)

[15] https://davidsuzuki.org/what-you-can-do/carbon-offsets/

- The Climate, Community & Biodiversity Standards (CCBS)
- Plan Vivo System
- ISO 14064-2
- GHG Protocol for Project Accounting

6.2 Carbon offsets for this project

Based on the total embodied carbon calculated for this project (1044 t CO_2e), Evergreen can make an investment to purchase carbon offsets for 100% of the project embodied carbon and claim a carbon-neutral construction project.

Offset prices can vary significantly based on several factors, including the type of offset project and the jurisdiction in which the offset is made. For example, landfill recapture of methane can be a relatively low-cost offset strategy, while biodiversity forest management can be higher-cost.

Three potential strategies are listed in Table 9, providing examples of lower-cost and higher-value options. All represent offsetting 1044 t CO_2e.

Table 9: Carbon offset options and pricing

Option	Description	Price Intensity ($ / t CO_2e)	Price to offset project emissions	Certification
1	Landfill gas recapture in New York state	4.65	$4,878	American Carbon Registry
2	Landfill gas recapture in Ontario	8	$8,392	ISO 14064-2
3	Forest management and biodiversity in BC	11.43	$11,990	Voluntary Carbon Standard 2007

7 Considerations for Future Projects

The insights gained in this project are summarized below, as general guidance for building construction project teams wishing to quantify and reduce their embodied carbon.

Defining LCA Project Objectives & Scope

1. Use an LCA or carbon-neutral industry standard.

- Following a specific standard for carbon accounting provides clear guidance on the assessment's scope and boundaries. This helps determine what materials, equipment or activities to include and what to exclude from the LCA scope. It also provides consistency between projects aiding comparability of results.
- Start the LCA data collection planning as early as possible in the design stage of the project and update as better data becomes available.

Education and Data Collection for the LCA

2. Create a detailed data collection plan prior to construction and host training/education sessions to familiarize the team with the intent and process of the LCA.

- Consider setting project requirements or incentives for trade participation in providing data to assist carbon tracking.
- See Appendix A for online training resources.

3. Set project goals and requirements around low-carbon materials and enhanced disclosure of material carbon data.

- Project goals should include a focus on specifying low-carbon materials and publishing embodied carbon documentation.
- Specifications should note that low-carbon products as demonstrated through publicly available third-party EPDs will be preferred.
- Requirements such as these may not be met on each project but will help shift the industry over time.

4. Consider the most effective way to gather on-site information during construction.

- For example, to calculate the total energy consumed during the construction process, it may be efficient to establish a system where all fuel used on-site is taken from a central fuel repository (and each trade billed for their individual consumption) and all electricity flows through a dedicated submeter. These values can then be accurately used to calculate total carbon from construction processes.

- This small amount of up-front effort will result in high-quality data on the emissions resulting from construction work.

5. Update and use BIM/Revit model for LCA.

- This project included an early design-phase BIM model, used as a quality control check to cross-reference on-site material quantities for reasonableness. Unfortunately, the BIM model was not updated as the design progressed so could not be used with confidence to obtain final material quantities.
- Future projects should be aware of the accuracy and value of design-stage BIM files vs. on-site construction data. If a BIM model is accurately made with complete geometries and material volumes and kept up to date as the design progresses, it can be used as the sole source of material quantity information.
- Consider speaking with the BIM team at project commencement to discuss if the model can be used for accurate material quantity take-offs throughout the project.

8 What's Next for Embodied Carbon?

This report highlights the importance of considering embodied carbon in construction and renovation projects, along with some challenges and future work required to guide low-carbon design and construction strategies.

Several initiatives are currently underway across Canada, North America and globally that aim to advance embodied carbon and LCA data, tools and methodologies. These efforts will better account for and reduce total life cycle carbon of the built environment. Some examples:

- The Canada Green Building Council (CaGBC) and the World Green Building Council (WGBC) have both identified embodied carbon as a priority issue. The WGBC has included embodied carbon requirements into a future low-carbon building standard framework, while the CaGBC updated their Zero Carbon Building Standard to strengthen and expand its approach to embodied carbon .

- The Government of Canada, through the Treasury Board Secretariat (Centre for Greening Government) and the National Research Council (NRC) are creating a national life cycle inventory database. It would include high-quality and regionally-specific values for each province. This will create consistent, accurate and regionally-appropriate LCA data. That will allow for robust, defensible and meaningful evidence-based results and comparison. This project will help create high-quality provincially-specific EPDs. The government is also considering mandatory low-carbon concrete requirements for future government projects.

- The Carbon Leadership Forum is an advocacy group committed to designing embodied and operational carbon out of our new and renovated buildings, to achieve a carbon neutral built environment by 2050.

The insights gained on this project will lead to a better understanding of how to reduce embodied carbon in construction.

What we have learned from the TD Future Cities Centre can also serve investors who are trying to reduce the carbon footprint of their portfolio and are investing in real estate and infrastructure. For those investing in real estate and infrastructure, focusing on energy efficiency or green building certifications (like LEED) alone is not enough. Those are no longer best practices. Construction should reuse existing buildings/materials where possible, and aim to be carbon-neutral, targeting both operational and embodied carbon.

De-carbonization efforts must include industry, and the creation, transport, install, maintenance and decommissioning of construction materials. Material manufacturers and industries that fail to evolve their business risk being left behind.

Policy makers, building owners, designers and construction teams are increasingly making embodied carbon a priority. The TD Future Cities Centre and other leading initiatives highlight the significant opportunities to move the construction industry towards a carbon-neutral future.

Appendix A – Low-Carbon Construction Building Skills Event

On September 26, 2018, the project partners – Evergreen, EllisDon, the University of Toronto's Civil and Mineral Engineering Department, and Mantle314 (formerly Zizzo Strategy) – hosted a full-day workshop for the building design and construction industry at Evergreen's Brick Works campus. The discussion included:

- An introduction to embodied carbon and why it's important.
- Using life cycle assessment (LCA) to quantify and reduce embodied carbon in construction.
- A case study (and site tour) of one of Canada's greenest construction projects, the carbon-neutral retrofit of the TD Future Cities Centre.

Image 1: Presentations and Panel Discussion from the Low Carbon Building Skills Pilot

The workshop provided practical training and resources on how future construction projects can reduce emissions and become carbon neutral, using one of Canada's most innovative examples.

To learn more, see the presentation slide deck, or the sessions that were recorded and uploaded to Evergreen's YouTube channel.

Appendix B – Detailed Results by Life Cycle Phase

					A			B	C
Boundaries	**Timing**	**Category**	**Sub-category**	**Total**	**A1-A3**	**A4**	**A5**		
Core	Present	Foundations and substructure	Steel	**1.30**	1.30	0.06			0.02
Core	Present	Foundations and substructure	Concrete and aggregates	**72.38**	64.91	0.98			7.34
Core	Present	Vertical structures		**55.10**	51.29	0.80			2.92
Core	Present	Horizontal structures	Floor - concrete and aggregates	**271.60**	237.20	7.33			25.62
Core	Present	Horizontal structures	Floors - steel	**14.10**	13.90	0.10			0.11
Core	Present	Horizontal structures	Floors - plastic	**25.97**	12.62	0.11			13.00
Core	Present	Other structures and materials	Curtain wall and windows	**50.34**	46.70	2.71			0.93
Core	Present	Other structures and materials	Doors	**2.33**	2.24	0.16			0.00
Expanded	Present	MEP	Electrical	**32.11**	27.05	0.12	2.61	2.05	0.07
Expanded	Present	MEP	Geothermal system	**123.56**	81.27	0.87	5.35	34.68	1.25
Expanded	Present	Other structures and materials	Washroom	**14.33**	8.86	0.33	0.00	5.06	0.08
Expanded	Present	Temporary materials		**2.20**	1.20	1.00			
Expanded	Present	Additional transportation	On-site equipment	**0.17**			0.17		
Expanded	Present	On-Site Energy Use		**53.1**			53.1		
Core	Future	Vertical structures	Washroom wall finish	**6.20**	2.90	0.02	0.03	3.10	0.10
Core	Future	Vertical structures	Classrooms structure and floor	**95.00**	89.00	2.60	3.10	0.00	0.92
Core	Future	Vertical structures	Classrooms walls and partitions - P7	**11.01**	5.85	0.07	0.17	4.70	0.25
Core	Future	Vertical structures	Roof gable	**10.00**	8.70	0.03	1.30	0.00	0.02
Core	Future	Horizontal structures	Classroom	**4.40**	3.20	0.36	0.67	0.00	0.15
Core	Future	Horizontal structures	Roof	**34.48**	31.74	0.40	0.91	0.94	0.30
Expanded	Future	MEP	Solar panels	**148.16**	72.76	0.81	0.74	73.57	0.28
Expanded	Future	MEP	MEP - % of total GWP	**16.11**	16.11				
			Totals	**1043.95**	778.80	18.86	68.15	124.10	53.36