POLICY REVIEW OF CARBON-FOCUSED LIFE CYCLE ASSESSMENT

in Green Building Design and Performance at the University of British Columbia

THE UNIVERSITY OF BRITISH COLUMBIA
sustainability

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LIST OF ABBREVIATIONS

BoM | Bill of Materials

CO2(e) | Carbon Dioxide Equivalent

EBD | Environmental Building Declaration

EPD | Environmental Product Declaration

LCA | Life Cycle Assessment

LCCA | Life Cycle Cost Assessment

LCI | Life Cycle Inventory

LCIA | Life Cycle Impact Assessment

GHG | Greenhouse Gases

GWP | Global Warming Potential

PCR | Product Category Rule

UBC | University of British Columbia

WBLCA | Whole-building Life Cycle Assessment

NZEB | Net-zero Energy Building

GLOSSARY OF TERMS

Bill of Materials | a summary of the estimated quantity of materials required to construct the building, which does not typically include waste material which is a bi-product of construction.

Building Product | goods or services used during the life cycle of a building.

Environmental Impact Category | environmental impact issue being examined. e.i. Global Warming, being measured by global warming potential (GWP).

Environmental Product Declaration | a third party verified report providing quantified environmental data (impacts) using predetermined parameters and, where relevant, additional environmental information for the product being studied.

Greenhouse Gases | emissions are those that trap heat in the Earth's atmosphere. Commonly these are carbon dioxide, methane, nitrous oxide, and fluorinated gases (such as CFCs, HCFCs, and HFCs found in refrigerants).

Life Cycle | consecutive and interlinked stages of a product from raw material acquisition or generation of natural resources to the final disposal.

Life Cycle Assessment | compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product throughout its life cycle.

Life Cycle Inventory | a collection of information on the flows to and from nature due to products, materials and processes which are part of a building.

Life Cycle Impact Assessment | a method of estimating the potential environmental impact of a products, materials and processes based on the flows determined in the life cycle inventory.

Net Zero | a state in which balance is achieved between carbon-emitting activities and actions that reduce or offset emissions from those activities, so that net annual emissions are equal to zero.

Net Zero Energy Building | a building which draws less energy from external sources than the on-site renewable energy which is exported on an annual basis.

Product Category Rules | set of specific rules, requirements and guidelines for developing environmental product declarations for one or more product categories.

System Boundary | describes what is being assessed within the life cycle of the system studied.

INTRODUCTION

Across British Columbia, Canada, jurisdictions are developing policies to reduce the greenhouse gas emission from economic activities, in an effort to keep global temperature changes below two degrees Celsius and slow climate change. For buildings, these policies have largely been focused on the reduction of operational energy and associated GHG emissions from building operations (e.g. B.C. Energy Step Code). As these changes are implemented the proportion of GHG emissions associated with the construction of building themselves–the embodied emission from the extraction, manufacture, construction and repair of materials and products–will become increasingly more significant.

The University of British Columbia (UBC) has been operating at the forefront of sustainability practices and policies. In 2010, UBC approved a Climate Action Plan with a target of reducing 100% of campus GHG emissions by 2050 relative to 2007 levels. The Vancouver Campus now emits 30% less GHG emission than it did in 2007, despite significant growth (21% increase in floor space and 30% increase in student population). Building on this work, UBC approved the Green Building Action Plan (GBAP) in 2018, which outlines a holistic pathway for academic and residential buildings at the UBC Vancouver campus to advance towards making net positive contributions to human and natural systems by 2035. The GBAP prioritized the reduction of embodied carbon emissions of buildings projects through lifecycle assessment (LCA).

Life cycle assessment (LCA) of buildings is both a science and a framework to quantify potential environmental impacts of buildings and their components throughout the different life cycle stages. There are several ways to utilize LCAs, which all strive towards reducing the environmental impacts of buildings now and in the future. In general, LCAs can be used:

- To inform the building design process and modify the building design to reduce its environmental impacts;
- As a post-construction assessment of building performance; and
- To set environmental impact benchmarks and targets for building typologies.

This policy review was conducted as part of an UBC Embodied Carbon Pilot research project led by the UBC Sustainability Initiative, and focuses on policy improvements in the implementation of LCA at UBC as a means towards achieving meaningful reductions in embodied carbon emissions in campus developments. The review itself was compelted by a Sustainability Scholars suring the summer of 2019. The research outlined within this report is intended to provide a concise summary and establish a common understanding of embodied carbon and LCA concepts, and serve as a reference for a UBC policy and planning staff. It may also provide useful for other organizations seeking to better understand and use LCA tools and methodologies to assess and address environmental impacts, such as the embodied carbon emissions, of their operations and activities.

The report is divided into three sections:

- Overview of LCA concepts, environmental impacts and tools;
- Canadian policy review; and
- Discussion of challenges and opportunities in implementing LCA for policy decisions.

Section 1 focuses on developing a common understanding of the LCA process, terminology and tools. It provides definitions for the common terminology which are frequently used and which build upon those provided in the Glossary of Terms. The section goes on to discuss how the concept of LCA methodology is applied to determine embodied carbon and other environmental impacts including the processes, procedures, and software tools which are commonly used to conduct these analyses.

Section 2 provides a summary of the numerous standards and green building certification programs which exist to provide uniformity and incentivize the construction industry to calculate and ultimately reduce embodied carbon. Particular focus is provided on the LEED Building Design & Construction (BD+C) v4 & v4.1 materials credit for Building Life Cycle Impact (LCI) Reduction, specifically Option 4 which relates to WBLCA. After establishing a common understanding of the common standards and certifications for LCA, the discussion focusing on existing policies and regulations which are in place, beginning with a global perspective and then decreasing in geographic scale by summarizing initiatives at the national level in Canada, the regional level in the lower mainland and then lastly at UBC Vancouver Campus.

Section 3 includes a discussion of the opportunities and challenges in the application of LCA analysis for design decision and policy implementation. To inform the discussion, a series of interviews were conducted with key staff and stakeholders from the University of British Columbia to understand the aspirations of the organization, as well as identify opportunities and challenges of LCA implementation at UBC. Additional interviews were conducted with members of the National Research Council (LCA)2 initiative and City of Vancouver to gather insights into national and regional efforts with regards to LCA, which may impact or influence the initiatives at UBC.

The research above, including the literature review and interviews, were assessed and consolidated into a set of recommendation for policy improvements in the utilization and implementation of LCA at UBC. The intent of is to help inform deliberations on existing policy improvement and new policy developments in service of the overall objectives of UBC to reduce the embodied carbon resulting from campus buildings.

SECTION 1: OVERVIEW OF LCA CONCEPTS, ENVIRONMENTAL IMPACTS AND TOOLS

LIFE CYCLE ASSESSMENT OVERVIEW

Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is both a science and a framework that can be used to quantify potential environmental impacts of products as a performance outcome of design, manufacturing, use and end of life choices. As illustrated in Figure 1, a product's life cycle stages, in this case a building, span across resource extraction, manufacturing and prefabrication, transportation, onsite construction, occupancy (operation, maintenance and renewal), and deconstruction (demolition and disposal). The above method, known as cradle-to-grave assessment, can be complimented with the benefits of reusing, recycling and recovering materials beyond the building lifecycle, which is known as cradle-to-cradle assessment.

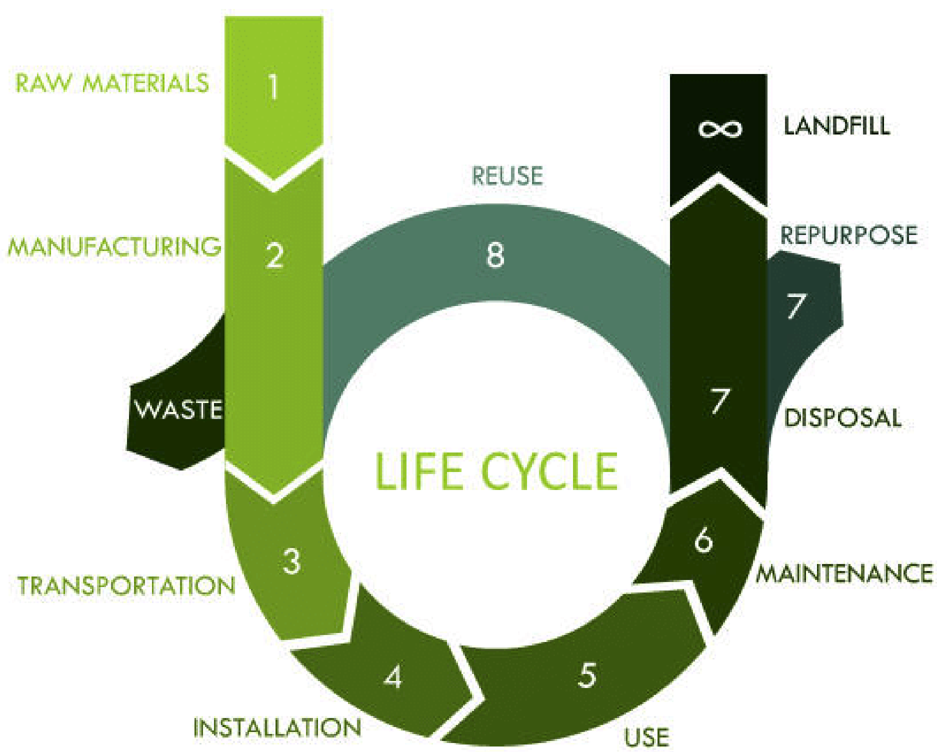

Figure 1: Flow diagram illustrating both cradle-to-grave and cradle-to-cradle product lifecycles (Source: Southwest 2016)

Whole Building Life Cycle Assessment (WBLCA)

The concept of whole-building life cycle assessment (WBLCA) is when the entire building is assessed comprehensively, as opposed to only an individual component. The WBLCA process allows building stakeholders, such as designers, developers, owners and operators, to better understand both the totality of the environmental impact of the building and the contributions of individual components. Through an impact assessment applied holistically, the results can be used by project teams to inform design decisions and by jurisdictional authorities to inform policy and regulatory standards. Ultimately, the aim is to make meaningful and efficient improvements to the ecological footprint of a specific buildings.

The life cycle stages of products in the overall LCA framework are further expanded in an WBLCA framework to add subcategories to each stage, as shown in Figure 2, which are common to nearly all building construction projects.

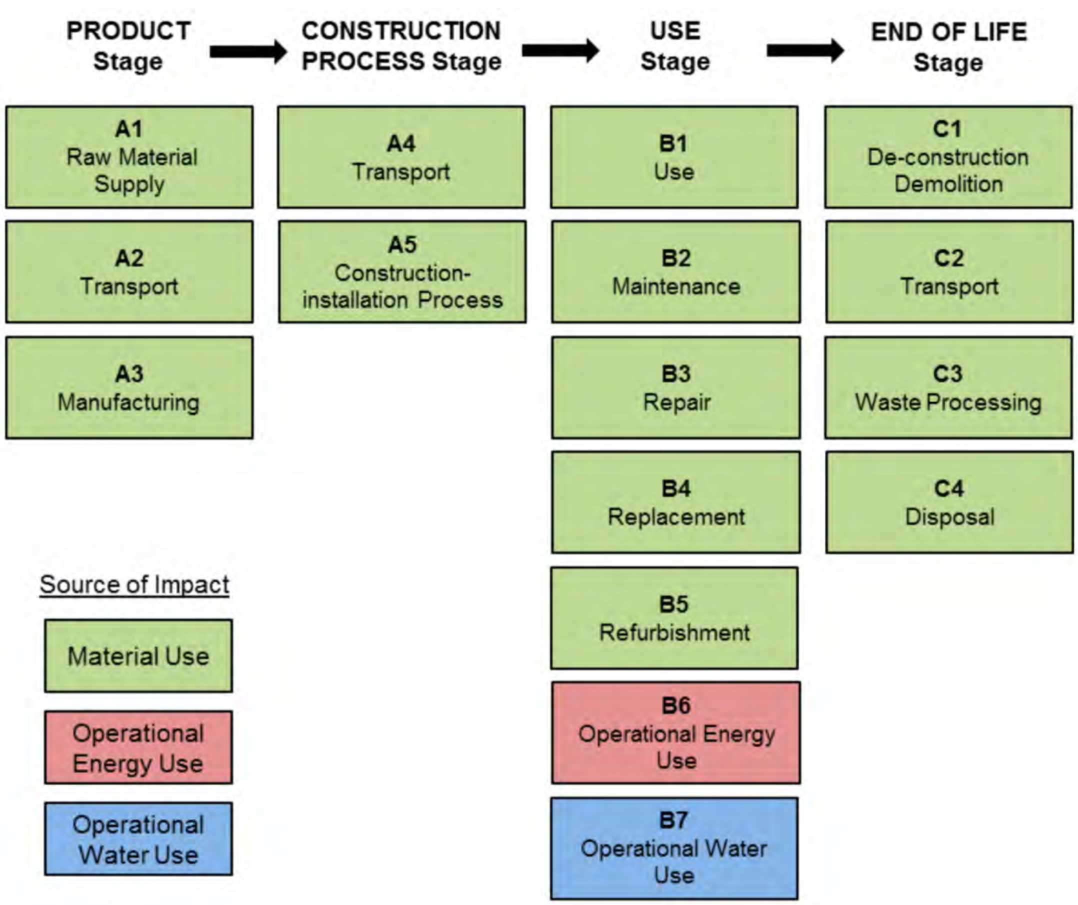

Figure 2: Stages contributing to the embodied carbon impacts over the life cycle of a building (Source: EN 15978:2011)

Embodied Carbon

Embodied carbon is named after carbon dioxide (CO2) but refers to numerous greenhouse gases which when emitted to the atmosphere are able to retain thermal energy and thereby leading to an increase in the average temperature of the Earth, referred to as global warming. Each of these gas compounds contribute differently and for accounting purposes, are therefore simplified into a carbon dioxide equivalent generally reported in kilograms (kg CO2 eq.) based on their individual potency in contributing to the global warming potential (GWP).

The phenomenon of global warming is more commonly referred to as climate change due to the other climate factors impacted by the warming of the earth such as precipitation and wind which in turn also impact the frequency and intensity of drought and flood events.

Embodied carbon assessments through WBLCA are a way to understand and quantify the greenhouse gases that are associated with buildings materials through material selection and construction methods. For the purposes of this report, embodied carbon includes all life cycle stages with the exception of operational uses.

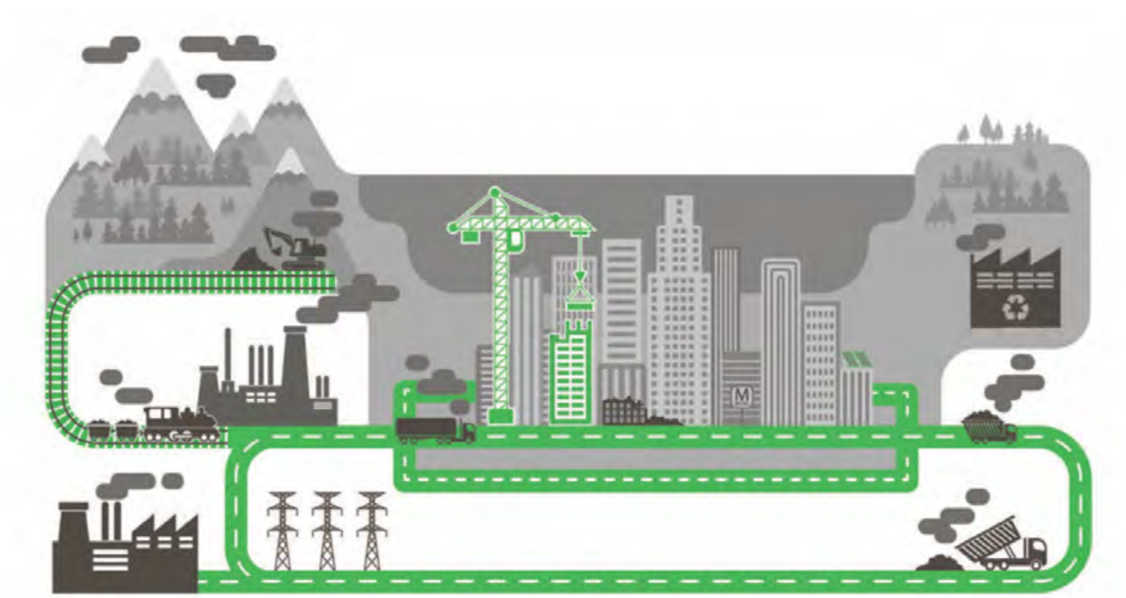

Figure 3: Embodied carbon accumulation generated by each stage of building lifecycle (Source: Bionova 2018)

Embodied carbon has largely been overlooked in the past since operating carbon has historically comprised the largest portion of the total carbon footprint of buildings. Therefore, there have been minimal incentives to measure or reduce embodied carbon. In addition, the use of LCA, as the methodology used to measure embodied carbon in buildings, requires development of a new scope of practice and capacity amongst the building industry (Zizzo 2017).

The focus on embodied carbon continues to increase for two primary reasons:

- The choice of building materials and construction methods have an immediate and often significant environmental impact on the rapidly escalating climate change emergency. As an example, the manufacture of building materials is estimated at 11% of the global greenhouse gas emissions (UNE 2017); and
- As technological improvements and efficiencies in operational carbon emissions continue to progress, the embodied emissions are becoming a greater proportion of the total emissions. This is illustrated in Figure 4.

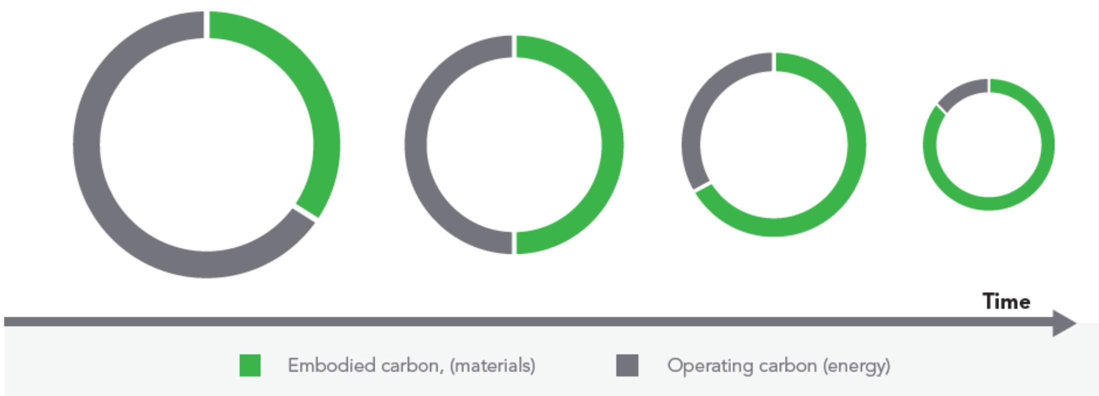

Figure 4: The increasing percent contribution of embodied carbon as operating carbon is reduced (Source: Bionova 2018)

Environmental Impact Categories

Although the focus of this report is on embodied carbon and the resulting GWP, embodied carbon is only one of many environmental impact categories which can be measured by LCA. As mentioned before, LCA is a methodology to estimate environmental impacts from the building life cycle, one of which is the embodied carbon.

Different impact categories measure factors that could contribute to the restoration or degradation of regional or global ecosystems, waterways, finite resources, climate and human health. The most common impact categories are defined as follows:

- Global Warming Potential | Describes potential changes in local, regional, or global surface temperatures caused by an increased concentration of greenhouse gases in the atmosphere, which traps heat from solar radiation through the “greenhouse effect”. These trapped gases lead to an increase in the average temperature of the Earth’s atmosphere known as global warming but more commonly referred to as climate change due to the other climate factors impacted such as precipitation and wind which in turn also impact frequency and intensity of drought and flood events. Generally reported in kilograms of carbon dioxide equivalent [kg C02 eq.] (Bare 2011 & Carbon Leadership Forum 2019).

- Ozone Depletion Potential | Describes the potential effect of substances in degrading the stratosphere ozone layer and thereby reducing its ability to prevent ultraviolet radiation from reaching Earth's surface. Ozone depletion can lead to an increased potential frequency of skin cancers and cataracts in humans along with negative impacts to crops, marine life, and building materials. It is generally reported in kilograms of chlorofluorocarbons equivalent [kg CFC-11 eq.] (Bare 2011 & Carbon Leadership Forum 2019).
- Acidification Potential of Land and Water | Describes the acidifying effect of substances which lower the pH level in water and soil, which can damage ecological areas and threaten the survival of certain species. Sulfur dioxide and nitrogen oxides from fossil fuel combustion have been the largest contributors to acidification (USEPA 2012), And it is generally reported in moles of hydrogen ion [mol H+] or kilograms of sulfur dioxide equivalent [kg S02 eq.] (Bare 2011 & Carbon Leadership Forum 2019).
- Eutrophication Potential | Describes the effect of excessive additional nutrients to soil or water, causing certain species to dominate an ecosystem and compromise the survival of other species. Release of fertilizers is one of the dominant contributor to eutrophication, with phosphorus and nitrogen having the most detrimental effects on freshwater and coastal environments respectively. It is generally reported in kilograms of nitrogen equivalent [kg N eq.] (Bare 2011 & Carbon Leadership Forum 2019).
- Formation Potential of Tropospheric Ozone Photochemical Oxidants (Smog Potential) | Describes the presence of substances such as carbon monoxide and volatile organic compounds (VOCs) in the atmosphere, forming photochemical smog. The troposphere is the lowest layer of the Earth's atmosphere and ozone within this layer is considered a GHG. Smog is primarily generated through combustion of fossil fuels and is harmful to both ecosystem and human health. It is generally reported in kilograms of nitrogen oxide equivalent [kg NOx eq.] or kilograms of ozone equivalent [kg O3 eq.] (Bare 2011 & Carbon Leadership Forum 2019).
- Non-Renewable Energy Consumption | Measures the amount of fossil fuels, used both directly and indirectly, in the building activities and raw materials. It falls within the wider overall category of resource depletion and is intended to assess the reduction of existing non-renewal energy sources. It provides an estimate of the potential energy required for extraction from more inaccessible resource reserves in the future as the result of the depletion of existing finite reserves. It is generally reported in mega joules of energy consumed [MJ surplus] (Bare et al. 2003 & Bare 2011).

The environmental impact of a building can be calculated as the summation of all of the above environmental impact categories. However, there are other impact categories beyond those defined above. For example, the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI), which was developed by the United States Environmental Protection Agency, includes impact categories which focus on human health criteria (Bare 2011 & USEPA 2012). The assessment of these human health impact categories it is not usually required as part of the WBLCA, as outlined in the international standards. However, other regulations and voluntary standards exist, such as the WELL Building Standard, which do specialize on human health and wellbeing impacts of infrastructure including detailed analysis of material selection impacts. There are opportunities, albeit challenging, to integrate environmental and human health impacts of materials so that they are considered together.

The overarching objective of the WBCLA process is to quantify each of the impact categories to inform decisions aimed at reducing any one impact effectively with consideration of other impacts, in order to reduce the overall impact of the building.

Object of Assessment and System Boundaries

Buildings are both complicated and individually unique through their combinations of different assemblies consisting of many products and, therefore, it is important to define the scope of the WBLCA.

There are two scoping considerations when establishing what is to be included in the assessment:

- The object of assessment – which materials are to be included; and
- The assessment system boundary - which of the life cycle activities that the object of assessment undergoes are to be included (Athena 2014).

Building material components are often referenced according to UNIFORMAT II (see Table 1 for breakdown), which provides a consistency in the element breakdown between structure, envelope, partitions and finishes, which, in concept, provides clarity on which of these components is included in the assessment (Athena 2014).

MATERIALS (UNIFORMAT II)	LEED V4
A1010 Standard Foundations	required
A1020 Special Foundations	required
A1030 Slab on Grade	required
A2010 Basement Excavation	required
A2020 Basement Walls	required
B1010 Floor Construction	required
B1020 Roof Construction	required
B2010 Exterior Walls	required
B2020 Exterior Windows	required
B2030 Exterior Doors	required
B3010 Roof Openings	required
C1010 Partitions	optional
C1020 Interior Doors	optional
C1030 Fittings	required
C2010 Stair Construction	required
C2020 Stair Finishes	required
C3010 Wall Finishes	required
C3020 Floor Finishes	required
C3030 Ceiling Finishes	required
Groups D-G	not included
Operating Energy	not included
Operating Water	not included

Table 1: Building components for LCI reduction - LEED BD+C v4.0 (Source: USGBC 2013)

The second requirement for determining the scope of an LCA is in determining the system boundaries which relates to the lifecycle stages of the materials and resources being incorporated into the project. Life cycle stages are divided into product development, construction, use and end of life (see Table 2 for breakdown).

As will be discussed later in this report, UBC mandates that LCAs be completed for new construction and major building renovation projects in accordance with LEED v4.0 building certification system (UBC GBAP 2018). The LEED v4.0 has defined the building components and life cycle stages which are to be considered within an LCA in order to gain credits, which are shown in Tables 1 & 2 respectively. Due to the LEED framework being used by UBC and more widely throughout the North American construction market, it will be referenced throughout this report to provide context and an examples of LCA applications (Athena 2014).

LIFE CYLCE STAGE	INFORMATION MODULE	LEED V4
PRODUCT	A1 Raw Material Supply	required
	A2 Transport	required
	A3 Manufacturing	required
CONSTRUCTION INSTALLATION	A4 Transport	required
	A5 Construction-installation Process	required
USE	B1 Use	optional
	B2 Maintenance	required
	B3 Repair	optional
	B4 Replacement	required
	B5 Refurbishment	optional
	B6 Operational Energy Use	not included
	B7 Operational Water Use	not included
END OF LIFE	C1 De-construction & Demolition	required
	C2 Transport	required
	C3 Waste Processing	optional
	C4 Disposal	required

Table 2: Materials and resources credit for building LCI reduction - LEED BD+C v4.0 (Source: USGBC 2013)

Operating energy and water are not included within the LEED v4.0 requirements for the building LCI reduction credit since this credit is focused on embodied carbon only. Operational energy and water use reductions are addressed by other credits in the Energy and Water categories respectively, and have much more weight in the overall certification of the building, highlighting the significance of these categories' contributions to the emitted carbon of a building.

WBLCA Process and Procedures

In order to conduct an LCA, an inventory of data for all materials and processes within the building is required along with a methodology to estimate the potential environmental impact of these materials and processes.

The general process for conducting a whole-building LCA is as follows (Athena 2014):• Obtain the design information for the proposed building including intended use and project location;

- Conduct material quantity survey to generate a bill of materials (BoM);
- Perform modeling using preferred environmental inventory database (LCI) and impact assessment methodology (LCIA) with or without the assistance of an LCA software tool;
- As an optional step, repeat the above for a reference building and compare the results against the results from the proposed building; and
- Review the results of the LCA against previously set performance targets (or against the reference building) to ensure compliance. If objectives are not achieved, iterate the design.

LCA SOFTWARE TOOLS

Prior to the development of LCA tools, substantial expertise and understanding of the scientific principles was required along with the compilation of an extensive database of reference information in order to complete a WBLCA. In order to streamline the process, software tools have been developed to make LCA accessible to non-LCA specialists in the field. These tools are now widely used by architects, engineers and researchers to simplify the assessment process and access consolidated databases of accumulated industry knowledge on the environmental impacts of building product supply chains. LCA software tools bring the LCI databases and the LCIA methods together and additionally helps practitioners address assumptions, all of which influence the results and outcomes of an LCA. Each of these three elements of the assessment will be described in subsequent sections of this report in greater detail.

Currently WBLCA tools are most effective at estimating the environmental impacts associated with building materials, operational energy use, and operational water use (Athena 2014). LCA development, research and practice has been focused on these areas so far as they tend to contain the largest contributing factors, which are often referred to as 'hotspots' for individual buildings. Embodied carbon analysis focuses strictly on the building materials and excludes analysis of operation energy and water use.

The following section is intended to provide a high-level overview of the current functionality of LCA tools, all of which are under continuous enhancement. The general requirements for LCA tool inputs, LCI databases, scenarios, LCAI methodology, and outputs will each be discussed as they interrelate to each other as shown in Figure 5.

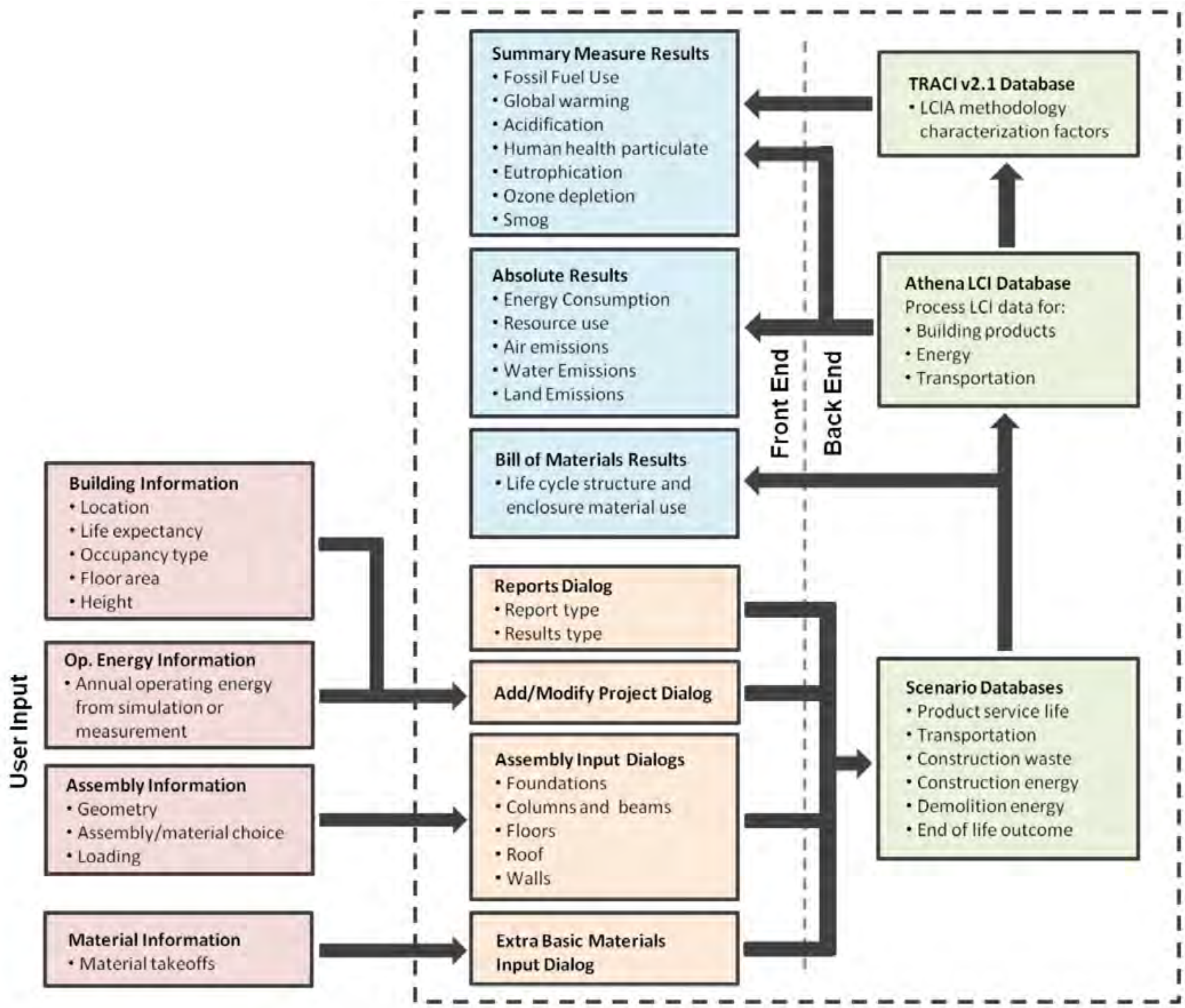

Figure 5: LCA Tool Sample Process from Athena IE4B (Source: Athena 2014)

LCA Tool Inputs

Although each LCA tool varies in its interface setup, the basic inputs related to building information, which are required to conduct an LCA, are similar across platforms. The primary input into all LCA tools is a bill of materials (BoM) for the building, which is to be analyzed on a component basis to determine the environmental impact of each material component and then summed according to assemblies (e.g. total environmental impact of the concrete for the building foundation).

The BoM has traditionally been generated as part of cost estimations through direct quantity survey takeoffs from the building design, with precision increasing as the design becomes further developed and detailed. The proliferation of computer-aided design software and building information models (BIM) has streamlined the process of generating a BoM by using the 3D building model to automatically output a BoM, which, in some cases, is able to automatically interface with the LCA software to input the building material information (e.g. Tally with Revit).

Another functionality of LCA tools is the ability of the software to estimate the BoM without a detailed design, resulting in the ability to conduct analysis earlier in the design process. This is accomplished by using common building typologies and design features to estimate a BoM from building assembly information such as geometry (e.g. floor area and height) and loading (e.g. occupancy type and material choices). Estimating the BoM through building assemblies in the conceptual and preliminary design phases may be beneficial in that it allows for actions to be taken to reduce embodied carbon or other impact categories prior to commitment to particulars of the design. It is to be expected in LCA analysis that the BoM will be revised as the design and construction of the building progresses, which is one of the primary drivers for automating the generation and integration of BoM information into the LCA software in order to reduce the manual effort required to update, iterate and run scenarios for the building.

The location of the building is also a required input for the LCA tool in order for it to estimate the environmental impact based on the presumed use of locally available materials and the transportation associated with mobilization of the materials to the construction site.

Other inputs that can be requested or required by the LCA tool are building life expectancy and operational energy/water information which are often excluded from analysis that focus on embodied carbon emissions.

LCI Databases

LCI databases are constructed of a summation of the resource flows of product systems throughout their life cycle. More simply, they summarize the total transactions of materials, energy, water, as well as the resulting emissions to air, water and land for individual products which are then gathered into a database. LCI is affected by assumptions about the material inputs such as supply chain characteristics, transportation, replacement rates, and end-of-life fate (Teshnizi 2019). It is worth noting the importance of the underlying LCI data be regionally appropriate for the building being studied which can have a significant impact on the environmental impacts of similar products (Athena 2014). For example, aluminum production which are powered by coal and hydroelectric power generation with all significantly differing carbon emissions, particularly if they are from different countries with differing environmental regulations related to coal energy production.

LCI data comes in two basic categories; product specific information and industry averages. In order to standardize the form and information of product specific information, environmental product declarations (EPDs) have been created and standards guide their scope. More specifically, an EPD is defined as a third party verified report providing quantified environmental impacts data using predetermined parameters and, where relevant, additional environmental information for the product being studied (BRE 2016). In the absence of an EPD, environmental impacts for a product can be drawn from direct research and/or estimates based on analysis of similar products. Lastly, industry averages are useful as they can provide more appropriate estimates based on uncertainty. For example, a building design teams is unlikely to specify specific suppliers for key materials since this removes competition in the supply market. However, they should still be interested in determining how the design decisions are likely to affect the embodied carbon of a design, say by substituting materials. Industry averages allow for these assessments to be done without certainty of product supply which can be required for many logistical reasons. Regardless of the form of the data, LCI databases must be compliant with the international standards ISO 14040 and 14044 and should have LCI data of origin to as closely as possible to the project location for accuracy (Athena 2016).

There are two main global-level LCI databases which are EcoInvent and GaBi which have approximately 12,800 and 30,000 datasets respectively from various industry sectors and regions. Both supply a good deal of the data accessed and applicable for use in Canada. In 2011, the Canadian Interuniversity Research Center for the Life Cycle of Products (CIRAIG) also started the development of a life-cycle inventory database for Québec and currently partners with EcoInvent and Athena LCI Databases (Teshnizi 2019).

LCIA Methodology

An LCIA methodology is used to calculate the estimated potency of the stressor for each environmental impact category based on the calculated estimate of the amount of chemical emission or resource used. In North American construction projects, the LCIA utilized is typically TRACI v2.1 for which further detail will be provided. However, it is worth noting that LEED v4.0 includes provisions to allow for alternate methodologies to be used including CML v2001 (or newer) developed by four Dutch ministries and ReCiPe, v1.07 (or newer) developed by the National Institute for Public Health and the Environment of the Dutch government but which are not applied in North America (Athena 2016) but used almost exclusively throughout the rest of the world (GaBi 2019).

The TRACI v2.1 methodology, which was created by the United States Environmental Protection Agency, estimates potency (i.e. the power or concentration of the chemical) based on the best available models and data for each impact category. For some impact categories, including global warming potential, there is international consensus on the relative potency of the chemicals. For other impact categories, the relative potency may be dependent on models related to chemical and physical principles and/or experimental data. In some cases, the individual stressors do not simply have one potency factor, but a varying potency factor by location. Generally, TRACI v2.1 focuses on average characterization of potency for North America (USEPA 2012). However, accuracy of the assessment can be increased by using regional and product specific information in the assessment, which is increasingly being done by the existing and new LCA tools.

Scenarios and Assumptions

Assumptions are required to determine product material and energy use based because estimates of product service life, transportation, construction waste and energy, demolition waste and energy, and end of service life outcomes vary the results. Due to the number of assumption parameters which can be altered and thus adjusting the results of the assessment, these assumptions are assembled into scenario databases (Teshnizi 2019).

LCA Tools Outputs

The common outputs from LCA tools are the estimated impacts in the environmental categories caused by the use of materials, energy and resources. These outputs are generated by assessing the impacts of different potency as determined through the LCIA methodologies with the specific quantities and assumptions from an individual building or product.

For example, multiple GHGs contribute to a detrimental environment impact to various levels, and using the LCAI methodology, these individual impacts are used to determine an overall global warming potential (GWP) reported in kilograms of carbon dioxide equivalence [C02 eq.].

COMPARISON OF LCA TOOLS

The development of LCA tools is continuously in flux, with software development continuously improving existing tools and new developers entering the market. The choice of LCA software by designers and consultants depends on several factors, such as the project's location, availability of a BIM or 3D model, software cost and their own expertise with each software.

The functionality of each tool varies, and a comparative analysis will be provided herein to provide insights into the advantages and disadvantages of a few of the prominent LCA software tools currently available. The analysis has been limited to the leading software tools considering their use in the North American and European markets, albeit others exist but have not yet been adapted for North America or have not yet garnered significant industry users. The comparative analysis of LCA tools for this report includes the following three products; Impact Estimator for Buildings (IE4B) developed by Athena Sustainable Materials Institute from Canada, Tally developed by KT Innovations from the United States, and OneClick LCA developed by Bionova from Finland. The comparative analysis is summarized in Table 3 based on the following page with brief descriptions to follow which highlight the functionality of each software tool.

Although not in widespread use, the Building for Environmental and Economic Sustainability (BEES) which was developed by the Department of Commerce in conjunction with the USEPA is also discussed as it provides an understanding of initiatives by the United States Government.

WBLCA can alternatively be approached from first principles, using LCA practitioner software tools such as SimaPro and GaBi. This is a complex process undertaken by LCA professionals and will require careful adherence to the data, method and boundary provisions of the programs (Athena 2014).

LCA TOOL NAME (DEVELOPER)	IMPACT ESTIMATOR FOR BUILDINGS (ATHENA)	TALLY (KT INNOVATIONS)	ONECLICK LCA (BIONOVA)
LEARNING CURVE	Easy to learn the basics	Easy to learn, requires knowledge of Revit®	Easy to start, wide range of functionality
TIME TO DEVELOP LCA	Slow manual takeoffs, preloaded design options	Quick BIM integration, slow design options	Quick BIM mapping and design options
SOFTWARE INTEGRATIONS	BoM Import	Revit® integration, no BoM import	Many integrations with design software
CREATING A BUILDING MODEL	Define Assemblies and BoM Import	Detailed BIM, Revit® model required	Carbon designer, BoM import, and BIM
DESIGN OPTIONS COMPARISONS	Simple to compare options	Challenging to compare options	Wide range of comparisons
RESULTS REPORTING	Graphs, reports and tree results preview	View detailed graphs and reports	Graphs, reports and ranked EPDs
DATA SOURCES	Proprietary LCI and limited EPDs	GaBi LCI and limited EPDs	Most publicly available EPDs and generic data
COST	Free	$1.0k per year + Revit	$0.7k per year + Revit (optional)

Table 3: Comparison of LCA Tools (Source: Adapted from Pak 2019 – DRAFT)

Impact Estimator for Buildings®

The Impact Estimator for Buildings®, known in short form as IE4B, is developed and managed by the Athena Sustainable Materials Institute. The software has capabilities which allow it to inform the design process, particularly the conceptual design phase, through its use of preloaded building assemblies which can estimate building materials (Athena 2014). Athena has the only market-ready Canada-wide LCI database with about 200 construction materials in its library and IE4B is free for commercial use. However, it is a proprietary database meaning that the underlying data is not available to software tool users which can lead to uncertainty in comparing results against those produced from other tools and sources (Teshnizi 2019).

The Bill of Materials Import feature of Athena allows users to import a BoM from an existing design in a CAD program directly into the software, thereby accounting for all the materials in the building without entering individual assemblies or entering all the materials by hand. This functionality is completed by using the export a bill of materials to an Excel or a delimited text file from the CAD program used for the design (Athena 2019).

Tally®

Tally® is developed and managed by KT Innovations in partnership with Autodesk Sustainability Solutions. The software streamlines LCAs by enabling the collection of a detailed bill of materials (BoM) from Revit® modelling software. Revit was created by Autodesk and it is the most widely adopted building information modelling (BIM) software currently used by architects, engineers and contractors. The use of Tally requires a BIM model in Revit in order to do the calculations, which makes the material quantity extraction and generation of a BoM more straight forward, but is only applicable to projects with an existing Revit BIM model. The accuracy is dependent on the level of detail and precision of the modelled elements in Revit. BIM models often do not reflect the actual volume of materials unless they have been modelled for this purpose, which then required further BoM analysis to improve the accuracy of the LCA input.

Tally utilizes a custom designed LCI database that combines material attributes, assembly details, and architectural specifications. The environmental impact data in Tally is attained through collaboration with thinkstep and use of their GaBi 8.5 2018 database, which is intended to represent 2017 values for the United States. Where representative data is unavailable, proxy data is used. The datasets used, their geographic region, and year of reference are listed for each entry which provides transparency (Tally 2016).

The cost of Tally software is approximately USD$700 per license per year and also requires a current version of Autodesk Revit, which is approximately an additional USD$2,300 per license per year. Educational licenses are available for non-commercial use (Tally 2016 & AutoDesk 2019).

One Click LCA®

OneClick LCA® was developed by Bionova Ltd. for the European market and has recently been adapted to North America. The software relies on publicly available manufacturer specific Environmental Product Declarations (EPDs) which can be used for comparison of product environmental impact.

In North America, One Click LCA utilizes LCI data from the following sources: One Click LCA generic construction materials database, ASTM, CSA Group, IERE Earthsure, FPInnovations, NREL, NRMCA, NSF, SCS Global, UL Environment & Quartz. They also provide the option to license the EcoInvent database to supplement the information provided to improve the localization of the LCI databased used for analysis. All data in the database is used based on a dynamic algorithm which ensures users will only be able to choose data in conformity with the data quality requirements of the target certification they are working with, such as LEEDv4 in North America.

There are several versions of One Click LCA® software which are classified as Starter, Business and Expert software tiers, each within increasing tools, functionality and reporting capabilities; prices are USD$790, USD$1700, USD$3000 per license per year. Similar to Tally discussed above, in order to utilize the BIM model integration functionality provided in the Business and Expert tiers of the software, a current version of Autodesk Revit is also required at approximately USD$2,300 per license per year (AutoDesk 2019). Lastly, One Click LCA Expert includes the Carbon Designer, an early design tool which has similar functionality to the preloaded building assemblies discussed for Athena above and utilizes basic inputs (i.e. floor area, number of storeys, material type) to estimate typical material quantities (Bionova 2019).

Building for Environmental and Economic Sustainability (BEES)

Building for Environmental and Economic Sustainability (BEES) was developed by the National Institute of Standards and Technology of the U.S. Department of Commerce with support from the U.S. Environmental Protection Agency. Initially released in 1997, the software was a pioneering program aimed at supporting decision making to select environmentally-preferred, cost-effective building products. The latest revision of the software was BEES Online 2.0 which was released in 2018 but does not appear to be fully operational based on a preliminary review of the online portal. The software is noteworthy because of its continued use of a blended approach of assessing both environmental impacts and economic performance indicators of a project and then combining them into an overall performance measure using the American Society for Testing and Materials (ASTM) standard for multi-attribute decision analysis (NIST 2018).

SECTION 2: LCA POLICY REVIEW

In this section an overview of the numerous programs and regulations will be provided which are aligned with the objectives of embodied carbon reduction. It is worth noting that not all of these programs require the LCA methodology to be applied nor do they provide quantifiable results on embodied carbon reduction but are none-the-less incentivizing decisions which reduce embodied carbon of buildings. Examples include policies that encourage the use of local and recycled materials, green procurement programs, and policies that aim to reduce and divert construction, renovation, and demolition waste from landfills. These policies are important precursors to embodied carbon policies because they help to build industry capacity and knowledge but will not be discussed in detail within this report.

LCA STANDARDS

Standards aimed at reducing the environmental impacts of the built environment, have historically focused on addressing the operational energy use and emissions of buildings because it has comprised the most significant portion of total carbon usage.

In the last 15 years, there has been significant development in standards for LCAs, which provide frameworks and guidance in the area, as well as the supporting information which is relied upon in completing the assessments such as terminology, methodology, and EPDs.

The network of standards, an example of which is shown in Figure 6, highlights the complicated and interrelated system. Conducting an LCA requires knowledge of a raft of standards to ensure that the implementation of building-level and product-level assessments are compliant with the underpinning standards. This is a considerable undertaking and investigation of the standards reveals that there are some areas where different interpretations are possible (BRE 2016). LCA software tools are of significant advantage in this way, since they integrate these standards and ease the burden on the LCA practitioner. However, practitioners should ensure that the tool and its underpinning standards are appropriate for the regional context to which they are being applied.

A brief summary is provided below for many of the key standards in the LCA field of which practitioners should be aware.

ISO 14040

International Organization for Standardization (ISO) 14040 describes the principles and framework for LCA including: definition of the goal and scope of the LCA, the LCI phase, the LCIA phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements (ISO 2006).

Although ISO 14040 covers LCA and LCI studies, it does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA. The intended application of LCA or LCI results is considered during definition of the goal and scope, but the application itself is outside the scope of this International Standard (ISO 2006).

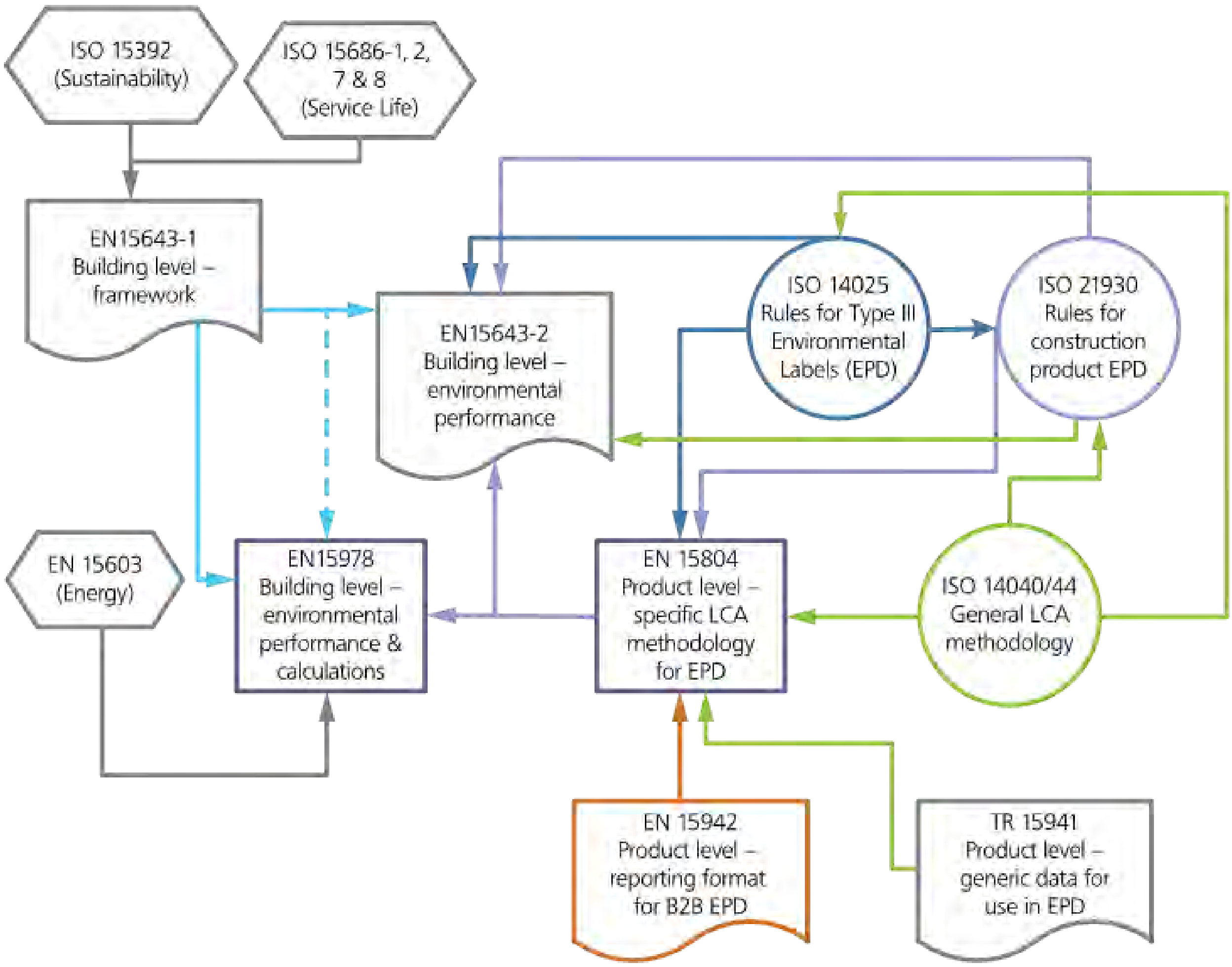

Figure 6: Interactions between environmental assessment EN and ISO standards (BRE 2016)

ISO 14044

ISO 14044 specifies requirements and provides guidelines for LCA including: definition of the goal and scope of the LCA, the LCI phase, the LCIA phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements (ISO 2006).

EN 15643–1 & 15643–2

The European EN 15643 is a two part standard, released in 2010 and 2011 respectively, for the assessment of buildings for the sustainability of construction works. The framework applies to all types of buildings over their entire life cycle. The standards developed under this framework do prescribe levels, classes or benchmarks for measuring performance. Part one being the general framework including social, environmental and economic performance. Part two provides the framework specific to the environmental performance of a building based on specific principles and requirements (BRE 2016).

EN 15804

The European EN 15804 standard provides PCR for all construction products and services. It provides a structure to ensure that all EPD of construction products, construction services and construction processes are derived, verified and presented in a harmonized way (BRE 2016).

EN 15978

The European EN 15978 standard, released in 2011, provides the calculation rules for the assessment of the environmental performance of new and existing buildings and is increasingly becoming the common method for describing the system boundary of WBLCA (Athena 2014). The standard requires identification of a ‘functional equivalent’, i.e. reference building, for the building to enable a valid basis for future comparisons to other buildings.

ASTM E2921

The American standard ASTM E2921-16a provides criteria that building design teams shall use to compare the environmental impacts associated with a reference building design and a final building design, including additions to existing buildings where applicable. It provides minimum requirements when conducting WBLCA for the purpose of attaining building rating system and code compliance and deals specifically with material selection for initial construction, including associated maintenance and replacement cycles over an assumed service life (ASTM 2016).

GREEN BUILDING CERTIFICATIONS

The demand for accountability and consistency in sustainable building practices has resulted in the proliferation of building certifications with each program typically operating on a voluntary compliance basis. Although there is significant overlap in the methodologies and general objectives of these systems, they vary in the specific building performance objectives and geographic region applicability. This review addresses only those which have specific requirements, albeit often optional for the overall program, related to WBLCAs and reduction of embodied carbon in buildings.

LEED® Building Design & Construction: Building Lifecycle Impact Reduction Credit

Leadership in Energy and Environmental Design (LEED) is the dominant voluntary green building rating system in North America and is used extensively internationally. Numerous Canadian cities have incorporated LEED into their green building policies and some municipalities and provinces, including the Province of British Columbia, require new government buildings to be LEED certified (Zizzo 2017).

In 2013, the release of LEED Building Design & Construction (BD+C) v4 (USGBC 2013) included a new materials credit for Building Life Cycle Impact (LCI) Reduction with the intent to encourage adaptive reuse and optimize the environmental performance of products and materials. The credit provides the following options:

- Option 1 - Historic building reuse (5 points)
- Option 2 - Renovation of abandoned or blighted building (5 points)
- Option 3 - Building and material reuse (2–4 points)
- Option 4 - WBLCA (3 points)

Option 4 serves as incentive for design teams to undertake WBLCA of the structure and enclosure for new construction projects. In order to be awarded the three points within the LEED framework, a minimum of 10% reduction must be demonstrated in comparison to a reference building, in at least three of the six impact categories, one of which must be global warming potential. No impact category assessed as part of the life-cycle assessment may increase by more than 5% compared with the baseline building. At least three of the following impact categories must be selected for reduction:

- Global warming potential (mandatory);
- Depletion of the stratospheric ozone layer or ozone depletion;
- Acidification of land and water sources;
- Eutrophication;
- Formation of tropospheric ozone or smog potential; and
- Depletion of nonrenewable energy resources.

The credit requires that the reference and proposed buildings must be of comparable size, function, orientation, and operating energy performance as defined in LEED EA Prerequisite Minimum Energy Performance. The service life of the baseline and proposed buildings must be the same and at least 60 years to fully account for maintenance and replacement. The same life-cycle assessment software tools and datasets shall be used to evaluate both the reference building and the proposed building, and report all listed impact categories. Data sets must be compliant with ISO 14044 (USGBC 2013).

The LEED steering committee strives to balance the capacity of the industry, such as expertise in conducting LCAs, with the urgency for action due to the severity of the environmental impacts which the actions are to mitigate. With the release of LEED v4.1 in 2018, the Building LCI Reduction credit was significantly revised, including Option 4, as follows with the intent of increasing voluntary adoption of the credit (USGBC 2018):

Option 4 - WBLCA (1-4 points)

- Path 1: Conduct a LCA of the project's structure and enclosure (1 point).
- Path 2: Conduct a LCA of the project's structure and enclosure that demonstrates a minimum of 5% reduction, compared with a baseline building in at least three of the six impact categories, one of which must be GWP (2 points).
- Path 3: Conduct a LCA of the project's structure and enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building, in at least three of the six impact categories, one of which must be GWP (3 points).
- Path 4: Meet requirements of Path 3 while demonstrating a 20% reduction in GWP. Also incorporate building reuse and/or salvage materials into the project's structure and enclosure for the proposed design (4 points).

The revisions to the Building LCI Reduction credit in LEED v4.1 provide alternative credit routes which require less effort and less stringent performances requirements while also reducing the points for these pathways.

Lastly, the LEED Building LCI Reduction credit has been identified as one of the six regional priorities for the Lower Mainland area of British Columbia which provides an extra credit when a minimum three point threshold is achieved which further incentivizes projects to pursue this credit within the region.

CaGBC's Zero Carbon Building Standard

The Canadian Green Building Council (CaGBC) Zero Carbon Buildings Standard is intended to assist in the transition to lower-carbon buildings while reducing GHG emissions in Canada by 30% by 2030. The CaGBC standard provides a path for buildings to be certified as zero carbon through design (for new construction) or performance (for existing buildings). The framework addresses embodied carbon as one of five building carbon footprint components. It requires applicants seeking certification to report their Energy Use Intensity (EUI) to promote transparency and knowledge growth on zero carbon buildings within the industry (Zizzo 2017). At this point, no reduction in embodied carbon is necessary, however the collection of data is useful to build a benchmark of embodied carbon emissions of buildings in Canada. This also familiarized the building industry with the term and measurement of this indicator in preparation for reduction requirements in the future.

International Living Building Standards

As part of the materials requirements of the Living Building Standards, projects must calculate the total embodied carbon and purchase an offset for 100% of that value from an approved provider of offset credits. Based on research conducted by Zizzo Strategy Inc., the Living Building Standards may be the only rating program that mandates embodied carbon measurement and offsetting (Zizzo 2017).

BREEAM

Building Research Establishment Environmental Assessment Method (BREEAM) was first published by the British company Building Research Establishment (BRE) in 1990. Although BREEAM remains a primarily European rating system, it is used in more than 70 countries. Furthermore, several countries including the Netherlands, Spain, Norway, Sweden and Germany have developed their own country specific BREEAM schemes which are adapted to the local context.

BREEAM UK New Construction introduced building LCA into the scheme in 2011 which incentivizes projects to start the materials design using LCA at the conceptual design phase (BRE 2018). The LCA requirements, based on EN 15978, utilizes a comparative design basis without mandatory minimum performance requirements, but does required that a pre- approved LCA tools be utilized for the assessment (Zizzo 2017).

The BREEAM UK New Construction has Mat 01: Environmental impacts from construction products - Building life cycle assessment which offers the following credits to projects (BRE 2018):

- Comparison of the LCA results with a benchmark during concept design and technical design (only offices, retail and industrial buildings)
- Comparison of the LCA results with a benchmark during technical design (all buildings)
- Comparing concept-level superstructure options during concept design
- Comparing detailed superstructure options during technical design
- Comparing concept-level substructure and hard landscaping options
- Comparing concept-level core building services options (exemplary credit)
- Aligning LCA and LCC for the options (exemplary credit)
- Third party verification of the accuracy of the LCA work (exemplary credit)

CURRENT LCA POLICY AND FUTURE TRENDS

Global Context

Although monitoring of embodied carbon is still an emerging field in Canada, as will be discussed in the following sections, it has already been widely adopted in other countries. Systems to monitor embodied carbon are already in place in twenty-six countries encompassing all continents, except Africa. Nationally standardized systems are found in European countries including Germany, Finland, France, the Netherlands, Belgium, Norway, Sweden, and Switzerland. Furthermore, there has been a significant recent expansion and adoption of embodied carbon systems globally as indicated by the more than doubling of such systems in the last 5 years. Review of these international systems for addressing embodied carbon resulted in the following categorizations of methods, identified and listed here according to increasing efficiency (Bionova 2018):

- Carbon reporting |Calculate the construction project's embodied carbon and report it;
- Comparison in design | Calculate difference in embodied carbon of proposed design against a self-declared reference design;
- Carbon rating | Calculated embodied carbon is compared against a scale from best to worst to determine rating without maximum value being applied;
- Carbon caps | Calculate embodied carbon to verify that is does not exceeding the predetermined CO2e limit; and
- Decarbonization | Reduce embodied carbon to a minimum, then compensate all residual emissions by own energy export or buying offsets.

Canadian Context

The federal government of Canada has recently provided funding to the National Research Council (NRC) to undertake research focused on embodied carbon reduction through the Low Carbon Assets through Life Cycle Assessment (LCA)2 Initiative. The (LCA)2 has funding for four years, ending in 2023, with the mandate to (NRC 2019):

- Execute research required to fill knowledge gaps;
- Develop datasets, LCA guides and benchmarks;
- Raise awareness and build capacity for LCA;
- Support uptake and best practice; and
- Support creation of new design tools, or the revision of existing tools, as required.

The desired outcome of the (LCA)2 initiative is to create high quality, regionally appropriate LCA data, guidelines, tools and direction on how to integrate LCA into procurement decision making to minimize embodied carbon. Figure 7 below depicts the organization structure and the interconnectivity of research and outputs from the (LCA)2 initiative. It will be used to construct a framework to enable low-carbon procurement with the objective of achieving meaningful reductions in embodied carbon in green buildings.

Partnership has been prioritized as part of the (LCA)2 initiative in order for it to be successful in enabling both the public and private sectors to incorporate embodied carbon assessment into their procurement processes. The (LCA)2 program will be a collaboration between federal, provincial, and municipal levels of government, academia, materials industry stakeholders (i.e. aluminum, concrete, steel and wood associations), tool development industry and NGOs in order to ensure the outputs of their research are successfully supporting and integrating with the initiatives already underway by these entities, many of which have been leaders in the LCA field.

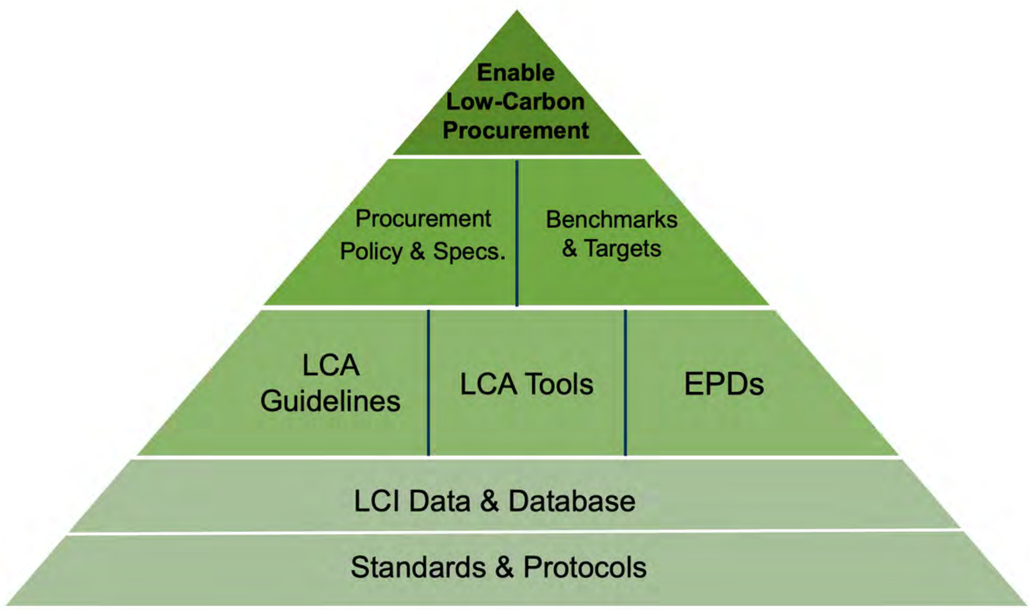

Figure 7: (LCA)2 Initiative approach framework to enable low-carbon procurement (Source: NRC 2019)

The (LCA)2 initiative framework begins with understanding and aligning with existing standards and protocols to avoid duplication of effort in the subsequent areas. Using this common basis, the initiative intends to develop regionally or provincially specific LCI databases, starting with average based data, and moving into product and supply chain specific data, to improve accuracy of the dataset over time. The research will exclusively focus on structural, envelope and select other key building materials in its initial phase. Once released, this information will be publicly accessible and will be available to LCA practitioners to use in their calculations of embodied carbon. It is anticipated that LCA tool providers will supplement their LCI with this information which will improve assessment accuracy, consistency and transparency; issues which are discussed in more details in the Challenges of LCA Application section of this report.

Regional Context

The City of Vancouver is a leader in North America in setting municipal policies to reduce GHG emissions. Vancouver established targets through the Zero Emissions Building Plan to reduce operational emissions from new buildings by ninety percent by 2025 using emissions from 2007 as the benchmark. Furthermore, Vancouver is targeting zero operational emissions for new buildings by 2030 (CoV 2016).

Vancouver acknowledges that embodied emissions are proportionally increasing as a component of the overall building life-cycle emissions due to operational efficiencies, which are being realized through innovations and optimization. As a result, municipal staff are beginning to collect data from new developments in order to inform future incentives, policies, and if required regulatory mechanisms, which would work in combination to reduce the embodied emissions of new buildings.

Vancouver's Green Building Policy for Rezoning (GBP4R) requires development projects applying for rezoning to be designed to and meet low-emissions green building standards such as LEED Gold certification and International Living Building Standards. As one of the first embodied carbon policies in North America, the GBP4R requires that GWP impacts for each building be estimated using WBLCA (CoV 2017). For consistency in LCA calculations, projects must:

- Include all envelope and structural elements, including footings and foundations, and complete structural wall assemblies, structural floors and ceilings, 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;
- Assume a building lifetime of 60 years. If the service life of a product used in initial construction is greater than the building's assumed service life, the impacts associated with the product may not be discounted to reflect its remaining service life;
- Use an assessment boundary which accounts for cradle-to-grave impacts, including resource extraction, product manufacturing and transportation, building construction, product maintenance and replacement, and building demolition/deconstruction/disposal (EN 15804/15978 modules A1-A5, B2-B4, and C1-C4). Operational energy and water consumption are excluded.
- Use an LCI database that is ISO 14040, 14044, and 21930 compliant, and regionally-specific, if possible; and
- Use TRACI for LCIA.

Projects are also encouraged, but not required, to report:

- The lifecycle impacts associated with other building elements that are excluded from the mandatory embodied carbon reporting;
- Other environmental impacts, such as ozone layer depletion, acidification, eutrophication, photochemical ozone creation, primary renewable energy use, fresh water consumption, human toxicity, respiratory inorganics, eco-toxicity, and other impacts; and
- A breakdown of impacts by activity, life-cycle stages, product category, and material type.

For projects pursuing LEED v4, calculations created to demonstrate achievement of the Building LCI Reduction credit, Option 4, are acceptable to meet the intent of the embodied carbon requirement. The policy requirements vary depending on the type of building with the policy being more strenuous for projects over 152 metres (500 ft) tall (Zizzo 2017).

Lastly, Vancouver recently established an ambitious target for new buildings and construction projects to achieve reduction in embodied carbon emissions by 40% by 2030, as part of the Climate Emergency Response (CoV 2019). These reductions are to be in comparison to a 2018 baseline. Although no actions have yet been set in order to achieve this target, this document does also direct municipal staff to report back to council by Fall 2020 with recommendations for embodied emissions reductions.

UBC's Sustainability Policy and LCA Requirements

UBC is a leader in a global network of post-secondary institutions that have turned their campuses into research, development and demonstration sites for sustainable behavior, infrastructure and community (UBC 2014). The Campus as a Living Laboratory approach challenges the UBC community to develop interdisciplinary collaboration that use campus buildings and infrastructure to advance research and learning opportunities, including demonstrations of innovations in design and technologies. As an agent of change, the University aspires to teach future sustainability leaders, and also to work with private, public, NGO and community partners to learn together how to foster sustainability in the larger world outside the campus (UBC 2014).

In 2010, as part of the UBC Climate Action strategy, the target was set to become a net zero campus by 2050 (UBC 2010). The requirement for carbon neutrality states that all GHG emissions will either be reduced or offset – essentially making the overall target of 100% reduction. UBC continues to monitor their performance against this target and has reduced its GHG emissions 30% as of the end of 2015 below 2007 levels (UBC 2019).

UBC has also recently approved a Green Building Action Plan (GBAP) in response to both the urgency for climate change action and as a guiding document to assist in achieving the goal of becoming a net zero campus by 2050. The GBAP outlines a holistic pathway for buildings at the Vancouver campus to make net positive contribution to human and natural systems by 2035 (UBC 2018). The plan encompasses both institutional buildings on academic lands as well as residential and mixed-use buildings in neighbourhoods within the campus. The vision outlined in the GBAP is articulated through goals, targets, and actions within the following component areas: energy, water, materials and resources, biodiversity, health and wellbeing, quality, climate adaptation, and place and experience, which are shown in Figure 8.

Embodied carbon is specifically addressed within the materials and resources component area of the GBAP with the following identified actions:

- For institutional buildings, implement policies for reduced embodied carbon in buildings, starting with a requirement to report embodied carbon, followed by incremental reductions.
- For residential buildings, create an integrated policy for building materials that considers reduced environmental impact, healthy material requirements, and life cycle analysis.

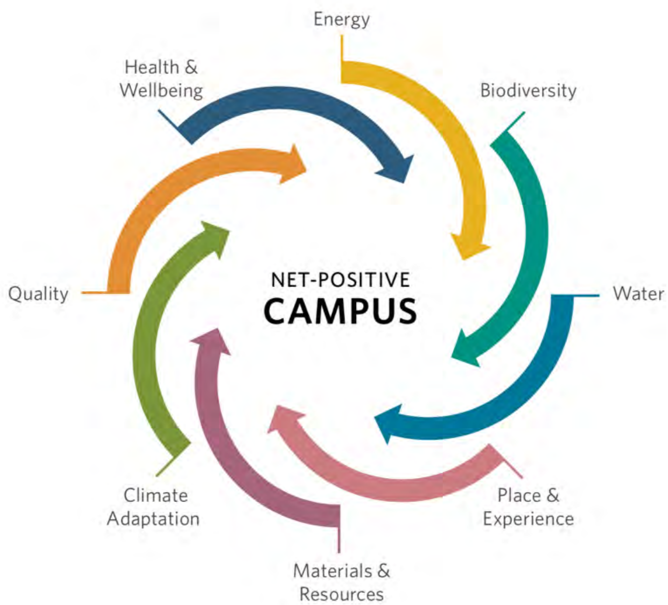

Figure 8: UBC Green Building Action Plan Component Areas

UBC also requires, through the UBC Technical Guidelines, that the target design life for the structure and envelope must be a minimum of a 100 year service life which will be outlined during the design phase in a service life plan that should include planned replacements (UBC 2017). Durability and the performance requirements for building elements such as the structural system are therefore critical to achieving the mandated lifespan. The extended lifespan in turn reduces the embodied carbon emissions from a building due to reduced requirements for replacement or repair.

Academic Buildings

UBC requires LEED Gold Certification for new construction and major renovation projects according to the current version of the UBC LEEDv4 Implementation Guide (UBC 2016). The Guide is intended to provide project teams with UBC-specific direction on LEED credits for the campus, clearly identifying credits that are mandatory and/or priorities because they align with UBC policies. The requirement for LEED Gold Certification by UBC is reinforced by mandate from the Province of British Columbia that all new campus construction and renewals are required to be LEED Gold or equivalent certified (BC 2008).

Materials and Resources Credit for Building Lifecycle Impact Reduction are required to comply with LEED BD+C v4 - Option 4 for WBLCA, which is worth 3 points. The UBC LEED Implementation Guide encourages project teams to identify a specialist to facilitate the LCA analysis early in the design process, and link this effort to the Integrative Process credit, as well as align it with the UBC Sustainability Process for Major Capital Projects (UBC 2016). LCA specialists tend to be consultants with specialized knowledge of the LCA process and software tools which can provide both guidance and technical skills to assist in the reduction in the environmental impacts from the construction of the building project. The role of LCA specialist may be a separate individual from a sustainability consultant, who often are more generalists in the overall green building process and best practices.

Residential Buildings

The University of British Columbia has developed the Residential Environmental Assessment Program (REAP) which is a framework for mandating and measuring sustainable building practices for market-based and staff/faculty/student residential developments. REAP is similar in structure to other green building rating systems like LEED but was designed specific to meet the objectives of the University and be applicable to multi-family residential buildings built in the campuses neighbourhood.

All multi-family residential development projects at UBC must participate in the program and must achieve at least a REAP Gold Certification through obtaining both mandatory and optional credits. Although the choices made to achieve many of the REAP Credits will influence the environmental impacts of a development project, those most directly relate to embodied carbon are found in the Materials and Resources (MR) category with the following credits categories:

- MR 1 – Recycled Content and Reused Materials, which provides credits if thresholds for material reuse and recycled material content are achieved;
- MR 2 – Regional Materials, which provides points for locally manufactured and/or sourced materials from within an 800 km radius of campus;
- MR 3 – Certified and Non-Endangered Forest Products, which provides credits for provision of lumber, plywood, hardwood, and flooring which is certified as meeting the requirements of CSA Z809 or the Forest Stewardship Council;
- MR 4 – Building Product Ingredients, which provides credits for use of products that contain or generate less potentially harmful chemicals.

Although all the MR credits are optional as part of the REAP system, they are in general alignment with best practices to mitigate environmental impacts of construction and many would also reduce the embodied carbon of a building.

Furthermore, in the Innovative and Design Process category, credit ID 1.1: Life-Cycle Assessment allocates 4 points for performance of an LCA for the project's structure and enclosure. In order to receive the points, it must be demonstrated that a minimum of 5% improvement over a reasonable reference building was achieved for three of the five environmental categories, which are aligned with the LEED LCI credit. Documentation of the LCA must be provided no later than the building occupancy phase (i.e. post-construction) in order to achieve the points. Credit ID 1.1 is an optional credit and none of the developments on campus to date have voluntarily opted to pursue the credit.

The current version of REAP is version 3.1 and is under review to be updated for improved alignment to the University's vision and sustainable development goals. REAP version 4.0 is planned to be in place for the upcoming Stadium Neighbourhood, and it is intended to add credits for climate adaptation and embodied carbon.

SECTION 3: DISCUSSION OF CHALLENGES AND OPPORTUNITIES

CHALLENGES WITH LCA APPLICATION

This section outlines some of the challenges of LCA application, identified throughout the literature review, interviews with key stakeholders and review of LCA software tool recommendations.

Software Tools

The existence of multiple software tools in the LCA market is creating competition but is also leading to implementation challenges. Each tool provides a unique combination of interfaces, input requirements, assumptions, LCI databases, LCIA methodologies, and output information; these combination of differences leads to varying results depending on the tool which is used for the assessment. Owners, including both UBC and the City of Vancouver, are hesitant to dictate the required tool for assessment but also want consistency and comparability of results between projects, especially when developing policies and targets.

As LCA practice is relatively new, tools are altered and updated in order to make each program more competitive in the market. LCA users are encouraged to continually transition with the software updates since the most current versions should generally render the most accurate results, but updating creates challenges in tracking or comparing results from one project to the next. This limits the reliability of the data for benchmarking and performance targets due to variances in the underpinning assumption and information which are used to generate the LCA results.

LCI Databases

Although LCA is a science, assessments are generally conducted using best estimates of environmental impact and not direct measurements in order to make the assessments cost effective (Athena 2014). The LCI databases behind these estimates are constructed by utilizing data from a variety of sources, some of which is public information while some is not, which results in hybrid databases. Some LCA tools use LCI databases that are proprietary and a “black box” to those conducting the assessment, and even those that are open source may be difficult to navigate. This makes it challenging for users to understand the causes of the results or why there are variations between different products or buildings.

There is an effort both internationally and within Canada to address this issue through transparency of data, and development of a national level, Canada-specific database (EcoInvent, Thinkstep, EC3, CIRAIG & NRCC 2019). It should be noted that this report can make no assertion on the varying levels of accuracy which can be achieved based on different data sources for each tool.

Hybrid LCI databases also use a combination of impact information, some of which is based on regional or national averages, while other information is locally or product specific (NRCC 2019). Results generated based on the average data will lack the precision of the locally specific information and therefore may not accurately estimate the actual environmental impact of the project. For example, the method with which a forest is harvested has significant implications on the environmental impact of a wood product and therefore the differences in forestry practices between regions or manufacturers could be meaningful when compared individual but obscured when assess through a singular industry average. Conversely, locally specific information may not be applicable to localities outside that of their intended use and risk providing an inaccurate assessment of the environmental impact of the project.

Environmental Product Declarations (EPDs)

EPDs are intended to provide transparent information on individual products to allow for consumers to better understand the environmental impacts of the products which they are purchasing. An EPD is to be completed in accordance with product category rules (PCR) that establish which stages of a product's lifecycle are included and which are excluded from the LCA. A PCR is created by program operators such as the International EPD System, which is from Sweden. Challenges arise when multiple PCRs exist for the same product, although this is rare, as there is no limitation to the number of program operators which can issue a PCR for a product and there is not always universally agreement on what impacts and parts of the process should be included in the analysis. For example, the burning of wood waste to dry new wood products is considered carbon neutral according to some PCRs but certainly does generate carbon emissions (Milton 2015).

Coordination is required to address reliability and consistency issues with EPDs, which could benefit from governmental leadership. In Belgium, the government is actively focused on improving EPDs through legislation which sets out rules around environmental claims and the establishment of a national EPD database in alignment with international standards. Any manufacturer that wishes to make an environmental claim about a product must first upload an EPD to the database (Zizzo 2017).

Independent verification of EPDs also remains an issue (NRCC 2019). Generally program operators only require a review of paperwork submitted by a manufacturer to ensure PCR requirements are met, and no further analysis or on-site verification of claims is performed.

Lastly, as material re-use and recycling processes improve, the quantification of the environmental impact of these repurposed materials, especially those which do not have EPDs, becomes more important. There are generally deemed to be benefits in the re-use or recycling of materials, but the reality may be more complex, in particular as materials with greater environmental risk factors are considered for reuse, which may require significant refinement and transportation.

Assumptions

All LCA methodologies and tools, including both WBLCA and EPDs utilize assumptions to predict the performance of a building over its life cycle. The scenarios produced by the LCA tools rely on these assumptions, such as maintenance requirements or replacement rates throughout the lifecycle of the project or end-of-life outcomes (e.g. recycling or landfill), which may or may not change with technical advancements and other innovations. In the absence of certainty in these areas, significant assumptions are required in scenario generation for LCAs which lead to uncertainty in the results. These assumptions are not always clear for LCA tool users, nor are the impact that they have on the results.

Undefined Decision Frameworks

In practice, the ability to quantify the environmental impacts using LCA methodologies and tools does not necessarily lead to straightforward environmental impacts decision making. LCA results can be complex, and the importance of every impact category may or may not carry the same weight, depending on the specific circumstances of the project, as well as regional and global priorities. Additionally, the individuals or organizations responsible for these environmental decisions often do not have established valuation criterion to assess the tradeoffs which frequently occur between the environmental, societal and economic pillars of sustainability (Purvis 2019). These will not be discussed at length within this report but as a first step prior to any organization conducting an LCA, the environmental impact categories of priority need to be identified so that they can be included. The prioritized impact categories should reflect the values of the decision-making individuals or organizations, while considering their mandates, regulations and guidelines.

Furthermore, LCA are also used retroactively to justify a design decision based on environmental, social and economic criterion. This may be useful for setting future precedents and as a policy justification for integrating LCA into the earlier design phases of projects, but when an assessment is completed retroactively it does not provide an opportunity to alter course or to actively guide the design process or decision making for a project or organization in meeting their environmental targets.

OPPORTUNITIES FOR LCA IMPLEMENTATION AT UBC

LCAs may be used in different ways, all of which strive towards improving decisions in order to reduce the environmental impacts of buildings. In general, LCAs can be used:

- To inform decisions during the design process;
- As a post-construction assessment of building performance; and
- To set policy benchmarks and targets for building typologies.

Fully integrating LCAs into the project delivery processes for all new buildings would potentially utilize each of the above three methods of assessment. Information from past projects would be used to inform design decisions on new projects, tracked to confirm performance and then subsequently used to update benchmarks, in an iterative and adaptive learning process. However, it may not be feasible to implement each of these three applications LCA immediately. Therefore, it is recommended that further analysis and engagement be completed to determine which methods bring the most initial value (i.e. reduction of embodied carbon and other environmental impacts) and advance UBC towards its policy goals.

Based on the information reviewed in preparation of this policy review and conducted as part of an Embodied Carbon Pilot research project, the following opportunities for policy improvements in the implementation of LCA at UBC were identified.

Develop a database of project information which can be used to establish policy targets and benchmarks for embodied carbon (and other environmental impacts):

- Collect LCAs from project consultants to gain insights into results and fundamental assumptions of the assessments. Submittals should include actual LCA tool files along with the information submitted to LEED for credit certification, and could may be used as validation of whole-building performance to meet UBC targets of net zero for both buildings by 2035 and the entire campus by 2050.
- Create a new submittal requirement for all new buildings (including those in the market-based developments) which includes the BoM of the major building components and the carbon intensity of those materials, which would act as a starting point for better comparability between projects and establish average carbon intensities of different typologies. In order to improve consistency, it is recommended that a standardized format be created so that all consultant submissions provide complete, consistent and easily manageable data.
- Revise the UBC LEED Implementation Guide to make the Building LCI Reduction credit, Optional 4 – Pathway 3 under LEED v4.1 a minimum requirement for UBC projects.
- Consider internalizing LCA assessment and/or review processes to improve consistency, institutional understanding and transparency. This may be a long term consideration depending on the rate of development on campus and integration of LCA into the sustainability framework for new buildings or an alternative to pursuing a more prescriptive approach to LCA requirements, criteria and reporting.

Leverage UBC dual role as a major developer and a research university to improve best practices in the implementation of LCA in design and policy:

- Identify opportunities for alignment with other polices and standards. Alignment of regional policies is likely to improve the outcomes of any program as developers, designers and contractors operating in the region gain familiarity and are able to translate learning between projects in different jurisdictions.
- Monitor developments in LCA tools, industry capacity (i.e. designer and consultant knowledge and skills) and manufacturer transparency (i.e. LCIs & EPDs) to identify opportunities for improvement in existing embodied carbon analysis, and advance policy requirements.
- Support governmental initiatives, such as $(LCA)^2$, working on the standardization of assessment methods and inputs, and to improve benchmarks for data gathered by other municipalities and institutions.
- Support academic research that advances LCA methodologies, tools, databases, and applications, especially when addressing one of the above points.

As the inclusion of embodied carbon targets becomes more common and LCA tools and databases improve, there are additional areas of potential future research and piloting that can be supported through policy:

- Request that project teams develop end-of life plans, which document information on the building materials in terms of materials composition, deconstructability, reusability and recyclability.
- Produce performance-based specifications for construction materials that integrate environmental objectives, such as reducing embodied carbon emissions, into product procurement requirements. These specifications should be created in collaboration with design experts and engineers to avoid mandating non-viable requirements which would unduly restrict design flexibility and may in turn be counter-productive to the objectives.
- Consider integrating analysis of LCA into UBC Sustainability Process for major projects in a similar manner to that of operational energy. Sophistication of assessments for WBLCA may have not yet reached the required level of accuracy, certainty of results and streamlined process yet, but may overcome these deficiencies in the near future.
- Through partnership with local municipalities and other organizations, develop industry facing guidelines for WBLCA and Embodied Carbon, based on benchmarks and performance targets.

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Interviews

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APPENDIX A : STRATEGIES AND BEST PRACTICES FOR REDUCING EMBODIED CARBON

RECOMMENDED STRATEGIES

The collective industry experience of professionals who have worked on LCAs is rapidly expanding as the field continues to mature. The body of knowledge gained through this experience has been condensed into best practices which can be used as general guidance in the absence of more detailed analysis. Best practices should not be construed as universally applicable, but can be beneficial for governing bodies, developers, owners and professionals all of whom may have limited experience in LCA but who are interested in reducing the environmental impact of building development.

There are multiple strategies for reducing the embodied carbon in building materials which can generally be sorted into the following categories (Athena 2017):

- using less material in a building;
- rehabilitating existing buildings rather than building new;
- material manufacturing changes;
- material durability and
- designs that enable durability through adaptability;
- design that enables durability of materials (e.g. accessibility for maintenance, adaptability for changes in occupancy);
- design for deconstruction and product capture for reuse;
- product substitution;
- waste minimization; and
- reuse of waste.

These strategies above can be achieved through actions taken by governmental leadership and through proactive integration of LCAs into the design process by owners.

As an additional reference, the BC Ministry published the Environment and Climate Change Strategy guide which also provides guidance on using low carbon materials, specifically focused on achieving LEED v4.0 credits, with a focus on wood and Portland-limestone Cement (Equilibrium 2017).

Governance Strategies

1. Promote development of industry knowledge and encourage capacity building in the field of LCA through a strategic and staged implementation of incentives, policies and regulatory requirements.

2. Set open compliance requirements to verify outcomes of the LCA to ensure that the results can be verified while avoiding ‘black box’ methodologies which limit the value, repeatability, and future comparisons to the analysis.

3. Develop embodied carbon benchmarks and set targets or caps for common building types to discourage the use of carbon-intensive designs and constructions. Setting energy ratings and mandatory maximum energy consumption for buildings has been an effective means of reducing energy consumption of new buildings and by extension the same process can be applied to reduce embodied carbon. However, it is important to note that limiting carbon may result in increases in other environmental impact categories and therefore is best when done in collaboration with a WBLCA which considers these other impacts.

4. Consider renewal source resource availability, supplies, and sustainable extraction to avoid implementing policies which shift demand patterns beyond the available sustainable resource yield levels. Allocate resources to the monitoring, study and proactive restocking of sustainable materials sources. For example, premature harvesting of forests to meet increased short-term demand would result in harvests which have less than the maximum sustainable yield and further deplete the ability to meet future renewable resource demands. Hence, we would need to plan ahead and start planting more trees now to meet the demand in the coming decades (Milton 2018).

Owner Strategies

5. Convene design professionals including architects, engineers, and sustainability consultants early in the project to identify and action opportunities for efficiency prior to commitment to any option. The early phase of the project greatly influences the embodied carbon impacts for better or worse. Opportunities to reduce the impacts are available later on, but their overall impact tends to be more limited and less cost-efficient (Bionova 2018).

6. Consider multiple environmental impacts beyond simply carbon emissions and strive to ensure that all product impacts are included in the LCI.

7. Choose action, even small actions, over no action. When a thorough WBLCA is not able to be integrated into the project, consider assessment of only the structural systems since they almost always comprise the largest source of embodied carbon in the building—up to 80%, depending on the building type (Melton 2018).

8. Design to mitigate end-of-life impacts through planning for service life extension and consideration of flexibility, adaptability, reuse, disassembly, recyclability.

9. Reduce construction impacts through review of mobilization, demobilization, sequencing requires and attempting to minimize waste materials, particularly those associated with temporary works.

Material Selection Strategies

Reduction of Resource Use

10. Choose and specify low-carbon products, including innovative new materials, through analysis of manufacture specific EPD data instead of relying on anecdotal product knowledge.

11. Source and use locally available, natural, recycled or reused materials wherever possible.

12. Nested and lightweight components reduce the impacts of material transportation.

13. Avoid overdesigning building form and design of layout plan.

14. Avoid disposable components requiring regular replacement.

Concrete Design Best Practices

15. Concrete has a large carbon footprint because of the process used to make the binder portland cement which by some estimates is responsible for five percent of total global CO2 emissions. Replacing some cement with supplemental cementitious materials (SCMs) like fly ash or blast-furnace slag will reduce the embodied carbon of the concrete (Melton 2018). Cure times and subtle color differences can be a barrier when using SCMs but in many cases, such as foundations, these are not significant barriers.

16. Consider working with the structural engineer on a performance-based concrete specification that sets environmental requirements. It is also important to use an honest baseline when conducting comparative analysis since 100 percent cement concrete mixes are rarely used in construction (Melton 2018).

Steel Design Best Practices

17. Carbon footprint of the steel manufacturing process varies significantly based on the process used. Consider specification of recycled steel, particularly for concrete reinforcement. Also consider sourcing steel from facilities that utilize electric arc furnaces (EAFs), opposed to basic oxygen furnaces (BOFs), where the electrical grid which supplies power for manufacturing is powered by clean forms of energy. (Milton 2018)

18. Consider minimizing moment frames because they require more steel than shearwall and braced-frame systems to achieve equivalent serviceability. Moment frame systems consist of columns and beams without diagonal members which minimizes obstructions and are used to create open-space floor plans. The industry range for cost increase between braced and moment frames can vary, but is typically between 200 percent and 400 percent with the costs being associated with additional materials and labour for erection of the structure (Richard 2014)

Renewable Materials Design Best Practices

19. Ensure that assessments do not unduly reward the use of renewable materials by discounting the true impacts of their extraction, processing and manufacturing. For example, once the wood is harvested, it requires significant energy to be kiln-dried; most of this energy comes from burning waste wood, which is given a free pass as “carbon neutral” by the U.S. Environmental Protection Agency (Milton 2018).

Enclosure Design Best Practices

20. Building enclosures are generally contribute the second most embodied carbon to a building after the structural system in part due to the high embodied carbon of aluminium which is used for curtainwall systems. They also have high operational impacts, so it’s best to minimize their use. (Milton 2018)

21. Seek alternatives to foam insulation due to the associated blowing agents which have high embodied carbon, particularly extruded polystyrene (Milton 2018).

22. The impact of cladding can be reduced by selecting lightweight materials which reduce the load on the structural system of the building. In some cases, decorative cladding can be eliminated altogether.