UBC EMBODIED CARBON PILOT

Summary Report

THE UNIVERSITY OF BRITISH COLUMBIA
Sustainability Hub

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AUTHORSHIPS

This report summarizes a three-year study conducted by the University of British Columbia's Sustainability Hub (formerly UBC Sustainability Initiative) and involved a comprehensive research team of staff and students:

- Angelique Pilon, Director, Urban Innovation Research
- Binoy Mascarenhas, Interim Director, Urban Innovation Research
- Diana Lopez, Research Manager
- Zahra Teshnizi, Research Manager
- Megan Badri, Research Technician
- Rashmin Sorathiya, Research Technician

UBC Student Research Assistants:

- Aljhon Lorenzana, Department of Civil Engineering
- Anber Rana, Department of Civil Engineering (UBC Okanagan)
- G. Mackenzie Walker, School of Community and Regional Planning
- Gavin Pattman, School of Architecture and Landscape Architecture
- Hassan Al Bqaei, Department of Civil Engineering
- Krista Kals, School of Architecture and Landscape Architecture
- Mandi Unick, Department of Civil Engineering
- Olivia Yee, Department of Civil Engineering
- Vu Quynh Nhu (Natalie) Nguyen, School of Architecture and Landscape Architecture

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Athena Sustainable Materials Institute was a key partner in this Pilot, providing valuable expertise and insight into the protocol and processes for LCAs and benchmarking practice.

The benchmarking working group formed knowledgeable individuals from Athena Sustainable Materials Institute, National Research Council Canada (LCA^2 Initiative), and UBC provided valuable feedback and key contributions to guide the research conducted in Phase 3 of the Pilot.

The Zero Emission Building Exchange (ZEBx) facilitated the connection to projects through the Net-Zero Energy Ready Challenge, as well as opportunities for engagement with the larger building industry.

UBC Campus + Community Planning supported the data collection for UBC Campus buildings, and provided valuable input and feedback to help shape this study.

Lastly, the authors would like to thank all the project teams for sharing documentation and information to enable LCA of their buildings, and for their time and energy invested in the Pilot.

Cover photo: UBC Campus Energy Centre. Credit: Don Erhardt / UBC Communications & Marketing.

EXECUTIVE SUMMARY

This report summarizes our work over the past three years (2019–2021) examining the practice of whole-building life cycle assessment (WBLCA) for the purpose of reducing embodied carbon in the built environment.

To achieve that goal, we undertook a series of activities. This included:

- Preparing, conducting, and analyzing multiple LCAs on 10 buildings.
- Developing a bill of materials generation methodology and outline of LCA parameters.
- Reviewing policy and practices for carbon-focused WBLCA.
- Reviewing policy and practice for lessons on WBLCA benchmarking.
- Pilot testing a small-scale benchmarking case study.

Through this project, we learned that:

- There are multiple factors that affect consistency, reliability and variability of WBLCA results, which means these results are rarely comparable.
- Due to the complexity and variability in WBLCA, practitioners need much more guidance than is currently available to them.
- In particular, creating the bill of materials (the key user input for a WBLCA) requires a structured process to facilitate reliability, accuracy and comparability of results.
- It is important to determine the parameters for the WBLCA before conducting the assessment and even before starting to collect project data. Without a well-established set of parameters, the goal of the LCA is unlikely to be accomplished and the LCA process may be difficult and disorganized.
- Current WBLCA policy and practice does not support reliable benchmarking due to a lack of consistent and detailed requirements and guidance. Practitioner decisions on WBLCA method and scope can have more influence on the assessment results than the selection of materials.
- Benchmarking would be supported with a well-structured and representative bill of materials database.

The implications and benefits of this work include:

- Improving WBLCA practice and enabling embodied carbon policy by identifying challenges, trade-offs, and information gaps in WBLCA that need to first be addressed.
- Enabling accurate assessments, embodied carbon benchmarks and performance targets by applying our methodology for creating a bill of materials.
- Improving consistency of LCA across building projects, by developing more detailed guidance and structure.
- Supporting development of a bill of materials database for the purpose of benchmarking.
- Supporting the intentions and workplan of the Canadian LCA[2] initiative led by the National Research Council Canada[1].

For our next step, we will continue to pursue opportunities for knowledge mobilization and exchange with WBLCA practitioners, policy makers and LCA experts in Canada to realize the benefits from this work as they are implemented in the building industry. The findings, recommendations and guidelines resulting from these three years, as well as ongoing work, will inform the development and implementation of benchmarking tools and infrastructure led by the Athena Sustainable Materials Institute in 2022–2023[2].

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1. BACKGROUND

The UBC Embodied Carbon Pilot (Pilot), conducted by the University of British Columbia's Sustainability Hub (formerly the UBC Sustainability Initiative) was a multi-year research study on the practice of conducting life cycle assessments (LCA) for quantifying embodied carbon. The objective of the Pilot was to identify issues and solutions for enabling more effective use of LCA in reducing embodied carbon in the built environment. The findings from the Pilot can help inform new policies and practices in utilizing LCA, however, additional work will be necessary to implement them, beyond the scope of work of the Pilot.

Embodied carbon emissions refer to the greenhouse gas (GHG) emissions attributed to materials throughout their life cycle: resource extraction and production, installation, use, and end of life. LCA is the scientific method for quantifying embodied carbon and other environmental impacts. Embodied carbon in LCA is included in the global warming potential (GWP) impact category and generally reported in kilograms of carbon dioxide equivalent (kg CO_2 eq). LCA can be applied to any type of product, including buildings as a whole (i.e. whole building LCA or WBLCA) or only a portion of their individual components. The input data for a WBLCA is the project's bill of materials, which is a list of the different materials and quantities in the building.

WHY FOCUS ON EMBODIED CARBON?

Buildings are significant contributors to the raising levels of GHG emissions, which are causing a climate crisis. Historically, GHG emissions associated with the operation of buildings have been the most significant[3]. However, as operational energy consumption and emissions are reduced, the embodied emissions from building material choices are becoming proportionally more significant, accounting for about half of the total carbon emissions of global new construction in the next 30 years[4].

WHY STUDY LCA?

The use of LCA is becoming more common in green building programs and sustainability policies as a means to drive reductions in carbon emissions. However, these assessments are complex and their accuracy is relative to the quality of the input data and the decisions made throughout the process. Moreover, reliable reference values, such as baselines or benchmarks, are necessary to compare and assess the environmental performance of buildings and set performance targets. There is a clear need for standardization in methodology, input data, reporting and benchmarking to advance LCA practice and policy, and to leverage its full power for reducing embodied carbon in the built environment[5].

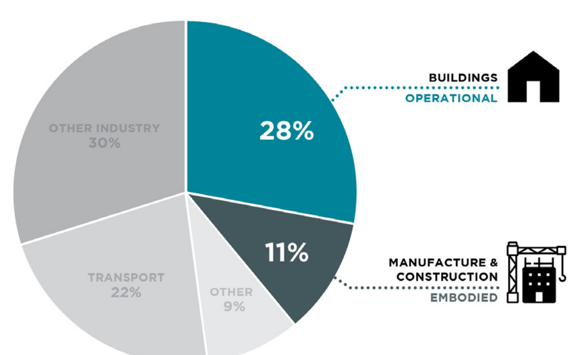

Figure 1: Share of global energy-related CO_2 emissions[3]

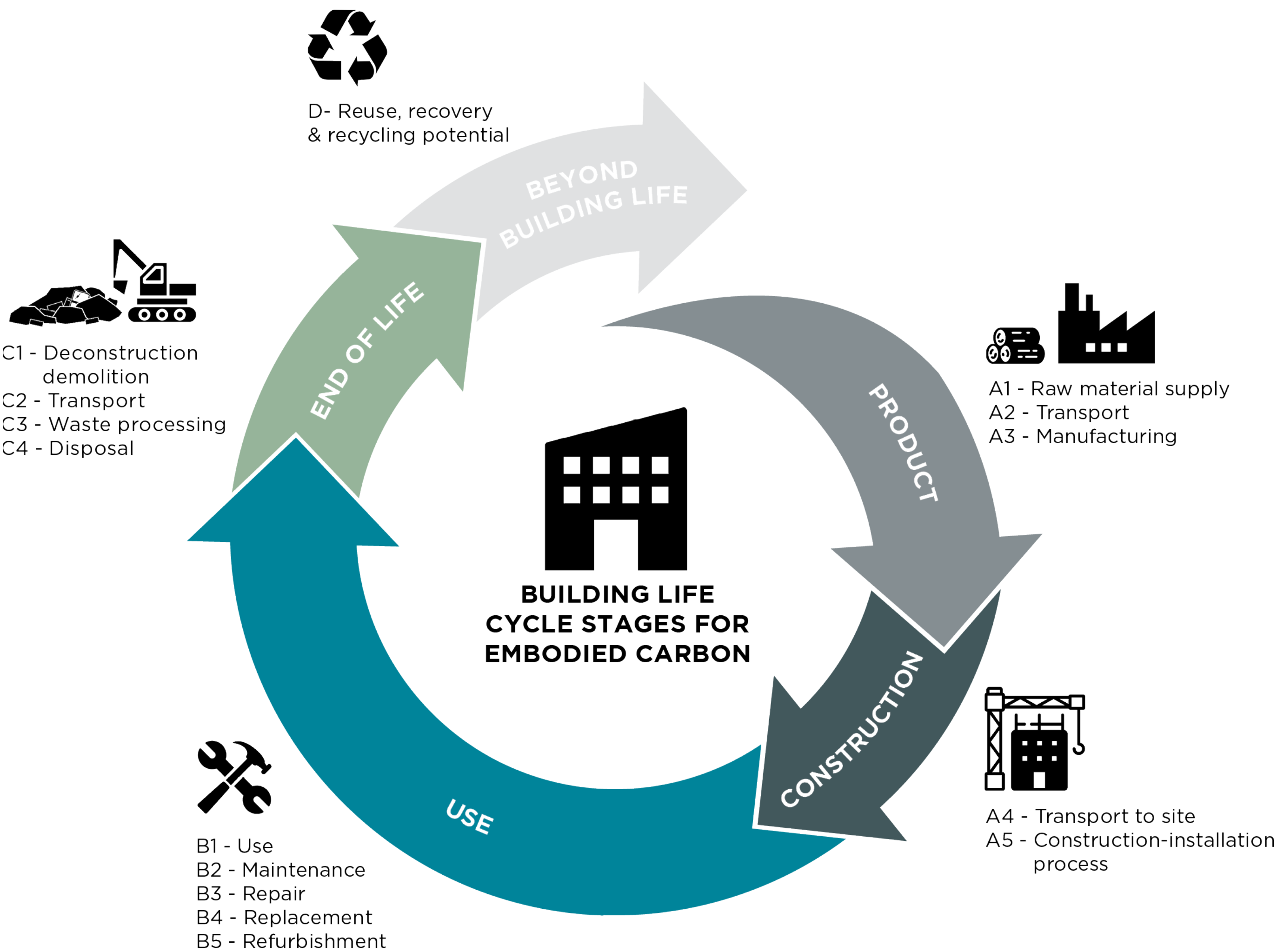

Figure 2: Embodied carbon building life cycle stages and modules per EN 15978:2011[6]

2. GOALS

This project set out to study the practice of conducting LCA to measure a building's embodied carbon and uncover lessons in how to use LCA more effectively. This learning could then be used to inform the development of policies and guidelines on embodied carbon emission from building materials through the establishment of benchmarks and eventually performance targets.

We conducted this work in three one-year phases. Each phase built on knowledge (and leveraged data) from previous phases of the Pilot, as well as from LCA work preceding these three years, such as the LCAs conducted for two UBC student residences (Brock Commons Tallwood House and Ponderosa Commons Cedar House).

PHASE 1

The primary goal of Phase 1 was to uncover knowledge gaps and challenges within the LCA procedures. The objective was to understand the process of conducting embodied carbon assessments with the purpose of performance reporting, policy creation, and benchmarking, and to understand the factors that may affect the consistency, reliability, and variability of results.

PHASE 2

In Phase 2 we continued with the goal of uncovering additional challenges in the LCA process by diversifying the building typologies, data sources and LCA tools used in Phase 1. We also sought to address the knowledge gaps discovered in Phase 1 and 2 by providing guidance aimed towards a more standardized approach to LCAs. Specific guidance on the collection, organization and manipulation of WBLCA input data is necessary to support the creation of consistent assessments to advance the use of LCA in policy and practice.

PHASE 3

In Phase 3, the goal was to understand the process and implications of creating embodied carbon benchmarks, specifically the application of a material-based benchmarking methodology. The objective was to provide recommendations for policymakers and LCA experts to increase reliability and comparability of assessments for benchmarking purposes and to inform the development of WBLCA benchmarking tools and infrastructure.

3. PARTNERSHIPS

This project was enriched by partnerships with key organizations working in LCA, embodied carbon and related topics. These partnerships are described below.

ATHENA SUSTAINABLE MATERIALS INSTITUTE (ATHENA)

Athena is a non-profit research collaborative bringing LCA to the construction sector. They were a close collaborator throughout the three phases of the Pilot providing expert guidance and advice to the research team in the technical aspects of conducting LCAs, as well as results analysis and reporting. Athena's Impact Estimator tool was extensively used to conduct most of the assessments in the Pilot and they provided valuable insights and guidance for an effective utilization of the tool. Additionally, the experiences from the Pilot is helping to inform their work on the development of guidelines, benchmarking methodology and infrastructure.

ZERO EMISSION BUILDING EXCHANGE (ZEBx)

ZEBx is an industry hub that facilitates knowledge exchange to accelerate market transformation for zero-emission buildings in British Columbia. They were a key partner in facilitating access to data from buildings and communication pathways with the project teams through the Net-Zero Energy Ready Challenge, which were leveraged to conduct most of the assessments in Phase 2. We also collaborated closely with them to develop educational materials and participate in their educational programming to connect our research with the building industry.

NATIONAL RESEARCH COUNCIL CANADA (NRC)

The National Research Council Canada (NRC), through the Low Carbon Assets through Life Cycle Assessment (LCA²) initiative, is developing a Canadian specific life cycle inventory (LCI) database and associated LCA guidelines. We engaged with members of this initiative through a benchmarking working group, were they provided feedback on our research activities. The National Guidelines for WBLCA published by NRC, and developed in close collaboration with Athena, were influenced by our research findings and recommendations.

UBC CAMPUS + COMMUNITY PLANNING

Throughout the Pilot, we engaged with the Campus + Community Planning department at UBC to exchange knowledge about LCA policy that informed and enriched the research. Findings and learnings from the Pilot in turn helped inform future on-campus policy, including the development of guidelines around the use of LCA in campus development projects, as well as future benchmarking and target development under the new Green Building Action Plan[7].

CITY OF VANCOUVER

As part of their response to the climate emergency declaration, the City of Vancouver is setting ambitious targets for carbon reduction in the near future, including a 2030 target for project teams of 40% reduction of embodied emissions below 2018 levels[8]. They are also exploring how to improve practices around setting baselines and benchmarks. As leaders in sustainability and subject matter experts, we consulted with them periodically to seek feedback and exchange findings and lessons learned from our work.

4. ACTIVITIES

Over the three years of the Pilot, we conducted a number of research activities, which are summarized in this section.

CREATE A UBC MASS TIMBER BUILDING INVENTORY (PHASE 1)

We developed an inventory of buildings located at the UBC Vancouver campus that include mass timber in their structural systems. From this inventory, we were able to select projects with diverse functions, sizes, designs, project teams and data sources to be used as buildings of study for Phase 1.

REVIEW OF POLICY AND PRACTICES FOR CARBON-FOCUSED LCA (PHASE 1)

As part of the contextual analysis for the Pilot, in Phase 1 we conducted a policy review of carbon-focused LCA to identify challenges and opportunities with LCA as a tool to reduce embodied carbon in buildings. We conducted a review of relevant academic and non-academic literature, regulations, standards, guidelines and green building rating systems, as well as a practical review of LCA tools applicable to North America. We also conducted a series of interviews with key staff from UBC, National Research Council LCA[2] initiative and City of Vancouver. The study was documented and published in the report *Policy Review of Carbon-focused Life Cycle Assessment*, which features an overview of key LCA concepts, a comparison of existing LCA tools for North America, mapping of LCA policy and standards, and an analysis of motivations to conduct WBLCAs including green building certifications. We also discuss the opportunities and challenges in the application of LCA for design decision-making and policy implementation, as well as national and regional actions with regards to embodied carbon reduction. Finally, the report identifies a variety of strategies and best practices for reducing embodied carbon in buildings.

PREPARE, CONDUCT AND ANALYZE LCA (PHASE 1)

In Phase 1, we conducted nine assessments on three UBC campus buildings with different types of data sources (e.g. quantity takeoffs from project drawings and cost estimates) and tested different LCA software tools (e.g. Athena Impact Estimator and One Click LCA). See Appendix for full table of assessments.

This was done to explore the process of conducting LCAs and to analyze the factors that may affect consistency, reliability and variability of results.

To conduct the LCAs we first developed a detailed and accurate bill of materials (BoM) for each assessment and then input it into the LCA tool of choice. For the BoM, the scope included major building components—foundation, structure, and envelope—which are generally the most significant contributors to embodied carbon emissions.

After conducting the assessments, we analyzed the impact that the project data sources, LCA tool of choice and LCA practitioners may have on the assessment inputs (BoMs) and outputs (calculated embodied carbon). Throughout this activity we also documented the processes, assumptions, and issues encountered, which also served as an input for analysis. The objectives, methodology, results, analysis and findings were documented in the *UBC Embodied Carbon Pilot, Phase 1 Final Report*.

Phase 1 Buildings of Study

FIRST NATIONS LONGHOUSE

Single-storey institutional office building featuring a heavy timber structure.

BIOENERGY RESEARCH AND DEMONSTRATION FACILITY

Energy generation facility (biomass) with an exposed mass timber hybrid structure.

CAMPUS ENERGY CENTRE

Energy generation facility (hot water) with an exposed mass timber hybrid structure.

PREPARE, CONDUCT AND ANALYZE LCA (PHASE 2)

Based on the lessons learned from Phase 1 of the Pilot, in Phase 2 we developed the BoM Generation Methodology, which details and refines protocols to quantify the building materials and generate the building's bill of materials. We then applied and tested this methodology by conducting nine assessments on seven buildings with different types of data sources (e.g. material quantities exported from BIM models) and testing different LCA software tools (e.g. Tally). See Appendix for full table of assessments.

In order to expand the scope of buildings for Phase 2, we partnered with the Zero Emission Building Exchange (ZEBx) to gathered project documentation from five high-performance building projects from across British Columbia, who were participating in the Better Buildings BC's Net-Zero Energy-Ready (NZER) Challenge. We also included two other buildings located on the UBC Campus. The variability in types of buildings was a key aspect that we wanted to explore in Phase 2. As a result, the chosen buildings have a range of uses, sizes and structural materials, and varying levels of energy performance.

After conducting the assessments, we analyzed the impact that the LCA scope (object of assessment, life cycle stages and reference study period), material categories and high-performance envelopes in particular may have on inputs (BoMs) and outputs (calculated embodied carbon). We also discussed the evolution of the BoM throughout the LCA process, as well as benefits and challenges of the different project data sources we used in both phases. The BoM Generation Methodology, results (LCA profiles), analysis and findings were documented in the internal report *UBC Embodied Carbon Pilot, Phase 2 Final Report.*

Phase 2 Buildings of Study

2150 KEITH DRIVE

Ten-storey energy-efficient office building in East Vancouver with nine storeys of mass timber structure over one concrete ground floor.

825 PACIFIC

Seven-storey multi-purpose arts and culture hub in downtown Vancouver featuring a concrete structure and designed to Passive House standards.

CARRINGTON VIEW (BLDG A)

Four-storey high-performance, wood-frame building within a solar-powered complex in Kelowna, BC.

SFU PARCEL 21

Energy-efficient student residence complex (2 buildings) in SFU Burnaby campus, with a four-storey wood-frame building on a concrete parkade and a six-storey wood-frame building.

UBCO SKEENA

Six-storey Passive House certified student residence located on UBC's Okanagan campus (UBCO), with five levels of wood frame construction built above a concrete ground floor.

TRIUMF INSTITUTE FOR ADVANCED MEDICAL ISOTOPES (IAMI)

Five-storey concrete facility, with two levels below grade located at UBC's Vancouver campus.

BROCK COMMONS PHASE 2 (SOUTH TOWER)

Thirteen-storey concrete student residence in a student housing complex at UBC's Vancouver campus.

DEVELOP THE BOM GENERATION METHODOLOGY (PHASE 2)

Based on the LCAs conducted in Phase 1, in Phase 2 we started by defining a comprehensive list of parameters that need to be determined before conducting an LCA, as well as a set of steps to create a detailed BoM of a building that can then be used to conduct the assessment. This BoM generation methodology is based on the phases of LCA outlined in the ISO 14040 standard. We also identified the different types of BoM created throughout the process as the project data is manipulated into a format that can be assessed using an LCA software tool. The methodology guidelines are published in a report titled *UBC Embodied Carbon Pilot, Bill of Materials Generation Methodology*.

Developing a comprehensive system for the collection, organization, and manipulation of building and materials data is necessary to support the creation of consistent BoMs to advance the use of LCAs in policy and practice. The BoM Generation Methodology aims to address the need for more detailed guidance for BoM-based WBLCAs.

In addition, we also developed a WBLCA reporting template to include all the relevant parameters and methodology information about the assessment, as well as the most relevant results relating to embodied carbon emissions, including GWP broken down by building element, life cycle stage and building material. The LCAs conducted in Phase 2 are reported using this template and can be found in the *UBC Embodied Carbon Pilot, Phase 2 Final Report*.

REVIEW LCA POLICY AND PRACTICE WITH A FOCUS ON BENCHMARKING (PHASE 3)

In Phase 3, we started by reviewing how parameters, as defined in the BoM Generation Methodology, are being established by LCA practitioners and in green building standards and guidelines. This was done to identify challenges in WBLCA practice and policy regarding reliability and comparability of assessments, and recommend actions to improve it for benchmarking purposes.

We conducted a literature review in which we reviewed 28 policy documents (e.g. standards and guidelines), 16 policy reviews and 20 academic papers. We also conducted and participated in knowledge exchange sessions with local LCA practitioners from architecture and consultant firms (4 sessions with 11 professionals), and with policymakers from LCA and the green building industry at the municipal, provincial and federal level in Canada and the United States (10 sessions with 11 professionals).

For each parameter, we reviewed how it is addressed by regulations and standards, what requirements exist for the mandatory parameters (or options for the non-mandatory parameters), and what type of guidance they provide. We also included common practices from the literature and from the knowledge sharing sessions with LCA practitioners. Details of the review, as well as the analysis and recommendations, were documented in the internal report *UBC Embodied Carbon Pilot, Phase 3 Final Report*.

BENCHMARKING CASE STUDY (PHASE 3)

In Phase 3, we conducted an exploratory case study adapting the BoM-based benchmarking methodology approach proposed by Athena[5] and NRC[9]. Our study follows a highly simplified approach based on a small building sample, and comparing it to a building of study. For the building sample we used data from seven buildings sourced in Phases 1 and 2 of the Pilot (see Figure 3). The building of study is Vienna House, a seven storey, 120-unit dedicated affordable housing rental building in Vancouver, British Columbia targeting Passive House certification[10]. This is a new building project currently under design development from which we sourced a Class C cost estimate to create the Building BoM.

We followed the steps as outlined below:

1. Compilation of BoMs for the building sample set.
2. Creation of the Building of Study BoM.
3. Material selection for BoM Benchmark assembly.
4. Conduct LCA on BoM Benchmark and Building of Study BoM.
5. Comparison and interpretation of LCA results.

Throughout the process we documented our observations, identified considerations for creating the BoM database, which is the key technical component of the benchmarking methodology, and provided recommendations of what the BoM database should include.

Figure 3: Building sample set and building of study

5. FINDINGS

The Pilot set out to study the practice of conducting LCA to measure a building's embodied carbon and uncover learnings for effectively leveraging LCA in policy and practice. Throughout the three years of research, we were able to gain an understanding of the current state of LCA practice in the building industry and challenges that need addressing through more effective policy. Our findings support hypotheses from previous experiences with conducting WBLCA and address early steps towards establishing embodied carbon benchmarks and performance targets for buildings.

THERE ARE MULTIPLE FACTORS THAT INFLUENCE VARIATION IN RESULTS

In Phase 1 of the Pilot, the research team conducted LCAs with the goal of identifying factors that may affect consistency, reliability and variability of results. Five main factors were identified:

1. Availability of project data sources that contain information on the building materials and their quantities.
2. Means of determining which building components and materials should be included in the assessment (object of assessment).
3. Means of determining which life cycle stages are included in the assessment (system boundary).
4. Methods of generating a BoM to categorize and quantify the building's specific materials.
5. Selection of the embodied carbon software or web tools that calculate the embodied carbon emissions of the materials and products.

LCA RESULTS ARE GENERALLY NOT COMPARABLE

When conducting the assessments, we found significant variations across these factors, each of which required interpretation by the research team and in turn led to variations across results. There was significant variation in BoMs, both in terms of the list of materials and their respective quantities, for the same building based on different project data sources and generation methods. In some cases, the variation reflected changes throughout the design development process, others were based on differences in scope between project data sources or input methods used in the tools. In addition, assessment results vary widely depending on numerous factors such as scope, data source, BoM generation method, and tool, which means results between assessments are not comparable and have limited usefulness.

ASSUMPTIONS IMPACT LCA INPUTS/RESULTS

Our experience conducting multiple LCAs highlighted the complexity of embodied carbon assessments, and the extent to which user decisions and assumptions impact both the inputs and outputs of assessments. We uncovered the challenges, trade-offs, and information gaps encountered by project teams in developing accurate BoMs and the effect that has on the resulting embodied carbon impacts.

THERE IS A LACK OF GUIDANCE ON HOW TO PREPARE AND CONDUCT LCAS IN CURRENT PRACTICE

From our experience conducting the assessments in Phase 1, we found that the process of data preparation prior to input into the LCA tool remains largely unstructured. There are a number of decisions and assumptions inherent in the creation of a BoM, which contribute to the variations in LCA results. Greater guidance and standardization are needed to ensure that the process of developing BoM information for LCAs is consistent across building projects so that it can be used to establish accurate embodied carbon emissions benchmarks and performance targets.

The BoM Generation Methodology developed in Phase 2 aims to address the need for more detailed guidance for BoM-based WBLCAs by describing a set of procedures for establishing the parameters of the LCA and generating a building's BoM for input into an LCA tool.

Based on the factors discovered on Phase 1, in Phase 2 we defined a comprehensive list of parameters that need to be determined before conducting an LCA:

- Goal of the LCA and assessment timing.
- Scope of the LCA, which consists of:
    - Object of assessment: building components to be assessed.
    - System boundary: life cycle stages included in the LCA.
    - Reference study period: time period over which the building is being assessed[6].
- Available project data sources, which can be classified by the level of accuracy as:
    - Primary, from purchase orders and receipts.
    - Project-specific, from project drawings, BIM model and cost estimates.
    - Product-specific, from EPDs.
    - Secondary, from industry averages[9].
- Appropriate assessment tool, which should be chosen based on the:
    - System boundary it can assess, such as only production or the full building life cycle.
    - Input methods it allows, such as direct input of BoM or BIM integration.
    - Databases it uses to map the materials and assess their environmental impacts.
    - Format and level of granularity of the results.

Once the assessment parameters are defined, the process to create a BoM for input into an LCA tool can be outlined in these four steps (see Figure 2):

1. **Building data extraction:** material quantities are extracted from the project data source. Assemblies within the object of assessment are organized in Excel, creating the project's Raw Data.
2. **Quantity calculations:** calculations are performed to convert the material quantities from the Raw Data into commonly used units, then consolidated into the Building BoM.
3. **Material mapping:** materials from the Building BoM are matched to the closest materials available in the LCA tool's database and assigned to categories based on the tool's classification system, creating the Modified BoM.
4. **Input into LCA tool:** the Modified BoM is input into the tool, which may make additional adjustments based on its internal algorithms, or require additional information from the user.

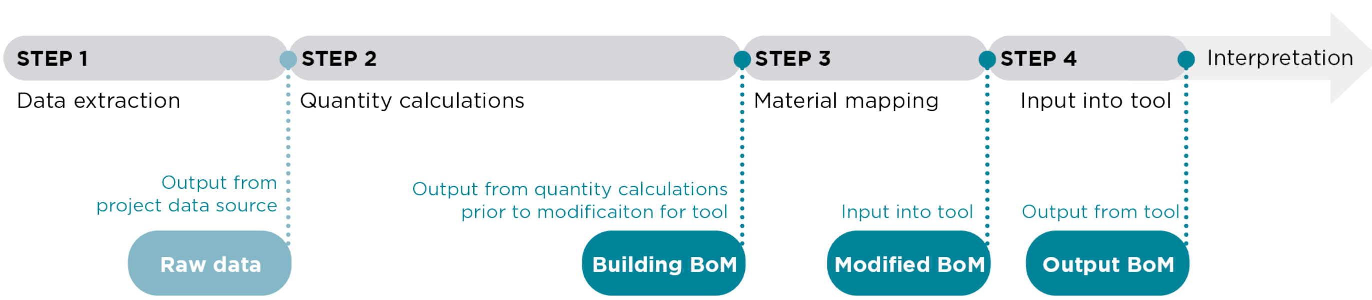

Figure 4: BoM generation process and the BoMs produced in each step

We also identified the different types of BoM created throughout the LCA process as the project data is manipulated into a format that can be assessed using an LCA software tool (see Figure 2):

1. **Raw data:** extracted directly from the project data source with no significant processing. Requires further breakdown of assemblies, calculation or translation into standard units and organization into a building classification system.
2. **Building BoM:** the processed raw data becomes the Building BoM. This is the most accurate representation of the materials specified in the building design or contained in the actual building.
3. **Modified BoM:** the Building BoM is then transformed into the Modified BoM by mapping the building materials to the options available in the WBLCA tool's database. The modifications can include greater or less specificity on materials,w adjustment of quantities or units, substitution of materials using proxies, or exclusion of materials.
4. **Output BoM:** After the Modified BoM is input into the LCA tool, the tool's internal algorithm may apply further modifications to the material quantities, such as addition of construction waste factors, alterations to the units of measure or addition of extra materials.

We found that the methodology worked well with the range of assessments conducted in Phase 2. While the four steps outlined above generally occur in the stated order, we found that specific tasks in each step can overlap and vary depending on the project data sources, quality of information, and LCA tool. However, the basic structure of the process is the same for all assessments.

DECISIONS ABOUT PARAMETERS AND METHODOLOGY SIGNIFICANTLY INFLUENCE INPUTS AND OUTCOMES

We have found that it is important to determine the parameters for the LCA before conducting the assessment and even before starting to collect project data. Without a well-established set of parameters, the goal of the LCA is likely to be unaccomplished and the LCA process will be challenging and inconsistent. Parameters should be determined by the goal of the LCA and provide a framework for decisions made throughout the LCA process.

In terms of influence on LCA inputs, we found that the BoM changes substantially in terms of scope, naming, quantity breakdown and units of measure depending on which step in the LCA process it corresponds to (i.e. raw data, building BoM, modified BoM or output BoM). There is also a correlation (and tradeoff) between the time and effort required to quantify materials from a data source, and the level of flexibility that that data will have for the purposes of LCA.

In terms of influence on the outcomes (i.e. LCA results), the most significant portion of the embodied carbon emissions are made up by a building's structure and envelope in terms of the object of assessment, and the product life cycle stage, in terms of the system boundary. In particular for high-performance buildings, the envelope can be of more significance compared to a conventional building built to code due to significant environmental impacts associated with the wall insulation.

In addition, we also observed that each LCA tool has its own way of displaying results and attention should be given to the format and level of granularity the tool provides to determine whether it will be useful for the purpose of the LCA.

CURRENT LCA PRACTICE DOES NOT SUPPORT BENCHMARKING

We found that current LCA policy and practices have different suggestions, requirements or procedures for LCA parameter, which does not support the production of standardized WBLAs for benchmarking. Moreover, decisions regarding methodology and LCA parameters, such as object of assessment and system boundary, can have more influence on the LCA results than the selection of the proposed building's structural system and construction materials[11]. Inconsistency also broadens the gap for assessment comparability and poses challenges when creating the database of existing buildings for benchmarking purposes.

In response to these findings, we proposed actions to enable the creation of benchmarks for LCA practice:

- Widespread adoption of the NRC National Guidelines[9] in practice, policy, and tools.
- Generate consensus and develop guidance for the production of WBLCAs for benchmarking purposes, including details on data sources and project phase, LCA goal and scope, methodology, result interpretation and comparability.
- Streamline LCA project-specific data sources in collaboration with quantity surveying institutes and associations in Canada.
- Develop a Canadian LCI database that can be adopted by LCA tools across the country.

A BOM DATABASE WILL SUPPORT BENCHMARKING

From our observations of the case study, we identified considerations for creating the BoM database, which is the key technical component of the benchmarking methodology. The BoM database should include:

- A standardized taxonomy and boundary to the object of assessment, and detailed meta data.
- Guidelines on the use of alternative or proxy materials and conversions of units of measure.
- Options and guidelines for end-of-life scenarios based on regional practices.
- A significant number of building types, materials and construction techniques representative of construction practices in North America.
- A flexible format that adapts to the main WBLCA tools in the region.

6. KNOWLEDGE MOBILIZATION

PRESENTATIONS AND OUTREACH

The findings, recommendations and guidelines that emerged from this Pilot have the potential to improve practices of the use of LCA for estimating embodied carbon and establishing embodied emissions benchmarks. One of the goals of the Pilot has been to share our learnings and experiences, provide valuable information to practitioners and policymakers, and contribute to the body of knowledge and expertise being developed in British Columbia and throughout Canada.

To this end, throughout the three years we have presented at and participated in conferences, webinars, workshops and committees, and are active in industry groups, such as the local chapter of the Carbon Leadership Forum. We actively engaged with some of the project teams of the buildings we selected to conduct LCAs on and gave presentations on our progress and learnings to these teams. We conducted numerous presentations with our key project partners, and participated in many of the policy and industry discussions around the topics of LCAs and embodied carbon, as well as the expansion of mass-timber building projects. For instance, members from our team led the embodied carbon working group composed of university faculty and staff that created recommendations for UBC's new Climate Action Plan. These recommendations were informed by learnings from the Pilot.

PUBLICATIONS AND REPORTS

For each phase, we produced and published documents that have been widely shared with relevant organizations in British Columbia and through UBC communication channels. The documents listed below can be found on the UBC Sustainability website.

- *UBC Embodied Carbon Pilot, Phase 1 Final Report*: summarizes the methods results, findings and recommendations of the first phase of the Pilot.
- *UBC Embodied Carbon Pilot, Phase 2 Final Report* (internal): outlines the methodology, results, and analysis of the assessments conducted in the second phase of the Pilot.
- *UBC Embodied Carbon Pilot, Phase 3 Final Report* (internal): summarizes the literature review, knowledge sharing sessions and benchmarking case study conducted in the third phase of the Pilot.
- *Policy Review of Carbon-focused Life Cycle Assessment*: produced in Phase 1, it contains a review of current policies, practices and tools related to LCA and embodied carbon.
- *UBC Embodied Carbon Pilot, Bill of Materials Generation Methodology*: produced in Phase 2, it describes a standardized and detailed methodology to set parameters and conduct BoM-based WBLCAs.
- *Life Cycle Assessment Practice to Estimate Embodied Carbon in Buildings*: a playbook and video series produced in Phase 2 in collaboration with ZEBx and part of the ZEBx's Net Zero Energy-Ready Playbook Series. These materials reflect on the learnings from the Pilot and integrates elements from the *Bill of Materials Generation Methodology*.

ONGOING WORK AND NEXT STEPS

We will continue to pursue opportunities to present the experiences and learnings from the three phases of the Pilot to policy-makers at the municipal and provincial level, LCA practitioners and organizations that use LCA in their voluntary certifications and whose work is informing LCA policy in Canada. This effort will include targeted presentations towards specific audiences, as well as larger-scale conferences and workshops. Our project partners are also part of our primary audience since these organizations are developing regulations, guidelines and tools that can benefit from our research to improve their own work.

In addition, the findings, recommendations and guidelines resulting from the three years of the Pilot will serve as a stepping stone for future work on LCA policy and benchmarking. We are currently collaborating with the Athena Sustainable Materials Institute in the development and implementation of benchmarking tools and infrastructure through research activities[2]. This project is also being funded by BC Forestry Innovation Investment through the Wood First Program.

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APPENDIX

Buildings of study for Phases 1–3, assessment tool and data source of LCAs conducted for the Pilot.

BUILDINGS/LCA TOOLS	ATHENA IE4B	TALLY	ONE CLICK LCA	EC3
UBC Bioenergy Research and Demonstration Facility	Cost estimates			
UBC Brock Commons Phase 2 (South Tower)			BIM model	
UBC Campus Energy Centre	Project drawings Cost estimate BIM model		Project drawings	Project drawings
UBC First Nations Longhouse	Project drawings			
UBC TRIUMF Institute for Advanced Medical Isotopes (IAMI)	BIM model	BIM model		
UBC Okanagan Skeena Residence	BIM model	BIM model		
2150 Keith Drive		BIM model		
825 Pacific	BIM model			
Carrington View (Building A)	Cost estimate			
SFU Parcel 21	BIM model			
Vienna House	Cost estimate			

THE UNIVERSITY OF BRITISH COLUMBIA
Sustainability Hub

2260 West Mall
Vancouver BC, V6T 1Z4
sustain.ubc.ca