Policy Research on Reducing the Embodied Emissions of New Buildings in Vancouver

ZERA SOLUTIONS

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Acronyms and abbreviations

LCA: Whole-building Life Cycle Assessment (LCA) is an internationally accepted scientific method, intended to be used to quantify embodied carbon and other environmental impacts in buildings, and can be the basis of an embodied carbon policy (Zizzo, Kyriazis, & Goodland, 2017).

GWP: Global Warming Potential (GWP) is one of the environmental impact indicators reported in LCA. Here GWP refers to the embodied carbon emissions from production, use (excluding operation energy and water), and end of life phases of a building lifetime reported in kg Co_2 eq. See Embodied Emissions.

Carbon-dioxide equivalent (or CO_2eq.): refers to global warming that is caused by all greenhouse gases released by activity. In addition of the carbon dioxide (CO_2), it includes the impact of other gases (Bionova Ltd., 2018).

Embodied Emissions: In the context of this report, embodied emissions refer to embodied carbon. This is the total impact of all the greenhouse gases emitted by the construction and materials of a building. It includes the impacts of sourcing raw materials, manufacturing, transport, and wastage in the process, during maintenance, repaired, or disposal or recovery.

BoM: Bill of Materials (BoM) refers to the list of building materials used for assessing the embodied environmental impacts of buildings through LCA.

Athena IE: The Impact Estimator for Buildings is an open-access software tool developed by Athena Sustainable Materials Institute to be used by design teams to explore the life cycle environmental footprint of different material choices and core-and-shell system options.

1. Introduction

Many recent climate-change policies reference “net-zero” (either energy or carbon) for buildings. However, a building is not truly “net-zero” until it has paid back or offset its initial carbon debt. The debt is the embodied Global Warming Potential (GHG) emissions associated with materials, manufacturing, and other processes that are upstream of building occupancy. Additionally, the debt is not paid until future carbon emissions in terms of end-of-life decommissioning has been considered as illustrated in Figure 1.

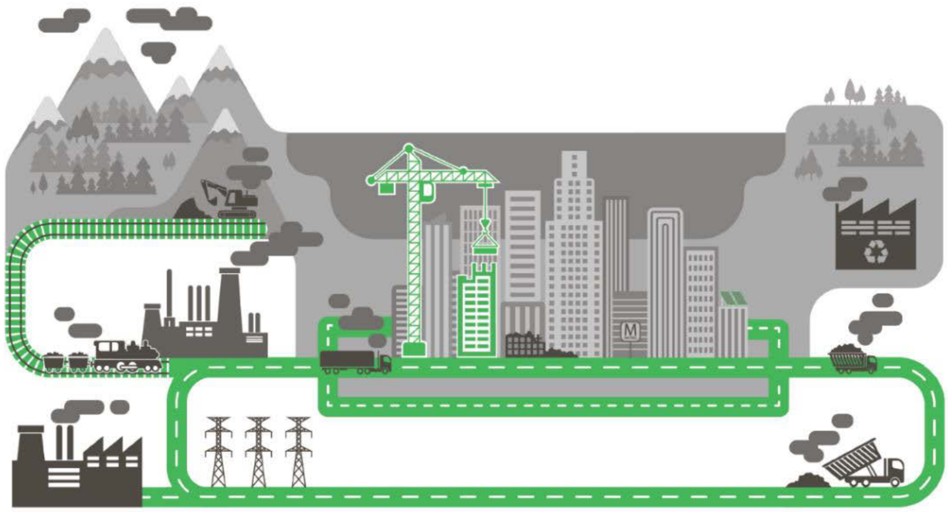

Figure 1 Embodied carbon emissions arise from the life cycle material flows of buildings (Bionova Ltd., 2018)

Leading jurisdictions with policies for addressing embodied carbon estimate that approximately 20% of GHG emissions of a building are embodied (Zizzo et al., 2017). For building constructed between now and 2050, embodied carbon is estimated at 50% (Bionova Ltd., 2018). This figure rises once an annual 2% decarbonization rate is factored in, making embodied carbon the dominant source of GHG as shown in Figure 2. Given these projections, it is important to create policies to address embodied carbon.

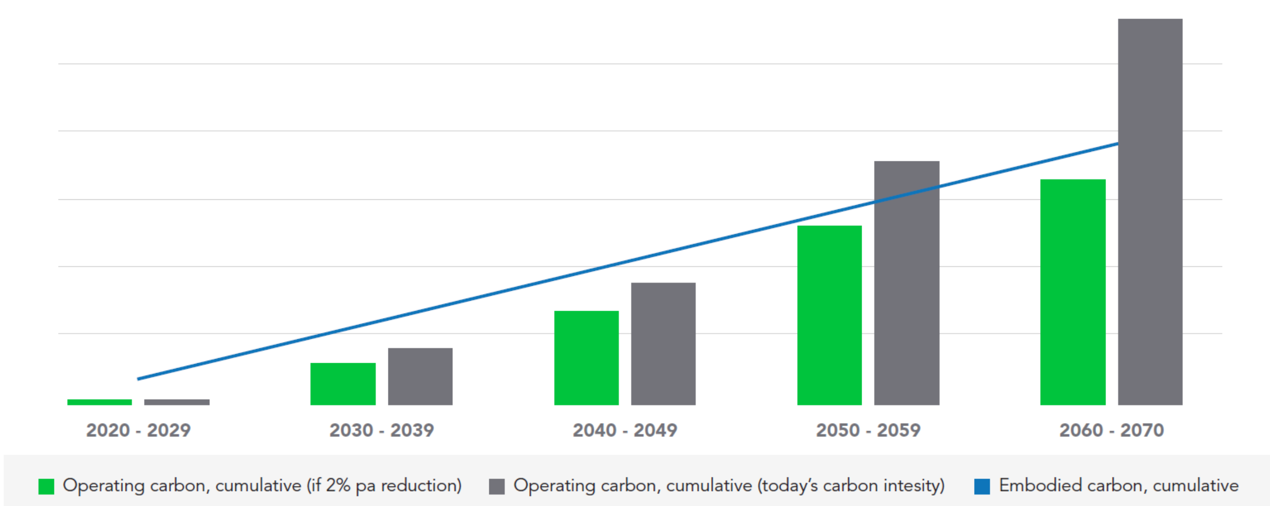

Figure 2 Embodied and operating carbon for new buildings 2020-2070 (Bionova Ltd., 2018)

The City of Vancouver's Zero Emissions Building Plan (2016) (ZEBP) seeks to reduce the operational carbon emissions of new construction in Vancouver to zero by 2030. The first steps in implementing this plan will bring the operational emissions into the same order of magnitude as embodied emissions. With further restrictions on operation emissions in future updates, the share of embodied emissions in total lifecycle emissions will continue to grow and become dominant as mentioned above.

With this in mind, the ZEBP calls for reporting of embodied carbon emissions (hereon referred to as the embodied emissions) in new construction. The purpose is to build capacity and allow further research into potential policy approaches for reducing embodied emissions.

This reporting requirement has been in place for new rezoning applications received since May 2017. The City of Vancouver (hereon referred to as the City) has received submissions containing embodied emissions calculations that helps the City to explore future policy updates (City of Vancouver, 2017).

Zera Solutions analyzed selected submissions in order to assess the quality of the current submissions as well as improvement opportunities in the requirements. Additionally, the City wanted to create a road map for reporting and reducing embodied emissions in new buildings. To develop this road map, Zera Solutions reviewed the policies of the leading jurisdictions around the world and interviewed key regional stakeholders.

This document details the findings of Zera Solutions. The specific research objectives were:

Objective 1: Review current process, enforcement, and outcomes

- Review a sample of submissions for completeness, consistency, and overall quality.
- Make recommendations to the City for improvements to the embodied emissions reporting requirements in the bulletin *"Green Buildings Policy for Rezoning - Process and Requirements*[1]*"* (City of Vancouver, 2017). The goals of improvements are to make the scope and detail of submissions consistent for all applicants, and to ensure that any information important to future policy development is being captured.

Objective 2: Review the best policy approaches to embodied emissions and guides to low embodied emissions design

The intent is to summarize the recent literature on:

- Best policy approaches toward embodied emissions for new buildings, and
- Resources for industry to voluntarily reduce embodied emissions in construction. This will inform a new guide[2] that will be developed by the City or a selected consultant.

Objective 3: Develop a conceptual roadmap and next steps for the City's embodied emissions policy

Based on the findings from objectives 1 and 2, as well as through interviewing the local subject matter experts (such as representatives from Athena Sustainable Materials Institutes[3]), create a conceptual roadmap and recommended next steps to regulate reductions in embodied emissions of construction in the City. These recommendations will include:

[1] Hereon referred to as "the bulletin"

[2] To be called "*Guide to Low Embodied Emissions Design"*

[3] http://www.athenasmi.org

- The infrastructure and resources that are necessary for successful implementation of the next steps of the embodied emission policy. These include local benchmarks, databases and software tools, and standardization of Life-Cycle Assessment (LCA) practices.
- Further research required, including feasibility and cost analysis of embodied emissions reporting and reduction of local projects.

The rest of this report is structured as follows: Chapter 2 presents a review of 28 of the embodied emissions submissions under the current requirements in the bulletin. The chapter also provides recommendations for improving the requirements. The reviewed submissions are listed in Appendix D.

Chapter 3 summarizes the key takeaways from the recent literature (2016-2018) on the best policy approaches to embodied emissions. A list of the literature and resources reviewed is presented Appendix A. The list is categorized by the topic area such as: benchmarking, case studies, building LCA guidelines, low embodied emissions material selection guides, and policy reviews. Appendix B provides a list of relevant Canadian, North American, European, and International policies.

Relying on the findings from the previous chapters, as well as the experts' input (Appendix C[4]), Chapter 4 recommends a conceptual road map and next steps for the City to regulate and reduce embodied emissions.

[4] Appendix C also provides a list of embodied emissions stakeholders, experts, and thought leaders, both internal to the City and external.

2. Current process and improvement opportunities

28 of the embodied emissions assessments that have been submitted to the City as part of the current Green Buildings Policy for Rezoning were reviewed for completeness, consistency, and overall quality.

Section 6.2 of the bulletin requires all the projects to report the embodied emissions intensity in $kgCO_2e/m^2$, $kgCO_2e$, and the equivalent annual embodied emissions intensity in $kgCO2e/m^2/year$. The specified assessment scope is (City of Vancouver, 2017):

- Include all envelope and structural elements (including parking structure), including footings and foundations, and complete structural wall assemblies (from cladding to interior finishes, including basement), structural floors and ceilings (not including finishes), roof assemblies, and stairs construction, but exclude excavation and other site development, partitions, building services (electrical, mechanical, fire detection, alarm systems, elevators, etc.), and parking lots;
- Assume a building lifetime of 60 years;
- Include 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). Operating energy and water consumption are excluded;
- Database used must be ISO 14040, 14044, and 21930 compliant, and regionally-specific, if possible;
- Method used must be the US EPA’s Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI);
- 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.

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

- The life cycle impacts associated with other building elements that are excluded from the mandatory Embodied Carbon reporting.
- Other calculated life-cycle indicators and 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;
- A breakdown of impacts by activity (materials/products, transportation, on-site activities, wastage, etc), life-cycle phases (extraction, manufacturing, construction, use/maintenance, end of life), product category (structure, foundation, wall, glazing, etc.), and material type (steel, wood, concrete, plastic, etc).

Section 2.1 discusses the findings and takeaways from the reviewed submissions. Section 2.2 provides the recommended improvements on the embodied emissions requirements in the bulletin (City of Vancouver, 2017). The improvement includes a new template for collecting data.

2.1. Key findings from the current submissions

For all projects, consultants used the assessment scope specified in the bulletin mentioned above. Further, all consultants used Athena's whole building LCA tool Impact Estimator for Buildings[5], which is named in the bulletin. The projects reviewed, with a detailed list of key information provided or missing is presented in Appendix D.

There are two key findings. The first is that the submissions support the literature that embodied emissions in high efficiency buildings are as significant as the operational emissions. This is discussed in Section 2.1.1. The second is that providing a clear estimation scope narrows embodied emissions variations across the projects. However, there is still a considerable variation which is explored in Section 2.1.2.

2.1.1. Embodied emissions significance

Table 19 in Appendix D shows a comparison of the equivalent annual embodied emissions intensity with the annual operation emissions limits (GHGI) over the 60 years life time of buildings – specifically, the columns "*Annual eq. Embodied*" and "*CHGI Limit*". The comparison shows that the annual equivalent embodied emissions are comparable to the annual operational emissions in all projects. In 14 out of the 28 projects, the annual equivalent embodied emissions are even higher than operational emissions.

This result may appear to show a higher embodied emission contribution compared with Bionova's (2018) estimate. According to them, for building constructed between now and 2050, embodied carbon is estimated at 50%, and if the energy source decarbonization rate is factored in, embodied carbon will become the dominant source of GHG.

We note that, the majority of electricity in Vancouver is sourced from Hydro, which already has minimal carbon emissions. In addition, the sample projects evaluated here have a considerably higher operational efficiency compared to an average building in the region. As a result, we see that contribution of embodied emissions is already surpassing the 50% mark.

This begs the question: if buildings are already efficient, and the electricity is clean, why do we need more policies?

The reason is that, the majority of the embodied carbon impacts are incurred before occupancy of a building and are thus irreversible. As Zizzo et al. (2017) said: "not only is embodied carbon a significant proportion of a building's overall carbon footprint, but reductions in embodied carbon are realized in the short term, which is a critical consideration given that global carbon emissions need to be urgently reduced to meet international climate commitments".

Thus, it is crucial for the City to introduce policies and regulations to limit embodied emissions, alongside operational emissions.

[5] https://calculatelca.com/software/impact-estimator/

2.1.2. Variations in embodied emissions

As the ultimate goal for the City is to reduce the embodied emissions in buildings, this section explores the reason behind the variations in the reported embodied emissions. This review showed three key contributors: structural material choices, differences among consultants in material quantity take-off, and inclusion of underground parkade area in the total floor area[6]. The following sections discuss these in more detail.

2.1.2.1. Material quantities

Since materials are the main contributor to embodied emissions, an analysis of differences in material quantities per gross floor area was made.

Since submitting material quantities was not one of the City's requirements, not all of the projects submitted bill of materials (BoM). Only three consultants in 11 projects out of the 28 project did so[7]. To conduct a meaningful statistical analysis to understand the key materials that contribute to GWP, there is a need for a larger number of projects with BoM. However, an initial correlation analysis on this set of data indicates:

- There is a strong positive correlation between the weight of metal (aluminum and steel) (kg/m^2) and volume of concrete (m^3/m^2) used per gross floor area and GWP (kg CO_2 eq./m^2) with correlation coefficients of 0.89 and 0.90 respectively. That means projects with higher quantities of concrete and metal have a higher GWP (Figure 3 and Figure 4). Aluminum is mostly used for door and window frames whereas steel is used structurally as concrete rebar, in screws and bolts, and in galvanized panels.
- There is a strong negative correlation between the volume of wood used per gross floor area (m^3/m^2) and GWP (kg CO_2 eq./m^2) with a correlation coefficient of -0.89. This means that projects with higher quantities of wood have a lower GWP (Figure 5). Wood is used for the superstructure, exterior wall and windows of some of the Low-rise developments.
- The quantity of other materials such as gypsum or insulation did not show a significant correlation with GWP.

Therefore, one reason behind the variation in the GWP (kg CO_2 eq/m^2) of similar projects in the conceptual design stage is the choice of structural and envelope material (wood vs reinforced concrete). Buildings with hybrid wood and concrete structure and wood envelopes tend to have a lower GWP than those with concrete structure and steel envelope (Figure 6).

[6] The correlation between the building's height and embodied emissions per gross floor area is not significant.
[7] Those consultants are: Sebastien Garon, Matt Bowick, and E3.

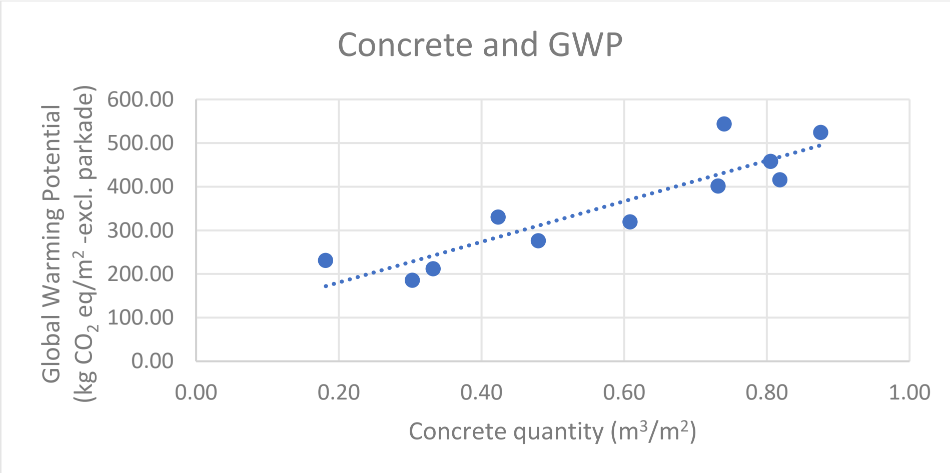

Figure 3 Correlation between the quantity of concrete and GWP

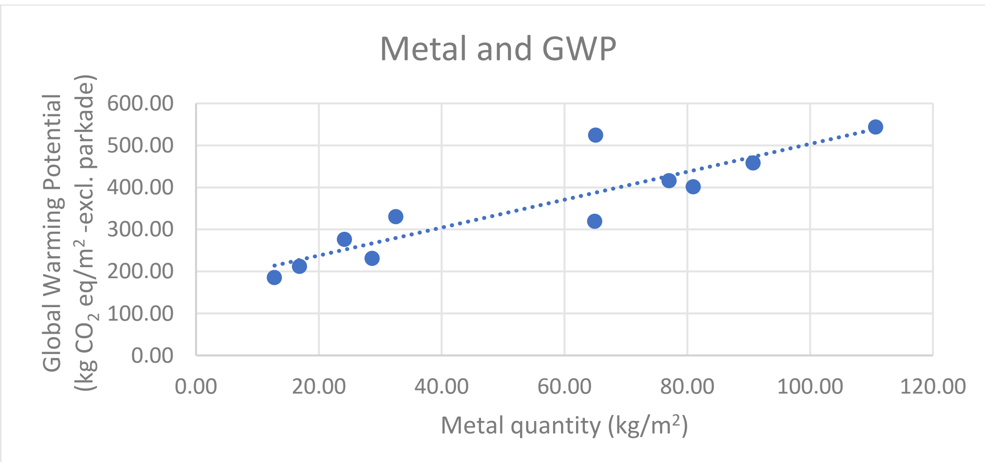

Figure 4 Correlation between the quantity of metal and GWP

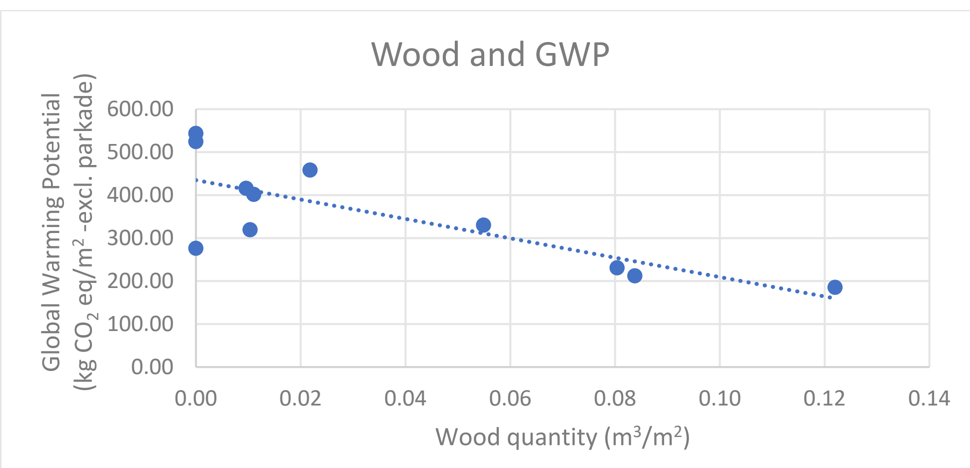

Figure 5 Correlation between the quantity of wood and GWP

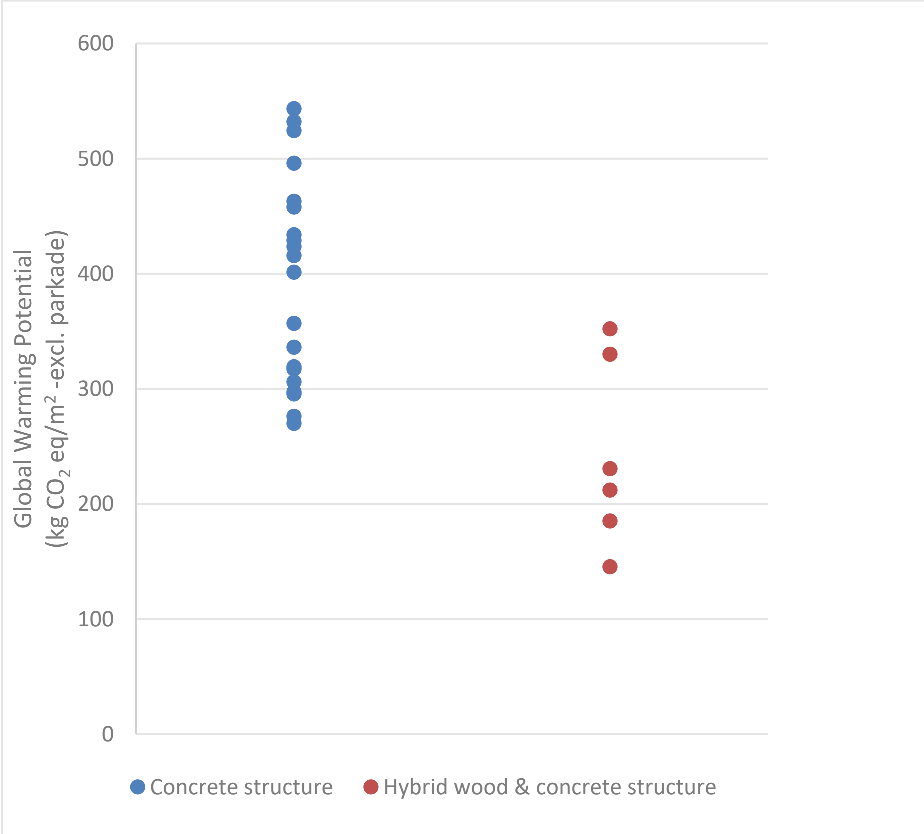

Figure 6 GWP of buildings with concrete vs. hybrid wood/concrete structure

2.1.2.2. Variations among different Consultants

The second reason identified was the variation between the material quantity estimates from different consultants.

Although structural type is one reason for the embodied emission variations, Figure 6 shows that there is still a considerable variation within the same structure type that is not explained. As it can be seen in the Table 19 in Appendix D, some consultants have generally estimated higher quantities of materials compared to others. This resulted in higher impacts as seen in Figure 7.

For instance, Matt Bowick assessed the concrete quantity and embodied emissions of 441 West 59th Ave to be 0.88 m^3/m^2 and 524 Kg CO_2 eq./m^2 respectively. On the other hand, E3 estimated for 2230 Harrison Dr. 0.61 m^3/m^2 and 319 kg CO_2 eq./m^2 respectively. This is while both projects are low-rise residentials with concrete structure[8].

[8] It is the opinion of the author that a reasonable range is 50-100 Kg CO_2 eq./m^2

To understand the reason behind the variation in the quantity of concrete in the two project, further investigation into the material take-off methods of the two consultants is required. Therefore, Zera Solutions recommends that the City request further details from the consultants. Alternatively, the City should conduct quantity take-off of the sample projects to evaluate the take-off methods and assumptions done by the consultants.

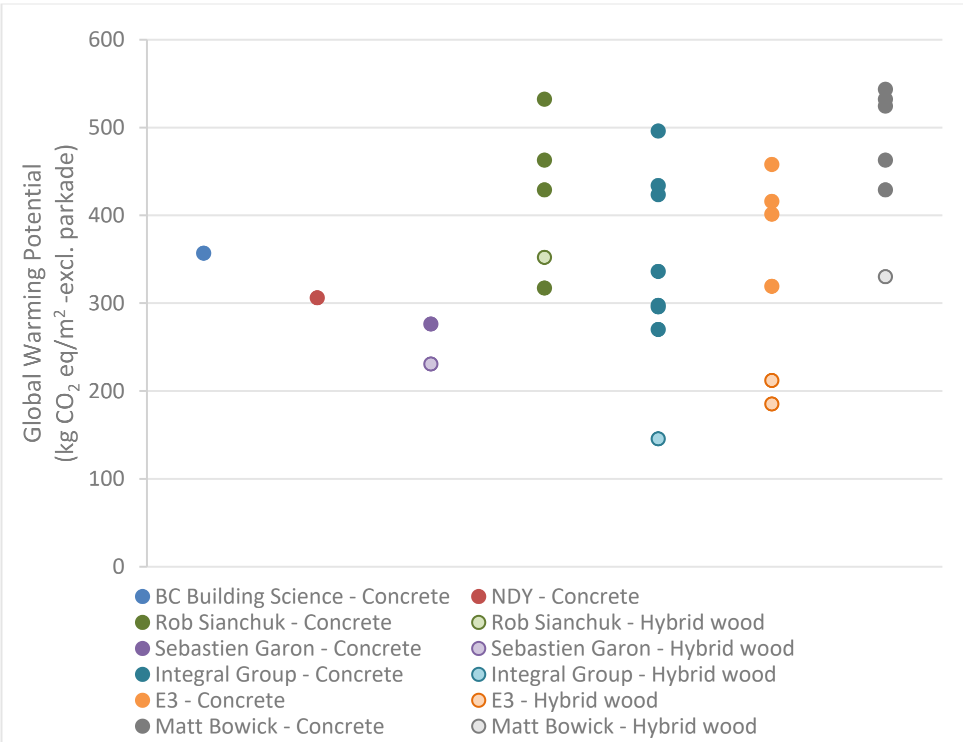

Figure 7 GWP based on the consultants for concrete and hybrid-wood structures

2.1.2.3. Inclusion of parkade in gross floor area

The third reason identified was the inclusion of the underground parkade area in the embodied emissions evaluation.

Figure 7 shows considerable variations among projects of a single consultant as well. For instance, the embodied emissions in concrete-structure buildings with steel stud envelops as assessed by Integral Group ranges from 270 to 496 kg CO2 eq./m2. This is a 200 kg CO2 eq./m2 variation.

A key finding in this review is that while the materials used in the underground parkade is included in the embodied emissions assessment, the parkade floor area isn't. Consultants explained that the reason for exclusion is to make it consistent with operation emissions assessment (GHGI).

To illustrate the effect of including the parkade floor area, we took Integral Group data and factored in the parkade floor area. The result is shown in Figure 8. The figure illustrates that doing so reduces embodied emission variation.

By excluding the gross floor area of the parkade, but including the materials used in the parkade, projects with larger parkades will show higher embodied emissions per gross floor area. This might be a favorable method if the City intends to discourage having large parkade areas. However, if projects are required by code to have a certain parkade area, they are unable to eliminate the parkade area to reduce its embodied impact.

Therefore, Zera Solutions recommends that the minimum parkade area required by code to be included in the gross area for calculating embodied emissions per gross floor area. This is incorporated in a new template that standardize data entry discussed in section 2.2.

For the additional parkade area, while the materials should be included in the embodied emissions calculation, their floor area should not be included in the gross floor area calculation. This will encourage project teams to limit the parkade area to the minimum mandatory area.

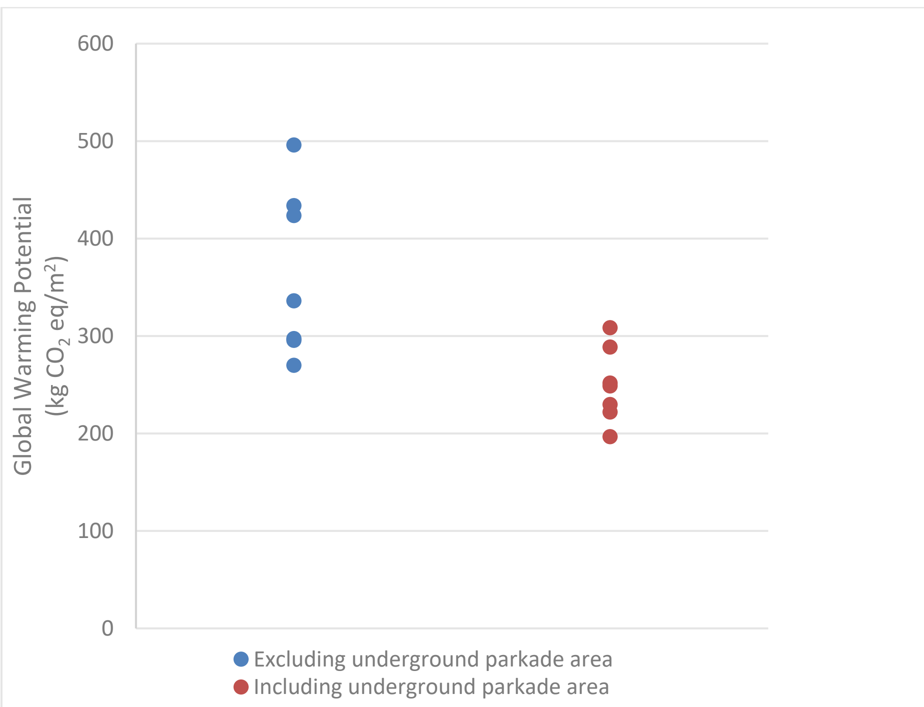

Figure 8 GWP of concrete structures assessed by Integral Group: including vs. excluding the parkade gross floor area

2.2. Recommended improvements for embodied emissions submissions

In reviewing the sample of embodied emissions submissions, certain shortcomings in the requirements were identified. This are discussed in Section 2.2.1. To remove these shortcomings and improve the embodied emissions estimates, Section 2.2.2 provides a preliminary template. This template was presented to the key experts which were interviewed, and their feedback is presented in Appendix C.

2.2.1. Shortcomings of current submissions

The shortcomings of the current requirements specified the City in bulletin (2017)[9] are:

- Not specifying whether underground area should be included/excluded in calculating embodied emissions per gross floor area (see Section 2.1.3).
- Not asking for the Bill of Materials (BoM). This is further discussed in Section 2.2.1.1.
- Optional requirement for submitting embodied emissions breakdown by building elements and lifecycle phases. This is further discussed in Section 2.2.1.2.
- Optional requirement for submitting other environmental impacts. This is further discussed in Section 2.2.1.3.
- Lack of a consistent format, which results in inconsistency in the level of detail, which in turn complicates the review process.

2.2.1.1. Material breakdown by assembly groups

As submitting the BoM is not a requirement, not all the consultants have submitted this information. Section 2.1.1 and 2.1.2 used the material quantity information that was provided by 11 out of 28 submissions to assess the key contributors to the embodied emissions results. As an example, E3 provided a breakdown of material quantities by assembly groups as shown in Table 1. Having the material quantity data allows further investigation into the key materials contributing into the overall embodied emissions. It also helps in the submission auditing process of the submissions.

2.2.1.2. Embodied emissions breakdown

Currently the requirements only ask for embodied emissions in kgCO2 eq., kgCO2 eq./m², and the equivalent annual embodied emissions intensity in kgCO2 eq./m²/year. While this data is necessary for the City to develop embodied emissions policies, it does not provide enough understanding to the project team on where the key areas are that they can explore to reduce the impacts. Understanding key areas of impacts serves the City's ultimate goal, which is reducing embodied emissions in buildings.

Providing emissions breakdown by lifecycle phases, elements, and material types is optional, and was thus provided by only one consultant. E3 provided different building elements as shown in Figure 9. They also provided breakdown of by lifecycle phase as shown in Figure 10.

Such breakdowns are a valuable guide for the project team to identify the areas of focus where they can have the most impact in embodied emissions reduction. For instance, in elements breakdown in Figure 9, one can observe that projects 1 to 4 can get a noticeable reduction in emissions by focusing on the impacts of columns and beams. On the other hand, one observes that for projects 5 and 6, beams and columns impacts are relatively small, and that focusing on the walls impacts is more strategic.

[9] See Section 2 for detailed requirements.

For life cycle phase breakdown, Figure 10 shows that product phase constitutes more than 75% of the total impacts. This indicates the importance of the impacts from the production of the building elements, which includes resource extraction, and manufacturing of the original products used in buildings. Based on this, one recommendation Zera Solutions discusses in Chapter 4 is to narrow the embodied emissions limits to the product phase (Environmental Product Declarations - EPDs).

E3 also reported the benefit beyond building life (phase D) for their projects. This value is displayed in Figure 10. Phase D shows the impacts of reusing and recycling materials at the end of buildings lifetime, as well as the carbon sequestration in wood and concrete[10]. The graph shows that the first two project, which have hybrid-wood structure and envelope, have the potential to offset a considerable portion of their negative impacts.

Based on these examples, Zera Solutions recommends asking for a breakdown of the total embodied emissions by life cycle phase and elements. This will enable the project teams to focus on the areas where more reduction opportunity exists.

2.2.1.3. Other lifecycle impacts

Submitting the environmental impact indicators other than embodied carbon (Global Warming Potential) is another optional requirement. These impact indicators are potentials for Ozone Depletion, Acidification, Eutrophication, Smog, and Non-renewable Energy Use. These indicators are currently optional because the focus of the current policy is on embodied carbon (GWP). However, this information may help inform the future environmental policies by providing data from actual projects. Zera Solutions suggests collecting this information, especially since most LCA software tools (such as Athena IE) provide these impact indicators with no extra effort required.

[10] “Carbon is sequestered in wood during photosynthesis as the tree grows. When the tree is cut down this carbon is stored in the wood products until combustion or decay. Concrete gradually sequesters carbon from the atmosphere through a chemical process that occurs when it is exposed to air and moisture during its life cycle” (University of British Columbia, 2018)

Table 1 Bill of materials for 2230 Harrison Drive, project 1 in Figure 7 (credit: E3)

Material	Unit	Total Quantity	Columns & Beams	Floors	Foundations	Roofs	Walls	Project Extra Materials	Mass Value	Mass Unit
#15 Organic Felt	m2	14,109.3367	0.0000	24.8202	0.0000	7,460.9647	6,623.5518	0.0000	10.2969	Tonnes
#30 Organic Felt	m2	958.0613	0.0000	0.0000	0.0000	958.0613	0.0000	0.0000	1.3788	Tonnes
1/2" Moisture Resistant Gypsum Board	m2	1,259.8146	0.0000	0.0000	0.0000	1,259.8146	0.0000	0.0000	11.3509	Tonnes
1/2" Glass Mat Gypsum Panel	m2	2,236.8280	0.0000	0.0000	0.0000	0.0000	2,236.8280	0.0000	22.1372	Tonnes
3 mil Polyethylene	m2	2,157.1156	0.0000	0.0000	0.0000	0.0000	2,157.1156	0.0000	0.1618	Tonnes
Ballast (aggregate stone)	kg	41,422.3200	0.0000	0.0000	0.0000	41,422.3200	0.0000	0.0000	41.4223	Tonnes
Blown Cellulose	m2 (25mm)	1,203.4642	0.0000	0.0000	0.0000	1,203.4642	0.0000	0.0000	0.7702	Tonnes
Concrete Benchmark 2500 psi	m3	1,118.5312	0.0000	1,118.5312	0.0000	0.0000	0.0000	0.0000	2,561.3570	Tonnes
Concrete Benchmark 3000 psi	m3	1,451.1569	0.0000	1.9419	928.6158	476.6538	43.9454	0.0000	3,328.0396	Tonnes
Concrete Benchmark 4000 psi	m3	889.9599	889.9599	0.0000	0.0000	0.0000	0.0000	0.0000	2,052.6232	Tonnes
Concrete Tile	m2	377.6655	0.0000	0.0000	0.0000	377.6655	0.0000	0.0000	29.4579	Tonnes
Double Glazed Hard Coated Argon	m2	1,450.4273	0.0000	0.0000	0.0000	0.0000	1,450.4273	0.0000	23.4869	Tonnes
Extruded Polystyrene	m2 (25mm)	18,682.5101	0.0000	55.5775	175.2983	12,128.6865	6,322.9478	0.0000	22.9795	Tonnes
FG Batt R20	m2 (25mm)	10,331.3592	0.0000	0.0000	0.0000	0.0000	10,331.3592	0.0000	2.7827	Tonnes
Fiber Cement	m2	2,694.2520	0.0000	10.0584	0.0000	0.0000	2,684.1936	0.0000	37.7007	Tonnes
Galvanized Sheet	Tonnes	0.6016	0.0000	0.0000	0.0000	0.6016	0.0000	0.0000	0.6016	Tonnes
Modified Bitumen membrane	kg	28,918.1443	0.0000	0.0000	0.0000	28,918.1443	0.0000	0.0000	28.9181	Tonnes
Nails	Tonnes	1.4693	0.0000	0.0007	0.0053	0.7079	0.7554	0.0000	1.4693	Tonnes
Rebar, Rod, Light Sections	Tonnes	365.0495	269.3151	56.6987	7.8068	29.6688	1.5602	0.0000	365.0495	Tonnes
Roofing Asphalt	kg	25,426.8286	0.0000	0.0000	0.0000	25,426.8286	0.0000	0.0000	25.4268	Tonnes
Screws Nuts & Bolts	Tonnes	0.8738	0.0000	0.0000	0.0000	0.0000	0.8738	0.0000	0.8738	Tonnes
Small Dimension Softwood Lumber, kiln-dried	m3	33.2892	0.0000	0.0000	0.0000	2.0161	31.2731	0.0000	14.8251	Tonnes
Softwood Plywood	m2 (9mm)	2,839.7786	0.0000	0.0000	0.0000	0.0000	2,839.7786	0.0000	13.4151	Tonnes
Vinyl Clad Wood Window Frame	kg	6,142.4438	0.0000	0.0000	0.0000	0.0000	6,142.4438	0.0000	6.1424	Tonnes
VR 1/2" Drainage Mat	m2	1,652.4798	0.0000	0.0000	0.0000	1,652.4798	0.0000	0.0000	1.5992	Tonnes
VR 20 mil Root Barrier	m2	1,652.4798	0.0000	0.0000	0.0000	1,652.4798	0.0000	0.0000	0.8327	Tonnes
VR Extensive Growing Medium	m2 (25mm)	2,446.8303	0.0000	0.0000	0.0000	2,446.8303	0.0000	0.0000	47.4073	Tonnes
VR Protection Sheet	m2	1,652.4798	0.0000	0.0000	0.0000	1,652.4798	0.0000	0.0000	0.6610	Tonnes
Water Based Latex Paint	L	5,785.2517	0.0000	10.8192	0.0000	0.0000	5,774.4325	0.0000	4.3389	Tonnes
Welded Wire Mesh / Ladder Wire	Tonnes	1.2860	0.0000	0.0000	1.2860	0.0000	0.0000	0.0000	1.2860	Tonnes

Figure 9 GWP of buildings assessed by E3: breakdown by building elements (credit: E3)

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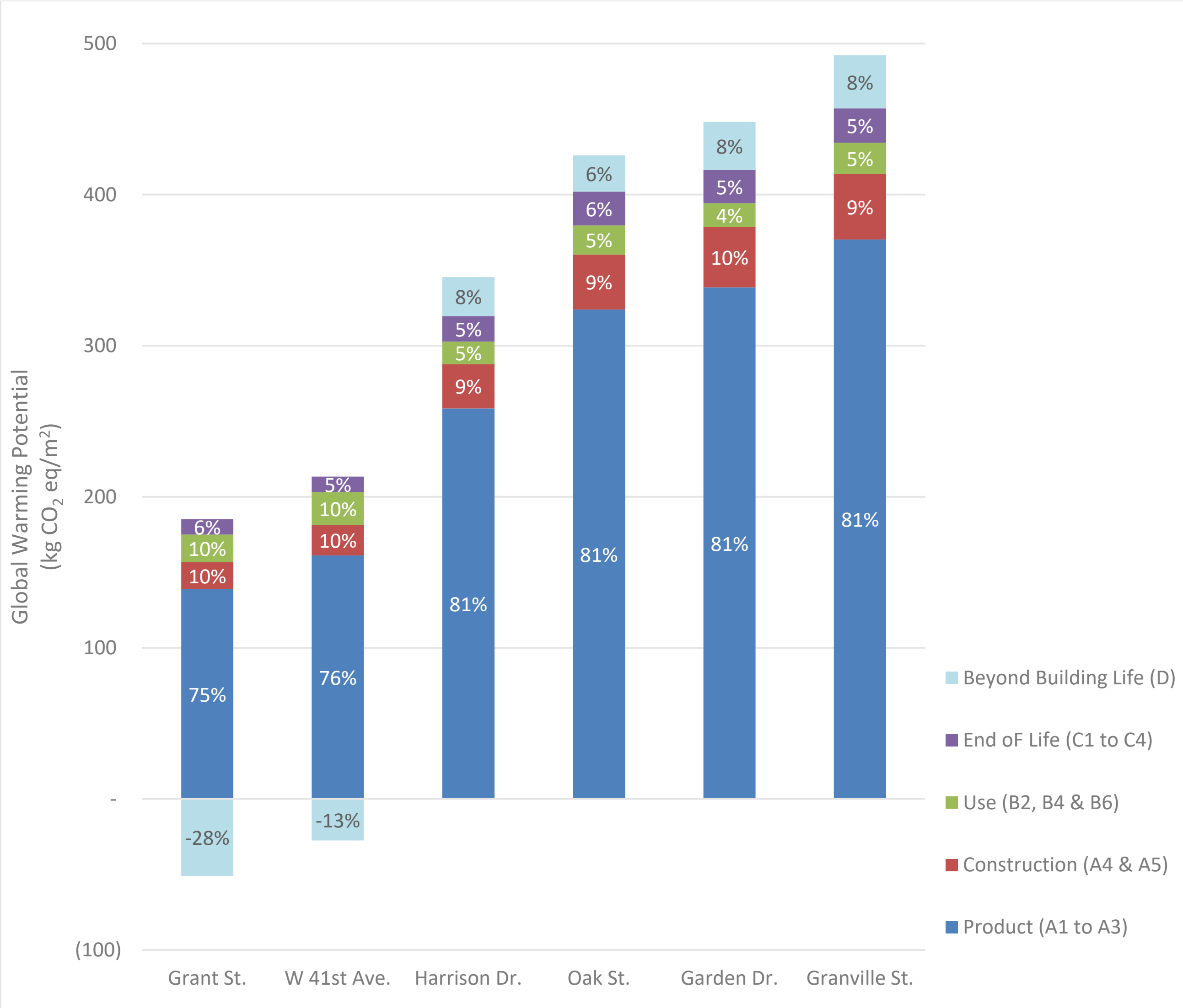

Figure 10 GWP of buildings assessed by E3: breakdown by life cycle phases

2.2.2. Recommended embodied emissions submission template

This section provides a template for reporting embodied emissions. This template addresses the shortcomings discussed in section 2.2.1 and standardizes the format. Zera Solutions recommends developing an online submission form or an Excel form to facilitate the review, auditing and data analysis.

This template shows the information to be collected, and not the layout design. This is because the layout needs to take into account the collection method (i.e. excel vs online form). Another possibility is to have this information exported directly from Athena IE or other software tools accepted by the City.

General information:

Project Address:

LCA Assessor (Consultant name)**:**

Date of Assessment: yyyy-mm-dd

Approval/ Permit Stage: ☐ Rezoning ☐ Building ☐ Occupancy

Project Type: ☐ Residential Low-Rise (< 7 storeys) ☐ Residential High-Rise (7+ storeys) ☐ Office ☐ Retail ☐ Hotel ☐ Other

Gross Floor Area: Total (Include minimum mandatory parkade and non-heated areas): _____m^2
Parkade only: _____m^2

Estimated Number of Residences: Residential: _____ Office: _____ Retail: _____ Hotel: ______ Other: _____

Building Height: Above Grade: _____m Below Grade: _____m Typical Floor Height: _____m

Number of Levels: Above Grade: _____ Below Grade (include parkade): _____

Elements Layers:

Provide an overview of the materials used in the key elements, including insulation

Foundation & Basement: (75 words)

Columns & Beams: (75 words)

Floor: (75 words)

Roof: (75 words)

Stairs: (75 words)

Exterior Walls: (75 words)

Exterior Windows & Doors: (75 words)

Embodied Emissions

Life Cycle Phases Included:
■ A1-Raw material supply ■ A2-Transport ■ A3-Manufacturing
■ A4-Transport ■ A5-Construction-installation
■ B2-Maintenance ■ B3-Repair ■ B4-Replacement
■ C1-Deconstruction/Demolition ■ C2-Transport
■ C3-Waste processing ■ C4-Disposal
☐ D-Benefits and loads beyond the building's life cycle*
Optional, exclude from total GWP and report separately

Elements Included:
■ A1010-Standard Foundations ■ A1020-Special Foundations
■ A1030-Slab on Grade ■ A2020-Basement Walls
■ B1010-Floor Construction ■ B1020-Roof Construction
■ B2010-Exterior Walls ■ B2020-Exterior Windows
■ B2030 Exterior Doors ■ B3010 Roof Coverings
■ B3020 Roof Openings ■ C1010 Partitions[11] (optional)
■ C2010 Stair Construction

[11] It is recommended that partitions be added to the City's embodied emission assessment scope as they constitute about 8% of the multi-unit residential buildings according to Bowick & O'Connor (2017)

Material quantity assessment method: ☐ BIM Model ☐ LCA Software
☐ Construction estimator ☐ Other: __________

Global Warming Potential (GWP)[12]:

Total (A-C): _____ kg Co^2 eq. _____ kg Co^2 eq./m^2 * _____ kg Co^2 eq. /m^2/year *

** total gross floor area: Include minimum mandatory parkade and non-heated areas * 60 years*

Breakdown by Life Cycle Phase:

Product (A1-A3): _____ kg Co^2 eq./m^2 *
Construction (A4-A5): _____ kg Co^2 eq./m^2 *
Repair & Replacement (B3-B4): _____ kg Co^2 eq./m^2 *
End of Life (C1-C4): _____ kg Co^2 eq./m^2 *
Beyond Building Life (D): _____ kg Co^2 eq./m^2 *

** total gross floor area: Include minimum mandatory parkade and non-heated areas * 60 years*

Breakdown by Elements[13]:

Foundation & Basement (A1010, A1020, A1030, A2020): _____ kg Co^2 eq./m^2 *
Floor (B1010): _____ kg Co^2 eq./m^2 *
Roof (B1020, B3010): _____ kg Co^2 eq./m^2 *
Stairs (C2010): _____ kg Co^2 eq./m^2 *
Exterior Walls (B2010): _____ kg Co^2 eq./m^2 *
Exterior Windows & Doors (B2020, B2030, B3020): _____ kg Co^2 eq./m^2 *
Partitions (C1010): _____ kg Co^2 eq./m^2 * (Optional)

** total gross floor area: Include minimum mandatory parkade and non-heated areas * 60 years*

Breakdown by Materials[13]:

Metal: _____ kg Co^2 eq./m^2 *
Concrete: _____ kg Co^2 eq./m^2 *
Gypsum: _____ kg Co^2 eq./m^2 *
Glass: _____ kg Co^2 eq./m^2 *
Wood: _____ kg Co^2 eq./m^2 *
Plastic: _____ kg Co^2 eq./m^2 *
Other: _____ kg Co^2 eq./m^2 *

** total gross floor area: Include minimum mandatory parkade and non-heated areas * 60 years*

Strategies to reduce Embodied Carbon:

(75 words)

Other Environmental Impact Indicators:

Ozone Depletion Potential (A-C): _____ kg CFC_{-11} eq/m^2 *
Acidification Potential (A-C): _____ kg SO_2 eq/m^2 *
Eutrophication Potential (A-C): _____ kg N eq/m^2 *
Smog Potential (A-C): _____ kg O_3 eq/m^2 *
Human Health Particulate Potential (A-C): _____ kg $PM_{2.5}$ eq/m^2 *
Non-renewable Energy Use (A-C): _____ MJ/m^2 *

** total gross floor area: Include minimum mandatory parkade and non-heated areas * 60 years*

[12] GWP breakdowns should be automatically generated by LCA tools.

[13] Athena Impact Estimator is currently not equipped to provide these breakdowns, especially breakdown by materials. However, according to Athena, they can easily implement changes to specifically serve the needs of the City (see Appendix C, Interview summary with Jennifer O'Connor and Matt Bowick).

Template continued from previous page in table form…

Bill of Materials:

Materials			**Total Quantity** (per gross floor area)	**Elements** *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Steel	Bolts, Fasteners, Clips	kg/m^2										
	Cold Rolled Sheet	kg/m^2										
	Hot Rolled Sheet	kg/m^2										
	Galvanized Decking	kg/m^2										
	Galvanized Sheet	kg/m^2										
	Galvanized Studs	kg/m^2										
	Metal Panel	m^2/m^2										
	Structural Steel	kg/m^2										
	Metal Cladding	kg/m^2										
	Open Web Joists	kg/m^2										
	Nails	kg/m^2										
	Rebar, Rod, Light Sections	kg/m^2										
	Screws Nuts & Bolts	kg/m^2										
	Steel Sections & profiles	kg/m^2										
	Steel Plate	kg/m^2										
	Steel Tubing	kg/m^2										
	Wire Rod	kg/m^2										
	Welded Wire Mesh / Ladder Wire	kg/m^2										
	Other	kg/m^2										
Total ***		kg/m^2										

Materials			Total Quantity (per gross floor area)	Elements *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Aluminium	Aluminum Extrusion	kg/m²										
	Aluminum Window Frame	kg/m²										
	Aluminum Clad Wood indow Frame	kg/m²										
	Aluminum Casting	kg/m²										
	Aluminum Cold Rolled Sheet	kg/m²										
	Other	kg/m²										
	Total ***	kg/m²										
Concrete	Concrete Blocks	Blocks										
	Concrete Block Thickness (")	-										
	Concrete Tile	m²/m²										
	Mortar	m³/m²										
	Concrete benchmark	m³/m²										
	Concrete psi	-										
	Concrete Fly Ash %	-										
	Portland Cement	kg/m²										
	Portland Lime Cement	kg/m²										
	Precast Concrete	m³/m²										
	Precast Insulated Panel	m²/m²										
	Precast Insulated Panel with Brick Veneer	m²/m²										
	Precast Panel	m²/m²										
	Other	kg/m²										
	Total ***	kg/m²										

Zera Solutions
For a Future to Flourish

Materials			Total Quantity (per gross floor area)	Elements *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Gypsum	Fire-Rated Type X Gypsum Board	m^2/m^2										
	Gypsum Fibre Gypsum Board	m^2/m^2										
	Moisture Resistant Gypsum Board	m^2/m^2										
	Regular Gypsum Board	m^2/m^2										
	Glass Mat Gypsum Panel	m^2/m^2										
	Gypsum Board Thickness (")	-										
	Joint Compound	kg/m^2										
	Stucco over metal mesh	m^2/m^2										
	Stucco over porous surface	m^2/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Glass	Glass Fibre	kg/m^2										
	Double Glazed Hard Coated Air	m^2/m^2										
	Double Glazed Hard Coated Argon	m^2/m^2										
	Double Glazed No Coating Air	m^2/m^2										
	Double Glazed Soft Coated Air	m^2/m^2										
	Double Glazed Soft Coated Argon	m^2/m^2										
	Triple Glazed Hard Coated Air	m^2/m^2										
	Triple Glazed Hard Coated Argon	m^2/m^2										
	Triple Glazed No Coating Air	m^2/m^2										
	Triple Glazed Soft Coated Air	m^2/m^2										
	Triple Glazed Soft Coated Argon	m^2/m^2										
	Fiber Glass Insulation	m^3/m^2										
	Glazing Panel	kg/m^2										
	Spandrel Panel	kg/m^2										
	Glass Felt	m^2/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										

Materials			**Total Quantity** (per gross floor area)	**Elements** *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Clay	Clay Tile	m^2/m^2										
	Modular Brick	m^2/m^2										
	Ontario (Standard) Brick	m^2/m^2										
	VR Growing Medium	m^3/m^2										
	VR Growing Medium	m^3/m^2										
	Ceramic tile flooring	m^2/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Stone	Ballast (aggregate stone)	kg/m^2										
	Aggregate Crushed Stone	kg/m^2										
	Aggregate Natural Stone	kg/m^2										
	Aggregate Manufactured	kg/m^2										
	Crushed Recycled Concrete	kg/m^2										
	Mineral Filler Crushed Stone	kg/m^2										
	Mineral Filler Natural	kg/m^2										
	Natural Stone	kg/m^2										
	VR Coarse Aggregate Natural	kg/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										

Materials			Total Quantity (per gross floor area)	Elements *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Other Inert	Fiber Cement	m^2/m^2										
	Fly Ash	kg/m^2										
	Hydrated Lime	kg/m^2										
	Mineral Surface roll	m^2/m^2										
	Mineral Wool Batt Insulation	m^3/m^2										
	Silica Fume	kg/m^2										
	Slag Cement	kg/m^2										
	Water	kg/m^2										
	Ceiling Tile	m^2/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Wood	Blown Cellulose	m^3/m^2										
	Cedar Wood Bevel Siding	m^2/m^2										
	Cedar Wood Shiplap Siding	m^2/m^2										
	Cedar Wood Tongue and Groove Siding	m^2/m^2										
	Cross Laminated Timber	m^3/m^2										
	Glulam Timber	m^3/m^2										
	Laminated Veneer Lumber	m^3/m^2										
	Large Dimension Softwood Lumber, kiln-dried	m^3/m^2										
	Oriented Strand Board	m^3/m^2										
	Paper Tape	kg/m^2										
	Parallel Strand Lumber	m^3/m^2										
	Pine Wood Bevel Siding	m^2/m^2										
	Pine Wood Shiplap Siding	m^2/m^2										
	Pine Wood tongue and groove siding	m^2/m^2										
	Small Dimension Softwood Lumber, kiln-dried	m^3/m^2										
	Softwood Plywood	m^3/m^2										

Materials			**Total Quantity** (per gross floor area)	**Elements** *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Wood (Continued)	Spruce Wood Bevel Siding	m^2/m^2										
	Spruce Wood Shiplap Siding	m^2/m^2										
	Spruce Wood tongue and groove siding	m^2/m^2										
	Unclad Wood Window Frame	kg/m^2										
	Wood/Wood Fiber Panels	m^2/m^2										
	Fibreboard	m^3/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Polyethylene (PE)	3 mil Polyethylene	m^3/m^2										
	6 mil Polyethylene	m^2/m^2										
	Polyethylene Filter Fabric	kg/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Polystyrene (PS)	Expanded Polystyrene	m^3/m^2										
	Extruded Polystyrene	m^3/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Polyisocyanurate (PI)	Polyiso Foam Board (unfaced)	m^3/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										

Materials			Total Quantity (per gross floor area)	Elements *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Polypropylene (PP)	Polypropylene	kg/m^2										
	Polypropylene Scrim Kraft Vapour Retarder Cloth	m^2/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Polyvinylchloride (PVC)	PVC Membrane	kg/m^2										
	PVC	kg/m^2										
	PVC Window Frame	kg/m^2										
	Vinyl Clad Wood Window Frame	kg/m^2										
	Vinyl Siding	m^2/m^2										
	Resilient flooring	m^2/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										
Bitumen	Organic Felt	m^2/m^2										
	Bitumen	m^2/m^2										
	Emulsified Asphalt Primer Coat	kg/m^2										
	Emulsified Asphalt Tack Coat	kg/m^2										
	Glass Based shingles	m^2/m^2										
	Modified Bitumen membrane	kg/m^2										
	Organic Felt shingles	m^2/m^2										
	Roofing Asphalt	kg/m^2										
	Other	kg/m^2										
	Total ***	kg/m^2										

Materials			Total Quantity (per gross floor area)	Elements *(optional)*								
Material Groups	Materials*	Units**		Foundation	Basement	Columns & Beams	Floor	Roof	Exterior Walls	Exterior Windows & Doors	Roof	Stairs
Rubber	EPDM membrane	kg/m²										
	Other	kg/m²										
	Total ***	kg/m²										
Paint	Solvent Based Alkyd Paint	L/m²										
	Solvent Based Varnish	L/m²										
	Water Based Latex Paint	L/m²										
	Other	kg/m²										
	Total ***	kg/m²										
Other Oil Derived	Air Barrier	m²/m²										
	Fibreglass Window Frame	kg/m²										
	Thermoplastic Polyolefin Membrane	m²/m²										
	MDI resin	kg/m²										
	Polyester felt	kg/m²										
	VR Drainage Mat	m²/m²										
	VR Root Barrier	m²/m²										
	VR Protection Sheet	m²/m²										
	VR Separation Fabric	m²/m²										
	Carpet Tile	m²/m²										
	Other	kg/m²										
	Total ***	kg/m²										

** Material list is based on Athena IE material breakdown.*

*** Units are material weight, area, or volume per building total gross floor area (include minimum mandatory parkade and non-heated areas)*

**** The total quantities should be automatically generated (weight per gross floor area), using building materials' thickness and density.*

…end of template.

2.2.3. Recommended scope for the embodied emission limits

LCA methodology considers the environmental impacts throughout the whole life cycle of a system. For buildings, the life cycle includes product, construction, use, end of life, and impact beyond the building's life time (Figure 11).

Based on the regional LCA experts' recommendations (Appendix C), the City should require a Cradle-to-Grave LCA reporting, with Module D being reported separately. This encourages the industry to consider environmental impacts of buildings throughout their whole life cycle.

Additionally, the City should require using project-specific data in the LCA reporting for the life cycle phases for which specific data is available. Requiring project-specific data use helps projects to more accurately identify the areas in which there are opportunities for reducing the impacts. As shown in Figure 11, in the building permit stage, project specific data should be required for product and transportation to site (cradle-to-site). At occupancy permit stage, project-specific data requirements should expand to construction and installation impacts (cradle-to-handover).

The City should pay closer attention to product phase. This is for two reasons. First, as shown in Figure 10 the product phase constitutes more than 75-81% of the embodied emissions. Although the graph is based on a small number of projects submitted to the City, this trend is supported in various previous studies[14].

The second reason is that the current common LCA software tools and databases are more mature for the product phase. Therefore, project teams' decisions to reduce emissions from the product phase can be reflected more accurately. On the other hand, the impacts from construction, use and end-of-life cannot be reflected accurately. This is because the data for these phases are either partially based on local or regional industry averages or input by users without sufficient data quality assessment measures.

By requiring the use of actual transportation distances and construction impacts at building and occupancy permits stages, the City can help improve the local databases and tools. However, there is a need for audits to ensure of the data quality. One argument that some may make against asking project-specific data for construction phase is that the impacts of this phase are small relative to the product phase[15]. However, these impacts occur prior to the building operations. Thus, reducing them will have an immediate benefit to the climate change goals. The City should, however, consult with the construction industry to identify the most effective methods for reporting this data.

[14] For instance, the embodied carbon benchmark analysis of BC multi-unit residential buildings conducted by Athena Sustainable Materials Instate showed the range 72-82% among the 10 project they reviewed (Bowick & O'Connor, 2017).

[15] According to Bowick & O'Connor (2017) the construction stage contribution to the overall building embodied emissions is less than 10%.

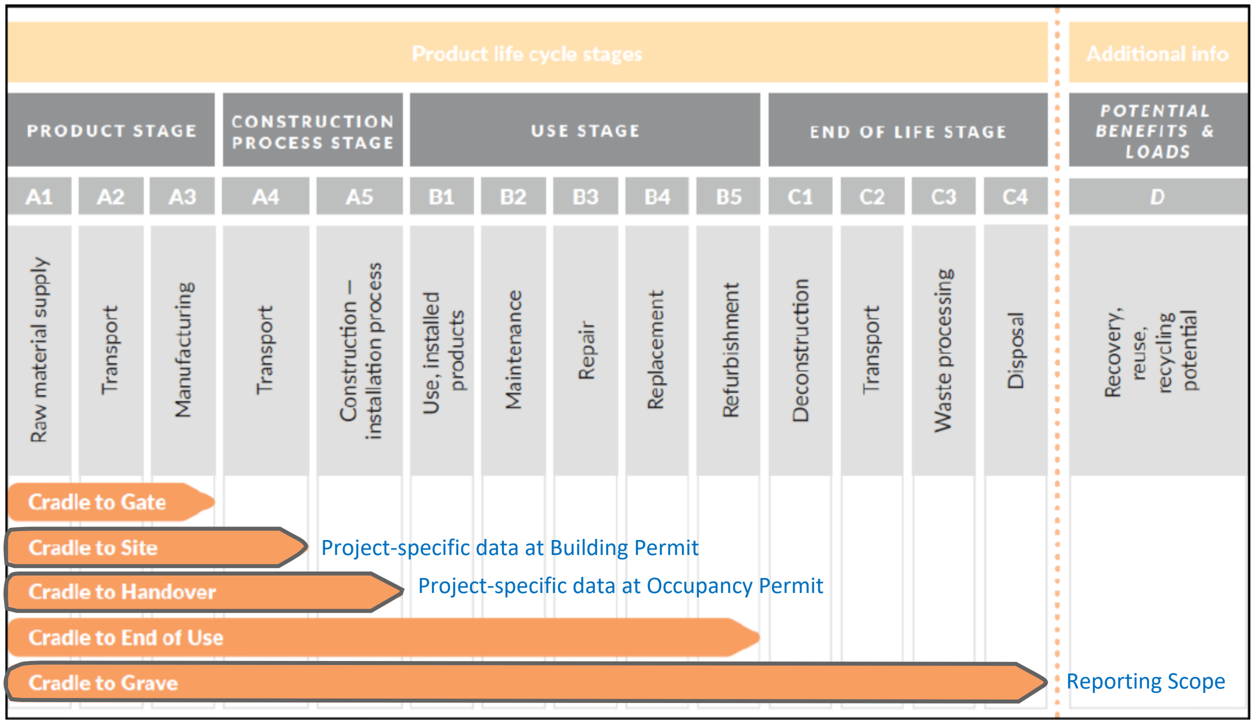

Figure 11 Recommended building system boundaries for oembodied emissions assessments (Adapted from: Mistretta & Guarino, 2016)

3. Literature review: embodied emissions policy and guidelines

The second objective for this research was twofold: First to review the best policy practices around the world to help develop the roadmap for the City. Second, identify the best resources that can help the City develop a guide for project teams to reduce embodied emissions in design.

Sections 3.1 summarizes the key takeaways from two reports prepared in the past two years. These reports review the latest policies and programs around the world that are intended to reduce embodied GHG emissions of buildings emissions of buildings (Bionova Ltd., 2018; Zizzo et al., 2017).

Section 3.2 provides an overview of the guidelines for designers for reducing embodied energy and embodied GHG emissions.

3.1. Best practice policy review

Section 3.1.1 summarizes the infrastructure required for a successful embodied carbon policy and Section 3.1.2 summarizes examples of jurisdiction which have, or are developing successful embodied emissions policies.

3.1.1. Infrastructure required for the embodied carbon policies

Prior to the implementation of an embodied carbon policy, more work is required to develop regional or national technical tools, systems and resources necessary for the building industry to ensure program consistency and integrity. The technical infrastructure of an embodied carbon policy should include (1) a consensus-based methodology based on standards, (2) High-quality, publicly accessible databases, and (3) simplified whole-building LCA software tools (Zizzo et al., 2017).

3.1.1.1. Consensus-based methodology based on standards

The most used and robust standards for construction LCA available today are the ones developed by the European Committee for Standardization (CEN). Standards developed by CEN Technical Committee 350[16] include the EN 15804 for construction products and EN 15978 for buildings. Recently, ISO 21930 was published, and its key technical provisions align with the EN 15804. Relying solely on product scale standards (ISO 14040 and ISO 14044) for construction works LCA is not advisable.

Currently, in North America, the CEN standards are being used to further the goals of harmonization of building sector LCAs. The overall structure and scoping rules for completing LCAs on building products and whole buildings are equally applicable to the North American context.

[16] Sustainability of Construction Works
https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:481830&cs=181BD0E0E925FA84EC4B8BCCC284577F8

3.1.1.2. High-quality, publicly accessible databases

To estimate the embodied emissions, the resource flow in and out of the system throughout the life cycle of a building and the consequential environmental impacts needs to be calculated. Given the complexity of this process, such assessment heavily relies on databases providing this information. These databases are: Life Cycle Inventory (LCI) and Environmental Product Declaration (EPD) databases.

Life Cycle Inventory (LCI) databases:

LCI databases entail resource flows in and out of product systems throughout their life cycle, including materials, energy, water, and emissions to air, water and land. LCI is affected by assumptions about the material inputs such as supply chain characteristics, transportation, replacement rates, and end-of-life fate.

The two main global-level LCI databases are ecoinvent[17] (with 12,800 datasets from various industry sectors) and GaBi[18] (with approximately 30,000 datasets from various industry sectors). These supply a good deal of the data currently being accessed in Canada. The Canadian Interuniversity Research Center for the Life Cycle of Products (CIRAIG) started the development of a life-cycle inventory databank for Québec in 2011 and currently partners with ecoinvent. Athena is the only Canada-wide LCI database with about 200 construction materials in its library. However, it is a closed, proprietary database. As LCA grows, more locally specific data will invariably follow.

Increasingly, these databases support the requirements of widely accepted standards (such as those published by ISO and CEN) and will work consistently regardless of the software package. However, ensuring data meet the quality requirements described in these standards can be costly. For this reason, voluntary LCI databases such as the U.S. Life Cycle Inventory Database (another source of data used in Canada) must be managed for quality by consultancies that use the data or by software providers that have an interest in ensuring that their software users can confidently and reliably access high-quality data.

Environmental Product Declaration (EPD) programs

Environmental Product Declaration (EPD) contains environmental impact data for products based on an LCA that has been conducted in compliance with applicable ISO standards. As of January 2017, over 6,000 construction product EPDs had been published globally [19]. There are at least ten EPD programs currently in operation in North America. Several of the leading North American EPD program operators are working together to harmonize the way product category rules are developed.

[17] www.ecoinvent.org
[18] www.gabi-software.com/canada/index
[19] https://infogram.com/47216efb-7256-4a5e-acc3-04ce046cbdf8

3.1.1.3. Simplified whole-building LCA software tools

Whole-building LCA software tools simplify the LCA process in user-friendly, construction-specific interfaces. The background LCI data and methods are embedded in the software, plus these tools incorporate LCA scenario data and, in some cases, assist the user in material takeoff calculations.

Underlying data can come from public and proprietary databases and from EPDs. Whole-building LCA tools are organized in a building context (e.g., by material assemblies and building sub-components). These tools are commonly restricted to particular geographic regions based on their underlying data, although some tools claim global coverage.

These tools differ in terms of their alignment to standards, the scope of the life cycle that they address, and their regional applicability. Two whole-building software packages are currently available for specific application in North America: Impact Estimator for Buildings from the Athena Institute[20] and Tally from KT Innovations[21]. Two other globally marketed software tools are One Click LCA by Bionova Ltd. [22] originated in Finland and E-Tool originated in Australia [23].

3.1.2. Best practices for embodied emissions policies around the world

Bionova (2018) conducted an in-depth review of a wide range of environmental and sustainability regulations, voluntary certifications, standards, and guidelines applied to buildings around the world to identify the best practices to address embodied carbon[24]. Appendix B provide lists of the international, Northern European, Continental European, and Northern & Southern American systems reviewed by Bionova (2018).

Bionova (2018) suggests that while improving just carbon intensity of materials through methods such as requiring EPD is essential, it is not sufficient. To see an overall improvement, it is necessary to “require rethinking materials efficiency and materials use in building design” as a whole. “The focus of the regulation needs to be the process of designing and delivering buildings”. This report identified the following approaches in the systems that have been most successful in reducing embodied carbon emissions of buildings:

---

[20] http://calculatelca.com/software/impact-estimator
Free desktop software tool using Athena Institute customized industry data and scenario data, USLCI database profiles, ecoinvent, and other publicly available data such as EPDs.
[21] http://choosetally.com/
Autodesk Revit plugin, US $695 primarily relies on EPDs. Supplemented with generic data using customized thinkstep GaBi data and some EPDs.
[22] www.oneclicklca.com
web-based application with Revit plugin, starting around CAN $500 per year, primarily relies on EPDs, Supplemented with generic data
[23] http://etoolglobal.com/
web-based application that’s is free for unassisted use, the underlying data is unclear.
[24] Their criteria only include systems that are used at least regionally, as opposed to being used in one city or organization.

1. **Targeting early stages of projects:** Targeting embodied carbon at early planning and design stages and iterating it as the project design evolves, encourages materials awareness when change is most efficient and cost-effective.
2. **Setting carbon caps for common building types:** Setting a cap ensures all projects consider embodied carbon very early on at their target setting. For the purposes of embodied carbon reductions, it is more efficient to set reductions for carbon only rather than for all the environmental impact indicators. Caps should allow almost any well-managed project to meet the targets. Caps will incentivize decarbonization for projects whose carbon impacts reach the maximum allowed threshold. The caps can be initially set only for common building types, as those are the ones with the largest overall construction volume.
3. **Applying a fixed method for setting cap values:** For systems working in a single country or context, best practice is to apply either a fixed scale for the threshold values, or a clear and normative methodology to develop those on a project level. Fixed threshold values will simplify the process from the point of view of the project team, but the lost flexibility may mean that specific types of projects will be getting either an advantage or a disadvantage. A normative and verifiable methodology for defining threshold values should allow accounting for differences to carbon performance arising from other building code requirements, such as acoustic, fire-proofing, seismic and structural specifications.
4. **Providing incentives carbon reduction below the caps:** To achieve best results, it is advisable to combine the cap with carbon performance ratings or incentives. Incentives with direct financial value are rare[25]. Other examples of incentives that cities can provide for embodied carbon reduction include expedited permitting process, requiring carbon performance reporting or meeting performance thresholds in tenders, land sales competitions, zoning, density bonus, and corresponding discount from municipal permitting fees.
5. **Setting rules and requirements based on official standards:** Standards provide comparability, trust and efficiency.
6. **Setting open compliance requirements and verify outcomes:** Open compliance requirements are a public assessment methodology which anyone can access and implement. Closed systems limit innovation, in particular the development of digital design technologies including building information models (BIM), parametric design and optimization, and integrated design processes. The verification can target the calculation tools, as well as LCA results.

3.1.2.1. Case Studies

Below are examples of green construction rating systems and policies that have successfully combined numerous best practices mentioned above and shown their effectiveness (Bionova Ltd., 2018; Zizzo et al., 2017).

[25] The only cases were identified in the public procurement domain from the Swedish Trafikverket and the Dutch Rijkswaterstaat, where carbon performance may unlock a cash bonus.

Netherlands:

Scale & Types: National & Regulation

Assessment Methodology: The national assessment method called "Assessment Method: Environmental Performance Construction and Civil Engineering Works" (Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken) is published and updated by an independent association, Stichting Bouwkwaliteit (SBK)[26]. The method is based on EN 15804 and EN 15978 with national adaptations, including health impact accounting. The assessment method converts the 11 LCA impact categories to a shadow price which is expressed in Euro. All impacts are transformed into a monetary value, which is divided by the building gross floor area and assessment period length. The assessment period is 75 years for residential, 50 for offices.

Databases & Tools: The national environmental database (Nationale Milieudatabase (NMD)) is also published and updated by SBK since 2012. Applying the method to a project requires the use one of the three whole-building LCA software tools that has been previously verified and approved by SBK.

Government requirements/incentives: The version of the Building Act, entered into force in January 2013, required all residential and office buildings whose surface exceeds 100 m^2 to account for their embodied impacts at the building-permit-application stage in the form of an LCA using the national assessment method and associated database. The regulation was revised in January 2018 to set a mandatory environmental impact cap for buildings at 1.00 EUR per square meter and year.

The Netherlands first attempted such a policy in 2003. It was not successful due to significant resistance from major stakeholders. The next decade saw significant advancements, many of which were actively developed together with the same stakeholders who had originally pushed back. In 2010, a government-led project was started to harmonize EPD programs and whole-building LCA tools.

France:

Scale & Types: National & Incentive

Assessment Methodology: Énergie Positive & Réduction Carbone (E+C-) is issued by the French Ministry of Ecology, Energy, Sustainable Development and Spatial Planning. It has been developed together with the industry. E+C- mandates inputting operation energy of buildings as well as the embodied in the LCA. The methodology calculates the values for a 50-year period and divides it by total building area. The system provides a degree of adjustment for projects with underground car parking, as well as high altitude projects[27]. Third-party verification (by e.g., Cofrac[28] or its European counterparts) is only done for projects applying for E+C- label. The label has an entry level (Carbone 1) and the good performance level (Carbone 2) with specified maximum carbon emissions for different building types, as specified in Table 2.

[26] https://www.bouwkwaliteit.nl/

[27] The embodied carbon caps are increased by 700 kg CO_2e, for each above-ground parking place and by 3000 kg CO_2e for each underground parking place the local zoning bylaws require from the.

[28] https://www.cofrac.fr/en/cofrac CoFrac is a private non-profit association designated as the sole national accreditation body.

Table 2 French E+C- embodied carbon limit values by building type

BUILDING TYPE	ENTRY LEVEL: CARBONE 1 – KG CO2E / M2	GOOD PERFORMANCE: CARBONE 2 – KG CO2E / M2
Single family or row houses	700	650
Apartment buildings	800	750
Office buildings	1050	900
Other regulated building types	1050	750

Databases & Tools: E+C- requires the use of French generic data as well as INIES[29], the national database, which gathers EPDs abiding by the European Standard 15804 and its French annex. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database. Software tools implementing the methodology are verified and approved by government, examples are: One Click LCA, ThermACV, ELODIE, ClimaWin, and NovaEQUER.

Benchmarking: The HQE Performance initiative is a pilot project (by the same organization that administers the HQE green building rating program[30], which has an LCA component) to establish whole-building LCA benchmarks, beginning with office buildings and multi-unit residential buildings.

Government requirements/incentives: France government has a primary legislation in place requiring regulation of carbon footprint of new buildings. Before enacting the secondary legislation (decree), the government has prepared E+C- as a pilot programme. E+C- offers building labels and incentives at building permit stage. The government offers financial assistance for builders/developers for additional costs of LCA studies. The improved performance level can be used as a criterion in public procurement or zoning, in effect working as a density bonus in different cities. Results are submitted to the government as online documents containing the essential inputs as well as the results in a technically analysed format. The result files are automatically verified for completeness of the content by upload portal. This information will likely be used to calculate statistics and document best practices. The pilot program is expected to become mandatory in 2020

Austria:

Scale & Types: National & Incentive

Assessment Methodology: no formal government-set methodology, but Austrian Institute for Healthy and Ecological Building (IBO[31]) has published Ökoindex 3, which is the closet thing to a national embodied impact evaluation methodology. Ökoindex 3 is a weighted score of global warming potential, primary energy depletion, and acidification, expressed as an A to E rating. The scale of performance has been fixed by IBO. There are demands to revise this methodology to be in line with EN 15804.

Databases & Tools: The calculation data applied for these analyses and the assessment tools are provided by Baubook[32] online platform, managed by a private entity of which IBO and Energy Institute

[29] http://www.inies.fr/home/
[30] http://www.hqegbc.org/buildings/certifications/
[31] https://www.ibo.at/en/
[32] https://www.baubook.info/?SW=6&lng=2

Vorarlberg[33] are among the shareholders. Baubook tools are free for construction industry, but it there is a fee to assess and list manufacturers' products (~150€).

Government requirements/incentives: The mandatory governmental environmental rating system (klimaaktiv), applies the Ökoindex 3. Performing well in this certification can make residential buildings eligible for an additional environment-related subsidy. This certification has been applied to over 500 buildings. The regulations are defined and managed at the level of the individual states, so they vary greatly. For example, in Tirol the embodied impact performance improvement is translated into cash using a scoring scheme, whereas in Vorarlberg, performance improvements release a 35-year low-interest loan (1.75% interest rate).

Norway:

Scale & Types: National & Assessment system

Assessment Methodology: FutureBuilt is a decade-long pilot program that has provided skills, experience, and proof on how to design and construct buildings with minimum 50% life-cycle emissions. Each project should have (at a minimum) four calculations, including:

- Reference building, in the beginning of concept design, using specific rules set by FutureBuilt (referansebyg), based on energy regulation for building types, building size, floor number and type-specific material use for each part of the building, and location and type specific transport patterns as well as other choices allowing adjustment of, for example, foundation work due to site specific foundation conditions.
- Targeted building, in the early design phase. This must show at least a 50% reduction in GHG emissions compared to the reference building.
- Actual building – as built. All products sourced with EPDs must use EPDs for the calculation.
- Extended commissioning status – two years in use. All energy use and transport emissions must be using the realized consumption and actual travel pattern data.

The calculations are done for a 60-years period.

Databases & Tools: Information not found in the reviewed resources.

Government requirements/incentives: The Norwegian government property arm Statsbygg implements a similar process for improving its own projects. This type of methodology is also used by other Norwegian investors. Some of the FutureBuilt projects also received energy investment subsidies.

[33] http://www.alpbc.eu/Energy-Institute-Vorarlberg.html
EIV is a non-profit organization that offers services to support sustainable energy systems.

Belgium:

Scale & Types: National & EPD database and building LCA tool

Assessment Methodology: Regional governments (Brussels, Flanders, and Wallonia) are cooperating to develop a voluntary LCA-based methodology to calculate building-level impacts, which may evolve into future regulation.

Databases & Tools: Belgium has a national EPD database (B-EPD[34]) run by the Federal Public Service of Health, Food Chain Safety and Environment. The national database is also intended for use in whole-building LCA, in coordination with a future LCA assessment tool for building elements known as “MMG”[35].

Government requirements/incentives: A legislative document (Royal Decree) requires manufacturers wishing to make environmental marketing claims must submit an EPD to the database.

Finland:

Scale & Types: National & databases and standard method

Assessment Methodology: Finland Ministry of the Environment is currently in the process of finalizing a simplified carbon calculation method for building designers that includes both new construction and renovation (Finland Ministry of the Environment, 2018). Some areas of interest in this method that that can inform CoV’s method development are:

- **Elements included:** The assessment pays attention to the entire building, the site elements, and the main building service systems. It excludes the site vegetation, soil, temporary scaffolding or protective covers during construction (see Figure 12).

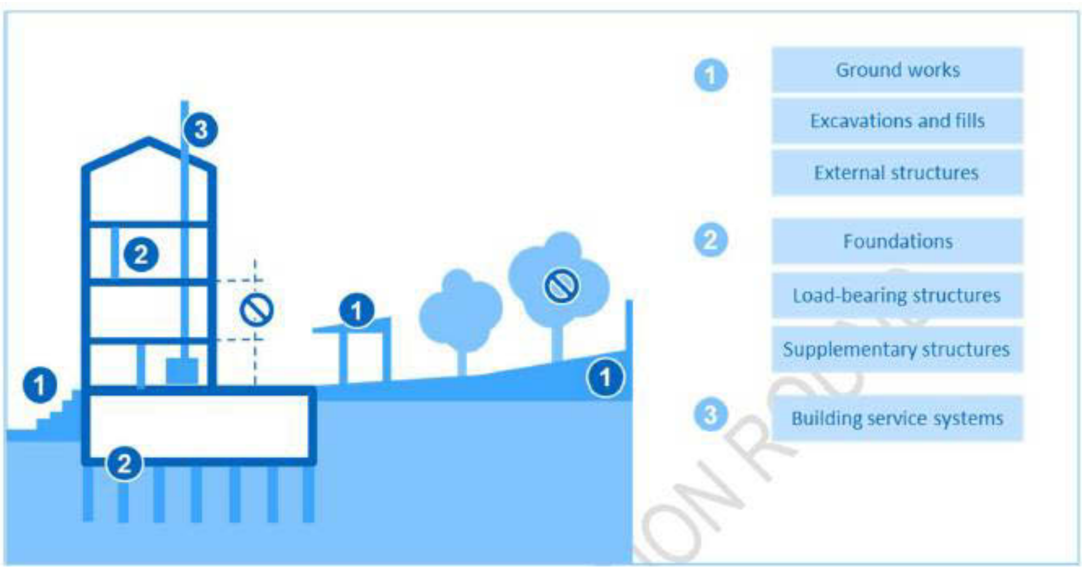

Figure 12 The assessed parts of the building in the proposed Finish method
(Copied from draft for consultations of Finland Ministry of the Environment, 2018).

[34] https://www.health.belgium.be/en/database-environmental-product-declarations-epd
[35] https://www.totem-building.be/services/rest/downloads/download?id=5&lang=EN&transId=17

- **Life cycle phases:** Manufacturing of products (A1-3), transportation to site (A4), construction site operations (A5), repairs and replacements (B3-4), demolition/deconstruction (C1), transport to waste processing sites (C2), waste processing (C3), and final disposal (C4) are the phases that are included in the new building carbon footprint assessment. Refurbishment (B5) is assessed separately for renovation projects. Impacts and benefits beyond building lifetime (D) is also assessed and reported separately as handprint.
- **Functional unit:** The result of the assessment is divided by the building's heated net floor area to allow comparison of different buildings.
- **Calculation Method:** The carbon footprint can be assessed using a simplified or specified method. The simplified carbon footprint assessment can be used early in the design process. The assessment can be updated with more detailed information once the building is put into service.
    - **Simplified method:** This method includes project-specific calculations for the production (A1-3). Default table values are used for other life cycle phases. The table values are averages of carbon footprint calculations of buildings previously assessed in Finland with a 20% uncertainty factor added (See Table 3).
    - **Specified method:** This method includes instructions for the analysis of the carbon footprint of the other modules when they can be assessed in more detail.
- **Quality of data used**: The quality and reliability of the data used in the specified method calculation must be reported using Table 5. As shown in Table 6, the quality of the data is assessed on a scale of 0-3 in accordance with the Level(s) system of the European Commission (Dodd, Cordella, Traverso, & Donatello, 2017).
- **Reporting:** Table 4 shows the minimum reporting requirements of new building. This includes a breakdown of the impacts from before use (A1–5), during use (B3–4, B6), after use (C1–4), and impacts beyond the building life cycle (D).

Databases & Tools: A national database of construction product and process emissions as well as standardised scenarios of the development of the missions during the long life cycle of buildings are being prepared to support the assessment method.

Government requirements/incentives: The Ministry of the Environment's roadmap to low-carbon construction has a plan to introduce assessment of the carbon footprint of buildings and building-type-specific emission limits as part of Finland's building regulations in the 2020s. In addition to the carbon footprint (module A-C), the carbon handprint of construction is evaluated. This describes the possibilities for storing and sequestering carbon dioxide during a building's life cycle or avoiding emissions after its life cycle (module D).

Table 3 Table values for emissions during the life cycle in the Finish simplified calculation method (These values are preliminary and will be updated in the final version).

Typical emissions (kgCO_2e / m^2)

A1–3 Manufacturing	(calculated with project-specific data)	
A4 Transportation to site	10.20	Average for Finland
A5 New construction site works	27.30	Consumption of fuels and energy
B3–4 Energy consumption of repairs[12]	2.16	Production of materials to be estimated separately
B6 Operational energy use	(calculated with project-specific data)	
C1 Demolition site works	7.80	Consumption of fuels and energy
C2 Transportation to further processing	10.20	Average for Finland
C3–4 Waste processing and final disposal	15.60	
Total	**73.26**	kgCO_2e / m^2

Table 4 The minimum content of reporting the emission impacts of a new building in the Finish calculation method (Copied from draft for consultations of Finland Ministry of the Environment, 2018)

Basic information of the assessed building	
Information about the construction site	- Building code - Address - Building type
Technical details of the building	- Floor area - Number of floors - Number of cellar floors - Primary frame material - Energy class
Results of the assessment	
Emissions before use (modules A1–5)	+/- xxx kg CO_2e / m^2
Emissions during use (modules B3–4, B6)	+ xxx kg CO_2e / m^2
Emissions after use (module C)	+ xxx kg CO_2e / m^2
Emission impacts beyond the building life cycle (module D)	+/- xxx kg CO_2e / m^2
Carbon footprint (sum A–C)	**+ xxx kg CO_2e / m^2**
Carbon handprint (sum A–D)	**- yyy kg CO_2e / m^2**
Assessment and used data	
Information of person preparing the assessment	- Name - Education - Date of preparing the analysis - Date of updating the analysis
Input data of the analysis	- Simplified / specified method - Used environmental product declarations - Stage when preparing the analysis (building permit / implementation) - Used calculation software - Possible observations concerning the reliability of the data
Scenarios used in the analysis (only when using the specified analysis method)	- Transportation distances (A4, C2) - A5 Construction work - B3-4 Repairs and replacements - B6 Operational energy use - C End of life cycle - D Impacts external to the life cycle

Table 5 Form for reporting the quality of the data used in the Finish specified calculation method (Copied from draft for consultations of Finland Ministry of the Environment, 2018)

Life cycle modules	Technological representativeness	Geographical representativeness	Temporal representativeness	Uncertainty	Total	Minimum requirements
A1–3 Manufacture of products						Data at least on level 2.
A4 Transportation to site						Geographical representativeness must be at least on level 3.
A5 Construction site						Geographical representativeness must be at least on level 2.
B3–4 Repairs and replacements						Geographical representativeness must be at least on level 2.
B6 Operational energy use						Data at least on level 2.
C1 Demolition work						No minimum requirements
C2 Transportation to further processing						No minimum requirements
C3 Waste processing						No minimum requirements
C4 Final disposal						No minimum requirements
D Impacts external to the life cycle / carbon handprint						The data on products containing carbon storages or binding carbon at least on level 2. No other minimum requirements.
Total						

Table 6 The classification of the data used in the Finish specified calculation method (Copied from draft for consultations of Finland Ministry of the Environment, 2018)

The classification of the data used in the calculation				
	0	**1**	**2**	**3**
Technological representativeness	Not assessed	Data does not sufficiently correspond with the technical specifications of the product	Data partly corresponds with the technical specifications of the product	The used data corresponds well with the technical specifications of the product
Geographical representativeness	Not assessed	The data refers to a completely different geographical context (e.g. Italy instead of Finland)	The data refers to a similar geographical context (e.g. Norway instead of Finland)	The used data refers to a specific geographical context
Temporal representativeness	Not assessed	There is over 6 years between the validation and utilisation of data	There is 2-4 years between the validation and utilisation of data	There is less than 2 years between the validation and utilisation of data
Uncertainty	Not assessed	Modelled or equivalent data are used. The correctness and accuracy has been qualitatively assessed (e.g. an expert judgement by a supplier and process operator)	Modelled or equivalent data are used, whose correctness and accuracy have been evaluated as satisfactory, and are supported by a quantitative uncertainty analysis	Project-specific and validated data are used, whose correctness and accuracy have been evaluated as satisfactory (e.g. a completed and verified environmental product declaration)

Switzerland:

Scale & Types: Municipal & Regulation with national scale vision

Assessment Methodology: Minergie is the most widely used Swiss national green building rating system. Minergie-Eco, which is a version of this standard, includes a performance target or whole-building embodied energy.

Databases & Tools: Lesosai[36] is a Swiss LCA tool respected in Europe. It offers both operation and embodied energy/carbon impact calculations. Lesosai is underpinned by a large database for commonly used materials in Europe and the associated life cycle impact data ('Liste Ökobilanzdaten' published by KBOB with data from Ecoinvent). Boundary conditions are set in accordance with the Swiss standard for embodied energy and carbon, SIA 2032 (Tanner et al., 2012).

Government requirements/incentives: Switzerland has a national call-to-action – 2000 Watt Society[37] developed by Federal Institute of Technology. It aims to limit per-capita energy, including embodied energy, to 2,000 watts (48 kWh/day). The initiative is adopted by over 100 cities, towns, and cantons across Switzerland and Germany. Although, the 2000 Watt Society vision has not yet been translated into clear requirements for every sector at the national level, Zurich is leading in turning this national vision into policy. With public support, they have included the 2000 Watt Society goal by 2050 in their municipal code, which is similar to a city constitution. This include a target of 8.5 kg CO_2e/m^2 for life-cycle embodied carbon in residential buildings. Zurich as well as several other Swiss municipalities requires whole-building LCA for all new government buildings, with an embodied carbon performance target for some building types. Zurich requires compliance with the Minergie-Eco standard for new construction of city buildings (Zizzo et al., 2017).

State of California, United States:

Scale & Types: Federal & regulation

Assessment Methodology: Information not found in the reviewed resources.

Databases & Tools: Information not found in the reviewed resources.

Government requirements/incentives: The California green building code, CalGreen, includes an optional LCA path, along with a range of performance measures related to energy efficiency, solid waste diversion, etc. A recently introduced bill, **Buy Clean California Act (AB 262)**[38], incentivizes and later mandates EPD reporting from all bidders for steel, flat glass, and mineral wool insulation products used in new federal buildings. The Act will set carbon limits for these products in July 2021. This new bill would modify the way that the "lowest responsible bidder" is determined by requiring the awarding department to use GHG emissions information to calculate the lowest bid (Zizzo et al., 2017).

Voluntary building certifications:

The following assessment systems were not reviewed in depth in this study. However, they can inform CoV embodied carbon policy.

[36] http://www.lesosai.com/en/
[37] https://www.2000-watt-society.org
[38] https://www.dgs.ca.gov/pd/Programs/Engineering/AB262.aspx

- **LEED V4.1:** Option 4 of "building life-cycle impact reduction" material credit provides up to 4 points for: conducting an LCA of new building's structure and enclosure, reducing at least GWP and 2 other impact categories specified by 5% or 10%, or incorporate building reuse and/or salvage materials into the project's structure and enclosure reduce the GWP by 20% and two other impact indicator by 10%. No impact category assessed as part of the life-cycle assessment should increase by more than 5% (U.S. Green Building Council, 2018).
  The baseline and proposed buildings must be of comparable size, function, orientation, operating energy performance. They should have the same service life and use the same life-cycle assessment software tools and data sets (U.S. Green Building Council, 2018).
- **CaGBC Zero Carbon Building Standard:** This is a voluntary Zero Carbon certification for both new and existing buildings. Project teams are required to evaluate energy use holistically, including embodied GHG emissions associated with structural and envelope materials. While the program requires applicants to conduct a "cradle-to-grave" LCA of the project, the embodied carbon requirement has been limited to reporting and does not set any performance targets (Zizzo et al., 2017).
- **BREEAM UK NC 2018:** BREEAM LCA requirements are based on EN 15978. Projects are required to use previously approved LCA tools. There is no mandatory minimum LCA performance requirement. The design options comparisons can be based on carbon performance.
  BREEAM incentivizes larger projects (offices, retail and industrial buildings) to start materials design using LCA at the conceptual design phase, before planning permission is applied for. This allows for easy design adjustment when improvements are identified.
  The BREEAM "Mat 01 Environmental impacts from construction products - Building life cycle assessment" offers the following credits to projects:
  - 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 Life-Cycle Costing for the options (exemplary credit)
  - Third party verification of the accuracy of the LCA work (exemplary credit)

  The benchmarks are clearly determined by BREEAM to represent the average (mean) environmental impact of a given building use type as a performance comparator. A BREEAM LCA benchmark is expressed as a value in EcoPoints[39] per functional unit (e.g. 2.5 BRE EN EcoPoints / 1 m^2 (net internal area)) (BRE, 2018).

- **Living Building Challenge:** As part of the LBC materials requirements, projects must calculate the total embodied carbon and purchase an offset from an approved provider of offset credits. LBC may be the only rating program that mandates embodied carbon measurement and offsetting (Zizzo et al., 2017).

[39] BRE EN EcoPoints are indicators that is made up of a broad set of individual environmental indicators which are then combined into a single value (BRE, 2018).

3.2. Guidelines for project teams to reduce embodied emissions

This section provides a summary of best practice guildelines for designers on how they can reduce the embodied emissions of buildings. The information in this section is based on the following:

- The brief overview of design strategies for reducing embodied carbon in building provided by Zizzo et al. (2017).
- Two guidelines developed by IEA EBC Annex 57[40] targeted specifically to design professionals and consultants as the starting point for the integration of embodied impacts assessment into the design process and reducing embodied energy and GHG emissions through design (Birgisdóttir, Houlihan-Wiberg, Malmqvist, Moncaster, & Rasmussen, 2016; Lützkendorf, Balouktsi, & Frischknecht, 2016).
- The guide published by BC Ministry of the Environment and Climate Change Strategy on using low carbon materials for LEED v4, with a focus on wood and Portland-limestone Cement (Light house, Equilibrium, 2017).

3.2.1. How LCA can help?

LCA can provide an overview of the areas with the most significant environmental impacts. This allows the project team to prioritise their optimisation efforts and focus on minimising the negative effects from the most significant areas. These areas of focus can be (1) the life cycle phases, (2) the building elements, and (3) materials with the highest impacts (Birgisdóttir et al., 2016).

Areas of focus can help project teams to allocate resources where the most impact is. For instance, section 2.2.1.2 showed an analysis of the significance of different life cycle phases and element types in the embodied emissions of a sample of the submitted projects.

A whole life cycle approach allows considering the trade-offs between embodied and operational impacts in the early design phase (Birgisdóttir et al., 2016). As another example, section 2.1.1 showed a comparison of embodied vs. operation impacts of the projects submitted to the City for rezoning approval. The project teams are able to see the relative impacts of their decisions on the two values. For instance, reducing the insulation thickness will reduce the embodied emissions, but can potentially increase operational emissions and vice versa.

This analysis should be done in early design phase. As noted by Birgisdóttir et al. (2016b), “Design choices made early in the design process are influential in constraining possibilities for reducing embodied energy and emissions, as well as operational energy use and greenhouse gas emissions later on. It is therefore

[40] Energy in Buildings and Communities (EBC) is a program of the International Energy Agency (IEA). EBC’s aim is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. Annex 57 is an EBC project that focuses on evaluation of embodied energy and CO_2 equivalent emissions for building construction (Birgisdottir et al., 2017).

important to involve these reduction considerations as early as possible in the design and construction process".

However, one challenge with identifying the areas of focus is that in the early design phase, the available information is often not sufficient for making a detailed assessment of embodied impacts. Thus Table 7 lays out the recommended actions and the type of instruments that designers can use throughout different design and construction phases to support the calculation and reporting of embodied impacts. Table 8 dives deeper into the details of designers' influence on reducing embodied impacts during design and tendering process and on better incorporating embodied impacts considerations into the process.

Table 7 Action for design professionals to influence embodied impacts of a building in different project stages
(Lützkendorf et al., 2016)

PHASE	DESIGNER'S TASK	COURSE OF ACTION IN RELATION TO EMBODIED IMPACTS	TYPE OF INSTRUMENT
Pre-design stages (Client's brief)	Definition of general project goals and requirements, as well as formulation of building performance targets	Provision of assistance to clients via a discussion or checklist for the setting of project-specific targets, either more quantitative (e.g. "budgets" for EC and/or EG in the same manner as economic budgets or benchmarks) or more qualitative (e.g. specifications for the selection of construction products and methods), for the reduction of embodied impacts;	Benchmark values (e.g. sourced from within the design team/firm or the public domain/national standards) or validated rules-of-thumb/empirical values at building level
	Selection of assessment methods	Provision of assistance to clients in terms of reviewing options for formal assessment of embodied impacts (and other sustainability aspects)	National/international standards or building assessment/certification systems
	Decision on new construction or refurbishment	Provision of assistance to clients via a comparison and assessment of the two variants based on embodied impacts considerations along with operational impact considerations to support them in their decision-making	Reference values for building structures, construction methods, construction products, construction processes or case studies
Preliminary design stages (concept/ schematic design)	Decision on the underground construction/ size of the foundations	Examination of alternatives **at the building level** including considerations of embodied impacts	Systems providing average values of embodied impacts for various types of foundations and construction method
	Decision on the construction method and main building materials		
Design development (detailed/ coordinated design)	Optimisation of structural and environmental performance of building components	Examination of alternatives **at the component level** (e.g. load bearing structure, facade, windows) including the consideration of embodied impacts (e.g. web-based element catalogue)	Web-based element catalogue
	General material selection	Examination of alternatives **at the product groups level** including the consideration of embodied impacts (e.g. web-based information on building products and databases)	Product comparison tools Product databases
Preparation of contracts/ Tendering	Preparation of tender documents	Integration of requirements to reduce embodied impacts into the tenders for individual works; Demand for product and manufacturer specific EPDs or LCAs from manufacturers and suppliers	
Construction monitoring	Supervision of works	Determination of the actual installed products according to the type, quality and quantity Collection of specific EPDs or LCAs, quality assurance	Information on the type, quality and quantity of the installed products, EPD's
Object documentation	Preparation of building documents	Compilation of information on the type and quantity of installed materials including also information on the respective embodied impacts into a final document, as well as compilation of instructions for inspection, servicing and maintenance, as well as instructions for deconstruction and recycling	

Table 8 Main design tasks and embodied impacts checkpoints during the design and tendering process (Lützkendorf et al., 2016)

PHASES	MAIN TASKS	CHECKPOINTS
PRELIMINARY DESIGN STAGES	1. Choice of project (demolition, new construction, refurbishment) 2. Choice of site and local interfaces (climate, utilities) 3. Choice of design concept (relation to the site, geometry, configuration of the premises, zoning, glazed parts) 4. Choice of constructive systems 5. Choice concerning the building's durability and adaptability 6. Choice of the thermal performance of the envelope 7. Choice of energy supply systems	- Consider the embodied impacts of decisions 1-7 - Consider embodied impacts trade-offs - Set embodied energy and emissions target ("budget")
DESIGN DEVELOPMENT	8. Choice of construction principle 9. Choice of main building materials 10. Choice of building components 11. Choice of building concept (arrangement of rooms) 12. Choice of energy systems concept (e.g. optimization of façade) 13. Assessment of the consequences of end of life scenario 14. Assessment of the consequences of maintenance cycles 15. Choice of materials for surfaces and finishing elements 16. Choice of building site equipment 17. Choice of construction and transport processes	- Consider embodied impacts of choices 8-14 together with technical, commercial and other environmental criteria holistically to produce an overall design - Include embodied impacts assessment in all significant appraisals of design options - Update embodied impacts assessment based on the final cost plan - Incorporate embodied energy and embodied GHG emissions assessment into sustainability assessment
PREPARATION OF CONTRACTS/ TENDERING	18. Choice of specific products (e.g. specification, sourcing) 19. Choice of contractors (credentials)	- Determine procurement requirements with respect to embodied impacts - Check material specification, sourcing, documentation, etc. - Assess the credentials of contractors against the requirements for embodied impacts

3.2.2. Reducing embodied emissions through design and construction tactics

Once the areas with high impacts are identified, multiple tactics for reducing embodied carbon are available to the designers of building projects.

Figure 13 categorizes these into three groups: design strategies, material selection, and construction. The following sections provide more explanations on some of the tactics as discussed by Birgisdóttir et al. (2016b).

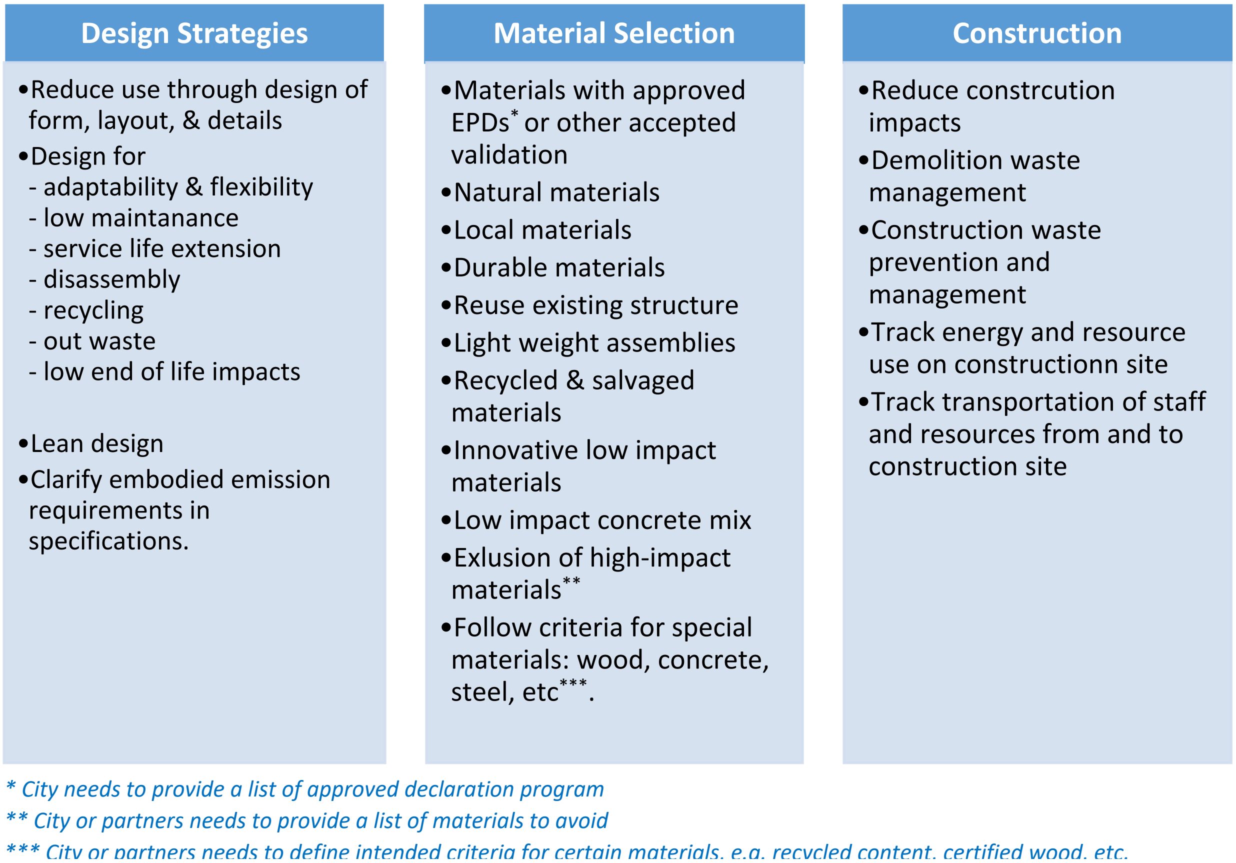

Figure 13 Design, material selection, and construction strategies for reducing embodied carbon
Based on: (Birgisdóttir et al., 2016; Mistretta & Guarino, 2016; Zizzo et al., 2017)

3.2.2.1. Design Strategies

The first category for reducing buildings embodied emissions is through design strategies. Some of these strategies are: reducing the embodied impacts through building form and layout, designing for flexibility and adaptability, designing for low maintenance and service life extension, and designing for low end of life impacts (Birgisdóttir et al., 2016b).

1. Building form and layout plan

Reducing buildings size and increasing their density contributes to reduction of the total embodied and operation emissions. However, the emissions per floor area may remain the same (Figure 14). Additionally, such design decisions are also affected by many other criteria and not only environmental impacts.

A larger volume does not always result in higher emissions. A sloped roof can offer a larger surface for (integrated) PV-panels. In this case the extra emissions from adding more material and the increased energy output can balance out.

2. Design for flexibility and adaptability

Flexible and adaptable buildings can have an extended service life time and need less material use during refurbishment. To prevent unnecessary design complications and increase impacts, adaptations should only be used for expected changes.

The benefits associated with flexibility and adaptability are not accounted in the existing assessment tools and methodologies. It is because fixed building life time and average element life time are used.

Such design considerations include (Figure 15):

- Separation of building services that have different life time facilitates maintenance and replacement of individual components. Figure 16 shows how designers can assess the ease and frequency with which products should be replaced.
- Prefabricated elements are easy to install and replace. Additionally, if the building is expanded, they can be reused.
- Over dimensioning of the building structure can increase the flexibility, as it allows changing the function to one with higher demands. However, this can also lead to an unnecessary increase in embodied emissions if this is not carefully done.

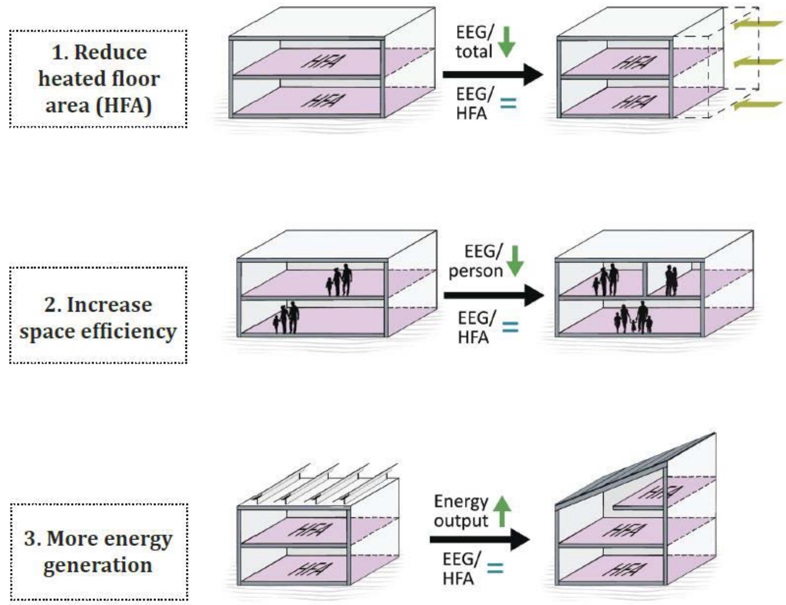

Figure 14 Reduce overall emissions by form and layout design (Birgisdóttir et al., 2016)

***EEG:** embodied energy and GHG emissions*

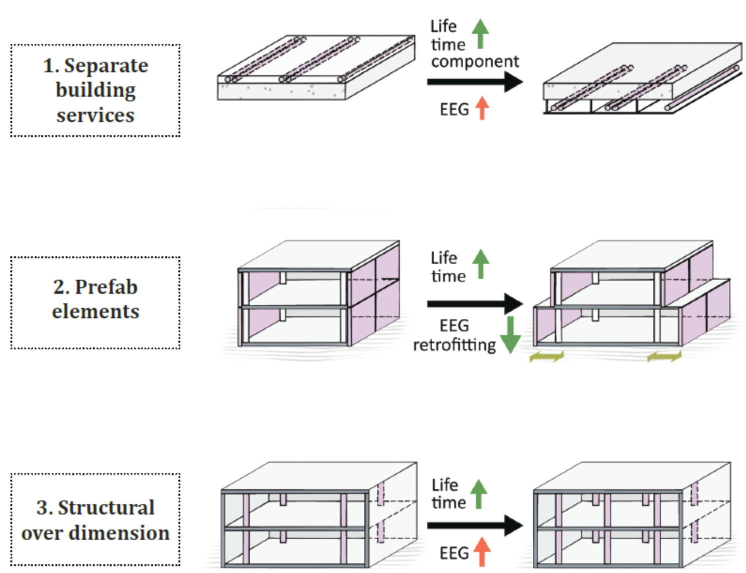

Figure 15 Reduce overall emissions by design for flexibility and adaptability (Birgisdóttir et al., 2016)

***EEG:** embodied energy and GHG emissions*

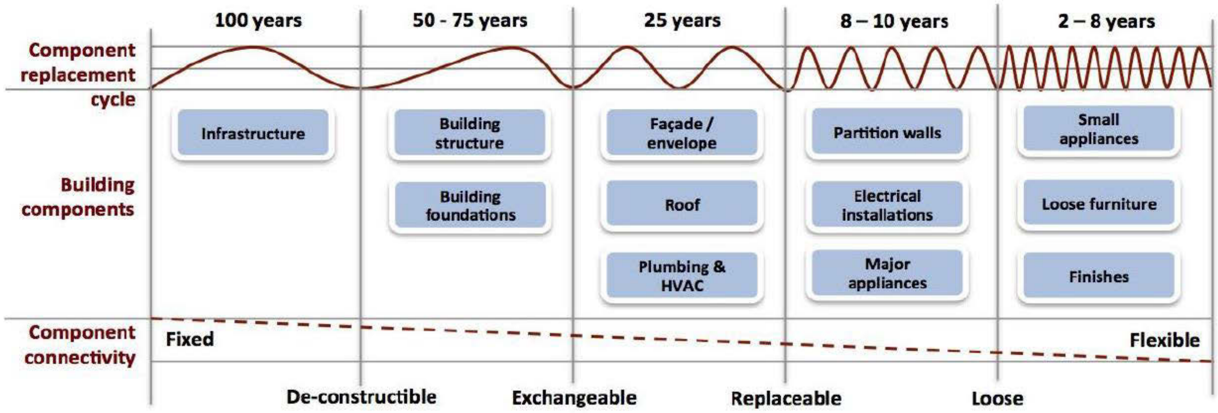

Figure 16 Typical life cycles of buildings and their components (Zizzo et al., 2017)

3. Low maintenance and service life extension

Design for low maintenance includes (1) choosing easy-to-maintain surfaces and, (2) protection of materials to increase their durability.

Increasing the service life requires (1) increasing the durability of materials, (2) replacement of components and, (3) renovations.

Such efforts often imply increased embodied emissions during production stage to ensure an increased durability. Additionally, studies show that for many reasons, some of which are beyond designers control, buildings frequently do not last as long as the designed service life (O'connor, 2004). Therefore, increasing the material use to make a building more durable should only be considered when the building is designed for a longer service life.

Examples include (Figure 17):

- Durability can be increased by protecting the weaker elements (e.g. windows and doors).
- An extra external layer can increase durability as well as the thermal performance. However, the effects on the architectural expression of the building should be considered
- Where required, over dimensioning the structure or adding extra materials can make the building more resistant to natural phenomena, such as earthquakes, and thus increase the overall life time of the building.

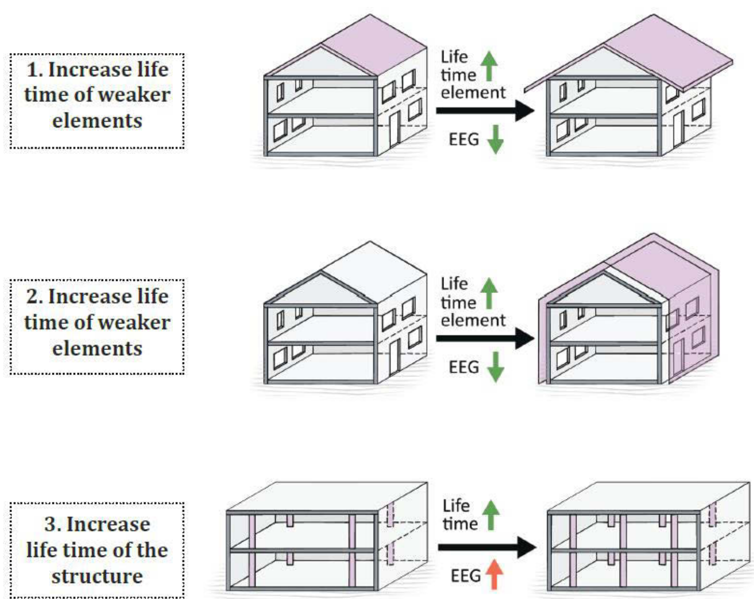

Figure 17 Reduce overall emissions by design for low maintenance and service life extension (Birgisdóttir et al., 2016)

EEG: *embodied energy and GHG emissions*

4. Design for low end of life impacts

There are two approaches to designing for a low impact end-of-life phase: design for disassembly and design for recyclability. These approaches mostly influence emissions beyond the building's life time (Module D).

When only a small ratio of recycling is considered, there is no benefit and the impact is higher than in a scenario with no recycling. This is because transportation to the recycling facility has a higher impact than landfilling or incineration. However, in scenarios with a higher potential for recycling and reuse there is a significant decrease of impacts in module D.

Another concern with such strategies is that, it is difficult to predict further development of recycling technologies and building practice and even the future use of buildings is unsure. However, we can assume that at least technologies that are known today shall be developed and increasingly used.

3.2.2.2. Material Selection

The second strategy for reducing embodied emissions is substituting typical materials with alternatives such as natural materials, recycled or reused materials, innovative materials with lower impacts, using light-weight assemblies, and reusing of existing building structures as further discussed below:

1. Natural materials:

Case studies reviewed by IEA EBC Annex 57 researchers show that natural bio-based materials, which use low or no processing energy for their production, can reduce emissions. Natural materials can be sorted into 3 groups: inorganic, renewable plant-based, and animal-based products.

According to Light house and Equilibrium (2017), wood and Portland-limestone Cement[41] (PLC) are two building materials that offer opportunities to reduce the embodied carbon of a building in B.C. A variety of wood products are manufactured in B.C. and PLC is manufactured by two suppliers in the Lower Mainland. In addition to wood and PLC products, there are other low carbon building materials currently available within the Canadian and US markets including Supplementary Cementitious Materials (SCM), rammed earth, bio-fiber blocks, straw bale, and hempcrete.

[41] Canadian PLC is produced by integrating regular Portland cement clinker with 6-15% limestone, resulting in 10% less CO_2 than regular Portland cement.

We next describe how natural materials can replace traditional construction materials in different building element. These is based on solutions used in case studies reviewed by IEA EBC Annex 57.

Load bearing walls:

Examples of substitutions include (Figure 18):

- Timber elements can (partially) replace masonry, concrete and steel load bearing structures
- Masonry can be replaced with unfired clay products (e.g. rammed earth). This material has a higher thermal mass, but a lower thermal performance.
- Timber and masonry build-up walls can be replaced with straw bales, but it requires special design and protection from moisture, pest, and fire.

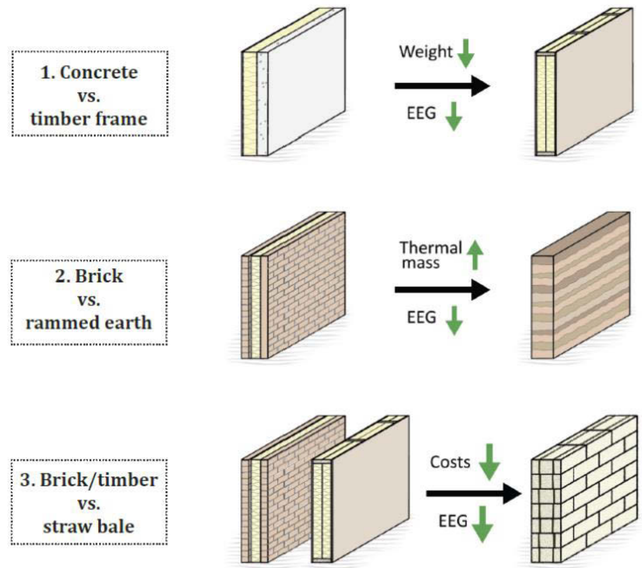

Figure 18 Alternative natural bio-based materials for load bearing walls (Birgisdóttir et al., 2016)

***EEG:** embodied energy and GHG emissions*

As shown in the above examples natural materials might

- need different design and construction details.
- have different technical parameters such as thermal mass, thermal properties, fire safety, acoustics etc.
- require extra protection against fire, moisture and pests.

Foundations:

Foundations typically accounts for a large share of the embodied emissions. However, so far, the potential environmental benefits of alternative solutions for the high emission materials in the foundation have not been documented.

Non-load bearing envelope:

Examples of such substitutions include (Figure 19):

- Insulation, which has a relative high impact, could be replaced with natural alternatives such as wood fibre or hemp-lime insulation. However, these materials are not pressure-resistant, and hemp-lime has a weak thermal performance.
- Metal based curtain walls, which often have a short life time, can be replaced with wooden alternatives
- Substituting cement with clay plaster is a simple way to achieve significant reductions. It also helps balance indoor humidity and is simple to prepare. However, further research is needed to determine the durability.

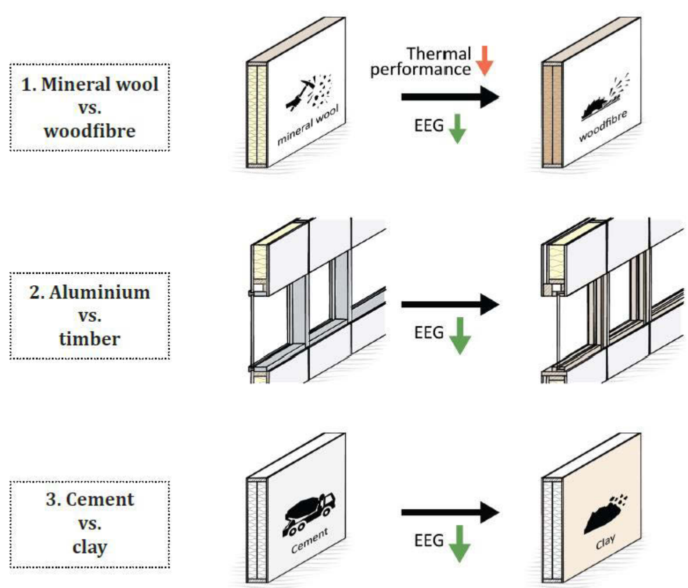

Figure 19 Alternative natural bio-based materials for non-load bearing walls (Birgisdóttir et al., 2016)

***EEG:** embodied energy and GHG emissions*

2. Recycled & reused materials and components:

If recycling or reuse processes require less energy than production with virgin materials, using secondary materials can reduce emissions. It is important to ensure the recovered materials do not contain any dangerous contaminants. Examples of such substitutions include (Figure 20):

- Bricks and parts of foundations can be integrated into the new construction. However, if additional structures are needed for extra support the potential reductions can be reduced.
- High-quality upcycled materials from waste can reduce emissions, if the upcycling facility has low impacts.
- Crushed concrete can be used as aggregates in new concrete, but the embodied emissions reduction is small.

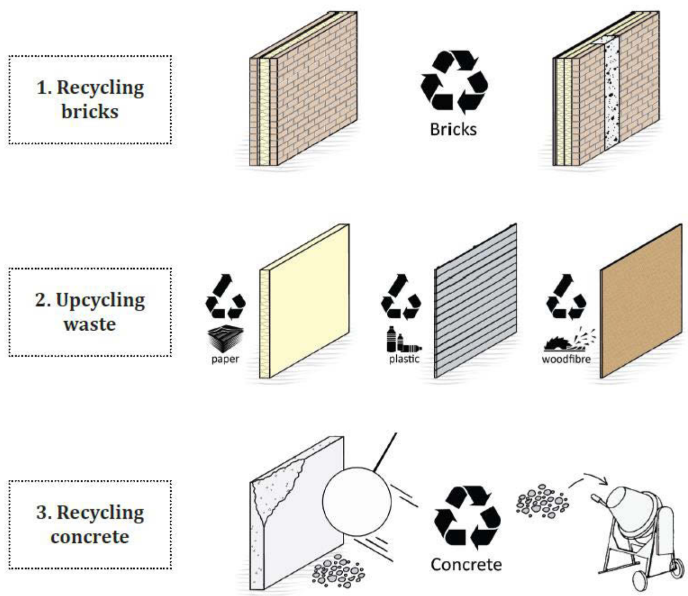

Figure 20 Alternative recycled and reused materials and components (Birgisdóttir et al., 2016)

3. Innovative materials

Innovative materials can improve mechanical and thermal properties, surface treatment, and durability. Due to such improvements, they may reduce the total amount of units needed in the building, thus reducing the emissions at a whole building level. When considering these alternatives, it is crucial to consider human and ecosystems health impacts throughout their life cycle, the financial implications, and regional availability.

Despite significant developments in innovative materials, there are only few published cases that provide evidence for the potential of innovative materials to reduce emissions at a building level. Examples are (Figure 21):

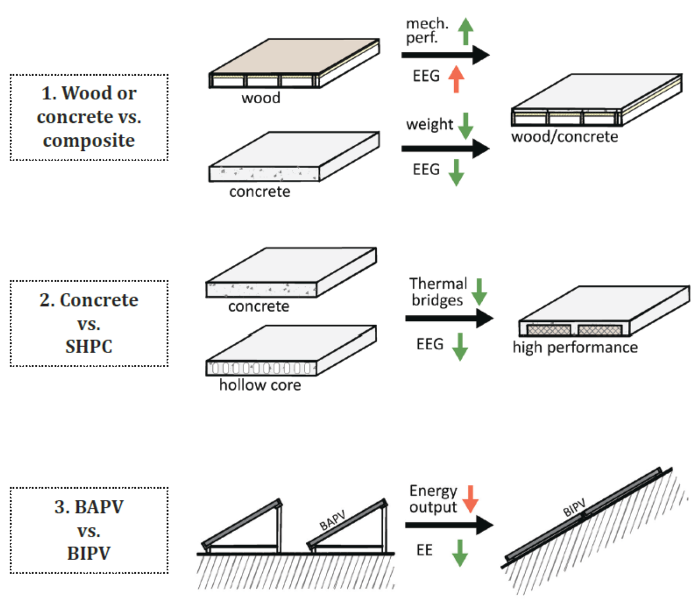

Figure 21 Alternative innovative materials (Birgisdóttir et al., 2016)

EEG: *embodied energy and GHG emissions*

- When a wood alternative for a concrete structure is not possible, due to mechanical performance requirements, a wooden-concrete composite can be a viable option.
- Ultra High-Performance Concrete[42] (UHPC) and Subtle High-Performance Concrete (SHPC) with integrated wood shavings have lower emissions than standard concrete. SHPC also decrease thermal bridges compared to UHPC
- Building integrated photovoltaics[43] (BIPV) replaces roofing materials. Although BIPV has a lower energy output compared with Building Adapted photovoltaics (BAPV), its overall impacts are lower, due to the elimination of traditional roofing materials.

5. Light-weight assemblies

Decreasing the volume and or weight of the structure has shown to have considerable potentials for reducing emissions. Some examples implemented in case study projects are (Figure 22):

- Replacing solid concrete and clay with cellular concrete, hollow core concrete, and multi-cell clay can significantly reduce structure's weight and embodied emissions.
- Replacing concrete with wood structure reduces the building weight, and therefore the amount of foundation materials needed.
- Certain foundation designs such as strip foundation, rather than raft foundation, can significantly reduce emissions. However, building materials may deteriorate faster in strip foundations if they are not protected from exposure and will thus have a shorter lifetime.

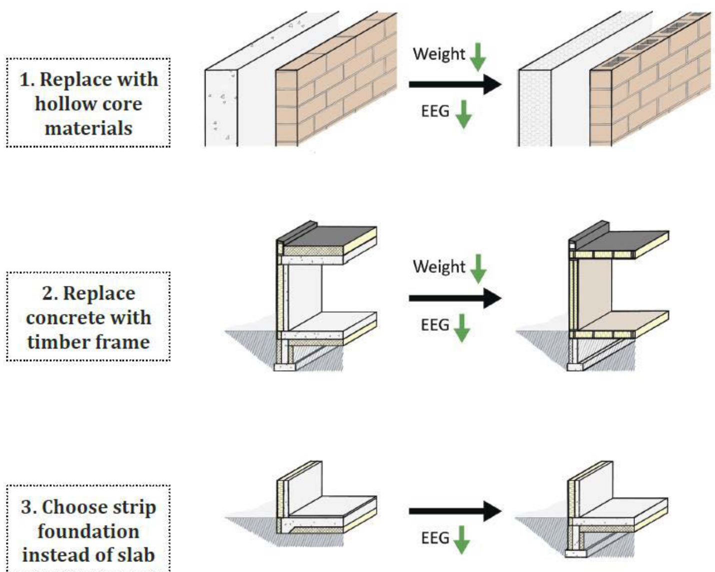

Figure 22 Alternative light-weight construction (Birgisdóttir et al., 2016)

***EEG:** embodied energy and GHG emissions*

6. Reuse of building structures

Reusing parts of the existing building structure is a strategy that reduces resource use and the emissions. A further opportunity is the use of smart facade technologies in the refurbishment phase. An example is the use of double skin facades as an alternative to single skin refurbishments. This may increase the relative embodied emissions of the façade. However, it will balance out with the operational savings.

[42] https://www.cement.org/learn/concrete-technology/concrete-design-production/ultra-high-performance-concrete
[43] https://www.wbdg.org/resources/building-integrated-photovoltaics-bipv

3.2.2.3. Reduction of construction phase impacts

The third category is reducing the embodied impacts during the construction phase, which includes transportation of materials and products to site and the impacts on site during construction and installation processes.

Since the production phase normally dominates the total embodied energy and emissions, the construction phase is often neglected. However, as these impacts occur prior to the building occupancy, reducing them can have an immediate impact on achieving climate change commitments.

An important factor affecting the embodied emissions during the construction phase is the energy type used, and whether construction takes place during the heating season or not. Project valuation and the duration of the construction are not significantly correlated with the embodied emissions.

The following are considerations that can reduce construction phase emissions (Figure 23):

- Using construction sheds with higher quality and better insulation offers potential to reduce the energy used during the construction phase.
- If available, heating the sheds with district heating instead of electricity can result in lower emissions.
- Using LED lighting instead of conventional lighting in sheds can also reduce impacts.
- Different structural materials have different impacts on the embodied emissions during the construction phase. For instance, wood has lower embodied emissions, but requires more energy during the construction phase.
- Waste material makes up a significant share of the total embodied energy of the building, of which most happen during the construction phase. An increase of prefabricated components decreases the waste generation on site.
- Transportation of materials to the site typically accounts for a low share of the total energy and emissions. However, a prefabricated construction system implies a higher share of energy associated

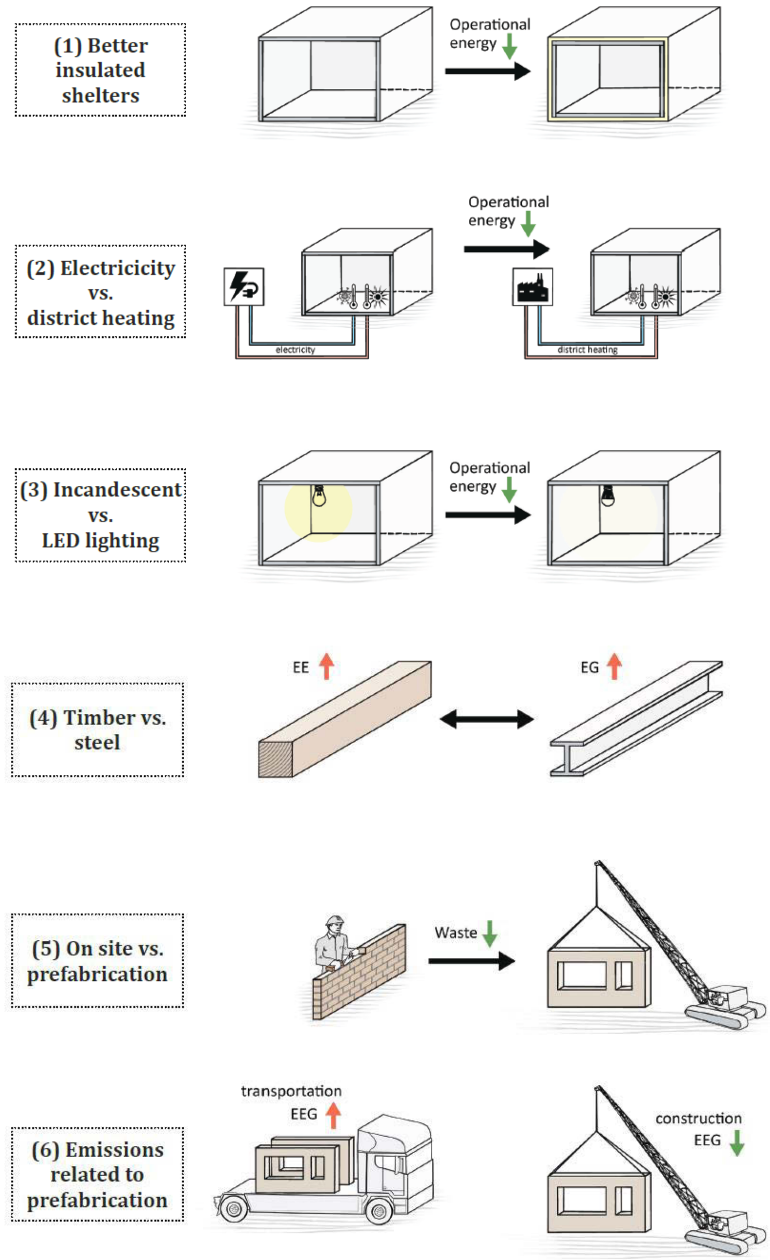

Figure 23 Reduction of construction stage impacts (Birgisdóttir et al., 2016)

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with the transportation. The modules do have an advantage on on-site energy use. Therefore, a trade-off needs to be considered between transportation to the site and on-site energy use.

3.2.3. Concluding Remarks

It should be noted that the strategies discussed above are interconnected and can sometimes be considered both positive and negative. In addition, the feasibility and emission reduction potential of each individual design strategy is heavily influenced by a number of factors such as climate, topography, building code requirements, and cultural preferences.

To help design and construction teams to realize potential value of these strategies, it is important that building material databases and LCA software tools take into account the positive and negative impacts of these solutions. The databases and software tools that are currently available to the industry mostly rely on average industry values and hence miss the nuances of the solutions that a team may incorporate in their project.

4. Conceptual roadmap and next Steps

This section provides a road map and the recommended steps for the City of Vancouver to improve its embodied emission policies. The rationale for the recommended steps is discussed in Section 2.2 and 3.1. Figure 24 shows the steps required. These steps are further elaborated in the following sections.

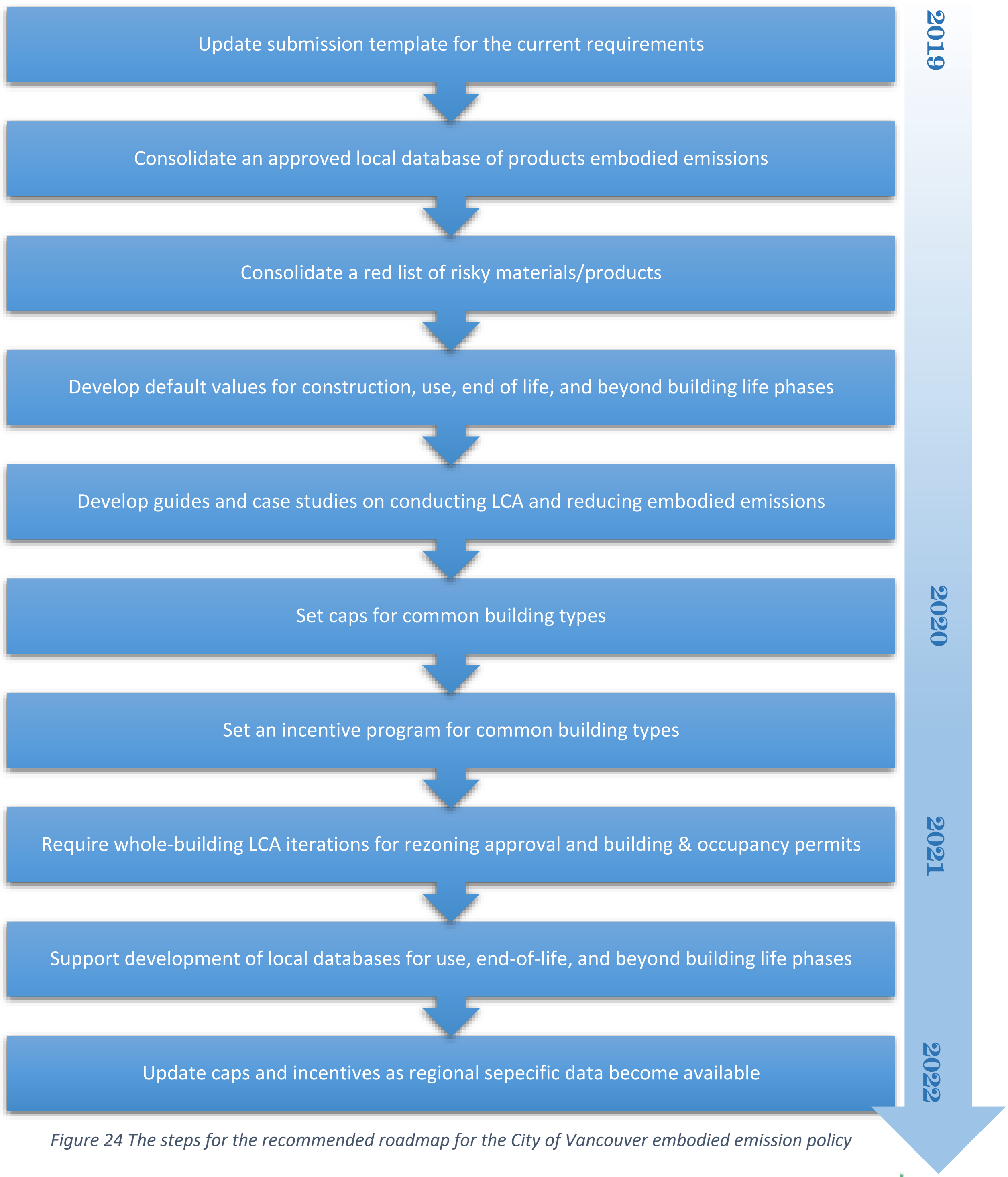

Figure 24 The steps for the recommended roadmap for the City of Vancouver embodied emission policy

4.1. Update submission template for the current requirement

The data collected through the City's current embodied emissions requirements, specified through the bulletin was analyzed in Chapter 2.1. Based on the findings, a data collection template was suggested in Section 2.2.2. The template assumed no change in the methodology and scope of embodied emissions submissions in order to allow adding the template to the bulletin as soon as possible. New submissions using the template will provide higher quality data that can inform the next steps, especially for setting the caps/baselines as explained in step 4.6.

4.2. Consolidate an approved local database of products embodied emissions

To ensure the assessment quality and consistency, the City or an approved partner organization (e.g. CaGBC, Athena, etc.) should consolidate an open local database of construction materials and products embodied emissions. This database should rely on EPDs, LCI databases and other resources that comply to ISO 21930:2017[44] and EN 15804: 2012[45].

The process of consolidating available data and ensuring comparability among various datasets is very challenging, and according to some LCA experts, maybe even impossible with existing EPDs. This is because of variations in key aspects of LCA studies and reports that are currently available such as scope, methods of data collection or calculation procedures (BRE Centre for Sustainable Products, 2016; Pomponi & Moncaster, 2018). However, if efforts are made early in the development of policy and regulatory procedures to standardize the methods and data sources for embodied carbon measurement and reporting, we can prevent the variations.

The City should then require all building LCA software tools to only use the approved database for reporting to the City.

4.3. Consolidate a red list of risky materials/products

The City should set prescriptive direction to ban the use of materials with known environmental or health hazards throughout their life cycle. These materials can be identified by drawing on the current body of knowledge. Examples of such databases are Healthy Product Declaration Open Standard[46], Perkins and Will Precautionary List[47], Living Future Institute Red List[48]. The City should also require the use of wood certified by organizations such as Forest Stewardship Council[49].

[44] Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services
[45] Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products
[46] https://www.hpd-collaborative.org/
[47] https://transparency.perkinswill.com/lists/precautionary-list
[48] https://living-future.org/declare/declare-about/red-list/
[49] https://ca.fsc.org/en-ca

4.4. Develop default embodied emission values for construction, use, end of life, and beyond building life phases

Currently there is no sufficient product and project-specific data available for life cycle phases beyond product phase, construction, use (repair and replacement), end of life, and beyond building life. the City or an approved partner organization should work with experts and industry representatives to develop default impact data for these phases. These default values can be based on the industry averages for specific project types and materials and products. The City should then require all the approved LCA software tools to use this data for these phases. An example for this approach is Denmark, which is presented in section 3.1.2.1 of the report.

4.5. Develop guides and case studies on conducting LCA and reducing embodied emissions

The City should develop a guide on how to conduct LCA. This will help improve the consistency of the reports. The guide should include detailed instruction on how to conduct material quantity assessment as well as the scope and method for conducting LCA.

The City should also provide a guide and case studies on how to reduce embodied emissions through design and construction tactics. This information can be organized similar to Building Path Finder[50] to show various paths that projects can use to achieve a certain amount of embodied impact reduction.

A summary of the relevant information identified in the literature is summarized in Section 3.2. To ensure the solutions in the guide will reduce the embodied emissions, the City or a consultant should assess them in a comparison with a baseline building.

4.6. Set caps for common building types

To encourage embodied emissions reduction, the City should set an embodied (carbon) emissions cap for common building types. Best practices on how to set a cap is discussed in Section 3.1.2.

The feedback received from the local LCA experts through interviews (see Appendix C) indicates a preference towards defining a normative and verifiable methodology for defining threshold values rather than setting fixed values. Such methodology should account for building code requirements – such as minimum parkade area, acoustic, fire-proofing, seismic and structural specifications – as well as other key factors such as building type, material use for each part of the building and foundation requirements due to site conditions. This is similar to Netherlands approach described in section 3.1.2.1.

There are a few downsides to setting a normative methodology. Firstly, such caps are typically complex to calculate. Second, normative approaches allow for playroom in increasing the total embodied emissions of a building and risks the overall carbon reduction goals.

[50] http://www.buildingpathfinder.com/

Therefore, Zera Solutions recommends a combined top-down and bottom-up approach for setting the caps for each building type on a per gross floor area or ideally on a capita basis. A per capita approach is similar to the Swiss 2000 Watt Society vision (see section 3.1.2.1) and allows total reduction of carbon emissions rather than a relative reduction. City can set this cap value based on the City's carbon reduction goals (e.g. for 2030 or 2050) and the estimated population of the City.

4.7. Set an incentive program for common building types

The caps should be supplemented with an incentive program to reward projects which reduce their impacts from the threshold defined by the City. For consistency with other regional standards, the City can match the reduction thresholds with LEED V4.1, that are 10 and 20%.

The types of incentive programs that Bionova Ltd. (2018) identified in their review of the embodied emission programs around the world are provided in Table 12. The incentive program can be combined with similar program that are set for operational embodied emissions.

4.8. Require whole-building LCA iterations for rezoning approval and building & occupancy permits

The City can should require cradle-to-grave LCA assessment, with impacts beyond building life (Module D) to be reported separately. The City should then grant permits under the condition of embodied emissions below the set caps.

For larger projects (Part 3), the City should require three iteration of LCA reporting at rezoning approval and building & occupancy permits. The project should maintain the embodied emissions level below the cap at all the three stages of reporting. Projects that can prove impacts below the threshold for the incentive, will benefit from the incentive program.

At the building permit stage, when more detailed information on building materials and products are available, the LCA should use actual transportation distances for A4 impact assessment. At the occupancy permit stage, the City should mandate or incentivize using actual transportation as well as construction data for module A4 and A5 assessment, rather than the industry averages.

4.9. Support the development of local databases for use, end-of-life, and benefit beyond building life

The City should work with the industry and research partners to advance local databases on the embodied emissions from use, end-of-life, and beyond building's life phases. These databases should provide product specific information regarding the building elements' lifetime[51], their maintenance and repair impacts, end of life scenarios, recycling and reusing and carbon sequestration potentials.

[51] It is known to the author that RDH and Local Practice Architecture have in house knowledge of building element life time for the local buildings.

4.10. Update caps and incentives as regional sepecific data become available

As the databases on other life cycle phases grow, the City should then define caps and incentives for these phases.

The City's efforts to develop a consistent LCA assessment method and consolidate databases can contribute to and benefit from Low-Carbon Assets through Life Cycle Assessment Initiative led by National Research Council of Canada (Guest, Nightingale, Urquhart, & Zhang, 2019). Thus, it is highly recommended that, whenever possible, the City collaborates with this federal scale initiative to accomplish the steps recommended above.

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Appendix B. Best practice embodied emissions policies

Table 14, Table 15, Table 16, and Table 17 provide lists of the international, Northern European, Continental European, and Northern & Southern American environmental and sustainability regulations, voluntary certifications, standards, and guidelines applied to buildings reviewed by Bionova (2018) for the way they address embodied carbon.

Below are the descriptions of the meaning of the column headings in these tables:

Type explains the legal status of the system. It can be either a Certification, Regulation, Standard or Guideline.

Embodied carbon indicates whether embodied carbon or LCA is addressed by the system directly, and whether it is a requirement or optional. When a simplified approach is used, it's documented with 'No - Simplified', and when it is one of possible methods but not a preferred approach in terms of its effectiveness, it is recorded as 'No - May use'.

Carbon reduction by specifies the embodied carbon reduction methodology the system is using. The definitions for these options are provided in Table 9. Each of the methods has its advantages and disadvantages. The main advantages and disadvantages of the considered methods are outlined in

Table 10.

Cap/Rating type is the mechanism for setting embodied carbon cap or rating (if applicable for the system). These options are defined in Table 11.

Carbon incentive explains if there is an incentive available for embodied carbon performance. These options are defined in Table 12.

Product EPD use specifies whether the system also promote specifying better products, besides building level performance. These options are defined in Table 13.

Table 18 is a summary of embodied carbon policy in a selection of leading countries developed by Zizzo et al. (2017). Details of these policies can be found Appendix 1 of their report.

Table 9 Five main methodologies used to address embodied carbon in increasing order of efficiency (Bionova Ltd., 2018)

METHOD	HOW DOES IT WORK?	EXAMPLES
1. Carbon reporting	Calculate the construction project's embodied carbon and report it	EN 15978, BREEAM Int'l
2. Carbon comparison	Compare design options for carbon; for example, design baseline and proposed designs and show improvements against a self-declared baseline value	LEED v4, Green Star, BREEAM UK
3. Carbon rating	Evaluation of carbon performance. Variable scale from best to worst on which a project's carbon is rated, but no effective maximum value applied. Fixed scale or clear methodology	DGNB, BREEAM NL
4. Carbon cap	Calculate the project's embodied carbon and prove it is not exceeding the CO2e limit	Énergie Carbone, MPG
5. Decarbonization	Reduce carbon to a minimum, then compensate all residual emissions by own energy export or buying offsets	Living Building Challenge, NollCO2

Table 10 Advantages and disadvantages the main embodied carbon reduction methods (Bionova Ltd., 2018)

Method	Advantages	Disadvantages
1. Carbon reporting	Reporting carbon is easy Builds knowledge and skills.	If reporting is the only requirement, design and impacts may not improve.
2. Carbon comparison	The most cost-effective way to influence. Options must be understood prior to acting.	Comparison is not necessarily leading to best option being built. This may become a formality in some projects.
3. Carbon rating	Incremental performance improvements provide additional incentive via better rating.	As also a poor rating is also allowed, the less ambitious projects may not improve at all.
4. Carbon cap	All projects must meet the stipulated threshold.	Setting the cap to a level where it is effective in carbon reduction and yet cost-efficient is hard.
5. Decarbonize	Direct cost from higher carbon emissions is an incentive to reduce as far as possible.	Systems aiming at complete decarbonization need a great deal of political will and suitable incentives to be widely applied.

Table 11 Methods for setting embodied carbon cap or rating thresholds

METHOD	DESCRIPTION	WHERE THIS IS USED
1. Self-declared	This is not considered a threshold method. End users declare their own baseline performance. This provides flexibility for use, but makes applying it as an effective cap impossible. Because of this, these systems are classified as 'Carbon comparison' systems.	LEED v4, all other infrastructure tools
2. Methodology	Threshold values are generated using a well-defined baseline calculation method. This ensures different users have clear guidance on how to create the performance thresholds for their specific project. This allows accounting for project specificities, and results to verifiable threshold values.	FutureBuilt, HS2 (infrastructure)
3. Fixed scale	Threshold value, or scale, is fixed for the building type and results mechanically from given parameters without judgement being applied. In the French E+C- system the mandatory parking requirement allows adjustment of the threshold values to allow for parking structure, for example. This method is not well suited to infrastructure projects.	BREEAM NL, DGNB and Énergie Carbone

Table 12 Carbon incentive options for embodied carbon performance

INCENTIVE	DESCRIPTION	USED IN
1. Rating points	Systems that award rating points for the application of LCA, or achieving savings quantifiable with LCA.	LEED v4, DGNB 2018, BREEAM International 2016
2. Funding condition	Public funding program or state procurement setting it a funding condition to achieve carbon target.	State policy in Minnesota and California, United States
3. Density bonus	Meeting a carbon performance level may make a project eligible for additional gross floor area rights.	French E+C- scheme's good performance level (when enacted by city-level plan)
4. Cash impact	Either carbon offsetting funded by the constructor, thus ensuring carbon emissions lead to real cash cost for project; or a carbon performance payment.	Decarbonization e.g. Living Building Challenge, and carbon performance payment Rijkswaterstaat
5. Mandatory	Carbon criterion is a simple requirement. The criterion itself can be set up differently in different systems where it's mandatory.	Dutch MPG regulation and allowed level of the French E+C- scheme (when the law enters in vigor)

Table 13 Options for promoting product EPD use besides building level embodied emissions performance

METHOD	DESCRIPTION	WHERE THIS IS USED
1. Documentation	Document that project has purchased products that have product-specific EPDs.	BREEAM International
2. Use in LCA	Use product-specific EPD data in your building level LCA	Miljöbyggnad 3
3. Buy low-carbon	Additional requirement separately of LCA to compare and choose products that have EPD, and that are comparatively better	LEED v4

Table 14 International systems and their key embodied carbon reduction information (Bionova Ltd., 2018)

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP / RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
Active house specification	Europe	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	-
Level(s)	Europe	Certification	Optional	1. Carbon reporting	-	-	2. Use in LCA
EN 15978	Europe	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
EN 15804	Europe	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
EN 15643-5	Europe	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
LEED v4	International	Certification	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	3. Buy low-carbon
BREEAM International	International	Certification	Optional	1. Carbon reporting	-	1. Rating points	1. Documentation
Living Building Challenge	International	Certification	Required	5. Decarbonize	-	4. Cash impact	-
EDGE	International	Certification	Optional	2. Carbon comparison	-	-	-
HQE International	International	Certification	Optional	2. Carbon comparison	-	1. Rating points	3. Buy low-carbon
SBTool	International	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
DGNB International	International	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Zero Carbon Certification	International	Certification	Required	5. Decarbonize	-	5. Mandatory	2. Use in LCA
ISO 14040	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO 14044	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO/FDIS 21929-1	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO FDIS 21931-1	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO 21930	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
One Planet Living	International	Certification	No - May use	Not determined	-	-	-

Table 15 Northern European systems and their key embodied carbon reduction information (Bionova Ltd., 2018)

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
DK-DGNB	Denmark	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Bolig+	Denmark	Certification	No	-	-	-	-
RT Ympäristötyökalu	Finland	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	-
Rakennusten elinkaariarviointi	Finland	Regulation	Required	Not determined	Not determined	Not determined	2. Use in LCA
Building Performance Metrics	Finland	Standard	Optional	1. Carbon reporting	-	-	2. Use in LCA
Home Performance Index	Ireland	Certification	Optional	1. Carbon reporting	-	1. Rating points	3. Buy low-carbon
Powerhouse	Norway	Certification	Required	5. Decarbonize	3. Fixed scale	5. Mandatory	2. Use in LCA
BREEAM NOR	Norway	Certification	Optional	3. Carbon rating	2. Methodology	1. Rating points	3. Buy low-carbon
FutureBuilt	Norway	Certification	Required	3. Carbon rating	2. Methodology	5. Mandatory	2. Use in LCA
Statsbygg requirements	Norway	Regulation	Required	4. Carbon cap	2. Methodology	5. Mandatory	3. Buy low-carbon
NS 3720	Norway	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
NollCO2	Sweden	Certification	Required	5. Decarbonize	3. Fixed scale	4. Cash impact	2. Use in LCA
Miljöbyggnad	Sweden	Certification	Required	1. Carbon reporting	1. Self-declared	1. Rating points	2. Use in LCA
BREEAM SE	Sweden	Certification	Optional	1. Carbon reporting	-	1. Rating points	3. Buy low-carbon
Klimatdeklaration av byggnader	Sweden	Regulation	Required	1. Carbon reporting	Not determined	Not determined	2. Use in LCA
Swan Label for Buildings	Sweden	Certification	No	-	-	-	-
DREAM	UK	Certification	No - Simplified	Simplified method	3. Fixed scale	1. Rating points	-
BREEAM UK	UK	Certification	Optional	2. Carbon comparison	3. Fixed scale	1. Rating points	3. Buy low-carbon
Home Quality Mark	UK	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	1. Documentation
London Plan 2018	UK	Regulation	Optional	1. Carbon reporting	-	5. Mandatory	-
Whole life carbon assessment for the built environment	UK	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
PAS 2080	UK	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
PAS 2050	UK	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
SKA Rating for Fit-outs	UK	Certification	No	-	-	-	3. Buy low-carbon

Table 16 Continental European systems and their key embodied carbon reduction information (Bionova Ltd., 2018)

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/ RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
IBO ÖKOPASS	Austria	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	3. Buy low-carbon
Klimaaktiv	Austria	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
ÖGNB / TQB	Austria	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	1. Documentation
ÖGNI	Austria	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
2014-05-22/34 Arrêté royal fixant les exigences minimale	Belgium	Regulation	Required	Simplified method	-	5. Mandatory	1. Documentation
Milieugerelateerde materiaalprestatie van gebouwelementen	Belgium	Regulation	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	2. Use in LCA
SBToolCZ	Czech Republic	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	-
Arrêté du 9 juillet 2014 modifiant l'arrêté du 23 décembre 2013	France	Regulation	Optional	Simplified method	-	5. Mandatory	1. Documentation
Bâtiment à Énergie Positive & Réduction Carbone	France	Certification	Required	3. Carbon rating	3. Fixed scale	3. Density bonus	2. Use in LCA
Bâtiment Bas Carbone	France	Certification	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	2. Use in LCA
Bâtiment Durable Francilien	France	Certification	Optional	2. Carbon comparison	3. Fixed scale	1. Rating points	3. Buy low-carbon
Bâtiment Durable Méditerranéen	France	Certification	Optional	2. Carbon comparison	3. Fixed scale	1. Rating points	3. Buy low-carbon
BEPOS & BEPOS+ Effinergie 2017	France	Certification	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	2. Use in LCA
Haute Qualite Environnementale	France	Certification	Optional	2. Carbon comparison	-	1. Rating points	3. Buy low-carbon
BNB	Germany	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
BREEAM DE NC 2018	Germany	Certification	Optional	1. Carbon reporting	-	1. Rating points	1. Documentation
DGNB-DE 2018	Germany	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Nachhaltiger Wohnungsbau	Germany	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Casaclima Nature	Italy	Certification	No	-	-	-	1. Documentation
Criteri ambientali Minimi	Italy	Certification	No - May use	Not determined	-	-	1. Documentation
GBC Home	Italy	Certification	No - May use	Not determined	-	-	1. Documentation
Sistema Edificio	Italy	Certification	No	-	-	-	-
Protocollo ITACA	Italy	Certification	No	-	-	-	3. Buy low-carbon
Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken	Netherlands	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA

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Table 17 North & South American systems and their key embodied carbon reduction information

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
AQUA	Brazil	Certification	Optional	2. Carbon comparison	-	1. Rating points	2. Use in LCA
GBC Brasil Casa e Condomínio	Brazil	Certification	No	-	-	-	3. Buy low-carbon
GBC Brasil Zero Energy	Brazil	Certification	No	-	-	-	-
Built Green (Canada)	Canada	Certification	No	-	-	-	-
Public Services & Procurement Canada (PSPC)	Canada	Regulation	Required	1. Carbon reporting	1. Self-declared	2. Funding criteria	2. Use in LCA
Quebec's Wood Charter	Canada	Regulation	Required	2. Carbon comparison	1. Self-declared	2. Funding criteria	2. Use in LCA
Zero Carbon Building Standard	Canada	Certification	Required	1. Carbon reporting	-	5. Mandatory	2. Use in LCA
Certificación de Vivienda Sustentable	Chile	Certification	No	-	-	-	1. Documentation
CES - Certificación de Edificios Sustentables	Chile	Certification	Optional	1. Carbon reporting	-	-	3. Buy low-carbon
Casa Columbia	Colombia	Certification	No	-	-	-	3. Buy low-carbon
Criterios ambientales para el diseño y construcción de vivienda urbana	Colombia	Guideline	No	-	-	-	-
Codigo tecnico de construccion sostenible v2	Peru	Regulation	No	-	-	-	-
BREEAM USA New Construction	USA	Certification	Optional	Not determined	Not determined	Not determined	Not determined
Buy Clean California Act (AB-262)	USA	Regulation	Optional	Simplified method	-	2. Funding criteria	1. Documentation
ASTM E2921	USA	Standard	Optional	1. Carbon reporting	-	-	-
Built Green (United States) / Green Point	USA	Certification	No	-	-	-	-
California Green Building Code 2016	USA	Regulation	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	1. Documentation
Green Globes	USA	Certification	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	1. Documentation
Guiding Principles for Sustainable Federal Buildings	USA	Regulation	No - May use	Not determined	-	-	3. Buy low-carbon
International Green Construction Code	USA	Regulation	Optional	2. Carbon comparison	1. Self-declared	-	1. Documentation
LENSES	USA	Certification	No - May use	Not determined	-	-	-
Minnesota B3 Guidelines	USA	Regulation	Required	2. Carbon comparison	1. Self-declared	2. Funding criteria	2. Use in LCA
National Green Building Standard ICC-700	USA	Certification	No	-	-	-	-

Table 18 Leading embodied carbon policies: summary, by country (Zizzo et al., 2017)

Country	Overview	Policy Name	Policy Type/Phase	Referenced Dataset	Tools	Scope	Performance Requirements
Belgium	Publishing to national EPD database is mandatory for all construction products making environmental marketing claims. National LCA calculation methodology in development.	B-EPD.	Requirement for EPD publishing. Voluntary calculation methodology in development for buildings to use EPD database to run WB-LCA.	B-EPD Database.	Voluntary national calculation methodology and tool in development; expected to be launched by 2018.	Construction products making environmental marketing claims.	No.
France	National program on energy and life-cycle carbon (including embodied carbon) performance in buildings. Voluntary now during pilot, but expected to become mandatory ~2020. Creation of EPDs mandatory for products using environmental labels.	Pilot program Energie Positive et Réduction Carbone includes embodied carbon calculations.	Regulatory building label pilot program. Expected to become mandatory in future.	INIES. LCA results uploaded to national E+C- database.	Various tools have been validated under the program.	New buildings. Does not apply to renovations unless project requires new permits. Includes operational energy.	Program has two levels of LCA-based performance requirement benchmarks, also called thresholds (Carbon 1, low performant. Carbon 2, high performance). An LCA is required and all impacts are calculated (same impacts as on EPD) but only energy and carbon have relevant thresholds.
Germany	BNB (Bewertungs-system Nachhaltiges Bauen) (which includes whole-building LCA) Silver certification required.	BNB Assessment System for Sustainable Building.	German government custom building rating program (similar to DGNB, the most popular voluntary German building rating program).	ÖKOBAUDAT. Building performance results to be shown in future site "eBNB".	eLCA: free LCA software for federal buildings.	New federal government buildings over 2M EUR (~$2.8M CDN).	No. Higher points achieved through higher LCA performance, but no minimum performance required.
The Netherlands	Required to submit 11 LCA-based metrics, including total life-cycle embodied carbon.	Dutch Building Code (Bouwbesluit 2012), Article 5.9.	Required for building permit.	Milieudatabase.	National Assessment Method (GWW). At least four national LCA tools exist.	New residential & office buildings over 100 m^2 (and extensive renovations).	Not yet. To be introduced in future.
Sweden	Transport Authority requires carbon accounting for projects.	Ruling TDOK 2015:0007.	Policy applies during transportation infrastructure planning, design, and construction.	Klimatkalkyl makes use of pre-calculated embodied carbon calculations for 94 transportation infrastructure solutions, on a unit basis.	Klimatkalkyl ("climate calculator") is an LCA-based design tool for infrastructure (e.g., roads, bridges, rail).	Transportation Authority requirement applies to projects over 50M SEK ($7.5M CDN).	Not specified. However, monetary incentives are offered to contractors who can reduce embodied carbon below design calculation through low-carbon material selection.
Switzerland	City of Zurich requires that all new government buildings be Minergie-Eco standard certified, which requires an LCA calculation (i.e., of embodied energy).	2000 Watt Society vision anchored in municipal code. Minergie-Eco certification.	Mandatory municipal policy. Voluntary national building certification program (Minergie) is used to support policy directive. Only Minergie-Eco (one of several versions of Minergie) requires LCA.	Swiss KBOB dataset (national dataset), based on ecoinvent data.	There are multiple tools available.	Mandatory policy is applicable to new government buildings in Zurich. Minergie-Eco is applicable to new and existing buildings of all types. Not applicable to infrastructure.	Minergie-Eco has "deep grey energy" (Swiss term for "embodied energy") performance standards for six building categories.
United Kingdom	No requirements exist. Voluntary rating system and embodied carbon-related aspirational goals in place.	Green building rating system: BREEAM.	Voluntary standards: BREEAM (buildings), CEEQUAL (infrastructure), and Home Quality Mark (residential) include LCA options.	ICE database.	BRE's "Impact" method.	Some municipalities require BREEAM, but not all BREEAM projects must do LCA.	No. Home Quality Mark provides additional points for higher LCA performance, but no minimum performance is required.

Appendix C. Interview notes and list of experts

Summary of Interviewees suggestions

Jennifer O'Connor, President & Matt Bowick, Senior Research Associate, Athena Sustainable Materials Institute

Feedback on current submission requirements (section 2.1)

- The results from the current CoV rezoning policy submissions are actually not very scattered given the design variations. To improve that CoV can:
  - Set a **workshop with the LCA consultants** that have done the current LCA submission to ask for their comments and recommendations for updating the requirements and reduce uncertainties.
  - Develop a **guideline on how to conduct LCA**, to make the methods consistent.
  - Require the **inclusion of underground parkade** in the total gross floor area, because excluding it may encourage parking lot.
  - Develop a **guideline on conducting material quantity take off**. This is more important for building permit stage, as more detailed bill of material is available.
    - It should be noted that BIM models are not necessary more accurate. The accuracy of material quantity extracted from BIM models, is directly affected by the accuracy of the BIM model and the level of details included in it.

Feedback on the submission template (section 2.2.2)

- Develop a standard accounting tool for material take off (e.g. in Excel format).
- Require bill of materials for building permit stage and not at rezoning stage.
- This level of detail (such as bill of materials and environmental impact breakdowns) is unnecessary and does not add value to the policy.
  - Instead set strong policy requirement and rely on the expertise of LCA practitioners to advise the project team where the hot spots are and how they can reduce their embodied impacts.
  - At the moment, **Athena IE is not ready to provide breakdown by material type or element type**.
  - Some of the recommended outputs are not currently possible to generate by the Impact Estimator. However, the software can easily be updated to specifically serve the needs of the City, if the City can fund that work. Bear in mind that the IE4B is the only tool available for free, with Canadian data, and does not require Revit.
- It is **expected that LCAs from rezoning stage are not accurate.** It is because a lot of material related decisions are not made yet.
  - At this phase, usually there is no foundation plan, no assembly design, and no specific decision on materials and components other than the main structure.
  - It may not add any value to ask the project team for their plan to reduce the embodied impacts.
  - The main benefit of asking for embodied emission assessment at the rezoning stage is creating capacity and encourage an LCA approach from the early design stage.

Feedback on the roadmap template (section 4)

- It is **not advised that the assessment scope be limited to cradle-to-gate,** as significant impacts **from the** whole building life cycle may be neglected.
- It is **not advised to limit the assessments to existing EPDs.**
    - It is often surprising how little difference there is between brand-name and industry-average data, and how little impact on final results this yields.
    - The majority of construction products do not have brand-name LCA or EPD data available, and requiring EPDs in the City's policy is unlikely to motivate any change in that.
    - A lot of the existing brand-name EPDs are not comparable as they have different scope, unit, method, or quality. Also a large number of current EPDs are based on the old version Product Category Rules and are to expire.
    - EPD data is typically only cradle-to-gate.
    - It's still early days for EPDs, and many people don't understand the limitations in the utility of EPDs at this point in time. Note as well that brand-name product specifications for any project can change at the last minute, so an industry-average product is probably a safer assumption in an LCA. Finally, note that the Impact Estimator is highly regionalized, meaning that product LCI data and transportation assumptions are closely keyed to the project location

    These points and a number of other technical reasons, raise a serious challenge to any pre-conception that EPD data is better than industry-average LCI/LCA data. They show that it is very difficult if not impossible to conduct an accurate whole building LCA using EPD data. In fact, EPDs are not intended for that purpose.

- A **vetting process for the national database** is crucial.
- It is crucial that all projects use **a single software tool**, so they are comparable.
- Asking actual construction data for A4-5 can benefit the whole LCA community, as construction data is the poorest data among all life cycle phases.
    - It is recommended to **ask for input from construction and site managers** to ensure this ask is feasible.
- Limiting the requirement to Global Warming Potential is acceptable, as it makes understanding of LCA easier for non-LCA professionals.
- Rather than specifying a set caps, set **embodied emission benchmarks** for the common building types. This allows project teams to understand where their project stand compared to other projects in each project stage (e.g. rezoning, development, etc.). They can use this to reduce the impacts if they are above the benchmark. More details on the recommended benchmarking method is available in recent Athena Institute publications by Bowick & O'Connor (2017) and Bowick, O'Connor, & Meil (2017).
    - Setting a single universal cap based on the current submissions is risky, because it is not clear what elements/materials the project teams have included/excluded in their assessments.
    - The downside of using a project-based baseline is that the project teams might arbitrary set their baseline higher than the industry norms to be able to easily reduce impacts from the baseline.
    - A benchmark can be set by assessing the embodied impacts of the average material quantity per gross floor area of a large number of buildings (e.g. in 100 Mid-rise MURBs).

- It is recommended not to rush into reducing the impacts, especially through prescriptive measures, such as preferring one material type over the other. It is best to allow the industry to come up with innovative solutions for different material types.

Anthony Pak, CEO, Priopta Innovations

Feedback on the submission template (section 2.2.2)

- It is important to clarify **guidelines for material take off**. For instance, bill of materials taken from BIM models are different with what is generated through Athena Impact Estimator.
    - If it is possible, CoV can ask the project team to use construction estimation data and/or methods.
- There should be a clear **purpose and justification for asking for the bill of materials**. Otherwise it is an unnecessary paperwork to ask. For instance, if City intends to create benchmarks using the bill of materials.
    - If legally possible, there may be value in **asking for the LCA model** instead (e.g. Athena IE file).
    - This would be more challenging if consultant used Tally software, as the LCA model is connected to the Revit model, so they would need to submit the BIM model to the city.
- **Breakdown of impacts is valuable**, especially if the LCA tool can recognize components that have the highest impact and have potential for impact reduction.

Feedback on the roadmap (section 4)

- **Recommend using LEED v4.1 approach for embodied carbon reduction policy**
    - Rather than setting a fixed cap, it might be better to use LEED V4.1 approach (see section 3.1.2.1), which will also reduce confusion and create alignment with the LEED LCA credits. Mandate a certain percentage of reduction (e.g. 10%) and incentivize more reduction (e.g. more than 20%) from the baseline.
    - By enabling the consultant to define the baseline and then require a percentage reduction (eg. 10% or 20%), we don't need to worry about setting the right cap threshold by building type, nor do we limit what LCA software and databases are used. They just need to use the same software / database between baseline and proposed design to ensure results are comparable.
    - The key to making this policy successful is creating clear guidelines on how to define the baseline building. We should gather all of the LCA consultants and discuss potential ways that the baseline definition could be gamed (eg. Setting 0% SCM for concrete) and develop criteria for baseline setting to prevent that.
    - Require consultants to submit a narrative that describes what were the changes between the baseline and proposed design, which led to the reduction in impacts. Through this narrative, we would see whether the design changes meet the intent of this requirement for actually reducing embodied carbon.
    - Mandating LEED's LCA credit approach would by itself already be a major policy innovation. For example, if there is a requirement to reduce GWP by 10% to receive Building Permit, it would require all design teams to actually focus on reducing embodied carbon, rather than just disclosing LCA results but not integrating it into design considerations.

- **Setting a fixed cap (kgCO2e/m2) will be challenging and not recommended.**
    - Using the current submissions to set a cap is not recommended, because the rigor of current submissions is not clear. It is better to use a systematic parametric assessment to assess the impacts of common archetypes (maybe ASHREA archetypes) and use common material and product and possible alternatives to set caps and reduction goals
    - The cap threshold will vary widely depending on building type and materials used. There can also be large variations in results generated by different software, as they all use different underlying LCI/EPD databases. If a different cap was set for each building type and depending on the software used, it may be too complicated.
    - If you set the cap too high, it doesn't incentivize reduction. Set the cap too low, and it may exclude certain material design options. To set the cap at the right level to incentivize reduction in embodied carbon would require a detailed analysis, potentially doing Parametric LCAs for multiple building types, and also comparing results between different software.
    - I don't think it is a good idea to mandate the use of a specific software, as there are lots of innovations currently happening with the LCA software tools and databases. Each tool has different strengths and weaknesses, and if we limit to a specific software at this point, we may limit future improvements in the market of LCA software. For example, Athena IE is the only free tool at this point, but it also has the slowest pace of development compared to the other software tools. Since Athena IE does not contain many manufacturer specific EPDs, if we only allow the use of Athena IE to comply with this policy, we cut off incentive from manufacturers to create EPDs as it's not being used within Athena IE to evaluate design options on projects.
    - While fixed GHGI caps work well for operational energy use, it is important to remember that Energy Modeling is about 10-20 years ahead of where Building LCA is at. Use of LCA within the buildings industry is still relatively new, and I think more efforts need to be made on benchmarking before we can be confident in setting the right GHGI targets for embodied carbon.
- **Software comparison:**
    - Athena IE
        - My understanding is that Athena's Life Cycle Inventory (LCI) database includes mostly industry average data as well as some manufacturer specific EPDs. I believe most of their data is based on their past research and studies. They have Canadian and US specific data.
        - Athena is great for early design, and likely will be the main LCA tool that consultants use at the Rezoning stage, since there is likely no BIM model (which is required for Tally) at that stage of the project. It's also the only free LCA software. Since you can't compare results across different LCA software, as they all have different underlying databases with different assumptions, it would be unlikely that consultants would switch to use another LCA software at the Building Permit or Occupancy stages, if they used Athena IE at Rezoning.
        - Athena Impact Estimator is well suited for early design when there is no BIM model (or for projects that won't have a BIM model). One of the big strengths of the Impact

Estimator is how it can estimate the material quantities based on simple user inputs (eg. span between columns or floor area) and the material assembly options selected.
        - Athena also has a Bill Of Materials (BOM) import option, enabling takeoffs from Revit model, however it is not as tightly integrated with BIM as Tally or One Click LCA.
        - Athena is free.
    - Tally
        - Tally is a Revit LCA plugin, which relies on the GaBi LCI database and their own database of construction assemblies. Given that the material takeoffs are linked to the Revit model, the material takeoffs are likely more accurate compared to Athena. It also has more detailed modeling options for things that aren't in the BIM model, such as rebar type and spacing.
        - However, it may be more challenging to compare different material design options, as it may require actually modeling geometry changes in Revit instead of changing dropdown menu options in Athena.
        - Tally costs approximately $1K/yr, and if the LCA consultant doesn't have Revit (which is required), then it costs $3K/yr Revit License (CAD).
    - One Click LCA
        - One Click LCA is from Europe and is relatively new to North America, so it isn't as widely used here. It relies on publicly available EPDs as well as its own internally developed generic materials datasets based on Ecoinvent LCI database. It has the largest amount of manufacturer specific EPDs available for comparison. It has a Revit plugin like Tally, but also has a web app for managing material assignment and comparing design options.
        - They recently created a new tool called the "LCA Carbon Designer", which creates a simplified model that may be appropriate for Rezoning. This model can later connect with the BIM model if it is available at a later stage in the project. I believe the cost is between $1K to $4K/yr depending on license, plus extra for some add-ons like Carbon Designer. It can be used with Revit but does not require it
- **EPD Database**
    - There are other current efforts focused on improving EPDs both at the National level (NRC's Low Carbon Canada through Life Cycle Assessment) and the upcoming EC3 tool.
    - EC3 is an open source EPD tool that is being developed by Skanska and Microsoft, which should be released sometime in 2019. Phil Northcott from Port Moody is working on the software side of this effort. Click on the "See an example" links to see screenshots of the tool: https://buildingtransparency.org
    - Make sure one type of material is not favored above another without strong scientific consensus.

- Make sure **one type of material is not favored above another** without strong scientific consensus.

Ryan Zizzo, Founder and COO, Mantle 314 – Formerly Zizzo Strategy

Feedback on the submission template (section 2.2.2)

- It is good to ask for **impact breakdown by life cycle phase**, but it might get overwhelming to ask for breakdown by element and material. It might be better to **ask for the LCA model inputs** (material selections and quantity) instead.
    - If LCA is assessed by inputting the BoM, element impact breakdown is not possible to generate, but breakdown by materials can still be provided. Such breakdown helps the team understand the areas with highest impacts.
- LCA tools that are currently being used in Canada: Athena IE and One Click LCA, Tally. However, Athena is the only free tool.
- Ask the project teams to specify the project stage at which LCA was conducted, e.g. preliminary design, schematic design, issued for construction, etc.
- Ensure the assessments are consistent in the building elements that they include/exclude.
    - For **renovation, it is advised to include the finishes.**
- Ask for more information on their **confidence on the quality of the LCA assessment**
    - A good example for this is the data quality reporting requirement in carbon footprint assessment method developed by **Finland Ministry of the Environment** (see Table 5).
    - The projects can be asked to submit **lists of EPDs and product transportation distances** used in the LCA assessment.
- It is **reasonable to ask for the BoM** used in the LCA model, as it provides a better understanding of the model.

Feedback on the roadmap (section 4)

- The LCA assessment should be required for **rezoning approval, with updates for development and occupancy permit** stages.
- **Limiting the LCA to A1-A3 at the rezoning stage is a reasonable approach,** given the poor quality of data and uncertainty for the next life cycle phases. This will encourage simpler and low embodied carbon materials.
    - **State of the California** requires embodied carbon below a threshold for A1-A3 phases through Buy Clean California Act (see section 3.1.2.1).
    - However, **currently EPDs are not consistent.** The City can support the national database creation initiative – led by National Research Council (2019) – through consolidating a Lower Mainland regional database.
    - City can also **lead by mandating their own projects require EPDs** to be created for major structural materials used and to make their EPD data publicly available. An example for this approach is a State of Washington, Department of Enterprise Services building that required EPD creation and publishing for all concrete mixes used[52].
- It is **reasonable to ask for A4-A5** at the occupancy stage to improve the quality of currently available data. Currently, Athena IE does not ask for actual transportation distances and uses average data that is not visible to the user.

[52] https://www.sellen.com/wp-content/uploads/Measuring-and-Reducing-Embodied-Carbon-Dave-Walsh.pdf

  - CoV and other governments should work with Athena and other regional experts to create a **Vancouver specific database and tool**, in which transportation distances and other construction options are specific to this region and are shown to the user.
  - To ensure the end of life is not neglected, CoV can work with the waste industry to improve **circular economy approaches**.
- Requiring **reduction from a set value is better than a project-specific baseline building meeting code requirements only.** Because a baseline building allows for arbitrary baseline setting.
  - If a project must show their performance against a cap / benchmark, **both the benchmark and project performance should be calculated with the same software**, as there is a 15-30% difference between estimates of different software tools. Therefore, teams should be provided with a 'baseline bill of materials' for a given archetype, and potentially some other benchmark factors such as SCM% and transportation distance, for example. They can then calculate the embodied carbon of that benchmark and compare against their project, using same tool of their choice.
- The eventual goal should be requiring **offsetting the embodied impacts**. This approach is taken in **Living building Challenge** (see 3.1.2.1).
- For **red list materials check Swedish Green Building Council** approach, as they are a leader in considering human toxicity in their assessment system (see the list of contacts).

Helen Goodland, Managing Partner, Brantwood Consulting

Feedback on the submission template (section 2.2.2)

- It would be much more valuable and effective if the City develops a smart and **centralized permitting system**. Through such a system, a lot of information requested in the template can be prepopulated with default values based on the industry trends similar project or with project-specific values which are entered by the applicant in other permit forms.
- It is **reasonable to ask for detailed bill of materials**. It helps the City gather a better understanding of the most impactful materials in the region. However, detailed bill of materials may not be available at the rezoning stage, because most of the details are not designed yet.
- At the beginning, **limit LCA reporting to elements with major elements**, **those for which good data is available for, and those with opportunities to reduce their impacts**, e.g. structure and envelope. However, this approach should only be used as a temporary "on boarding" strategy to get industry familiar with the process.
  - Data on mechanical systems are not rigorous yet (even in European databases). Additionally, they don't offer much opportunity to reduce the embodied impacts.
  - Exclude partition as their impacts are not significant compared to elements such as structure and envelope.
  - Have clear compliance requirements and clear **compliance assessment methods**.

Feedback on the roadmap (section 4)

- It is better to **ask for LCA through all the life cycle phases rather than only product phase**, even if some phases are based on industry average data. As more accurate and project-specific data become available, they will replace the average data.

  - Steel and concrete industry would disagree with excluding end-of-life scenarios. Because their products typically offer high recyclability potential.
- To simplify the process, especially in the rezoning stage, the City can set **default values for common assemblies**. The project team can be incentivized to replace the default values with project-specific values, when they become available.
- Asking for **multiple submissions at different permit stages might be a challenge** for smaller projects. In general, it is best to define stricter requirement for larger scale projects that have access to more resources and expertise.
- Before defining any cap, CoV must assess its requirements in pilot projects. It is best if these are larger scale project.
- Rather than defining separate caps for embodied and operation emissions, it might be better to set a **combined cap for operation and embodied impacts**. This allows some flexibility in design and materials selection decisions.
- Recommended best practices to learn from: Nederland and Switzerland approaches (See section 3.1.2.1).
- Resources to look into:
  - "Operational & Embodied Energy/Carbon Framework" developed by Intep and Brantwood Consulting (2012). This report recommends a framework for mid-rise multi-family residential buildings in the City of Vancouver to achieve the Greenest City Action Plan goals – become carbon neutral by 2020. The report considers both embodied and operation impacts and builds on Swiss experience and approach.
  - "Development of a Common Material Metric for the UNEP SBCI Sustainable Building Protocol" developed by CIRAIG (2014) for the UN Materials Technical Advisory Committee. This report recommends globally-applicable measurement and reporting metrics, protocols and templates that indicate the sustainability of building materials in a building scale for inclusion in the UNEP-SB Protocol.
- Efforts in reducing embodied emissions should be integrated with the circular economy efforts.

List of experts

- European jurisdiction with best practices
  (Zizzo et al., 2017)
    - Belgium
    - France
    - Germany
    - The Netherlands
    - Sweden
        - Sue Clark, Director of International Programs, Sweden Green Building Council (referred to by Ryan Zizzo for red list materials)
    - Switzerland
    - United Kingdom
    - Finland
        - Panu Pasanen, Chief Executive Officer, Bionova Ltd. (referred to by Ryan Zizzo)
    - Singapore
- LCA consultants/experts:
    - Rob Sianchuk
    - James Salazar
    - Matt Bowick
    - Jennifer O'Connor
    - Anthony Pak
    - Sébastien Garon
    - Ryan Zizzo, based in Toronto
- Researchers and research institutes:
    - Omar Swei, Assistant Professor, Department of Civil Engineering, UBC (has previously worked with Athena in developing tools and has extensive experience in developing LCA models in the US)
    - Adam Rysanek, Assistant Professor in Environmental Systems, School of Architecture and Landscape Architecture, UBC
    - Angelique Pilon, Director of Urban Innovation Research, UBC Sustainability Initiative
    - Annie Levasseur, Chair of Scientififc Committee, CIRAIG (recommended by Helen Goodland)
    - Cécile Bulle, Université du Québec à Montréal, CIRAIG
    - Pascal Lesage, Polytechnique Montréal, CIRAIG, LCI database
- Embodied carbon policy makers and experts:
    - Ryan Zizzo, based in Toronto
    - Helen Goodland
    - Kyle Reese, Senior Project Manager, UBC Project Services (he was the UBC contact for the "Operational & Embodied Energy/Carbon Framework" report (2012).
    - John Madden john, Director of Sustainability and Engineering, UBC Campus and Community Planning
    - Jennifer O'Connor
    - Tina Dilegge, Program Manager of Carbon Leadership Forum, manages Embodied Carbon Network, also worked on Buy Clean Washington policy.

  - Kate Simonen, Founder of Carbon Leadership Forum and Embodied Carbon Network, wrote book on LCA in buildings, works with Tina on Buy Clean Washington policy
- Industry representatives:
  - Clint Undseth, local co-chair of the National Zero Waste Council Construction Taskforce
  - David Redfern, local co-chair of the National Zero Waste Council Construction Taskforce
  - Adam Auer, Cement Association of Canada
  - Matt Dalkie, Lafarge Holcim, expert on Concrete and LCA/EPDs
  - Tareq Ali, Canadian Institute of Steel Construction
  - Sonya Zeitler Fletcher & Opreet Kang, Forestry Innovation Investment
  - Peter Moonen, Canadian Wood Council
  - Kathy Wardle, Perkins+Will
  - Graham Twyford-Miles, Stantec
  - Heidi Nesbitt & Michel Labrie, Local Practice Architecture
  - Mark Porter & Linda Wojcicka, Associated Engineering
  - Allison Holden-Pope, ONE SEED Architecture + Interiors
    (presented on low embodied carbon materials for single-family homes at Buildex 2019, session W23)
  - Chris Magwood, The Endeavour Centre, Ontario
    (Presented and Passive House Conference 2018 on low-embodied carbon design)
- Federal governments
  - Chris Lindberg, Environment Canada Circular Economy Lab
  - Geoffrey Guest, Construction Research Centre, National Research Council of Canada, Research Officer (leading the Low-Carbon Assets through Life Cycle Assessment (LCA) Initiative, Referred to by Anthony Pak)

Appendix D. Reviewed City of Vancouver's embodied emissions submissions

Table 19 List of the reviewed embodied emission submissions

Address	Building type	Structure	Envelope	Consultant	Underground parkade	Parkade Area (m^2)	Ventilated Area (m^2)	Concrete Quantity (m^3/m^2)	Metal Quantity (kg/m^2)	Wood Quantity (m^3/m^2)	Embodied CO^2 eq./m^2 total	Embodied CO^2 eq./m^2 excluding Parkade	Annual eq. Embodied CO^2 eq./m^2 *excluding Parkade*	GHGI Limit ($kgCO2/m^2$)	Note
3070 Kingsway	Low-rise Residential	Not Available	Not Available	Rob Sianchuk		980	3,533	Not Available	Not Available	Not Available	248.17	317.01	5.28	5.00	• Gross floor area is not specified. The quantities are extracted from Zero Emissions Building Plan Energy Checklist. • Structure material and type are not specified.
2109 East Hastings	Low-rise Residential	Not Available	Wood Studs	Rob Sianchuk		Not Available	3,437	Not Available	Not Available	Not Available	Not Available	352.05	5.87	5.00	• Gross floor area is not specified. The quantities are extracted from Zero Emissions Building Plan Energy Checklist. • Structure material and type are not specified. • GWP is 352 if the total GWP is divided into the gross floor area, but it is reported as 278 kg CO_2 eq./m^2
55-115 SW Marine Dr	Low-rise Residential	Not Available	Wood Studs	Rob Sianchuk		1,220	3,933	Not Available	Not Available	Not Available	636.72	834.23	13.90	5.00	• Gross floor area is not specified. The quantities are extracted from Zero Emissions Building Plan Energy Checklist. • Structure material and type are not specified. • GWP is 834 if the total GWP is divided into the gross floor area, but it is reported as 261 kg CO_2 eq./m^2
4787 Cambie St	Low-rise Residential	Concrete	Steel Studs	BC Building Science	Yes	Not Available	-	Not Available	Not Available	Not Available	Not Available	356.74	5.95	5.00	• It is not clear whether the gross floor area includes parking.
2230 Harrison Drive	Low-rise Residential	Concrete	Wood Studs	E3	Yes	Not Available	5,687	0.61	64.93	0.01	Not Available	319.03	5.32	5.00	
8444 - 8480 Oak St	Low-rise Residential	Concrete	Wood Studs	E3	Yes	Not Available	4,229	0.73	81.00	0.01	Not Available	401.21	6.69	5.00	
2542-2570 Garden Dr & 2309-2369 E 10th Ave	Low-rise Residential	Concrete	Wood Studs	E3	Yes	Not Available	6,230	0.82	77.06	0.01	Not Available	415.63	6.93	5.00	
4575 Granville St.	Low-rise Residential	Concrete	Wood Studs	E3	Yes	Not Available	2,228	0.81	90.74	0.02	279.91	457.81	7.63	5.00	
2601-2619 E Hastings	Low-rise Residential	Concrete	Concrete panels	Integral Group	Yes	1,860	5,618	Not Available	Not Available	Not Available	221.98	295.48	4.92	5.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.
610-644 Kingsway	Low-rise Residential	Concrete	Concrete panels	Integral Group	Yes	2,063	6,996	Not Available	Not Available	Not Available	229.61	297.30	4.96	5.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.
8030-8130 Oak St, 988 W64th Ave	Low-rise Residential	Concrete	Concrete panels	Integral Group	Yes	6,202	10,205	Not Available	Not Available	Not Available	308.40	495.84	8.26	5.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.
1668-1684 Alberni	High Rise Residential	Concrete	Steel Studs	Integral Group	Yes	8,029	21,564	Not Available	Not Available	Not Available	196.67	269.89	4.50	6.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.
1068-1080 Burnaby St & 1318 Thurlow St	High-rise Residential	Concrete	Steel Studs	Integral Group	Yes	4,837	14,403	Not Available	Not Available	Not Available	251.56	336.04	5.60	8.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.

Address	Building type	Structure	Envelope	Consultant	Underground parkade	Parkade Area (m^2)	Ventilated Area (m^2)	Concrete Quantity (m^3/m^2)	Metal Quantity (kg/m^2)	Wood Quantity (m^3/m^2)	Embodied CO^2 eq./m^2 total	Embodied CO^2 eq./m^2 excluding Parkade	Annual eq. Embodied CO^2 eq./m^2 *excluding Parkade*	GHGI Limit ($kgCO2/m^2$)	Note
950 W 41st Ave	High-rise-other	Concrete	Steel Studs	Integral Group	Yes	27,775	59,370	Not Available	Not Available	Not Available	288.48	423.45	7.06	8.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.
2218 Main	High-rise Residential	Concrete	Steel Studs	Integral Group	Yes	4,856	6,526	Not Available	Not Available	Not Available	248.64	433.68	7.23	8.00	• Interior Walls in corridors are specified as steel stud, but it is not clear whether they are included in GWP estimate.
1070 Barclay St.	High-rise Residential	Concrete	curtain wall	Matt Bowick	Yes	Not Available	64,710	0.74	110.70	-	Not Available	543.30	9.06	8.00	-
441-463 West 59th Ave	Low-rise Residential	Concrete	Steel Studs	Matt Bowick	Yes	Not Available	5,730	0.88	65.09	-	Not Available	524.14	8.74	5.00	-
888 W. Broadway	High-rise-other	Concrete	Not Available	NDY	Yes	20,698	31,886	Not Available	Not Available	Not Available	117.91	306.00	5.10	8.00	• The total GWP (kg CO_2 eq.) is not specified. • Structural materials and types are not specified
1066-1078 Harwood St & 1065 Harwood St & 1332 Thurlow St	High-rise Residential	Concrete	Not Available	Rob Sianchuk	Not Available	Not Available	33,050	Not Available	Not Available	Not Available	Not Available	428.74	7.15	8.00	• Gross floor area is not specified. • Structural materials and types are not specified
339 East 1st Ave	High-rise-other	Concrete	Not Available	Rob Sianchuk	Not Available	8,246	13,398	Not Available	Not Available	Not Available	286.46	462.75	7.71	8.00	• Gross floor area is not specified. • Structural materials and types are not specified
425 W 6th Ave	Low-rise-other	Concrete	Not Available	Rob Sianchuk	Not Available	Not Available	-	Not Available	Not Available	Not Available	Not Available	532.00	8.87	8.00	• Gross floor area is not specified. • Structural materials and types are not specified
3510 Fraser St	Low-rise Residential	Concrete	Not Available	Sebastien Garon	Not Available	Not Available	4,500	0.18	28.71	0.08	Not Available	230.56	3.84	5.00	
177 W Pender	High-rise Residential	Concrete	Steel Studs	Sebastien Garon	No	-	-	0.48	24.19	-	275.98	Not Available	Not Available	8.00	
1535-1557 Grant St.	Low-rise Residential	Hybrid wood	Wood Studs	E3	Yes	Not Available	2,982	0.30	12.77	0.12	Not Available	185.11	3.09	5.00	
146-186 W 41st Ave & 5726 Columbia St	Low-rise Residential	Hybrid wood	Wood Studs	E3	Yes	Not Available	8,877	0.33	16.87	0.08	Not Available	211.85	3.53	5.00	
686 E 22nd Ave, 3811-3833 Fraser St & 679 E 23rd Ave	Low-rise Residential	Hybrid wood	Wood Studs	Edge	Yes	1,620	9,550	Not Available	Not Available	Not Available	151,294	176,958	2,949.31	5.00	• Outside the range
2715 West 12th Ave	Low-rise Residential	Hybrid wood	Wood Studs	Integral Group	Yes	54	1,273	Not Available	Not Available	Not Available	139.43	145.33	2.42	5.00	
8636-8656 Oak St	Low-rise Residential	Hybrid wood	Wood Studs	Matt Bowick	Yes	Not Available	5,871	0.42	32.55	0.05	Not Available	329.95	5.50	5.00	