ULI Center For Leadership mTAP

Livable Buckhead

Embodied Carbon Case Study and Reduction Analysis

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Life Cycle Carbon Emissions in Buildings Overview (Task 0)

Introduction

Addressing life cycle carbon emissions (LCCE) in the built environment is paramount to achieving sustainable construction practices and mitigating the environmental impact of buildings. LCCE encompasses the total carbon footprint associated with a building's entire lifespan, from raw material extraction and construction to operational use and eventual demolition. This comprehensive analysis illustrates the intricacies of LCCE, its contributing factors, assessment methodologies, and strategies for reduction.

Sources of Life Cycle Carbon Emissions

LCCE in buildings can be categorized into two primary sources:

1. Embodied Carbon Emissions: Emissions generated through raw material extraction, transportation, manufacturing of construction products, on-site construction activities, maintenance, replacement of materials, demolition, disposal, or recycling processes.
2. Operational Carbon Emissions: Emissions resulting from the operation of the building, including heating, cooling, lighting, plug loads, and water heating, typically arising from on-site combustion of fossil fuels or the consumption of purchased electricity.

Contributing Factors

Several factors contribute to the life cycle carbon emissions associated with buildings:

1. Material Selection: The choice of construction materials significantly influences LCCE, with high-embodied-carbon materials like concrete and steel contributing substantially to the overall carbon footprint.
2. Construction Processes: Energy-intensive processes, such as concrete production and material transportation, play a crucial role in determining LCCE.
3. Energy Use: The operational phase, encompassing energy consumption for heating, cooling, and lighting, contributes significantly to a building's carbon emissions.
4. Maintenance and Renovation: The frequency and intensity of maintenance and renovation activities impact LCCE due to additional material and energy inputs.

Life Cycle Assessment (LCA) Methodology

Life Cycle Assessment (LCA) is a systematic approach to evaluate the environmental impacts of a product or system throughout its entire life cycle, from raw material extraction to end-of-life disposal. LCA provides a holistic perspective, considering aspects such as energy consumption, emissions, and resource depletion.

The stages involved in an LCA include:

1. Goal and Scope Definition: Clearly delineating the objectives, boundaries, and functional unit of the assessment.
2. Life Cycle Inventory (LCI): Quantifying inputs and outputs at each stage of the product life cycle.
3. Life Cycle Impact Assessment (LCIA): Evaluating the potential environmental impacts of the identified inputs and outputs.
4. Interpretation: Analyzing and interpreting the results, considering the context and limitations, to inform decision-making and identify areas for improvement.

LCA methodology can be applied at various phases of development, including design, as-designed analysis, and as-built analysis, each with its own set of inclusions and exclusions.

Establishing Baselines and Targets

Existing studies, such as the Carbon Leadership Forum's Embodied Carbon Benchmark Study and literature values for embodied carbon by building/material type, provide baseline benchmarks for LCCE. Case studies, like the Residential, Commercial, and Institutional Building Benchmark from Canada, also contribute to establishing baselines.

Organizations like Architecture 2030 have issued embodied carbon targets to meet 2030/2040 carbon goals. These targets call for a 40% reduction starting in 2025 and reaching zero or near-zero carbon buildings by 2040. Less aggressive targets may aim for 10-20% reductions from current baselines by 2030, with periodic increases to achieve net-zero emissions by 2040/2050.

Strategies for Reducing LCCE

To achieve LCCE reduction targets, the following strategies can be employed:

1. Material Selection: Utilizing lower carbon footprint products as alternatives to traditional materials.
2. Design Optimization: Implementing efficient architectural designs that require fewer materials.
3. Construction Techniques: Employing prefabrication and better on-site operations management.
4. Reuse and Renovation: Reusing existing building materials or components where possible and using lower-carbon replacement materials for renovations.

See the below Figure 1 and Figure 2 for a simple and comprehensive roadmaps through embodied carbon measuring and reduction.

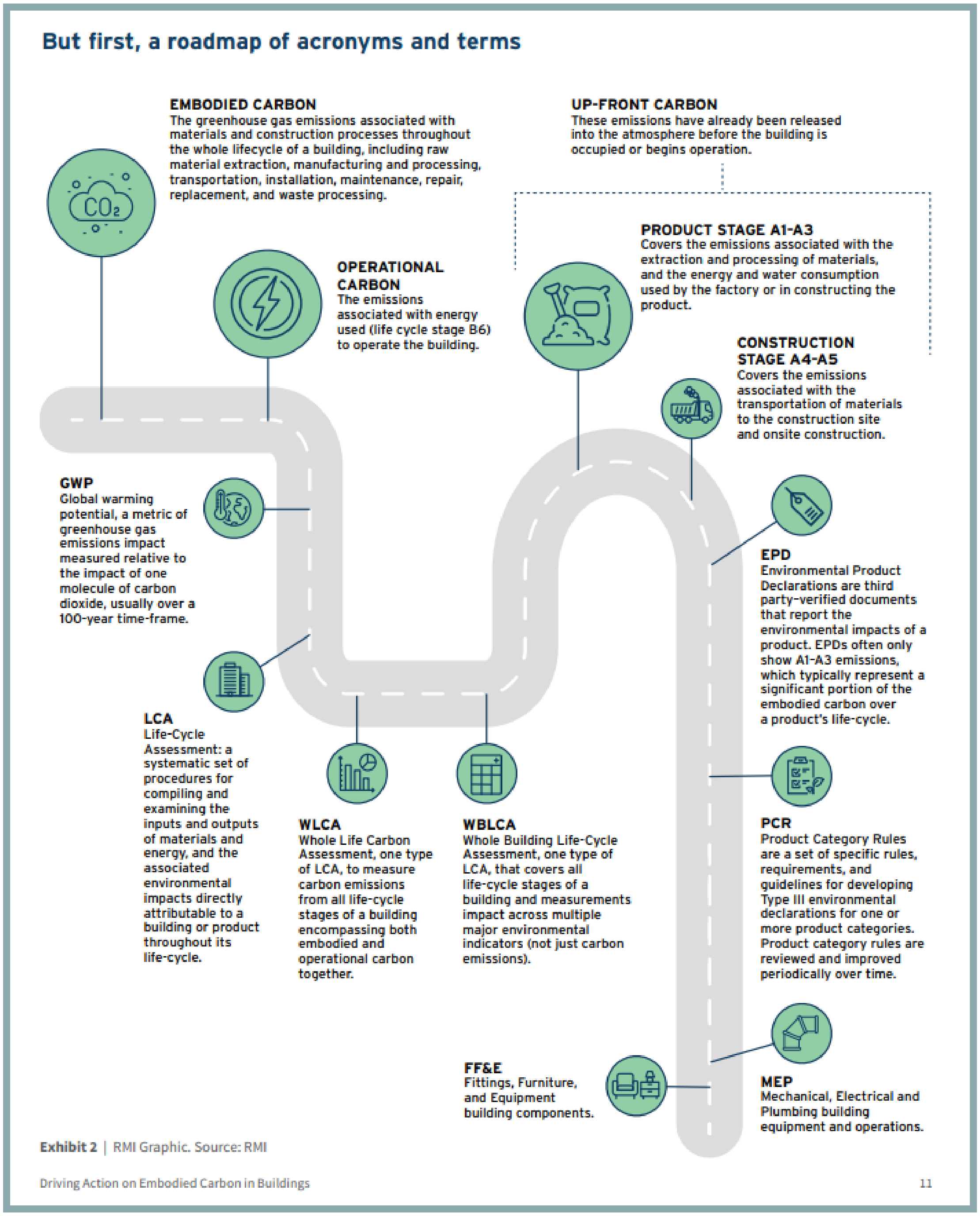

Figure 1: Embodied Carbon Acronyms and Terms

Phase	Design steps	Core objectives	Roles	Strategies & processes to reduce embodied carbon
EARLY DESIGN	0 Strategic definition	Requirements & target-setting, review project risks & alternatives, site appraisal, client's brief	C, D	**Question and clarify the programe and building need** Is a new building really needed? What are alternatives? Can an existing building be transformed/retrofitted instead? **Identify the embodied carbon baseline scenario** What is the building programe, which uses and areas are needed? What is the reference embodied/WLC carbon value to improve upon?
EARLY DESIGN	1 Preliminary studies	Feasibility studies, architectural competition, call for design proposals	C, D	**Build less: Reduce building size and resuse elements, materials** Can the functions/user requirement be satisfied with less built area? Which salvaged elements, products or material are available for reuse? **Set an embodied and whole life carbon budget from benchmarks** Use embodied carbon benchmarks of similar building projects to define a baseline for embodied and whole life carbon emissions early on
EARLY DESIGN	2 Concept design	Concepts, sketches, design proposals	C, D, S	**Opimise the building typology and shape (shape factor/form factor)** Can the building program and uses be fullfillfed with a compact shape be applied to reduce material use and structural requirements? **Perform an initial whole building LCA to identify hotspots to improve** Which are the most contributing building elements and materials? What are alternative solution to reduce embodied carbon emissions?
DETAILED DESIGN	3 Developed design	Design specification, building permit application	C, D, S, B	**Optimise the design of key building systems (structure, envelope)** Can we reduce material quantities? What are trade-offs in embodied and operational carbon, upfront embodied carbon and durability? **Specify low carbon materials, consider like-for-life subsitition** Can we achieve similar technical, functional, energy performance and better embodied carbon performance with alternative materials?
DETAILED DESIGN	4 Technical design	Detailed technical design, procurement of products and services	C, D, S, B	**Optimise the design of technical services (MEP/HVAC) and finishings** Can we reduce complexity of the MEP/HVAC systems and systems using low carbon refrigerants? Can we minimize finishes where not necessary and select carbon storing or otherwise lower carbon alternatives? Particularly for frequently changed fitouts. **Ask manufacturers for environmental product declarations (EPDs)** Verified EPDs are industry standard for disclosing environmental performance information, require EPDs for informed product selection.
DETAILED DESIGN	5 Manufacturing & construction	(Pre-)Fabrication of construction products and components, construction and supervision	C, D, B, T	**Establish guidance and targets to reduce construction waste** How do we ensure minimal waste of materials and energy off/on site? **Evaluate and document all material and energy flows** How material/energy-efficient is the production and construction, how much is wasted and how can we reduce waste?
DETAILED DESIGN	6 Handover & commissioning	As-built documentation, building hand over, commissioning and testing	C, D, S, B, T	**Document the as-built whole life carbon of the building** Update the LCA model and results as needed. **Sharing is caring: Publish the WLC/LCA data for open benchmarking** Improve collaboration, transparency and accountability by contributing the WLC/LCA results to open benchmarking initiatives.
USE PHASE	7 Operation & management	Facilities and asset management, maintenance, renovation, fit-outs	C, D, B, T	**Choose to improve carbon performance when replacing products** When products reach end-of-life, can we replace them with low carbon alternatives of similar technical, functional, aesthetic performance? **Establish carbon reduction targets for future renovation and fit-outs** How can we optimize maintenance to reduce replacement needs? Where necessary, how can we enable future replacement with low carbon alternatives?
USE PHASE	8 End-of-use, reuse & recyce	Decommissioning, deconstruction, reuse, recycling	C, D, S	**Determine the potential to reuse or recycle the building or parts of it** Which building parts, elements, or materials can be reuse/recycled/ upcycled/downcycled? How can we increase the circularity potential with targeted deconstruction strategies?

Strategies & processes

- **Avoid** material use, build (with) less, reuse, recycle
- **Shift** to bio-based materials and regenerative solutions
- **Improve** non-renewable materials and processes
- **Measure** materials use and carbon emissions, WLC/LCA
- **Collaborate** to break silos via shared targets and priorities

Roles & responsibilities

- **C** Clients (developers, funders)
- **D** Design professionals (architects & engineers)
- **S** Sustainability professionals (WLC/LCA consultants/staff)
- **B** BIM/VDC professionals (managers, modellers)
- **T** Contractors, builders (pre-fabrication, installation)

Figure 3. Milestones and opportunities for reducing embodied carbon across the building design process

Decision support table illustrating milestones and opportunities in different design steps for reducing embodied and whole life carbon. The recommendations indicate the primary strategies (avoid, shift, improve) and primary roles (clients, design professionals, sustainability professionals, BIM/VDC professionals (BIM: building information modeling; VDC: virtual design and construction), contractors) responsible for specifications and processes to consider. Based on IEA EBC Annex 72, Frischknecht et al. (2023), Passer et al. (2023), and Embodied Carbon Toolkit for Architects.

Figure 2: Milestones and Opportunities for Reducing Embodied Carbon Across the Building Design Process

EMBODIED CARBON BENCHMARKING (TASK 1)

According to their website, The Carbon Leadership Forum (CLF) accelerates the transformation of the building sector to radically reduce the greenhouse gas emissions attributed to materials (also known as embodied carbon) used in buildings and infrastructure.

CLF maintains a database of embodied carbon footprint of buildings by building type. While not without its limitations, it is the only trusted source of information available for benchmarking embodied carbon performance of buildings.

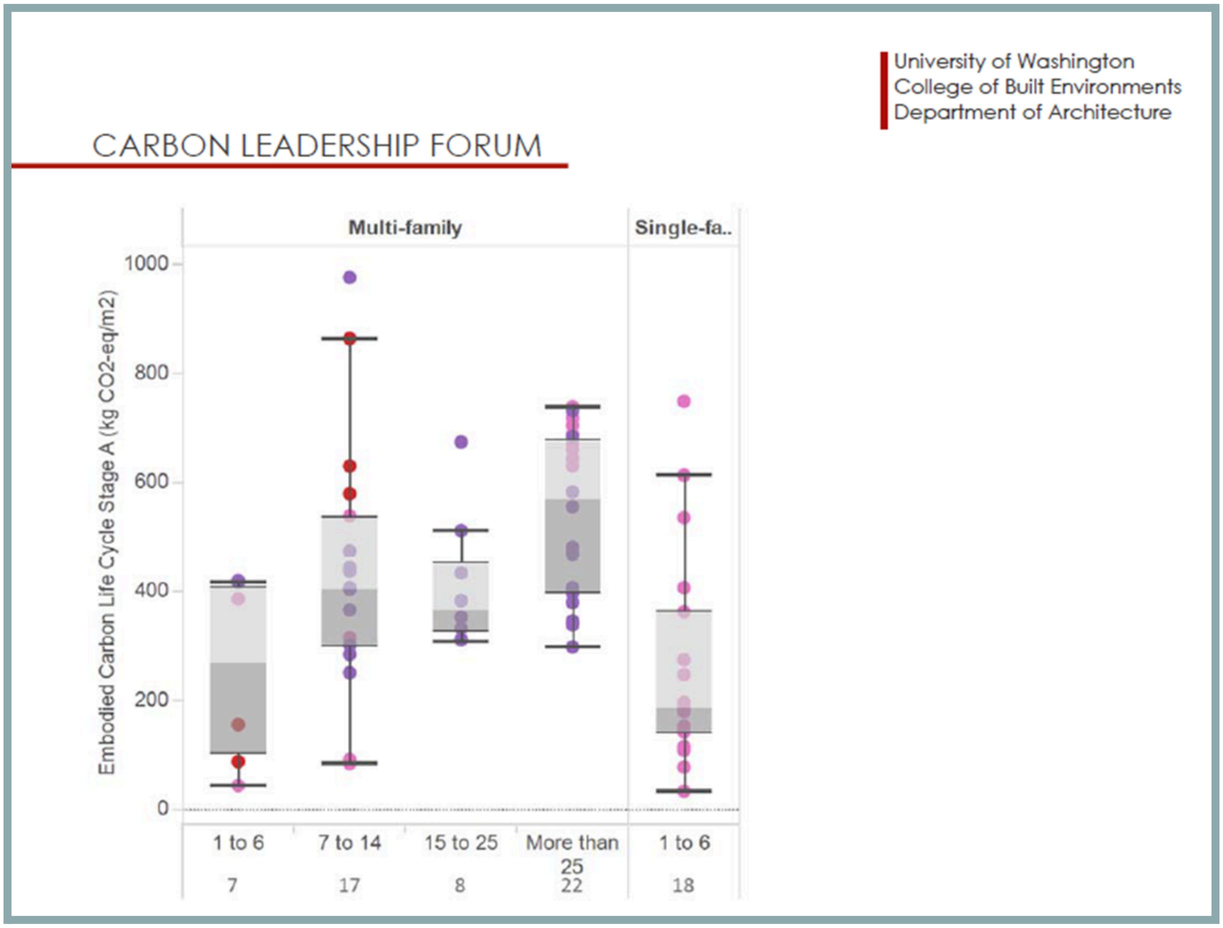

Figure 3: Embodied Carbon per m² of Residential Buildings

Per the chart above, based on multifamily buildings in CLF's database v1, the Stage A embodied carbon benchmark for the 15-25 stories range is 373 kg CO2e/m2.

Based on the mTAP team's professional experience with similar building types, including multifamily, student housing, and hotels, it is reasonable to expect that a business-as-usual multifamily building constructed in 2024 would be approximately 10% better than CLF's benchmark of 373, at 336 kg CO2e/m2.

While 336 kg CO2e/m2 would just have been a theoretical data point in our study, in the absence of a BIM-model-based Life Cycle Assessment (LCA) exercise, this number becomes the actual baseline upon which our embodied carbon reduction strategies will be evaluated.

Again, given the lack of absolute quantities coming from a BIM model, the team's professional experience and judgment suggest the following breakdown for the baseline embodied carbon of the building under analysis:

Table 1: Embodied Carbon Baseline by Category

Category	Embodied Carbon Baseline (kg CO2e/m2)
Structure (70%)	235.2
Enclosure (20%)	67.2
Interiors (10%)	33.6
Total for stages A1-A3* (100%)	336

*See below for more context on context for Whole Life Carbon stages A1-A3.

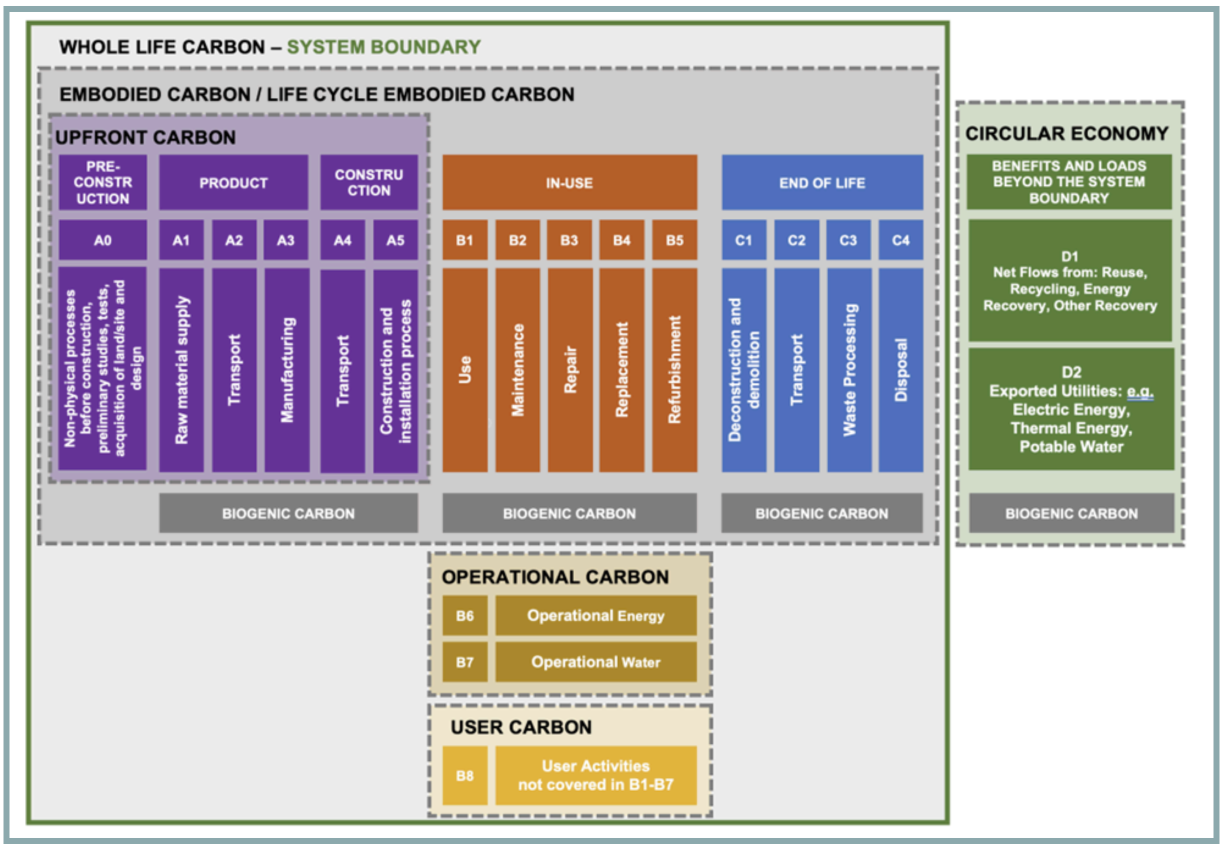

Figure 4: Whole Life Carbon Stages

Given the time availability and outsized impact of structure (70%) and enclosure (20%), interiors were left out of this study's scope. However for project teams with interiors as a greater focus, Environmental Product Declarations (EPDs) are available relatively easily and optimization should not be a challenge.

Embodied Carbon Reduction in Structure

The optimization potential for embodied carbon in structure, of which concrete can be around 75% of the opportunity, is highly dependent on design team explorations and availability of concrete mixes in a project's region. While several publications were studied in this area, availability of reliable information is scarce and subjective.

One authoritative source for embodied carbon reduction potential for concrete is the National Ready Mixed Concrete Association (NRMCA). Their publication 'The Top 10 Ways to Reduce Concrete's Carbon Footprint' has the following recommendations:

- Communicate carbon reduction goals
- Ensure good quality control assurance
- Optimize concrete design
- Specify innovative cements
- Specify supplementary cementitious materials
- Specify admixtures
- Set targets for carbon footprint
- Don't limit ingredients
- Sequester carbon dioxide in concrete
- Encourage innovation

Their conclusion reads:

> ***"There is no silver bullet to making concrete with zero carbon footprint. It can be done, but not at the volume and cost demanded by today's building owners. For some concretes (sic) on a project, the carbon reduction might be 90%, others closer to 70%, and still others around 30%. All these reductions lead to concrete with a significantly lower footprint than most concrete projects. If you choose to set carbon footprint targets, this will lead to the greatest reduction, but you cannot expect to meet these targets without implementing these top 10 ways to reduce concrete's carbon footprint."***

The same publication has a multifamily project example from Los Angeles that shows a very high potential of 24% reduction in concrete and rebar. See graphic below.

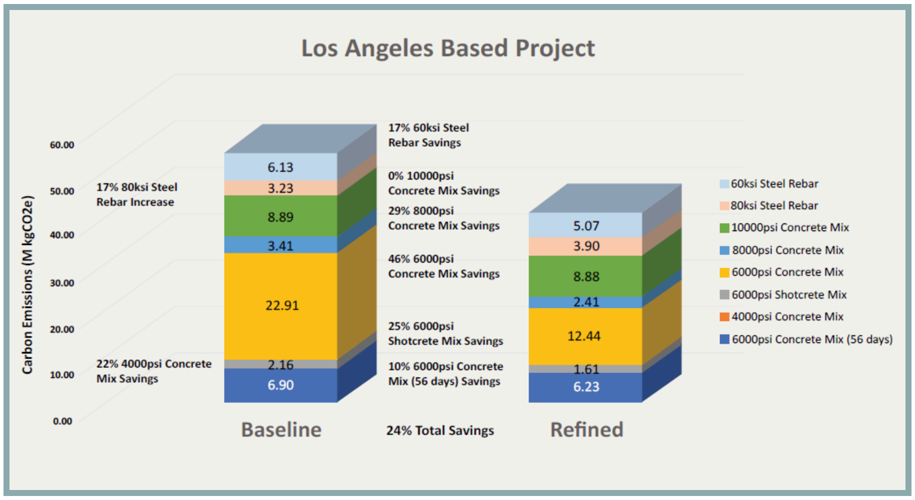

Figure 5: Example project reduction from concrete and rebar

Based on this NRMCA datapoint and other project experience, the mTAP team assumed the following good, better, and best reduction potential for structure alone.

Embodied Carbon Reduction in Windows

Comparative data on windows' embodied carbon was hard to come by, especially in the American context. However, an exhaustive study by Italian researchers titled "Embodied Energy and Embodied GWP of Windows: A Critical Review' compared a total of 116 EPDs for window products with the following characteristics:

- Glazing
  - Double Glazing
  - Triple Glazing
- Framing
  - PVC Framing
  - Aluminum Framing
  - Steel Framing
  - Wood Framing

Particularly in the area of windows with double glazing with aluminum framing, they found that the average reduction from maximum embodied carbon was at 28%. Based on this data point, the mTAP team assumed the following for good, better, and best reduction potential for windows alone.

Embodied Carbon Reduction in Structure + Windows

As we combined the good, better, and best reduction potentials of structure and windows based on the 70% and 20% weighting respectively, we arrived at the following combined reduction potential.ECI in the figure below stands for Embodied Carbon Intensity in kg CO2e/m2

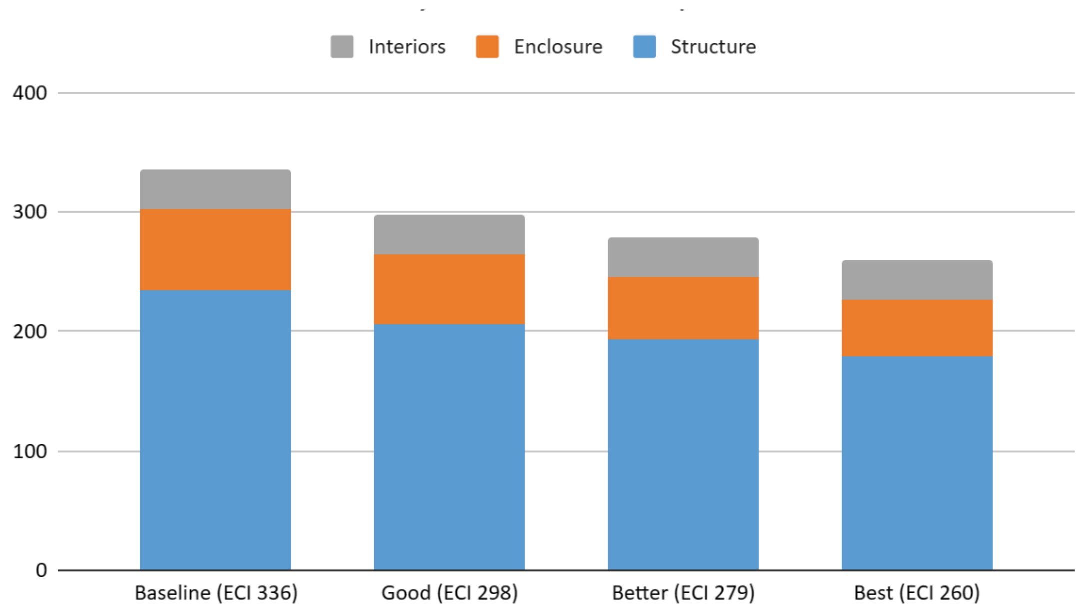

Figure 6: Embodied Carbon Intensity: Baseline vs. Improvements

Table 2: Weighted calculation of good, better, and best improvements over baseline

Reduction Category	Reduction Amount (%)			
	Baseline	Good	Better	Best
Structure Embodied Carbon Reduction (~70% of the baseline is subject to this)	0%	12%	18%	24%
Windows Embodied Carbon Reduction (~20% of the baseline is subject to this)	0%	14%	21%	28%
Combined Reduction Potential (100% of the baseline is subject to this)	0%	11%	17%	22%

Based on our project experience, the good, better, and best scenarios from the table above of 11%, 17%, and 22% embodied carbon reduction from baseline based on structure and enclosure improvements is a reasonable approximation. Any future ordinance or incentive structure that Livable Buckhead is considering for embodied carbon can take these ranges into consideration with a high level of confidence.

LEED's Incentivization of LCA and Reduction Ranges

While there are several green building certification systems out there, Leadership in Energy and Environmental Design (LEED) is the most used and institutionalized of them all.

The Building Life-Cycle Impact Reduction credit under LEED's Materials & Resources category considers a total of six impact categories including embodied carbon (aka global warming potential). After simplifying the credit language for this study's purpose, here is an outline of LEED's incentivization of embodied carbon reduction under this credit:

- Conduct an LCA (no reduction needed) - 1pt
- 5% reduction - 2pts

- 10% reduction - 3pts
- 20% reduction - 4pts

The chapter that follows will outline incentivization recommendations for Livable Buckhead based on our study's findings and LEED's approach.

Embodied Carbon Reduction Analysis (Task 2)

There are several proven materials and design techniques developers can use to reduce their project's embodied carbon. Using the LCA model and findings from Task 1, this section will explore how much the Baseline Project ("Project) could reduce its embodied carbon by modifying the material and design choices originally made by the Project developer. Like the rest of this case study, this section will focus on the structural and enclosure materials and design choices of the Project.

First, this section will outline how structural and enclosure materials would contribute to the most significant reduction in embodied carbon: structural steel and concrete and enclosure materials like gypcrete, insulation and curtain walls. Second, these materials and the techniques in which developers can reduce each of their embodied carbon will be introduced. Lastly, the cost analysis for each material or technique will be presented.

Concrete, steel and gypsum board are three construction materials that contribute significantly to a project's embodied carbon levels. Because of this, developers should focus their resources and design on techniques that reduce their use. This section will provide detail into each of these three materials and their contribution to embodied carbon.

Concrete

Concrete is a structural material used in almost every project regardless of asset type or density. Concrete has a large embodied carbon footprint because of the process in which one of its main ingredients is made - binder portland cement. Some research estimates that concrete production contributes to 5% of global carbon emissions. During the design phase of a project, it is incorporated into the structural system of a building (concrete podiums, concrete columns, concrete floors and ceilings) especially in 5+ story buildings like the Project.

There are two ways to reduce the embodied carbon footprint of a project via its concrete based structural system: reduce traditional concrete with supplementary cementitious materials (SCMs) like fly ash or blast-furnace slag or reduce the need for concrete as much as possible through efficient design.

When used in conjunction with traditional concrete, SCMs can reduce the need for 100% pure concrete foundations, columns, and/or elevator shafts. They are relatively simple to work into the concrete design of a project and do not increase the cost of a project's structural system. The downside of SCMs is that they can increase the cure time for the concrete which extends the construction time of a project; and they can affect the color of concrete which could affect the design intent of a project if the SCMs are used in visible concrete.

The more efficient and cheaper way to reduce embodied carbon within a project's structural concrete is to design it using the minimum amount of concrete needed to be structurally viable. Often, structural engineers over-design the structural system of a building - too many columns, overly conservative foundation strength, too many foundational walls, etc. Additionally, structural engineers join a project team after the architect has set the building footprint which increases the likelihood that the structural system will be inefficient. If the structural system is designed alongside the architect's concept-stage design (building footprint, unit layout, etc.), it is easier for the structural engineer to ensure that the foundation, walls and columns carry the load of the building with the minimum amount of materials. Overall, the use of SCMs and/or emphasizing more efficient structural design with consultants results in cost savings versus cost increases on a project. As much as a 10% price decrease on overall concrete costs can be expected for other residential developments similar to the proxy building studied.

Steel

Similar to concrete, steel contributes to a significant amount of embodied carbon in development projects. It is used (most times alongside concrete) to provide structural support throughout a building's system. Steel can be used as columns or bracing and framing tools within walls and ceilings. According to research, steel contributes approximately 6.6% of global greenhouse emissions - more than concrete.

There are two ways in which a project can reduce its embodied carbon footprint associated with steel: first, use recycled steel and second, design more efficiently.

Most developers and general contractors do not specify or require their projects to use North American recycled steel. The use of recycled steel on a project is dependent on the availability of recycled steel at major steel manufacturers in North America. If the supply of recycled steel decreases, most steel manufacturers will produce new steel to make up for the lack of supply. The best way to ensure that a project or building uses recycled steel (and thus, reduces its embodied carbon footprint) is to require the subcontractor to procure recycled steel as available.

The second method of reducing steel embodied carbon is to design buildings more efficiently at the early stages of the design process. Often in design, a lack of coordination between the structural engineer and architect leads to an overabundance of steel columns or framing. If the architect and engineer work together early on before either of their designs are final, then the structural engineer can reduce unnecessary steel columns and bracing. This requires developers to bring on their structural engineers as early as possible before an architect has finalized the building footprint. Overall, the use of recycled steel and/or emphasizing more efficient structural design with consultants results in no cost increases.

Enclosure Materials - Insulation and Aluminum Curtain Walls

Enclosure materials like blown-in foam insulation and aluminum curtain walls account for up to 15% of a building's embodied carbon footprint.

Foam insulation releases a significant amount of high embodied carbon blowing agents. Unfortunately, its the easiest way for buildings to meet local and international building code requirements to have continuous insulation along a building's enclosure. The easiest way to reduce the use of foam insulation is to introduce mineral wool into the design. Unlike foam insulation, mineral wool is made of natural rock materials, and it is placed in the cavity between a building's structural skeleton (steel, wood or brick) and its exterior sheathing. In addition to mineral wool's efficiency, it is also less expensive than traditional foam insulation.

Curtain walls are used to protect the outer enclosure of a building from weather. They provide no structural support for the building and can be made out of glass, steel, or aluminum. All types of curtain walls contribute to a building's embodied carbon footprint. But, aluminum curtain walls are the worst offenders because they often require aluminum shading systems (more materials). One design technique to reduce the use of aluminum curtain walls is to decrease the curtain wall depth from 7 ½ inches (typical depth) to 4 ½ inches and supplement the curtain wall with glue lam vertical mullions. The use of glum lam mullions reduces the amount of aluminum curtain wall used and it provides structural strength to the walls - which also means the amount of structural steel being used can be reduced. Overall, the use of mineral wool or small depth curtain walls has a price benefit on projects similar to the proxy building studied. In fact, developers could expect a 5% price discount using these design methods and materials.

Voluntary LCA/Embodied Carbon Program (Task 3 and 4)

The United States has relatively few examples of code-oriented embodied carbon requirements or incentives. Some jurisdictions have voluntary programs aimed at project recognition and aspirational goals. While many jurisdictions have green building requirements mostly related to building performance and energy efficiency, only a handful have true requirements specifically aimed at reducing or capping embodied carbon in the built environment. These typically fall into "performance-based" programs, which typically require a Whole Building LCA, or "prescriptive" programs, which typically cap the Global Warming Potential (GWP) of certain products. Below are highlights of the most well-known and successful programs.

- CALGreen has specific embodied carbon requirements for non-residential buildings over 100,000 SF (or schools over 50,000 SF). The requirements are met one of three ways.
  - Building Reuse: Reuse at least 45% of an existing structure and exterior. When reuse is combined with new construction, the total addition area using this pathway is limited to double the area of the existing structure.
  - Performance: Complete a whole building lifecycle assessment (WBLCA) demonstrating 10% lower embodied carbon emission than a baseline project design.
  - Prescriptive: Document environmental product declarations (EPDs) for listed materials (steel, glass, mineral wool, concrete) that are on average lower than a specified threshold
- Denver Green Code
  - Specifies maximum GWP for concrete and steel based on strength.
- Portland Low Carbon Concrete Program
  - Maximum GWP for concrete only
  - Standard looks at EPDs for concrete specified and caps GWP values based on strength.
  - Portland also has rules that encourage reuse of buildings and materials and deconstruction over demolition.

In pursuit of becoming "Georgia's greenest community" it is recommended that Livable Buckhead pursue, at least initially, a voluntary embodied carbon reduction program to encourage awareness and the construction of sustainable buildings within its district. It is also recommended that Livable Buckhead pursue a program that is performance-based, since that is the most accurate, effective, and resilient to changes within the industry. The following three-step, high-level process is recommended for implementation.

- **Phase 1: introduce a voluntary reporting program for projects.**
  - Encourage new-build projects to voluntarily report Whole Building Life Cycle Assessment results with Livable Buckhead.
  - Encourage the LCA methodology to comply with "LEED v4 Building life-cycle impact reduction" "Option 4 whole-building life-cycle assessment" (a majority of buildings obtaining LEED certification would already meet this requirement).
  - Incentives for reporting would be recognition and collaboration with Livable Buckhead.
- **Phase 2a: Incentive-based voluntary LCA study**

- Use LEED v4 scoring standards to allow projects meeting LEED v4 “Building life-cycle impact reduction” to obtain development incentives.
  - LEED v4 requires projects to produce LCA studies that show the following.
    - The LCA must be calculated for six listed environmental impact categories (global warming potential; depletion of the stratospheric ozone layer; acidification of land and water sources; eutrophication; formation of tropospheric ozone; and depletion of nonrenewable energy resources) with three of them, including global warming potential, demonstrating at minimum a **10 percent reduction**.
    - No category of impacts may increase by more than 5 percent, compared to the baseline design.
  - It is recommended to require that projects meeting the requirement specifically show embodied upfront carbon reduction (A0-A5) of at least 10% over baseline.
  - Incentives for this requirement could be centered around the following areas in SPI-9 or SPI-12 code.
    - Height/density bonus.
    - Open space reduction.
  - “Block area” bonus leading to height/density bonus.
- **Phase 2b: Required LCA study with optional incentive thresholds.**
  - Require an LCA for all projects over a certain threshold or of a certain type.
  - All qualifying projects must present LCA findings to Livable Buckhead.
  - Submitted LCAs do not have to show reductions or meet certain requirements.
  - Projects with LCAs meeting Phase 2a requirements are still eligible for above-referenced bonuses.
- **Phase 3: Required LCA study and performance thresholds with optional incentive thresholds.**
  - Use a system similar to Phase 2b, but in Phase 3 the LCA performance standards in Phase 2a become required for all projects.
  - It is recommended to limit the enforcement of the requirement to buildings of a certain type/size (e.g. affordable housing or projects <50,000 SF exempt from the requirement).
  - A tiered system could be used to reward higher performing projects such as the following.
    - All projects required to submit LCAs with 10% embodied carbon reduction and 10% reduction across all categories.
    - Projects meeting **20% embodied carbon reduction** would now be eligible for incentives previously granted to projects meeting 10% embodied carbon reduction under Phase 2.

Sources and Additional Information:

Embodied Carbon Reduction: Interiors Resources

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Benchmarking and best practice resources

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- https://www.nrmca.org/wp-content/uploads/2022/07/Top10WaysReduceConcreteCarbonFootprint.pdf
- Embodied Energy and Embodied GWP of Windows: A Critical Review: https://www.mdpi.com/1996-1073/14/13/3788

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