Thornton Tomasetti

Embodied Carbon Action Plan

Prepared for

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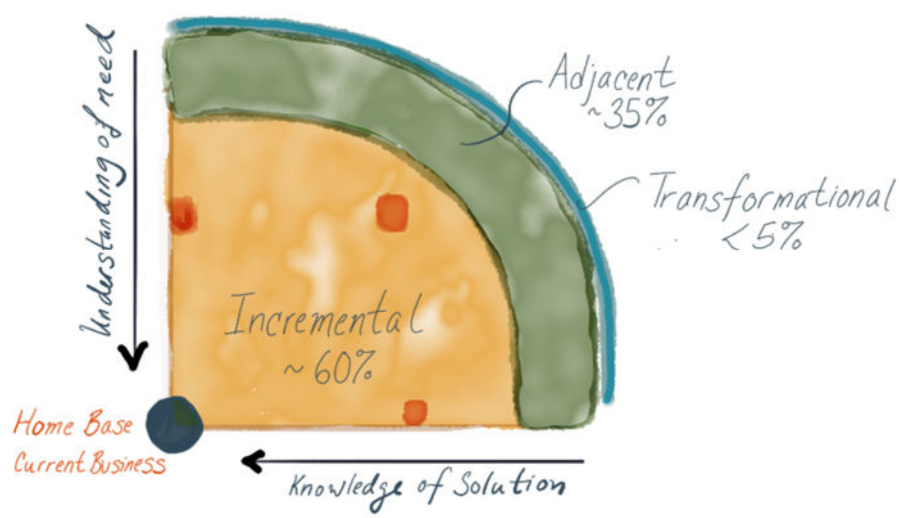
Executive Summary

Thornton Tomasetti is an employee-owned organization of 1,500 engineers, scientists, architects, and other professionals collaborating from more than 50 offices worldwide. We're committed to being a sustainable and enduring organization and the global driver of change and innovation in our industry. Here are some of the ways we make lasting contributions to our environment and our communities:

- Promoting and applying creative means to reduce carbon in our projects.
- Committing to achieve carbon neutral business operations.
- Influencing policies and practices for sustainability and resilience in our industry and communities.

Because the building sector generates up to 40 percent of global carbon dioxide emissions, we have a responsibility to be part of the solution to this urgent problem. Our role in combating climate change goes beyond sustainability consulting: Our structural engineers calculate and help reduce embodied carbon – the carbon footprint of building materials – in the buildings we design. We helped conceive and develop the SE 2050 Challenge, which states, "All structural engineers shall understand, reduce, and ultimately eliminate embodied carbon in their projects by 2050." We strongly uphold our responsibility – as defined by the engineering code of ethics for the safety, health and welfare of the public – to help reduce embodied carbon in the built environment. This Embodied Carbon Action Plan (ECAP) details our strategy for meeting the ambitious goals of the SE 2050 Commitment.

We approach innovation through a framework of incremental, adjacent, and transformational solutions. Through this lens, we'll use education, reporting, embodied carbon reduction strategies, and advocacy to help meet our goals.



Strategies for achieving these goals fall into the following categories:

- Incremental
  - Design improvements and optimizations such as ideal layouts, systems selection, and material volume reductions.
  - Improved concrete mix designs, use of mass timber, and modular construction.
- Adjacent
  - Adaptive reuse, structural health monitoring, material production improvements, and use of carbon-sequestering materials.
  - Changes in concrete and structural steel production.
- Transformational
  - Influencing related industries to transform building delivery, including decarbonization of the electrical grid and transportation systems.

We have established a number of targets that we'll track and re-evaluate annually:

- Education
  - By the end of 2021, we gave more than six internal presentations to educate all Thornton Tomasetti staff on our embodied carbon goals, strategies, and progress.
  - In 2022, we created an in-depth workflow to assist engineers in calculating embodied carbon on their projects.
  - By the end of Q1 2023, we provided embodied carbon education and training to 100% of our structural engineers. We provided them with training and resources to know what embodied carbon reduction capabilities we have and to understand how to deliver them to clients and deploy them on their projects.
- Reporting
  - As of May 2023, we have submitted a total of 42 projects to the SE 2050 database.
  - By the end of 2023, we will have submitted a total of 100 projects to the SE 2050 database.
  - By the end of 2030, we'll include 90 percent of all new projects larger than 100,000 gross square feet in the SE 2050 database.
- Embodied Carbon Reduction Strategies
  - In 2022 we developed Thornton Tomasetti standard embodied carbon specifications for deployment of timber alongside concrete and steel (already deployed),and created an in-house presentation encouraging their use.
  - By June 2023 we'll perform an analysis of our historical data to identify and set ambitious targets for the highest-impact projects (e.g. large concrete projects, stadiums, and tall buildings).
  - By the end of 2025, we'll achieve a 25 percent reduction in average embodied carbon for structural frames from our 2019 benchmark.
  - By the end of 2030, we'll achieve a 40 percent reduction in average embodied carbon for structural frames from our 2019 benchmark.
- Advocacy
  - Historically, each year we have provided more than twelve external presentations related to our embodied carbon goals, strategies, and progress to clients, peers and other organizations.
  - We will continue to provide at least twelve external presentations and training related to embodied carbon each year.
  - By the end of 2025, we'll engage with three adjacent industries or entities that, while not directly affecting design and construction strategies, are critical to helping solve the problem of eliminating embodied carbon.

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1.0 Education

Sharing knowledge about sustainable technologies and strategies – especially in the emerging area of embodied carbon – is vital to participating in integrated design processes and contributing to sustainable project solutions. Since many structural engineers are unfamiliar with embodied carbon calculation for projects, and since they are key players in embodied carbon reduction, it's crucial that they acquire a working knowledge of the subject. We approach educational materials with the understanding that technical staff may be at different levels of knowledge. We'll share resources and knowledge primarily through our Embodied Carbon Community of Practice (CoP).

By 2030, we envision a future in which all engineers understand the impacts of materials. We hope to see our staff completing embodied carbon takeoffs and tracking this data over the lives of projects. We've already seen an encouraging increase in requests for early-stage studies addressing embodied carbon. Continuously increasing engagement throughout this critical decade will help us meet our carbon-reduction targets.

1.1 Goals

Refer to the executive summary above.

1.2 Strategies

1.2.1 Company Engagement

Thornton Tomasetti launched its Embodied Carbon Community of Practice (CoP) in early 2020 as a response to growing interest and urgency in addressing embodied carbon at the firm level. Communities of Practice cultivate innovation by encouraging employees with similar interests and expertise to collaborate, share knowledge, and develop best practices. The Embodied Carbon CoP has the following six goals:

- Firmwide understanding of what embodied carbon is and why its reduction is important.
- Improved expertise in the reduction of embodied carbon in projects.
- Increased collaboration across practices to cultivate more sustainable project outcomes.
- Formulation of standards that guide our design process.
- Development of new and improved tools that accelerate embodied carbon reduction.
- Industry leadership in embodied carbon reduction.

We accomplish these goals through five working groups:

- The Education and Resources working group maintains an embodied carbon resource and presentation library, develops case studies of embodied carbon projects, and offers general education to our staff and clients.
- The Materials and Specifications working group develops specifications for concrete, steel, and timber; advocates to material suppliers for Environmental Product Declarations (EPDs); and provides research on, and innovation in, local carbon and carbon-sequestering building materials.
- The Assessment and Methodology working group advances the firm's methodology for embodied carbon assessments, promotes understanding of the best available knowledge and resources in the industry, and participates in an annual embodied carbon count for our projects.

- The Industry and Market Leadership working group informs the Community of Practice of industry efforts and opportunities for involvement, closely monitors and follows industry trends, and garners participation in industry-wide embodied carbon initiatives and organizations.
- The Transportation working group engages members of our transportation practice who design bridges and other transportation infrastructure. This working group will report on initiatives and advances in the transportation sector, allowing for cross-practice collaboration to make larger impacts on embodied carbon reductions.

1.2.2 Embodied Carbon Reduction Champion

In accordance with SE 2050 Commitment requirements, Thornton Tomasetti has selected an Embodied Carbon Reduction Champion. Senior Associate Patrick Kenny, of our Boston, MA office, who will facilitate and advance our Embodied Carbon Action Plan and reduction efforts. Patrick currently serves as the co-leader of our Materials and Specifications working group.

Patrick will initiate and organize our embodied carbon reduction efforts by communicating with individuals from various offices, as an initial resource and will help direct questions to the Community of Practice and the Embodied Carbon Reduction Champion. He will also assist in the collection of embodied carbon data.

2.0 Reporting

For the past 12 years, Thornton Tomasetti has measured the embodied carbon in our structural projects and contributed to industry research for embodied carbon benchmarks. Each year, we conduct an embodied carbon audit on projects that have reached key milestones (schematic design, design development, or construction documents) in the previous calendar year. Well before 2050, we expect that most of our projects will help populate the SE 2050 database, along with data from other firms, to set and track data-driven targets in order to meet 2050 reduction goals.

2.1 Goals

Refer to the executive summary above.

2.2 Strategies

2.2.1 A History of Data Collection

To measure the embodied carbon of our projects over the past 12 years, we collect metadata such as location, use type, construction type and material type, including strength, mix design, etc. We also collect material volume quantities for all structural elements on each project. Since its inception, this practice has produced data on more than 600 Thornton Tomasetti projects. We summarized this data in an embodied carbon measurement study published in 2019, which reported these significant findings:

- The largest driver of embodied carbon reduction in structures over the previous seven years had been a market-driven trend toward the increased use of recycled steel and supplementary cementitious materials such as fly ash.
- LEED-certified buildings show slightly lower embodied carbon levels than non-LEED buildings.
- All building types except for aviation, sports, and mission critical facilities hold the highest proportion of embodied carbon in their floor slabs. Alternative, low-carbon slabs such as hollow-core, voided slabs, or timber floors may reduce embodied carbon. In aviation and mission critical

structures, the foundations hold the highest levels of embodied carbon, while in sports structures; embodied carbon is concentrated primarily in the structural framing.

- Mission critical structures such as hospitals and data centers have the highest overall levels of embodied carbon of any asset category.
- Tall buildings hold the highest proportion of embodied carbon in their columns rather than in their foundations.

We save all of Thornton Tomasetti's project metadata, material quantities and carbon quantities in a centralized database. This database has been instrumental in helping Thornton Tomasetti develop our own building and materials use benchmarks. The data has also been widely shared throughout industry and academia, forming the backbone of many industry-wide benchmarking exercises, such as the Carbon Leadership Forum's Embodied Carbon Benchmark Study.

2.2.2 Beacon – An Embodied Carbon Calculator for All

Recognizing the important leadership and collaborative role that Thornton Tomasetti plays in realizing a zero-carbon future, we released Beacon, our open-source embodied carbon calculator tool, in January 2020. Free to download and use, Beacon is user-friendly, quick to implement in Revit, and designed with structural engineers in mind.

This Revit plugin quantifies embodied carbon by applying carbon coefficients to each material type, based on our collected materials metadata. Assessments have included life-cycle stages A1-A3 (raw material extraction and processing, transport to the manufacturer, and manufacturing).

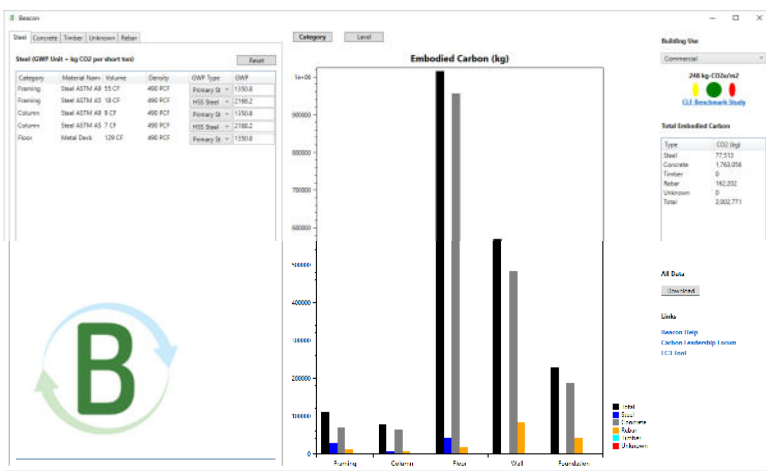

Figure 1: Beacon Interface

2.2.3 Data Collection Methodology

Beacon can categorize material quantities for each family type in a model – framing, columns, floors, walls, and foundations – and separate structural elements by material type: steel, concrete, rebar, and timber. It also lets you specify carbon coefficients for each material type. We source these from industry, manufacturer, or product-specific EPDs.

For broad use, we pre-populated Beacon with U.S. industry average carbon coefficients from the following association/council EPDs:

- Concrete – National Ready Mix Concrete Association

- Steel – Metal Building Manufacturers Association
- Timber – American Timber Council
- Reinforcement – Gerdau

Thornton Tomasetti's offices are encouraged to use manufacturer-specific EPDs, then regionally specific EPDs, before applying U.S. industry-standard EPD carbon-coefficient values. EC3 is the most common source of this information. The background data Beacon uses to calculate embodied carbon can be downloaded as an Excel file to allow for further examination and population into our central embodied carbon database.

By default, Beacon and EPD data incorporate only LCA stages A1-A3. Though this is a good starting point, best practice would be to include A4-A5 (transport to the building site and installation) as well, at a minimum. Recognizing this as an opportunity for incremental improvement and development of the tool and calculation process, we're reviewing ways to include this scope within Beacon. We're also in the process of incorporating embodied carbon measurement into our BIM standards to ensure quality and consistency in our data.

2.2.4 Industry and Academic Collaboration

Thornton Tomasetti recognizes the importance of collaboration with our trusted partners, industry colleagues, and academics. In late 2020, we identified an opportunity with the University of Washington for a research collaboration around our embodied carbon data. We packaged and anonymized the data for student consumption. Students formed teams and proposed research questions based on a list of topics solicited from members of our Embodied Carbon CoP:

- Understand and identify trends in Thornton Tomasetti's project performance based on LEED achievement levels.
- Understand how building size (height, area, etc.) affects embodied carbon in projects.
- Categorize projects by attributes such as market sector, material type or structural system, or presence of recycled materials.

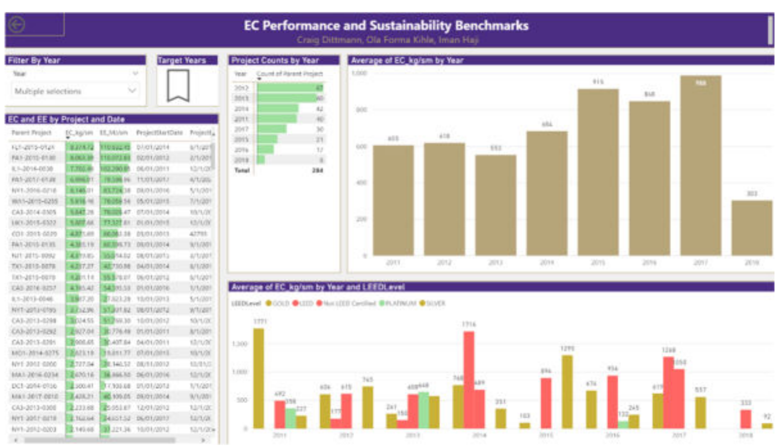

Figure 2: Dashboard Displaying EC Statistics

3.0 Embodied Carbon Reduction Strategies

Embodied carbon reduction is the fundamental purpose behind this Embodied Carbon Action Plan – and the overarching objective of the SE 2050 Commitment. Without first making progress on our goals for education and data reporting, setting goals for reduction based on rigorous statistics or grounded in data becomes difficult. Until the SE 2050 database sets industry-wide benchmarks we recognize that every project has potential to reduce embodied carbon. The team should set a baseline design that considers business as usual. Next, we should explore strategies to quantify relative reductions from this baseline.

3.1 Goals

Refer to the executive summary above.

3.2 Strategies

At the highest level, design teams should consider new projects or developments with the following principles in mind:

- Build collaboratively – work with other designers and suppliers to achieve the following principles.
- Build wiser – understand the impacts of our design decisions through calculation and measurement and communicate them.
- Build lighter – consider lighter weight systems, such as timber, to reduce demands on columns and foundations.
- Build with low carbon materials – consider procurement and the source of materials and their environmental footprint.
- Build for the future – begin to consider building end of life and integrate design for deconstruction.

With a project-specific embodied carbon framework in place, the team can engage members of the supply chain to adopt this set of design goals during procurement. The structure itself represents a substantial portion of a building's total embodied carbon. Structures can be optimized through lean design, thereby reducing the volume of material used and the demand on foundations.

3.2.1 Building Geometry

Project massing, grid spacing, locations of the cores, and structural depth can all have significant impacts on material volumes. Does the shape respond to the local environment and design criteria (e.g., wind)? At the concept stage, these choices should be refined to ensure the building is working efficiently. Accordingly, materials comparisons and structural-system bay studies are critical at the concept stage to determine schemes with the lowest embodied carbon. This could include optimizing the column grid to decrease slab thicknesses and beam depths.

As part of these early studies, identifying the most significant embodied carbon contributors in the structure and focusing strategies for reductions is key to success. Since floor slabs typically have the highest contribution, prioritizing their analysis over that of lower embodied carbon contributors will have a greater impact. Reducing spans and overhangs can also significantly lower material volumes. Consider incorporating columns into standardized layouts.

Due to the significant concrete volumes many projects require, another area of focus is retaining elements and basement structures. Minimizing excavation can save embodied carbon and reduce project costs. Lowering structural weight by incorporating voids wherever possible is another potentially effective strategy.

3.2.2 Materials Strategies

Concrete

Significant embodied carbon savings can be achieved through the concrete materials specification and procurement process. We recommend reviewing mix design alternatives with a life-cycle assessment expert. In general, the production of cement (a primary component of concrete) produces large quantities of global emissions. So limiting cement is an effective approach to limiting embodied carbon.

Specifications are critical for maximizing reductions. If possible, use performance-based, low-carbon concrete specifications. Though it may seem counterintuitive, do not over-specify cement replacement. This can limit your supplier's options. Instead, contact concrete suppliers early and work with them to ensure they can meet specification targets.

Over 50 percent cement replacement can be achieved in superstructure elements. However, substitutes can have an impact on rate of strength gain. The structural engineer must be well aware of the mix designs and coordinate with the general contractor's schedule for elements like post-tensioned floors that require early strength gain. For the same reason, substructure elements can often have even higher cement replacement, as these elements are not necessarily time-critical for strength gain. Cement replacement material may vary by location and batch plant capabilities. Cement replacement potential can also be expanded by specifying longer, early-age-strength times, from 28 to 56 days.

The cement content of a concrete mix varies with concrete strength. Engineers can use this knowledge to optimize the design of concrete structures for embodied carbon. In some cases, a higher strength (and higher embodied carbon) mix reduces the total volume of concrete required enough to produce the structure with the lowest carbon footprint. In other cases, a higher volume of low strength concrete will be optimal. Our goal is to measure and design for embodied carbon just as we do for cost and structural performance.

Though aggregate adds a smaller portion of the embodied carbon contribution, reductions are still possible. Designers can specify recycled aggregate, although it is important to verify the origin of these products to confirm that they are really lower in embodied carbon.

Steel

Steel sourced from electric arc furnaces (EAFs) has lower embodied carbon than steel from blast oxygen furnaces (BOF), typically around 50 percent less in the United States. This is mainly because EAFs tend to use much more recycled content. 100 percent of U.S.-produced hot-rolled steel standard wide flange shapes are produced using EAFs. However, cold-formed steel, including plates and HSS, makes up a higher percentage of BOF-produced steel. Steel industry experts generally agree that sourcing steel from mills that use EAFs results in lower embodied carbon than using steel from a mill that uses BOFs, even if not all the steel at the mill using EAFs is manufactured using electrical energy. Understanding the component parts of the steel manufacturing process is integral to devising effective approaches to reducing the embodied carbon of steel projects.

The engineer should engage the fabricator early in the design process to promote the use of simpler connections and detailing. It is recommended that engineers specify EAF mills or minimum recycled content percentages, where possible. We'll consider designing for reuse. For example, using bolted connections instead of welded ones allows steel members to be disassembled and used again.

Timber

Timber is an important material choice for carbon reduction, as it is the only one of the top three building materials that naturally stores carbon. Consider using timber products such as CLT wherever possible, but keep in mind that they must be used correctly. There is no point in removing resources from nature's great carbon sinks, only to discard them to decay or burn, producing emissions later. Hence, it's important that products originate from a sustainably sourced forest (e.g., FSC certified) and that we seek reuse. Where possible, avoid placing a concrete screed topping on CLT deck, as this increases the carbon footprint and limits the potential for material reuse.

A mass-timber frame is lighter than its steel and concrete counterparts, which can result in lower gravity loads. However, in some cases, it can produce higher uplift forces due to lateral loads. Foundations and substructure need to be factored into the overall embodied carbon analysis.

3.2.3 Specifications

Thornton Tomasetti is developing performance-based specifications for structural projects across the company that address embodied carbon – particularly, the development of concrete, steel, and timber specifications. We've revised our standard structural specifications to omit language that restricts embodied carbon savings opportunities. For example, we've updated our cast-in-place concrete specification to remove limits on fly ash (and other cement replacements) in interior concrete, while adding requirements for blended hydraulic cements and carbon-dioxide mineralization. These specifications performance-based rather than prescriptive and aim toward a total project embodied carbon reduction target instead of prescribing a reduction for every mix.

4.0 Advocacy

Structural engineers don't have complete control over how projects are designed and built – the design process includes a number of stakeholders and decision makers, often with competing objectives and interests. This is a fundamental challenge for the SE 2050 Commitment. Educating and engaging our clients and collaborators is important to realizing the lowest carbon in our projects. By 2050, we envision an AEC industry that is aligned in establishing goals to reduce embodied carbon and create a built environment comprising net-zero buildings.

Thornton Tomasetti has been proactively guiding our clients in the reduction of embodied carbon in a number of ways:

- Providing corporate-level client and developer education as they create frameworks for net-zero emissions and alerting them to the importance of including embodied carbon in their net-zero targets.
- Offering low-carbon specification and procurement strategies.
- Developing project-specific and element-specific embodied carbon targets.
- Prioritizing low-carbon design efficiency measures and ensuring that clients understand carbon offsetting and the associated costs.
- Establishing embodied carbon company targets.

Moving forward, we'll declare our SE 2050 Commitment on project proposals where appropriate, and we'll discuss setting embodied carbon targets for each project.

4.1 Goals

Refer to the executive summary above.

4.2 Strategies

4.2.1 Communicating with Clients and Partners

Incorporating embodied carbon mitigation strategies into a project requires communication and coordination throughout the duration of the project. Success begins before the project starts – communicating with the owner on RFP sustainability goals. Addressing embodied carbon in the built environment is often deeply tied to organizational global carbon-reduction commitments. Referring to embodied carbon as "Scope 3 Emissions" can ensure you're speaking the same language as your client. When pursuing projects, we seek to partner with AEC firms who share our motivation to address embodied carbon in design.

Once a project starts, the concept design conversation with the owner, architect, and sustainability consultant should focus on setting targets for reduction. Benchmarking against similar buildings the team or owner has built, or against industry data, is important for setting goals. Once you have set your goals for reduction, your team should evaluate the project's massing and structural systems.

The structural engineer's expertise is critical in the early stages of projects for optimizing elements such as slabs, framing systems, and foundations for low embodied carbon. During design development, the internal engineering team should consider concrete strengths and individual member designs – and invite suppliers to participate in the conversation if possible. During construction document development and bidding, the general contractor and local suppliers should be informed of the project's embodied carbon goals and specifications. Finally, during construction administration, the general contractor, supplier and owner should be involved in EPD review, reporting, and benchmarking.

4.2.2 Policy Change and Adjacent Industries

The real root of the embodied carbon issue isn't in how we design and procure our materials – it's in the fossil fuels used to extract and transform raw materials into products, transport them, power our buildings and process the materials at the end of their lives. As designers, we can make decisions about products available on the market. We can incentivize manufacturers to invest in lower-carbon technologies. But without a global commitment to decarbonization and divestment from fossil fuels, the goal of zero embodied carbon emissions cannot be achieved.

As adopters of the SE 2050 Commitment, we have a responsibility not only to advocate within the AEC industry – but also to lend our voice to supporting renewable energy policy. Substantial global investment in clean electricity infrastructure and technology will be critical to achieving low embodied carbon building design. AEC industry groups and organizations must support local, regional, and national policies that promote decarbonization.

Thornton Tomasetti will perform the following activities as part of the SE 2050 Commitment:

1. Look for opportunities to engage in local, regional, and national policy developments that aim to reduce embodied carbon.

2. Expand our decarbonization services to include adjacencies with embodied carbon reductions.
3. Revisit this Embodied Carbon Action Plan annually and revise it as needed, based on the newest information available on embodied carbon reduction.