LOW-CARBON CONCRETE

IMPLEMENTATION STRATEGY

MAGNUSSON KLEMENCIC ASSOCIATES

Structural + Civil Engineers

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1. INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

To meet global emissions targets and curb the negative effects of climate change, ambitious sustainability goals must be set and exceeded in the design of the buildings we create. Given the large carbon footprint of the built environment, a unified approach to the environmental performance of structural materials can produce a substantial positive impact.

Each individual project presents an opportunity to optimize the environmental performance of the structural materials and doing so will produce positive sustainability outcomes for the project and the industry at large.

This guide aims to illustrate that through proper communication and planning, ambitious environmental outcomes can be achieved. These positive environmental outcomes can often be accompanied by cost benefits to the project.

This guide is not attempting to address all parts of a project's low-carbon potential. It is also not attempting to answer the early project decisions of what structural system or materials to consider, or if the building should be an adaptive re-use or new construction project. Those decisions should happen before this guide comes into use.

While the specification and procurement ideas behind this guide can be adopted to other materials and systems, this guide is a narrow focus on two of the biggest embodied carbon point sources within a typical Type 1 non-combustible construction project: the concrete and the steel structural frame.

1.2 OBJECTIVES

The objectives of this guide are as follows:

- Illustrate the environmental impact of structural materials.
- Provide sample language for contract and bid documents.
- Encourage adoption of this approach to specifying and bidding sustainable structural materials.
- Unify the nature of requests to the structural material suppliers.

2. LIFE-CYCLE DECISION MAKING – EMBODIED CARBON

2.1 INTRODUCTION TO EMBODIED CARBON

Greenhouse gases are commonly associated with climate change. These gases include a variety of substances, such as carbon dioxide, nitrous oxide, and methane, but because carbon dioxide is the most common among them, "carbon" has become the shorthand vernacular used worldwide. The metric used to measure carbon and its effect on climate change is called Global Warming Potential (GWP), reported in kilograms of carbon dioxide equivalent, or "kg CO2eq."

Buildings and infrastructure have a significant impact on global carbon emissions. The cumulative impact of the processes, materials, and products that go into creating these structures can be estimated by identifying the individual carbon impact of each.

"Embodied carbon" is the term for the carbon emissions from all aspects of the project's life-cycle (material production, material transportation, etc.) unrelated to its operations. The structural materials of a project are often the largest contributors to the project's overall embodied carbon. Procurement of these materials, and careful selection between various material suppliers, is one of the most effective methods to control and ultimately reduce their embodied carbon impact.

2.2 ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)

Today, the best source of embodied carbon data is an Environmental Product Declaration (EPD). For a given material, EPDs report data for these (6) environmental impact categories:

- Global Warming Potential (GWP): in units of kg CO2eq/kg.
- Ozone Depletion Potential (ODP): in units of kg CFC-11/kg.
- Acidification Potential (AP): in units of kg SO2/kg.
- Eutrophication Potential (EP): in units of kg N/kg.
- Smog Formation Potential (SFP): in units of kg O3/kg.
- Non-Renewable Energy Consumption (NREC): in units of MJ.

There are various types of EPDs available. The most specific type of EPD, and therefore the most desirable, is referred to as a product-specific, Type III EPD. This represents an EPD for a specific material from a specific manufacturer that has been third-party verified. Although EPDs that are product-specific but not third-party verified may be available, they are not desirable.

When an EPD has been created for a generic material that is representative of an average manufacturer, it is referred to as an industry-average EPD. The National Ready Mix Concrete Association (NRMCA), American Institute of Steel Construction (AISC), Concrete Reinforcing Steel Institute (CRSI), and American Wood Council (AWC) have all created industry-average EPDs for their respective materials.

By collecting EPDs for structural materials and setting early goals about the environmental performance of those materials, carbon reductions below a baseline may be achieved. The Embodied Carbon in Construction Calculator (EC3) Tool provides an extensive and ever-growing database of EPDs, both product-specific and industry-average. Additionally, the EC3 Tool provides guidance for setting project baselines and targets. Baselines should be regional and material-specific. Targets for reduction should be ambitious enough to exceed and advance the performance standard of the region.

2.3 LIFE-CYCLE ANALYIS OVERVIEW

To organize and track a project's impact, its life span can be broken out into different stages. Each stage represents a different timeframe in a project's life-cycle, from beginning to end, and is associated with varying levels of carbon emissions. These stages, identified below, are described in detail in the international standards EN 15978 and ISO 14040.

- Product Stage: raw material extraction, transportation, and manufacture into building materials
- Construction Stage: transportation of building components and their construction or installation
- Embodied Use Stage: upkeep of building components, including maintenance and replacement
- Operational Use Stage: energy and water consumption due to building operations
- End-of-Life Stage: demolition of building and disposal of waste

Figure 2.3.1 – Whole-Building Life-Cycle (Source: MKA)

2.4 IMPACT OF THE PRODUCT STAGE

The total embodied carbon in a project accumulates throughout the life-cycle stages, and decisions at each stage impact the final project outcome. The Product Stage, shown in modules A1-A3 of Figure 2.3.1, occurs prior to the start of construction and includes the extraction of raw materials, their transportation to a manufacturing site, and their manufacture into project components.

Although results vary by project type, this is often the most impactful stage of a project's life-cycle, as illustrated in Figure 2.4.1. Within the Product Stage, the effect of each material depends on the material quantities of the particular project, as well as the environmental performance of the selected materials. Focusing attention on the Product Stage has a large impact on the total embodied carbon of a project.

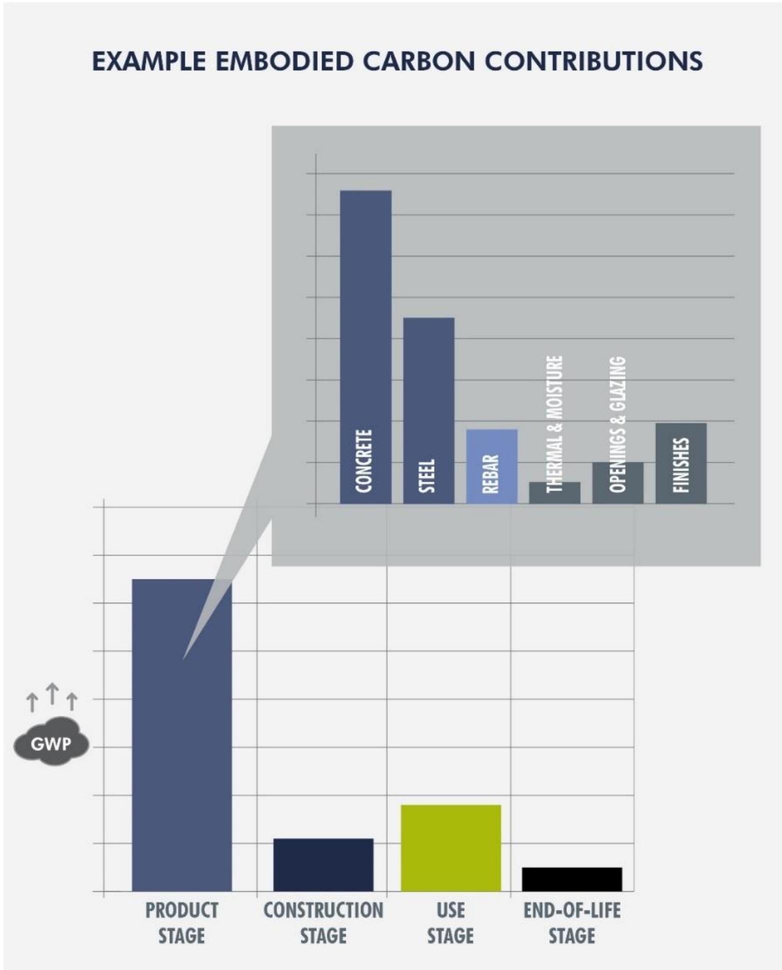

Figure 2.4.1 – Embodied Carbon Impacts from Sample Low-Rise Building (Source: MKA)

EPDs also make the Product Stage the simplest to quantify. Because impacts from the Product Stage occur prior to building construction, this stage requires less speculation once building components have been determined and suppliers for these have been chosen.

2.5 IMPACT OF CONCRETE

Concrete deserves attention both because it embodies a considerable amount of carbon and because the reduction of that embodied carbon requires coordination and planning. The embodied carbon in concrete is largely due to the energy consumed in the manufacturing of cement and the off-gassing of CO2 that comes from the resulting chemical reaction. Cement replacements therefore present a significant opportunity for carbon reduction. Because adjustments to mix designs impact both the concrete performance and the environmental result, coordination with concrete suppliers during early design phases is crucial. Concrete suppliers need time to test mix designs, stock materials, and fully incorporate carbon reduction strategies into their operations.

Beyond concrete mix design considerations, strategies for reducing the total carbon impact from concrete that should be considered typically include:

- Structural design optimization, making sure materials and systems do more than one job whenever possible (two for one design choices).
- Utilize Performance-Based Concrete Specifications to allow for supplier flexibility in mix designs.
- Reduce concrete strength where possible to lower cement content in mix designs.
- Relax concrete date of strength requirements as much as construction schedule will allow to lower cement content in mix designs.
- Consider formwork systems and sequencing which limit the requirement of early strength-gains to only critical locations. This will lead to lower cement content in mix designs.
- Compare EPDs from material suppliers to inform supplier selection.

2.6 GLOBAL WARMING POTENTIAL BASELINES AND TARGETS

As discussed in Section 2.2, numerical targets for EPD impact categories should be ambitious enough to exceed and advance the performance standard of the region.

Structural engineers can work together with the General Contractor to ensure that benchmarks are regionally suitable. If GWP benchmarks are too high, then the project has not accomplished anything the material suppliers were not already doing. If GWP benchmarks are too low, then the quality of the material can suffer.

Achievement related to the GWP baselines established through this process will be a primary focus when considering subcontractor bids. It is recommended that this baseline be understood by the design and construction teams, but not directly published in the specifications. Including GWP maximums in specification language is not recommended. A competitive bidding process should drive towards the lowest GWP suppliers can competitively provide, which may be lower than the pre-established baselines.

3. TIMELINE

It is recommended that the stakeholders (Owner, Design Team, Contractor) collaboratively populate a Low-Carbon Concrete Responsibility Timeline which establishes action items for various stakeholders at various milestones in the project.

Important milestones include (but are certainly not limited to):

- Optimize project layout and structural design materials.
- Synchronize approach across Specifications, General Notes, and Bid Documents.
- Select material suppliers based on project-determined combination of price and GWP.
- Reconcile estimated quantities and GWP with as-built quantities and GWP.

4. IMPLEMENTATION & REALIZATION OF LOW-CARBON STRUCTURE

4.1 GENERAL NOTES

General Notes reiterate requirements of the Specifications and dictate mix performance criteria for various structural elements. Consider only specifying mix design requirements for strength, modulus (where applicable), shrinkage, and date of strength achievement which provide flexibility for suppliers to achieve carbon reductions through cement replacement. Of note, the concrete mixes in the General Notes do not directly specify a water/cement ratio, although the water/cement ratio is an aspect of the ACI exposure class considerations. This provides a higher degree of freedom to the supplier to realize environmental performance in the product, while still achieving structural and durability criteria.

Construction schedule can often drive the strength gain requirements of concrete mixes. Formulating mix design requirements together with input from the contractor allows the contractor to find opportunities to achieve environmental goals while still meeting the structural performance criteria.

Sample EPD Request language can be as follows:

- FOR EACH MIX DESIGN, THE MATERIAL SUPPLIER SHALL INCLUDE AN ENVIRONMENTAL PRODUCT DECLARATION (EPD) IN CONFORMANCE WITH PROJECT SPECIFICATIONS. THE THIRD-PARTY-VERIFIED EPD WILL BE USED TO DOCUMENT THE ESTIMATED GLOBAL WARMING POTENTIAL (GWP). ALL GWP INFORMATION SUBMITTED SHALL BE IN THE FORM OF kg CO2eq/CY.

See next page for an example performance-based mix specification table.

CONCRETE MIX SPECIFICATION TABLE

LOCATION	f'c* MIN (PSI)	EXPOSURE CLASS**	MAX SHRINKAGE LIMIT (%)	MAX AGGREGATE SIZE (IN)	MODULUS (KSI)
MISCELLANEOUS CONCRETE, CURBS, SIDEWALKS	3,000	F2, S0, W1, C1	-	1	-
EXTERIOR SLABS ON GRADE/BUILT-UP SLABS	4,000	F2, S0, W1, C1	0.04	1	-
INTERIOR SLABS ON GRADE/BUILT-UP SLABS	4,000	N	0.04	1	-
MISCELLANEOUS CONCRETE WALLS	4,000	N	0.04	3/4	-
BASEMENT WALLS	6,000 8,000 WHERE NOTED ON ELEVATION	N	0.05	1	-
SPREAD/WALL FOOTINGS, GRADE BEAMS	6,000	F0, S0, W1, C0	0.05	1	-
PILASTERS	6,000	N	0.04	3/4	-
CONCRETE ON STEEL DECK (LEVELS P5-1)	4,000 6,000 WHERE NOTED ON PLAN	F0, S0, W1, C1 F1, S0, W1, C1	0.04 0.04	3/4 3/4	- -
CONCRETE ON STEEL DECK (ALL OTHER LEVELS)	4,000	N	0.04	3/4	-
MILD REINFORCED SLABS	6,000	N	0.04	3/4	-

* ACCEPTABLE TIMING TO ACHIEVE CONCRETE STRENGTH GAIN SHALL BE DETERMINED BASED ON CONTRACTOR INPUT. WHILE A NOMINAL CONCRETE STRENGTH OF f'c WILL BE UTILIZED FOR FINAL PROJECT ACCEPTANCE CRITERIA, TRIAL BATCHES SHALL REPORT THE STANDARD DEVIATION FOR THE TESTED MIXES AS WELL AS THEIR EXPECTED CONCRETE STRENGTHS.

** CONCRETE EXPOSURE CLASSES ARE BASED ON CHAPTER 19 OF ACI 318-14. THE DESIGNATION "N" INDICATES THE FOLLOWING: F0, S0, W0, C0.

Figure 4.1.1 – Example Concrete Mix Design Table from General Notes (Source: MKA)

4.2 SPECIFICATIONS

Project Specifications should include language that requires the General Contractor to submit EPDs for all components considered and tracked for embodied carbon reduction. EPDs should be product-specific, Type III EPDs conforming to ISO standards. The EPDs should cover, at a minimum, the life-cycle Product Stage, or Modules A1-A3.

Specifications should also call for the contractor to submit a Bill of Materials that provides project quantities, itemized by application and type, and Recycled Content Documentation. The GWP for each item, based on EPDs, should also be included.

Sample Concrete Specification language:

- **Environmental Product Declaration (EPD):** Submit product-specific Type III EPDs conforming to ISO 14025 and ISO 21930 including Life-Cycle Assessment Modules A1-A3 which at a minimum must include Global Warming Potential (GWP 100 year).
- **Bill of Materials:** Submit estimated amount of each concrete mix to be placed prior to the start of construction and actual amount placed at completion of construction. Report any assumptions and allowances included in amounts.
- **Alternative Concrete Technologies:** Alternative processes for mixing of concrete, such as carbon dioxide mineralization, are acceptable provided this process is included in the laboratory trial batches and corresponding concrete mix submittals, subject to the engineer's approval.
- **ASTM C595 and C1157 Cements:** These cement types are acceptable provided they are included in laboratory trial batches and corresponding concrete mix submittals, subject to the engineer's approval.

4.3 BID DOCUMENTS

Like the Contractor RFP, subcontractor bid documents should also include language regarding embodied carbon, most importantly the requirements to provide product-specific, Type III EPDs and a table of quantities for each product with its associated GWP.

The Contractor can instruct bidders to submit both a base bid and an alternate voluntary bid. The base bid should reflect the lowest-cost bid, reflective of 'business as usual,' while reporting GWP. Alternate voluntary bids should reflect an embodied carbon reduction from the base bid while identifying potential cost and schedule impacts. By collecting both sets of information from suppliers, the team may make informed decisions balancing carbon, cost, and schedule.

An alternate bid approach helps the team target best-value alternatives. Asking questions about embodied carbon and reviewing a variety of bids often leads to significant carbon reduction at little to no additional cost, simply from researching and presenting alternative options.

Usage	Specification	Volume	Design Team Estimate			Supplier BASE Bid			Supplier ALTERNATE BID		
			kg CO_2eq/cy	kg CO_2	Projected Cost	kg CO_2eq/cy	kg CO_2	Cost	kg CO_2eq/cy	kg CO_2	Cost
			Project Baseline Est.			Product-Specific EPD			Product-Specific EPD		
Floor Slabs	4,000psi NWC	5,000	263	1,315,000	$ 600,000	251	1,255,000	$ 550,000	251	1,255,000	$ 621,500
	4,000psi LWC	20,000	446	8,920,000	$ 600,000	410	8,200,000	$ 550,000	385	7,700,000	$ 621,500
Foundations	5,000psi NWC	10,000	329	3,290,000	$ 700,000	276	2,760,000	$ 675,000	229	2,290,000	$ 762,750
	7,000si NWC	15,000	490	7,350,000	$ 700,000	327	4,905,000	$ 725,000	242	3,630,000	$ 819,250
Other Concrete (5 other mixes)		650		2,300,000	$ 600,000		2,200,000	$ 600,000		810,000	$ 678,000
	Total	50,650		23,175,000	$ 3,200,000		19,320,000	$3,100,000		15,685,000	$3,503,000
	GWP REDUCTION		-			-	-17%	-3%	-	-32%	9%

Figure 4.3.1 – Example Concrete Base Bid vs. Alternative Bid (Source: MKA)

When comparing bids, alternate bids may realize larger carbon reductions, but may carry a cost premium. In many cases, a supplier can provide a cost-neutral product while still realizing a benefit to the environmental performance. In Figure 4.3.1 above, the "Alternate" bid offers improved environmental performance, but at a cost premium. The "Base" bid provides a strong environmental performance while still providing a cost-effective product.

4.4 TRACKING QUANTITIES AND RESULTS IN CONSTRUCTION

Once the material bids have been awarded and construction starts, the Contractor and the Design Team will work together to compare as-built quantities to the design team quantity estimates.

As structure is constructed, the Contractor ensures that the material being placed matches the EPDs that were submitted. Adjustments to materials and mix designs made during the construction phase should be accompanied by an updated EPD as required, depending on the scale of the change.

The Design Team can utilize a variety of tools to track quantities, but the Revit model is often one of the most powerful tools in this exercise. "Tally" is a plug-in for Revit which uses the modeled elements in the Revit model to produce a report on the building's GWP. As project-specific EPDs are provided and construction progresses, switching over to the Embodied Carbon in Construction Calculator (EC3) tool allows for easier tracking of EPDs and of project-wide GWP reporting.

5. ADDITIONAL MATERIAL CONSIDERATIONS

5.1 OVERVIEW OF STEEL

Structural steel represents a large carbon opportunity and its strategies for reduction in embodied carbon are somewhat uniform. Compared to reinforced concrete, structural steel is effectively a homogenous material. As such, the decision points are limited but impactful. These decision points include recycled content of the steel and the steel fabrication's energy source. Structural steel that has been fabricated using energy from a renewable energy grid has a significantly lower embodied carbon impact than structural steel which has been fabricated using energy from a coal-fired power plant. This information would be reflected in the EPD of the steel.

5.2 STRUCTURAL STEEL

Some strategies for reducing the total carbon impact from structural steel are as follows:

- Utilizing high-grade steel where most effective (columns, trusses, etc.)
- Evaluating use of different lateral systems, for example steel buckling restrained braced frames
- Optimizing steel detailing practices (camber, size variation, column splicing, etc.)
- Compare EPDs from material suppliers to inform supplier selection

5.3 STEEL REINFORCEMENT

Some strategies for reducing the total carbon impact from steel reinforcement are as follows:

- Utilize high-grade rebar where most effective (columns, walls, foundations, etc.)
- Optimize reinforcement detailing practices (lap splices, development lengths, curtailment, etc.)
- Compare EPDs from material suppliers to inform supplier selection.

6. CONCLUSION

In pursuit of curbing carbon emissions and decelerating the negative effects of climate change, this report outlined an opportunity to achieve increased environmental performance in structural materials.

There are many worthwhile pursuits in setting and achieving sustainability goals, and this report is only a small segment of what can be done in the design of the buildings we create. There will continue to be improvements to the industry processes which push us even further towards achieving our goals.

Taking a unified approach to the environmental performance of our buildings can produce a substantial impact. Communication, planning, and documentation are all key to the illustrated approaches but as with any collective effort which benefits many people, we can achieve our shared goals by working together.