Design with a Carbon Conscience: Estimating Embodied Carbon at the Planning Level

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Northeast Sustainable Energy Association (NESEA)
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Designing with a Carbon Conscience:
Estimating Embodied Carbon at the Planning Level

NESEA BuildingEnergy Boston 2/28/2022
Carbon Conscience Team

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BE SURE TO WASH YOUR HANDS AND ALL WILL BE WELL.

CLIMATE CHANGE

RECESSION

COVID-19
We know how to design Energy Positive projects. BUT... how can we design Carbon Positive projects?
Global Carbon Emissions by Sector

- **Building Operations**: 28%
- **Concrete, Steel & Aluminum**: 22.7%
  - Concrete: 11.1%
  - Steel: 10.1%
  - Aluminum: 1.5%
- **Transportation**: 23%
- **Industry**: 20.3%
  - (incl. building finishes, glass, equipment, and plastics, rubber, paper, other)
- **Other**: 6%

Source: 2018 Global ABC Report, IEA

(approximate, 2017)
Carbon Positive projects would also track embodied carbon emissions from building and sitework materials.
Embodied Carbon Life Cycle Analysis

NEW CONSTRUCTION

EXTRACTION → ASSEMBLY/MANUFACTURER → TRANSPORTATION

MATERIALS

OPERATIONS

BUILDING LIFESPAN

DISPOSAL

Source: Atelier 10
A planning tool can consider embodied carbon in materials for both architecture and landscape
From the Earliest Concept Design Phase

Majority of environmental impact is determined in the early design stages.
Embodied Carbon Estimates

Material Quantity \times \text{Embodied Carbon / Material} = \text{Project Embodied Carbon}
Sources: Calculators, Programs

Other Resources and citesources of information.

Additional Embodied Carbon Calculators
- OneClick LCA: The engineer’s software of choice for LCAs as well as embodied carbon calculations. [https://www.oneclicklca.com/]
- Beacon (for structural systems), from the Embodied Carbon Lab at Thornton Tomasetti: [https://corestudio.gitchub.io/beacon/]
- Kaleidoscope (for facades, flooring) from Payette: [https://www.payette.com/kaleidoscope/]
- EA Tool (for structural systems) from SOM: [https://www.som.com/news/new_tool_measures_emissions_from_buildings]

Additional LCA resources
- U.S. Life Cycle Inventory Database: [https://www.nrel.gov/lci/EPD]
- International: [https://www.enviroedge.com/]

Energy Modeling Programs
- CeweTool (energy modeling for individual buildings and neighborhoods): [https://www.cewetools.com/]
- IES VE (whole building energy simulation): [https://www.iesve.com/software/building-energy-modeling]
- DesignBuilder (performance analysis tools): [https://designbuilder.co.uk/]

Additional Resources:
- Carbon Smart Materials Pallette: [https://materialspalette.org/]
- EPD QuickSheet: [https://architecture2030.org/epdquicksheet/]
- Architecture2030: [https://architecture2030.org/]
- USGBC - How LEED V4.1 addresses embodied carbon: [https://www.usgbc.org/articles/how-leafv4-1-addresses-embodied-carbon]
- Climate Positive Design - Resource Recommendations: [https://climatepositivedesign.com/resources/]
- Society for Ecological Restoration Resource Center: [https://www.searc.org/]
- iTrees (for detailed arboriculture tools): [https://www.itrees.org/]
- EcoGIS (monitor energy consumption and CO2 emissions): [http://www.ecogis.info/]

Architecture & Building Systems (Tally, Athena, EC3)
Planning (EcoGIS, Presto, iTrees)
Landscape (Climate Positive / Pathfinder)
Project Planning: Architecture, Landscape, Infrastructure

Ecosystem Services

-300 kgC
+25 kgC
+100 kgC
+50 kgC
+1200 kgC
+20 kgC
+60 kgC
+30 kgC
-30 kgC
+10 kgC
+10 kgC
+50 kgC
-40 kgC
-300 kgC
-80 kgC
-10 kgC
+300 kgC
-100 kgC
-30 kgC
+10 kgC

Landcape Calculator

Infrastructure Calculator

Products LCA / EPD Data

Architecture Calculator
Embodied Carbon Estimates

Architecture:
- Program
- Structural System
- Facades

Landscape:
- Undisturbed soils
- Demolition and prep
- Hardscape
- Softscape
Carbon Conscience: Alpha
Carbon Conscience: Beta

### Stored + Sequestered Carbon

- **Turf**: -96 tCO₂ stored carbon
- **Informal Landscape**: -549 tCO₂
- **Native Edge Landscape**: -352 tCO₂
- **Formal Quad Landscape**: -54 tCO₂
- **STEM**: -1700 tCO₂ stored carbon with timber frame

### Emitted Carbon

- **Turf**: 1,061 tCO₂ - 1,733 tCO₂
- **Informal Landscape**: 109 tCO₂ - 217 tCO₂
- **Native Edge Landscape**: 17 tCO₂ - 43 tCO₂
- **Formal Quad Landscape**: 211 tCO₂ - 343 tCO₂
- **STEM**: 1,408 tCO₂ - 2,622 tCO₂
- **Dining Addition**: 196 tCO₂ - 493 tCO₂
- **Bresnahan**: 2,890 tCO₂ - 6,527 tCO₂
- **Housing Addition**: 7,355 tCO₂ - 17,825 tCO₂
- **Gym Addition**: 1,074 tCO₂ - 4,340 tCO₂
- **Harrington Reno**: 1,915 tCO₂ - 4,825 tCO₂
- **Power Plant Reno**: 363 tCO₂ - 1,469 tCO₂
- **New Paths**: 1,022 tCO₂ - 1,602 tCO₂
Architecture Land Uses
Developing the Architecture Data Set
Carbon Leadership Forum: Benchmark Study, 2017

Embodied Carbon per SM, Whole Building averages, 1007 Building Survey
Selection of Program Types

<table>
<thead>
<tr>
<th>Program</th>
<th>Embodied Carbon Cost (High) kg CO2 eq/m²</th>
<th>Embodied Carbon Cost (Low) kg CO2 eq/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Family Residential</td>
<td>160</td>
<td>374</td>
</tr>
<tr>
<td>Educational</td>
<td>227</td>
<td>459</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>325</td>
<td>471</td>
</tr>
<tr>
<td>Mercantile</td>
<td>274</td>
<td>528</td>
</tr>
<tr>
<td>Office</td>
<td>251</td>
<td>534</td>
</tr>
<tr>
<td>Lodging</td>
<td>253</td>
<td>533</td>
</tr>
<tr>
<td>Healthcare</td>
<td>197</td>
<td>540</td>
</tr>
<tr>
<td>Mixed-Use</td>
<td></td>
<td>639</td>
</tr>
<tr>
<td>Multi-Family Residential</td>
<td></td>
<td>665</td>
</tr>
</tbody>
</table>

Legend:
- Embodied Carbon Cost (High) kg CO2 eq/m²
- Embodied Carbon Cost (Low) kg CO2 eq/m²
Primary Data Set Refinement: Structure

Embodied Carbon per SM, structural system averages, 639 Building Survey
Whole Building LCA Test: 4 Buildings, Bonnet Springs Park

Nature Center
Heavy timber & light wood framing structure

Event Center
Hybrid structure: steel columns, mass timber glulam beams and CLT roof

Children’s Museum
Steel & concrete composite structure

Welcome Center
Steel & concrete composite structure

$\text{kgCO}_2/\text{m}^2 = 161.6$  $\text{kgCO}_2/\text{m}^2 = 176.3$  $\text{KgCO}_2/\text{m}^2 = 330.3$  $\text{kgCO}_2/\text{m}^2 = 433.1$
## Secondary Data Set Refinement: Envelope

### Wall Assembly

- **Series 0: Monolithic/Foundation Walls**
  - **Clad Type 01**: C8 (CIP) C12 (CMU) C16 (CMF)
  - **Clad Type 02**: M4 (CIP) M6 (CMU) M12 (CMF)
  - **Clad Type 03**: EWA-01C (CIP)
  - **Clad Type 04**: EWA-02C (CMU)

- **Series 10: Unit Masonry Cavity Walls**
  - **Clad Type 01**: EWA-10C (CIP) EWA-10M (CMU) EWA-10S (CMF)
  - **Clad Type 02**: EWA-11C (CIP) EWA-11M (CMU) EWA-11S (CMF)
  - **Clad Type 03**: EWA-22C (CIP) EWA-22M (CMU) EWA-22S (CMF)
  - **Clad Type 04**: EWA-23C (CIP) EWA-23M (CMU) EWA-23S (CMF)

- **Series 20: Precast/Stone Wall Panel**
  - **Clad Type 01**: EWA-20C (CIP) EWA-20M (CMU) EWA-20S (CMF)
  - **Clad Type 02**: EWA-21C (CIP) EWA-21M (CMU) EWA-21S (CMF)
  - **Clad Type 03**: EWA-22C (CIP) EWA-22M (CMU) EWA-22S (CMF)
  - **Clad Type 04**: EWA-23C (CIP) EWA-23M (CMU) EWA-23S (CMF)

- **Series 30: Thin Panel Rainscreen Cladding**
  - **Clad Type 01**: EWA-30C (CIP) EWA-30M (CMU) EWA-30S (CMF)
  - **Clad Type 02**: EWA-31C (CIP) EWA-31M (CMU) EWA-31S (CMF)
  - **Clad Type 03**: EWA-32C (CIP) EWA-32M (CMU) EWA-32S (CMF)
  - **Clad Type 04**: EWA-33C (CIP) EWA-33M (CMU) EWA-33S (CMF)

- **Series 40: Panelized Metal Rainscreen**
  - **Clad Type 01**: EWA-40C (CIP) EWA-40M (CMU) EWA-40S (CMF)
  - **Clad Type 02**: EWA-41C (CIP) EWA-41M (CMU) EWA-41S (CMF)
  - **Clad Type 03**: EWA-42C (CIP) EWA-42M (CMU) EWA-42S (CMF)
  - **Clad Type 04**: EWA-43C (CIP) EWA-43M (CMU) EWA-43S (CMF)

- **Series 50: Wood**
  - **Clad Type 01**: EWA-50C (CIP) EWA-50M (CMU) EWA-50S (CMF)
  - **Clad Type 02**: EWA-51C (CIP) EWA-51M (CMU) EWA-51S (CMF)
  - **Clad Type 03**: EWA-52C (CIP) EWA-52M (CMU) EWA-52S (CMF)

- **Series 60: Direct-Applied Finish System**
  - **Clad Type 01**: EWA-60C (CIP) EWA-60M (CMU) EWA-60S (CMF)
  - **Clad Type 02**: EWA-61C (CIP) EWA-61M (CMU) EWA-61S (CMF)
  - **Clad Type 03**: EWA-62C (CIP) EWA-62M (CMU) EWA-62S (CMF)

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- **Begin with Sasaki library of exterior assemblies**
- **LCAs for each assembly using Tally**
- **Create groups by cladding type, and assign factor**
Secondary Data Set Refinement: Envelope

Exterior Wall Assembly Groups

Wood Rainscreen 111
Masonry Veneer 114
Masonry Rainscreen
Metal Rainscreen 151

Embodied Carbon (GWP) per envelope type (kg CO2 eq./m^2) average and mean carbon cost.
Next Steps:

- Existing Structure Reuse
- Existing Structure Demolition
- New & Archive Projects WBLCA
Future Data Integration

**WBLCA**
- Public shared Buildings data set
- Sasaki Buildings data set
- Proprietary data set for WBLCA baselines
- Future public data set for WBLCA baselines

**Product EPDs**
- Annually updated material baselines (CLF)
- EPD dataset from Sasaki built work
- Alignment of databases between MM and AIA Material Pledge
- Future public data set for Products and Materials

**AIA 2030 COMMITMENT**

**Athena Impact Estimator for Buildings**

**GSA**
Landscape Land Uses
**Carbon Cycle**

- **Photosynthesis**: Converts CO₂ to Sugar → Carbon Captured
- **Respiration**: Release of CO₂ as product of metabolism → Carbon Released

**Decomposition**
- Break down and metabolization of biomass → Carbon Released, % of Carbon Stored

**Biosynthesis**
- Converts Sugar to Starches → Carbon Sequestered in Living Tissue
Carbon Sequestration is the amount of carbon actively stored or fixed from the atmosphere in vegetation or soils.
Carbon Sequestration by Ecosystem

- Globally, soil carbon represents more than half of the stock of carbon in forests.
- Forest landscapes have a larger proportion of carbon above ground than below ground, while meadow landscapes have a larger proportion of carbon below than above ground.
- Dead biomass is a larger proportion of carbon storage in forests than in meadows.
- Plant litter is a more important pathway for carbon into the soil in forests, than in grasslands.

Zac Kayler, Maria Janowiak, Chris Swanston - https://www.fs.usda.gov/ccrc/topics/global-carbon
Maximize High-Carbon Sequestration Land Uses

Comparative chart of restored ecosystems carbon sequestration potential by year

- Tropical Dry Deciduous
- Dry Meadows
- Subtropical Humid Forest
- Tropical Shrublands
- Tropical Moist Deciduous
- Dry Forest (Mediterranean)
- Boreal Forest
- Tropical Rainforest
- Prairie Grassland
- Temperate Wetland and Salt Marsh
- Mangrove
- Temperate Continental Forest
- Temperate Oceanic Rainforest
- Peat Swamp

Net Carbon Sequestration (80 years) (kg CO2 eq/m²)
Data Set for Hardscape and Softscape

<table>
<thead>
<tr>
<th>Parameter Quotation</th>
<th>QNT.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Materials Carbon Factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay Brick (Air/Sun Dried)</td>
<td>0.060 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Clay Brick (Baked)</td>
<td>0.230 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Stone (Quarried and Dressed)</td>
<td>0.073 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Cinder</td>
<td>0.226 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Mortar (1:3 cement to sand)</td>
<td>0.058 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Concrete (1:2.4, type 1 or 2)</td>
<td>0.058 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Precast Concrete</td>
<td>0.059 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Sand / Soil (Mined, screened)</td>
<td>0.002 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Aggregate Base (Crushed)</td>
<td>0.040 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Gravel (mined, screened, not crushed)</td>
<td>0.002 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Cinder Blocks (Aerated Concrete Block)</td>
<td>0.076 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Asphaltic Concrete (HMA)</td>
<td>0.059 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Bitumen Tar</td>
<td>0.410 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Polyurethane Resin</td>
<td>4.260 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Polyurethane Resin Bonded Aggregate</td>
<td>1.111 kg/kg</td>
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</tr>
<tr>
<td>Steel</td>
<td>0.482 kg/kg</td>
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</tr>
<tr>
<td>Galv. Steel</td>
<td>0.763 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>0.083 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Bronze</td>
<td>3.730 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td>2.460 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.240 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>2.600 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Timber (Rough Cut)</td>
<td>0.125 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Glue laminated timber</td>
<td>0.234 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Milled hardwood</td>
<td>0.243 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Milled softwood</td>
<td>0.274 kg/kg</td>
<td></td>
</tr>
<tr>
<td>HDPE (High Density Foam Polyethylene)</td>
<td>6.400 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Polycarbonate Plastic</td>
<td>6.038 kg/kg</td>
<td></td>
</tr>
<tr>
<td>ABS Plastic (Acrylonitrile butadiene styrene)</td>
<td>0.008 kg/kg</td>
<td></td>
</tr>
<tr>
<td>EPS (expanded polystyrene foam)</td>
<td>2.559 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Gecofoam (polystyrene foam)</td>
<td>0.008 kg/kg</td>
<td></td>
</tr>
<tr>
<td>LDPE (Polyethylene)</td>
<td>2.139 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Fiberglass</td>
<td>1.309 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Ceramic Tile</td>
<td>0.450 kg/kg</td>
<td></td>
</tr>
<tr>
<td>EPDM Rubber (Playground Surfacing)</td>
<td>3.700 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Engineered Mulch (Fiberglass Surfacing)</td>
<td>0.400 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Nylon/polypropylene carpeting (proxy for synthetic turf)</td>
<td>18.450 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Mulch</td>
<td>0.015 kg/kg</td>
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<tr>
<td>Lime</td>
<td>0.268 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Damp proofing/membrane</td>
<td>0.400 kg/kg</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>2.240 kg/kg</td>
<td></td>
</tr>
</tbody>
</table>

Simplified average coverages into about 200 unique landscape landuses that could be combined in relative ratios to create many options.
Test & Iterate
## Metrics

View carbon impacts update as you test landuse assumptions. Carbon units (tCO₂) are tonnes of CO₂ equivalent.

### Embodied Carbon (tCO₂)

<table>
<thead>
<tr>
<th>Landuse</th>
<th>CO₂ Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aromatic Shrubland</td>
<td></td>
</tr>
<tr>
<td>Coastal Formal Garden Landscape</td>
<td></td>
</tr>
<tr>
<td>Dry Mediterranean Mixed Forest Understory</td>
<td></td>
</tr>
<tr>
<td>Dry Mediterranean Mixed Shrubland</td>
<td></td>
</tr>
<tr>
<td>Event Lawn Turf</td>
<td></td>
</tr>
<tr>
<td>Grasslands and Pastures (Ruderal)</td>
<td></td>
</tr>
<tr>
<td>MetroPark Formal Garden Landscape</td>
<td></td>
</tr>
<tr>
<td>Orchard Groves Understory</td>
<td></td>
</tr>
<tr>
<td>Riparian Gallery Forest</td>
<td></td>
</tr>
<tr>
<td>Intensive Concrete CIP Hardcape</td>
<td></td>
</tr>
<tr>
<td>Moderate Concrete CIP Hardcape</td>
<td></td>
</tr>
<tr>
<td>Stone Paver Hardcape</td>
<td></td>
</tr>
<tr>
<td>Intensive Material Reuse Hardcape</td>
<td></td>
</tr>
<tr>
<td>Secondary Paths</td>
<td></td>
</tr>
<tr>
<td>Tertiary Paths</td>
<td></td>
</tr>
<tr>
<td>Playground</td>
<td></td>
</tr>
<tr>
<td>Fitness Court</td>
<td></td>
</tr>
<tr>
<td>Aggregate Hardcape</td>
<td></td>
</tr>
</tbody>
</table>

## Landuse Manager

Create and edit landuse elements, then assign materials to see impacts.

### Composite

- Park Phase 1
- ACA Phase 1
- CSA Phase 1
- Bridge Phase 2
- Total
Demonstration
https://carbon-conscience.web.app/
https://visualizations.sasaki.com/staging/carbon-conscience-public/

Measure carbon impacts. Build with a conscience.
Lessons Learned

*Note: following slides built from 2021 ASLA Conference: *Design with Carbon: Reconsidering Landscapes from Planning to Soils* by Christopher R. Ng-Hardy, Pamela Conrad, Deanna Lynn*
Maximize the carbon stored in plants and soil

Preserve and protect existing habitats, with a priority for mature forests and wetlands.
- Minimize Turf grasses
  - Fast-growing
  - Long-lived
- Long growing season
- Low maintenance
- Minimize hardscape

- Concrete & metals
  - Low impact to soils
- Less piping, more natural drainage
  - Cement substitutes: SCMs
  - Recycled materials & content
  - Permeable paving
- Minimize & reuse carbon embodied in materials

» » Reuse & recycle architecture and landscape elements
» » Select low-carbon materials, EPDs
  » » Prioritize local material
» Structures: Use wood & mass timber
» Facades: Use wood & thin masonry claddings, minimize glazing
Minimize Day 1 & Day-to-Day Emissions + keep carbon stored longer

- Electric/hand-powered equipment
- Organic v. chemical amendments
- Build & protect soil carbon
- Tree/plant litter management & recycling
- Protect existing trees + ecosystems
- Low water
Top 5 things we can do

- planting
- paving
- material selection
- specs
- O&M manual
Every design move has a carbon impact. Consider carbon from the onset of the design process. Set – and track – an embodied carbon budget. Reuse existing buildings and landscapes.

Less is more.
Questions?