Concrete for a Carbon Constrained Future

VERMONT INTEGRATED ARCHITECTURE, PC

Better Buildings by Design Conference
February 7, 2018

ENGINEERING VENTURES PC

Vermont Integrated Architecture

Engineering Ventures

VERMONT INTEGRATED
ARCHITECTURE, PC

INTRODUCTIONS

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February 7, 2018

ENGINEERING
VENTURES PC

Ashar Nelson

Subject: FW: Concrete

Hey Bob, Russ,

After our Better Buildings conference, I am reminded that concrete alone is responsible for 9% (that's NINE PERCENT) of the world's carbon emissions. It may be a small gesture, but I think we can improve our own use of concrete by thinking a little more strategically about our use of the material. Since you are the partner firm who mostly helps us work out our structural needs around concrete, we're looking forward to working with you to try to reduce the amount of concrete we use. I don't know if this means 6" frost walls , slab thicknesses designed to exact need not to the nearest inch, or looking at tweaking water-cement ratios to better meet exact structural needs. Obviously, we will try to do this in a way that doesn't add significant extra engineering time, but I think we owe it to ourselves/children/planet etc to add this to the list of things we consider in our work. With concrete price per yard rising, maybe it's more about using some of the money saved by reducing yardage to cover the extra engineering. Personally, I'd rather support you guys than the cement kilns up in Quebec.

Happy Friday!
Ashar

ASHAR NELSON
AIA, LEED AP BD + C
Principal

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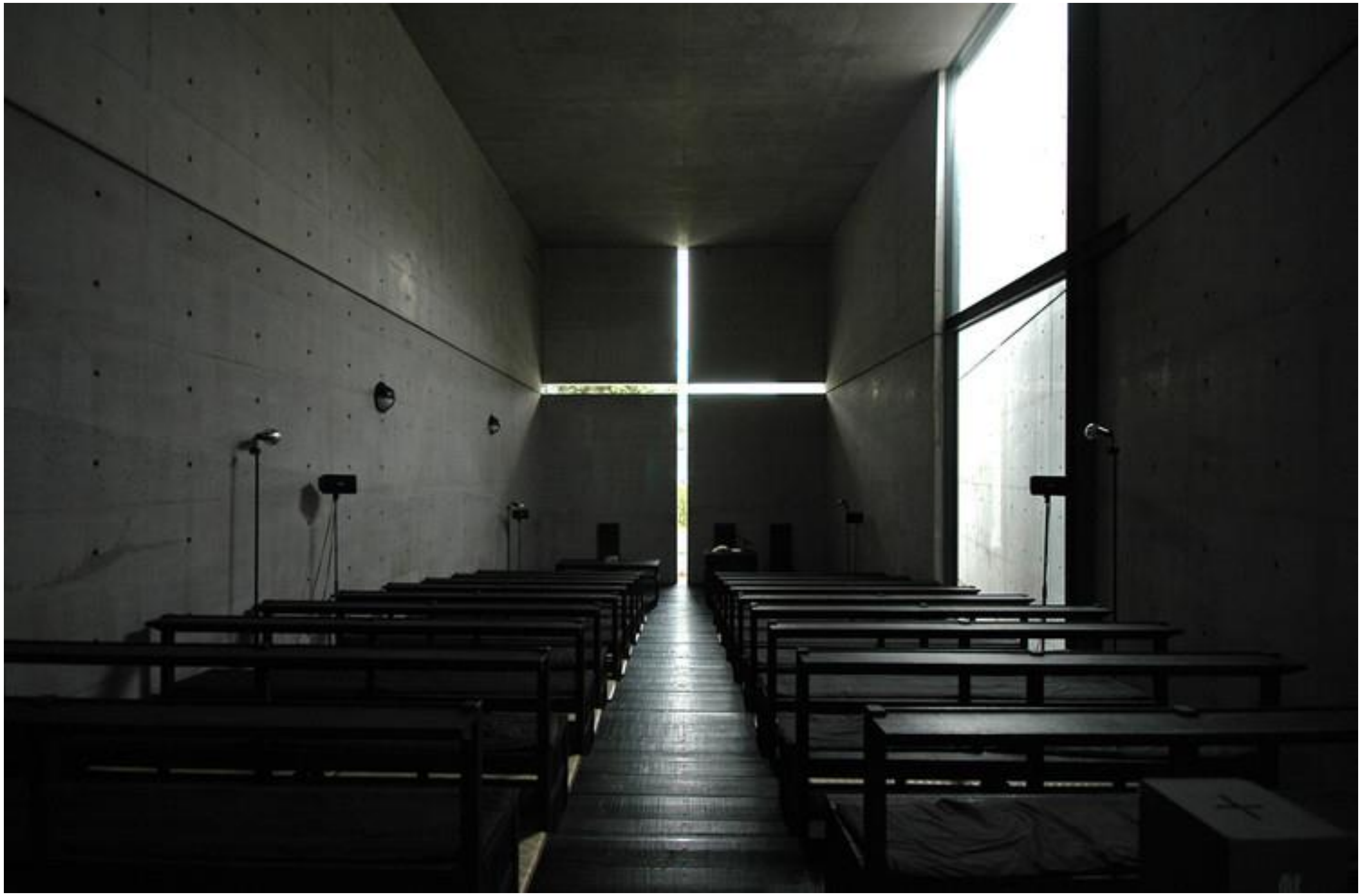
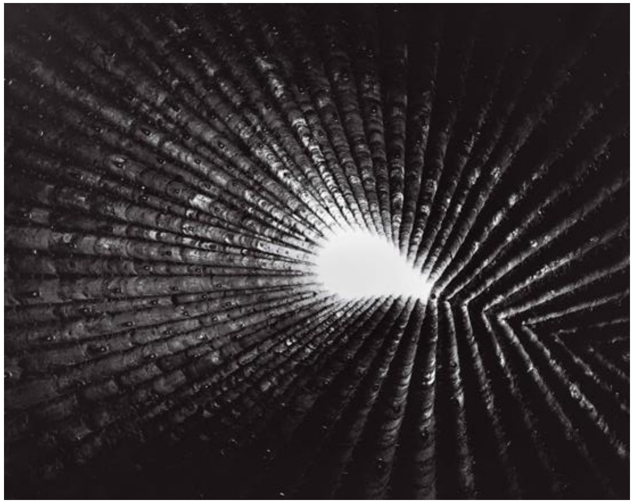
INSPIRATION



ANDO – CHURCH OF THE LIGHT

FELIX CANDELA – LOS MANANTIALES



ZUMTHOR – BRUDER CLAUSE FIELD CHAPEL

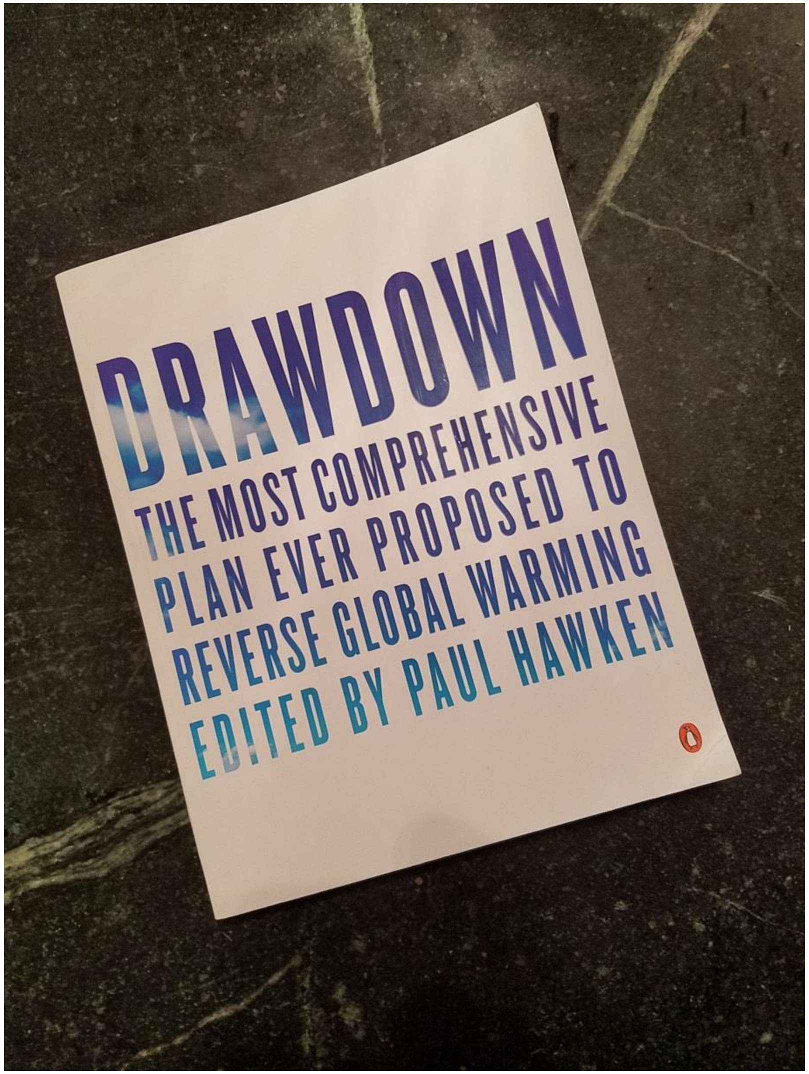
SOME STATISTICS

CONCRETE IS THE SECOND MOST CONSUMED MATERIAL ON THE PLANET (per PCA)

CONCRETE IS RESPONSIBLE FOR ALMOST A TENTH OF ANNUAL GLOBAL CARBON EMISSIONS

THE PRODUCTION OF CEMENT IS RESPONSIBLE FOR 4-7% OF ANNUAL GLOBAL CARBON EMISSIONS

ANNUAL GLOBAL PRODUCTION OF CEMENT IS 4.6 BILLION TONS, RELEASING ABOUT THE SAME AMOUNT OF CO2



DRAWDOWN

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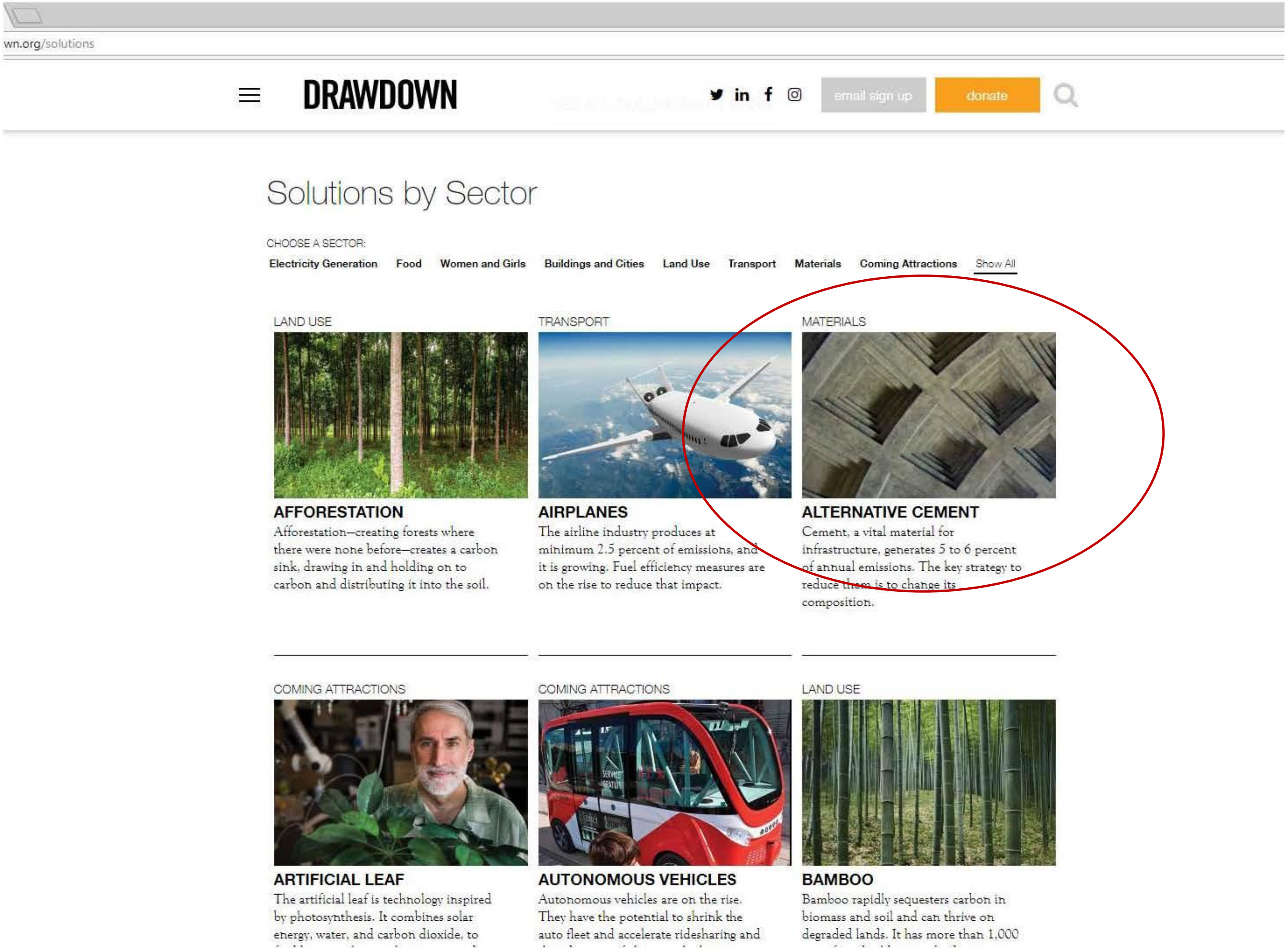
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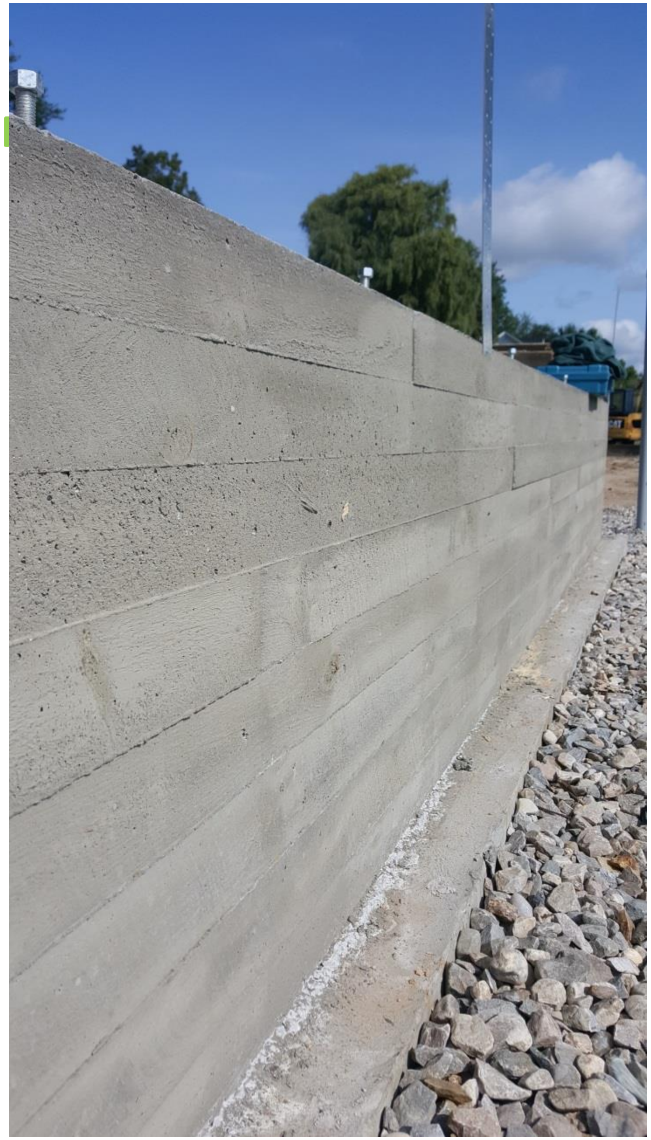
Solutions by Sector
CHOOSE A SECTOR:
Electricity Generation
Food
Women and Girls
Buildings and Cities
Land Use
Transport
Materials
Coming Attractions
Show All
LAND USE
AFFORESTATION
Afforestation—creating forests where there were none before—creates a carbon sink, drawing in and holding on to carbon and distributing it into the soil.
TRANSPORT
AIRPLANES
The airline industry produces at minimum 2.5 percent of emissions, and it is growing. Fuel efficiency measures are on the rise to reduce that impact.
MATERIALS
ALTERNATIVE CEMENT
Cement, a vital material for infrastructure, generates 5 to 6 percent of annual emissions. The key strategy to reduce them is to change its composition.
COMING ATTRACTIONS
ARTIFICIAL LEAF
The artificial leaf is technology inspired by photosynthesis. It combines solar energy, water, and carbon dioxide, to
COMING ATTRACTIONS
AUTONOMOUS VEHICLES
Autonomous vehicles are on the rise. They have the potential to shrink the auto fleet and accelerate ridesharing and
LAND USE
BAMBOO
Bamboo rapidly sequesters carbon in biomass and soil and can thrive on degraded lands. It has more than 1,000



CONCRETE

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CEMENT PRODUCTION

RUNS AT 1450 DEGREES

GENERALLY FOSSIL FUEL, MOSTLY COAL

ALTERNATIVE ENERGY SOURCES BEING EXPLORED (CKRC)

CEMENT IS USED IN MANY APPLICATIONS BEYOND CONCRETE

CEMENT KILN

TRANSPORTATION

ENERGY USED IN GETTING RAW MATERIALS TO BATCH PLANT

ENERGY USED IN GETTING CONCRETE TO BUILDING SITE

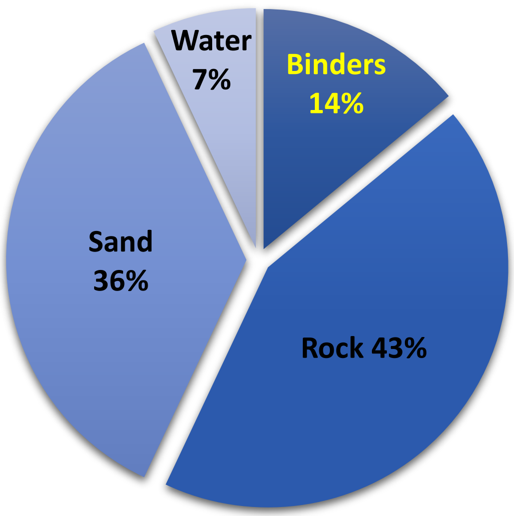
BUY LOCAL!

SLIDE TITLE

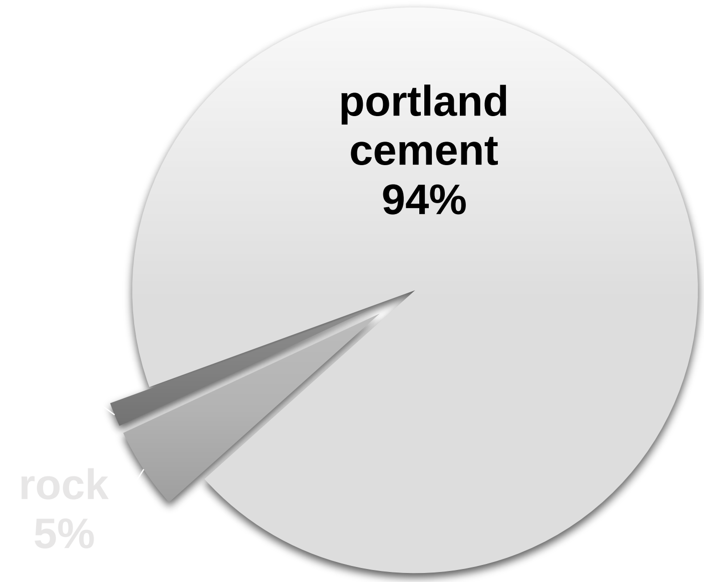
CONCRETE MIXES

WORKABILITY **DURABILITY** **FUNCTIONALITY** **STRENGTH**

Typical Mix Components by Weight



Carbon Intensity of Ordinary Concrete



$CaCO_3$ + ENERGY → CaO + CO_2

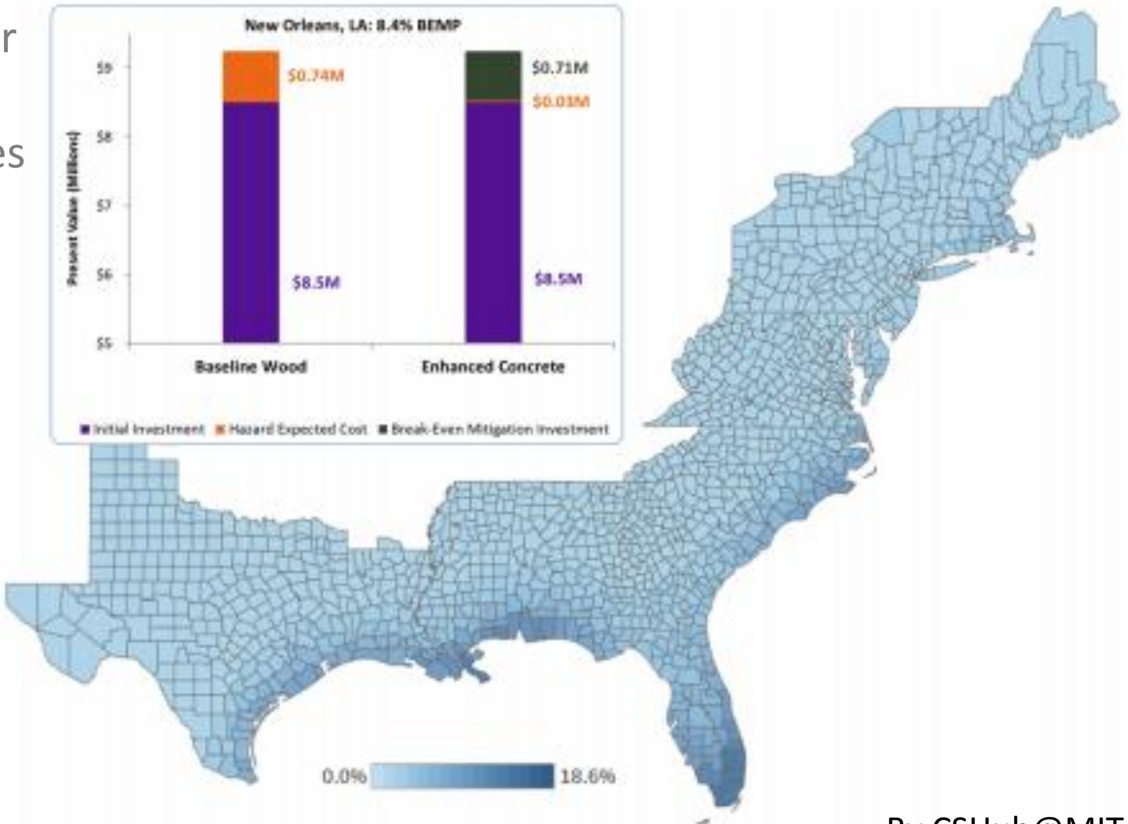
(Limestone + HEAT:1500ºC → Clinker + CO_2)

DURABILITY/RESILIENCY

STUDIES ON LIFE CYCLE COSTS

- Enhanced durability of concrete can offset Hazard Repair
- Building type, location and mitigation strategies are factors.

"The contribution of carbon related to damage from a seismic event could account for 25% or more of the total carbon footprint for the structure" -ATC-58



By CSHub@MIT

SCM's

EVERYDAY REPLACEMENTS

- Fly Ash (Class F and C)
- Slag
- Silica Fume
- Rice Husk Ash

ADJUST MIX TO USE

- Set Times
- Performance, Resiliency
- Strength

Resistance of Non Air-Entrained Rice Hull Ash Concrete to Freezing and Thawing in Saline Environment

"Fly ash's effects on concrete are also largely positive. Fly ash generally increases durability, decreases permeability, greatly improves sulfate resistance and allows lower water contents in the mix. It also improves the workability of the wet mix and improves the color of the final product, producing a warmer tone."

- HIGH VOLUME FLYASH CONCRETE USAGE FOR SKYTRAIN STATIONS, APRIL 2009

AAC (Autoclaved Aerated Concrete)

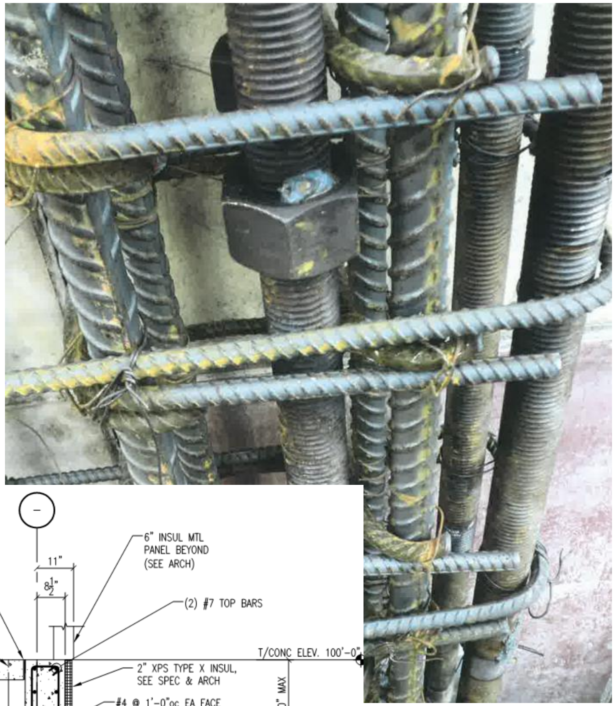
- Lighter Weight reduces overall structure and foundation “loads”; including transport and installation (~25-45 pcf vs. 150 pcf)
- Cement use is less per volume; up to 70% of volume can be Fly Ash are produced; ~7-10 times less Portland Cement at ~ 5-8 times less strength
- Autoclaving and transport energy CO_2 emission important factor
- As a more permeable cement based product AAC reduces operational energy use as insulator & absorbs/reabsorbs CO_2 more easily $[Ca(OH)_2 + CO_2 --- CO_3Ca + H_2O]$

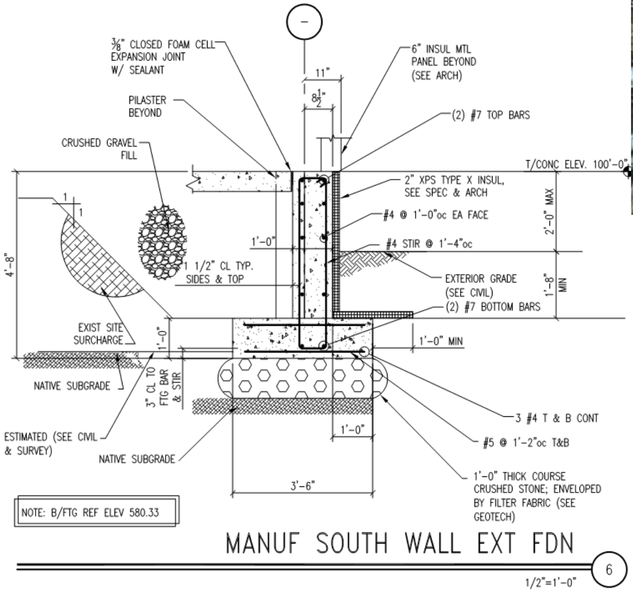
DAVIS CENTER, UNIVERSITY OF VERMONT

REDUCE CONCRETE

REDUCE VOLUME
- FPSF's - with EPS
- Corbels and ledges – not a full height "thick" wall
- Void Forms
- High-Strength or Post-tensioned reinforcing
- Embedded or threaded steel at high shear, high loads, connections
- Minimum Thicknesses

REDUCE LOADS
- Gravel Backfill on Retaining Walls
- Light-weight floor fills, aggregates,
- Fireproofing. i.l.o. minimum slab thicknesses for unprotected slabs



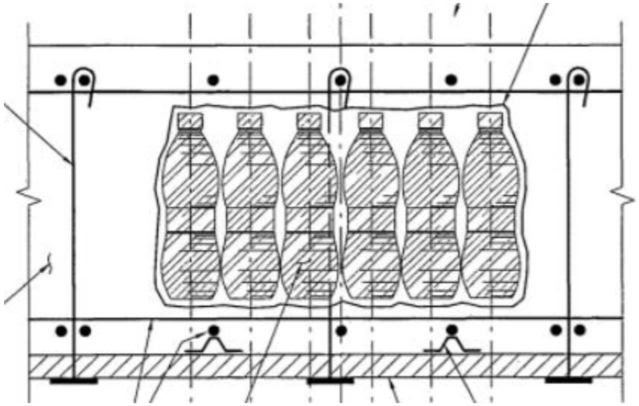


REDUCED FOOTPRINT

Environmentally Sustainable Form-Inclusion System

Lowering Overall Material Impact

- Recycled Plastic product or filler in tension zones
- Recycled Concrete Aggregate
- Recycled Cements
- Fillers
- Foam Insulation



Inventors	Mark P. Sarkisian, Craig W. Hartman
Original Assignee	Skidmore, Owings & Merrill Llp

MIT students fortify concrete by adding recycled plastic

Adding bits of irradiated plastic water bottles could cut cement industry's carbon emissions.

REDUCE CONCRETE AND CEMENT

REDUCE SLAB-ON-GRADE THICKNESS AND CEMENT USE

- Add Admixtures, not cement to meet w/cm or .45 for water-soluble adhered
- Use thin topping, self-leveling for finishes
- SCM's for Portland cement
- Less shrinkage, curling, moisture
- Flatter floors
- Thin up slab – 4.4 pounds of CO_2 per square foot per 1 inch of thickness
- Engineered design for code limit variance

* Jim D'Aloisio "Dramatic Reduction for Concrete Slabs on Grade" 11/1/14; jdaliosio.wordpress.com

CONCRETE VOLUMES - WALL COMPARISON

8” REINFORCED CONCRETE WALL (CONCRETE COMPONENTS)

- At 0% SCM is 18 pounds CO_2e per square foot
- At 20% SCM is 13 pounds CO_2e per square foot

8” REINFORCED CONCRETE MASONRY WALL (CMU COMPONENTS)

- AT 0% SCM in fully grouted, block and mortar 21 pounds CO_2e per square foot

8” REINFORCED ICF WALL (ICF [EPS] AND GROUT COMPONENTS)

- AT 40% SCM in fully grouted ICF 7 pounds CO_2e per square foot

COSTS

MARKET VALUE

- GWP Costs
- End-of-Life
- Externalized Costs
- Operational Energy and CO2 USE exceed
  Embodied Quantities
- Inertias

	ACI	NRMCA	ASCC	Composite Rank
Question 4				
Economic barriers				
Increased concrete cost	1	1	1	1
Longer construction schedule	2	2	2	2
Increased design cost	4	4	3-4 tie	4
Increased testing/inspection	3	3	3-4 tie	3

Lab and Field Data for Assessing the Impact of “Green” Concrete Mixtures on Building Construction” ASCC & Pankow 12/2013

PROJECT EXAMPLES

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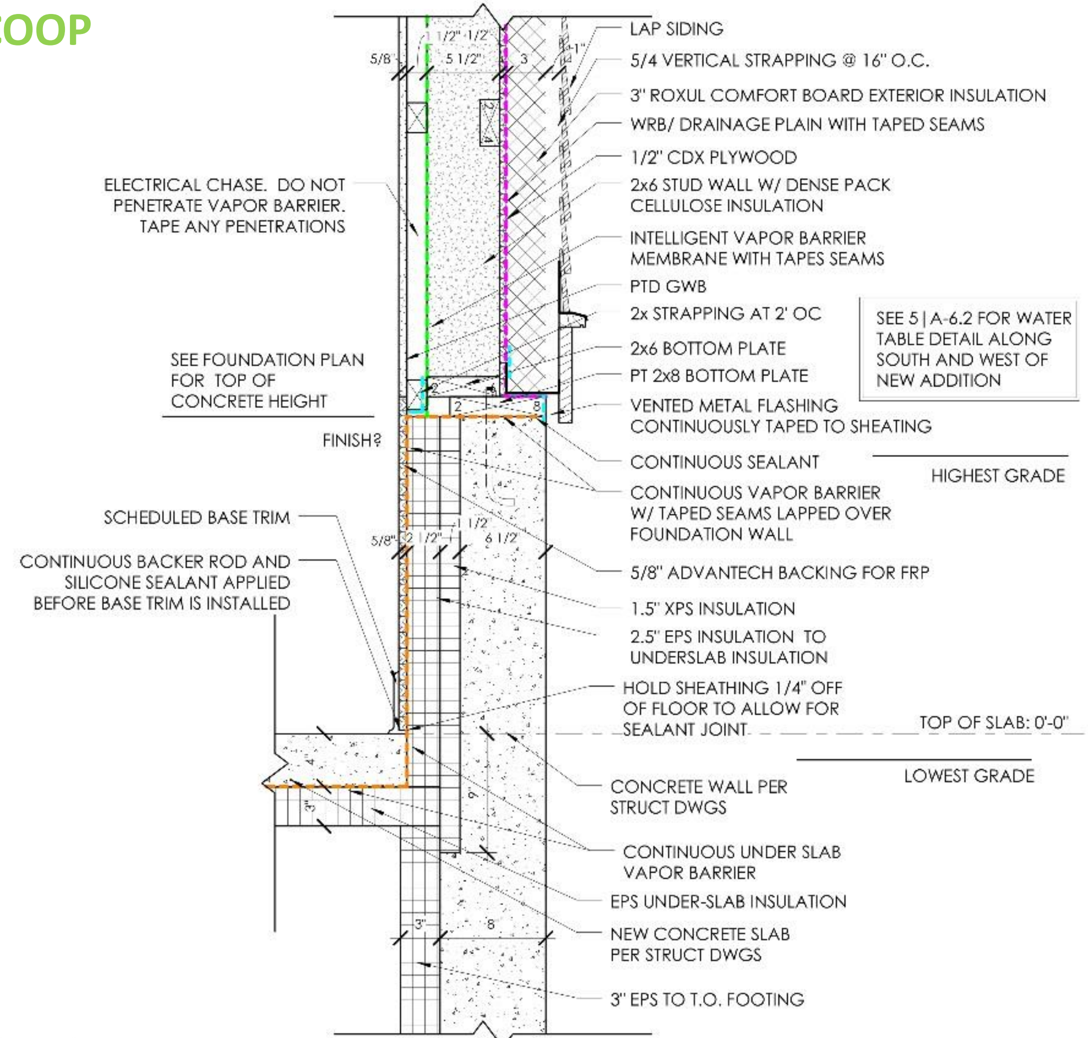
MIDDLEBURY NATURAL FOODS COOP

FROST WALL WITH STEM

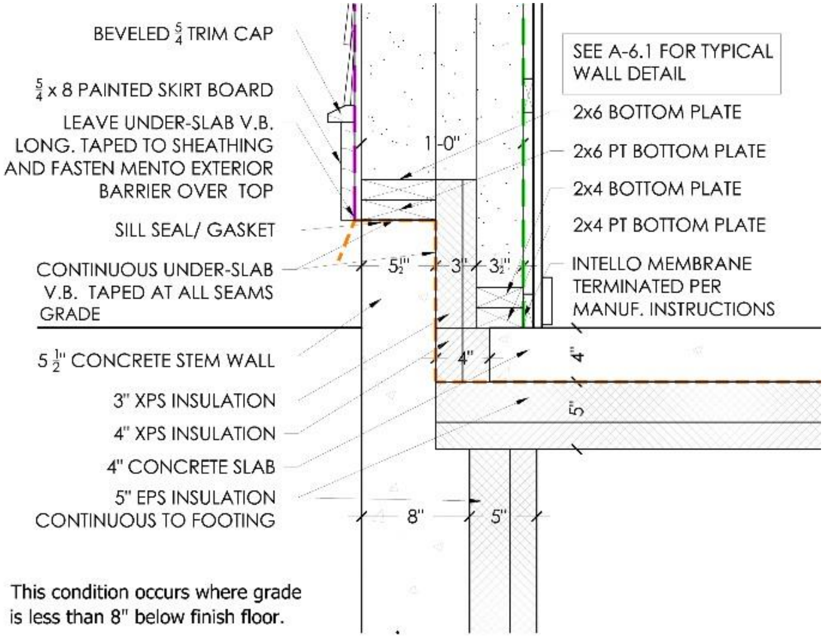


2 Typical Wall Section
1 1/2" = 1'-0"

WATERBURY MUNICIPAL CENTER

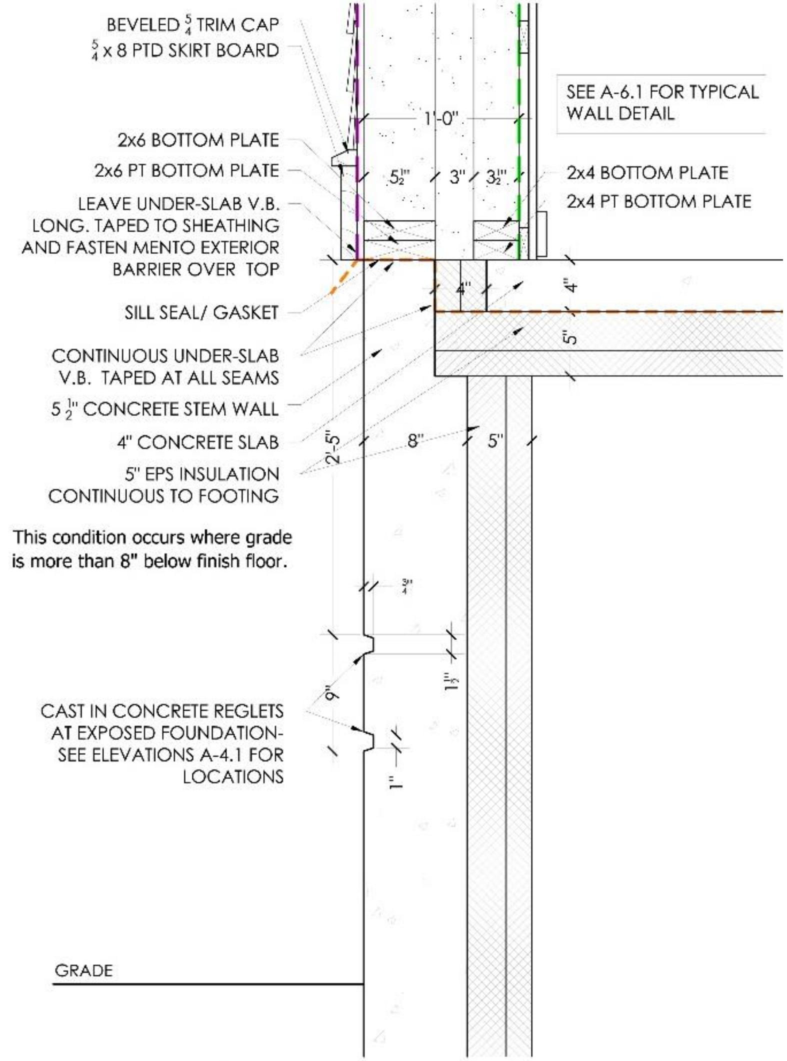
FROST WALL WITH STEM

EXPOSED FROST WALL (RETAINING)



1 Typical Foundation with Stem Wall

SCALE: 1 1/2"=1'



2 Typical Foundation

SCALE: 1 1/2"=1'

PROJECT EXAMPLES

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WATERBURY MUNICIPAL CENTER

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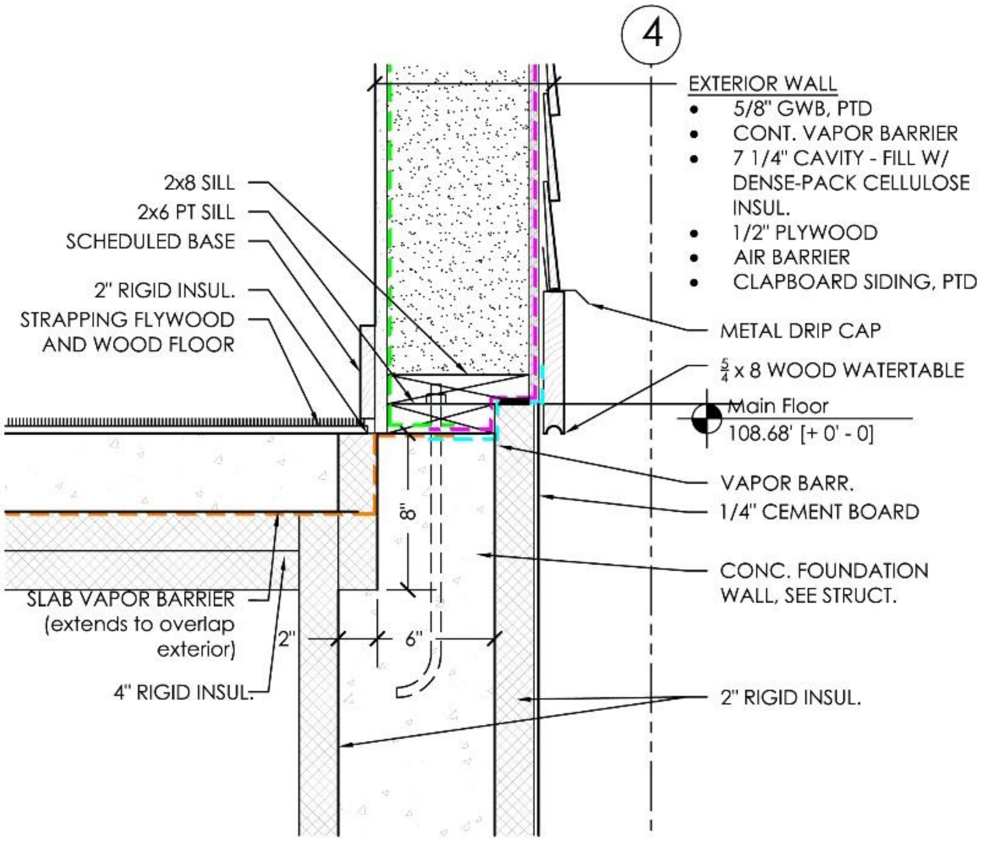
VARIATION – FROST WALL WITH STEM



3 Foundation Detail (typ.)

SCALE: 1 1/2"= 1'-0"

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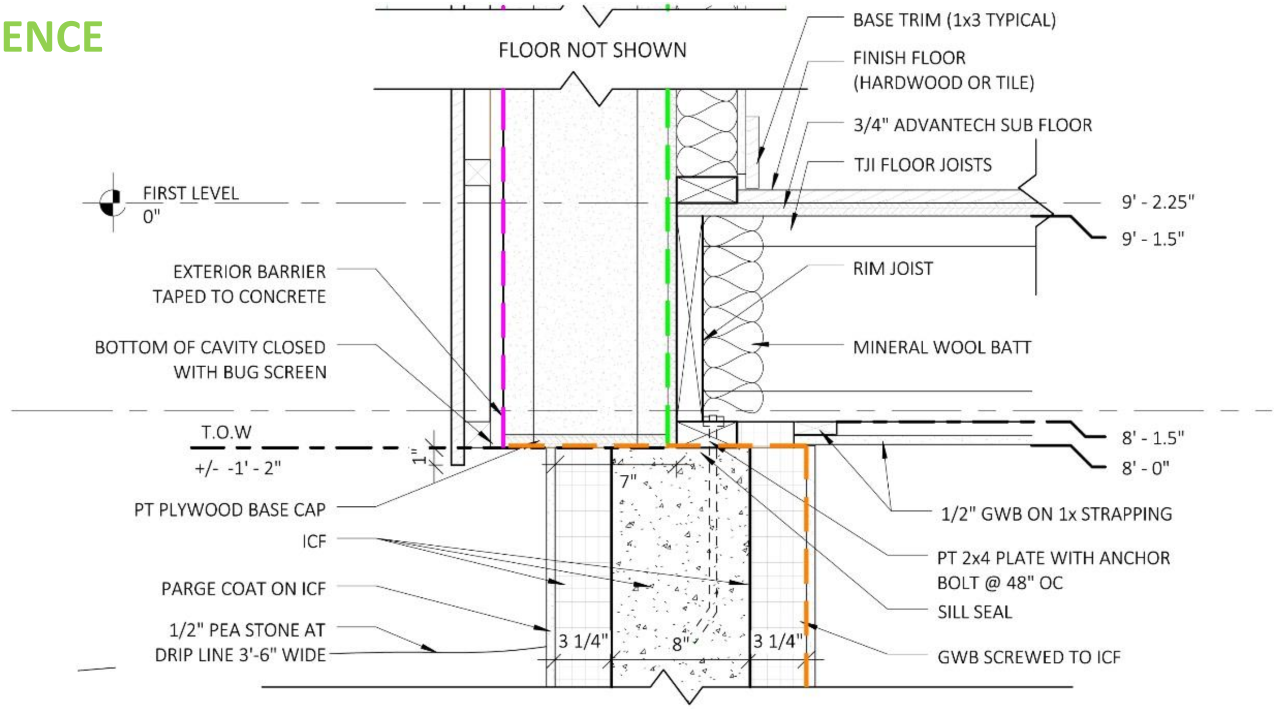
MIDDLEBURY RESIDENCE

ICF FOUNDATION

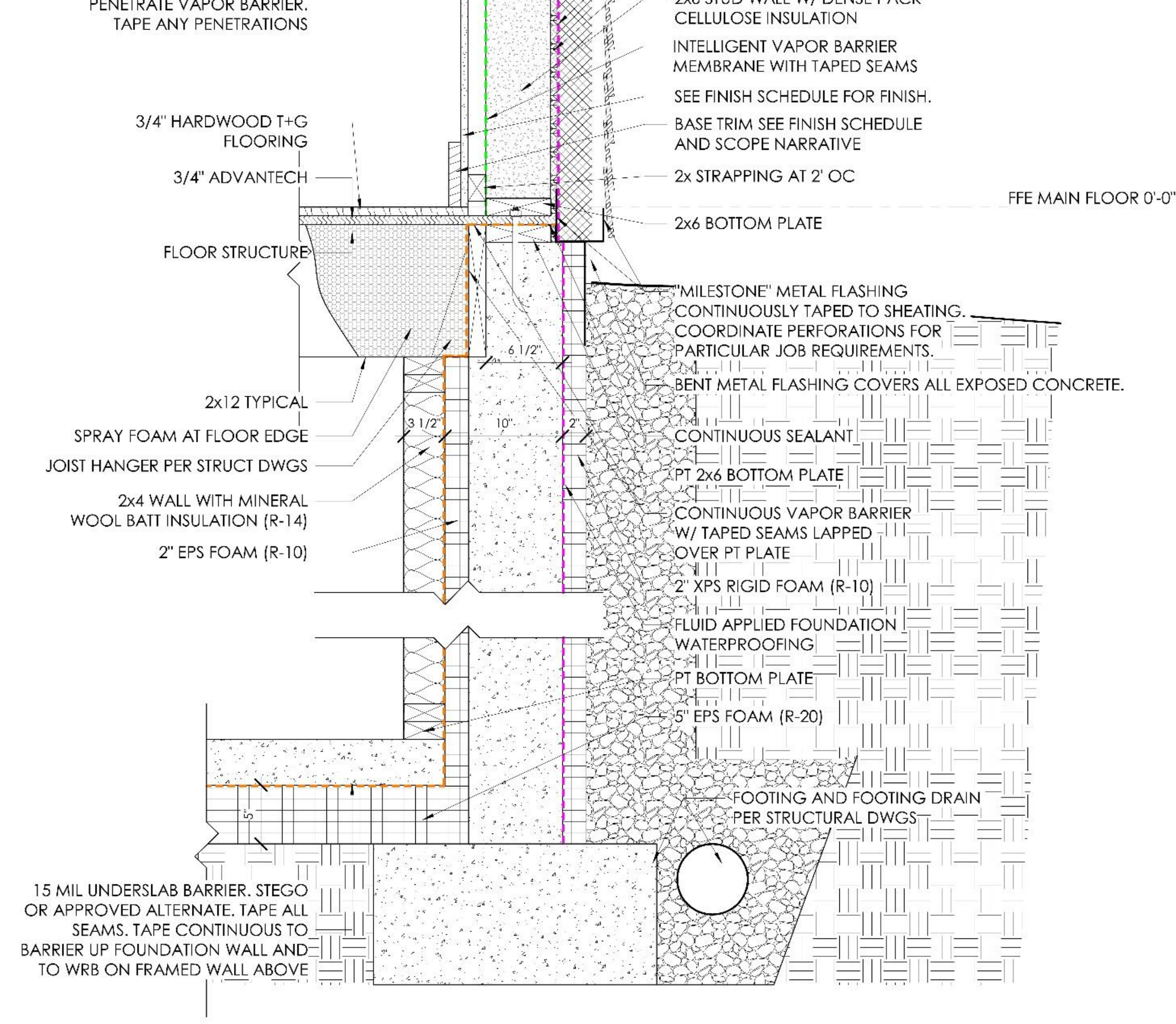


2 Typical Wall Section

A-5.1 SCALE: 1 1/2"= 1'-0"

MIDDLEBURY RESIDENCE

CORNWALL GUEST HOUSE



1 Typical Wall Section
1 1/2" = 1'-0"

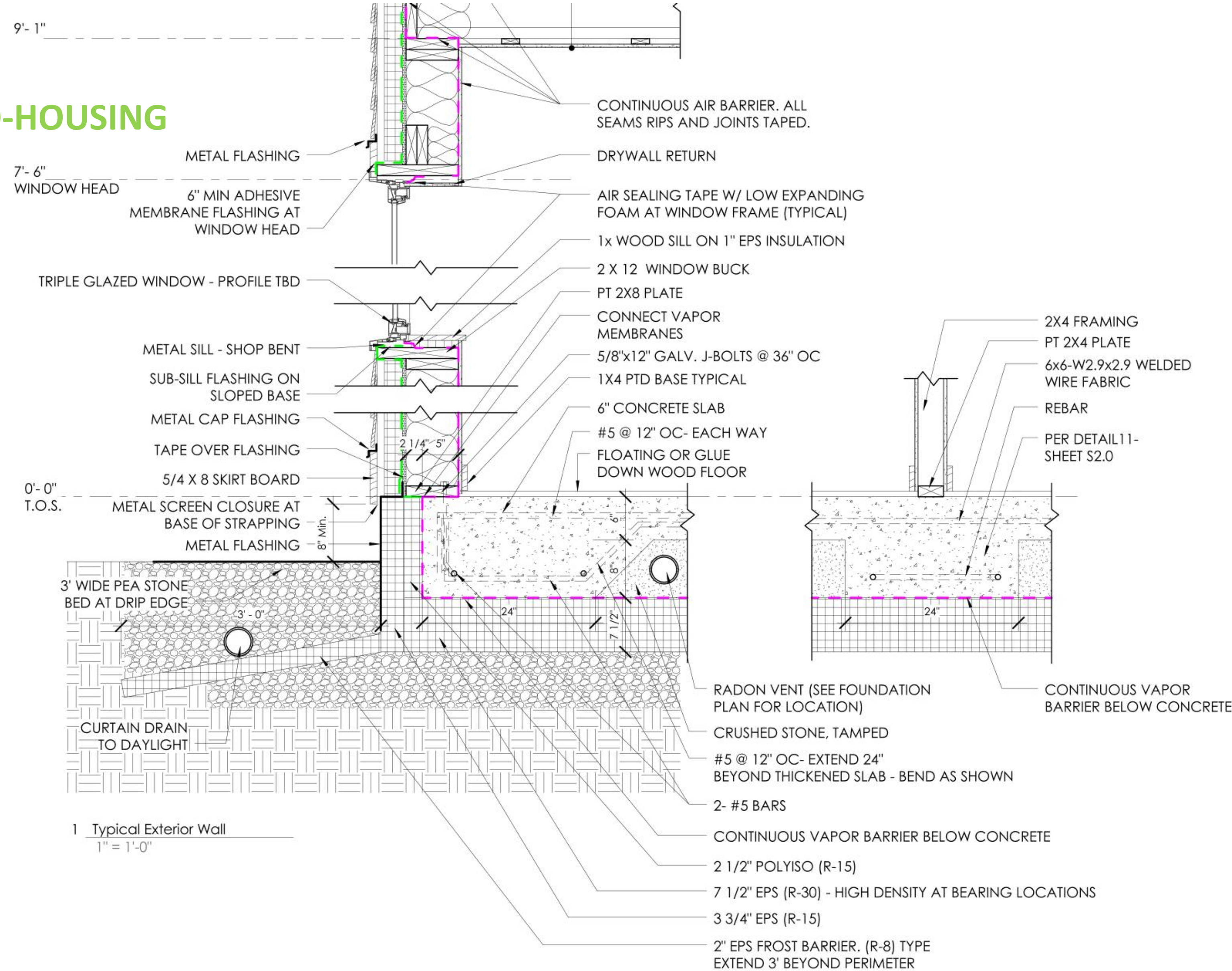
CORNWALL GUEST HOUSE

CORNWALL TOWN HALL
6” FOUNDATION WALL

CORNWALL TOWN HALL

6” FOUNDATION WALL

BRISTOL CO-HOUSING



PROJECT EXAMPLES

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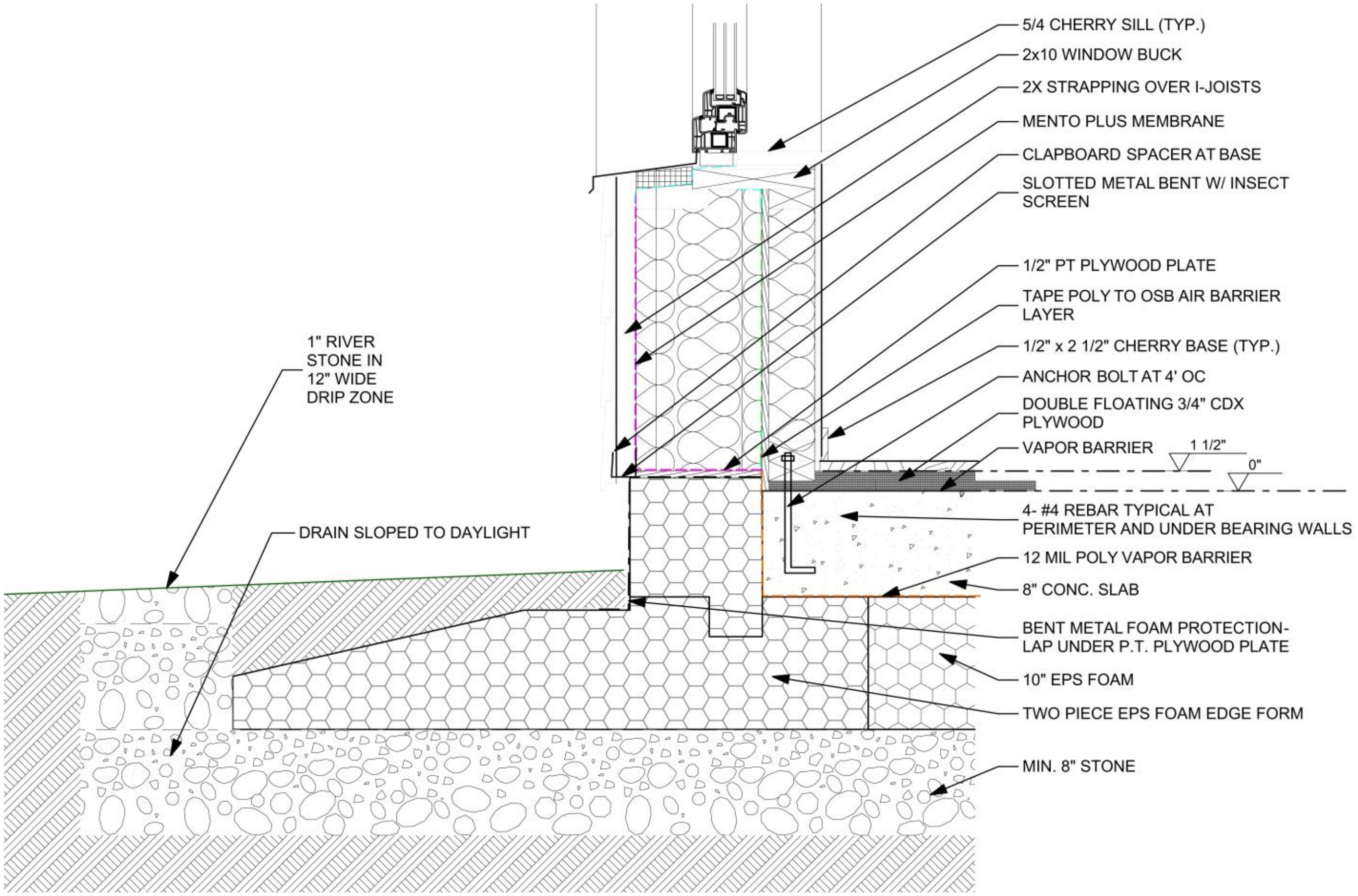
BRISTOL CO-HOUSING

CORNWALL RESIDENCE



CORNWALL RESIDENCE

CORNWALL RESIDENCE

VARIOUS PROJECTS

SLAB/FOOTING TREATMENTS

ST ALBANS STATE OFFICE BUILDING

SLIDE TITLE

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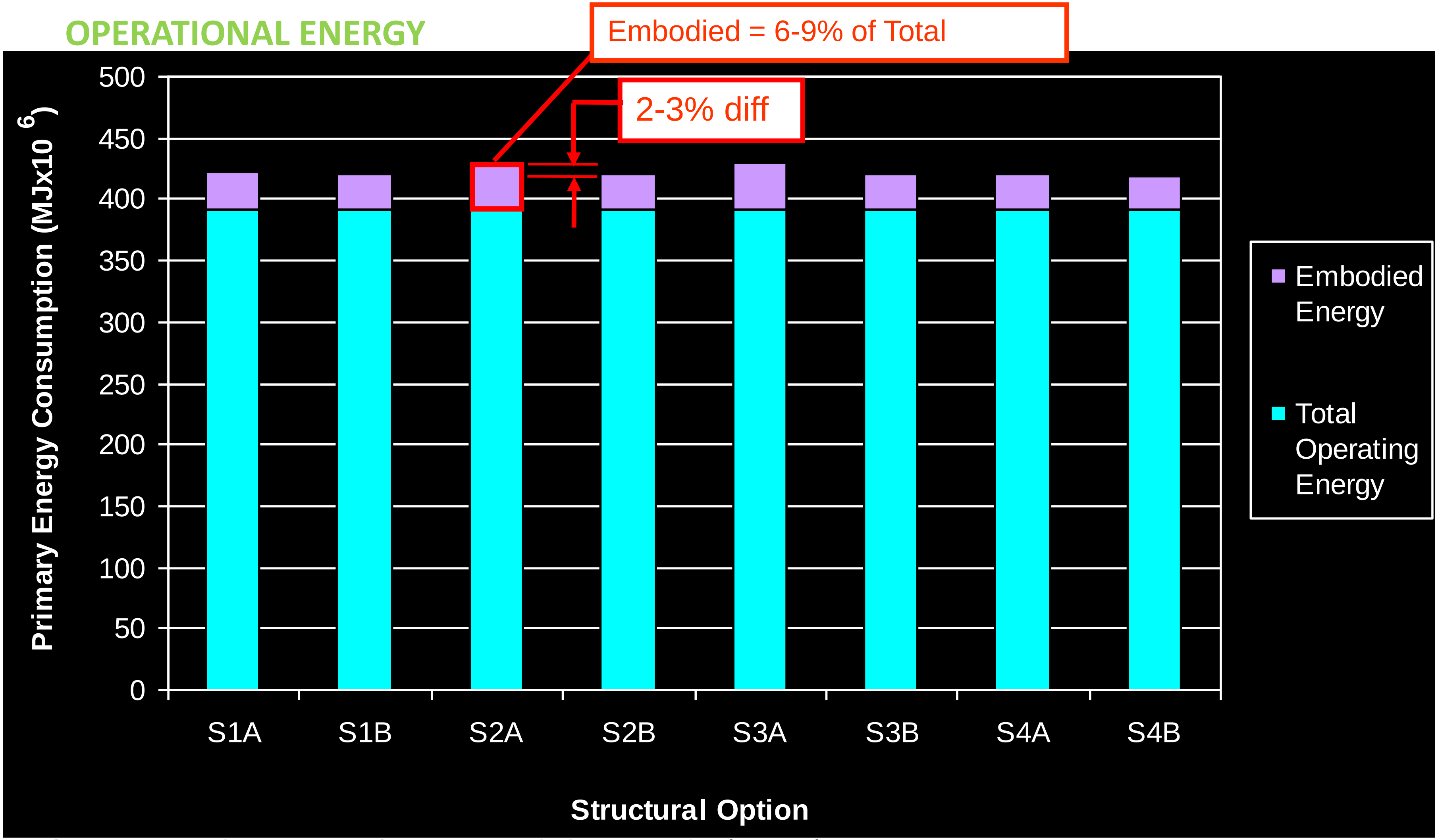
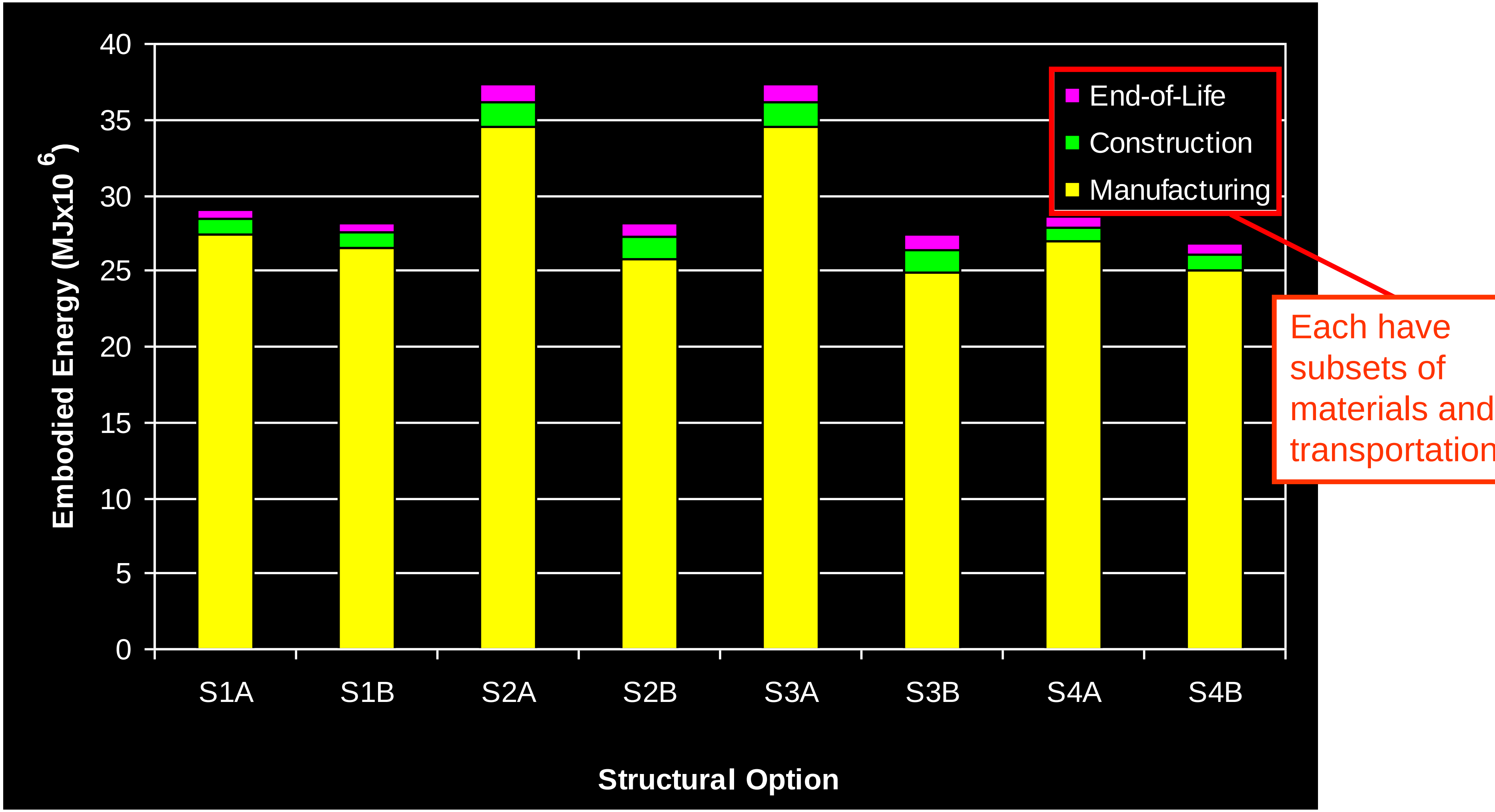
EMBODIED & OPERATIONAL ENERGY



ref: Structural Engineer's Sustainability Guide (ASCE)

EMBODIED ENERGY



ref: Structural Engineer’s Sustainability Guide (ASCE)

ADAPTIVE MATERIAL SUBSTITUTION/EPDs

Environmental Product Declaration

Permacon with CarbonCure

Life Cycle Inventory Data

Indicator	Units	Raw material supply	Manufacturing	Transportation	Total
Total Primary Energy Production					
Non-renewable fossil	MJ	556.5	1280	98.9	1935
Non-renewable nuclear	MJ	139.9	212.9	1.36	354.2
Renewable (solar, wind, hydro, geothermal)	MJ	15.8	22.7	0.170	38.6
Renewable (biomass)	MJ	13.2	7.07	0.044	20.3
Material Resources Consumption					
Non-renewable material	kg	1914	0.251	0.034	1914
Net fresh water (inputs minus outputs)	L	1.19E+05	1.65E+05	0.322	2.84E+05
Non-hazardous waste	kg	51.7	1.38	0.092	53.2
Hazardous waste	kg	5.24	0.052	2.69E-05	5.29

MATERIALS

- Masonry
- MSE Walls
- Precast
- CO2 Absorbing Cements

EPDs

Environmental Product Declaration

Permacon with CarbonCure

Life Cycle Impact Assessment Results

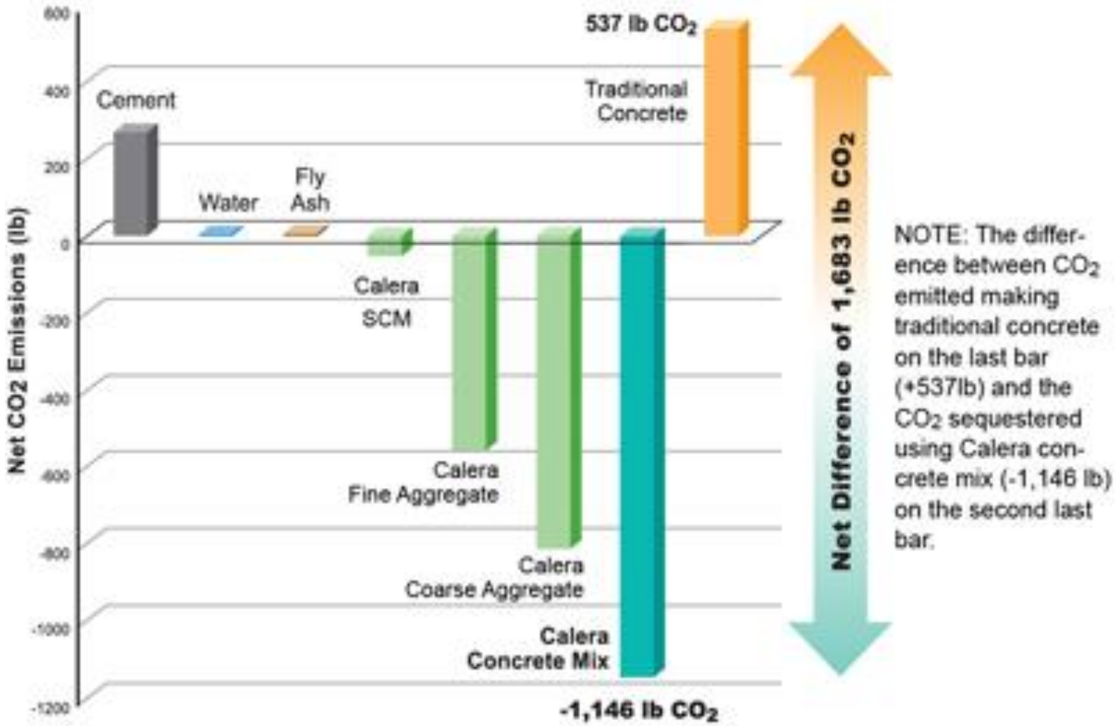
INFORMATION
(REF BUILDING GREEN, January 2018)

Indicator	Units	Raw material supply	Manufacturing	Transportation	Total
Acidification	kg SO_2 eq	1.55	0.662	0.045	2.26
Eutrophication	kg N eq	0.151	0.153	0.004	0.308
Global warming	kg CO_2 eq	298.7	88.9	7.46	395.1
Ozone depletion	kg CFC-11 eq	3.98E-06	1.91E-06	1.33E-08	5.90E-06
Smog	kg O_3 eq	18.6	2.59	1.18	22.4

ADAPTIVE MATERIAL SUBSTITUTION/EPDs

ALTERNATIVE MATERIALS

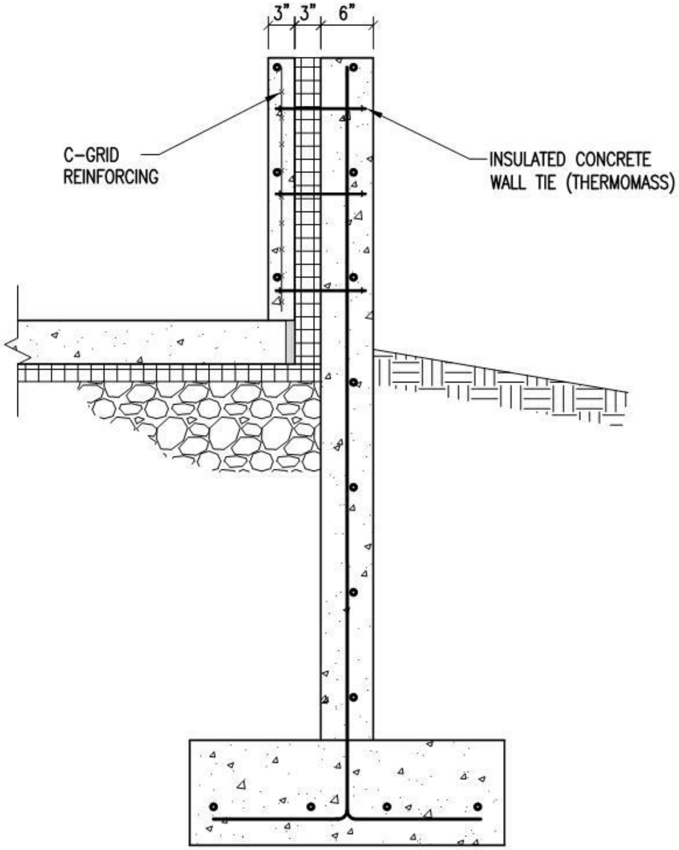
- Masonry
- MSE Walls
- Precast
- Magnesium Cements
- CO2 Absorbing Cements (Calera)
- Durable Concrete (CeraTech)



LOWER FOOTPRINT – FOAM INFILL

INSULATED WALL

- Less Concrete
- Durable Surfaces
- Like “sandwich” panels
- Thin pours w/ carbon-fiber Reinforcing



FORMWORK MATERIALS

REUSABLE MATERIALS

- Sawn Lumber – re-use as structure
- Fabric – reduced transport
- Panel Modules – design to sizing, more uses

END OF LIFE

RECYCLED CONCRETE AGGREGATE

- In concrete mixes and earth fills
- Reabsorb CO2 through specified process

Carbon dioxide uptake in demolished and crushed concrete

CO_2 Uptake During the Concrete Life Cycle
Nordic Innovation Centre Project 03018

SPECIFICATION MEASURES

Durability w/ SCM's

- Higher Chloride and Sulfite Resistance
- Lower Permeability
- Higher Strengths
- Lower ASR potential

Workability & Performance

- Gap graded aggregates to reduce cement volume
- Admixtures

Maximum Strength Limits

- Already specified in blast and other ductile concrete uses.
- Part of shrinkage controlled mixes
- Requires monitoring of concrete materials and mix properties

SPECIFICATION MEASURES

SCM Variations

- By function and location
- Strength limits and times
- By Mix Design

2.08 CONCRETE MIXTURES

A. Prepare design mixtures for each type and strength of concrete, proportioned on the basis of laboratory trial mixture or field test data, or both, according to ACI 301.

B. Cementitious Materials:
   1. Use fly ash pozzolan or ground granulated blast-furnace slag as needed to reduce the total amount of portland cement, which would otherwise be used by:
      a. 40 percent for perimeter foundation wall ftgs, individual and combined footings, including connective grade beams.
      b. 25 percent for perimeter foundation wall and beam elements with integral pilasters; site walls; pit walls; and pads
      c. 15 percent exterior, exposed slabs; and interior slabs-on-grade and slabs on metal deck.

Sourcing Cement or Pozzolans

- Dry Kiln Process
- EPD's
- Defined Emission Standards
- Mining Standards
- Magnesium-based Cements

Other Ingredients

- Non-potable water

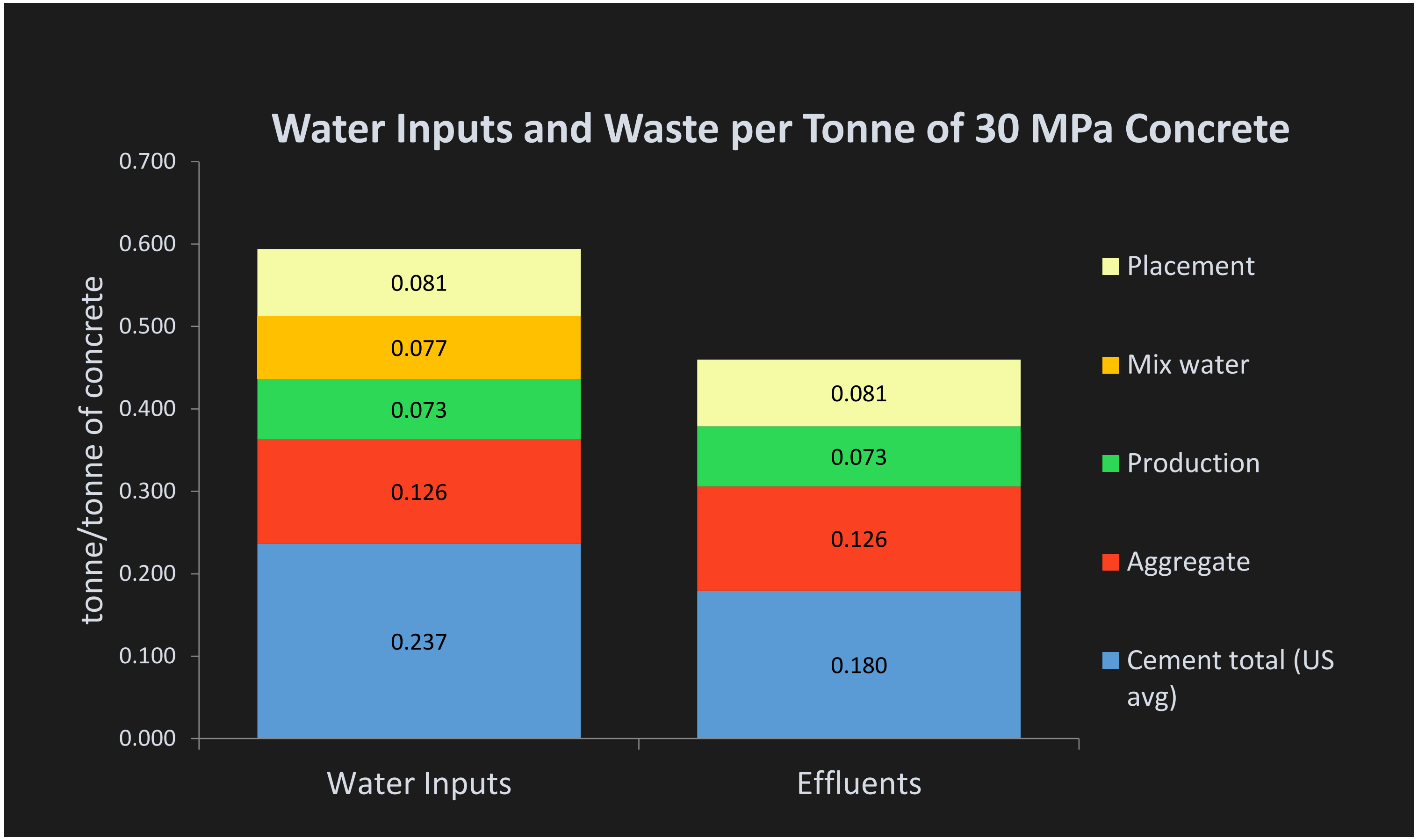
C. Water: Non-potable meeting ASTM C 94..

- Locally sourced aggregates
- Recycled Content Reinforcing

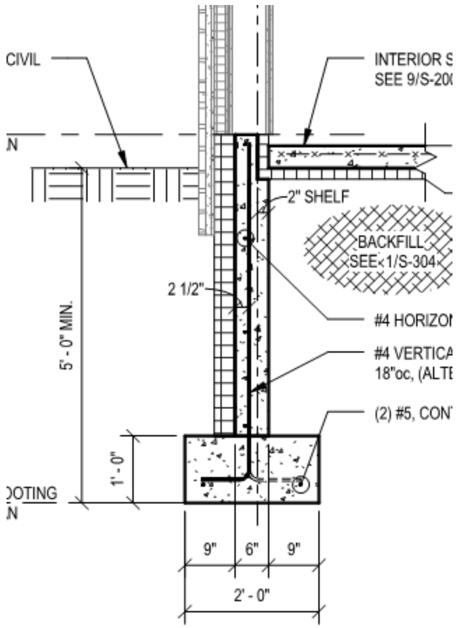
2.2 STEEL REINFORCEMENT

A. Recycled Content of Steel Products: Provide products with an average recycled content of steel products so postconsumer recycled content plus one-half of preconsumer recycled content is not less than 70 percent.

SPECIFICATION MEASURES



THIN WALL CASE STUDY



ADJUSTMENTS

- Based on "simplify backfill" & "prevent inadvertent damage"
- Impacts outlined

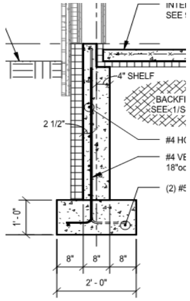
After much discussion, we request that the typical foundation wall be increased in thickness from 6" to 8". It is our opinion that the thicker wall will simplify the backfilling operation and prevent inadvertent damage to the wall during construction. Please issue the change In the next addendum. Thank you.

thought we were asked to focus on reducing the foundation wall thickness.

That's about 15-20 cy (3 tons of CO2) more of concrete, I think, and the reinforcing will go up a little just to keep it at minimum - as we were stretching at 6" - the horizontals would be #4@12".

6" FOUNDATION WALL

- Adequate for Load and Fit-up
- Conformed to estimate & bid targets to "reduce amount of concrete"



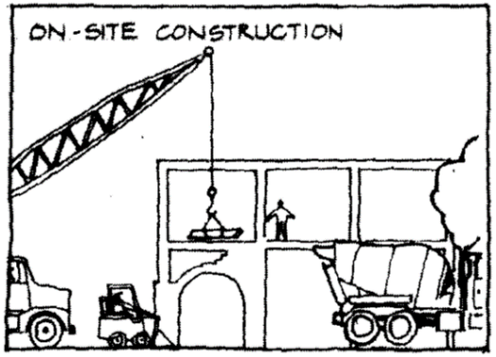
8" FOUNDATION WALL

- Adequate for Load and Fit-up
- 3 tons more CO2 at ~ 17 yds
- More reinforcement also (minimum required)
- Added Construction Cost

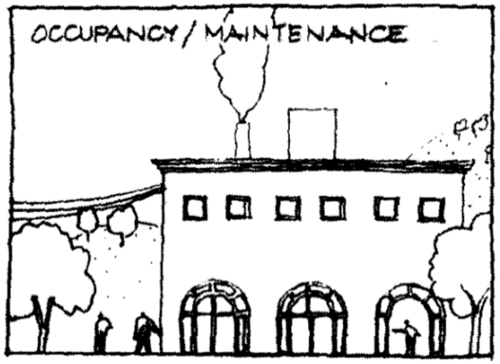
LIFE CYCLE ASSESEMENTS

LCA… a method of measuring total environmental impacts of a product or process from acquisition of raw materials to end-of-life.

1. Construction

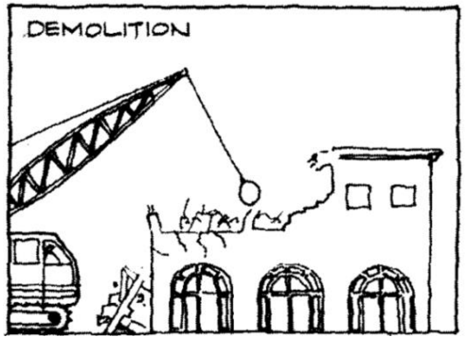


2. Operation

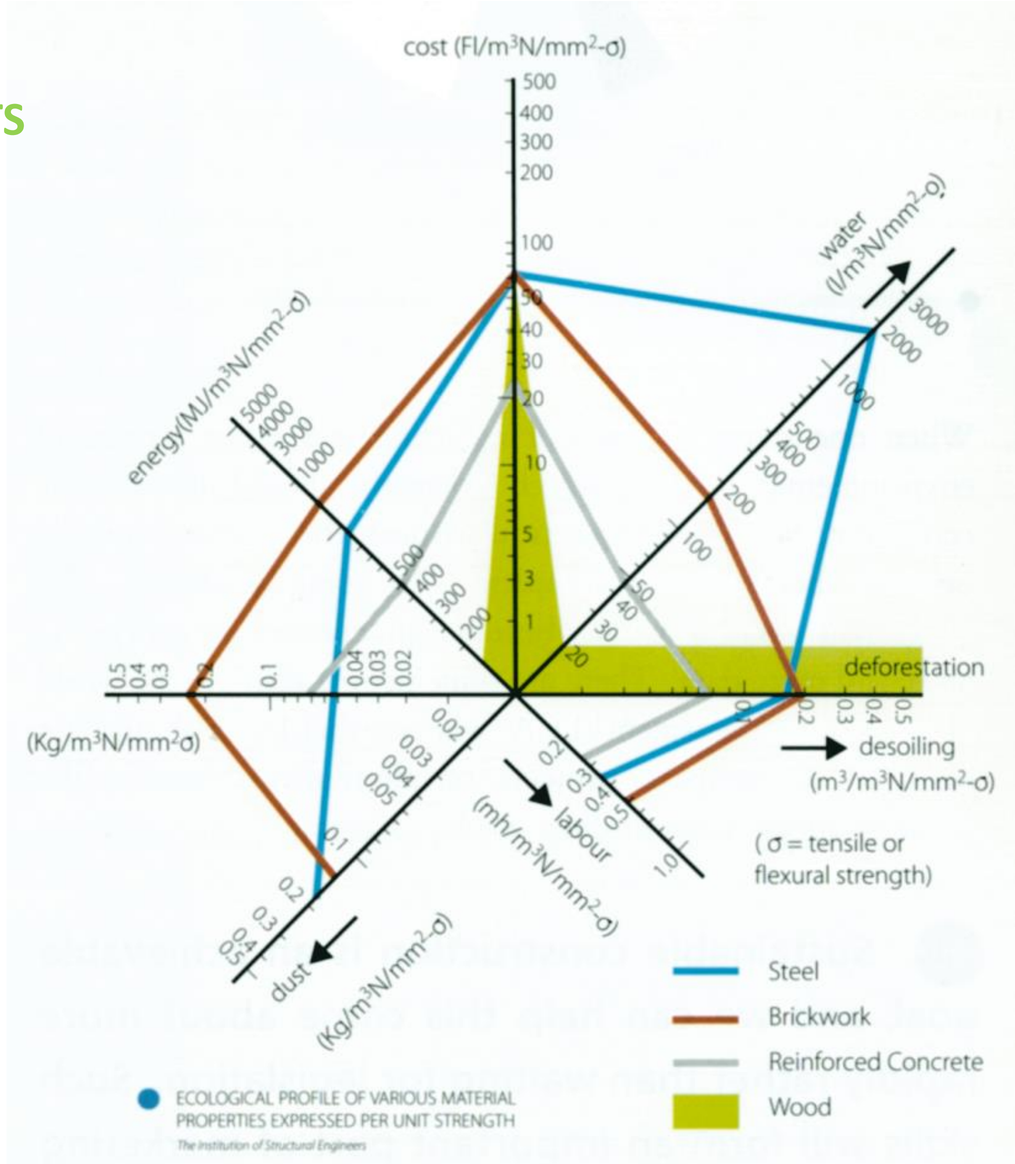


3. Renovation

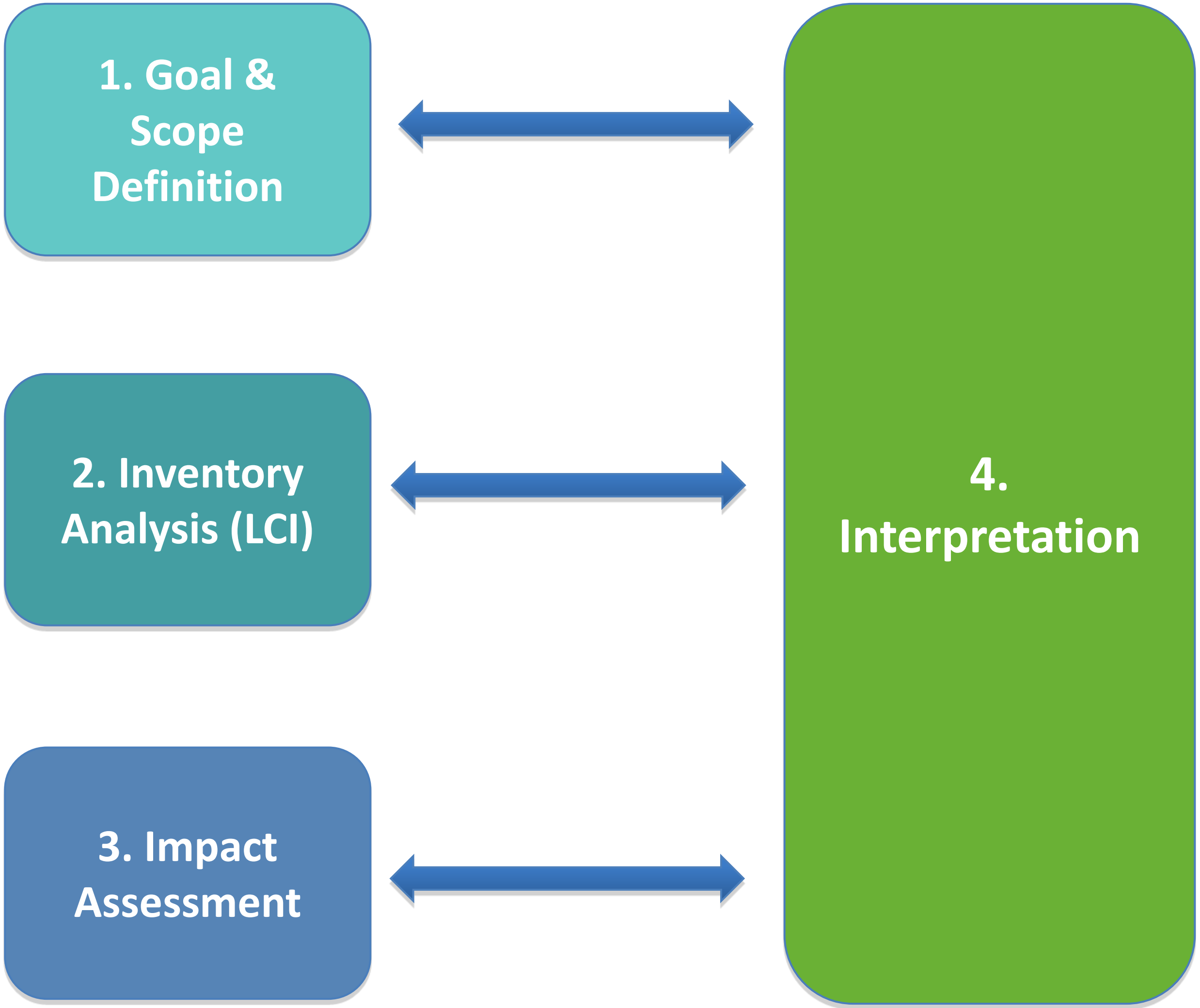
4. End-of-Life



LIFE CYCLE ASSESEMENTS



LIFE CYCLE ASSESEMENTS



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RELATED SUSTAINABILITY ISSUES

ASSOCIATED MATERIALS (REBAR, FORMWORK, CHEMISTRY, ETC) ALL HAVE THEIR OWN ENERGY AND ENVIRONMENTAL LOADS.

FORMWORK – SIMPLER SYSTEMS ALLOW STANDARD FORMWORK, LESS CUSTOM WORK AND/OR WASTED FORMS

THERMAL MASS – MUCH MORE RARE WITH HIGH PERFORMANCE ENVELOPES

CEMENT AND CONCRETE HAVE VARYING BENEFITS OR DRAWBACKS IN BUILDING RATING SYSTEMS

MATERIAL EFFICIENCY IS ONLY PART OF THE GAME – RIGHT-SIZE BUILDINGS

SCALE – WE CAN EXPORT IDEAS FROM SMALL VT TO LARGER MARKETS

TAKE-AWAY

IT'S UP TO YOU (US) TO CHALLENGE OUR MATERIAL STATUS QUO.

ALL MATERIALS HAVE A FOOTPRINT – THINK! ABOUT IMPACTS.

BE CREATIVE TO USE LESS. (MORE ENGINEERING, LESS MATERIAL)

AS ENERGY GETS MORE PRECIOUS, SMALL MOVES WILL COUNT MORE.

DETAILING – THINK ABOUT THERMAL CONDUCTANCE/BRIDGING

DETAILING – THINK ABOUT CONTINUITY OF MEMBRANES

REDUCE CONCRETE, AND REDUCE CEMENT IN THAT CONCRETE

THINK ABOUT THE WHOLE, INCLUDING LIFE TIME OF BUILDING

QUESTIONS??

A WORD ABOUT

THE CONFUSED AND IMPOVERISHED STATE OF ARCHITECTURAL RESEARCH…