Southeast DC Neighborhood Library Embodied Carbon Analysis

SEPTEMBER 2021

QUINN EVANS

FINAL REPORT

Project Title: Building Innovation Design Assistance – NZE Design Assistance & Embodied Carbon LCA Assistance

Building Innovation Design Assistance Grant
DOEE Grant # 2021-2101-USA-2

Award Period May 2021- September 2021

Grantee Organization: Quinn Evans

Contact: Julia Siple jsiple@quinnevans.com 202-591-2521

DC Public Library

Project Team

DC Public Library

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Silman

Contents

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KEY FINDINGS

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Summary Findings

- Even when re-use seems complicated and possibly resource-intensive, it still often results in overall emissions reduction – 20% for the SE DC Library
  - For this project, re-use makes the below-grade work more carbon intensive than building as part of a new structure, because underpinning the existing structure requires substantial concrete
  - This additional 19 tons of CO_2 is more than offset by the savings from having preserved the above-ground building components
- Savings from specifying lower-carbon concrete are substantial
  - In addition to SCMs, innovative technologies that store carbon in concrete (not quantified in analysis here) can further reduce emissions by ~5% or more
- For this project, optimizing structural design to reduce concrete and steel quantities was not a high-impact strategy (~2% reduction in embodied carbon)
- Lower embodied carbon concrete is a huge opportunity for savings

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Summary Findings

- Below grade construction methods can be a significant contributor to embodied carbon.
  - The sheet piles and shoring would require a significant amount of material, but because this is not designed and documented by the team it’s hard to quantify or encourage strategies for reduction.
- The project team will revisit the discussion of low carbon concrete when the concrete is getting subcontracted to confirm best available approaches.
- Plan to include in concrete specifications:
  - Requirement to calculate GWP or provide EPD
  - Minimum cement replacement of 35%
  - Performance requirements that would prioritize lower GWP mixes

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Introduction & Project Objectives

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Project Goals

- **Research strategies** for reducing embodied carbon, with specific focus on building reuse and high-impact materials (concrete + steel)
- **Develop a methodology** to estimate embodied carbon using early-stage building design information, allowing for comparison and scenario analysis before design is finalized
- **Conduct an embodied carbon analysis** for the SE DC Library project to understand relative impacts of the proposed strategies
- **Provide recommendations** that are both project specific and translate lessons learned for broader local application

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Grant Funded Activities

- Research & Benchmark
  - Available EPDs for concrete and steel
  - Develop a list of strategies for reducing embodied carbon in steel and concrete without impacting material performance or longevity.
  - Talked with local concrete supplier about carbon reduction strategies in specifications that are feasible with limited cost.**
- Conducted Embodied Carbon LCA
  - Developed reduced carbon design strategies for the concrete and steel components of the project
  - Quantified the amount of steel and concrete using the Building Information Model and cost estimates
  - Ran 2 versions of the LCA for comparison
    - One for the steel and concrete to be used in the renovation; and
    - One for assuming a total replacement
  - Further iterated on LCA to include analysis of strategies for reducing carbon to understand potential carbon savings
- Analyzed, Documented, and Shared
  - Describe and quantify the embodied carbon savings by reusing the existing building as compared to new construction;
  - Describe strategies considered in the LCA to reduce the embodied carbon of
  - the concrete and steel to be used during the planned renovation;
  - Describe how the results of the LCA will be utilized by future projects and
  - how/if the library's design decisions have been influenced by the results of the LCA;
  - Develop a summary PowerPoint to share with the client, District of Columbia Public Libraries, for use in community meetings; and
  - Document and share findings in a final report for DOEE.

**Not originally included in funded activities list

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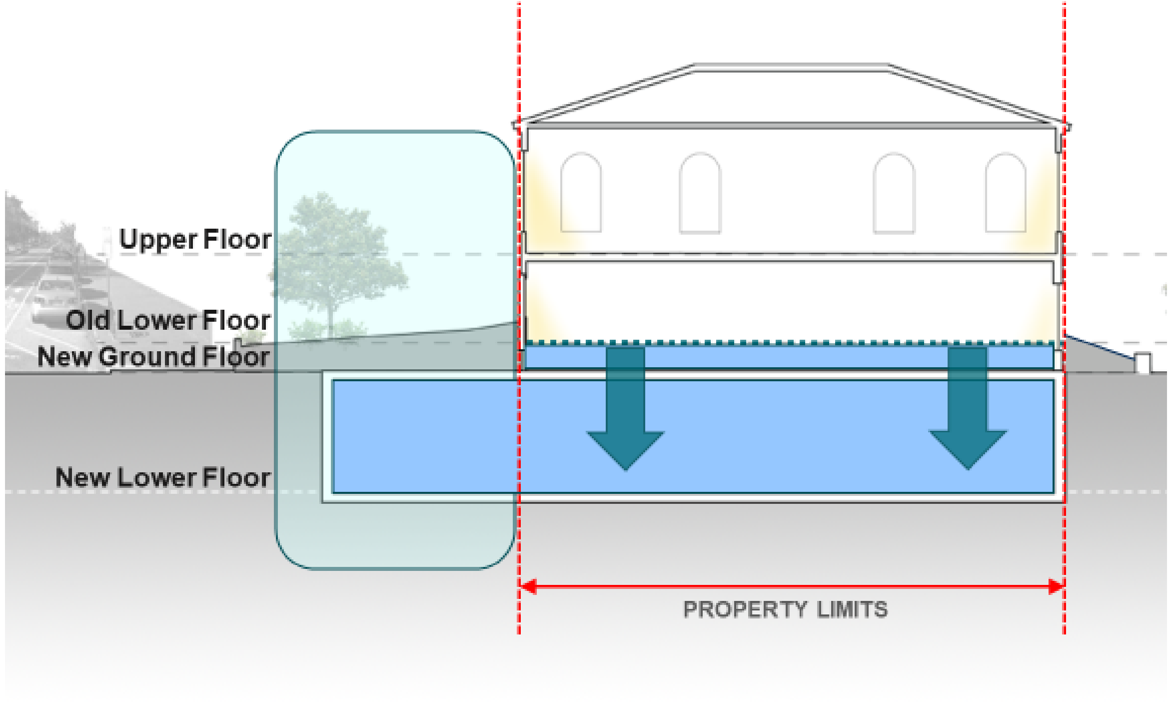
SE DC Neighborhood Library Project

- Renovation and expansion of a historic library in the Eastern Market neighborhood
  - Modernization of the existing 8,000 sf structure, new mechanical and electrical equipment
  - Addition of a new, accessible entrance
  - Expansion below grade to add a new 9,000 sf basement level
- Timeline:
  - Currently in schematic design phase
  - 2022: Design complete and construction documents developed
  - 2023-2024: Construction

Project Constraints



- Height Limit
  - Due to location in a historic district, cannot significantly increase the building height
  - Whether an addition or a new building, the only way to increase square footage is below ground
- Site Challenges
  - Tight urban site requires “underpinning” (supporting from below) at boundaries with neighboring buildings and substantial steel for support of excavation

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Embodied Carbon Basics & Reduction Strategies

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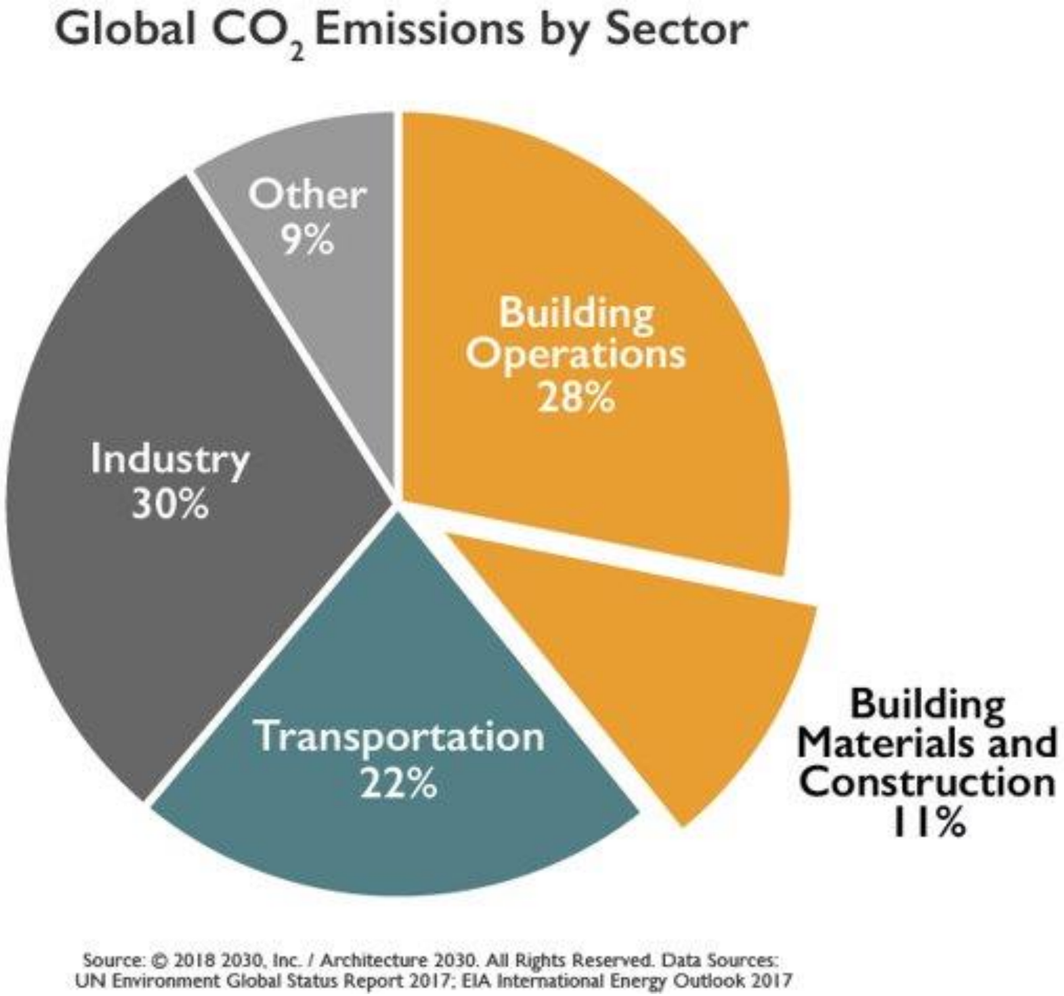
Embodied Carbon: Why it Matters



- Embodied carbon refers to the emissions associated with a building before the lights even turn on – the **emissions from extracting and manufacturing materials, the construction process, and end-of-life**
- Embodied carbon makes up **11% of annual carbon emissions**, globally

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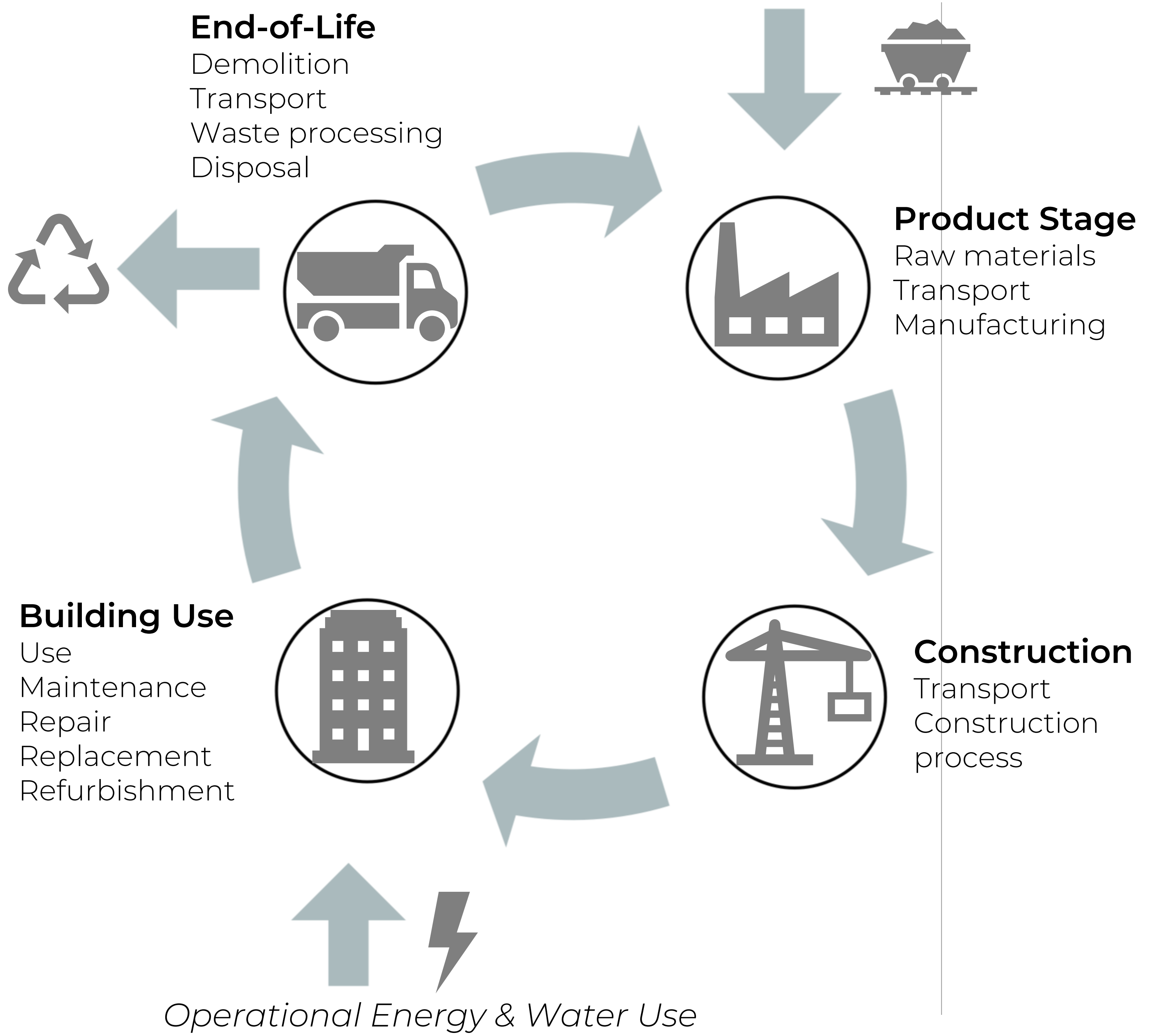
Embodied Carbon

Operational Carbon



Why Existing Bldgs for Carbon Reduction

Image Source: GreaterGreater Washington Image from Interactive Map Created By National Trust for Historic Preservation

- Construction has a substantial carbon impact is largely **spent** once the building is complete, unlike operational carbon that can be reduced over time
- **New buildings account for only 1%** of all our building stock each year
- Existing buildings avoid embodied carbon of new construction
- Existing buildings can be retrofitted have great operational carbon performance too

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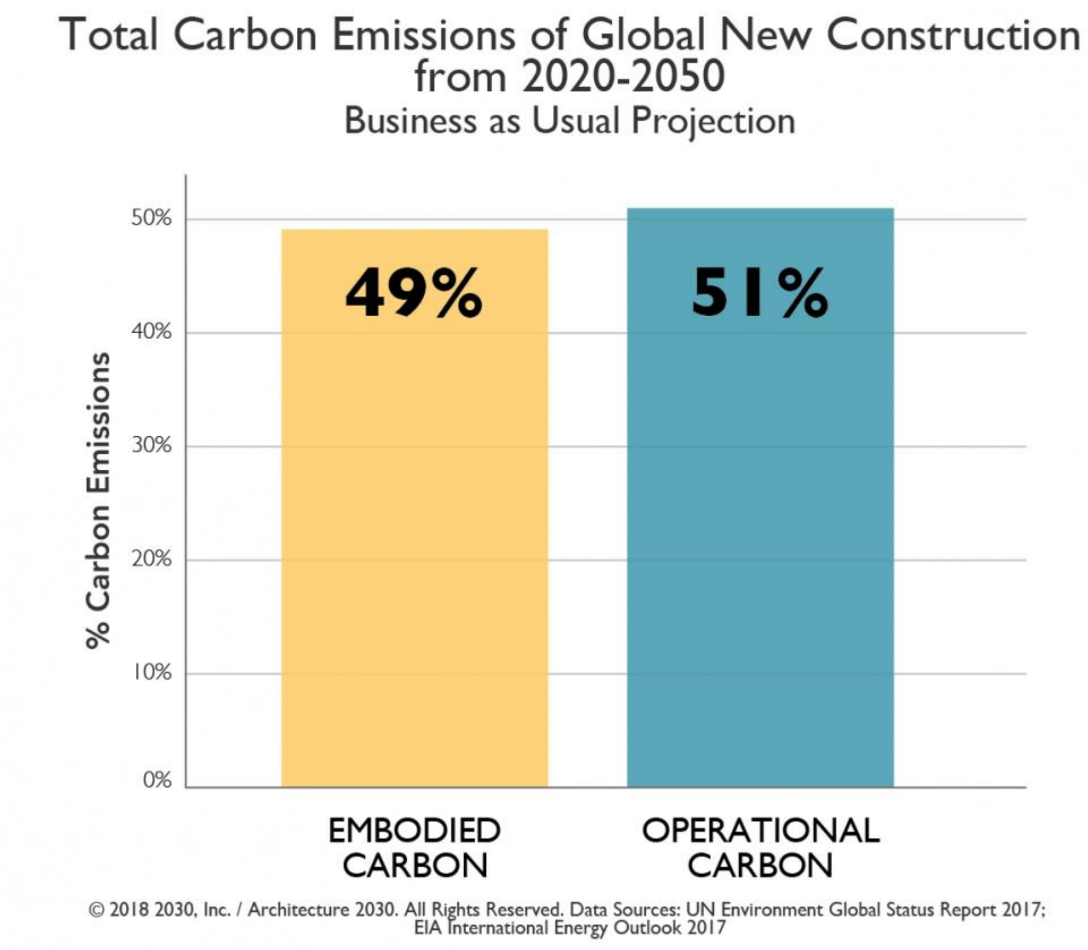
Embodied Carbon: Why it Matters



- Embodied carbon will make up almost half the emissions associated with new construction between 2020-2050
- As building operations are made more energy efficient, the relative importance of embodied carbon will increase

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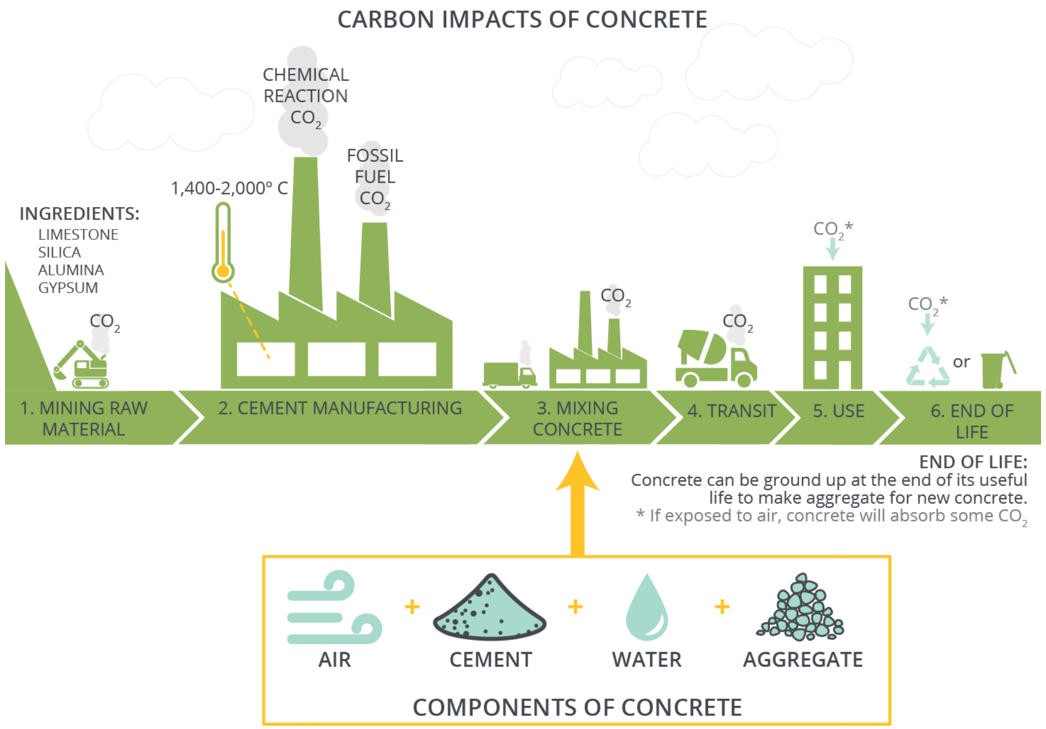
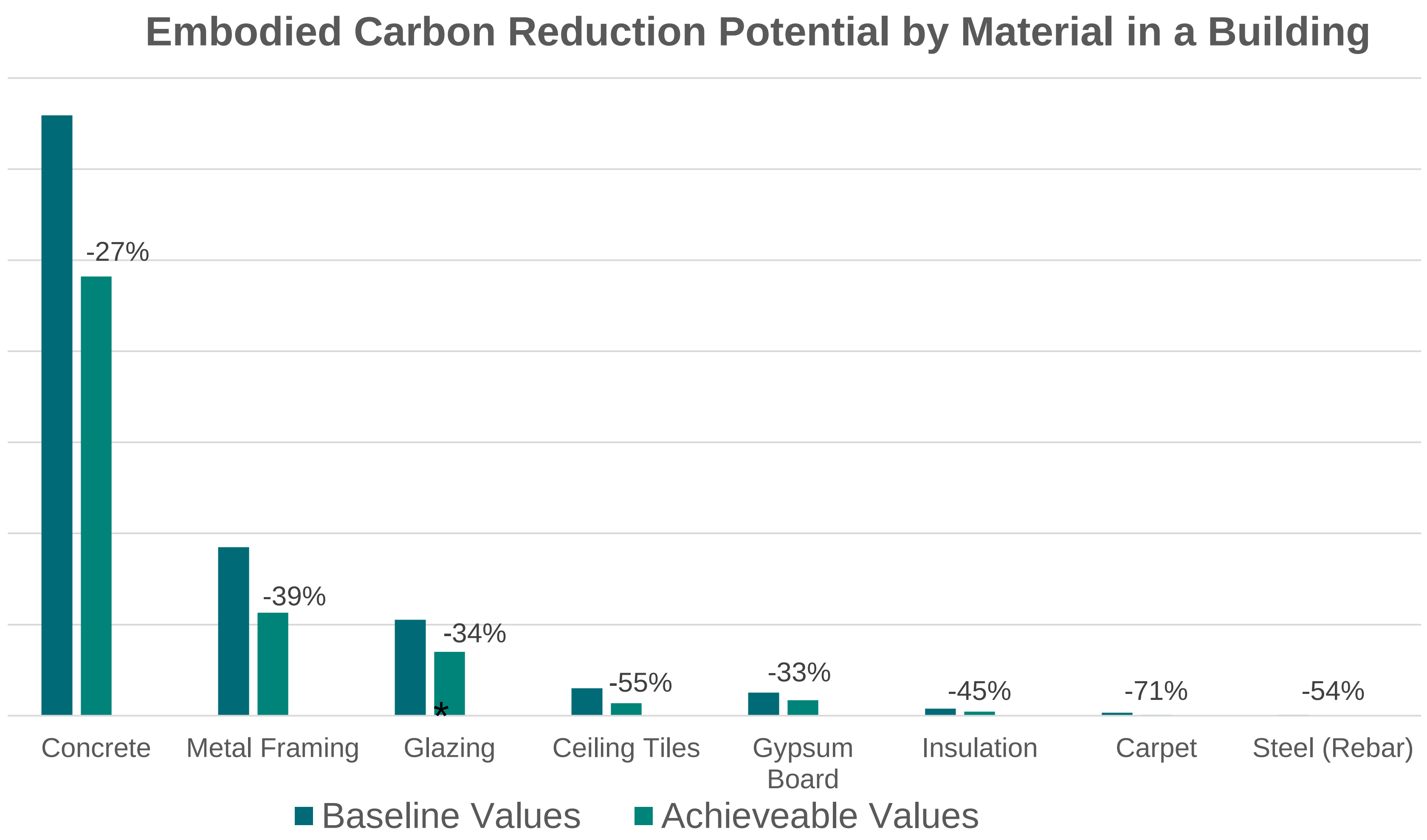
Opportunity for big impact in Concrete



- Concrete is responsible for 6-10% of all global carbon emissions
- If concrete were a country, it would be #3 emitter behind China and US
- Roughly 40% of carbon is emitted from burning fossil fuels in manufacturing, other 60% is related to the chemical reactions

Concrete and Structure have the most concrete in buildings



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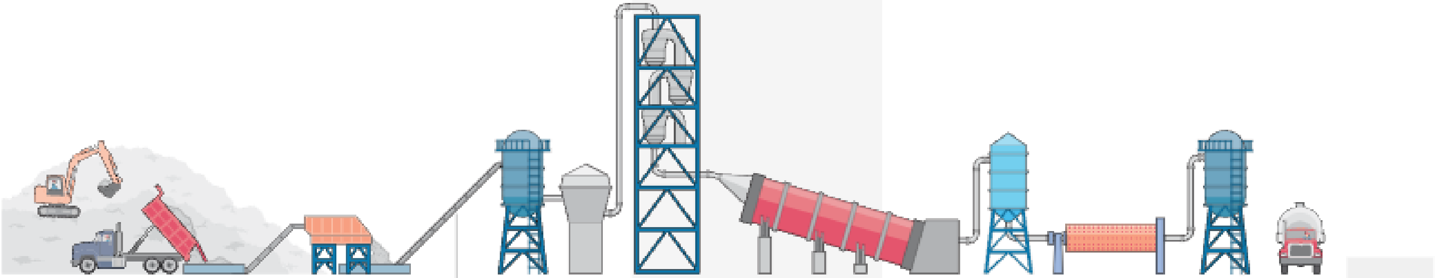
Where's all the carbon in concrete?

Cement manufacturing is a highly complex process.

Raw materials, energy, and resources | **Clinker and cement manufacturing**



	Quarry	Crusher	Transport[1]	Raw mill	Kiln and preheater/ precalcinator[2]	Cooler[3]	Cement mill	Logistics[4]	**Total**
Energy, mega-joule/ton	40	5	40	100	3,150	160	285	115	3,895
CO_2, kilogram/ton	3	1	7	17	479 Calcination process; 319 Fossil fuels	28	49	22	925

[1]Assumed with 1kWh/t/100m.
[2]Assumed global average, data from the Global Cement and Concrete Association, Getting the Numbers Right 2017.
[3]Assumed reciprocating grate cooler with 5kWh/t clinker.
[4]Assumed lorry transportation for average 200km.

McKinsey & Company

- During cement production, roughly 40% of the CO_2 generated is from the burning of fossil fuels in the manufacturing process, and the remaining 60% is from naturally occurring chemical reactions during processing

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Strategies to Reduce Embodied Carbon

1. **Re-Use**: Renovate and re-use buildings whenever possible, or preserve particularly carbon-intensive structural components
2. **Design with Less**: Optimize designs to reduce the use of the most carbon-intensive construction materials
3. **Smarter Specifications**: Specify low-carbon types of carbon-intensive materials

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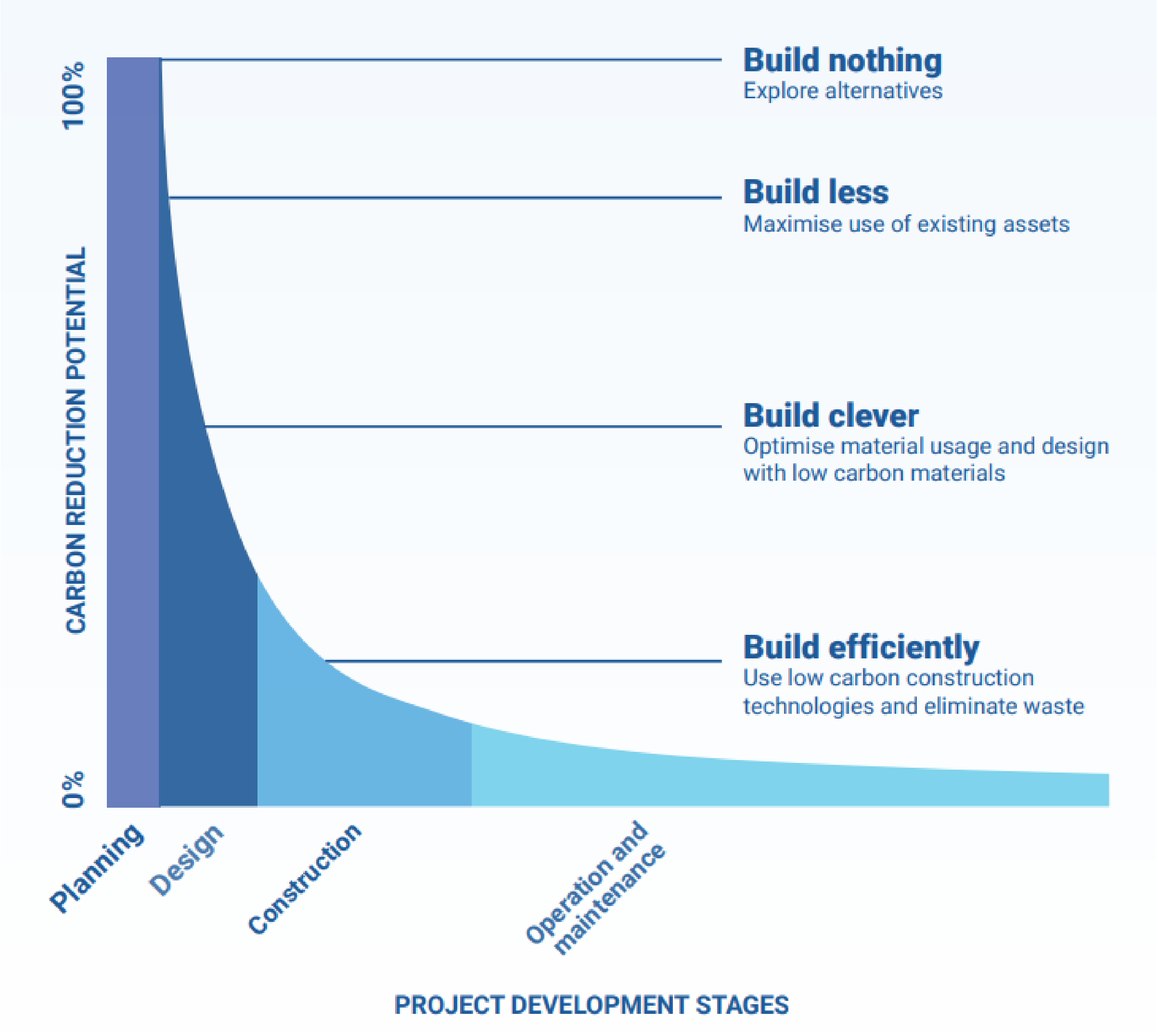
To Reduce Embodied Carbon, Start Early



- Decisions that have the biggest impact on embodied carbon are those made earliest in the design process
- Many existing embodied carbon tools focus on the very early or very late stages of design
- Build less (ie, re-use existing structures) and build clever (design with less + design with lower-carbon materials) offer substantial savings potential

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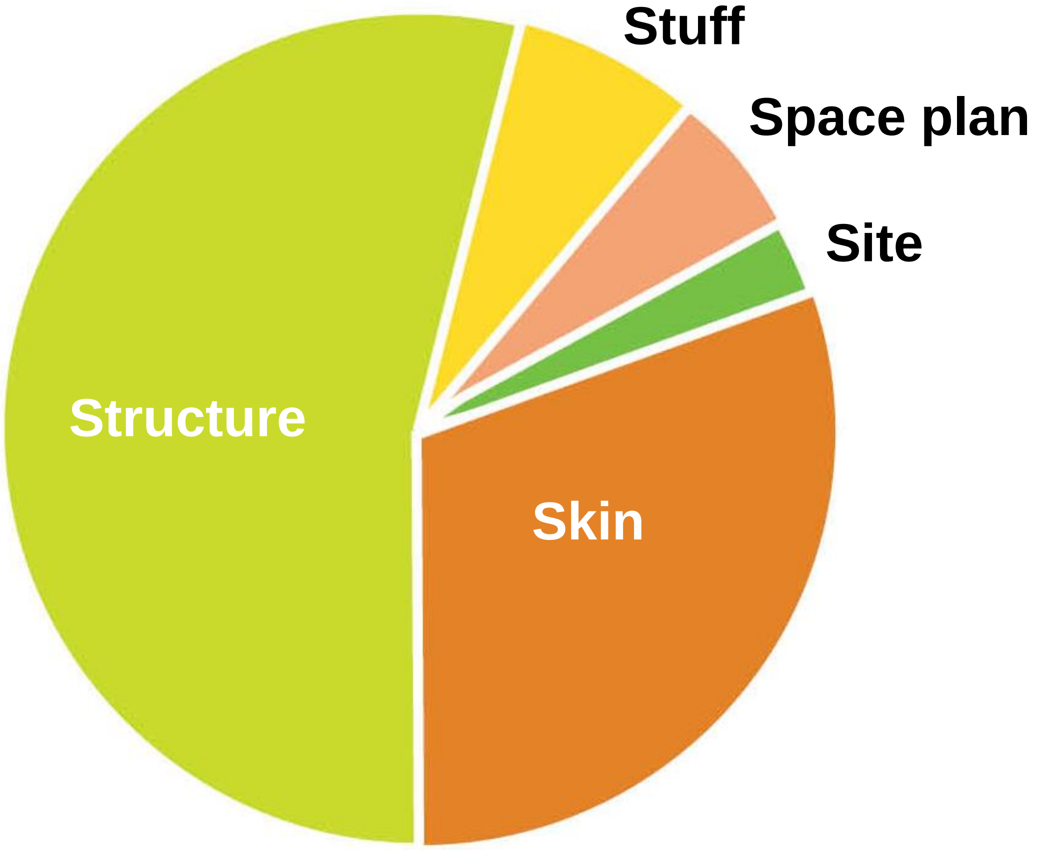
Source: Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon. World Green Building Council, 2019.

Strategy #1: Re-Use

- More than 50% of the embodied carbon of a typical building is in its structure – re-using structural components can have substantial benefits
- About 25% of embodied carbon is in the building envelope, which can also be re-used
- Re-using interiors, finishes, etc. offer more limited opportunities for emissions reduction (and may be harder to re-use)

Embodied Carbon in a Typical Building



Source: Architecture2030 and De Wolf, et.al; Structural Material Quantities And Embodied Carbon Coefficients: Challenges And Opportunities, April 2014

Strategy #2: Design with Less

- Concrete and steel are highly carbon-intensive and heavily used in construction
  - Cement, a component of concrete, is responsible for appx. 6%-10% of global carbon emissions)
  - Steel represents another 7-9% of global carbon emissions, of which about half is used in buildings
- Optimizing designs to use less of these two materials, or considering alternative structural systems (eg mass timber), can have a major impact
- Reducing other relatively carbon-intensive materials (eg glazing), can also have an impact

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Strategy #3: Smarter Specifications

Specifications can be used to drive selection of lower-carbon materials, especially for concrete.

- **Replace Cement** - Specifications that encourage the reduction of cement content in concrete can reduce the carbon footprint of the material:
  - Replacing up to 20% of the cement with alternative Supplementary Cementing Materials (SCMs) (such as blast furnace slag, pozzolans, fly ash) is increasingly common
  - Replacing greater shares can yield greater carbon reductions
- **Use Performance-Based Specifications**, which allow contractors greater flexibility to maximize use of SCMs. Also consider specifying maximum strength at day 56 (vs. 28).

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Strategy #3: Smarter Specifications

- Require **Environmental Product Disclosures** (EPDs), which provide information on the global warming potential associated with specific products

- If 3rd party verified EPDs aren't available at least require the calculation of the GWP

Product Description and Declaration Summary

A curtain wall is "an external non-bearing wall, intended to separate the exterior and interior environments." (AAMA/ WDMA / CSA 101/I.S.2/A440-05). The stick-built traditional curtain wall system is assembled at the building site where the frame or mullions and glass are connected piece by piece. Arcadia's curtain wall systems are offered in a variety of depths, profiles, and finishes, with framing thermally- or non-thermally improved.

Cradle-to-Gate Results Summary		
Declared unit: 1 m^2		
Mass per m^2: 36 kg		
Impact Results		
Global Warming Potential	kg CO2-eq	188
Acidification Potential	kg SO2-eq	1.2
Eutrophication Potential	kg N-eq	0.1
Smog Formation Potential	kg O3-eq	12
Ozone Depletion Potential	kg CFC11-eq	4.4 E-6
Primary Energy		
Non-renewable Energy	MJ	2,278
Renewable Energy	MJ	549
Resources Consumed		
Non-renewable Materials	kg	222
Renewable Materials	kg	0.9
Net Fresh Water	L	2,466
Non-hazardous Waste	kg	0.03
Hazardous Waste	kg	0.01
Other Declarations		
Recyclable content: aluminum 39%, glass 52%		
Hazardous materials in >0.1% of window: none		

The Arcadia curtain wall windows included in this EPD:

- ❖T500-OPG1500
- ❖T500-OPG6000
- ❖T500-OPG1900
- ❖T500-OPG2900
- ❖T500-OPG3000
- ❖T500-TI Beam 3 Series
- ❖T500-TI Beam 1 Series (5-1/2, 6-1/2, 8-7/16, 9-7/8)

Smarter Specifications: Concrete

Commercially Available Products & Strategies:

- **Replace Cement** - Specifications that encourage the reduction of cement content in concrete can reduce the carbon footprint of the material
  - Replacing up to 20% of the cement with SCMs (such as blast furnace slag, pozzolans, fly ash) is increasingly common. Replacing greater shares can yield greater carbon reductions
- **Use Performance-Based Specifications -** Allow contractors greater flexibility to maximize use of SCMs. Also consider specifying maximum strength at day 56 (vs. 28).
- **Strong Aggregate –** Weak or lightweight aggregate can require increased cement content in the concrete to make up the requisite strength

Emerging Products & Strategies – Carbon-Sequestering Concrete:

- **CarbonCure** – Injects carbon into concrete as it cures to reduce emissions by 4-6%, becoming available in the region
- **Carbon Aggregates** - Companies like Blue Planet are using carbon from cement production to 'grow' aggregate; not widely available

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Smarter Specifications: Steel

At the industry level, producers can use strategies to reduce the embodied carbon of steel significantly:

- Recycled steel can have a carbon footprint that is one fifth that of virgin material.
- Steel produced by electric arc furnaces uses an average of 93% recycled steel, while the average for basic oxygen furnaces is 25 – 37%.
- Unlike basic oxygen furnaces, which rely on combustion, electric arc furnaces are capable of using renewably-generated electricity.

At the project level, it is challenging to specify particular sustainability standards:

- Unlike concrete, which is mixed at local plants and relatively customizable, most steel is produced to meet broad industry standards
- There are also fewer product-specific EPDs for steel construction members; many suppliers are covered under industry association average EPDs

Use steel from North America

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Conversation with Contractor & Local Supplier

- Met with Whiting Turner and Schuster Concrete 9/21
- Discussed strategies for reducing carbon in concrete, what they're seeing in specs, and what they see as feasible and least cost impactful. Aim to understand what we can do for this project and what might be future opportunities.
- Takeaways
  - Have not seen carbon or GWP requirements in specs
  - Like the idea of performance specs and GWP targets but need information about how to calculate GWP
  - Hard to make EPDs quickly and cost effective
  - Schuster can do Carbon Cure but man other readimix companies cannot. Other companies are coming out with similar injection technologies.
  - Specifying a minimum SCM is the most feasible approach.
  - Comfortable with a 35% minimum.
  - This is an emerging topic, continue to have these conversations and express carbon priorities.
  - Would have less cost impact to ask for these GWP calculations on a bigger project.

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SE DC Library Embodied Carbon Analysis

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Embodied Carbon Analysis: Scenarios

Baseline: Demolish the existing structure, build a comparable new building with an additional below-grade level and new accessible entrance

Re-Use: Preserve the existing above-grade structure (including the building envelope, roof, and upper-level floor); add new below-grade level and new accessible entrance

Design with Less: Consider two options for below-grade design with varying concrete + steel quantities (Option 1 vs. Option 2)

Smarter Specifications: Consider concrete mixes that replace varying levels of cement with supplementary cementitious materials (SCMs). Replacing cement, the most carbon-intensive component of concrete, with SCMs reduces the embodied carbon of concrete.

- 0% Cement Replacement - Worst case
- 20% Cement Replacement – Increasingly common
- 50% Cement Replacement - Aggressive

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Embodied Carbon Analysis: Results

	Baseline: Demolish + Rebuild	Renovate + Re-Use Spec 0% SCM		Renovate + Re-Use Spec 20% SCM		Renovate + Re-Use Spec 50% SCM	
Design Option		*#1*	*#2*	*#1*	*#2*	*#1*	*#2*
Est. Embodied Carbon (tons CO_2)	667	531	522	477	467	387	375
% Reduction from Baseline		20%	22%	28%	30%	42%	44%

Design Option 1: Steel channels to support ground floor

Design Option 2: Concrete beams to support ground floor

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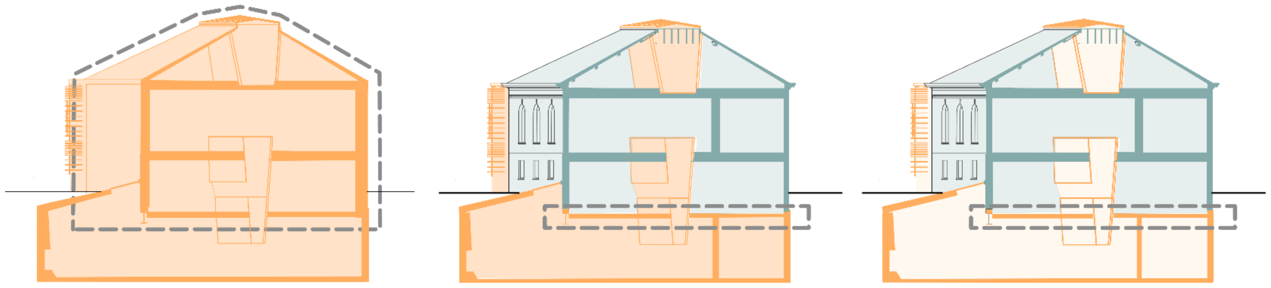
BENCHMARK:
Demolish & Build New

SCENARIO 1:
Renovate & Re-Use

SCENARIO 2:
Renovate & Re-Use with
Low-Carbon Materials



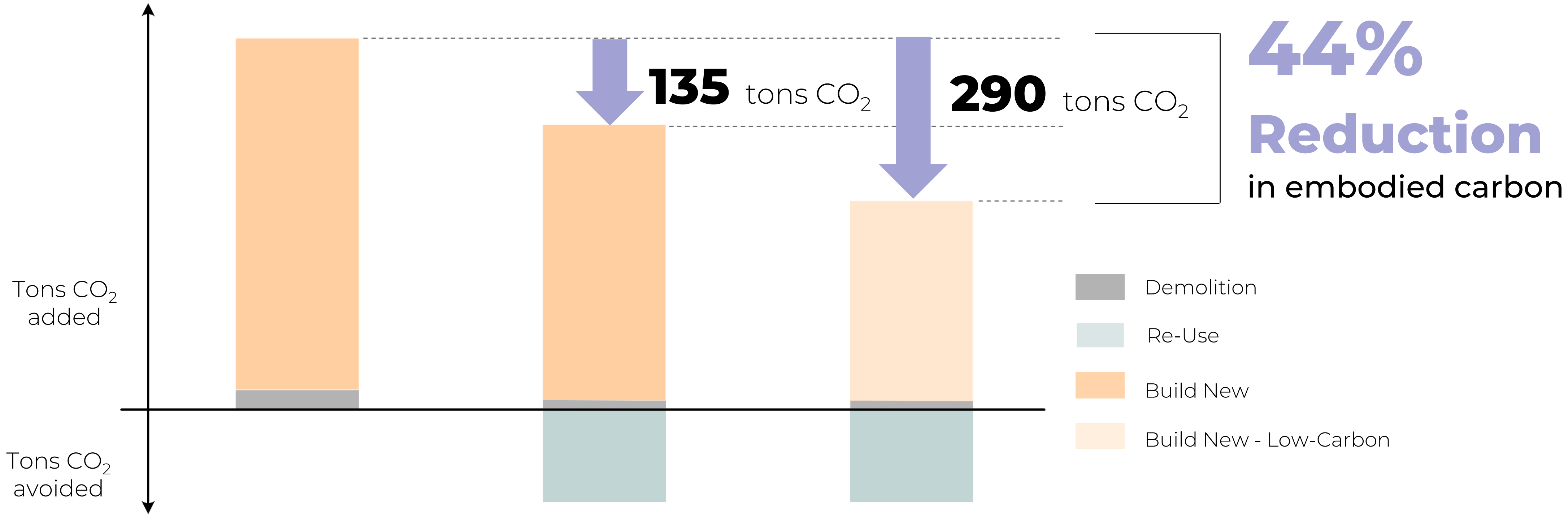


Image Source: QE 2021

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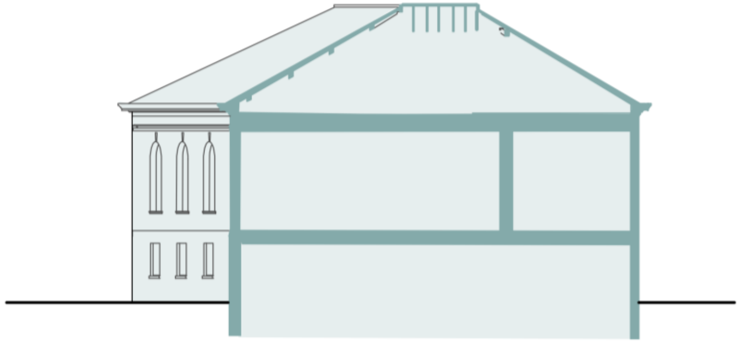
Methodology

Step 1: Existing Building Model

- **Demolition Emissions:**
  - Demolish & Rebuild Scenario - What are the emissions associated with demolishing the current building structure?
  - Renovate & Re-Use Scenario – What are the emissions associated with demolishing the existing foundation (to allow for the below-ground expansion)?
  - **Lifecycle Stages C1-C4 (End-of-Life Stage)**
- **Rebuild Above-Ground Structure (the ‘Replacement Cost’):** What are the emissions associated with rebuilding something comparable to the current above-grade structure?
  - Assume that even a new building would have a similar footprint / geometry (given site constraints) and similar masonry envelope / tile roof to comply with historic district requirements
  - Assume that the building would use a more typical modern concrete structural system (current structure is a mix of concrete and wood)
  - Excludes emissions from rebuilding current foundation, as new foundation and lower-level slab is included in addition / expansion scope
  - **Lifecycle Stages A1-A3 (Product Stage)**



Tool / Method

Athena Sustainable Materials Institute Impact Estimator

- Software tool that estimates lifecycle costs based on square footages / basic information about different assembly types and major building components
- Not precise, but able to provide estimates when exact quantities of different materials are not known, eg for existing structures

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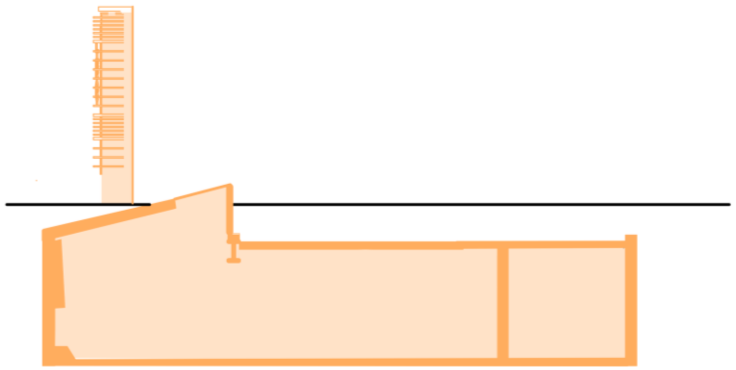
Methodology

Step 2: Addition / Expansion Model

- **Above-Ground Addition -** What are the emissions associated with the new accessible entrance tower?
  - **Lifecycle Stages A1-A3 (Product Stage)**
- **Below-Ground Expansion –** What are the emissions associated with the new lower level?
  - Demolish + Rebuild Scenario: Additional steel is needed for a below-ground work for support of excavation
  - Renovate + Re-Use Scenario: Below-ground work is more complex when part of an addition (vs. as part of a new construction project), and additional concrete is needed to underpin the existing building and neighboring structures
  - Does not include emissions from concrete formwork, which could be low-carbon / re-usable, or single-use, depending on contractor selection
  - **Lifecycle Stages A1-A3 (Product Stage)**



Tool / Method:

Silman Engineering calculations

- Based on quantities of concrete and steel, multiplied by carbon emissions per unit of material used
- Material CO_2 quantities based on industry-wide EPD's using national averages

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Challenges + Limitations

- Challenging to precisely model historic building assemblies using lifecycle analysis tools like Athena Impact Estimator
  - No *exact* match for certain components of the SE DC Library (eg, existing envelope assembly, slate roof)
- Hypothetical “Rebuild Above-Ground Structure” is subjective
  - This analysis assumes an entirely new building would have an above-ground structure comparable to the existing, but in reality it might be built very differently
  - Historic construction often uses more of materials such as wood and brick that are lower-carbon than concrete and steel, so this approach may understate the benefit of preserving historic structures (ie, the assumed carbon footprint to replace existing is too low)

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Challenges + Limitations, Cont.

- Addition / expansion estimates are focused on structural components (concrete & steel), which have biggest carbon impact, but exclude other building materials that would also contribute to total embodied carbon
  - Finishes, exterior cladding, glazing quantities, etc. not final at this stage and were not considered in the analysis
  - However, these would be essentially the same across all scenarios and would not impact the *relative* values
  - While early-stage analysis creates challenges, it also allows results to impact the design development and specifications
- Limited portion of the building lifecycle considered
  - This analysis considers end-of life emissions only for the demolition required to allow for the construction of the new or renovated building, ie, the embodied carbon up to the point of the building completion only
  - It does not include the construction process stage (A4-5), use stage (B1-7), or end-of-life stage (C1-C4) for the new/renovated library

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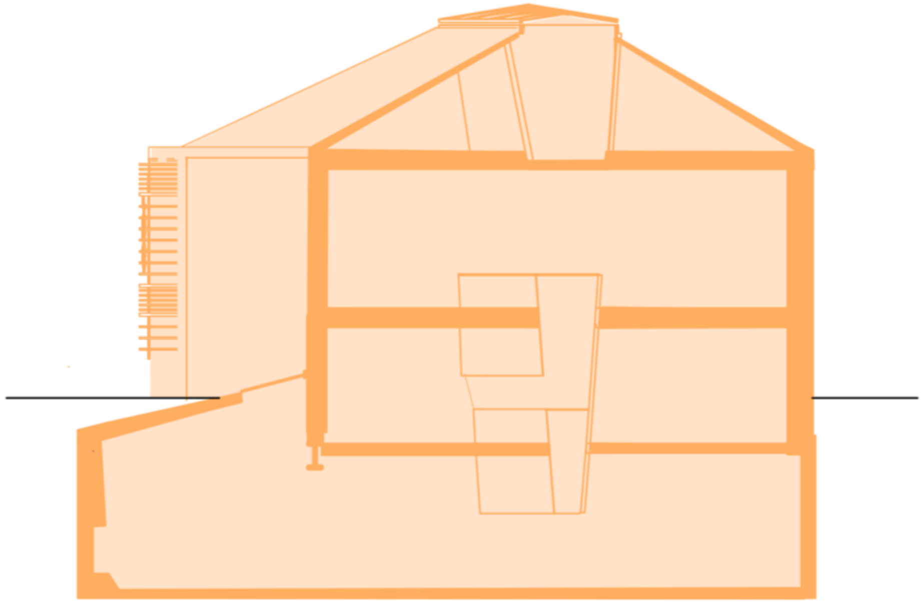
Analysis: Baseline Scenario



Project Component	Carbon Emissions (tons CO_2)
Demo Emissions	9.2
Rebuild of Above-Ground Structure	146
Expansion / Addition	512
TOTAL	**667.2**

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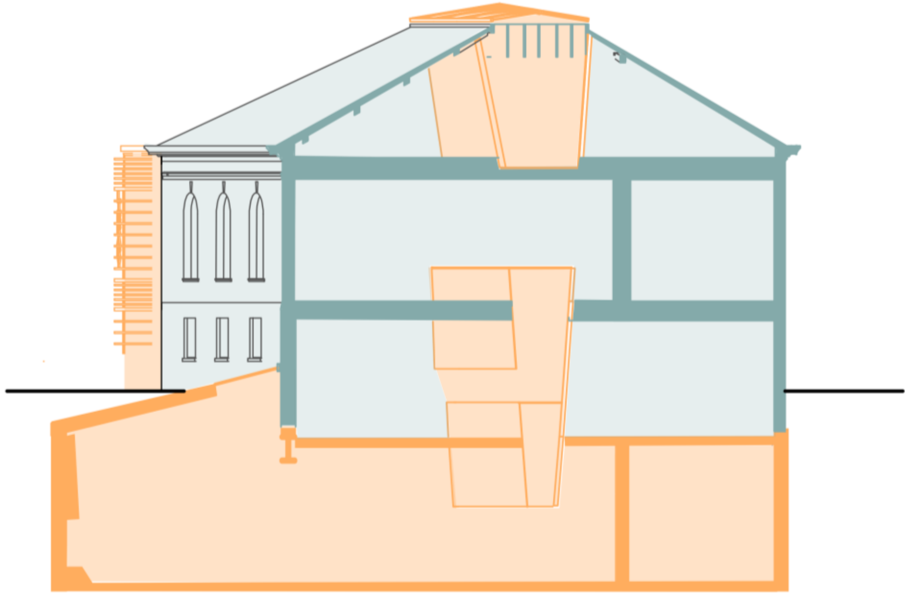
Analysis: Renovate + Re-Use

Worst-Case Specifications: 0% Replacement of Cement with SCMs



Project Component	Carbon Emissions (tons CO_2)	
Design Option	Option 1	Option 2
Demo Emissions	0.4	0.4
Rebuild of Above-Ground Structure	0	0
Expansion / Addition	531	522
TOTAL	**531.4**	**522.4**

Option 1: Steel channels to support ground floor

Option 2: Concrete beams to support ground floor

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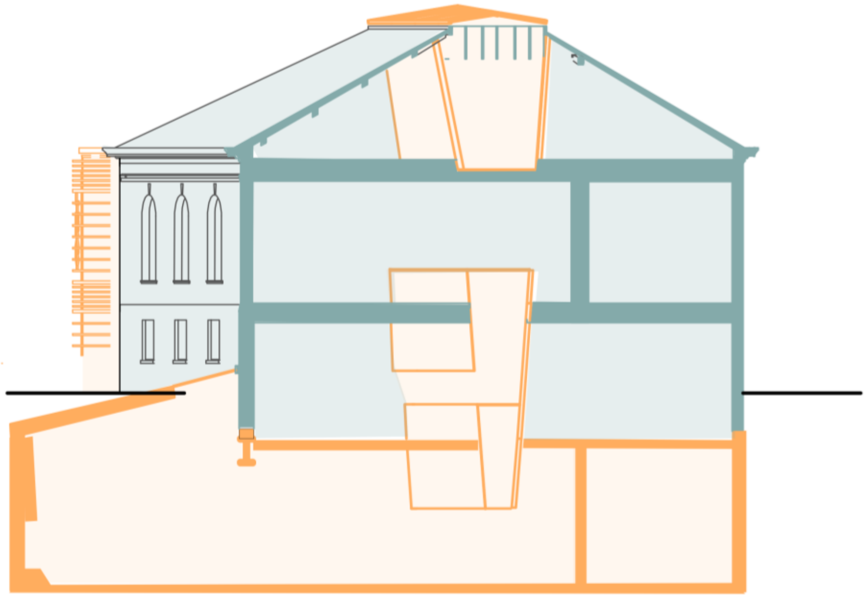
Analysis: Renovate + Re-Use

Increasingly Common Specifications: 20% Replacement of Cement with SCMs



Project Component	Carbon Emissions (tons CO_2)	
Design Option	Option 1	Option 2
Demo Emissions	0.4	0.4
Rebuild of Above-Ground Structure	0	0
Expansion / Addition	477	467
TOTAL	**477.4**	**467.4**

Option 1: Steel channels to support ground floor

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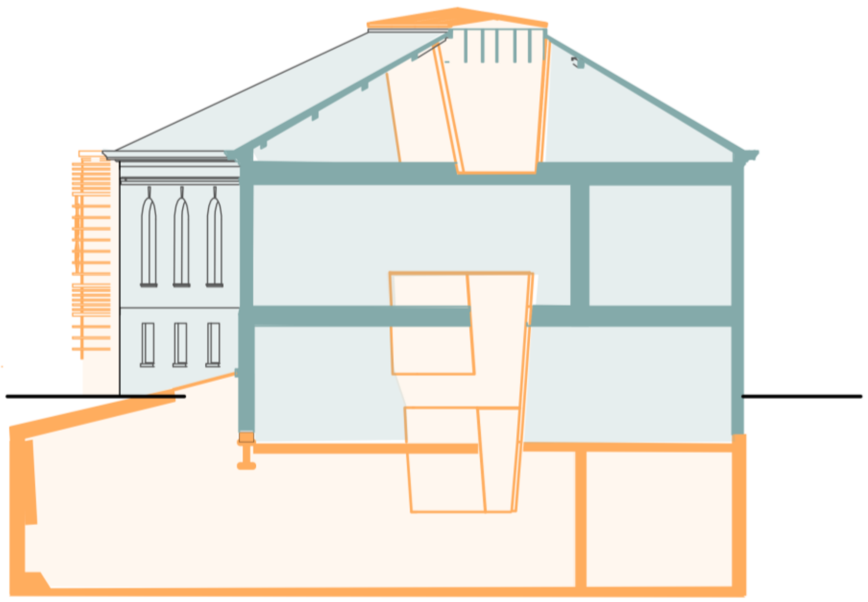
Analysis: Renovate + Re-Use

Aggressive Sustainability: 50% Replacement of Cement with SCMs



Project Component	Carbon Emissions (tons CO_2)	
Design Option	Option 1	Option 2
Demo Emissions	0.4	0.4
Rebuild of Above-Ground Structure	0	0
Expansion / Addition	387	375
TOTAL	**387.4**	**375.4**

Option 1: Steel channels to support ground floor

Option 2: Concrete beams to support ground floor

Embodied Carbon Analysis: Results

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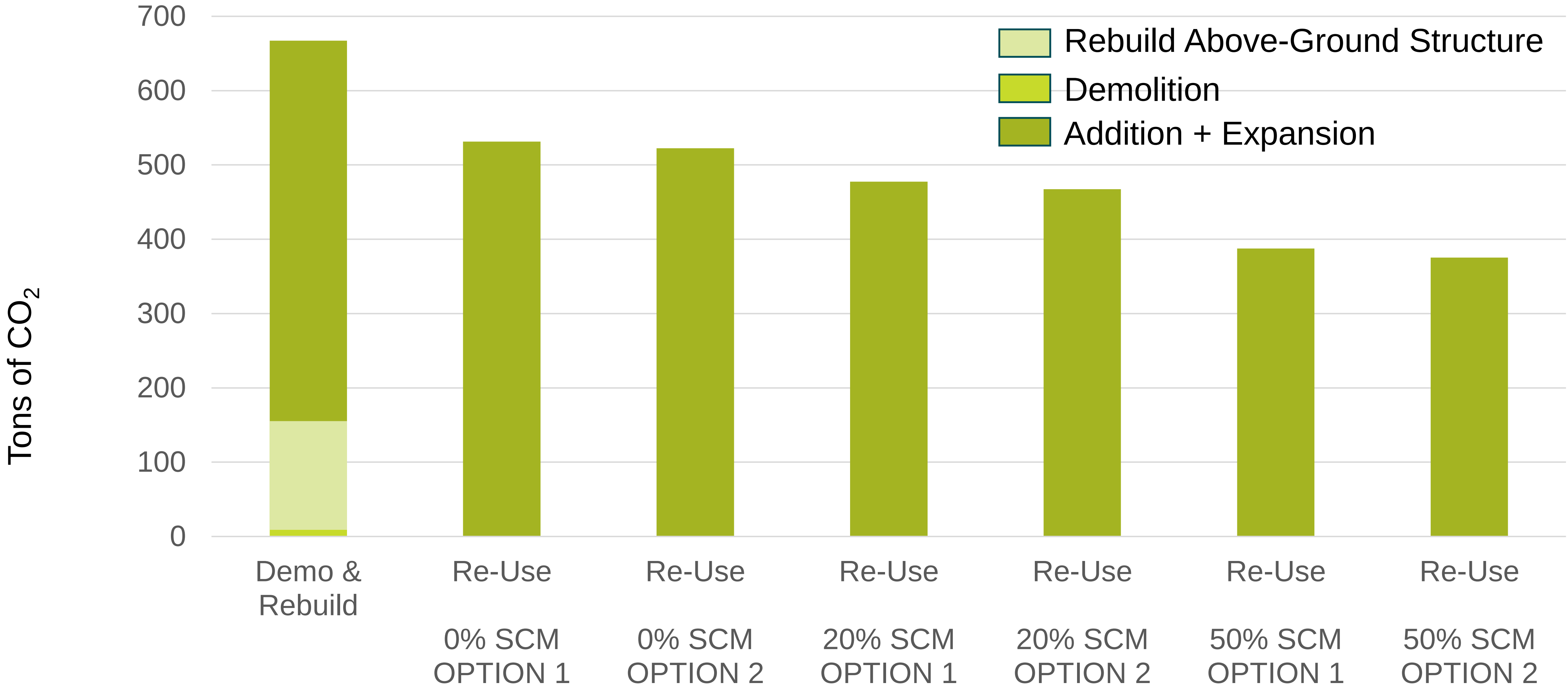

Option 1: Steel channels to support ground floor

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Summary & Lessons Learned

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Demolish & Build New

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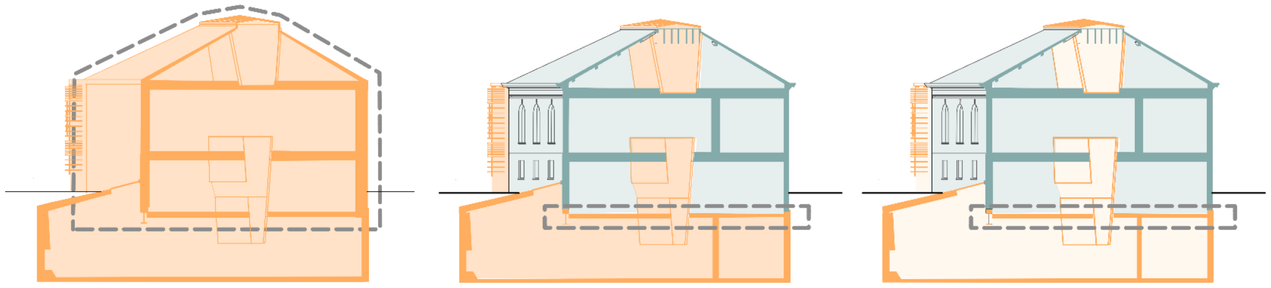
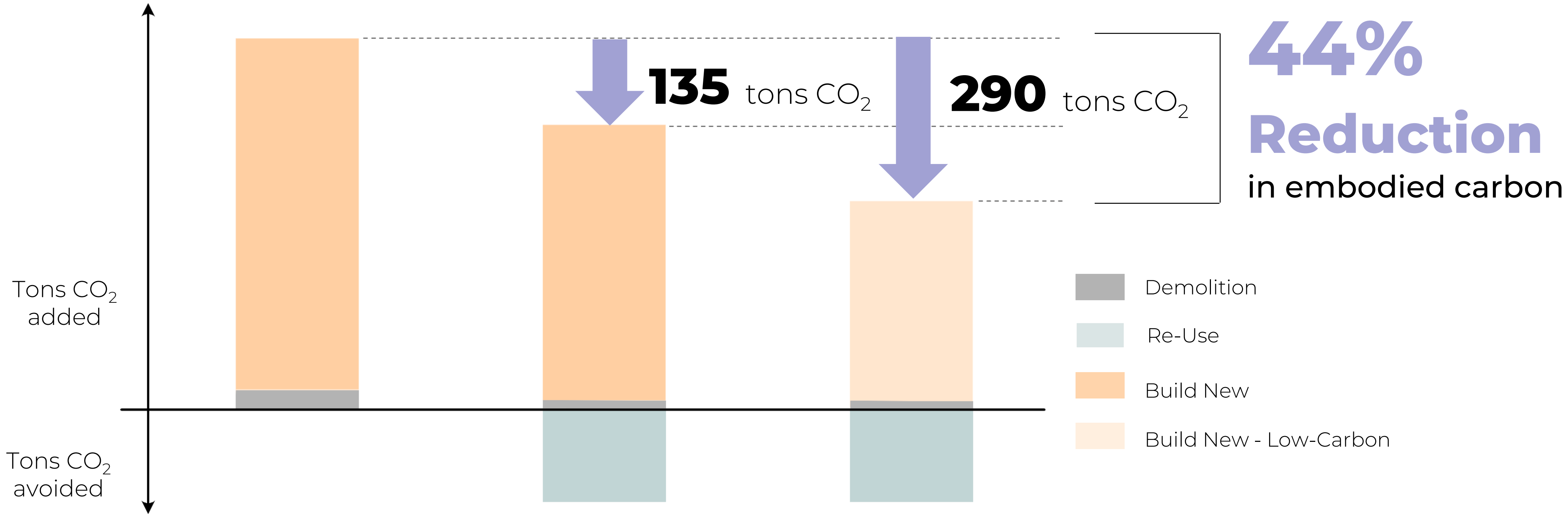
Renovate & Re-Use

SCENARIO 2:
Renovate & Re-Use with Low-Carbon Materials





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Summary Findings

- Even when re-use seems complicated and possibly resource-intensive, it still often results in overall emissions reduction – 20% for the SE DC Library
  - For this project, re-use makes the below-grade work more carbon intensive than building as part of a new structure, because underpinning the existing structure requires substantial concrete
  - This additional 19 tons of CO_2 is more than offset by the savings from having preserved the above-ground building components
- Savings from specifying lower-carbon concrete are substantial
  - In addition to SCMs, innovative technologies that store carbon in concrete (not quantified in analysis here) can further reduce emissions by ~5% or more
- For this project, optimizing structural design to reduce concrete and steel quantities was not a high-impact strategy (~2% reduction in embodied carbon)
- Lower embodied carbon concrete is a huge opportunity for savings

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Summary Findings

- Below grade construction methods can be a significant contributor to embodied carbon.
  - The sheet piles and shoring would require a significant amount of material, but because this is not designed and documented by the team it's hard to quantify or encourage strategies for reduction.
- The project team will revisit the discussion of low carbon concrete when the concrete is getting subcontracted to confirm best available approaches.
- Include in concrete specifications:
  - Requirement to calculate GWP or provide EPD
  - Minimum cement replacement of 35%
  - Performance requirements that would prioritize lower GWP mixes

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Where has this grant helped QE

- Having a quantifiable example of the value of building reuse helps us make the case.
- We have a clearer sense of the questions we can ask of our structural engineers and contractor.
- More clarity around strategies for reducing carbon in concrete and the why concrete in particular matters so much.

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Recommendations

Designers

1. Communicate the importance of reducing embodied carbon across project team and with client.
2. Reuse existing buildings wherever possible, particularly the structure.
3. Use as little new material as possible: right-size, limit waste.
4. Focus on Concrete Improvements or Alternatives: Include performance based GWP targets in the concrete spec. Work with local contractors and suppliers to help communicate the importance.
5. Advocate to drive improvement: we need more case studies, more EPDs, and more mandates from clients and jurisdictions to prioritize embodied carbon.

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Recommendations

Policy Makers – How can we make this standard practice faster?

1. Reference other jurisdictions that require low carbon concrete (Marin County for example)
2. Carbon Leadership has great tools for policy makers https://carbonleadershipforum.org/clf-policy-toolkit/
3. Require GWP of the mix designs (either calculated or verified EPD) to be submitted as part of permit.
4. Create a database of these numbers. (we can better manage what we see and measure, and in a local context)
5. Start with big projects and/or DC funded.

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Appendix

- Notes on structural design options

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Note on Design Options

- This analysis considered three design options in total: Options A, B, and C (as described in Silman's Structural Engineering Sketches dated as of 4.21.2021)
- Options A + B were almost identical, with the difference being essentially the amount of a rounding error. Option B was slightly higher in embodied carbon.
- Thus, this presentation only includes Option B as a worse case and Option C as a better case.
- Option B is described as Option 1 and Option C is described as Option 2 (to avoid confusion that presenting an Option B and C might create without also presenting an Option A).

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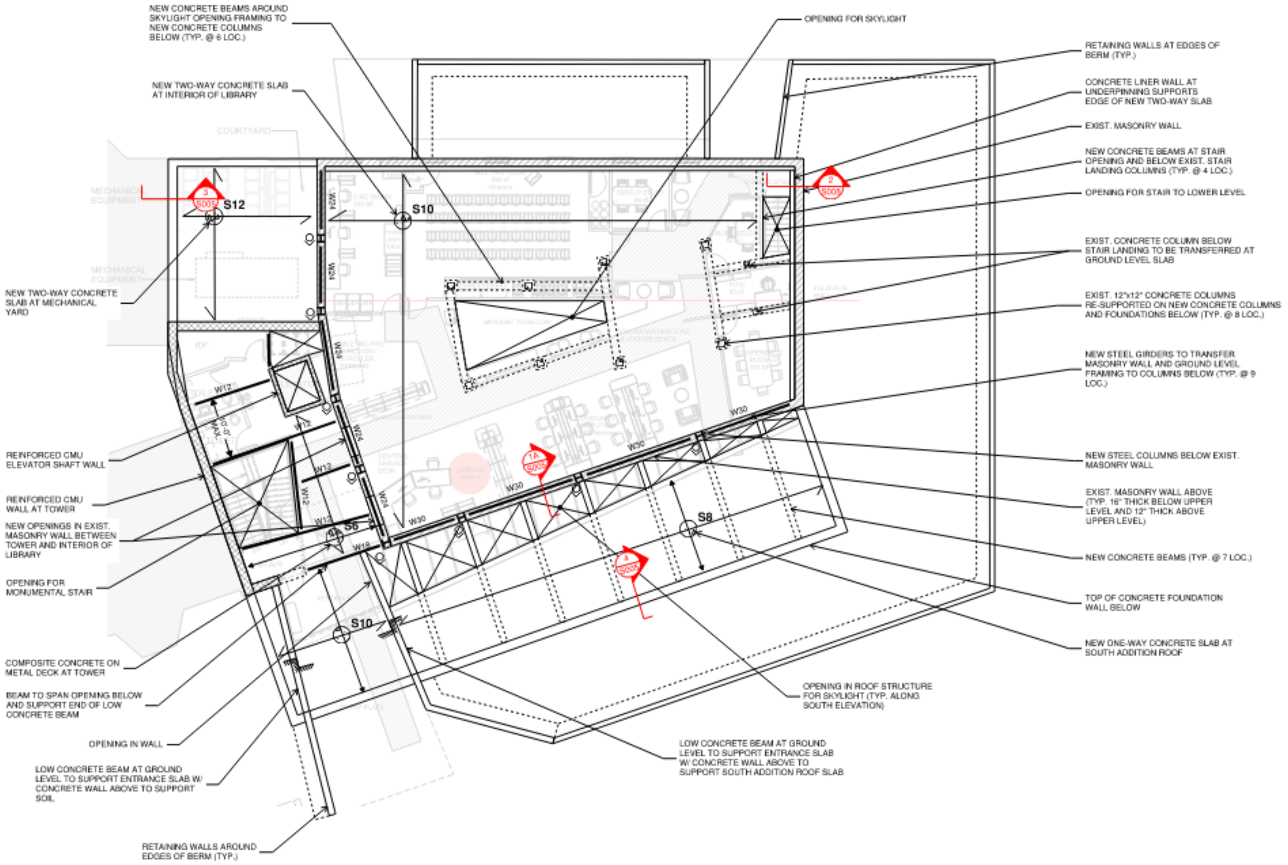
Option A

- Larger spacing between columns on south elevation
- Concrete beams
- Not included in the analysis (results very similar to Option B)

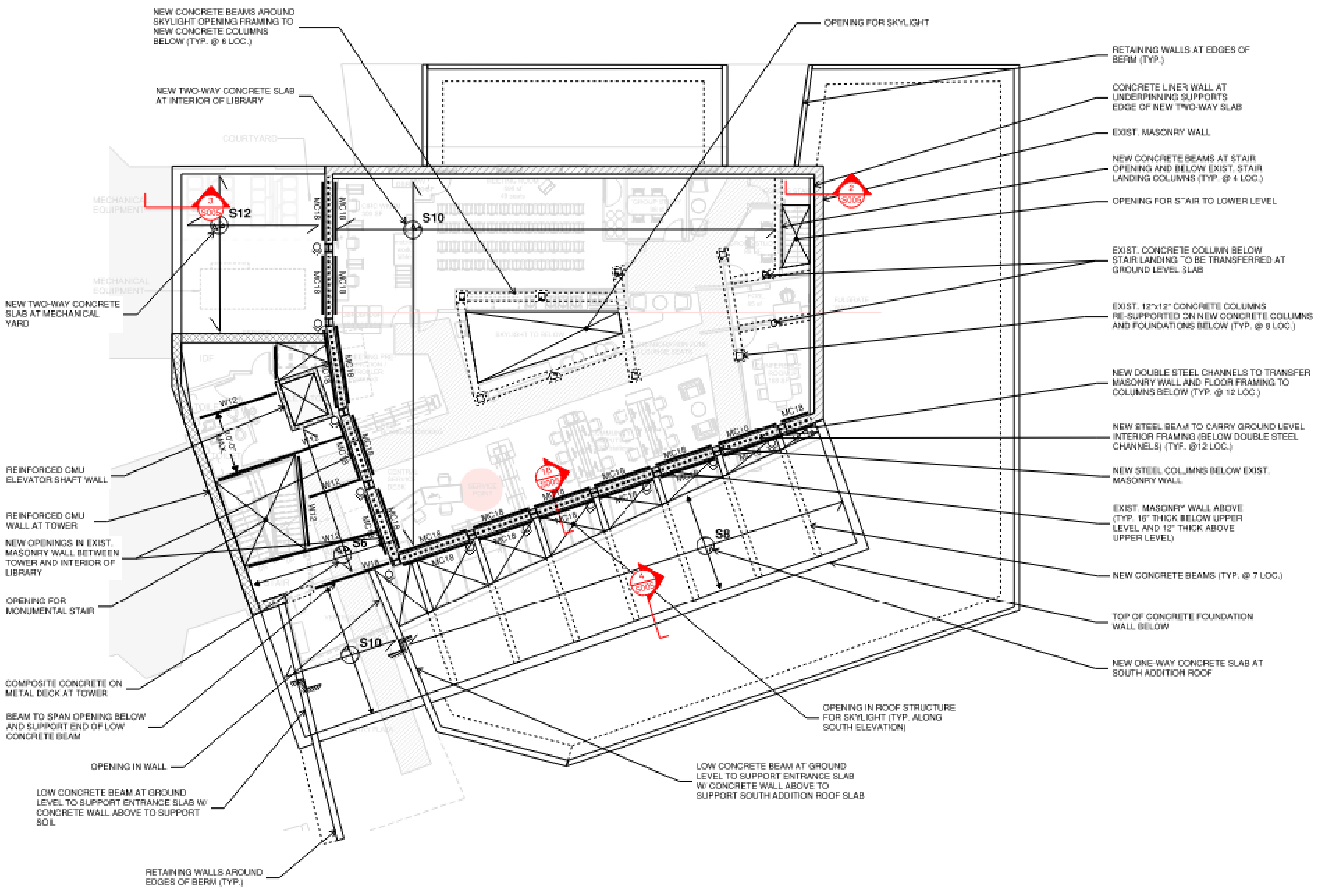


GROUND LEVEL FRAMING PLAN

OPTION A - LARGE COLUMN SPACING ON SOUTH ELEVATION

Option B (aka Option #1)

- Smaller column spacing on south elevation
- Steel channels as part of ground floor framing



GROUND LEVEL FRAMING PLAN

OPTION B - SMALLER COLUMN SPACING ON SOUTH ELEVATION (CHANNEL OPTION)

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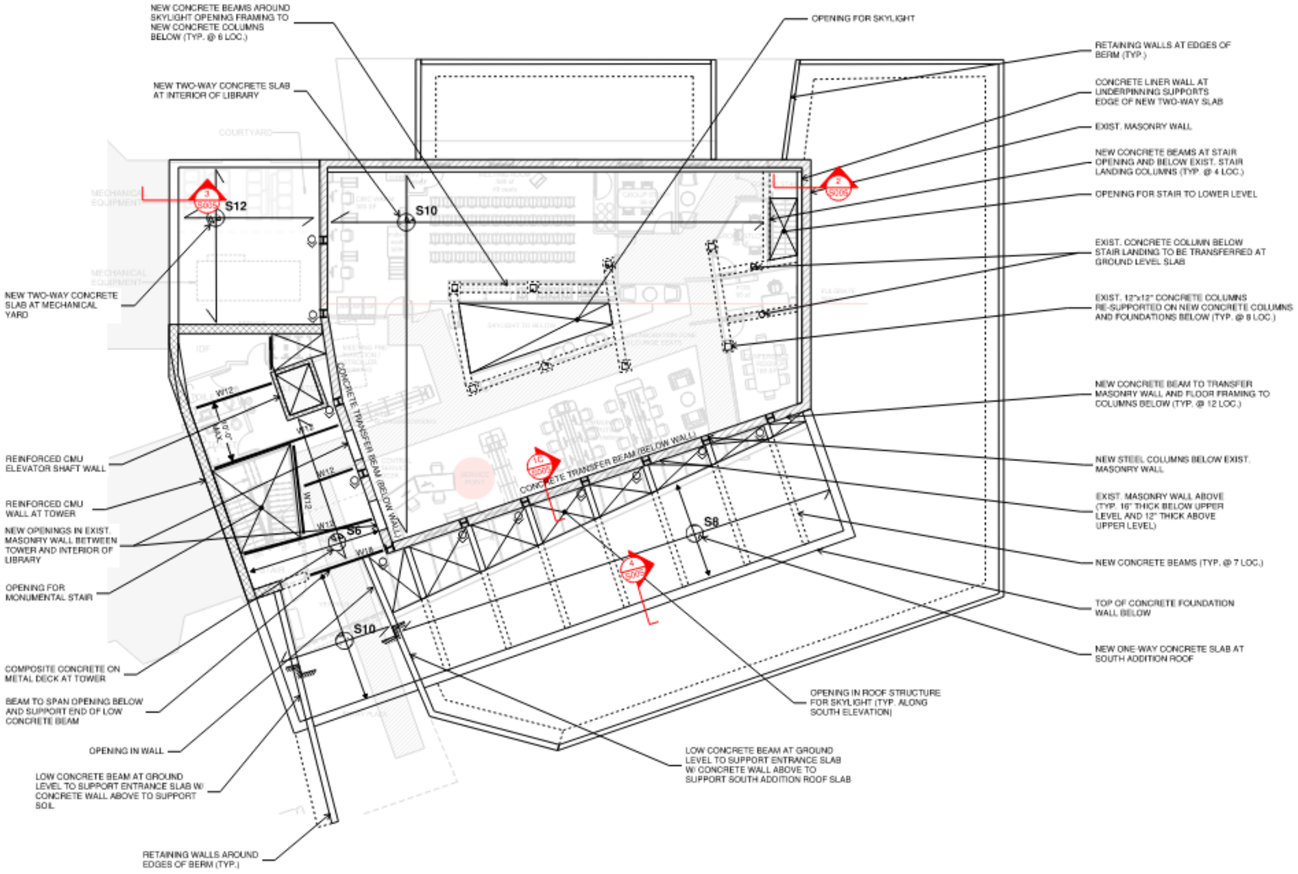
Option C (aka Option #2)

- Smaller column spacing on south elevation
- Concrete beams as part of ground floor framing



GROUND LEVEL FRAMING PLAN

OPTION C - SMALLER COLUMN SPACING ON SOUTH ELEVATION
(CONCRETE BEAM OPTION)