Backyard Carbon Sinks: A Prototype for a Net-Negative Carbon Accessory Dwelling Unit

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Figure 1. Net-negative Carbon Accessory Dwelling Unit. Image by author.

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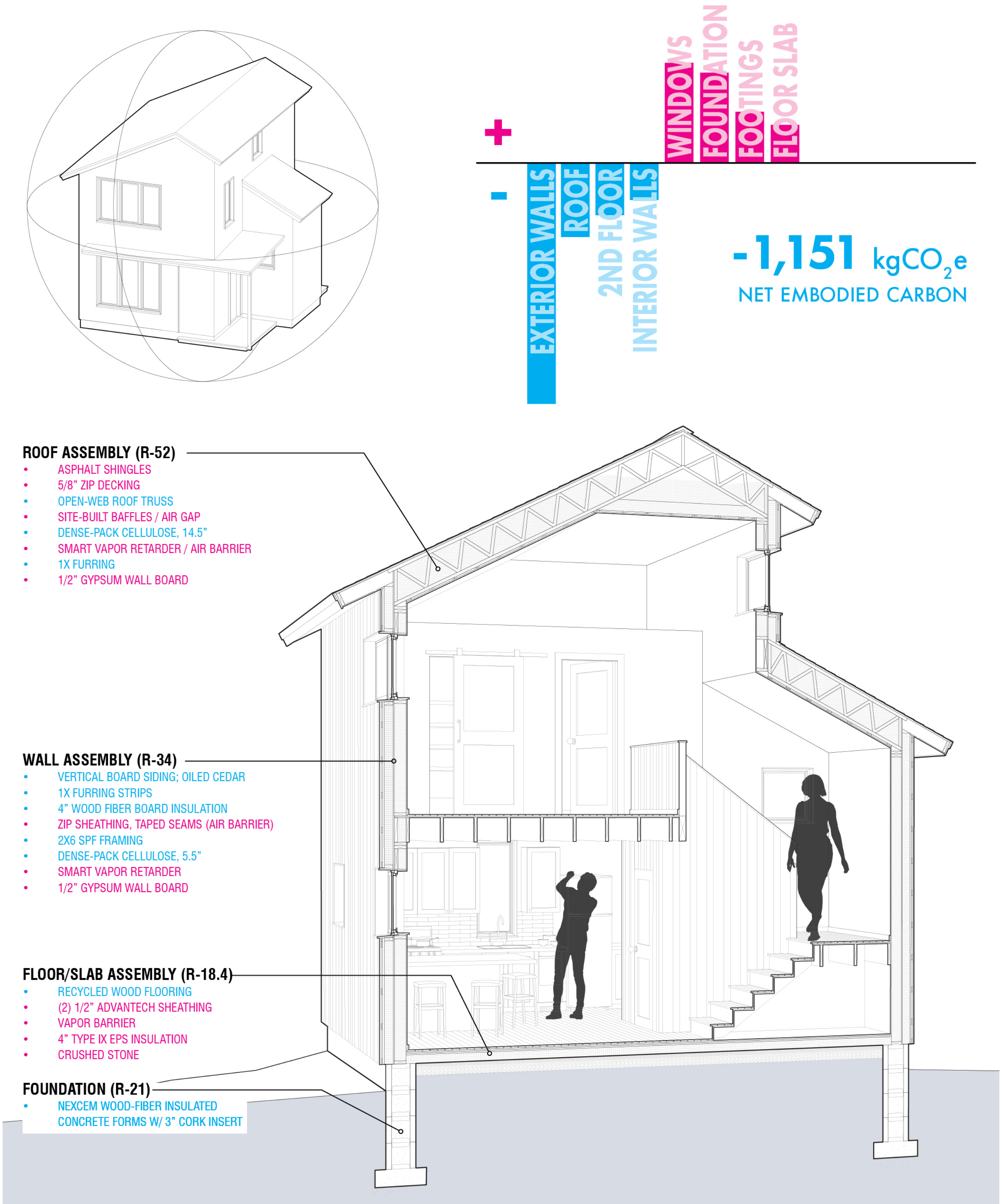
INTRODUCTION

The Backyard Carbon Sinks project asks whether a design can simultaneously address embodied carbon, operational carbon, and critical social issues such as affordable housing. Specifically, this project explores opportunities for net-negative embodied carbon building through the design of a modest, prototypical accessory dwelling unit (ADU). ADUs have received growing attention in the last decade as a possible solution to issues of affordable housing, density, and multi-generational housing.[1,2] Alongside this, due to their size and relative simplicity, ADUs also present a unique opportunity to experiment with de-carbonizing the building sector and to explore residential buildings as potential carbon sinks. Given the potential number of ADUs that could be constructed in the near future[3], this could be a significant opportunity for de-carbonization while also starting to address the multivariant housing crises facing many cities and municipalities.

Until recently, discourse, policy, and technological development around high-performance building has focused largely on operational energy, the energy consumed by buildings after they are constructed, throughout their lifetime.[4] This focus on operational energy is necessary, yet it has obscured the critical impact of embodied carbon, the up-front carbon emissions associated with building materials and construction. Turning the focus to embodied carbon is critical for three reasons. First, the emphasis on operational energy assumes that energy consumption is a reliable proxy for carbon emissions, which is not always the case. Second, multiple studies show that embodied carbon accounts for more than 40% of a building's overall carbon footprint.[5,6] As carbon free, renewable energy sources become more available, the initial embodied carbon of buildings is likely to become an even more significant component of this overall footprint. Third,



ROOF ASSEMBLY (R-52)

- ASPHALT SHINGLES
- 5/8" ZIP DECKING
- OPEN-WEB ROOF TRUSS
- SITE-BUILT BAFFLES / AIR GAP
- DENSE-PACK CELLULOSE, 14.5"
- SMART VAPOR RETARDER / AIR BARRIER
- 1X FURRING
- 1/2" GYPSUM WALL BOARD

WALL ASSEMBLY (R-34)

- VERTICAL BOARD SIDING; OILED CEDAR
- 1X FURRING STRIPS
- 4" WOOD FIBER BOARD INSULATION
- ZIP SHEATHING, TAPED SEAMS (AIR BARRIER)
- 2X6 SPF FRAMING
- DENSE-PACK CELLULOSE, 5.5"
- SMART VAPOR RETARDER
- 1/2" GYPSUM WALL BOARD

FLOOR/SLAB ASSEMBLY (R-18.4)

- RECYCLED WOOD FLOORING
- (2) 1/2" ADVANTECH SHEATHING
- VAPOR BARRIER
- 4" TYPE IX EPS INSULATION
- CRUSHED STONE

FOUNDATION (R-21)

- NEXCEM WOOD-FIBER INSULATED CONCRETE FORMS W/ 3" CORK INSERT

Figure 2. Wall Section with Proposed Assemblies and Net Embodied Carbon. Image by author.

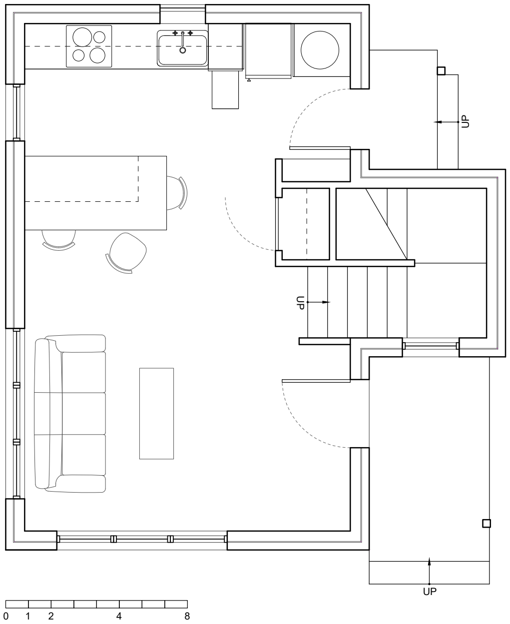


Figure 3. First Floor Plans. Image by author.

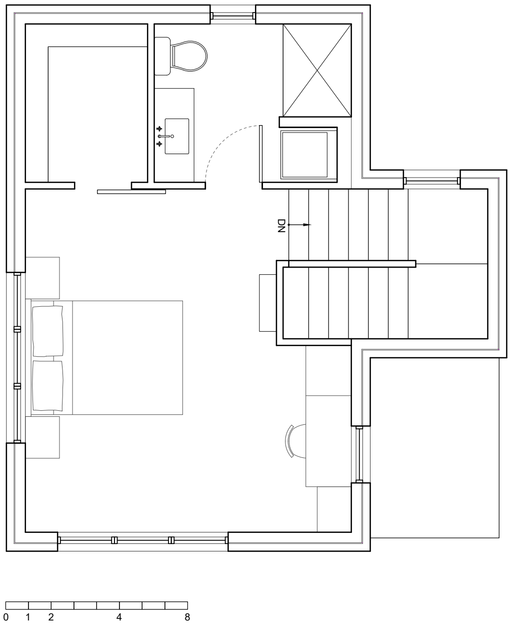
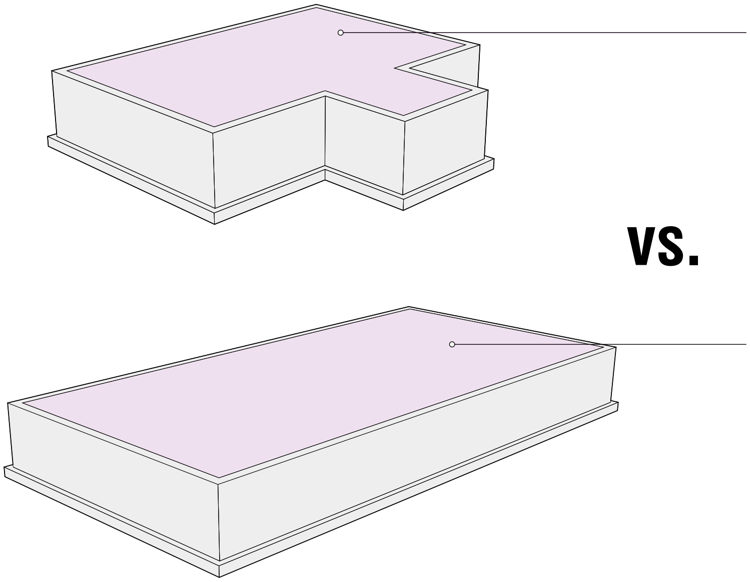


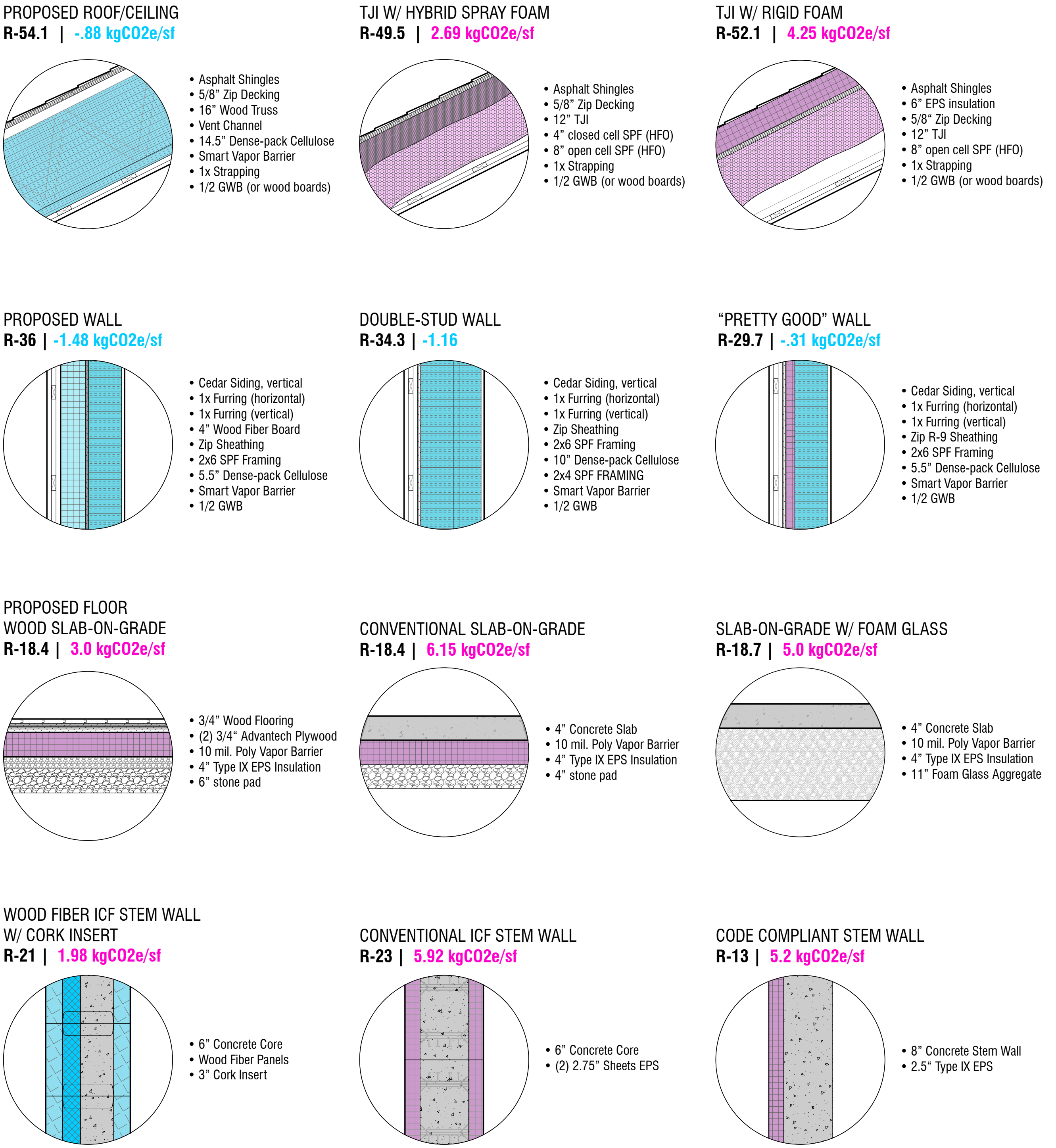
Figure 4. Second Floor Plan. Image by author.



2-STORY, 800 SQFT ADU
FOOTPRINT: 400 SQFT
SLAB: 360 SQFT / 120 CUFT
STEM WALL: 230 CUFT
FOOTING: 86 CUFT
TOTAL: 436 CUFT CONCRETE
~3,300 kgCO2e

1-STORY, 800 SQFT ADU
(assuming 20x40)
FOOTPRINT: 800 SQFT
SLAB: 746 SQFT / 249 CUFT
STEM WALL: 312 CUFT
FOOTING: 117 CUFT
TOTAL: 678 CUFT CONCRETE
~5,130 kgCO2e

Figure 5. 2-Story vs 1-story Foundation. Image by author.



PROPOSED ROOF/CEILING
R-54.1 | -.88 kgCO2e/sf

- Asphalt Shingles
- 5/8” Zip Decking
- 16” Wood Truss
- Vent Channel
- 14.5” Dense-pack Cellulose
- Smart Vapor Barrier
- 1x Strapping
- 1/2 GWB (or wood boards)

TJI W/ HYBRID SPRAY FOAM
R-49.5 | 2.69 kgCO2e/sf

- Asphalt Shingles
- 5/8” Zip Decking
- 12” TJI
- 4” closed cell SPF (HFO)
- 8” open cell SPF (HFO)
- 1x Strapping
- 1/2 GWB (or wood boards)

TJI W/ RIGID FOAM
R-52.1 | 4.25 kgCO2e/sf

- Asphalt Shingles
- 6” EPS insulation
- 5/8“ Zip Decking
- 12” TJI
- 8” open cell SPF (HFO)
- 1x Strapping
- 1/2 GWB (or wood boards)

PROPOSED WALL
R-36 | -1.48 kgCO2e/sf

- Cedar Siding, vertical
- 1x Furring (horizontal)
- 1x Furring (vertical)
- 4” Wood Fiber Board
- Zip Sheathing
- 2x6 SPF Framing
- 5.5” Dense-pack Cellulose
- Smart Vapor Barrier
- 1/2 GWB

DOUBLE-STUD WALL
R-34.3 | -1.16

- Cedar Siding, vertical
- 1x Furring (horizontal)
- 1x Furring (vertical)
- Zip Sheathing
- 2x6 SPF Framing
- 10” Dense-pack Cellulose
- 2x4 SPF FRAMING
- Smart Vapor Barrier
- 1/2 GWB

“PRETTY GOOD” WALL
R-29.7 | -.31 kgCO2e/sf

- Cedar Siding, vertical
- 1x Furring (horizontal)
- 1x Furring (vertical)
- Zip R-9 Sheathing
- 2x6 SPF Framing
- 5.5” Dense-pack Cellulose
- Smart Vapor Barrier
- 1/2 GWB

PROPOSED FLOOR
WOOD SLAB-ON-GRADE
R-18.4 | 3.0 kgCO2e/sf

- 3/4” Wood Flooring
- (2) 3/4“ Advantech Plywood
- 10 mil. Poly Vapor Barrier
- 4” Type IX EPS Insulation
- 6” stone pad

CONVENTIONAL SLAB-ON-GRADE
R-18.4 | 6.15 kgCO2e/sf

- 4” Concrete Slab
- 10 mil. Poly Vapor Barrier
- 4” Type IX EPS Insulation
- 4” stone pad

SLAB-ON-GRADE W/ FOAM GLASS
R-18.7 | 5.0 kgCO2e/sf

- 4” Concrete Slab
- 10 mil. Poly Vapor Barrier
- 4” Type IX EPS Insulation
- 11” Foam Glass Aggregate

WOOD FIBER ICF STEM WALL
W/ CORK INSERT
R-21 | 1.98 kgCO2e/sf

- 6” Concrete Core
- Wood Fiber Panels
- 3” Cork Insert

CONVENTIONAL ICF STEM WALL
R-23 | 5.92 kgCO2e/sf

- 6” Concrete Core
- (2) 2.75” Sheets EPS

CODE COMPLIANT STEM WALL
R-13 | 5.2 kgCO2e/sf

- 8” Concrete Stem Wall
- 2.5“ Type IX EPS

Figure 5. Embodied Carbon Analysis of Critical Assemblies. All R-values are effective R-Values. Calculated in WUFI Passive. Image by author.

there is a time-value to carbon such that carbon emissions today are more important than carbon emissions in the future.[7]

DESIGN

Designed by the author, an architect, in collaboration with a construction firm specializing in high-performance residential buildings, this ADU demonstrates that net-zero and even net-negative carbon buildings are possible with current, readily-available construction materials and technologies. The ADU is an approximately 800sf, one-bedroom, two-story residence designed to optimize recently revised zoning ordinances in multiple municipalities in Western Massachusetts. The critical assemblies rely on maximizing biogenic materials with negative embodied carbon while minimizing carbon-intensive materials such as concrete. Designing the ADU as a two-story unit maximizes the allowable floor area while minimizing the footprint of the dwelling. This basic design decision makes the ADU amenable to a wider variety of potential sites while also increasing the ratio of interior conditioned floor area to the foundation and floor slab, two assemblies that traditionally rely on carbon intensive concrete (See Figure 5). To further reduce concrete, the ground floor assembly employs a wood slab-on-grade system in place of a conventional concrete slab.

For the wall assemblies, multiple foam-free assemblies were evaluated including a double-stud wall system, a Larsen truss style system, and a cavity wall with exterior wood fiber board insulation. While all these assemblies serve as net carbon sinks, the cavity wall with exterior wood fiber board insulation was chosen because it functions as a "perfect wall"[8] with high vapor permeability while relying on relatively familiar details (as opposed to a Larson truss wall). For the roof/ceiling assemblies, a vented roof with dense-pack cellulose is the only conventional roof assembly that does not rely on carbon-intensive foam products. The foundations and footings remain the dominant carbon-positive assembly in the building. While wood foundation systems that maximize biogenic materials in place of concrete are becoming more popular, these retain a perception of risk that many architects, builders, and owners are hesitant to assume. Window assemblies also represent a relative high proportion of the embodied carbon. Given the cost and importance of windows for operational energy, a next step in this project is to carefully analyze the relationship between daylighting, views, and energy and carbon performance to optimize the size and number of windows.

Similarly, if this ADU is to address housing affordability then a future study would be to cross reference the carbon and energy performance with construction cost.

EMBODIED CARBON

The embodied carbon analysis of these assemblies and the ADU as a whole was completed with a beta version of the Builders for Climate Action Building Emissions Accounting for Materials (BEAM) tool. This tool was chosen precisely because it is a relatively simple tool intended for broad adoption within the field of high-performance residential design and construction. While there are potential limitations in using a proprietary software for analysis, one goal of this project is exploring how such a tool would inform the design process. Per the BEAM analysis, the proposed building achieves a net-negative embodied carbon of -1151 kgCO2e, making it a modest carbon sink. The ADU is also designed to achieve net-zero operational energy with the inclusion of a small solar PV array and sufficient solar access.

HYBRID CONSTRUCTION

This ADU is being developed and offered as pre-designed and pre-fabricated building available for purchase. Construction utilizes a hybrid building system where portions of the building – primarily wall and roof assemblies – are prefabricated off-site while other portions of the building are site-built. As a pre-fabricated building available for purchase, this prototypical ADU has the potential for significant impact in the region, while also putting forward a readily achievable model for net-zero energy and net-negative carbon construction with broad applicability.

ENDNOTES

1. Jake Wegmann, "Death to Single-Family Zoning...and New Life to the Missing Middle," Journal of the American Planning Association 86, no. 1 (January 2020): 113–19, https://doi.org/10.1080/01944363.2019.1651217.
2. Karen Kubey and Dana Cuff, "The Architect's Lot: Backyard Homes Policy and Design," Architectural Design 88, no. 4 (July 1, 2018): 62, https://doi.org/10.1002/ad.2322.
3. For example, recent changes to legislation have unlocked an estimated 8.1 million single family lots to potential ADU development in CA alone. Alysia Bennet, Dana Cuff, and Gus Wendel, "Backyard Housing Boom: New Markets for Affordable Housing and the Role of Digital Technology," Technology | Architecture + Design, 3:1, (2019), 76-88.
4. See for instance the almost exclusive emphasis on operational energy in the predominant green building certification programs like Passive House US, Energy Star, and LEED.
5. Ming Hu, "A Building Life-Cycle Embodied Performance Index—The Relationship between Embodied Energy, Embodied Carbon and Environmental Impact," 2020, 17.
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7. McDade, Erin, "Beyond Zero: The Time Value of Carbon." In The New Carbon Architecture: Building to Cool the Climate, ed. Bruce King (Canada: New Society Publishers), 7-15.
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