East Bay Carbon Storing Building

A Prototype Building Case Study for Alameda County

September 2021

CASBA

ARUP

VERDANT Structural Engineers

ARKIN · TILT ARCHITECTS
Ecological Planning & Design

with support from

STOPWASTE

Table of Contents

Preface

This prototype is offered to the Bay Area community of designers, builders, and policymakers to spark interest in the possibility of turning our buildings from a climate problem (carbon emitter) to a climate solution (carbon storage). We employed the best available building materials and technologies to make this a feasible building at the time of its design in 2019-2020. Fortunately, the field of biobased building materials is quickly evolving and innovating. We anticipate many advancements that would improve this prototype and its performance in carbon and other metrics that will make carbon storing buildings an even more viable option in the Bay Area. We consider this document a work in progress and look forward to updating it.

Acknowledgements

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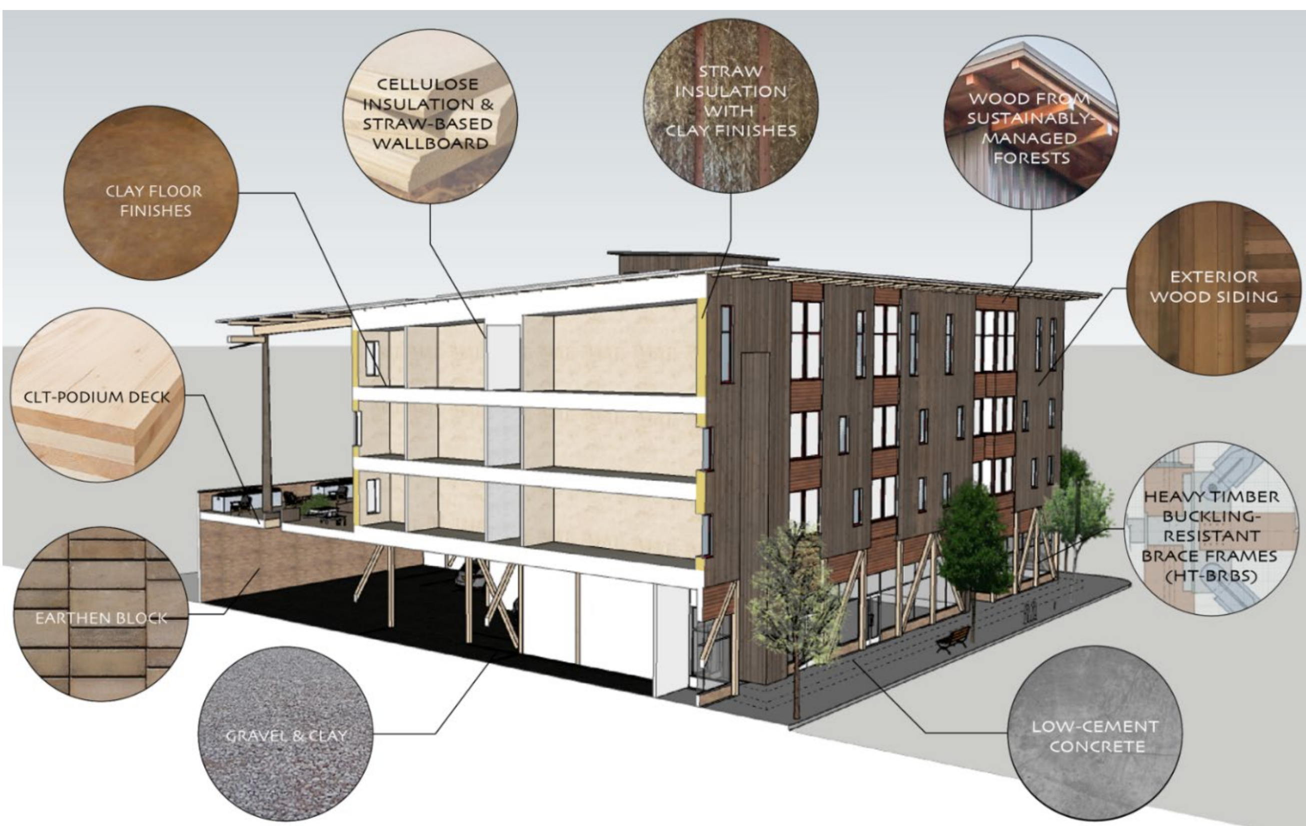
Summary

Scaling bio-based building materials beyond specialty projects or custom homes is possible and promises healthier outcomes for people, ecosystems, and the climate. In order to test feasibility and potential benefits, a team of architects, builders, and engineers designed a prototype of a building that could realistically be built in Alameda County.

While bio-based materials offer health and circularity benefits as well, the analysis in this study focuses on carbon. By employing 10 strategies, the prototype would emit about half of the embodied carbon (emissions along materials production supply chains) as using conventional material counterparts. It would additionally store double the carbon of its embodied carbon footprint in its mass, resulting in a significant overall net reduction in carbon in the atmosphere.

The Bay Area is anticipating significant volumes of construction in the coming decades. It would change the carbon equation if constructing buildings drew down carbon instead of emitting it. The construction industry could be called to play this role, reorienting the building sector away from harm and toward restoration. Local governments can review their building codes and other procedures and practices to identify any that inhibit more prevalent use of bio-based materials in their jurisdictions. They can also use economic development tools to stimulate markets for emerging materials.

This report consolidates the findings of the project team into a brief introduction. The full description of architectural and engineering analysis, details on each of the ten strategies, and resources for further exploration are available in the appendices.

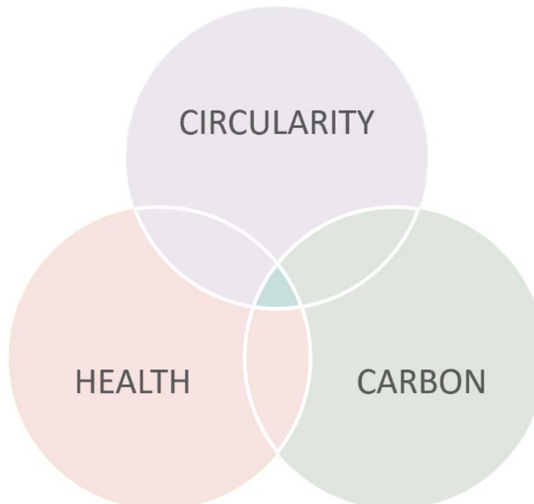


Introduction

The habitats we build shape our wellbeing. In recent years, the green building movement has examined the health and environmental impacts of the materials we use to build our habitats. Three goals have emerged as leading causes, though often pursued independent of each other, resulting in a sense of trade-offs and competing interests in certain attributes.

Bio-based building materials live at the intersection of three goals

Carbon. Building materials are responsible for at least 11% of global greenhouse gas emissions[1]. These emissions that occur along the supply chain of building materials - from resource extraction to processing and manufacturing are considered the "embodied carbon" of a product. While these are not typically included in a city's GHG accounting, they are significant in magnitude, *and* local governments have direct influence on the building materials used in their jurisdictions. Not all building materials are equally damaging to the climate. In addition to typically having a lower embodied carbon value than their conventional material counterparts, bio-based materials store carbon from the atmosphere in their mass, and can be grown with practices that sequester additional carbon into soil.



Circularity. Untreated bio-based materials can be disassembled and reused, or ultimately composted. This poses a preferable end-of-life outcome to many unrecyclable or difficult-to-recycle conventional building materials. Some bio-based materials like straw are made from agricultural waste, creating a market for a current waste product. Additionally, because bio-based materials are grown from biological nutrient cycles, they represent a productive use of the outputs of other material cycles - namely the compost created from organic outputs like wasted food.

Health. Biobased materials that are made with very few to no additives present less hazards to human and environmental health than highly-processed biobased composites or common fossil fuel-based alternatives. This can be seen in the flooring and insulation options, as well as millwork and cabinetry, on Healthy Building Network's Product Hazard Spectra found at https://homefree.healthybuilding.net/products. Insulation derived from fossil fuels is inherently flammable and needs to be treated with flame retardants to meet building codes, many of which have been historically problematic to human health. Other common chemicals of high concern include formaldehyde-based binders, organotin catalysts, and isocyanates, not to mention blowing agents with high global warming potential. In flooring, phthalate plasticizers, PFAS, excessive use of antimicrobials, and contaminated recycled content are of greatest concern and more often found in synthetic alternatives like carpet and vinyl than biobased products like solid wood, linoleum, cork and laminate flooring. For more on bio-based materials' benefits to these goals, see Appendix A: Detailed Material Strategies.

[1] Architecture 2030, 2018. https://architecture2030.org/new-buildings-embodied/

Scaling bio-based materials would yield social benefits

Equitable Access. A shortcoming of bio-based building materials to date has been their confinement to custom homes or specialty projects. There is a missed opportunity to offer similar health benefits to occupants of more affordable forms of housing and buildings. As local governments increasingly prioritize equity, they will seek ways to increase accessibility to healthy habitats for all.

Economic Opportunity. Many bio-based building materials can be grown and sourced in the immediate or neighboring bioregions. This creates economic opportunities for rural (and in some cases sub/urban) supply chains and revenue. In California, there is a cultural and economic divide between urban and rural areas, and creating a supply chain that connects the two is one way to mend this separation. Many of the material strategies described in this prototype are relatively low-cost in materials but require more labor - which means that while the total price may be comparable, a bigger proportion is being paid to local people.

Scaling carbon storing buildings is possible and impactful.

Many bio-based materials have been confined to single-family homes to date but there are examples in several other developed countries where they have scaled to larger, taller construction. While most mid-rise multi-family housing in California is already framed using wood construction (which can also be carbon storing), there are many other fossil-fuel based materials still commonly used in multifamily housing that can be replaced with carbon-storing materials instead.

We designed a four-story mixed-use building - a common building type being built in Alameda County - using a combination of bio-based building materials. Our goal was to explore the current potential of bringing carbon storing buildings to scale in medium density urban to suburban contexts. We found that the building emits less than 10 kgCO2e per square foot (compared to a more conventional 25-60 kgCO2e per square foot[2]) and stores nearly 20 kgCO2e per square foot, for a net benefit of -10 kgCO2e per square foot mitigated and stored. Or if divided over the 33 new dwelling units in this mixed-use building, this equals an average of -15 metric tons of CO2e per unit. If 20 thousand new dwelling units were constructed in the Bay Area each year[3] with a similar embodied carbon profile, this could mean a carbon benefit of 300 thousand metric tons CO2e of net carbon stored while the buildings are in service.

It is also important not to consider carbon benefits as the only driver of decisions around how we build our habitats. While our analysis centers on carbon emissions, we discovered that the use of these materials offers benefits to other measures of health and local economies. Further study on these co-benefits would inform government partnerships and initiatives that maximize the desired outcomes of using building materials to create better ecological, economic, and health outcomes.

We hope this prototype will inspire and catalyze the use of carbon-storing building materials throughout our built environment, starting with multi-family housing in the Bay Area!

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[2] https://carbonleadershipforum.org/embodied-carbon-benchmark-study-1/

[3] See Association of Bay Area Governments 2015-2023 Regional Housing Needs Allocation figure of 187,990 units during that planning timeframe. https://abag.ca.gov/sites/default/files/2015-23_rhna_plan.pdf

Imagine a Carbon-Storing Building...

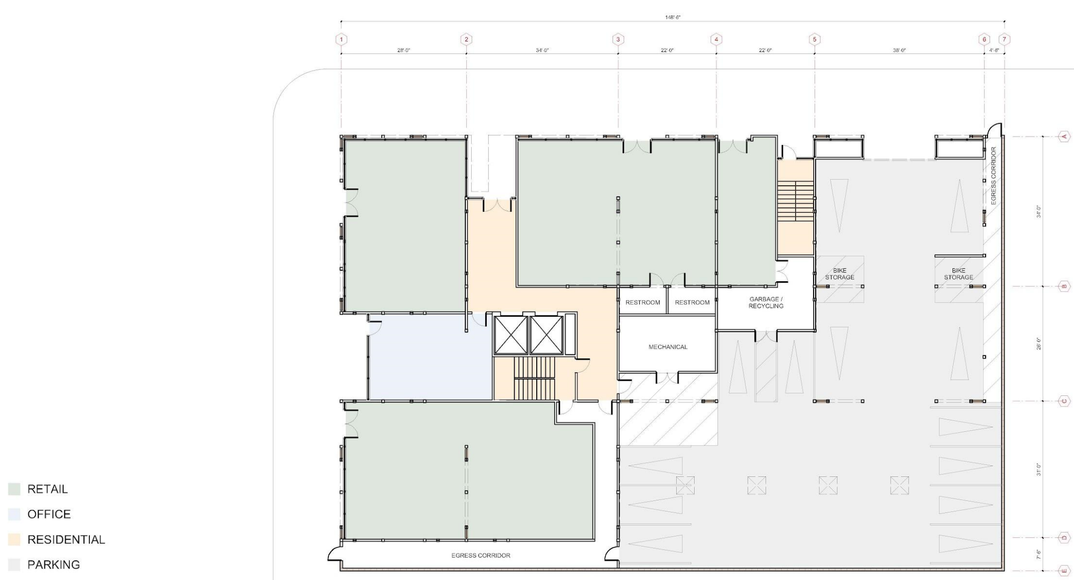
On a flat corner lot in the East Bay measuring 150 feet by 100 feet, there could be built a four story building that stores a million kg of carbon. Like most mixed-use buildings, the building consists of retail and parking on the ground floor, with apartment units above, with the addition of an outdoor space over the parking garage. The roof is covered by solar PV panels that also extend over the outdoor space and is supported by full redwood trunk columns.

Exterior Walls & Structure: The walls around the building perimeter are a hybrid assembly of wood framing and **strawbale infill**. They have a **clay plaster interior finish** and exterior cladding of horizontal **redwood siding**. There are large windows between the shear walls to provide additional access to daylight. The window sections of the walls are framed with wood, with **cork or Gutex™** rigid thermal breaks. The ground floor podium level is a **Cross-Laminated Timber** (CLT) podium deck supported by **glulam** framing, and a **heavy timber** buckling-restrained braced frame lateral system for seismic safety. The foundation consists of reinforced concrete.

Apartment Levels: There are 33 apartment units ranging from studios (6), one-bedrooms (9), two-bedrooms (9) and three-bedrooms (9). The walls between apartments are wood framed shear walls or acoustic partition walls that are insulated with dense pack **cellulose insulation**. Within apartment units, the walls between rooms consist of a double-layer of 2” **compressed straw panels**. The floors and roof are made of **engineered wood, plywood,** and **dense cellulose insulation**. The floors are finished with **poured clay** with **tiles** in the bathroom and other high-use zones.

2 UPPER FLOOR
SCALE: 1/16" = 1'-0"

Ground Level: The ground floor has four retail spaces totaling about 5,000 square feet together, and a parking garage with 13 parking spaces and bicycle storage. The storefront walls are **LamBoo™**. The ground floor interior has wood-framed partition walls with gypsum board finish and **cellulose batt** acoustic insulation. A **Watershed Block™** surrounds the parking area and offers fire separation. The parking garage floor is a compacted aggregate base. In retail and lobby spaces, the floor consists of **adobe clay slabs** over pumice base rock.



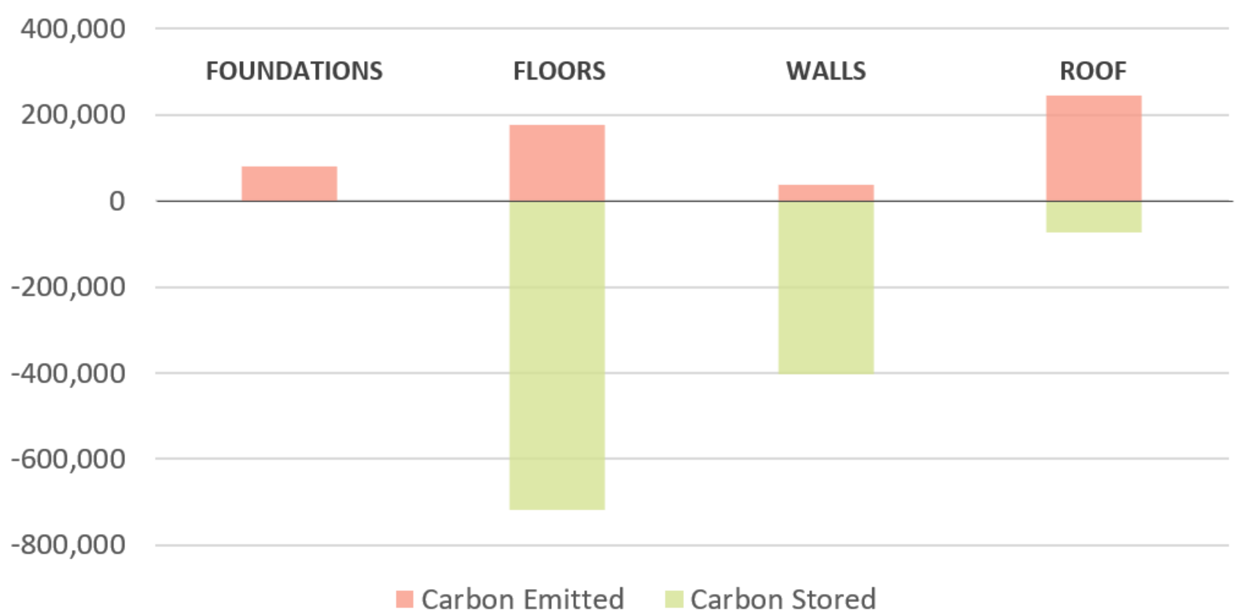
1 GROUND FLOOR
SCALE: 1/16" = 1'-0"

Carbon Difference: The carbon smart prototype materials have **about half of the embodied carbon impact** when compared to a similar building constructed with materials commonly used today. In addition, together these bio-based materials **store twice the amount of carbon as they emit**, making these materials a net carbon storing (rather than emitting) choice.

Fire Code Compliance

Fire code requires 4” heavy timber, and a minimum of 3 plys for CLT, for a 1hr rating between the parking area and residential above. A sacrificial CLT layer has been provided, as many building departments require, and thus increases the CLT to 7.5”.

Where Carbon is Emitted and Stored



Based on this design, the embodied carbon emissions associated with producing, transporting, and installing the building materials amount to about 550 metric tons CO2e, but these materials store double this, or 1,100 metric tons CO2, due to photosynthesis during growth of the plants that provide the raw materials of these products. The CO2 sequestered into the carbon mass within the bio-based materials of the carbon-smart building is the equivalent of ***nearly 3 million miles driven by a typical American car.*** On a gross floor area (GFA) basis, this amounts to a net carbon sink of almost 100 kg CO2/m2, or 10 kg CO2/sf which is about the amount of carbon dioxide emitted in the energy use of a typical condominium for 5 years. The distribution of this carbon emission and storage is shown in the chart in Appendix D.

In the following pages we present a complete concept-level design and description of a carbon-storing building, followed by a closer look at 10 strategies within the project. Each strategy targets specific assemblies within the building, and both carbon reduction and carbon storage is estimated, using the *Builders for Climate Action's 'Upfront' Materials Emissions Calculator*[4] (with some modifications), as compared to a more conventional choice of materials within the same type of assembly. While the structural floor and interior walls contain the greatest amounts of carbon storage, as noted earlier, these assemblies are already conventionally built with wood, a bio-based material. The strategies that are detailed in Appendix A focus on other areas of the building where carbon-storage options are not the norm.

Each strategy notes current challenges and local government actions that can help to overcome them. Additional explanation on how some of the less familiar materials can be used in multi-family construction is included in the Natural Building Material Assemblies section, found in Appendix C, as well as several references to the wealth of resources from CASBA and similar organizations.

A Closer Comparison

Each strategy presented below is also compared to more conventional construction for the assembly. For each comparison, an estimate was made of the difference in embodied carbon between the prototype and the more conventional assembly identified, and the additional carbon storage opportunity that comes from using materials from carbon-sequestering sources.

Carbon emissions are reported separately from storage due to the temporary nature of carbon sequestered in bio-based building products. "Reductions" below refers to the difference in carbon emissions while the "storage" refers to the carbon stored in the carbon mass of the bio-based materials. Together, these sum to a total "net carbon savings."

Some options have knock-on effects on other parts of the building design, such as when a difference in superstructure weight affects the size of foundation elements. The team included these differences in the comparison when considered significant. Note that some changes were deemed inconsequential when compared to the lack of precision expected in a concept-level design. A summary of the redesign consideration is shown in Appendix F.

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[4] Magwood, Chris. "Builders for Climate Action." https://www.buildersforclimateaction.org/. Accessed October 2020.

Table 1: Summary of carbon savings

#	Strategy	Compared to	Embodied Carbon Reduction (kg CO2e)	Carbon Storage Potential (kg CO2e)	Net Upfront Carbon Savings (kg CO2e)	Availability*	Cost
#1	Straw insulation & Clay walls	6” (R-19) fiberglass batt + ⅝” gypboard [max assumes spray foam instead]	-7,860 [max = 14,200]	72,500 [no change]	64,640 [max = 86,700]	Med - ample availability but needs specialist builders; potential for scaling via offsite prefab	Lower material cost, higher labor cost
#2	Cellulose interior insulation & straw-based MDF	Gypboard & fiberglass batt insulation in party walls and floors [min uses lowest EC gypboard and fiberglass]	15,400 [min = 700]	157,800 [no change]	173,200 [min = 158,500]	HIgh (cellulose insulation) to Med (straw MDF	Low (insul) to Med (straw MDF)
#3	Compressed straw board partitions	Studs & gypboard for in-unit room partitions [min uses lowest EC gypboard]	9,500 [min = 4,600]	107,000	116,500 [min = 111,600]	Low (compressed straw board)	Med (compressed straw panel)
#4	Clay floor finishes w/cork underlayment	LVT and carpet [min uses lowest EC carpet]	58,000 [min = -300]	4,100 [no change]	62,000 [min = 3800]	Med - depends on what is near the site, needs specialist builder	Lower material cost, higher labor cost
#5a	CLT podium, wood framing and HT BRB	Concrete PT podium and 10” concrete shear walls	317,300	377,100	694,400	High (CLT)	HIgher material cost, lower labor cost
#5b	CLT podium, wood framing and HT BRB	Pan deck podium with steel frame and HSS BRB	183,000	377,000	560,000	Med (HT BRB)	HIgher material cost, lower labor cost

#	Strategy	Compared to	Embodied Carbon Reduction (kg CO2e)	Carbon Storage Potential (kg CO2e)	Net Upfront Carbon Savings (kg CO2e)	Availability*	Cost
#6	Compacted gravel	Concrete slab-on-grade	46,200	n/a	46,200	High	Low, higher maintenance
#7	Low-cement concrete	Industry average concrete	26,200	n/a	26,200	HIgh	Med, little to no added cost, esp for foundations
#8	Partially grouted Earthen Block	Fully grouted CMU	25,000	n/a	25,000	Medium	Med, comparable to visual grade block; EMU more expensive than CMU but visually higher grade and less grout offsets cost.
#9	Exterior wood siding	Fiber-cement board	16,500	20,500	37,000	High	Med, large range in alternative siding products; higher than fiber-cement
#10	Wood sourcing from verified replenishment of harvests	Wood sourcing not verified for replenishment of harvests	n/a	800,500 (wood floor framing only additional)	800,500	High	

***Availability:**

- o Low – in prototype stage or one-off project precedent
- o Med – readily available but in small quantities
- o High – readily available to the East Bay Area and scalable

Local Government Strategies

The prototype demonstrates that creating a carbon-storing building sector is possible. To bring this building and others like it into reality, designers, builders, and suppliers will all need to adjust their practices. Local governments can play a role by removing barriers to what is currently uncommon building practices, and by supporting markets and supply chains for bio-based building materials.

1. Remove Barriers & Adopt Codes

Straw insulation

- Allow thicker walls without penalty to setbacks, floor area calculations, or other restrictions (e.g. use 6" equivalent for all)
- Allow overhang for lower R-value bio-based exterior walls to offset intrusion on interior lettable floor area.
- Adopt IRC 2015 code appendices S and R for low-rise residential and while there is no equivalent in the IBC, consider offering pre-approved alternate means and methods.

Cross-Laminated Timber (CLT)

- Adopt IBC 2021 code changes for wood construction.

Earth Masonry Units

- Accept code alternates to ASTM C 426 for lower shrinkage rate and a greater quantity of fines contained in the EMU. For greater carbon savings, accepting lower compression strength than permitted by the standard is also recommended.

Concrete Masonry Units

- Adopt Low Carbon Concrete code (see Marin County for example)

2. Support Markets & Supply Chains

Bio-based Materials in General

- Convene potential supporters to create a natural building materials lab (coordinate with local organizations such as Build It Green and Carbon Leadership Forum that may also be advancing these goals)
- Support carbon markets that would give credit for use of carbon-storing materials.
- Consider expedited plan check, reduced fees, or other incentives.
- Create purchasing policies or incentives focused more on what goes into building products, rather than just the category of building product (like Buy Clean CA).
- Place more government emphasis on "green" ventures via debt financing for capital costs. (CalPlant1 benefitted from 100% CA state green bonds to build their plant.)

Straw insulation

- Support prototyping of locally produced prefab straw bale panels; Incubate local production of compressed straw panels
- State incentives to use straw waste such as IRC, erosion control, banning of straw burning.

Wood siding

- Disincentives for vinyl siding, e.g. Albany, justified by toxins in fire (also in manufacturing)

Conclusion

Scaling carbon storing building materials is possible and necessary to shift the building sector from a climate liability to a climate asset. Each discipline and sector engaging with buildings will need to shift their practices. Just as this prototype report identified actions available to local governments, similar strategies could be identified for architects, engineers, developers, buildings, financial institutions, and all other roles. Cross-sector collaboration will unlock the potential to make these climate-beneficial buildings commonplace.

Author Bios

David Arkin, AIA, LEED AP, is a co-Director of the California Straw Building Association (CASBA), advocating for straw building by helping to bring strawbale construction, light straw clay and cob into the residential building code, and publishing 'Straw Bale Building Details, An Illustrated Guide for Design and Construction'. He is co-Chair of the Embodied Carbon Network's Renewable Materials Focus Group and serves on the AIA's 2030 Commitment Working Group. David and his wife Anni Tilt, AIA are the Principals of the award-winning ecological design firm Arkin Tilt Architects.

Massey Burke is the co-director of the California Straw Building Association and a natural materials design/build consultant in the San Francisco Bay Area. She works on research, design, and implementation of low-carbon and carbon-sequestering building techniques, with a specific interest in supply chains and bringing natural building materials into the urban fabric. She supports clients, architects, and contractors to design for and manage construction with natural materials, and she partners with organizations including Arup, StopWaste, the Carbon Leadership Forum, and others to generate technical information and help remove barriers to scaling up natural, carbon sequestering building methods.

Anthony Dente, P.E., As Principal at Verdant Structural Engineers (VSE) and Vice President of the Cob Research Institute (CRI), Anthony is committed to appropriate material use for all structural building systems. He has become a leader in the natural and green building communities through his dedication to environmentally sensitive, low embodied carbon, and structurally-sound building materials. His contributions span the areas of engineering, code development, education, and research. In addition to pushing all conventional materials toward a more environmentally friendly approach, his company has designed over 100 structures that use natural building wall systems such as straw bale, earthbag, adobe, rammed earth, and cob.

Miya Kitahara is Program Manager at StopWaste, a public agency in Alameda County working on energy and material efficiency. She has promoted the inclusion of embodied carbon in buildings, food, and goods among local government climate action plans in California. She is active in the Carbon Leadership Forum's San Francisco Bay Area chapter, and serves on the leadership team of the West Coast Climate and Materials Management Forum. She has worked in climate action with local governments across the Bay Area since 2006 and holds an MBA in Sustainable Enterprise.

Frances Yang leads Arup's Americas Sustainable Materials Consulting practice, promoting low carbon structures for our built environment. She serves on the AIA Materials Knowledge Working Group, as vice-chair of the SEI SE 2050 Sustainability Committee, and as a board member of the Carbon Leadership Forum. She has also vice-chaired the USGBC LEED Materials and Resources TAG and co-authored the chapter "Wood Like Never Before" in *The New Carbon Architecture*. Through Frances' role in creating the framework and calculations for this report, she has been truly inspired by the deep technical expertise in CASBA and believes that scaling carbon-storing building methods to mulit-family and commercial is more possible, and more imperative, than we think.

Resources

General

- BuildWell Source (Library) https://buildwellsource.org/
- New Carbon Architecture https://www.ecobuildnetwork.org/projects/new-carbon-architecture
- CarbonSmart Materials Palette https://materialspalette.org/
- International Living Futures Institute "Zero Carbon Certification" https://living-future.org/zero-carbon-certification/

Organizations

- CASBA https://www.strawbuilding.org/
- Builders for Climate Action https://www.buildersforclimateaction.org/resources.html
- Carbon Leadership Forum https://carbonleadershipforum.org/
- Architecture 2030 https://architecture2030.org/new-buildings-embodied/

Strawbale

- https://www.strawbuilding.org/Straw-Bale-Building-Details/
- https://www.strawbuilding.org/recommended-reading

Compressed Straw Board (or Panels)

- https://www.ortech.com.au/
- https://durrapanel.com/benefit/fire-resistant/

Clay

- The Natural Building Companion (p 315-328) – J.D.Racusin & A.McArleton (2012)
- Earth Construction (p 272-273, attached) – H.Houben & H.Guillaud (1994)
- A Handbook for Building Homes of Earth (Ch13, p91-92, Handbook attached) – Peace Corps, USAID, HUD (1981)
- Refined Earth Construction & Design with Rammed Earth – (p51, 56-63, will send in next email) – Martin Rausch (2015)
- In progres: ASTM Earthen Floor (guide) https://sn.astm.org/?q=features/earthen-floor-standard-aims-promote-sustainability-improve-health-ma19.html

Lamboo

- https://www.lamboo.us/rainscreen
- https://www.lamboo.us/exteriorresources
- https://b7393589-5223-4ace-b042-1ef6ade91e63.filesusr.com/ugd/da42be_a748964566d749b893227fd26720976a.pdf

Gutex™

- https://gutex.de/en/home/
- https://foursevenfive.com/products/thermal-insulation/gutex-wood-fiberboard/

ThermaCork™

- http://www.thermacork.com/

Watershed Block™

- https://watershedmaterials.com/

Embodied Carbon Calculators

- Builders for Climate Action Building Emissions Accounting for Materials (BEAM) calculator https://www.buildersforclimateaction.org/beam-calculator.html
- EC3 https://www.buildingtransparency.org/en/

Whole Building LCA Tools

These include the use and end of life stages for buildings and a wider set of environmental impacts that follow ISO 14040/44 standards for life-cycle assessment. The list below is limited to tools that provide North American data.

- Athena Impact Estimator http://www.athenasmi.org/our-software-data/impact-estimator/
- Tally https://www.choosetally.com/
- OneClick LCA https://oneclicklca.com/

List of Appendices

The following appendices are available for download online.

Appendix A: Detailed Material Strategies
Appendix B: Detailed Architectural Description of Carbon-Smart Building Prototype
Appendix C: Natural Building Material Assemblies
Appendix D: BEAM Calculator Results
Appendix E: Climate-Friendly Sourcing
Appendix F: Engineering Approach
Appendix G: Time to Give Straw Another Look
Appendix H: Fire Test of Strawbale Wall Assembly
Appendix I: Moisture Risk of Strawbale Wall Assembly