Transformative Materials Analysis

Kriegh, J., Magwood, C., Srubar, W.,Lewis, M., Simonen, K. (6.30.2021)

Use	Material	Development Stage	Mockup / Prototype Potential	Compliance Testing	Construction assemblies and prefabrication/modularization Potential	Carbon Storing Potential	Data - carbon storing	Potential Availability (RAW MATERIALS)	Potential Community Impact (job creation, reduces pollution burden, increases resilience...)	Reward	Risk	Reference/paper/case study	Total
Rating Methodology		5 - Early stage: R&D and lab testing. (24-36 mo) 3 - R&D/small scale deployment, testing/EPD req'd (12-24 mo) 1 - Product(s) deployed, scaling and/or code compliance and regional standards required (6-12 mo)	5 - Prototype would be revolutionary 3 - Prototype would be precedent-setting 1 - Prototype would confirm viability	5 - None exist or very minimal 3 - Testing to non-code standards 1 - Testing to some/all standards	5 - None established 3 - Prefabrication/modularization needs development but assemblies established 1 - Details and assemblies already established	5 - High: net storage of 1kgCO2/kg 3 - Moderate: 0.5-1 kgCO2/kg 1 - Low: 0-0.5 kgCO2/kg	5 - No verified documents 3 - LCA study(s) exist 1 - EPD existant	5 - Global 3 - Most Geographies 1 - Some Geographies	5 - High 3 - Moderate 1 - Low	5 - High 3 - Moderate 1 - Low	5 - High 3 - Moderate 1 - Low	5 - None or minimal 3 - Early explorations 1 - Peer reviewed	
Foundations													Score
	Earthen Floor Slab	5	5	5	5	1	3	5	3	5	5	5	5 52
	Rammed earth and oiled earthen floors	Technique has been developed at a small scale, with thousands of floors less than 2,000 ft2. Material properties understood but not measured. Material formulation and physical property testing R&D required to develop an approach that can scale to large slabs.	Skill set and materials exist to create a Mockup. Small, US-based supplier Claylin could provide mix and finishes for Mockup. Demonstrations of earthen floors are transformative, hard to believe "dirt floor" can be so resilient and beautiful.	None. Testing requirements and protocols well established. Small R&D and testing budget would have major impact.	In-situ application only, not suitable for prefabrication.	Substitution of earth material for concrete would provide very large carbon reductions. Addition of ag fibers and small quantity of carbon-storing aggregate would push the material into carbon storing territory. The carbon storage could be "tuned" by volume of CS aggregate to influence WBLCA results. Low-strength concrete is ~200-300 kgCO2e/m3. Earthen floor could reduce emissions by 90-95%.	LCA by Lola Ben-Alon https://www.natmatlab.com/publications-1 shows 17.2 kgCO2/m3 for a clay/sand/straw mix that could be used for earthen floors (no accounting for storage for the straw component). Plant-based polymerizing oil needs to be included, but will be close to net zero emissions.			Extremely low embodied carbon, can be made carbon storing, zero waste, long-lasting, material available globally. Existing concrete contractors have knowledge and ability to install.	Skepticism from designers, builders, code officials. Testing to establish parameters for material. Not as strong as concrete, but "strong enough?" Perceptions on impacts to schedule		
	Cement-Free Alkali-Activated Concrete	3	4	5	3	1	3	5	5	5	4	1	4 43
		Lab and engineering-scale prototypes and some R&D with ready-mix concrete companies are complete. Trial batches at U Colorado and US Concrete (or similar) required for full-scale prototype installation.	3-5 Highly feasible. Relationships and technical requirements established.	Small-scale R&D project with partners to optimize mixes and measure durability according to ASTM standards.	Potential for precast concrete panels.	Substitute would be very low-carbon option compared to traditional OPC concrete. Use of Blue Planet aggregate and/or Minus Material carbon-negative fillers could make it carbon-neutral or carbon-storing.	Multiple LCA studies exist; depends on mixture design formulation.			Up to 90% reduction in embodied carbon.	3-5 Acceptance/education; unfamiliarity with material.		
Structural													
	Mass Timber	1	1	1	1	3	1	3	1	4	1	1	1 19
		Technology and techniques well established, beginning to see wider adoption and use on large buildings. (Sustainable Forest Cycle)	Highly feasible. Demonstration projects already exist so need for Mockup/prototype not great.	Well established.	Assemblies and detailing well established.	? The big question! Work is ongoing to establish the value of carbon stored in mass timber products.	Industry efforts underway to evolve an appropriate LCA methodology			3-5 Key partner in bringing mass timber to larger scale & establishing sustainable forestry practices.	Not risky enough. The sector already has lots of momentum and players.		
	Bamboo structural columns and beams	3	3	3	3	5	3	3	3	5	4	2	2 39
		Bamboo glulam, cross laminated bamboo, and structural bamboo plywood already exist but have substantially less use/uptake compared to mass timber. Testing required for North American and European markets.	Highly feasible. Some manufactured products already exist. Very little use in North America, demonstration would be precedent setting. Potential for composite components and assemblies with other materials (e.g., Resource Fiber)	Testing protocols well established. Individual products will require testing.	Assemblies still in development. Much can be adopted from mass timber.	Shorter growth cycles and reduced soil disturbance result in more verifiable storage. Forestry practices require regulation and oversight.	Emissions: 210 kgCO2e/m3 from Net storage: ~1,000-1,400 kgCO2/m3 1 m3 = 875 kg 437.5 kg carbon content per 1 m3 1,605 kgCO2 per 1 m3			Bamboo has growth potential in global south. Microsoft helps establish a carbon storing technology that brings new forestry and manufacturing to less developed economies where majority of construction will take place in coming decades.	3-5 Developing products in markets outside NA and EU that may not be cost-effective in those markets.	1-3 Example: Resource Fiber's Bamboo Nail Laminated Timber System, Bamboo Biocomposite materials (plastics), Bamboo Industrial Fiber (3D printing)	
	Biofiber structural columns/beams	5	5	5	3	5	4	3	5	5	4	4	3 51
		Hemp & straw lumber; mass plywood made from ag-residue. R&D required for proof of concept.	Mockup/prototype would be first of its kind.	Protocols well established. No previous testing of materials in this configuration.	No assemblies yet developed. Mass timber can provide guidelines	High. Largest factor is glue/adhesive; better adhesives will achieve better carbon storage results	3-5 No LCA data currently. Figures would be similar to bamboo glulam (above).			Sidestep carbon storage debate surrounding mass timber by using annually renewed ag-residues for structural use.	3-5 Early development stage. Products exist, but have not been used for structural purposes.	44260	
	Mycelium tube structural	5	5	5	5	4	5	3	4	5	5	5	3 54
		Very early stage development; Initial material property testing required.	Feasible. Small-scale mockup/prototype could be completed after a round of initial property testing.		No assemblies yet developed. Could replace dimensional lumber.	3-5 LCA would need to be completed to confirm potential.	No LCA data.			Major disruption of structural materials market with first purpose-grown material	Very early development stage. Potential has to be confirmed with R&D and testing.		
	Algae carbon fiber	5	5	5	5	3	5	5	3	5	5	5	5 56
		Lightweight frameworks- Very early stage development; Potential for substructure for "growing" materials, conceptual	Mockup/prototype would be first of its kind.	5	High potential; can be integrated into panelized modules with other materials.	? LCA would need to be completed to confirm potential.	No LCA data.			Major disruption of structural materials market with first composite / purpose-grown material hybrid	Very early development stage. Potential has to be confirmed with R&D and testing.	Case study of structural framework	
	Algae - grown bricks	5	5	5	5	3	5	5	5	5	4	5	5 57
		Lab-scale testing complete; company formation complete. Engineering-scale prototype capability (12 months); commercial product availability (algae biocement) in 24-36 months.	Highly feasible if smaller scale (12 months); highly feasible for full-scale prototype (24 months).	Depends on final application; only a few ASTM tests required.	No assemblies yet developed.	Net-zero to moderately carbon storing; tremendous reduction in carbon compared to CMU blocks (target replacement).	No LCA data.			First application of algae brick technology; major disruption by using living (vs. once-living) building materials.	3-5 Proof of concept proven at lab scale; pilot/prototype scale is higher risk, but feasible in 12-24 months.	https://www.sciencedirect.com/science/article/pii/S2590238519303911 https://www.nytimes.com/2020/01/15/science/construction-concrete-bacteria-photosynthesis.html	
	Algae - grown carbon-storing limestone	5	5	5	1	5	5	5	5	5	4	5	5 55
	for OPC or alkali-activated cement concrete	Lab-scale proof of concept; Minus Materials received funding for engineering-scale prototype. Development requires funding for kg-scale prototype and first application in cement and concrete.	Feasible if small scale (12 months); highly feasible for full-scale prototype (36 months).	Chemical composition of limestone fillers; virtually no tests. Risk primarily related to producing fillers at-scale.	Details/assembly development not required as it just replaces ingredient in concrete	Extremely high; 1kg captures 1.83 kg CO2.	No LCA data.			First application of algae-grown limestone technology as a carbon-sink aggregate for cement and concrete; legitimizes a biological aggregate competitor to Blue Planet aggregates (chemical process).	3-5 High; microbial precipitation of aggregates feasible at-scale but currently at ~1g scale in the laboratory	https://www.colorado.edu/ceae/2020/03/17/srubar-will-use-new-nsf-award-create-carbon-sink-concrete https://www.nsf.gov/awardsearch/showAward?AWD_ID=1943554&HistoricalAwards=false	
Enclosure													
	Agriboard, straw SIP	1	1	1	1	5	3	3	5	3	1	3	1 28
		Been around a long time, developed strong technology; market break and development of better sheathing product required to break through; EPD and some assembly testing may be required	Very feasible, product exists today but is not widely known or used.	Full ASTM testing completed.	Structural insulated panel with fully developed assembly details.	Company LCA would need to be supported by EPD.	Company LCA shows 870 kgCO2 storage per panel at size of 24' x 9' x 8" http://www.agriboard.com/carbon/Embodied%20Energy-AgriBd.pdf			Major disruption of structural panel market.	Not a new product. Would be breathing new life into an older idea.		

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Enclosure														
	Strammit, compressed straw board	3	3	1	1	5	3	3	5	5	3	3	3	38
		Been around a long time, huge potential for interior partitions and additional exterior insulation; Development of commercial/industrial assembly detailing, EPDs and testing specific to panel design required	Very feasible, product can be imported from Europe for demonstration.	Full EU testing completed	Can be part of structural panel and/or used as interior partition wall system.	Company LCA would need to be supported by EPD.	Company LCA shows 549 kgCO2 storage per 1 m3 of material			Major disruption of interior partition market. Greater carbon storage potential exists in building interiors than exteriors. Makes high carbon storage possible in existing and large buildings. Built-in potential for design for disassembly.	Not a new product. Would be breathing new life into an older idea.			
	Hempcrete precast wall panels	3	3	1	1	4	3	3	5	5	4	1	1	34
		Small scale deployment in Europe has occurred; Development of commercial/industrial assembly detailing, EPDs and testing specific to panel design required	Very feasible. Products available or can be cast in situ for demonstration.	EU & UK testing completed for several product types.	Structural insulated panels and/or blocks.	44260	LCA studies exist proving carbon storage capabilities, depending on mixture formulatin: https://www.sciencedirect.com/science/article/abs/pii/S095965262031893X			5 Provide major support for nascent hemp farming sector. Highly fire resistant plant-based option.	3-5 Supply chain is in early development. Raw materials may be costly early in development.			
	Ecococon, straw wall panels	3	3	1	3	5	2	3	5	5	1	1	3	35
		1-3 Strong product, eager to expand into markets outside Europe; clay or lime panels for fire resistance; Production facility in eastern Europe. Potential for North American manufacturing is very high.	Very feasible. Product available for import for demonstration.	EU testing completed.	Structural insulated panels.	Very high. Company EPD would need to be updated for US market	1-3 Product EPD VTT-CRM-158424-18 shows 88.7 kgCO2e storage per 1 m2 of wall area			Minor investment for major impact. System is market-ready but currently obscure.	Low risk, system well developed.			
	Bamcore, bamboo SIPs	3	1	1	3	5	2	3	5	3	1	1	3	31
		Strong product, market-ready, potential to scale and combine with bamboo structural elements; US production facility just being established. Development currently at residential scale, would need testing to scale up to larger buildings.	Very feasible. Product currently available for demonstration.	US testing underway	Structural panels.	No EPD, but company LCA for whole building includes encouraging results. Figures should be similar to glulam bamboo (above). When combined with carbon-storing insulation, this system has very high carbon storage potential	1-3 Company LCA for whole building shows bamboo components to be carbon neutral in A1-A3 phases. https://www.bamcore.com/wp-content/uploads/2019/11/BamCore_Report_10-21-2019_Quantis.pdf			New idea ripe for major uptake. Can be manufactured in many locations globally. Easy to combine with local bio-based insulation.	Low risk, system meshes well with current engineering standards.			
	Ecovative Foam	4	5	1	1	4	3	3	3	4	4	3	3	38
		3-5 On-demand growth kit for insulation and partition panels. ASTM testing for building insulation completed. Production needs to scale to provide market ready products.	Very feasible. Product currently available for demonstration.	Testing complete.	High potential; can be integrated into panelized modules with other materials.	3-5 Unknown but likely very high; LCA needs to be performed to understand if biogenic storage outweigh impacts due to processing.	No EPD yet. Early company LCA shows near-neutral carbon results.			3-5 System is market-ready; coolness factor is high, but Microsoft will not be the first to implement.	3-5 Low risk; system well developed.			
	Earthen Precast Wall Panel	1	1	1	3	1	3	5	5	4	5	1	5	35
		Technique has been developed at a small scale- primarily residential.	Very feasible.	Testing complete for walls; would need some testing in location of application.	Prefabricated modules blocks availabe; more development is possible.	Substitution of earth material for concrete would provide very large carbon reductions. Addition of ag fibers and small quantity of carbon-storing aggregate would push the material into carbon storing territory.	LCA studies of rammed earth wall exist; shows low-embodied cabron potential.			3-5 Extremely low embodied carbon, can potentially be made carbon storing, zero waste, long-lasting, material available globally. Existing concrete contractors have knowledge and ability to install.	Skepticism from designers, builders, code officials. Testing to establish parameters for material. Not as strong as concrete, but "strong enough?"			
	Algae - grown brick veneer wall panels	5	5	5	5	3	5	5	5	5	4	5	5	57
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Design / Assembly / Construction														
	Vertical architecture	1	3	1	3	3	2	5	5	5	1	5	5	39
		Design for passive systems energy, Minimize foundation impacts by stacking stories and functions Use stack effect inside building to assist with					1 - 3			Cost! (land, mech, systems)				
	3D Printed Earth	5	5	5	1	1	3	5	5	4	5	4	5	48
		5 Icon- Austin, Columbia Lab	Would be revolutionary for data centers	Virtually no testing done on 3D printed earth.	Would have to be done on-site	Substitution of earth material for concrete would provide very large carbon reductions. Addition of ag fibers and small quantity of carbon-storing aggregate would push the material into carbon storing territory.	LCA studies of rammed earth wall exist; shows low-embodied cabron potential.			3-5 Extremely low embodied carbon, can potentially be made carbon storing, zero waste, long-lasting, material available globally. Existing concrete contractors have knowledge and ability to install.	3D printing of earth unproven at-scale. Skepticism from designers, builders, code officials. Testing to establish parameters for material. Not as strong as concrete, but "strong enough?"	44260		
	Design for Disassembly (DfD)	4	5	5	4	4	4	5	4	4	1	3	5	48
		All structural frames and enclosure panels designed for easy disassembly and re-use - Plan for secondary use at initial design phase- (community structural, affordable housing); Development requires a kit of parts panel assembly where the panel is switched out depending on the region and material availability but the panel assembly is similar	Mockup proof of concept- engage local underrepresented communities in the northwest to train in construction and production- mock up as a longhouse representing indigenous populations		3-5 Prefabricated assemblies are a key component of DfD techniques, to allow for easy replacement or deconstruction of panelized modules.	3-5 Building with biogenic materials for a carbon-positive future.	3-5 Data- panels are easily assembled and reassembled based - materials are tested in wall panels			3-5 Lead by example, spur industry, partnerships that are mutually beneficial (reciprocal)	Low risk; system to be developed.			

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