

Sticks N' Stones N' Straw N' Steel: Material Intensity in Building Construction

Building construction worldwide uses about 40% of mineral and metal products, and 25% of forest products²⁴

One example of how to reduce this is the "Super-block" or "Super-adobe" construction technique Nader Khalili²⁵, California architect/author and founder of the Hesperia, California based CalEarth Institute²⁶ invented that is very similar to rammed earth. Wet soil under pressure (mixed with a little cement) turns into a sturdy and long lasting building material. Khalili's innovation is to pump the soil into bags that are continuous coils, and bind them with barbed wire.

These small changes accomplish big things. The bags and steel reinforcement make the results proof against earthquakes, a way to avoid devastation such as regularly occur in Iran. The steel wire adds tremendous amounts of tensional and shear strength - something lacking in many traditional forms of earth based construction. Because the bags are a continuous loop, you may fill them by machine instead of by hand, reducing construction labor to something comparable to traditional stick built construction. The steel in the barbed wire is less than the steel in nails used for traditional wood frame buildings. There is less plastic in the sandbags than in the vapor barriers often used in conventional construction. There is less cement mixed in with the sub-soil dirt than is typically used in normal foundations, probably less than is often used in internal plastering alone. And since the bulk of the home is built from on-site dirt, you don't need to truck in huge amounts of construction material. Further, the only machinery used for foundation and shell phase of construction is digging out the subsoil dirt and pumping it into the bags. This technique can be used for the entire rough shell - foundation, floor, walls, roof, even rough cabinetry and built-in furniture. It can then be insulated and finished by conventional or low impact techniques, as you please.

Super adobe is sturdy and durable – an earthquake safe variation on a technique that has been know to last centuries in Iran. How sturdy? In Hesperia, the consultants who tested one for earthquake safety still don't know the limits of super-bloc strength. They intended to test one to destruction, but their bulldozer was not powerful enough to actually destroy it, no matter how hard they tried.

That Khalili is a poet as well as an architect probably influenced his choice of materials. He himself has said that he likes the fact that sandbags and barbed wire, often instruments of war, are used to create beautiful spaces for people to live in.

Think about the embedded energy saved by this technique – reductions in steel, and plastic, and cement and wood boards. It saves the power needed to transport these things - and construction electricity and fuel too. Durability means you replace buildings less often – more conservation; all this occurs before you have made one mill, factory or plant more efficient.

A brief survey of material intensity lowering building techniques follows in tabular form:

Savings in Building Construction			
Methods	Intensity Reduction (%) ⁱ	GHG Savings (%) ⁱ	Comments
Rehabilitate, don't demolish ²⁷ ; even if only frame and foundation recovered, savings is substantial	75%-90%	50%-80%	% reduction depends on portion of shell saved.
Super Adobe ²⁸	90%-99%	80%+	Low rise construction only. (cost ²⁸)
Straw Bale Walls ³⁰ - an agricultural waste that makes sturdy comfortable, climate controlled homes.	90%+	80%+	Low rise, other limitations (cost ³¹); Unlike many agricultural wastes, more is produced than can be used as a soil amendment; too much straw in soil is a nitrogen robber.
Strawboard ³²	75%	50%	Replace particle board, fiber board, most manufactured woods.
Bamboo ³³ - much less land, water, fertilizer per pound of output than wood. Responsible harvesting may leave roots intact, and plants alive.	90%	80%	Potential to cultivate native U.S. Bamboo ³⁴ and non-native varieties ³⁵ in U.S. or import from Latin American varieties too. (cost ⁱⁱ)
Truly sustainably harvested wood and salvaged/recycled wood	90%	80%	Thinning for benefit of forest health not lumber companies-- unlike harvest of prime trees, often falsely labeled thinning. True thinning could produce only a tiny percent of what current harvesting yields.
Wood/Bamboo framing in buildings 4 ³⁶ to 7 ³⁷ stories.	90% ³⁸	80%	Wood and bamboo frames in building from 4 to 7 stories save substantial impact compared to conventional concrete, brick or metal – common construction methods above three stories.
Wood Efficient Approaches to Design ³⁹	26%	10%	Cumulative with some other methods.
Geopolymeric Cement ⁴⁰ (roofing tile as one commercial example ⁴¹)	90%	66%	This alternative cement is based on natural silicates, which requires neither limestone nor anything like the amount of energy Portland Cement needs. Economical in uses where greater strength per lb makes up for MUCH higher cost per lb.
Rastra ⁴² - an efficient insulated concrete form made from recycled EPS plastic and cement	90%+	80%+	Shallow frost protected foundations ⁴³ or buildings around ten stories.
Pozzalano (fly ash and other waste or natural replacements for a portion of cement in concrete) + recycled steel	50%	25%	Useful to further lower impact of Rastra
Wood/Bamboo above seven stories	?	?	History & practice suggests possibility ⁴⁴
Skyscrapers need to make up higher embedded energy with operational efficiency			Skyscrapers will require more embedded impact than shorter buildings. To make up for this they need to attain operational efficiencies exceeding even "passive" smaller structures. After making them hyperefficient, solar cells can be added to make them net energy exporters. Because skyscrapers are so expensive to construct anyway, in many cases solar cells won't increase their cost by a significant percent, even at current photovoltaic prices.
Panelshake roof ⁴⁵ - from completely recycled ingredients	90%	80%	Recycling, not extended lifespan, lowers impact.
Linoleum, bamboo, cork, recycled wood, and recycled glass floors	75%-90%	50%-80%	All well known "green floor" techniques
Interface Carpet Tiles ⁴⁶	90%+	80%+	All carpet tiles lower intensity over conventional carpets because wear occurs faster in heavily traffic areas. With tiles, just the worn areas may be replaced – extending overall lifespan of carpet. In addition, the tiles are recyclable, and the backing has been designed to be recycled back into itself; that is, you can make backing material for Interface

ⁱ % Savings refer to part, construction stage or whatever technology listed replaces – not entire building.

ⁱⁱ Asian imports will always be more expensive than native North American wood. For bamboo to be competitive here, North America must turn to closer sources – native or Latin American.

			tiles from the old backing from old Interface tiles
Unburned clay based finishes ⁴⁷	85%	50%	
Other natural finishes	?	?	Huge variety, intensity unanalyzed. Some probably produce significant savings.
Low impact site design and grading ⁴⁸	75%	50%	
Mechanical Equipment (climate control, plumbing, ducting etc.)	75%	50%	Result of operating energy savings in buildings - dealt with in later sections on buildings
Pex ⁴⁹ - Advanced plastic plumbing as long lasting, and lower impact than copper.	90%	80%	More expensive than copper, but less labor to lay pipe; installed cost is the same or lower. Repairs are less expensive as well. Becoming standard.
Fiberglass window frames ⁴⁷ - Compared to aluminum, based on recycling % figures ⁵⁰ ; also lower impact and longer lasting than vinyl	80%	75%	100% recycled aluminum would have lower embodied impact than fiberglass ⁴⁷ , but higher operating impact. Vinyl, though better than aluminum, is a worse insulator than fiberglass
Cellulose insulation ⁵¹	80%	75%	Must be careful not compromise operating efficiency – insulating properties comparable to fiberglass, but not as good as foam.
Glazing, Plastics, natural gas piping, wiring			No savings in processes representing 10% of all embodied impact and energy.
Note: savings include increases in lifespan and durability unless stated otherwise			

In total, processes representing 10% or less of all embodied energy and impact in buildings may not be subject to significant reduction. Given the other reductions listed, this means that total embodied impact in building site preparation, construction and finishing can be reduced by 75% to 80% - at essentially zero market cost. Very roughly this would reduce energy consumption in site preparation, building construction, and finishing by a bit more than half.

End Notes

²⁴David Malin Roodman and Nicholas Lenssen, *Worldwatch Paper #124: A Building Revolution: How Ecology and Health Concerns Are Transforming Construction*. Single Page Summary of Book, March 1995, Worldwatch Institute, 22/Aug/2005 <<http://www.worldwatch.org/pubs/paper/124>>. (note one page summary, not entire 67 page paper)

²⁵ California Institute of Earth Art and Architecture, *Nader Khalili*. Jan 2004, California Institute of Earth Art and Architecture, 23/Aug/2005 <<http://www.calearth.org/khalili.htm>>.

²⁶California Institute of Earth Art and Architecture, *CalEarth Forum*. July 2005, California Institute of Earth Art and Architecture, 23/Aug/2005 <<http://www.calearth.org/>>.

²⁷Ernst von Weizsacker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four - Doubling Wealth, Halving Resource Use - The New Report to the Club of Rome* (London: Earthscan, 1997).

Wayne Trusty and Jamie Meil, *The Environmental Implications of Building New Versus Renovating an Existing Structure*. Jan 2001. ATHENA™ Sustainable Materials Institute, 23/Aug/2005 <http://www.athenasmi.ca/papers/down_papers/SB2000_paper.pdf>.

²⁸Ernst von Weizsacker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four - Doubling Wealth, Halving Resource Use - The New Report to the Club of Rome* (London: Earthscan, 1997).

Wayne Trusty and Jamie Meil, *The Environmental Implications of Building New Versus Renovating an Existing Structure*. Jan 2001. ATHENA™ Sustainable Materials Institute, 23/Aug/2005 <http://www.athenasmi.ca/papers/down_papers/SB2000_paper.pdf>.

²⁹ Amazon Nails, *Information Guide to Straw Bale Building for Self-Builders and the Construction Industry*, 2001). 2003. *Amazon Nails*, 23/Dec/2003 <<http://www.strawbalefutures.org.uk/pdf/strawbaleguide.pdf>>.p2.

³⁰Canadian Architect, "Measures of Sustainability - Embodied Energy," *Measures of Sustainability*, 2002, Canadian Architect, 02/Feb/2003 <http://www.cdnarchitect.com/asf/perspectives_sustainability/measures_of_sustainability/measures_of_sustainability_embodied.htm>.

³¹ Amazon Nails, *Information Guide to Straw Bale Building for Self-Builders and the Construction Industry*, 2001). 2003. *Amazon Nails*, 23/Dec/2003 <<http://www.strawbalefutures.org.uk/pdf/strawbaleguide.pdf>>.p2.

³² 4, "Wheat-Straw Particleboard,". *Environmental Building News*, no. 6 Nov/Dec 1995: Product Review, BuildingGreen.Com, 23/Aug/2005 <<http://www.buildinggreen.com/auth/article.cfm?fileName=040608a.xml>>.

³³ International Bamboo Foundation, *Bamboo Technologies | About Bamboo*. 15/May 2004, International Bamboo Foundation, 26/Oct/2005 <<http://www.bambootechnologies.com/allabout.htm>>.

International Network for Bamboo and Rattan, *International Network for Bamboo and Rattan (INBAR) | Bamboo and Rattan Facts*. 2005, International Network for Bamboo and Rattan, 26/Oct/2005 <<http://www.inbar.int/facts.htm>>.

International Fund for Agricultural Development, *Agricultural Research Grants | Programme for Development and Diffusion of Technologies for Smallholder Bamboo- and Rattan-Based Producers* –

Phase II. 2005, International Fund for Agricultural Development, 26/Oct/2005
<<http://www.ifad.org/grants/tags/518.htm>>.

³⁴ United States Department of Agriculture Natural Resources Conservation Service, *PLANTS National Database Reports and Topics - Arundinaria Gigantea*. 22/Aug 2005, United States Department of Agriculture Natural Resources Conservation Service <http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=ARGI>.

³⁵ David Linvill, Frank Linton, and Michael Hotchkiss, *Growing Bamboo in Georgia*. 9/May 2001, Cooperative Extension Service - The University of Georgia College of Agricultural and Environmental Sciences, 23/Aug/2005 <<http://pubs.caes.uga.edu/caespubs/horticulture/GrowingBamboo.htm>>.

Carol A. Miles, Chuhe Chen, and Tamera Flores, *Washington State University Bamboo Research Report 2000 - On-Farm Bamboo Production in the Pacific Northwest*, 2000). May 2001. *Extension Agricultural Systems Program, Washington State University Research and Extension Center*, 23/Aug/2005 <<http://agsyst.wsu.edu/BambooReport2000.pdf>>.

³⁶Kevin K. C. Cheung, *Multi-Storey, Multi-Family Wood-Frame Construction in the USA*, 27/Sep/2000). *International Conference on the Seismic Performance of Traditional Buildings:Istanbul, Turkey, Nov.16-18, 2000*. 15/Nov 2001. *International Council on Monuments and Sites: International Wood Committee*, 23/Aug/2005 <<http://www.icomos.org/iawc/seismic/Cheung-K.pdf>>.

³⁷Laura Soullière Harrison, "National Park Service: Architecture in the Parks (Old Faithful Inn)," *Architecture in the Parks: Excerpts from a National Historic Landmark Theme Study*, Nov 1986). 26/Feb 2001. *National Park Service - Department of the Interior*, 23/Aug/2005 <http://www.cr.nps.gov/history/online_books/harrison/harrison3.htm>.

Chateau at the Oregon Caves, *Oregon Caves Outfitters - An In-Depth Description of the Chateau*. 2003, Chateau at the Oregon Caves, 23/Aug/2005 <<http://www.oregoncavesoutfitters.com/AbouttheChateau.asp>>.

³⁸Jamie Meil et al., *CORRIM: Phase I Final Report - Module J: Environmental Impacts of a Single Family Building Shell - From Harvest to Construction (Review Draft)*. 23/Aug 2004. *Consortium for Research on Renewable Industrial Materials (CORRIM)*, 23/Aug/2005 <http://www.corrim.org/reports/final_report_2004/Module%2520J_%2520August%252023.pdf>.

³⁹ Ann Edminster and Sami Yassa, *Efficient Wood Use in Residential Construction: A Practical Guide to Saving Wood, Money, and Forests*, 1998). *Natural Resources Defense Council*, 19/Feb/2006 <<http://www.nrdc.org/cities/building/rwoodus.asp>>.

⁴⁰Zongjin Li, Ding Zhu, and Yunsheng Zhang, *Development of Sustainable Cementitious Materials. International Workshop on Sustainable Development and Concrete Technology: Beijing, May 20-21, 2004*. 25/Mar 2004, 23/Aug/2005 <<http://www.ctre.iastate.edu/pubs/sustainable/lisustainable.pdf>>.p57.

⁴¹Siloxo Pty Ltd, *Siloxo -Melbourne Australia*. Siloxo -Products and Services, 15/Aug 2003, Siloxo Pty Ltd, 18/Aug/2004 <<http://www.siloxo.com/products.htm>>.

⁴²Rastra Found., *What is RASTRA®*. 16/Mar 2005, Rastra Found., 4/Sep/2005 <http://rastra.net/rastracom/web-site/wi_ra.htm>.

⁴³ Rastra Found., *What is RASTRA®*. 16/Mar 2005, Rastra Found., 4/Sep/2005 <http://rastra.net/rastracom/web-site/wi_ra.htm>.pp1-2.

⁴⁴ Wooden pagodas the height of small skyscrapers have been documented historically.

China Internet Information Center, "Introduction," *China Through a Lens*, 25/Sep 2002, China Internet Information Center - Authorized Government Portal Site to China, 4/Sep/2005 <<http://www.china.org.cn/english/TR-e/43461.htm>>.

Edwin Karmioli, *Mysteries of Japanese Pagodas Unlocked*. 17/Aug 2002, Asia Times, 4/Sep/2005 <<http://www.atimes.com/atimes/Japan/DH17Dh01.html>>.

Bamboo is used as scaffolding in building skyscrapers today.

Mark Landler, "Foreign Desk: Hong Kong Journal; For Raising Skyscrapers, Bamboo Does Nicely (Abstract)," *NY Times*, no. Late Edition - Final 27/Mar 2002: Section A, Page 4, Column 3, 23/Aug/2005 <<http://query.nytimes.com/gst/abstract.html?res=FB0917F9385F0C748EDDAA0894DA404482>>.

Now there was one huge problem with traditional pagodas. While they were sturdy, and wonderfully insect and earthquake resistant, when exposed to fire they went up like, well, tinder. Fortunately, today there are all sorts of fire barriers you can wrap wood in. In point of fact, protected wood, guarded by a multi-hour graded fire barrier can be more fire safe than steel - because wood does not have the huge thermal conductivity steel has; it simply does not have the capability of growing as hot. How far beyond seven stories wood (and possibly bamboo construction) can grow safely is hard to guess. But seven stories is probably not the limit.

⁴⁵Michelle Clark Hucal, "Recycled Roofing," *Environmental Design and Construction*, no. Cool Roofing - May 2003 Supplement 1/May 2003, BNP Media, 5/Sep/2005 <http://www.edcmag.com/CDA/ArticleInformation/features/BNP__Features__Item/0,4120,97795,00.html>.

⁴⁶**Ibid Error! Bookmark not defined.** "Chapter 7, Muda, Service and Flow" pp.139-141.

⁴⁷Wuppertal Institute for Climate, Environment and Energy, *Material Intensity of Materials, Fuels, Transport Services*, Version 2;28.10.2003. May 2004. *Wuppertal Institute for Climate, Environment and Energy*, Wuppertal Institute for Climate, Environment and Energy, 5/Sep/2005 <http://www.wupperinst.org/Projekte/mipsonline/download/MIT_v2.pdf>.p3(clay),p8(cement).

American Clay Enterprises, *American Clay Finishes™ Clay Veneer Plaster Product Specifications*. 18/Dec 2003. *American Clay Enterprises*, 5/Sep/2005 <<http://www.americanclay.com/pdfs/ProductSpecs.pdf>>.

Athena Swentzell Steen and Bill Steen, *Artistry in Clay & Lime*. 3/Jun 2005, The Canelo Project, 5/Sep/2005 <<http://www.caneloproject.com/pages/workshops/clayartistry.html>>.

⁴⁸Michael Clar, *Buckeye Development, LLC - Pembroke Woods Low Impact Development*. Feb 2000, Buckeye Development, LLC, 5/Sep/2005 <<http://www.buckeyedevelopment.net/lowimpactdevelopment.htm>>.

⁴⁹U.S. Department of Housing and Urban Development Partnership for Advancing Technology in Housing, *Affordability and Value Through Housing Technology Program and Services Guide*. 20/Jun 2002. *U.S. Department of Housing and Urban Development Partnership for Advancing Technology in Housing*, 5/Sep/2005 <<http://www.huduser.org/publications/pdf/guidetoserv.pdf>>.p3.

⁵⁰The Aluminum Association, Inc., *Aluminum Association | Climate Change*. 2004, Environment and Climate Change - Conservation, Preservation, and Recycling, The Aluminum Association, Inc., 5/Sep/2005 <http://www.aluminum.org/Content/NavigationMenu/The_Industry/Government_Policy/Climate_Change/Climate_Change.htm>.

⁵¹Alex Wilson, "Insulation Materials: Environmental Comparisons," *Environmental Building News* 4, no. 1 Jan/Feb 1995, BuildingGreen.Com, 5/Sep/2005 <<http://www.buildinggreen.com/auth/article.cfm?fileName=040101a.xml>>.

More recent data from the United States National Institute of Standards and Technology suggests essentially the same thing.

Barbara C. Lippiatt, BEES 2.0 -Building for Environmental and Economic Sustainability Technical Manual and User Guide, Jun/2000). June 2000. Office of Applied Economics, Building and Fire Research Laboratory, National Institute of Standards and Technology, 5/Sep/2005
<<http://museum.nist.gov/exhibits/timeline/PDF/BEES.PDF>>.pp 62,65.

A contractor for the EPA analyzed the same BEES database and came to the opposite conclusion: United States Environmental Protection Agency Office of Research and Development, Framework for Responsible Environmental Decision Making (FRED): Using Life Cycle Assessment to Evaluate Preferability of Products, Oct 2000), EPA/600/R-00/095. June 2001. United States Environmental Protection Agency Office of Research and Development, 5/Sep/2005
<<http://www.lcancer.org/library/pdf/fred.pdf>>.pB-5.

Their conclusion does not seem to match the data. Where BEES database, as added up in manual site shows cellulose requiring about one fifth the energy input (for manufacturing and raw materials combined) as fiberglass, the FRED example shows cellulose requiring more than **20 times** the energy per kilogram. Since this varies from every other analysis ever done to be believed it would have to more specific as to where the difference came from.

For example the Minnesota Building Database shows about one tenth the global warming impact for cellulose as fiberglass

University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, "Minnesota Building Materials Database - Generic Fiberglass Batt," *Minnesota Building Materials Database*, 26/May 2004, University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, 5/Sep/2005
<http://www.buildingmaterials.umn.edu/07211_batt_be.html>.

University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, "Minnesota Building Materials Database - Blown Cellulose," *Minnesota Building Materials Database*, 26/May 2004, University of Minnesota College of Architecture and Landscape Architecture Center for Sustainable Building Research, 5/Sep/2005
<http://www.buildingmaterials.umn.edu/07210_blown_be.html>.