THE NEW CARBON ARCHITECTURE

BUILDING TO COOL THE CLIMATE

BRUCE KING

Introduction

The primary task of any good teaching
is not to answer your questions,
but to question your answers.

- Adyashanti, *The Way of Liberation*

Imagine:

You walk into a brand new building and immediately sense something is different. The structure is all exposed wood—columns, beams, even floor and roof are all great curving slabs of timber elegantly joined together from smaller pieces. The skin and insulation, which you can also see, are straw bound into shapes that shed rain and insulate walls. The foundation is soil from the site transformed by invisible microbes into strong concrete to hold everything up, and warm, leatherlike floors that need no additional covering. It should somehow look and smell like a barn, yet it feels more like an inviting bedroom or an elegant museum. It's nicer than any building you've ever been in before.

And it's not a handmade house in the woods—it's a new downtown office building, nine stories high, full of people and filling half a city block. It gathers all the power and water it needs, is elegantly lit by daylight, and processes all of its own water and wastes into soil for the courtyard gardens. And, though you can't see this, compared to what might have been built a decade earlier its construction put thousands of tons less carbon into the air—and pulled hundreds more tons *out* of the air to serve as walls, floors and roof.

The New Carbon Architecture: buildings made of sky. For the first time in history, we can and should build pretty much anything out of carbon that we coaxed from the air. We can structure any architectural style with wood, we can insulate with straw and mushrooms, we can make concrete—better concrete—with clay, microbes, smoke, and a careful look in the rear view mirror and the microscope. All of these emerging technologies and more arrive in tandem with the growing understanding that the so-called *embodied carbon* of building materials matters a great deal more than anyone thought in the fight to halt and reverse climate change. The built environment can switch from being a problem to a solution. And as a cool bonus, it doesn't matter whether or not you accept that climate change is anthropogenic: all the technologies described in the pages to follow make sense for a host of reasons, not least that they are much nicer buildings to occupy, and just happen to pull carbon out of the air.

Image courtesy of Darrel DeBoer, Architect

But to back up a bit . . .

Human beings started building about eight thousand years ago with the dawn of the agricultural revolution, and that extended worldwide moment was arguably the most disruptive in history for us and the rest of life on Earth. Rather than hunt and forage about the landscape for our food, we grew it in one spot, and next thing you know there was architecture, political states, wealth and poverty, Gutenberg and Einstein, global tension, Lady Gaga, and drive-thru wifi-enabled hamburger stands in Cairo.

And billions more of us.

We've been developing the art and science of building for these thousands of years, mostly learning from trial and error, but as of the last few centuries also learning and developing via science. We know an awful lot more about how things work than we ever did, but can also dimly see how much we still don't know, such as what most of the universe is made of.

Speaking of what things are made of, in many ways the history of architecture follows the development of materials—follows the history of people messing around with things they found in the landscape to get bricks, then boards, then toilets, then building-integrated photovoltaic panels. People learned to fire clay to make pottery and bricks, and when the kilns were made of limestone they discovered that the intense heat also changed the rocks: lime plaster, concrete, Pantheon. In some places the potters saw shiny metal come oozing out of certain heated rocks: copper, bronze, iron, Golden Gate Bridge. 200 years ago the predecessors of modern structural engineers in England placed iron bars in the newly-invented Portland cement concrete, and architects went wild like they never could before: the Sydney Opera House and every downtown skyline in the world with lights, plumbing and comfort hundreds of feet in the air. In some places people saw oil oozing out of the ground, then drying to tar: vinyl siding and the interstate highway system, not to mention plywood and air conditioning. And so on. Seems like the party would never stop, but of late the many large and hidden costs are come due, and we have to change not just the way we build, but what we build *with*.

Every modern industrial society has codified systems and materials of construction that are based on abundant fossil fuels, and on having an "away" where we can "throw things". All the laws, standards and codes are still rigidly that way, even penalizing and inhibiting those who seek better ways to build. For the past century it has been increasingly easy and cheap to extract, process, assemble and transport everything we use in construction, but that just won't last much longer. At this writing in early 2017, fossil fuels are surprisingly cheap due to a variety of global conditions (*Peak oil? Are you kidding?*), so to warn of their limited supply seems ludicrous. But the climate is definitely changing, and the effects are arriving harder and faster than we expected even ten years ago. The "heat, beat & treat" approach to making and processing materials is killing us, as is the notion that we can throw anything away into landfills, water, soil or air, because building materials account for about 10% of global carbon emissions and 25-40% of solid wastes. That just has to change. We have a new ball game.

Some of us who design and build have lately started noticing that Nature builds all sorts of things, and has been doing so for the four billion years of life on Earth. She has a hell of a head start on the trial-and-error path, and as such maybe we can and should peek over her shoulder and see if we can't cheat a bit. How does a mussel build its shell? How do spiders spin their webs? How does a redwood tree stand and remain very much alive at 115 meters—and why doesn't it grow higher? How do birds stay warm and dry at night?

When facing design challenges from the small (*How can I illuminate a surface or keep out rain?*) to the large (*Can nine billion human beings live on Earth without wrecking everything for themselves and the other critters, maybe even be a welcome presence?*), we might ask *"What would Nature do?"*.

Some simple and semi-obvious things come right to mind: Nature runs on solar and geothermal energy with no other external energy inputs, and Nature uses what is at hand either by growing it like a clam grows its shell, or harvesting nearby resources as for a bird's nest. There's no FedEx, there's no power grid, there are no artificial chemicals to worry about.

But you and I live in a highly interdependent industrial society, where the sudden disappearance of FedEx, the power grid, a huge multitude of problematic chemicals, and all the other trappings large and small of modern life, would make for a whole lot of suffering for a whole lot of people. We've built a better life for more and more of us, but at the same time made quite a mess, so can we clean it up? Can we wean ourselves off of the fossil fuel habit? This ship doesn't turn very fast, but can we plot a course to a world that works for everybody?

Sure. We're scarily clever creatures, technologically. It took less than two and a half years between Franklin Roosevelt authorizing the Manhattan Project and the first atomic explosion in the New Mexico desert (for better or worse). It took only eight years between John Kennedy's proclamation and Neil Armstrong's foot stepping onto the Moon's surface. And both of those projects were designed and executed by men and women using slide rules, unreliable wire telephony, and computers far less powerful than the average laptop of today. When we collectively set ourselves to do something, for better or worse, we tend to get it done. Of late there's been plenty of the "better" but also far too much of the "worse". How about let's change that, and get more better and less worse.

This book offers a few suggestions for a more-better built environment, not so much a road map as a collection of useful essays sketching a new palette of materials for a new century. "Net Zero" buildings that use less energy than they generate are a good start, but don't go nearly far enough; here we point out how to design and build truly zero carbon buildings: the New Carbon Architecture.

Image credit © SkyHawk Photography / Brian Haux

How much impact on climate change might this make? That would be a rich and nuanced topic for a graduate level thesis, and we hope someone takes up the challenge. But the short answer is: a lot. According to the United Nations Environment Programme[1],

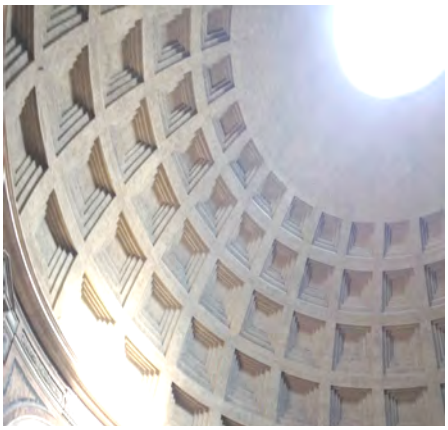
> *Though figures vary from building to building, studies suggest that . . . generally 10 to 20 percent of [global] energy is consumed in materials manufacturing and transport, construction, maintenance and demolition.*

Various and multiple other studies assign building materials 5 to 15% of global emissions, there being no consistent methodology nor data sets to draw from. Call it 10% of global emissions, and there's your impact. We propose to reduce that number to zero—and then beyond by a new "carbon positive" architecture that builds with the carbon enticed from sky. We are in technological reach, within a generation, of a global construction industry that is not only "Net Zero", generating more energy than it needs to operate, but in its materials pulls more carbon out of the air than it puts up. We can reverse the emissions engine.

I suppose it bears noting that we the authors are unabashed materials geeks (among other talents), but we're not dense. We recognize that the materials of architecture are not the only component of climate-friendly design, much less of climate work writ large. But we do want to make clear that carbon sequestering architecture is an essential component among the many emerging technologies and strategies for climate *cooling*, from energy to transportation to waste management to water. In particular, we have a keen eye on agronomy and the study of soils, and all the gazillions of amazing little creatures therein, for it's starting to look like that's where we will find real wealth and the wisdom to grow food, clothing and shelter in fantastic, lovely and healthy new ways—not to mention sequester stupendous amounts of carbon. We take pride and delight in joining the broader climate effort, and hope you will find useful the news we bring and the vision we share. It's a whole new and lovely ball game.


image courtesy of Arup (c) Redshift Photography

[1] *Buildings and Climate Change* United Nations Environment Programme, 2009



a word about "carbon"

I know you believe you understand what you think I said,
but I'm not sure you realize that what you heard
is not what I meant.

— Richard Nixon

Carbon. It's a good thing. Right up there, No. 6 in the periodic table, and one of the most common elements on Earth. Carbon is here because a very, very long time ago uncounted millions of first generation stars created it by nuclear fusion in their cores, then offered it by supernova explosion to the universe. Along with all sorts of other elemental fusion dust, it floated around, eventually to condense by gravity into planets and the world we know. And, as many have noted, it is the party animal of elements: it loves to bond with things like nitrogen, iron, hydrogen, and oxygen to make all sorts of interesting delights such as giraffes, redwood trees, poodles, and you. You read these words with carbon eyes, and hold this book with carbon hands. Please enjoy; not every blob of stardust gets to be conscious for a brief few moments under the sun and run around on a lovely planet with all sorts of other delightful carbon blobs. Congratulations, you lucky dog!

Carbon is a good thing, but too much of anything in the wrong place becomes pollution, or even poison. This book is but one of thousands of efforts to reverse the increase of gaseous carbon in the air, which is disrupting the climate in ways that we can't fully predict, and so far mostly don't like. So we enthusiastically join the growing conversation for climate solutions, but must first be clear about the terms we use. *Carbon* is bandied around a lot when often people mean slightly different things.

Carbon and *carbon dioxide* (CO_2), for example, are two different things, though they get interchanged quite a lot in climate conversations. The fraction of carbon in carbon dioxide is the ratio of weights: the atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44 because it includes two oxygen atoms that each weigh 16. To switch from one to the other, use this formula: one ton of carbon is equivalent to 44/12 = 3.67 tons of carbon dioxide. (Methane, or CH_4, a major greenhouse gas with 86 times the warming potential of CO_2, has an atomic weight of 16, so the ratio is less pronounced: a ton of carbon in your building equals 16/12 = 1.33 tons of methane in the air.) Plants like straw (about 35-50% carbon) or softwoods (about 50% carbon) *sequester* (that is, durably store) by absorbing carbon dioxide and releasing the oxygen. They feed us oxygen with their respiration, and we oxygen-breathing creatures feed them CO_2 with our respiration. Cool deal, huh? A ton of carbon in the forest or field—or as part of a building—represents or simply is 3.67 tons of carbon dioxide absorbed from the air.

Also, following convention, we will throughout the book use CO_2e to denote carbon-*equivalent* emissions from carbon and other gases such as methane, calibrated according to each's *global warming potential* (GWP) because some gases have ten or a hundred or even thousands of times the heat-trapping effect of carbon dioxide. Chapters one and two will define and expand on what we mean by *embodied carbon* aka *carbon footprint*, but from here on out we'll use those terms to connote embodied carbon equivalents, or eCO_2e. We might also sometimes be lazy and just say "carbon" when we mean CO_2e emissions, but trust you'll get the drift without confusion.

Finally: *embodied energy* and *embodied carbon*. Be warned that terms like *zero energy* (a.k.a. ZE), *net zero energy* (aka NZE), *zero net energy* (ZNE) are all increasingly tossed about in loosely interchangeable ways in conversation around building energy efficiency. Even more confusing, their close cousins *zero carbon* and *zero net carbon* are also appearing. This is a rather complex matter in itself, as terms change meaning with scale (product, building, community, nation, or globe?), with grid effciency (coal, hydro, nuclear, wind? etc.), time frame (daily, annualized, or lifetime?), and other factors. In the pages that follow, some authors will variously use embodied energy and embodied carbon, and for our purposes those are in tandem; that is, though the units for measurement are different, they rise or fall roughly in parallel. (In chapter 2, we discuss how they can diverge, as when products are manufactured with electricity from a coal-dependent grid vs. a hydropowered grid.) The growing consensus is that zero carbon (vs. zero energy) should be our societal goal across all industry, and so we will favor that term from here on out. Even better, we will also sketch out the possibility of a *carbon positive* architecture defined by more sequestered than ever emitted.

A book made of carbon, written by carbon for carbon, on how to build carbon shelter to protect us from a sometimes hostile carbon planet.

Shall we dance?

photo courtesy of Rael-San Fratello Architects

Buildings made of sky

Snapshots of the New Carbon Architecture

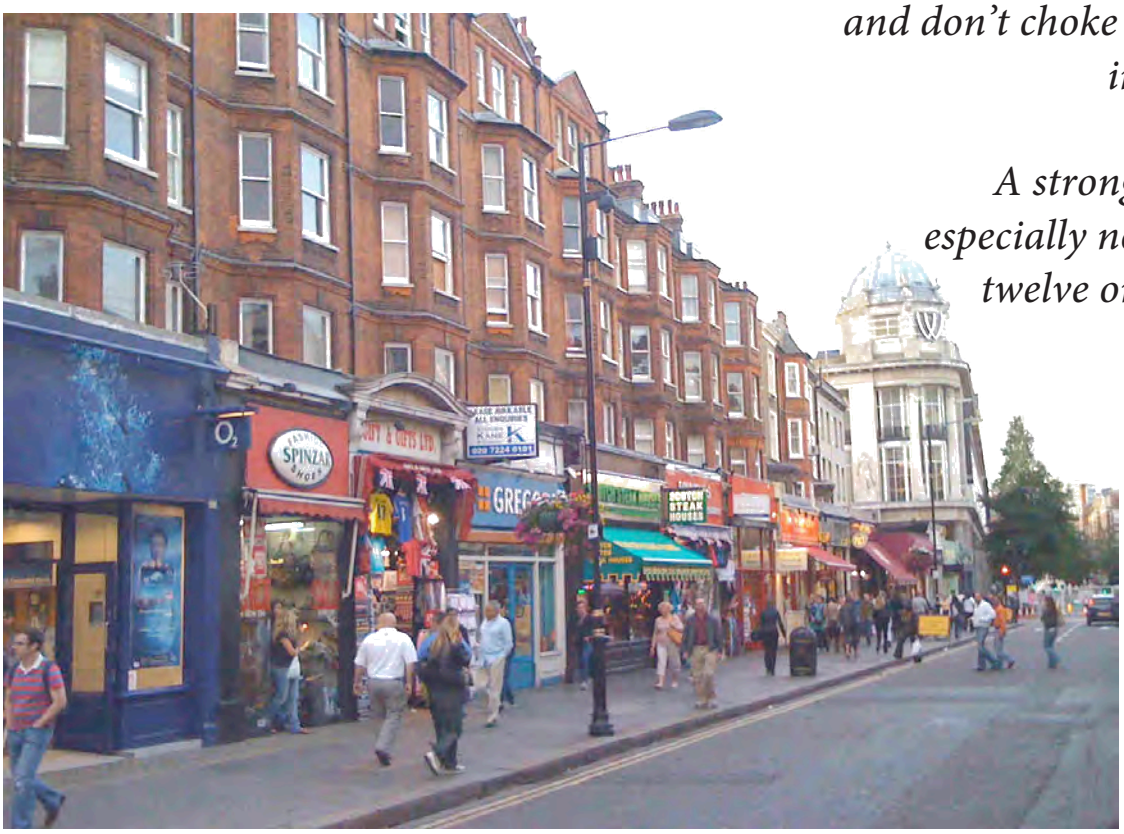
See pages following these photos for full picture credits and descriptions

Re-Build

If an existing building has decent bones—foundation, structure and enclosure—it will almost always be better to give it a deep green retrofit than to tear it down and replace it, even with a LEED platinum or net-zero structure.

Size matters

The classic cities of the world are lovely in great part because they're not too tall. They are accessible by stair, made of natural materials, and don't choke light and air from people inside or out on the street.



A strong argument can be made, especially now that we can build ten, twelve or more stories with wood, to keep things that way.

You don't need or want to build tall to get optimal density.

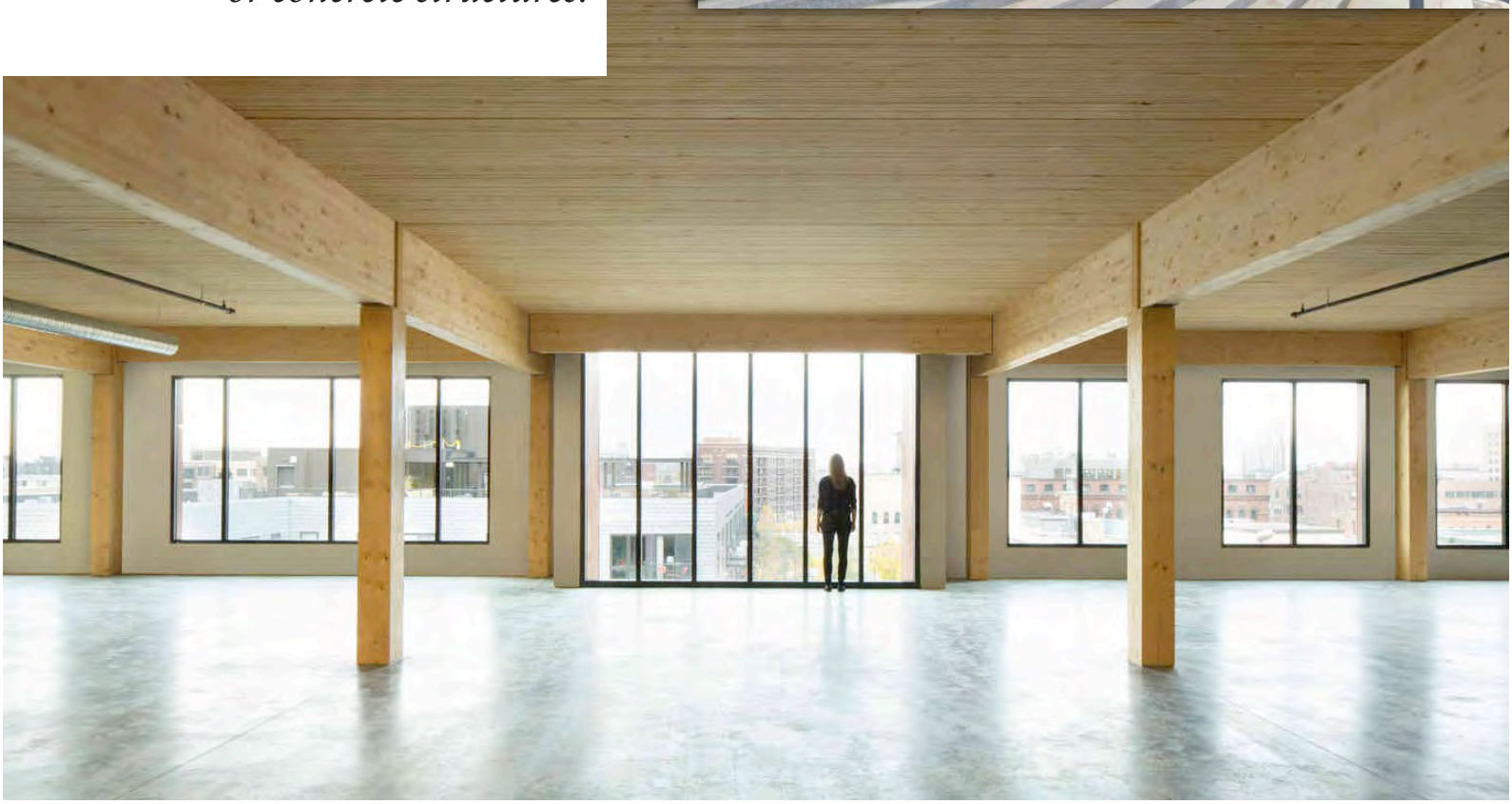
Wood

This is not your father's log cabin—

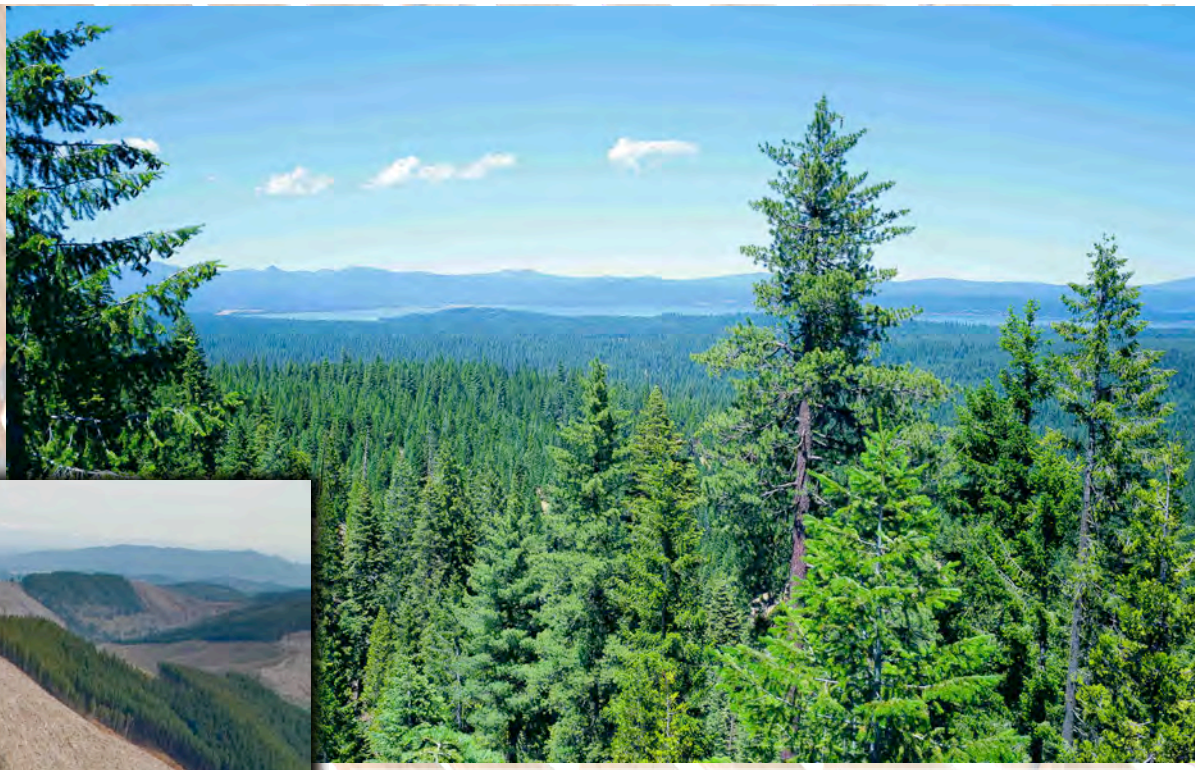
Mass timber and the expanding world of wood construction

Because it makes sense

Wild sculptural architecture is possible, but so is simple, attractive floor space that costs less than steel or concrete structures.



But not just any wood



Raise the standard

If we're going to use more timber in construction, let's work with forests for the long run.

Both of these photos are of certified forestry - under two different standards. The upper photo is the Collins Almanor Forest in Chester, California - the first privately held forest land in the USA to receive FSC (Forest Stewardship Council) certification. Logged six times in 75 years, it is still a vibrant, healthy forest with a broad mix of tree species across a range of age classes, including trees that are hundreds of years old.
photo courtesy of CollinsWood.com

The photo at left is of SFI (Sustainable Forestry Initiative) certified lands also in the Pacific Northwest. In the wake of a major storm, the denuded mountainside has sloughed huge quantities of mud into the stream below, harming water quality and fish — and what soil remains will lose much of its stored carbon.
photo courtesy of David Perry

Girl power

The growing popularity of straw bale and other natural building systems has attracted a wildly dispproportionate and welcome number of women into construction.

Straw

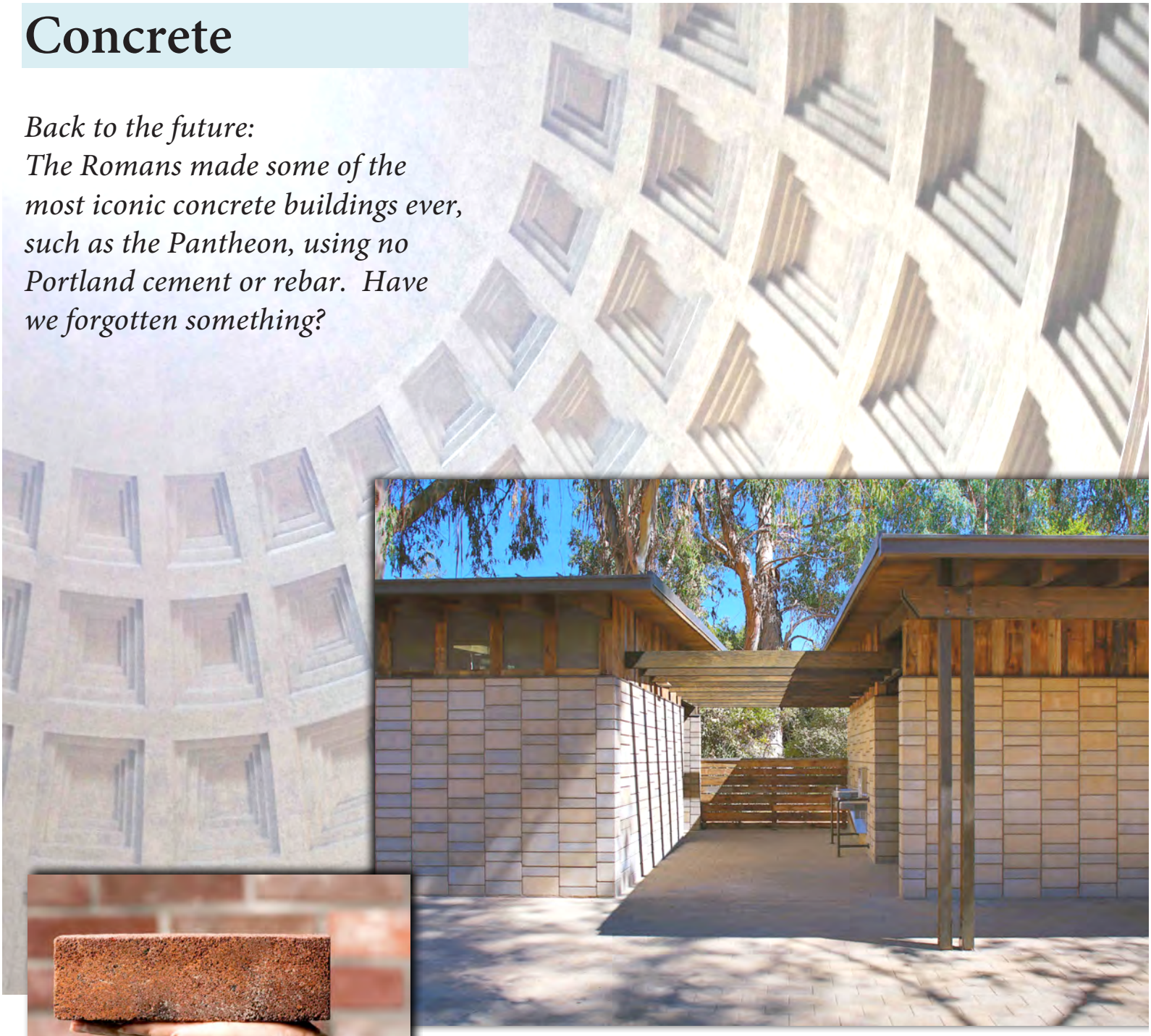
Hundreds of agricultural by-products and thousands of ways to use them—as finish, insulation, structure and more.

Going uptown

Companies like Ecococon in Europe are building lovely, computer-aided mass timber structures with straw insulation—net zero structures with minimal plastic.

Concrete

Back to the future:
The Romans made some of the most iconic concrete buildings ever, such as the Pantheon, using no Portland cement or rebar. Have we forgotten something?



Lot's of ways to make artificial rock

Just a few of the companies to watch: Watershed Media makes compressed earth blocks (above) that perform just like concrete blocks but with much less cement. BioMASON (above left) makes bricks with enzymes but no cement, and Blue Planet (left) makes limestone sand and gravel (solid carbon) with industrial emissions.

Don't build it, grow it!

We're only just starting to find out what the plant kingdom has to offer

Meet a fungi

Ecovative has pioneered mushroom insulation that grows until it fills whatever cavity it occupies.

The amazing grass

Spectacular bamboo architecture is appearing all over the world, taking advantage of bamboo's extraordinary strength. But companies like BamCore have figured out ways to turn those hollow tubes into flat, insulated panels for walls, floors and roofs.

Anything but smoke it

Hemp grows like a weed, and provides food, clothing, and now shelter: hempcrete is the natural foam insulation, and can be sprayed or hand-packed.

making it

localizing manufacture
and opening up the possibility
of zero waste

chip off the old block

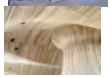
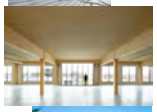
Evolution of the Concrete Masonry Unit, or CMU:
start with any fiber, such as straw, rice hulls, shredded plastic or rubber,
and add glue: could be clay, lime, or any of the bioadhesives coming online;
compress it for structural strength, or leave it fluffy for insulation—
building blocks using whatever you've got, made on the back of a truck.

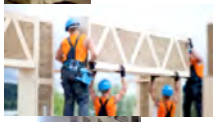
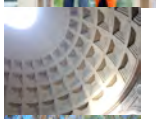
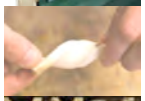
any shape you want

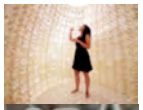
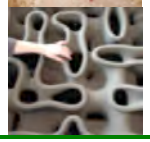
3-D printing using everyday
materials like sand, salt and wood

Photo and illustration log – Carbon Porn *in order of appearance*

Note to readers: None of the commercial entities mentioned here paid to be made visible—and apologies to the many others who deserve some exposure in the presentation of a New Carbon Architecture.

Carbon Porn	image #	thumbnail	*caption*	accreditation
	CP1		painting by Nino Gaetani, a 24 year old man with Down's Syndrome	B. King photo
	CP2		background image of mass timber Metropol Station, Seville, Spain	courtesy of Arup
	CP3		DPR Construction deep green remodel San Francisco, California	courtesy DPR Construction
	CP4		London, 2008	B. King photo
	CP5		National Assembly for Wales	courtesy of Arup (c) Redshift Photography
	CP6		Metropol Station, Seville, Spain	courtesy of Arup
	CP7		T3 Building, Minneapolis, Minnesota	Image Courtesy Ema Peter, MGA | Michael Green Architecture, DLR Group
	CP8		*(on page)*	*(on page)*
	CP9		*(on page)*	*(on page)*
	CP10		Christ the Light Cathedral, Oakland, California (also on cover)	B. King photo
	CP11			photo courtesy of Chris Magwood
	CP12		straw panels	B. King photo

CP13		straw "Stramit" type panels	photo courtesy of Ortech
CP14		wood structure + straw insulation – the Europeans are leading the way	photo courtesy of EcoCocon
CP15		Pantheon in Rome, Italy	B. King photo
CP16		Addition at Stanford University by architects Dorman Associates	Image credit © SkyHawk Photography / Brian Haux
CP17		bioMASON makes bricks using only enzymes from natural bacteria.	photo courtesy of bioMASON
CP18			B. King photo
CP19		Ecovative mushroom insulation in a stud wall cavity	photo courtesy of Ecovative
CP20		flexibility of Ecovative mushroom insulation	photo courtesy of Ecovative
CP21		split bamboo ends	B. King photo
CP22		a house made with BAMCORE bamboo panels	photo courtesy of Harvey Abernathey and BAMCORE
CP23		John Hardy Jewelry showroom, Sibang Kaja, Bali	photo courtesy of Darrel DeBoer, Architect
CP24		packing hempcrete in wall formwork	photo courtesy of Linda Delair

CP25		hempcrete in wall	photo courtesy of Chris Magwood
CP26		stacking straw blocks (company in stealth mode early 2017)	B. King photo
CP27		"Saltygloo" – an igloo made of 3-D printed salt	photo courtesy of Rael-San Fratello Architects
CP28		Sound Wall" made of 3-D printed rubber	photo courtesy of Rael-San Fratello Architects