Redshift
by AUTODESK

SUSTAINABLE CONSTRUCTION MATERIALS: BUILDING A CLEANER, HEALTHIER WORLD

Cover: At 40 stories, Canada's Earth Tower, a zero-emissions mass-timber building, will be the world's tallest hybrid wood tower. Courtesy of Perkins&Will.

SUSTAINABLE CONSTRUCTION MATERIALS: BUILDING A CLEANER, HEALTHIER WORLD

Introduction

In the wake of COVID-19, return-to-the-workplace protocols have underscored the need for healthy building interiors, with an emphasis on better-managed air quality, ample space to support social distancing, and so on. But the need for environmentally healthy structures existed long before the pandemic. Designing and constructing buildings with more sustainable materials contributes not only to our overall health but also to the health of the planet.

Around the globe, buildings generate nearly **40%** of greenhouse gas (GHG) emissions. And cement—the ingredient in concrete that makes it so strong and durable—is one of the biggest culprits. Cement production is the **third-largest source of CO2** in the world. While concrete is one of the foundations of modern construction, there is significant innovation underway to develop sustainable alternatives that emit little or no carbon or even remove or sequester atmospheric carbon.

My early exploration of the materials used to design and make everything around us—from electronics to buildings to highways—began more than a decade ago at Hewlett-Packard. Our goal was to create environmentally healthy printers and computers while considering the entire lifecycle of the product, from material extraction to e-waste disposal and, ultimately, closed-loop recycling. These were early days in what is now commonly known as design for circularity.

Today, companies and individuals are using new technologies to completely rethink common materials such as concrete, steel, wood, and brick, discovering ways to build with smarter and more sustainable materials. In these pages, read about creative start-ups that are converting industrial CO2 emissions into enhanced concrete and other materials. Learn about EC3, a new tool that helps designers measure and reduce embodied carbon—the GHG emissions that are generated from extracting, transporting, manufacturing, and installing materials. Find out how bamboo and mass timber offer designers and builders the promise of greener buildings and how new flexible, reactive materials can transform construction.

I'm excited about the opportunities to create more sustainable buildings. While these are still early days, there is so much potential. With a continued focus on materials and technology, I'm confident that more innovation is just around the corner.

LYNELLE CAMERON
Vice President, Sustainability and Foundation
Autodesk

A small group of innovators are competing against each other—and for the Earth—to develop solutions that convert industrial CO2 emissions into enhanced concrete and other materials.

HOW NEW CO2-CAPTURE TECHNOLOGIES CONVERT EMISSIONS INTO CONSTRUCTION MATERIALS

BY JEFF LINK

A coal-fired power plant outside Gillette, WY, is about the last place you'd expect to find convincing solutions for climate-change issues. But that's where the brightest minds in the growing field of carbon utilization are developing technologies to convert industrial CO2 emissions—capturing them and turning them into alternative fuels, enhanced concrete, carbon fiber, and other valuable materials, thereby reducing their accumulation in the atmosphere.

New carbon-capture technologies aim to help curb climate change.

After several rounds of competition, 10 finalists are in the running for a $20-million purse of the NRG COSIA Carbon XPRIZE. These teams are aiming to create diverse solutions that convert the most CO_2; they're betting that their systems can significantly reduce the carbon footprint of CO_2-producing power plants, using carbon dioxide and other chemical by-products to create marketable products.

The Intergovernmental Panel on Climate Change reports that to keep global temperatures within a livable range, carbon-emissions reductions are key to a broader CO_2 emissions-reduction strategy. Just switching to renewable energy doesn't necessarily mean zero-carbon—and even as renewables are developed, emissions still need to be targeted.

Renewable Energy Is Only Part of the Answer

"Some people are misguided," says finalist Mohammed Imbabi, a lecturer at the University of Aberdeen's School of Engineering and a member of the UK-based team CCM. "There is a stampede toward renewable energy. It relies on nature to drive it, but the equipment is man-made and has a huge embodied carbon footprint. There's a headlong rush into something that is still polluting the environment."

Founder and CEO of CO2Concrete Gaurav N. Sant leads the Carbon Upcycling UCLA team made up of the university's researchers and energy professionals. "If you look at the power sector—coal, natural gas, petrochemical, concrete—all these facilities are very carbon intensive," he says. "At the same time, these plants produce base materials to improve our quality of life. We're not going to get away from these materials and facilities. What we can do, instead, is reduce the accumulation of CO_2 emissions from these industries in the atmosphere by creating beneficial utilization pathways for CO_2."

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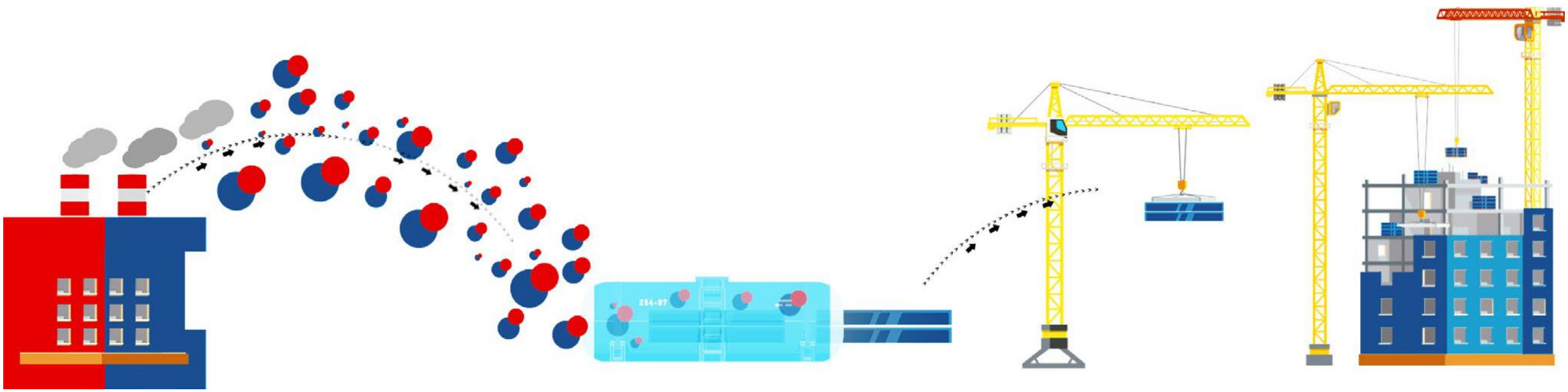
>
> **—Mohammed Imbabi,** Lecturer, University of Aberdeen, and a member of CCM



The Carbon Upcycling process: A CO2 emitter produces flue gas, which is captured and transformed into concrete through remineralization. Courtesy of CO2Concrete/Carbon Upcycling UCLA.

The CarbonCure system, including a CarbonCure concrete truck. Courtesy of CarbonCure.

One of those pathways is cement, the ingredient critical to giving concrete its strength—and the industry Sant's team is focusing on. According to estimates from the International Energy Agency, cement production accounts for about 7% of the world's 37.1 billion metric tons of global carbon emissions, second only to iron and steel manufacturing in the industrial sector.

The carbon-capture, utilization, and storage (CCUS) process is not a new idea, but it was prohibitively expensive before recent advances in materials science and chemical engineering uncovered new pathways for beneficial CO2 utilization. "When you think about carbon capture, the historical approach has been to secure pure CO2 in geologic formations or saline aquifers through pipelines that inject it into reservoirs in the ground," Sant says. "That can cost $150 a ton. The economics are hard."

Focus on Cement

Cement production may seem like a counterintuitive avenue for carbon storage. Historically, Sant says, it's a large-scale industrial process: Intensive manufacturing of Portland cement-based concrete emits high levels of gaseous CO2, and cement-producing furnaces require tremendous amounts of energy to reach reaction temperatures of up to 2,500 degrees Fahrenheit.

But improved understanding of CO2 mineralization (the conversion of gaseous CO2 into solid material carbonates) is changing cost and emissions scenarios. CO2Concrete's method channels flue-gas streams directly from factory smokestacks into a convection-oven-like chamber that operates at ambient temperature and pressure. Dilute CO2 is used to form a cementation agent that contains up to 60% carbon by weight, without the need for what can be a prohibitively expensive carbon-capture step.

The concrete produced by such CO2 mineralization is "functionally and cost equivalent to traditionally produced concrete," Sant says. And when evaluated on return-on-investment models that include carbon credits through programs such as California's cap-and-trade program, the method is far more profitable than making traditional cement or concrete, even without carbon taxes or penalties.

If broadly scaled, Sant says, the technology could put a sizable dent in the nearly 3 billion tons of CO2 emissions created annually by cement production, eliminating

Cement production accounts for about 7% of the world's 37.1 billion metric tons of global carbon emissions, second only to iron and steel manufacturing in the industrial sector.

CCM aims to convert CO2 into precipitate calcium carbonates for use in paper coatings, plastics, pharmaceuticals, and other products. Courtesy of CCM.

as much as 1 billion metric tons of atmospheric CO2 per year.

Sant is not the only one bullish about the prospects of carbon capture, storage, and utilization. The United States Department of Energy has invested billions of dollars in the technology, including funding for several research and development initiatives. A federal tax credit adopted by Congress in 2018 boosts the amount of money companies can recover for sequestering or redirecting carbon emissions; the International Energy Agency projects it to trigger $1 billion of new investment within six years.

Recycled CO2 Saves Money

Meanwhile, start-ups in a crowded field are vying to differentiate their business models, attract public and private investment, and rapidly scale operations. One of the farthest along the curve is finalist CarbonCure, a Canadian company that partners with concrete producers at about 150 plants across the globe—including Lafarge, Thomas Concrete, and Ozinga—to introduce recycled CO2 into existing production facilities.

Jennifer Wagner, CarbonCure's executive vice president of corporate development, credits the company's rapid growth to its value proposition. "Many of the solutions in the space only provide environmental benefits,"

"One of the problems you're dealing with is that you have to create a large enough sink to offset global CO2 emissions of 40 billion tons per year. You can't do that with cement alone."
—Mohammed Imbabi

she explains. "We provide environmental and economic benefits. Even if a company isn't concerned about climate change, they're all looking to save money."

Backed by investment from the Bill Gates–led $1 billion Breakthrough Energy Ventures fund, concrete producers purchase CO_2 in gas cylinders like those sold to soda producers. The CO_2 is piped through a two-unit injection system that can be grafted onto existing concrete mixers and batch house equipment. The resulting product is an enhanced ultrastrong concrete that saves an average of 25 pounds of CO_2 per cubic yard.

Other XPRIZE finalists, such as CCM, hope to leverage captured carbon more broadly across industries. "One of the problems you're dealing with is that you have to create a large enough sink to offset global CO_2 emissions of 40 billion tons per year," Imbabi says. "You can't do that with cement alone."

The $2.5-million machine CCM is planning to unveil in the final competition stage can convert CO_2 into precipitate calcium carbonates for utilization in paper coatings, plastics, pharmaceuticals, food, toothpaste, and other products. By reacting dilute CO_2 with magnesium brines from sources such as oil and gas plants, the technology can also create precipitated magnesium carbonate (PMC)—a lightweight, fireproof compound the company is developing for wallboard and insulation products.

Whether the versatility of CCM's technology will give it the edge over competitors when XPRIZE judges choose a winner in winter 2021 remains an open question. But as the range and ingenuity of these finalists shows, there's more than enough room for many carbon-capture approaches moving forward—hopefully toward a true zero-carbon future.

Read about the Embodied Carbon in Construction Calculator (EC3), a free, open-source tool that can help the construction industry increase transparency and reduce emissions.

Bamboo is fast-growing, sustainable, and stronger than steel—so why isn't it used more for standard construction? New techniques promise to liberate the material from tropical tropes.

BAMBOO TRANSCENDS THE TROPICS FOR CARBON-NEGATIVE CONSTRUCTION

BY ZACH MORTICE

It can be argued either way: Bamboo is a building material that's criminally underused in construction or one destined to remain a quirky, regional curio.

Luum Temple in Tulum, Mexico. Courtesy of Cesar Bejar.

The architecture firm Ibuku designed Moon House, a highlight of the Bambu Indah sustainable resort near Bali, Indonesia. Courtesy of Alina Vlasova.

Long ignored beyond the developing world, bamboo (a grass, not a tree) has the compressive strength of concrete and the tensile strength of steel. Unlike those materials, it sequesters carbon as it grows instead of emitting it while it's made. It replenishes rapidly, shooting up by as much as three feet per week. It's hollow and lightweight. "There's no wood that can compete with that," says Joana Gomes of the Mexican architecture firm CO-LAB, which recently designed Luum Temple, a bamboo pavilion in Tulum, Mexico.

Beyond bamboo's geographic specificity (it grows mostly in Central and South America and Asia), its irregular shape, thickness, and segment lengths make it difficult to mill and join together. Bamboo pieces don't fit together neatly, which introduces challenges when creating insulated wall assemblies, a necessity outside of tropical climes.

But designers are tackling these constraints, working on systems to make bamboo behave more like wood yet still express the plant's aesthetic properties, like its graceful segmented rhythms and aggregated textures. Harnessing bamboo's negative carbon footprint is one way the building industry could blunt the impact of climate change, which affects the tropical developing nations where it grows. "We're just starting to understand the potential of bamboo," Gomes says.

Bamboo is powerfully linked to specific places and contexts: Looking at a bamboo structure, one is reminded of the roar of a rainforest downpour or flashes of tropical birds on the horizon. Bamboo can evoke reverence for faraway places, as when applied to luxury hospitality projects. But this specificity also typecasts the material less favorably. "Bamboo is associated either with lowbrow informal architecture in Asia or Central America or kitsch vacation tropes, like *Gilligan's Island*," says Katie MacDonald, an architecture professor at the University of Tennessee Knoxville who's researching bamboo.

Designers are working on systems to make bamboo behave more like wood yet still express the plant's aesthetic properties, like its graceful segmented rhythms and aggregated textures.

Breaking the Stereotype

"To truly broaden the possibilities with bamboo, we need new and dynamic joinery systems that allow for the varying poles to be connected to each other efficiently, accommodating their irregularity," says Elora Hardy, founder of **Ibuku**, a Bali-based architecture firm that specializes in bamboo, designing projects such as the stunning Bambu Indah resort using Autodesk **AutoCAD**.

Architects have heeded this call. The American Institute of Architects gave a $30,000 Upjohn research grant to MacDonald, fellow University of Tennessee Knoxville professor Kyle Schumann, and **Virginia Tech**'s Jonas Hauptman to design a bamboo fabrication system promising extreme versatility in joining bamboo together. Using bamboo variants that are more solid than hollow, the team can cut lengthwise rectilinear sections. "What that allows us to do is mill flat pieces so it looks more like a timber slab," Schumann says.

Schumann and his research partners have designed a prototype milling machine that's similar in size to an antiquated microwave, with holes at either end where bamboo poles slide in. These poles are secured with a **chuck** that closes around the bamboo, "sort of like a camera aperture," Schumann says. The machine manipulates the pole across four axes, first scanning it to map the material, then cutting it with a CNC mill into any shape. "You can subtract any geometry that you can design within the thickness of the material," MacDonald says.

Using Technology to Maximize the Irregularity of Bamboo

The team's ultimate vision is a self-contained, field-operable box that could parametrically design assemblies and joinery methods on the fly, then fabricate and build them. "Whereas most digital fabrication technology is high cost and requires economies of scale, this project seeks to develop an affordable DIY machine that can leverage

A prototype bamboo milling machine designed by Kyle Schumann's team. (left)

Detail of joined milled bamboo slabs. (below)

Courtesy of Virginia Tech.

technology to make use of the irregularity of bamboo," MacDonald explains. With this versatility, balloon framing of smaller buildings would seem an intuitive use. In its most pared-down version—perhaps most useful for the emerging markets where bamboo grows—the machine would offer a preset menu of joints that users can select.

The University of Tennessee and Virginia Tech team (which used Autodesk Fusion 360 to plan parametric tool paths and model the machine prototype) is also researching structural bamboo wall panels, similar to cross-laminated timber. The team is investigating filling the gaps between milled planks of round bamboo with insulation; one approach is to let mycelium (mushrooms fungus) clog these gaps.

"The panelized system is about creating a more standardized geometry out of bamboo," MacDonald says, "whereas the CNC system is about creating an affordable system for custom geometries."

Assembling Luum Temple. Courtesy of CO-LAB.

"An Entirely New Spectrum of Possibilities"

CO-LAB worked with bamboo that was cut into rectilinear strips but used more traditional joinery methods. Luum Temple is a centerpiece of the firm's Luum Zama residential development, luxury real estate that sits lightly on the land and preserves much of the surrounding southern Mexican jungle. An open-air pavilion that can be reached only by foot, Luum Temple is meant to be a place for quiet meditation.

The pavilion is a monumental object and work of sculpture in its own right, coalescing around five 18-foot cantilevering catenary arches—shapes made possible by bamboo's elastic qualities. CO-LAB and builder Arquitectura Mixta cut long sections of immature, extra-pliable bamboo and bent them into shape, joining the links with aluminum straps every few feet.

Gomes wanted to build the pavilion with a structural system that was compatible with the catenary arches. Guided by a parametric design process, CO-LAB designed the triangular motif repeated throughout the structure, giving it a strong sense of rhythmic articulation. In this peaceful space, the geometric pattern that's warped across catenary arcs reaches out into the jungle in rich, tactile layers, appearing to be woven from fabric rather than constructed as a building. Gomes had planned to make the pavilion out of wood, but proximity of bamboo farms and experienced builders changed that. "It created an entirely new spectrum of possibilities for us," she says.

Another bamboo-centric project, the Sombra Verde pavilion, was designed by Carlos Bañón and Felix Raspall, architecture professors at the Singapore University of Technology and Design, and puts its fabrication technology credentials upfront. The duo (who practice as AIRLAB) designed the pavilion for Singapore's 2018 Urban Design Festival.

Each bamboo piece in the structure was scanned to map its dimensions; an algorithm

Sombra Verde. Courtesy of AIRLAB.

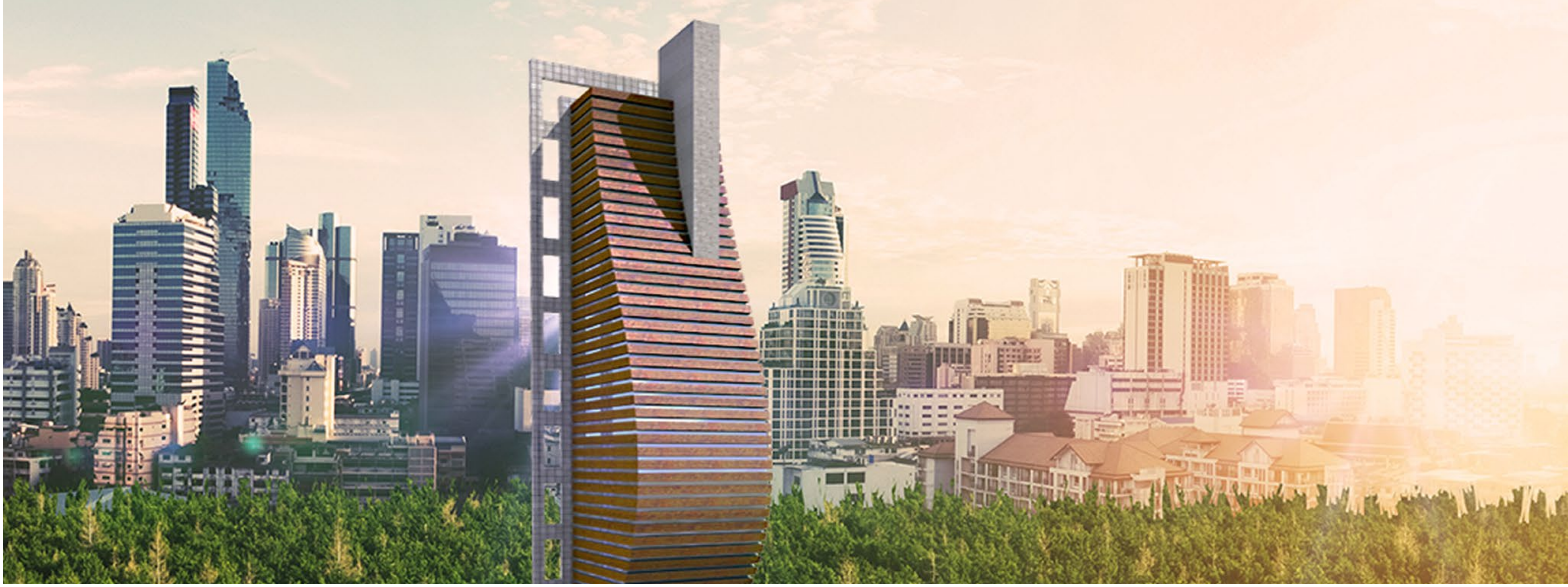
generated a plan to join the pieces together, specifying joinery nodes and required bamboo lengths. Each pole was cut to length and 36 3D-printed PLA (a plant-based polymer) joints that look a bit like cybernetic barnacles emerged from the printer bed. “Each one is different, but we give it a holistic solution,” Bañón says. The poles plug into the nodes by hand. Unlike Virginia Tech’s research, the process is a provisional way to build with bamboo that focuses its mass-customization muscle on the joints.

Once the structure was assembled, Bañón and Raspall were surprised by Sombra Verde’s strength and rigidity. “You imagine bamboo is flexible, but when you lift it, it’s solid and crazy stiff,” Bañón says.

Bamboo is well-suited to canopies or structures that need to be rapidly deployable or temporary. The pavilion was built in a day by only seven people, with no special equipment. It’s lightweight enough for four people to lift.

The next frontier for bamboo is assembling it in what Raspall calls “kinetic umbrella” applications—assemblies that move and change shape. Today’s task for bamboo research is locking elements in place; tomorrow’s agenda is joining assemblies together with the dynamic movement and flexibility inherent in the material’s properties.

Learn how a Hong Kong start-up is recycling ash from black-coal power plants into ceramic floor tiles that are both beautiful and sustainable.



Coming soon to a city near you: mass-timber skyscrapers. Image composite: Micke Tong.

Mass timber is poised to elevate the way things are built—literally—with taller, stronger, carbon-sequestering structures.

TIM-BER! BUILDERS HERALD THE COMING WAVE OF MASS-TIMBER CONSTRUCTION

BY ZACH MORTICE

In the Wild West that is the construction industry, there's a new sheriff in town: mass timber. "Within five years, or a little less, the question 'should this be a mass-timber project?' will be confronting most commercial projects," says Andrew Tsay Jacobs, director of the Building Technology Lab at Perkins&Will in Los Angeles.

"Mass timber" refers to composite-wood systems that combine multiple pieces of wood into larger structural elements whose strength often rivals that of concrete and steel structures. The wood elements are also a renewable resource that sequester carbon. Largely popularized in Europe for its enhanced building performance and sustainable attributes, mass timber is steadily creeping into more and more high-profile North American projects.

New Codes, New Opportunities: Are Builders Ready?

At the end of 2018, the International Code Council (ICC) approved new guidelines that will allow builders to create mass-timber structures as tall as 18 stories once the changes are ratified in 2021. The building code is changing "in a way that it hasn't in 100 years," Tsay Jacobs says. "It's probably the largest, most impactful code change in our lifetimes."

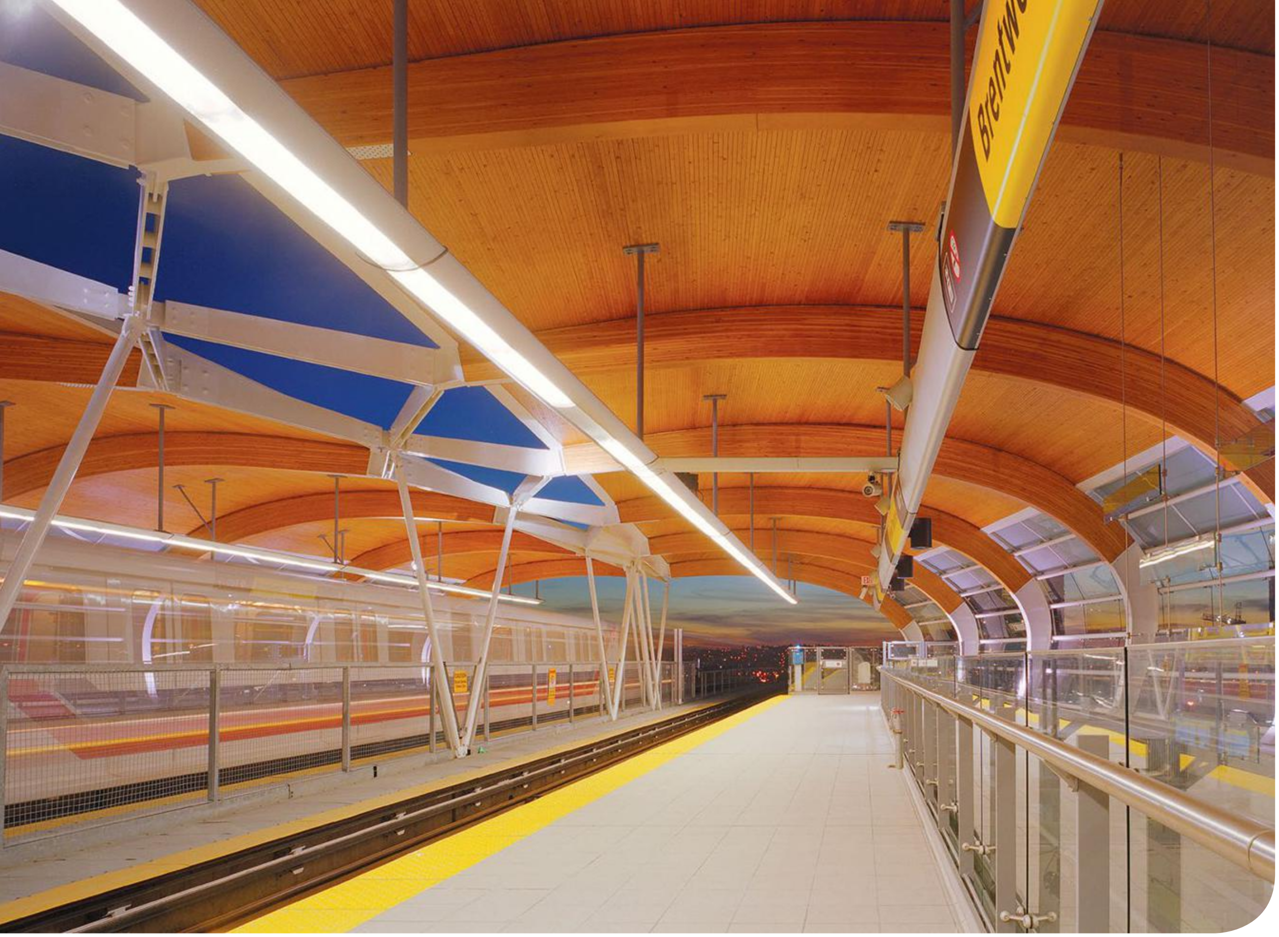
For risk-averse builders, however, adapting to mass timber means embracing big changes. Firms aren't yet equipped with resources like relevant cost-estimation tools and can feel constrained when it comes to finding the headroom to innovate. Additionally, working with prefabrication subcontractors adds legal and contractual burdens and can potentially undercut a contractor's own labor force. But, says Tsay Jacobs, "One experience with mass timber is usually all it takes for a contractor to begin to sing its praises. The ease of construction in preplanned projects is a huge benefit to general contractors, and the speed of construction is a huge benefit to developers."

Perkins&Will is exploring ways to reconcile these new approaches in design and fabrication at the Autodesk Technology Center in Boston. There, the firm conducted research investigating how the industrialization and automation of mass timber will change the industry. Its experiment included using an automated robot arm to build a wood pavilion out of nail-laminated timber (NLT). In partnership with developers and contractors, Perkins&Will's goal is to develop mass-timber solutions that integrate the design-to-fabricate-to-build process and make it as parametric and seamless as possible.

This structural medium will create new typologies for builders, giving them guidance for evolving their practices in a world where mass timber is omnipresent. That means builders need to take ownership of this transition. "If you don't address how that code change will affect your business, other developers, contractors, and fabricators will, and they'll solve the questions that mass timber asks," Tsay Jacobs says. "They'll take hold of the opportunities that mass timber gives over steel and concrete, and you'll be left scrambling."

Mass timber often rivals steel and concrete in strength. (above)

New codes will allow mass-timber buildings as high as 18 stories. (left)



Perkins&Will used mass timber to create the roof of the Brentwood SkyTrain station in Burnaby, British Columbia. Courtesy of Perkins&Will.

Mass-timber structures can be built 10%–30% faster than standard construction.

Shifting Processes to Planning Phases

In large part, building with mass timber requires adopting modular and prefab construction methods, shifting resources and labor from the jobsite to the factory floor and the preconstruction and planning phase. “It’s a clean jobsite,” Tsay Jacobs says. “It’s a jobsite that comes together like LEGOs. The pieces have to fit and have to be planned correctly.” Mass-timber structures can be built 10%–30% faster than standard construction, and because the process requires little skilled labor, builders have new flexibility in crew sizes.

The builder and developer LendLease, for example, has constructed a series of military hotels with veteran labor. “On-site, it’s as straightforward as you would imagine,” says LendLease’s resident mass-timber expert, Lisa Podesto. “A lot of people think there’s a catch. Connections are simple and it goes up really fast. What’s the catch? The catch is that it takes a lot of collaborative work before you get to the site.”

Given the recent emergence of mass timber in North America, building successfully with it requires more up-front study, communication, and time investment all around. “Traditional design-bid-build processes won’t work with mass timber,” Tsay Jacobs says, “because they don’t allow for comprehensive planning between designers and builders using a medium where well-established standards don’t exist yet.”

Mass-timber systems are not just acting as structures; they often contribute to fire, aesthetics, acoustics, and building envelope, and because the elements are prefabricated, the design has to account for these aspects as well as penetrations with a high degree of accuracy.

If designed in isolation without fabricators and trade partners, a mass-timber project will likely run into dimension discrepancies and material-sourcing issues. Mass timber is much better suited to design-build arrangements where contractors work closely with designers from the project’s inception. “Mass timber gives everyone the opportunity to come to the table earlier and develop seamless design-to-construct workflows,” Tsay Jacobs says.

When the construction of a new school required the removal of on-site trees, the project team decided to reuse the trees—as columns—throughout the building.

LEARN MORE

The current focus is on tall mass-timber structures, but the material can adapt to most places and project types. One entry-level way for builders to get started with mass timber is to use it as a roof deck. (Perkins&Will has used mass-timber roofs on train station projects in Vancouver and Montreal.)

Buildings with large footprints work well with cross-laminated timber (CLT) panel systems, which involve gluing segments of wood at perpendicular angles for added strength. The panels "take 5 to 20 minutes to install, and then you've suddenly got upward of 200 square feet of floor/roof deck completed, as far as structure goes," Tsay Jacobs says.

Podesto says the most practical mass-timber building types from a cost perspective are commercial office spaces. "This is where you see developers and design teams most successful in applying mass timber in a cost-competitive way," she says. "Most commercial office spaces are fairly standard post-and-beam steel systems; shifting these simple, repetitive structures to mass timber offers both a more distinctive product for the same price or less."

If You Build It, They Will Come

Like the design teams who are trying to figure out how to most efficiently use these new systems, the US supply chain is also working on refining efficiencies, creating new secondary processing industries and building in-house modeling and fabrication expertise while also working on plant and process efficiencies.

As more mass-timber fabricators come online and manufacturers refine their processes, services, and material offerings (the first plant east of the Rockies just opened up in Alabama), prices are likely to come down and product diversity will go up. Within five years of the code change, Tsay Jacobs says, you can expect to see an explosion of mid-rise mass-timber construction. "This is not a matter of 'if,'" adds Podesto. "It's a matter of 'when.'"

Concrete is an imperfect building material—staining, cracking, even collapsing under its own weight. New flexible, reactive materials promise to transform construction.

THE 4 FORCES THAT WILL TAKE ON CONCRETE AND MAKE CONSTRUCTION SMART

BY MASSIMILIANO MORUZZI

When it comes to building a bridge, what prevents it from having the most enduring and sustainable life span? What is its worst enemy? The answer is, simply, the bridge itself—its own weight.

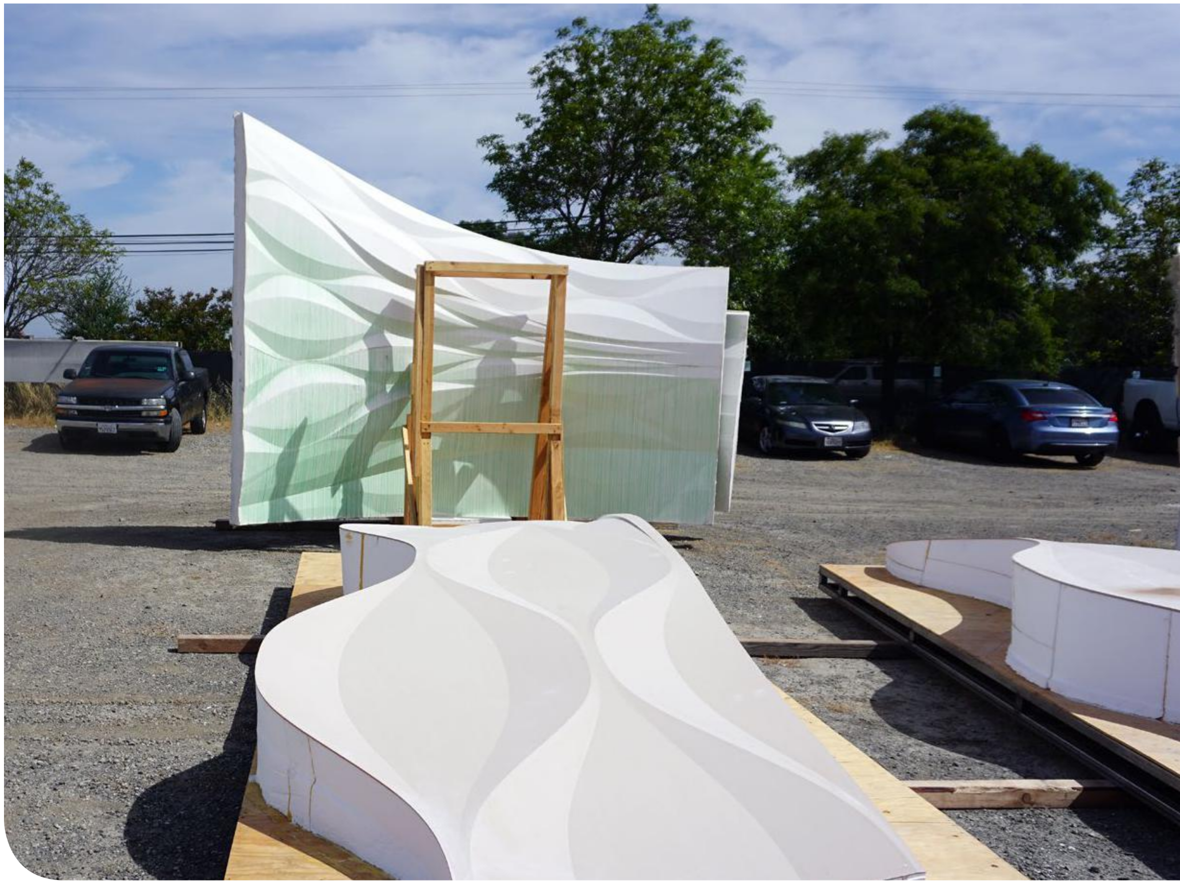
Built with today's construction processes, bridges and buildings are so overly massed with energy and material that they're inherently unsustainable.

The One Thousand Museum tower in Miami, one of Zaha Hadid's last designs, features a curving exoskeleton finished with glass fiber-reinforced concrete. Courtesy of Zaha Hadid Architects.

While concrete is quite literally one of the foundations of modern construction, it's not the best building material. It's sensitive to pollution. It cracks, stains, and collapses in reaction to rain and carbon dioxide. It's a dead weight: Take San Francisco's sinking, leaning Millennium Tower as an example.

Modern, smart construction can and will do better. A convergent set of technologies will soon radically change how the construction industry builds and what it builds with.

A holistic shift toward new materials, additive manufacturing, robotics, and a new generation of synthetic brains (including FPGAs, aka Field Programmable Gate Array devices) will drive innovative "construction workcells"—automated manufacturing ecosystems that will use robotics to build smart surfaces, objects, and even buildings. Combining these four forces will drive the construction industry through a sea change, enabling smarter and more sustainably built cities.



A close-up of the fabricated panels Kreysler constructed for the One Thousand Museum tower in Miami. Courtesy of Kreysler & Associates.

A convergent set of technologies will soon radically change how the construction industry builds and what it builds with.

Materials That Enable Smart Buildings and Infrastructure

Imagine construction robots having the intelligence to infuse smart functionality into building material. Say, for example, you're sitting in a room that feels too hot. It's unresponsive to your discomfort; it can't gauge what you want, and the temperature won't change until you turn down the thermostat. But if the room is built with a smart composite material, the wall acts more like a skin that can sense your mood and react to you.

A smart bridge or road can mean multiple things. It can be smart because Internet of Things (IoT) technology enables it to be responsive. Or it can be smart because it's sustainable, perhaps constructed with an advanced weave of natural and engineered fibers instead of concrete and rebar.

Achieving responsiveness requires embedding multifunctionality into the bridge or the road. Wouldn't it be way more efficient to 3D print a channel of wire into a bridge beam rather than add an external wire as a secondary process in construction? Why not integrate the functionality into one process?

With additive manufacturing, design complexity is never a challenge. Through robotics and 3D printing, smart infrastructure (bridges, roads, or houses) can be manufactured in ways previously impossible for humans to accomplish by hand. For example, people traditionally build more orthogonal, right-angled structures; 3D-printing robot workers operate without those human biases and constraints.

Tomorrow's construction projects will use more flexible materials—engineered substances such as carbon fiber and polymer or natural materials such as silk and cotton. There will be many more sustainable, lightweight, and cheaper alternatives to dense and inflexible concrete. These kinds of advances are already being used to create futuristic furniture and high-performance vehicles such as 3D-printed boats.

In-progress photos of the ONEOK Boathouse Pavilion in Tulsa, OK, composed of 130 sail-like, fiberglass-reinforced polymer panels. Courtesy of Kreysler & Associates.

Lifelike Materials That Self-Monitor and Self-Heal

Integrate sensors within lighter, more powerful materials that can carry information—and even store energy like a battery—and this new generation of construction will come to life. Unlike concrete, composite, FPGA-fused material is continuous and sustainable. With 3D printing, sensors and wires can be incorporated during the building process, giving bridge beams, roads, houses, and structures the ability to monitor themselves—measuring temperature, pressure, and other parameters like the human nervous system does. These structures could even communicate and repair themselves like the human body, which could result in longer building life spans.

Kreysler & Associates president Bill Kreysler has already pioneered this kind of reactive, lifelike material, incorporating it into projects ranging from the ONEOK Boathouse Pavilion at Tulsa's Gathering Place park to Zaha Hadid Architects' soaring One Thousand Museum residential tower in Miami. And thanks to Kreysler, who started his career building racing sailboats, fiberglass is now a common construction material.

Composite materials have also been central to the evolving automotive industry, which uses light, synthetic substances to cut vehicle weight and reduce emissions.

Meanwhile, the potential for biological-like responses in these kinds of materials makes the skin comparison even more apt. With increased sensory capabilities, a building will be able to instantly adapt to environmental changes. The walls of the future will be able to act like biological material and "heal" themselves when they're damaged.

Imagine that you're building with a smart fiber material. The fiber will have some resin inside, like your blood. Inside the resin, there will be a microbubble of an uncured, epoxy-like substance. When broken, the substance comes into contact with air and starts to oxidize. The process can seal cracks, reacting much the same way that a human body triggers a chemical reaction to begin healing a cut.

Like skin, the mechanical sensors will act like nerve endings, allowing for constant adaptation. Numerous self-healing concrete experiments have already shown this idea taking root, but using composite materials as building blocks will evolve the concept—and much more sustainably.

While it may seem like science fiction, all of this technology is real today. And with human support, these seemingly far-fetched ideas could become reality over the next decade. But for this kind of advanced construction to catch on in the mainstream, the industry needs to start experimenting by building landmarks to show that these projects are possible. By demonstrating new concepts on facades and other nonessential structural components, Kreysler and like-minded innovators can prove that these types of projects are safe, sustainable, affordable, and efficient.

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To show what's possible tomorrow, the construction industry needs to build educational and informational infrastructure today. The construction advances of the future will come only when builders embrace the potential of the present.

Panels on the One Thousand Museum luxury condos in Miami (left) and the ONEOK Boathouse Pavilion in Tulsa, OK (right).

Hy-Fi, a trio of circular towers created from mushroom bricks. Courtesy of The Living.

And Even More Materials Innovation

From greener, cleaner bricks to a database of building materials, see how innovators are helping to reduce waste and pollution and encourage materials reuse.

A Mass-Timber Product That's All Wood, All the Time

Move over, nail-laminated timber (NLT): Dowel-laminated timber (DLT) is a structurally efficient and affordable mass-timber panel that's well known in Europe and is catching on in the US, thanks to its ease of use with CNC machines and its all-wood composition. Instead of nails and screws, DLT uses wooden dowels to join laminations, making it easier and safer to mill and route than NLT. DLT can be used for floors, walls, and roofs structures. Learn more.

No-Fire Bricks Save Energy and Reduce Emissions

Aiming to reduce carbon emissions in masonry manufacturing, North Carolina-based company bioMASON grows brick in kiln-free, greenhouse-like conditions. The company's process uses bacteria that alters the pH balance of the surrounding aggregate material, allowing calcium carbonate to grow and bind the material with little to no carbon emissions. "It's similar to what microrganisms do [to make] coral reefs," says founder and CEO Ginger Krieg Dosier. The biological cement bricks are nearly the cost of regular bricks but are much better for the environment. Learn more.

The Magic of Mushrooms: Organic, Biodegradable Bricks

Hy-Fi, a trio of circular towers designed by The Living, showcased an innovative building material: mushroom bricks. Using bioengineering, the bricks were created from shredded corn husks and mycelium—the fungus that mushrooms are made of—and naturally grown with no carbon emissions and no waste. The nearly 40-foot-tall structure, which won the annual Young Architects Program in 2014, was featured at New York City's MoMA PS1 for three months, and then disassembled and composted. Learn more.

Show Me Your Material Passport

"Waste is simply material without an identity," says Thomas Rau, a Dutch architect and the developer of Madaster, a public database of materials in existing buildings and their potential for reuse. "If we track the provenance and performance of every element of a building, giving it an identity, we can eliminate waste." Each material in the database is tagged with a "passport"—a digital record of its characteristics and value, based on BIM data—so it can be recycled, resold, and reused. The Madaster database currently contains more than 2.5 million square meters of logged building materials. Learn more.

TAKEAWAYS

Companies and individuals are discovering ways to construct buildings with smarter and more sustainable materials—innovations that contribute not only to society's overall health but also to the health of the planet.

A few key points:

CO2-capture methods help right a wrong.

The future looks bright for technologies that capture carbon emissions and transform them into alternative materials.

Bamboo: a carbon-negative hero?

Harnessing bamboo's negative carbon footprint is one way that the building industry could blunt the impact of climate change.

Mass timber is massively promising.

Popular in Europe for its enhanced building performance and sustainable attributes, mass timber is gaining traction in high-profile North American projects.

Proof of concept starts now.

Self-healing *what*? By using cutting-edge technology and concepts on nonessential structural components today, innovators can show what's possible tomorrow.

Brush up on the history of composites and meet an Ohio-based start-up that's using them with great results.

The History of Composite Materials, From Brick to Bakelite to Biomimetic Hybrids

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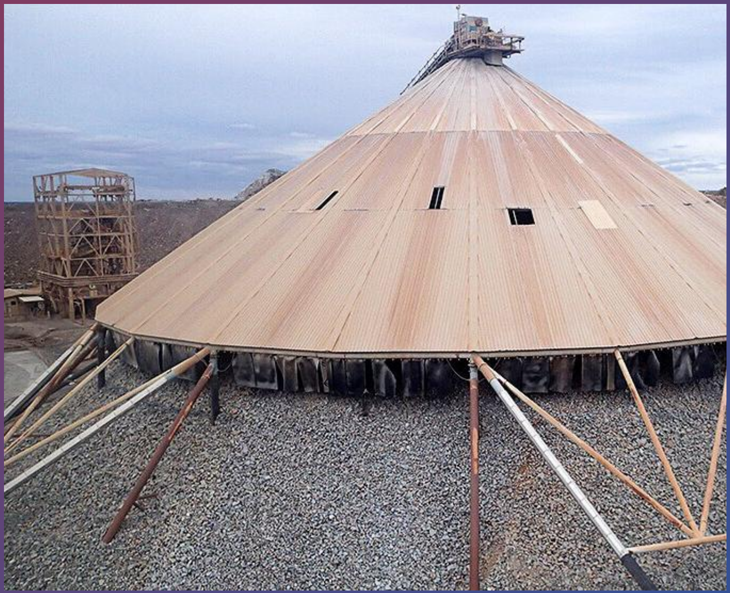

Advantic Uses Concrete and Steel Alternatives to Combat Crumbling Construction

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