THE REAL VALUE OF RESILIENT CONSTRUCTION

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EXECUTIVE SUMMARY

It can be challenging to define resilient construction let alone explain the value of it. Without an accurate basis to evaluate construction, designers may select building systems that don't offer the best long-term value. Several recent studies, such as cost comparisons of various building systems relative to one another and their actual environmental footprints, can help inform this discussion.

In order to make good construction choices, owners and designers need to have **current, accurate information.**

For many decades, codes have been pushed toward greater allowable areas and heights for buildings constructed with combustible materials by the industries that benefit from those changes. Newer products have captured the interest of architects and other designers, with claims of superior ability to sequester greenhouse gases, but inaccurate or incomplete accounting may have been used to show reduced carbon footprints.

Beyond environmental considerations, performance during a building's life should also be considered. For instance, in the event of a fire, buildings that meet minimum code requirements may remain intact long enough for occupants to escape. But if the building itself is not protected, that can result in complete structural loss (requiring total rebuilding), loss of material possessions, and community devastation. Non-combustible construction, alternately, can often allow for safe egress and protect the structure so that it can be repaired rather than replaced.

In order to make good choices, owners and designers need to have current, accurate information. Given a set of desired performance attributes, realistic carbon accounting, and documented cost comparisons of different building systems, decision makers may learn that resilient construction, leading to longer-lasting buildings, is often the best value for the money.

So why don't people demand more? Build better? Many simply don't know that building code compliance provides only minimum levels of safety, generally just designed to give people enough time to escape in the event of a disaster. Given that codes are intended to keep us safe, the average person equates code-compliance with resilience. But there can be a big difference between the two.

SECTION 1
WHAT IS RESILIENT CONSTRUCTION AND WHY DO WE NEED IT?

The degree to which a residential, commercial or public property uses resilient construction determines whether its occupants can safely shelter during natural disasters. It also means the structure itself can survive. If it can be repaired rather than replaced following a disaster, it's a faster and less expensive return to normalcy for emergency responders, for residential living conditions, and for business operations.

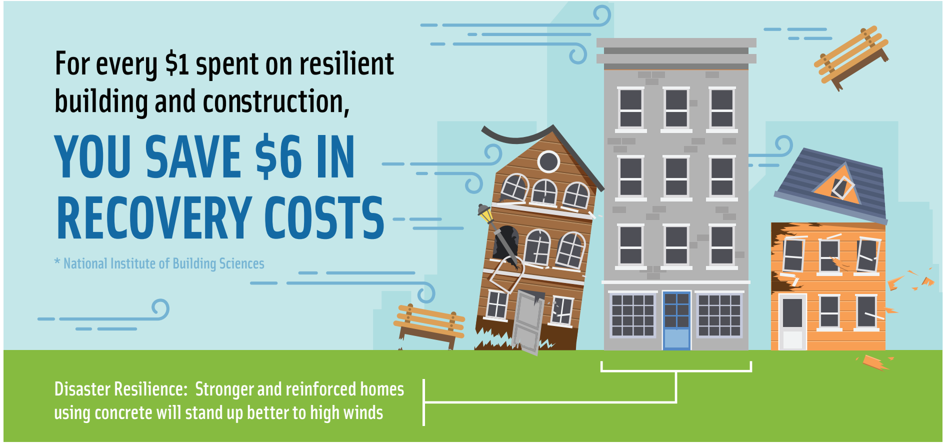
Disruption is kept to a minimum. Without resilient construction, disruptive events can have long-lasting implications. In New Orleans, for instance, the population was still only 56% of its pre-Katrina levels two years after the hurricane, and even today, has never fully recovered.

On a national scale, between 1996 and 2014, damages in the United States due to hazards (hurricanes, tornadoes, floods, earthquakes, wildfires, etc.) totaled over $377 Billion according to a National Weather Service report (MIT 2017b). And in 2017, it got worse. The U.S. spent more on natural disasters than any year on record, a whopping $306 billion (NOAA 2018). The money, representing property damage and spending for aid and relief costs, was needed as a result of hurricanes, wildfires, and other severe weather-related events. According to NOAA, there were 16 weather events in 2017 that each caused over $1 billion in damage (Fig. 1).

FIG. 1. U.S. 2017 BILLION-DOLLAR WEATHER AND CLIMATE DISASTERS MAP.

If there is a positive development to come out of the high cost of disasters, it's the recognition that costs can be reduced by investing in mitigation against the impacts of hazards. The National Institute of Building Sciences estimates that for every $1 spent on resilient building and construction, $6 in recovery costs can be saved (Fig. 2) (NIBS 2017/18).

FIG. 2. Resilient construction can save money.

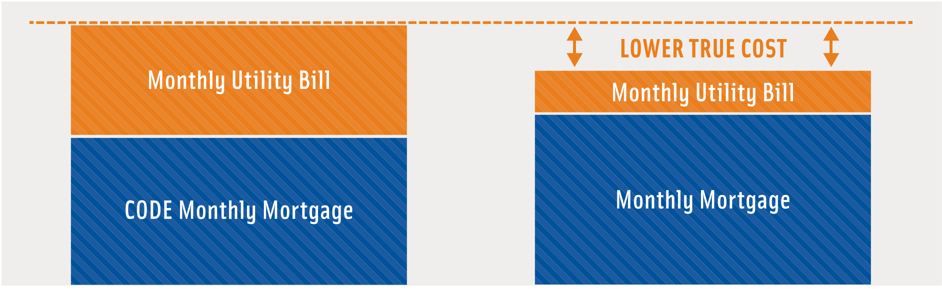


The U.S. spent more on natural disasters in 2017 than any year on record, a whopping **$306 billion** (NOAA 2018).

THE COST OF CONSTRUCTION: FIRST COST, MONTHLY PAYMENTS, AND LIFE CYCLE COST

Whether someone has a commercial or residential property, the cost to build (initial cost) significantly affects their choice of structural systems. But initial cost should not be the only factor they consider. Buyers want the best building they can get at a monthly payment they can afford. For example, an energy-efficient home might cost more to build, but save enough energy to reduce utility costs so that the owner has a lower total monthly payment (Fig. 3). More broadly speaking, if an owner plans to keep a building for any length of time, they can spread the cost of ownership over many years; having low energy and maintenance costs can really add up to significant savings for a lower life cycle cost.

FIG. 3. ENERGY-EFFICIENT HOMES LOWER MONTHLY COSTS (MORTGAGE + UTILITIES)



SECTION 2
CONCRETE CONSTRUCTION

Concrete structures are the backbone of modern society, including residential, commercial, public, and industrial applications. High-use areas, in particular, benefit from its strength and durability. And concrete provides another benefit: it can serve as the structural system and architectural finish.

The basic ingredients of concrete are cement, aggregates (stone/rock and sand), and water. Cement, a fine powder, reacts with water to bind the aggregates to make concrete. Fresh concrete is a fluid mixture that is placed into forms. Adequate water is necessary to hydrate the cement so that it can harden and gain strength. During placement, temperatures should be moderate (50F – 90F) for best results, though protective measures can be taken to place fresh concrete in colder or warmer conditions.

Hardened concrete is used in all climates and can handle wet, dry, hot or cold exposures. While concrete is strong in compression, it is much weaker in tension or flexure (bending) and is typically reinforced with steel bars to improve its ability to carry loads, especially with thinner sections.

VARIETY OF CONCRETE SYSTEMS

There are many concrete systems from which to choose and the most common ones are listed in the first column of Table 1. Some are site built while others are fabricated in factory-type settings and assembled at the site. They offer different advantages in terms of flexibility, speed of construction, and economy of repetition, to name a few. Some systems are more suited to smaller structures, while others are more suited to larger structures.

TABLE 1: COMPARISON OF RESILIENCE CHARACTERISTICS BY STRUCTURAL SYSTEM

Structural system	Resistant to penetration by wind-borne debris	Non-combustible (2-4-hour fire resistance)	Resistant to storm surge	Flood resistant	Mold and pest resistant
Cast-in-place concrete (CIP)*	✓	✓	✓	✓	✓
Precast concrete*	✓	✓	✓	✓	✓
Tilt-up concrete*	✓	✓	✓	✓	✓
Insulating concrete forms (ICF)*	✓	✓	✓	✓	✓
Concrete masonry units (CMU)*	✓ *(grouted & reinforced)*	✓	✓	✓	✓
Insulated Concrete panels (ICP)*		✓ *(requires noncombustible finish)*		✓	✓
Wood frame		*For 2-hr, code requires 1-2 layers of Type X drywall*		*Damaged by moisture*	
Manufactured wood/mass timber		*For 2-hr, code requires 1-2 layers of Type X drywall*	✓	*Damaged by moisture*	✓

*Concrete systems are assumed to be reinforced, properly designed and detailed with specified concrete compressive strength of 2500 to 4500 psi (17 to 31 MPa) for low-rise and residential construction and 6000 psi (42 MPa) for mid-rise up to 10 stories

**Manufactured wood includes cross-laminated timber (CLT), nail-laminated timber (NLT), glulam, etc.

COMPETITIVE AT EVERY LEVEL OF RESILIENCE

Two recent studies compared cost to build concrete buildings vs. identical wood and steel buildings (**http://www.buildingstudies.org/**). An initial cost study considered a four-story multifamily layout and six different building systems (Schneider 2017). This study took a comprehensive look at what it really costs to build. The first phase reported on three different cities. Numerous additional cities were added later to understand varying material and labor costs around the country. In these studies, wood (2x6) was taken as base value (100%). Because costs also fluctuate with time, results were reported for 3 time periods: December 2016, May and September 2017. As Table 2 shows, most concrete alternatives were from -5% to +20% of the cost of wood or steel frame, with one or more of them close to the same cost as the wood frame alternative (Schneider 2017). The studies consistently confirm that it's possible to build residential concrete buildings cost competitively, serving as a reminder to designers and owners to compare local costs for themselves. They might find that resilient construction costs a lot less than they expect.

In another study, two 10-story residential buildings were designed with structural systems of cast-in-place concrete versus mass timber (in this case, CLT, cross-laminated timber) (CKC 2018). Each system was optimized to be as cost-effective as possible. This study showed CLT to be from 14% to 33% more costly for the structural frame. These costs did not include fire protection or acoustical dampening for the CLT, which would both be required, and would add another 4% to 5% per square foot of building. The study also concluded that the concrete option would be less susceptible to floor vibration under dynamic loads and that CLT would experience excessive sideways drift under wind and earthquake loads unless concrete walls were used as shear walls for the CLT option. The CLT building would also need to accommodate differential vertical shortening between concrete and gravity-load carrying vertical wood members (CKC 2018). Addressing the various structural issues for mass timber systems would add cost to construction while still leaving unanswered some questions about long-term performance.

Addressing the various structural issues for **mass timber systems would add cost to construction** while still leaving unanswered some **questions about long-term performance.**

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Concrete systems can be competitive at every level of resilience. There is **usually a concrete solution that fits the needs and budget of any project.**

BUILDING COST COMPARISONS

Comparing construction costs for different systems can be tricky. Historical trends confirm that material prices vary with time (Fig. 4). The cost of materials and labor also vary with location, so the put-in-place cost changes not just with the material choice, but also depending on where and when you build. Despite the tendency to focus on initial cost, there is a good case to be made that life cycle cost is a truer measure of what it costs to own and operate a building over time.

Concrete systems can be cost competitive at every level of resilience. Depending on the size and application of a building, there is usually a concrete solution that fits the needs and budget of any project. As an example, an innovative system known as insulated concrete panels (ICPs) provides greater resilience than wood frame at a similar initial cost.

TABLE 2: COMPARISON OF RELATIVE INSTALLED COST BY STRUCTURAL SYSTEM

Structural system	RS Means, 2015 cost/sq ft of wall surface*	PCMA Initial cost study (first 3 cities), 2016/2017	CKC CLT feasibility study, 2018 cost/sq ft	Other sources
Project Scope	*Low-rise (1-3 stories)*	*Low-rise (4 stories)*	*Mid-rise (10 stories)*	*Low-rise (up to 4 stories)*
Cast-in-place concrete (CIP)	*$21.34-$21.44*	*NI[2]*	*$42-$46, $1-$2 additional for acoustical dampening*	
Precast concrete	*$17 (uninsulated) - $18.60 (insulated)*	*102% - 126%*	*NI[2]*	
Tilt-up concrete	*$11.14*	*NI[2]*	*NI[2]*	
Insulating concrete forms (ICF)	*N/A*	*114% - 121%*	*NI[2]*	
Concrete masonry units (CMU)	*$10.52-$12.95*	*95% - 106%*	*NI[2]*	
Insulated concrete panels (ICP)	*N/A*	*NI[2]*	*NI[2]*	*$6/sq ft of wall*
Wood frame**	*$10-$25 (depending on exterior finish)*	*100%*	*NI[2]*	
Manufactured wood/mass timber+	*N/A[1]*	*NI[2]*	*$48-$56, $2-$6 additional for fire protection and acoustic treatments*	

*RS Means 2015 Assemblies Cost Data: concrete walls are 6 in. thick, except for CMU, which is 8 in. thick (most common size). Wood is 2x6 stud wall with an insulated exterior finish of either wood siding, vinyl siding, cement, stucco, or brick. Concrete is 3000 or 5000 psi as noted, masonry is 2000 or 4500 psi plain finish. Costs for the CIP system are based on a minimum 5000 sq ft size. Many factors go into the choice of a building system and PCA does not promote one cement-based material over another.

**Structural insulated panels (SIPs) are about the same cost as installed wood frame per sq ft.

+Manufactured wood includes cross-laminated timber (CLT), nail-laminated timber (NLT), glulam, etc.
NA[1] – not available
NI[2] – not included

SECTION 3
WOOD CONSTRUCTION

Wood has a long history of use in the U.S. for construction, especially residential. In recent years, proponents of the wood industry have done a good job of marketing their products and systems. Though wood is widely used, it is worth considering its performance and cost to better understand what it truly offers.

VARIETY OF WOOD SYSTEMS

Wood products for buildings include plywood, dimension lumber (2x4s, 2x6s, etc.), manufactured joists, and mass timber members. Most of the products can be used in vertical and horizontal applications. The size and spacing of members are based on the intended loads to be carried. Newer mass timber products include cross-laminated timber (CLT) and nail-laminated timber (NLT), which are layers of alternately oriented dimension lumber glued or nailed into large panels. The panels are used for walls and floors of buildings. Building codes typically limit the size and height of structures that can be made with noncombustible materials, though codes are looking at introducing mass timber for greater heights ("Tall Wood").

Mass timber products, promoted as being more environmentally friendly than steel or concrete, have drawn a lot of attention to wood construction recently. Important unanswered questions about the environmental and performance claims associated with mass timber products are discussed below.

ADDING RESILIENCE TO WOOD ADDS COST

Wood systems are more susceptible to damage than steel or concrete systems. As a combustible product, wood can char or burn entirely, leaving no remaining structure intact. Wood is also affected by moisture, including humidity in the air, precipitation as rain or snow, and in extreme circumstances, storm surge in coastal areas. Wood that is wetted can experience warping, mold growth, and rot, along with other negative consequences. And over time, wood can shrink or sag.

To make wood systems more resilient, a designer has to take additional steps, such as beefing up connections or adding protective treatments for moisture or fire, and that adds significant cost. Whether the local weather is at risk of tornadoes, hurricanes, wild fires, or storm surge, wood can be affected. At similar levels of resilience to concrete, wooden structures often lose their initial cost advantage. And resilient construction is increasingly necessary all over the country. Studies discussed above show concrete systems can be first cost competitive with wood systems, and, because most buildings are used for several decades or longer, a case can be made to use life cycle cost analysis (LCCA) to provide a more accurate cost of ownership. Over time, the greater inherent resilience of concrete buildings leads to bigger savings with longer use.

WOOD COSTS ARE UNPREDICTABLE

The cost of wood products tends to vary widely, which can have a big effect on cost estimating. Buildings are designed well in advance of the start of construction, with lead time usually on the order of several months. As Fig. 4 shows, wood has a history of material price instability. Fluctuations in wood costs are somewhat unpredictable, and may be a result of shipping distance and tariffs, as wood comes from both domestic and international sources. No matter the cause, price uncertainty makes it hard to provide a client with accurate costs, which can also affect project financing.

Contrast the price instability of wood with concrete, which has historically exhibited very consistent costs without dramatic swings (Fig. 4). Concrete is always a local product, with most projects located less than 15 miles from a ready mix plant (NRMCA 2014).

The U.S. Green Building Council's LEED rating system continues to recognize the importance of sourcing products close to a project site by awarding material credits based on shipping mode and distance—lower energy transportation methods and shorter distances being preferred. Because concrete is produced close to where it is used, transportation costs are minimized and local industry and jobs are supported.

At similar levels of resilience to concrete, wooden structures often lose their initial cost advantage. And **resilient construction is increasingly necessary all over the country**.

PRODUCER PRICE INDICES - COMPETITIVE BUILDING MATERIALS

(BASE: 2009 = 100)

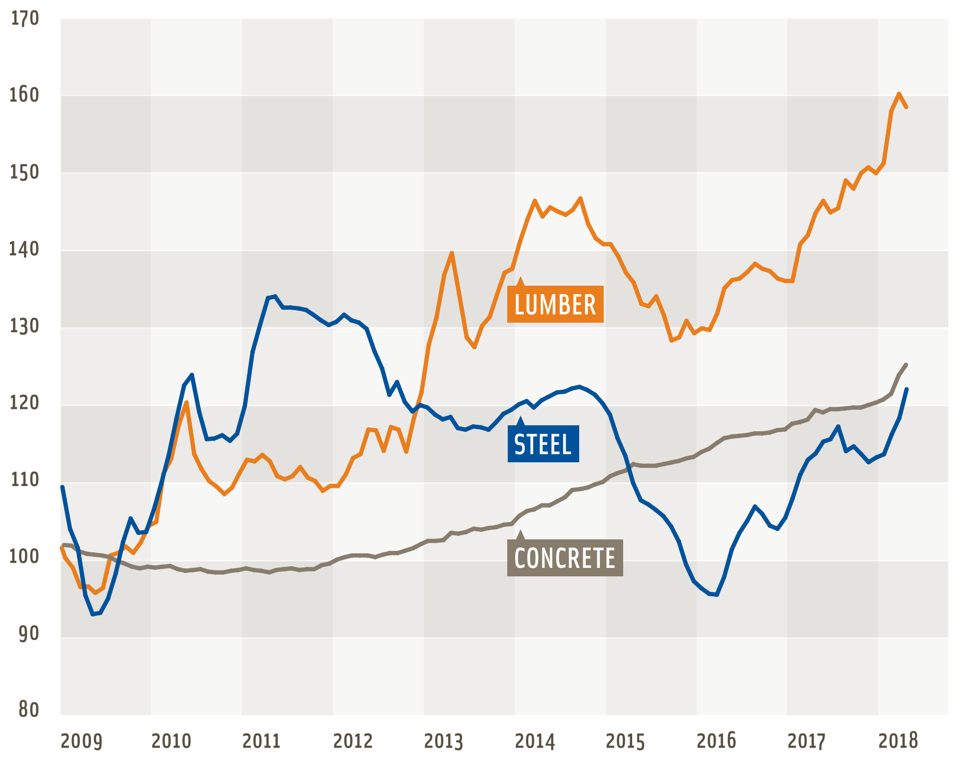

FIG. 4. Cost of lumber has increased more than 50% since 2009 levels. As shown here, lumber prices experience more fluctuations than concrete, which has very stable prices over long time periods, making it easier to estimate construction costs.

SECTION 4
THE COST OF MAINTENANCE AND VALUE OF DURABILITY

Generally, the more durable a building is, the lower the effort to maintain it. Because all buildings require upkeep and repair, structural materials and finishes that resist deterioration are good choices to help minimize costs for maintenance. There is tangible value in using durable materials for construction.

LOWER MAINTENANCE EQUALS CHEAPER TO OWN/OPERATE

No matter what type of building material is used, maintenance costs money. Finishes wear out. Paint and other protective coatings, such as for fire, are affected by sun, rain, heat, and cold. Oftentimes, the cost of maintenance is less about the materials and more about the labor.

LONGER LASTING MATERIALS REQUIRE LESS MAINTENANCE

Concrete lasts longer than wood in similar environments. Concrete is not affected by moisture; wood rots. Concrete is non-combustible; wood burns. For both structural frame materials and for finishes, concrete products offer advantages of greater durability and less need for maintenance, which usually translates to lower cost over time.

HAZARD-RESISTANT DESIGNS SAVE MONEY

Researchers at MIT developed a building life cycle cost analysis (LCCA) approach that combines initial construction costs along with the major categories of operational costs, including those associated with energy consumption and repairs due to damage from hazards (MIT 2017) (Fig. 5).

In hazard-prone areas, disaster-related repairs and maintenance costs can be significant, sometimes exceeding initial building costs. New research has made it possible to quantify the value of hazard resistance, making an economic case for investing up front in resilient construction to provide real ROI and save money over the life of a building (MIT).

CSHUB APPROACH: INCORPORATE QUANTITIVE HAZARD RESISTANCE INTO LIFE CYCLE COST

FIG. 5. Quantifying the impacts for all phases throughout a building's life is accomplished through a life cycle cost analysis.

The LCCA approach from MIT allows a cost comparison of hazard-resistant designs with conventional designs, a "Break Even Mitigation Percent" or BEMP. Using a calculation of a payback period for enhanced hazard resistance, initial investments in resilient construction can show reduced operating costs. For residential buildings, payback periods for hazard mitigation can be five years or less.

There is **tangible value** in using **durable materials for construction**.

TWO-STORY, WOOD-FRAME, SINGLE FAMILY HOME IN NEW ORLEANS

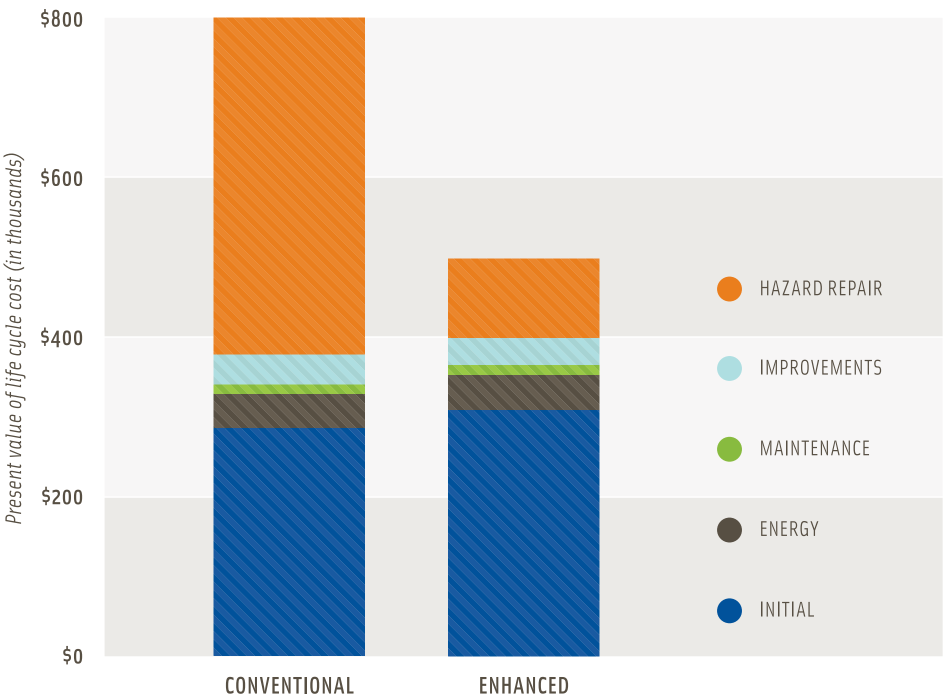

FIG. 6. The chart compares life cycle cost of a conventional and enhanced design for a two-story wood-frame single-family townhouse in the hurricane-prone city of New Orleans. Over a 50-year life, the expected cost of maintaining a conventional building to repair damage from hazards can exceed initial construction costs. By contrast, the enhanced building has slightly higher initial costs but significantly lower hazard repair costs.

SECTION 5
SUSTAINABILITY AND THE VALUE OF LONG LASTING BUILDINGS

The most sustainable building is one that is only built once. Structures that last a long time and are resilient against a variety of disasters are good for the planet because their environmental footprint can be spread over many decades.

Homes, workplaces, and entire communities are being built with **more attention to disaster resilience**.

A 2017 report by NAHB found that more than half the houses in the U.S. are nearly 40 years old and almost 40% are nearly 50 years old (NAHB 2017). Some were much older. Given that we already expect our homes to last so long, it makes sense to build them to be sustainable and resilient.

Striving for livable, healthy, and safe buildings is nothing new. In the 1990s, the sustainability movement came on strong. The U.S. Green Building Council (USGBC) developed a rating program (LEED™) with the philosophy of moving construction toward buildings that maximize efficiency in design and minimize the use of natural resources while working toward the same or better building performance. Designers educated themselves and consumers began asking for green construction.

People are also beginning to understand the tangible benefits of resilience. Homes, workplaces, and entire communities are being built with more attention to disaster resilience. For homes, there is the Institute for Business and Home Safety's (IBHS) Fortified Program; for workplaces, there is the United States Resilience Council's (USRC) rating system; and for communities, there is the example of Joplin, Missouri, who picked up the Greentown program to rebuild better following the 2011 tornado that wiped out most of the town.

SECTION 6
BUILDING EMISSIONS

In the U.S., more than 40% of carbon dioxide emissions each year are attributed to heating, cooling, and operating buildings.

That is more emissions than are produced by either transportation or industry (MIT 2018) and represents about 10% of the world's energy use each year (EIA 2016). Because energy efficient buildings use less energy, they reduce emissions, providing returns year after year. Even small improvements can have significant impact.

DESIGN PHASE

Code developers continually push for greater energy efficiency requirements for building codes. The increased operating efficiency results in two benefits: reduced emissions and lower cost to operate.

In addition to the economic benefits of more energy-efficient codes, there are broader social advantages for municipalities who promote better building design (and operation). Reduced emissions lead to cleaner air and better health for residents. As temperatures rise or fall, power demand increases for homes and businesses to maintain a comfortable interior temperature for either heating or air conditioning. As communities grow, they have to build new power plants. Energy-efficient buildings help reduce the need for additional power-generating capacity and help the environment. Municipal leaders have a responsibility to understand how buildings affect safety and the quality of life in their communities and to create the best environment possible for its citizens.

OPERATIONS PHASE

Operating buildings requires significant amounts of energy, amounting to 80%-90% of their lifetime emissions (Fig. 7) (PNBRC/Globe 2017). That's why minimizing a building's energy usage makes sense environmentally, and design and operating efficiency are the keys to reducing emissions (PNBRC/Globe 2017). While this is environmentally beneficial, there is also a financial benefit: it's cheaper to operate an energy-efficient home or office.

LIFETIME EMISSIONS OF BUILDINGS

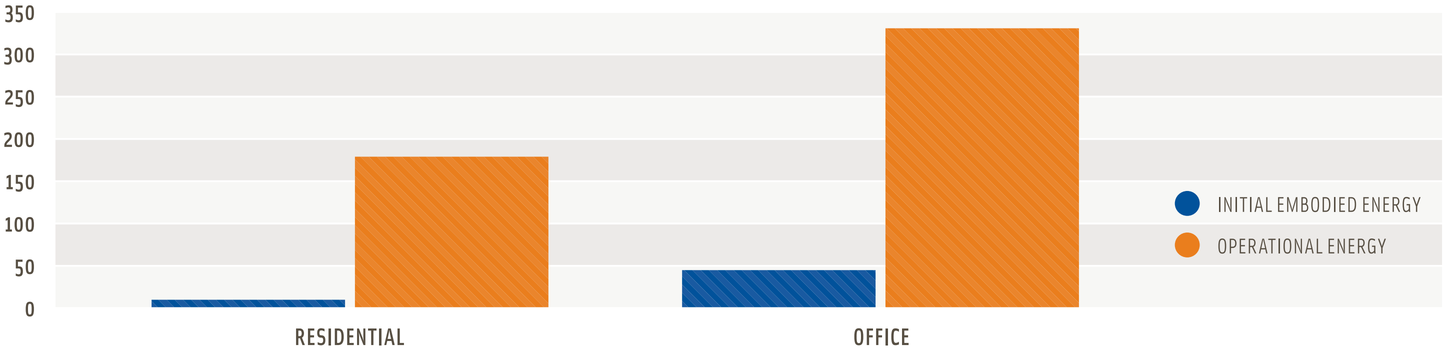

FIG. 7. The operational phase of any building far outweighs the construction phase in terms of energy use over a typical service life, such as 50 years, and the longer the building is in operation, the greater the benefit.

SECTION 7
CARBON

Carbon dioxide (CO_2) is a greenhouse gas and its presence in the atmosphere is associated with carbon emissions from all sorts of activities, both natural and those associated with human activity.

Wood buildings are perceived to be more environmentally friendly than concrete or steel buildings because trees capture CO_2 from the atmosphere and store the carbon in their trunks and branches. But that is not the entire story and the facts are more complex.

CARBON ACCOUNTING

Like other building products, wood materials for construction have an environmental footprint. In many studies, carbon accounting for wood used in the built environment is inaccurate because incorrect assumptions are made about carbon capture in forests and the impacts of wood harvesting and manufacturing (Lorenz 2016). In fact, if a complete ("cradle to grave") life cycle analysis (LCA) is considered, scientists have not yet shown that there is a net carbon storage in forest products (Fig. 8). Published studies on wood only evaluate a limited set of environmental impacts, and lack consistency in scope, transparency, and conclusions (Lorenz 2016).

PHASES OF CARBON SEQUESTRATION IN WOOD PRODUCTS: CO_2 EMISSIONS FOR WOOD PRODUCTS

FIG. 8. There are many phases in bringing wood products to market, and each one has CO2 emission implications.

There are several discrepancies with carbon accounting for wood products:

- not all trees are equal,
- not all forests are the same, and
- the way trees are harvested has a big impact on the ultimate carbon footprint of wood.

FOREST CHARACTERISTICS AND CARBON STORAGE

There is a tendency to consider all wood products the same, but that's a flawed approach. The vast majority of wood is not sustainably sourced. If a forest is sustainably managed, it can be a valuable carbon sink. But 90% of wood products do not come from sustainably managed forests, so the net effect of forests as carbon sinks is very minimal (Lorenz 2016). And even when wood does come from well managed forests, accounting practices for tracking carbon are incomplete. Increased transparency and standardized reporting of greenhouse gas (GHG) emissions is needed for all forest products, including wood products for construction (Lorenz 2016).

> ...wood building materials most often end up in **landfills to decompose and release their sequestered carbon.**

All trees are not equal. Age matters. The best way for a tree to store carbon is to allow it to grow to full maturity. Once it is harvested, most of the wood becomes waste. At most, 50% of wood at a sawmill ends up in long-lived products (PNBRC/Globe 2017). And only 15%-30% of initial carbon stored in the tree is retained in forest products (PNBRC/Globe 2017, Lorenz 2016).

It requires energy to harvest and manufacture the trees into usable products. It takes energy to ship products and manufacturers are not necessarily close to their markets (Fig. 9). When the wooden structure is finally in place, there are losses of carbon over the life of the building. And at the end of their useful life, wood building materials most often end up in landfills to decompose and release their sequestered carbon.

FIG. 9. After harvest, logs have to be transported to the sawmill, then shipped to other processing facilities or to wood product manufacturers, and moved again to where those products will ultimately be used, incurring more greenhouse gas debt.

All forests are not equal. "Frontier" forests, sometimes called "old growth" forests, are large, intact, natural ecosystems that are relatively undisturbed. They are big enough to maintain all of their biodiversity and they also store more carbon per acre than newer forests. Frontier forests provide "carbon capital" because they store substantial amounts of carbon in both standing trees and in the soil, so they are a non-renewable resource (Fig. 10). Worldwide in 2010, fewer than one-third of all forests were still considered frontier forests, and the deterioration in the quality of forests affects the amount of carbon stored in them, not to mention the carbon dioxide and methane emissions that occur during deforestation (Lorenz 2016). Short rotation periods and clear cutting prevent some species of trees from absorbing their optimal quantities of carbon, if only allowed to grow longer. Short rotation periods are of little value from a carbon management perspective, but are economically preferable to certain species of trees and for certain markets (PNBRC/Globe 2017).

FIG. 10. Frontier forests store substantial amounts of carbon.

In parts of the Pacific Northwest, rotation periods can be as short as 30 years, which limits the extent of carbon storage and impairs the long-term viability and productivity of the soil and forest ecosystems. If carbon capture were truly the goal, it would be better to leave the forest alone, which is also beneficial for biodiversity (Lorenz 2016). It is estimated that frontier forests currently store approximately 477 billion tons of carbon, more than all carbon that would be released from fossil fuel burning in the next 50 years (at late 1990s global emission rates) but the effect of that is diminished for every old growth tree that's removed. Harvesting wood releases carbon into the atmosphere as CO_2, and with frontier forests, it's irreversible (Lorenz 2016). And harvesting old-growth creates a severe carbon debt that is not repaid for centuries (Fig. 11) (PNBRC/Globe 2017). In recent decades, CO_2 emissions from human-induced changes to forests exceed CO_2 emissions from the transportation sector (Lorenz 2016).

CARBON RECOVERY AFTER OLD-GROWTH IS HARVESTED

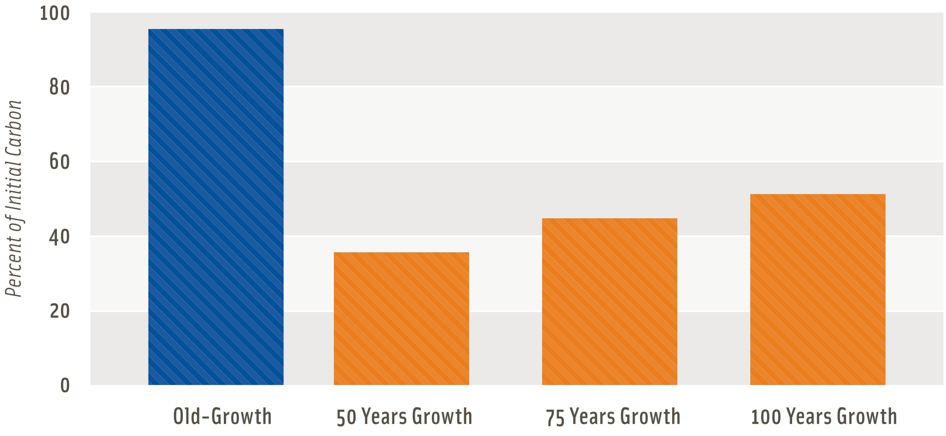

FIG. 11. When trees in a frontier forest are harvested for use, it requires several centuries to recapture carbon.

> No matter the source, **carbon dioxide that is released into the atmosphere has a negative effect.**

CARBON IS CARBON

Some people try to distinguish between "black" carbon (fossil-fuel derived) and "green" carbon (bio-mass), but that's controversial. No matter the source, carbon dioxide that is released into the atmosphere has a negative effect.

SECTION 8
CONCRETE PROVIDES COMFORT

Concrete buildings offer energy efficient, strong, solid construction with protection from extreme weather while minimizing the potential for property damage. Reinforced concrete buildings stand up to destructive forces like fire, high winds, and storm surge. Yet strength and durability alone are not enough: buildings have to be comfortable, too.

THERMAL MASS REDUCES TEMPERATURE SWINGS

Concrete is a heavy material (it weighs about 150 lb per cubic foot), so it takes a lot of energy to heat or cool it. That means it changes temperature slowly. This phenomenon is called "thermal mass." Concrete building systems provide thermal mass, which translates to more consistent temperatures for occupants and decreased energy usage to heat or cool buildings. When owners are asked what they want in a home or place of business, comfort and energy efficiency (low energy bills) often top the list. In survey after survey, performance features that save energy, such as well insulated walls, are mentioned repeatedly. Thermal mass can help, especially when insulation is used along with the concrete.

ENERGY EFFICIENCY OF THE BUILDING ENVELOPE

The building envelope separates the interior from the exterior, so it should have no leaks and should have a good capacity to hold heat or cold in or out, depending on the climate. If the shell can achieve these two functions, the living and working spaces will be more comfortable. Tight building envelopes eliminate gaps in the exterior walls, which otherwise create drafts or cold/hot spots. Many concrete wall and floor systems are continuous, so there are fewer joints to seal than with frame construction. The wall itself should be made of materials that block temperature movement between the interior and exterior. The thermal mass of concrete walls slows down heat transfer, and adding insulation improves the envelope's resistance to temperature changes.

LOWER ENERGY BILLS ARE IMPORTANT

Saving money on heating or cooling bills is important to consumers. Even so, the temperature in the home or office has to be comfortable because people spend a lot of time indoors. In a 2013 survey by the National Association of Home Builders, researchers asked "green" home purchasers about features and benefits they valued the most (NAHB 2013). Two-thirds said that having an energy efficient home was important in their decision to buy or build and were satisfied with the energy performance of their home.

In the same NAHB survey, over 90% of owners said their green home maintained more consistent temperatures and was less drafty than a non-green home and 86% said they had lower utility bills. Not only were most (90%) satisfied they had done the right thing, almost all (94%) would recommend a green home to a friend.

SECTION 9
HEALTHY INTERIORS

A healthy living or work space promotes both physical and psychological well-being. That requires good air quality and circulation, comfortable temperatures, good lighting, and sound control.

Hardened concrete is inert. It **does not off-gas and contributes to good indoor air quality.**

PRIVACY

One of the biggest complaints of multifamily occupants (and a top reason for moving) is noise from neighbors or the outside. The same features of concrete building systems that make them energy efficient make them good for privacy, too. The tight envelopes block outside or between-unit noise to maintain a quiet interior. Concrete construction provides sound attenuation, blocking out unwanted noise.

GOOD INDOOR AIR QUALITY, PEST FREE

Hardened concrete is inert. It does not off-gas and contributes to good indoor air quality. Many other building materials are made with harmful chemicals. Concrete is approved for use in hospital settings and food preparation areas, so it's recognized as being a safe material. Unlike wood, concrete is not organic, so pests cannot eat concrete and find it hard to penetrate.

RESISTS ROT

Concrete hardens when cement and water are mixed together. The resulting "artificial stone" is durable under water and in hot climates. It is not subject to rot that would occur for wood with warm, wet exposures.

SECTION 10
SAFETY FOR THE HOME OR BUSINESS

Concrete structures are inherently robust; they offer built-in safety. Reinforcing concrete with steel bars ("rebar") makes structures even more resilient. Public buildings, private homes, and businesses that resist damage from extreme weather and natural disasters generally last longer.

...during an extreme weather event. It can literally be **the difference between life and death**.

With concrete construction, people are safer, the damage from major storms is less severe, and affected communities will spend less energy and fewer resources on emergency response, reconstruction, repair, and recovery. Communities that are built resiliently also can return to normal conditions faster after experiencing a destructive event.

FIRE RESISTANCE

Concrete is non-combustible. Concrete walls, floors, and roofs are recognized by building codes as providing a good fire rating, usually a 2-hour rating for 3 to 5 inches of concrete. This helps protect occupants and allows them time to escape. It also may protect the structure so it can be repaired following the fire event. Wood is combustible. Typical cross sections with wood stud framing require a layer of drywall on each side to protect the members and achieve a 1-hour rating.

PROTECTION FROM WIND-BORNE DEBRIS

In high wind events, anything can get picked up and thrown around. This includes everyday objects and construction debris as other buildings start to fall apart. Two-by-four boards from frame walls can act like missiles traveling at over 100 mph. Concrete walls can stop penetration of wind-borne objects. Frame walls with common exterior finishes and interior drywall can be penetrated by these objects. Sheltering inside a concrete building affords more protection than inside a wood or steel frame structure. That's why safe rooms and community shelters are usually made with concrete systems.

PEACE OF MIND

There's a lot to be said for having somewhere safe to stay during an extreme weather event. It can literally be the difference between life and death.

SECTION 11
POST-DISASTER IMPACTS

Following a disaster, in addition to addressing the loss of power, homes, and lives, communities are often tasked with the difficult and costly job of managing the large amounts of debris that may be generated (EPA 2019). This may include waste soils and sediments; trees, limbs, and shrubs; man-made structures (e.g., collapsed homes, buildings, or bridges); and personal property (Luther 2017).

Cleaning up this debris is time-consuming and costly, **extending the recovery from the disaster.** Resilient concrete construction provides a means to **reduce these catastrophic losses.**

Large quantities of debris can make recovery efforts difficult by, for example, hindering emergency personnel, damaging or blocking access to necessary infrastructure, and posing threats to human health and the environment. Improperly managing debris, especially if it's contaminated, can have detrimental long-term repercussions and may lead to future environmental, health, or safety problems, such as groundwater contamination (Luther 2017).

Cleaning up this debris is time-consuming and costly, extending the recovery from the disaster. In each case, it falls on Federal Emergency Management Agency (FEMA) to quantify what happened. In 2017, two of the more devastating hurricanes were Harvey and Maria. In August of that year, Harvey created an estimated 8 million cubic yards of debris, enough to fill NRG Stadium, the 1.9 million square ft home of the Houston Texans, more than two times over (Niiler 2017). Less than a month later, in Puerto Rico, Maria created 6.2 million cubic yards of debris, enough to fill about 43 football stadiums with piles of waste 8 stories high (Waste360 2017). As large as those volumes are, they pale in comparison to Hurricane Katrina, one of the most catastrophic natural disasters in U.S. history, which resulted in more than 99 million cubic yards of debris, totaling greater than $3.7 billion in debris removal costs alone (EPA 2019, FEMA 2006).

Resilient concrete construction provides a means to reduce these catastrophic losses, both financial and environmental. As shown in Fig. 2, $1 spent on resilient building and construction can save $6 in recovery costs. And building more resiliently can also help keep materials out of landfills, preventing organic material, such as timber, from decomposing and generating landfill gas (LFG). LFG contains roughly 50 percent methane, which is more harmful than CO_2.

SECTION 12
RESILIENCE EQUALS VALUE

If buildings are to meet the needs of occupants while still having minimal impact on the environment, they should operate with low energy use and last a long time, even if they are hit with natural disasters. Those criteria are a good marriage of sustainability and resilience.

Incorporating hazard resistance into new construction can lead to **reduced operating costs over a typical life cycle of a building**.

Concrete structures are durable and disaster resistant, and serve as strong anchors for a community. Studies have shown that there are financial benefits of investing more money in initial construction to prevent major damage from weather and disaster events to go along with the safety considerations. Incorporating hazard resistance into new construction can lead to reduced operating costs over a typical life cycle of a building.

The choice of building materials and systems plays a big role in mitigating the damage from a disaster. Concrete systems can provide resilience at any level. When disaster strikes, resilient construction can save lives and reduce suffering besides saving money on repair costs. That's a good investment. Concrete buildings are good for the health and safety of a community, have low life cycle cost, and often have competitive first cost. That's the real value of resilience.

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