Sustainable Design: It's the Least You Can Do!
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Lisa Podesto, PE
Megan Stringer, SE
Karyn Beebe, PE
Nick Pauli, PE
Ryan Miller, SE
Josh Pilorin, PE
Anthony Court, SE

Sustainable Design Committees
of SEAOCC, SEAONC, SEAOSD, SEAOSC

Abstract

This paper presents a summary of sustainable design strategies that every structural engineer can readily implement (at a minimum) as well as highlighting emerging technologies in the field including resilient design strategies, life cycle assessment (LCA) to quantify and reduce carbon impacts of buildings, and new timber systems available as alternative building materials. This compilation of the latest in sustainable structural design is being presented by the Structural Engineers Association of California's (SEAOC) Sustainable Design Committee.

The time is now for structural engineers to make an impact on the industry as we now have the tools and a clientele eager to consider our contributions to sustainability and to a more resilient built environment.

Introduction

Sustainability is now a mainstream consideration on projects. While architects have focused in large part on improving energy efficiency, the structural engineer is increasingly being looked upon to make decisions that will help reduce the embodied environmental impacts of the structures they design. Green building codes, standards, and rating systems are recognizing the contribution of embodied impacts by adding measures for life cycle assessment.

Material and system selection should be carefully considered for each project, yet tradition is what commonly dictates many design decisions. Occasions for optimization and reuse and increasing markets for salvaged materials are improving opportunities for creative structural solutions. Considering the eventual deconstruction of a building with the intent that the building components could be reused in another form is another sustainable strategy that can be employed. The performance, reliability, and reparability of structural elements can also contribute to sustainable design. In addition, collaboration with other design professionals to understand how day-lighting, thermal mass, energy modeling, and cooling and heat gain strategies relate to structure and how the structure can in-turn enhance these features is important to heightening the value of the structural engineering contribution. By considering material and structural system selection, specifications, designing for future adaptability or deconstruction, the performance/resilience of the structure in a natural or man-made disasters, among others, structural engineers can incorporate sustainability into their projects every day.

You don't have to be a "Green" structural engineering company to build better buildings; a few slight shifts in standard practice can make all the difference. It might be easier than you think.

Green Codes and Rating Systems

Sustainable design has been initiated mostly through green building rating systems and more recently has gained enough momentum to evolve into code requirements. Most green code provisions are still voluntary but are transitioning from incentivized to mandatory over time. Green building codes are a good place to start when evaluating simple things you can do as a designer while green rating systems provide an indication as to what might become mandatory in the future.

The two main buildings codes that address sustainability used in the US are: the International Green Construction Code (IgCC) and California's CALGreen building code. The intent of a building code is to improve standard construction practices in order to achieve a minimum level of performance, in this case environmental performance. Both codes have mandatory prescriptive provisions as well as voluntary provision. Looking at the sections addressing material conservation that are most directly relevant to the structure we see requirements for:

- the amount of recycled materials used or the recycled content required are listed,
- stipulations on the amount of supplementary cementitious materials (SCM) to be used in concrete mixes
- options for conducting a whole building LCA of the design building

Similar to the green codes, there are green rating systems that address environmental impacts from materials, three main ones are listed below. These rating systems are voluntary but indicate what sustainability targets are being set and where the industry is going.

- LEED v4
- Green Globes
- Living Building Challenge

Green codes and rating systems often share a similar categorization of areas for improving the environmental footprint of a building. For example LEED offers points in Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation and Regional Priority. While the structural engineer has the largest opportunity for impact in the materials and resources category, this paper discusses efforts to assist with energy efficiency, indoor environmental quality, innovation and regional priority.

Knowing that not every project will be motivated for some level of green certification, there are a number of things that can be done regularly on every day projects that will lessen the impact of buildings on the environment and move the profession forward into a more sustainable future, starting with things that are fairly standard in our structural documents like specifications and moving into design and detailing decisions and finally into more holistic design considerations.

This paper explores five suggestions that are t*he least you can do* (in order of difficulty):

1. Review your specifications
2. Be Material Efficient
3. Use lower impact materials
4. Improve detailing
5. Consider alternate design methods

Review your Specifications

Updating your specifications is an easy and effective thing every structural engineer can do. As a general guideline, engineers should be sourcing local materials where possible, asking for Environmental Product Declarations (EPD's) - described later in this section - to be included where available, and should be careful to not sole source anything. This requires that engineers have a good understanding of material procurement which has benefits beyond just sustainable sourcing, it can also help with cost management and project scheduling. Beginning with standard structural material specifications, some changes to consider can include:

Concrete:

- Specify at least 30% supplementary cementitious materials (SCM's) in elevated concrete. In most parts of the state mixes are available to meet these requirements without much additional cost to the project.
- Consider providing 56 or 90 day strength requirements for foundations or shear walls, as these elements do not see significant loading at early stages.
- Use recycled aggregates in your concrete mix. Work with your concrete supplier to determine what is best for the project. Recycled aggregate can replace typical gravel used in a mix with little to no impact on concrete strength and shrinkage
- Consider a performance-based specification (discuss with supplier). Setting strength, cure time and other performance criteria allow concrete plants a flexible way to meet project objectives and keeps pricing competitive while still meeting improved sustainability expectations.

Wood:

- Specify sustainably sourced and harvested wood. Wood Species used for structural purposes like Douglas-Fir, Hem-Fir, Spruce Pine Fir, and Southern Pine are typically sourced in North America where sustainable forestry practices are enforced. Specifying lumber certified to PEFC (SFI, ATFS, CSA) or FSC is also an option especially for wood coming from other continents.
- Specify lumber species that grow locally in California such as Douglas-Fir and Hem-Fir. This increases the chance of more regional sourcing.
- Consider specifying pine beetle killed timber (also known as standing dead wood or blue stained wood), where available. While western Canadian supplies of blue stained SPF are diminishing increasing supplies of SPF-S from the north central will continue to grow.

The structural properties have not been altered by the pine beetle.

Steel:

- Require ISO 14001 certification for steel mills. This level of certification indicates that mills are at least tracking their environmental impacts but does not ensure a specific level of performance.
- Limit welding where possible. Welding fumes present a health hazard and effect air quality.
- Consider requiring documentation indicating recycled content

Updating the other specification sections to incorporate sustainable strategies should also be considered. For a few resources of sustainable specifications, see the list below:

- **Speclink-E:** Third-party specifications software, with built-in module for LEED v4 Specifications
- **Federal Green Construction Guide for Specifiers:** This resource is dated (only up to LEED v3), but is free with comprehensive recommendations for sustainable CSI Master formatted specifications.
- **Industry/Professional Organizations:** NRMCA, AISC, and AWC all have examples specifications and industry wide EPDs available for reference on their website.

EPDs are critical to structural engineers being able to determine the environmental performance of the building materials we design with and specify. An EPD communicates a material's cradle-to-gate life-cycle environmental performance but does not set a specific performance criteria, similar to ISO 14001. The goal of EPDs are to encourage transparency. If manufacturers can track their emissions and waste, once aware, they may take steps to improve their processes voluntarily. This also gives specifiers a tool to evaluate the environmental performance among other design criteria. The first step is to ask for an EPD, the second is to evaluate it. While you will continue to ask for EPDs, evaluation will likely be more front-loaded. Like buying a new brand of cookies for the first time, you tend to look at the fat and sugar content and compare to your favorite brand. But over time you will begin to get a feel for what products have a better/worse health benefits. Similarly, over time you will have a feel when reviewing EPDs as to what products have a better/worse environmental performance and this evaluation won't need to take place as frequently. Once there are many EPD's for the same material, engineers will be able to specify a preferred list of manufacturer's that produce the material with a lower impact.

In the case of LEED, points are available for product disclosure and optimization, where products are chosen based on their life-cycle impact and reduced negative health effects to the manufacturer, installer, and end user.

Health Product Declarations (HPDs) and material "Red Lists" are also something to consider in specifications although they are more pertinent to secondary systems such as insulation, facades, and envelope assemblies than the structure. While EPDs aim for transparency with regards to emissions and waste, HPDs aim for transparency with regards to chemicals, toxicity and occupant health. .

Red lists go beyond transparency and seek to prohibit known hazardous ingredients such as flame retardants and phthalates (plasticizers). Large companies have started to require that their new offices and work spaces adhere to the requirements of these lists. Google, for instance, has even created its own database known as Portico that designers must use when specifying products.

Be Material Efficient

An obvious tenet of sustainability is to use less. All materials have impacts so using less materials in general will naturally reduce impacts.

Most structural design offices have typical systems they use to address different building types, configurations, and occupancies. Those decisions are typically based on necessary structural, cost, and availability criteria. There is an argument to be made about the importance of evaluating the environmental performance of a given structural system and including it as a metric in the decision making process. However, to simplify the transition into incorporating more sustainable methods, starting with ways to use less of the material you have already decided to use is valuable.

Reducing the weight of a structure is a very effective way to execute the goal of using less. For example, floors assemblies tend to be the heaviest component in a building. For multi-story applications, making an effort to design a lighter weight floor assembly even by 5% can have significant benefits effecting both the foundation size and seismic load on the building.

Efficient foundation design offers a great opportunity to reduce environmental impacts. Traditional practice has operated on the premise that mass concrete in foundations is cheap so why bother to be efficient. In reality, mass concrete uses high volumes of Portland cement, which is the single greatest material contributor to global warming in the building industry. By designing more efficiently, eliminating concrete waste and reducing cement content and unnecessary strength in the foundation system, we can significantly reduce the structure's environmental impacts and improve the structural engineer's contribution to sustainable design.

Utilizing strength design procedures instead of allowable stress design provides another simple opportunity to reduce material consumption. Strength design particularly in flexural design of concrete and masonry, as well as steel, can result in significantly more efficient use of materials and reduction in the use of Portland cement and other materials.

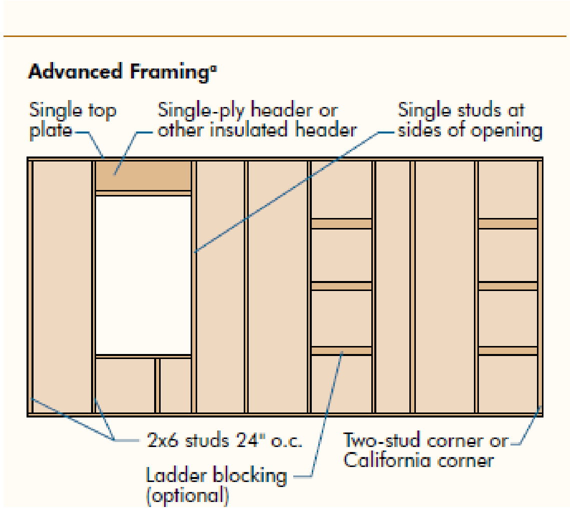


Figure 1. Advanced Framing **Techniques (apawood.org)**

Another great example of material efficiency is the concept of "advanced framing", historically used in light frame construction and a term that includes a suite of optional framing techniques illustrated in figure 1. These techniques require fewer structural pieces and therefore reduce the framing factor, in addition to material costs. While it reduces the number of pieces required, there is also a significant reduction in thermal bridging. There are several variations and combinations of techniques that can be implemented to achieve Advanced Framing and reduce the framing factor. The APA published an Advanced Framing Construction Guide, Form M400, available online at: www.apawood.org, which provides the details as well as an implementation strategy as follows:

1. Switch to 2x6 studs and, where permitted by structural code requirements, change the wall framing module from 16 inches on center to 24 inches on center. This change will increase cavity insulation depth improving the effective R-value of the assembly and the energy efficiency of the structure. In this case the increase in structural material volume from the increased stud depth is offset by the increased spacing. However, there are fewer pieces and thus less wasted in addition to significant improvements in thermal performance.

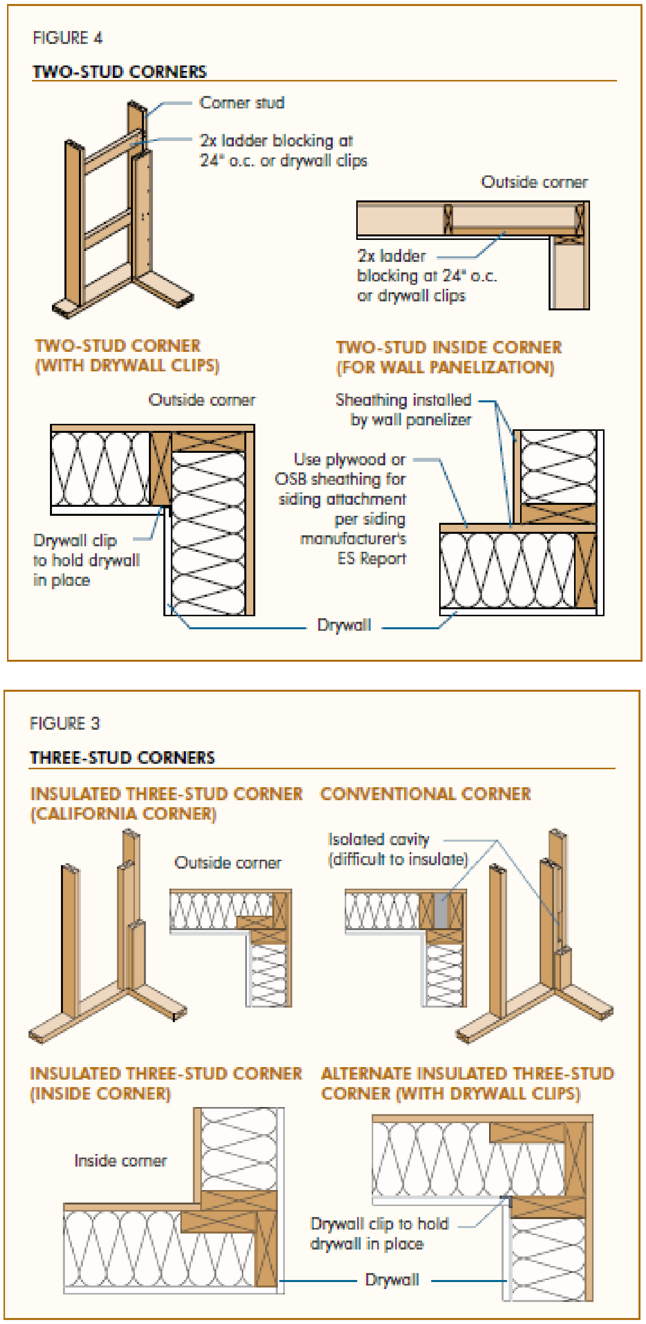


Figure 2. Advanced Framing Wall Intersection (apawood.org)

2. Incorporate intersecting wall techniques and energy efficient corners, such as three-stud corners and ladder junctions that allow for greater insulation volume and reduced opportunities for thermal bridging. See detail in figure 2.

3. Right size headers for loading (which can create a bit more construction coordination in regards to increased variation in header sizes but not likely to reduce productivity) and incorporate a space to insulate headers by reducing the thickness of the member. Similarly, a reduction of the number of trimmers/framing around openings again improves thermal performance of the exterior wall.

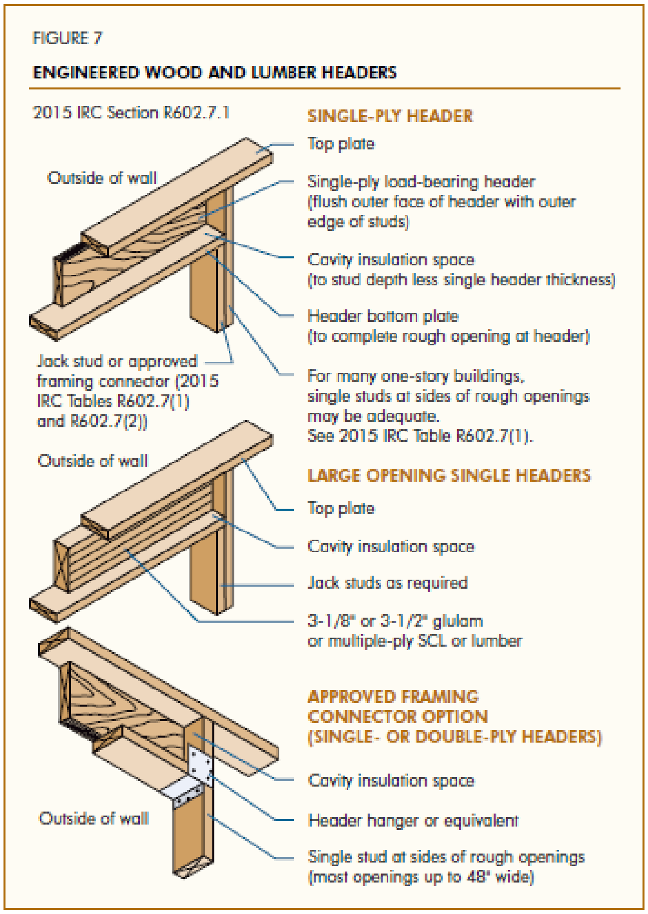


Figure 3. Insulated Header (apawood.org)

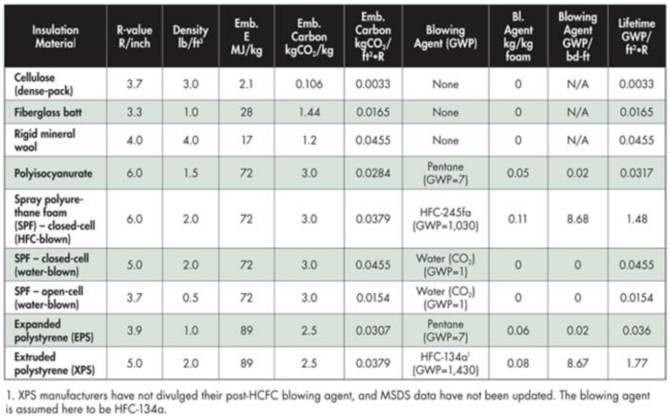
4. Eliminate double top plates. Because this step requires vertical framing alignment, including 24-inch on center floor and roof framing as well as non-industry standard stud lengths which may be difficult to source, it is often the last technique builders consider. For these reasons, many builders elect to retain double top plates. Furthermore, with our higher seismic loads in California, top plates function as the chords and drags in the lateral force resisting system. Therefore, the benefit received from eliminating one plate may not be worth the effort, unless splicing of the single top plate is carefully designed and executed.

Advanced framing not only offers an opportunity to be more efficient with structural materials but it also enhances the energy efficiency of a light frame building (as recognized by Title 24), while bringing down the cost of construction, without sacrificing structural performance. The builder does not have to implement all Advanced Framing techniques in order to benefit from a sustainability, energy efficiency, or cost standpoint.

Examples for using less with concrete and steel would include methods for voided slabs and castellated beams.

Using less is also a method for cost savings as long as the material reduction doesn't adversely affect the labor component of the project. One major hesitation with shifting design norms is the perception of cost (both in quality and dollars) associated with the construction learning curve. The most tempered way to address this is to make a few simple changes per project and provide time to get feedback from contractors and owners.

Using less of one material can often mean using more of another material. The caution here is to be aware of relative impacts and benefits. In the case of advanced framing, more insulation is a byproduct of the method. However, in this case the benefits of energy efficiency typically outweigh the impacts of incrementally more insulation. The choice of which insulation to use can actually have a significant impact on embodied impacts and should be weighed carefully. See figure XX. The global warming potential (GWP) payback period for most insulation is less than 5 years with the exceptions being for extruded polystyrene (XPF) and spray polyurethane foam (SPF) that could have over 100 year payback as discussed in the June 2010 Environmental Building News Article on BuildingGreen.com.



Insulation Material	R-value R/inch	Density lb/ft³	Emb. E MJ/kg	Emb. Carbon kgCO₂/kg	Emb. Carbon kgCO₂/ft²•R	Blowing Agent (GWP)	Bl. Agent kg/kg foam	Blowing Agent GWP/bd-ft	Lifetime GWP/ft²•R
Cellulose (dense-pack)	3.7	3.0	2.1	0.106	0.0033	None	0	N/A	0.0033
Fiberglass batt	3.3	1.0	28	1.44	0.0165	None	0	N/A	0.0165
Rigid mineral wool	4.0	4.0	17	1.2	0.0455	None	0	N/A	0.0455
Polyisocyanurate	6.0	1.5	72	3.0	0.0284	Pentane (GWP=7)	0.05	0.02	0.0317
Spray polyurethane foam (SPF) – closed-cell (HFC-blown)	6.0	2.0	72	3.0	0.0379	HFC-245fa (GWP=1,030)	0.11	8.68	1.48
SPF – closed-cell (water-blown)	5.0	2.0	72	3.0	0.0455	Water (CO₂) (GWP=1)	0	0	0.0455
SPF – open-cell (water-blown)	3.7	0.5	72	3.0	0.0154	Water (CO₂) (GWP=1)	0	0	0.0154
Expanded polystyrene (EPS)	3.9	1.0	89	2.5	0.0307	Pentane (GWP=7)	0.06	0.02	0.036
Extruded polystyrene (XPS)	5.0	2.0	89	2.5	0.0379	HFC-134a[1] (GWP=1,430)	0.08	8.67	1.77

1. XPS manufacturers have not divulged their post-HCFC blowing agent, and MSDS data have not been updated. The blowing agent is assumed here to be HFC-134a.

Figure 4. Insulation Impacts (BuildingGreen.com)

Use Lower Impact Materials

Designing using less material can only get you so far. Adjusting your choice of structural system and/material has the potential to have a larger impact on environmental performance.

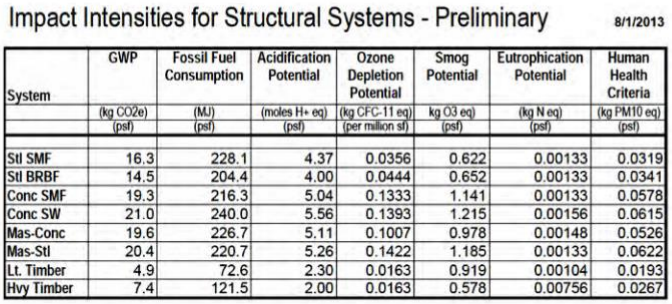
That performance is best measured by considering all of the environmental impacts of each component in a building in a life-cycle assessment (LCA). Data has been collected on thousands of building components from raw resource extraction to material disposal at the end of its' useful life that include all of the inputs (energy, raw materials, water, etc.) and outputs (emissions, waste, byproducts) required to make, maintain, and dispose of a product. This data can be used in a variety of software programs to evaluate design decisions.

While life-cycle assessment is a powerful and effective tool for comparing a range of impacts on various systems and materials, most engineers are not eager to run an environmental analysis on each of their building designs in an already cumbersome design process.

In a study initiated in 2013 by the SEAOC Sustainable Design Committee the implications of structural system selection were explored. The committee chose to evaluate a 6 story structure with an open floor plate of 150 feet by 90 feet. The vertical, lateral and foundation systems were designed using typical design criteria for an LA office building. Eight different structural systems were explored; two steel including a special moment frame (SMF) and a buckling restrained braced frame (BRBF), two concrete including a special moment frame (SMF) and a bearing shear wall (SW), two masonry including one with concrete floors and one with steel floors, and two wood including one light frame option and one heavy timber option.

The relative impacts of the different structural types can be seen in the preliminary comparative analysis in figure 5. Depending on how one chooses to measure environmental performance (ie. which impact category holds more weight) the conclusion on the highest performing system might differ.

Because there is a natural trade-off effect that can complicate the decision-making process, the challenge in comparing materials and systems is determining what impact measures are most important.


Impact Intensities for Structural Systems - Preliminary

8/1/2013

System	GWP	Fossil Fuel Consumption	Acidification Potential	Ozone Depletion Potential	Smog Potential	Eutrophication Potential	Human Health Criteria
	(kg CO2e)	(MJ)	(moles H+ eq)	(kg CFC-11 eq)	kg O3 eq)	(kg N eq)	(kg PM10 eq)
	(psf)	(psf)	(psf)	(per million sf)	(psf)	(psf)	(psf)
Stl SMF	16.3	228.1	4.37	0.0356	0.622	0.00133	0.0319
Stl BRBF	14.5	204.4	4.00	0.0444	0.652	0.00133	0.0341
Conc SMF	19.3	216.3	5.04	0.1333	1.141	0.00133	0.0578
Conc SW	21.0	240.0	5.56	0.1393	1.215	0.00156	0.0615
Mas-Conc	19.6	226.7	5.11	0.1007	0.978	0.00148	0.0526
Mas-Stl	20.4	220.7	5.26	0.1422	1.185	0.00133	0.0622
Lt. Timber	4.9	72.6	2.30	0.0163	0.919	0.00104	0.0193
Hvy Timber	7.4	121.5	2.00	0.0163	0.578	0.00756	0.0267

Figure 5. Impact Comparison (SEAOC SDC 2013 LCA Study)

Architects have chosen to focus their efforts on slowing the growth rate of green-house gas (GHG) emissions and reverse the effects of climate change by keeping average temperature rise to less than 2ºC which has been heralded by climate scientist as the tipping point (or point where effects cannot be reversed). Following this lead the embodied impacts that could be considered as priorities are:

- Global Warming Potential (GWP)– Carbon dioxide (CO_2) is the largest contributing factor to global warming and therefore serves as the metric for this measure. Other GHG's are often given an impact measure in terms of carbon dioxide equivalence (CO_{2e}). Because buildings are responsible for 40% of CO_{2e} emissions worldwide, it makes sense that this metric should be a priority for building designers.
- Fossil Fuel Consumption – The burning of fossil fuels is the largest human-cause of greenhouse gas emissions.

This is not to say that other impacts are not also worth minimizing, however, the effects of climate change are far reaching and potentially catastrophic if the trend becomes irreversible.

In general the timber buildings have significantly less impact, especially in the impact categories discussed above than the steel buildings, and the steel buildings have less impact than the concrete and masonry buildings; especially for GWP (Figure 6) and Fossil Fuel Consumption (Figure 7). However, structural engineering decisions cannot be made based on environmental performance alone. This is only one measure and must be considered alongside availability, cost, longevity and reliability.

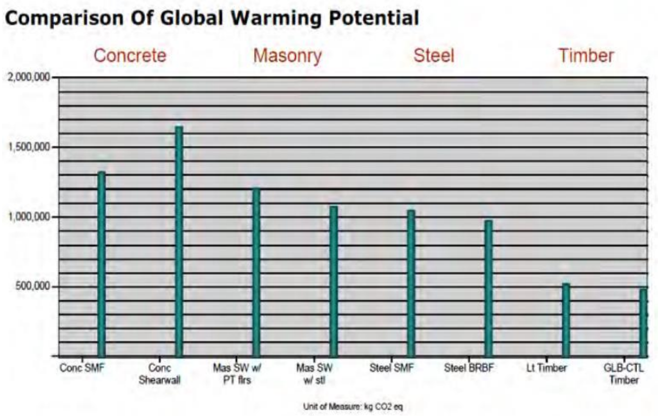


Figure 6. Structural System Comparison-Global Warming Potential

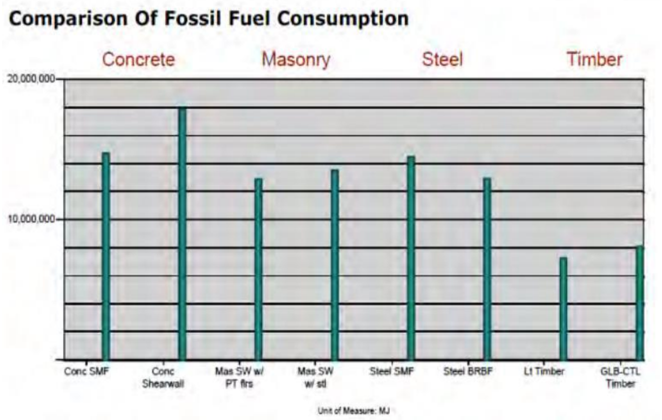


Figure 7. Structural System Comparison – Fossil Fuel Consumption

Where a particular structural material is pre-selected based on one of these other considerations, different lateral force resisting systems can still be compared in order to select the one with the least environmental impact.

Strategies for using lower impact materials can also include using salvaged, or recycled material and making sure to utilize supplementary cementitious materials where possible.

The use of supplementary cementitious materials (SCM's) is paramount in reducing GHG's and the carbon footprint of concrete. It is estimated that 7% of CO_2 emissions worldwide are directly attributable to the heating and calcination of limestone in the process of manufacturing cement. This is one of the reasons that concrete structural systems perform so poorly in the LCA study described above.

Improve Detailing

Once materials and systems decisions have been made, there are still design decisions, such as detailing, that can significantly improve the building's performance; both from an environmental perspective but also from an operating cost perspective.

Thermal bridging is the transfer of heat/cold through the building envelope into the conditioned space. Passive House Institute, a sustainable building organization in Germany, explains that a simplified way to determine if thermal bridging is present is to trace the building envelope in a drawing section. If it is possible to trace the envelope assemblies --i.e. insulation, air barrier, and vapor barrier where required--continuously without interruption from the structure or façade system then thermal bridging has been avoided. With proper detailing, a structural engineer can have a direct effect on eliminating thermal bridging.

A Civil and Structural Engineering News article (D'Aloisio, 2014) describes common areas of thermal bridging and possible solutions. The base plate of an exterior column can be isolated from the concrete foundation with an isolation block comprised of closed-cell, rigid polyurethane foam with a specified compressive strength placed between the top of the concrete footing and the bottom of the base plate.

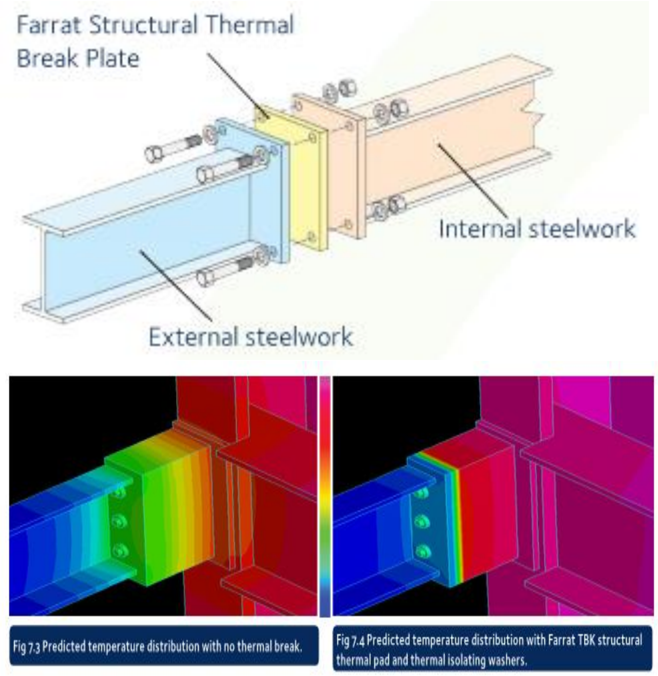


Figure 8. Performance of Thermal Break Plate (Farrat)

He goes on to describe a common problem of protruding structural elements such as canopies and awnings. There are now proprietary products such as Schock Isokorb, Farrat, or General Plastics that create a barrier between the exterior structural piece and interior envelope mitigating the thermal bridge. These products are available for structural steel and concrete applications. Manufacturer's provide literature with design considerations and guidelines for proper calculations.

The SEI/ AISC Thermal Steel Bridging Committee published an article in Modern Steel Construction (March 2012) where they reviewed five common conditions of thermal bridging in a midrise steel-framed building. For each detail, they compared energy savings from mitigated bridging to the added construction cost of the new detail. The revised details that provided the largest benefit were ones that replaced continuous support for intermittent support at architectural components and cladding such as roof edge angles, brick shelves, and lintels.

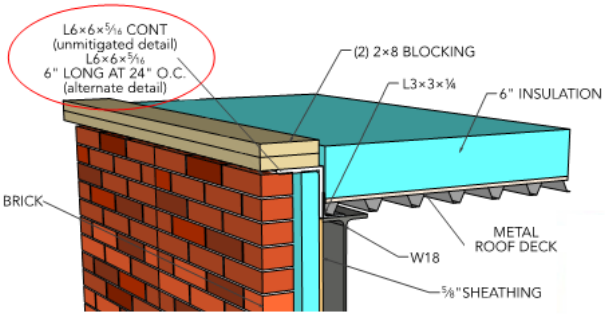


Figure 9. Thermal Bridging Example with Intermittent Support (Anderson, 2012)

While changes to standard details add design time and construction cost, these changes are needed to increase thermal efficiency in design and can be offset by the future energy savings.

Consider Alternate Design Methods

Structural design challenges such as material reuse, deconstructibility, designing for adaptability, and disaster resilience can offer some of the most interesting opportunities for innovation and often make the case that sustainable design can have significant economic benefits as well.

Reuse

Perhaps the most sustainable form of constructing a new building is to build it from old materials. Salvaged materials are becoming more readily available as they have gained popularity in aesthetic design. When designing with reclaimed material, the life-cycle can truly be a closed loop where the structure is reused for a new purpose at the end of its current useful life. With this in mind, a building designer can consider how to construct a building with an eye towards the end of the building's life, at which time it can be deconstructed and repurposed for a future use.

The manufacture of steel products is commonly done by using recycled steel. New steel can be as much as 80% to 95% recycled material. However, the process of recycling steel is very energy intensive. While using recycled material is inherently sustainable, a more sustainable alternative would be to use salvaged steel components, which avoids the energy consumption in the recycling process.

Reuse of wood materials is gaining popularity both for sustainability reasons and for aesthetic reasons. The American Wood Council provides several websites for accessing wood materials available for reuse:

- Building Materials Reuse Association
  - http://bmra.org
- USDA Forest Products Lab
  - http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr150.pdf
- Recycler's World
  - http://www.recycle.net/Wood/index.html
- North American Wood Reuse & Recycling Directory - http://reusewood.org/

Designing for Deconstructibility

As demand increases for salvaged material, the market place for building material reuse will become more robust and there will be more thought invested in the second life of building components. According to the United States Environmental Protection Agency (EPA) in the Design for Deconstruction manual, what is needed is a "new mental model that clearly envisions "waste as a valuable resource harvested from existing buildings and used to build new ones." The EPA manual also states that buildings are deconstructed based on a number of factors including cost of labor, landfill costs, ease of disassembly, value of recovered material, and having the time required to deconstruct. The structural engineer can play a role in giving deconstruction and subsequent reuse the best chances by detailing simple connections that are readily accessible and reversible and by using of materials and sections that will be "valuable" once recovered.

The design for deconstruction goes hand-in-hand with the reuse of salvaged materials. Reuse requires deconstruction of buildings which is made easier by thoughtful detailing of the members and connections. For example, bolted connections are much easier to disassemble than welded connections. In addition, concealed connections are difficult to evaluate and access, so connections should be readily accessible. Member sizes and geometries should be kept within reasonable limitations considering the process that may be employed for the disassembly of the pieces.

Adaptability

In the article *Achieving Sustainability through Durability, Adaptability, and Deconstructibility*, the definition of adaptability "is the ability of a structure to accommodate varied and often unknown future uses and changes with minimum of cost and effort." The publication *Reusable and Adaptable Wood Structures*, defines the adaptability of a structure occurs when a structure can be altered to accommodate a change of use, or a structure having the ability to be disassembled and reassembled into a new form. The intent of either definition is to aid the extension of a structure's lifespan. To achieve this, the structural engineer has the opportunity to employ design strategies to maximize a building's life expectancy and facilitate its adaptive reuse.

One of the simplest strategies to increase adaptability of a structure is to understand the purpose and the expectations of the structure's use. What is the expected lifespan of the building? What type of tenants are being sought? Is the use of the structure intended to be maintained over its lifespan? Does the building's use hinder adaptability in the future? Knowledge of the structure's expected use directly affects, though obvious, how the structural systems are to be chosen, located and integrated. However designing for unknown future uses can often cause inefficient material use in design. It is recommended to consider a reasonable level of adaptability for the highest possibility of future use. Redundancy and resiliency in the vertical and lateral force resisting systems provides adaptation to future modernizations of structures. As use changes or as program requirements change (e.g. educational facilities), modification of structural system might be required. Redundancy and resiliency in structures allow modifications such as additional openings in shear walls or reconfiguration of interior wall layouts to be achieved.

Equipment replacement is an inevitability of medical, educational and other institutional facilities where reserve capacity within the gravity and lateral force resisting system is crucial to the adaptability of a structure in performance and cost. Another adaptable building strategy is to layer building assemblies so that structure (typically intended for the life span of the building) is not intertwined with mechanical and electrical infrastructure (which are likely to be altered or replaced during the life of the building). This is sometimes called "Open Building" and essentially decouples building parts with different life cycles to facilitate adaptive change.

A building cannot operate without non-structural systems (i.e. electrical, mechanical, plumbing, etc.). The structural engineer has the opportunity to coordinate with other disciplines to strategically locate systems that can be easily replaced or enlarged with minimal impact to the structural system. In this case, a structure's utilities and technology could possibly be continually updated through its lifespan without costly renovations to the structural systems.

Disaster Resilience (Kneer, Maclise 2008)

In the sustainable design of buildings, disaster resilience refers to the ability of a building to withstand and remain operational or recoverable in response to a natural disaster. Disaster resilience, like adaptability can also refer to the ability of a building to adapt to climate change, or water and energy shortages

From a structural engineering perspective, considering the buildings ability to remain useable after a seismic or wind event can contribute to not only the reduction in environmental footprint associated with rebuilding but also supports the sustainability of the community by keeping buildings functional for post disaster living and working.

The 1999 SEAOC Bluebook outlines a set of seismic performance objectives intended for the general building stock. Typical buildings designed in accordance with Bluebook recommendations are intended to:

- Withstand minor earthquakes without damage, (Operational building performance).
- Withstand moderate earthquakes without structural damage and with only minor nonstructural damage, (Immediate Occupancy building performance).
- Withstand major earthquakes (MCE) without collapse but with probable structural and non-structural damage, (Collapse Prevention building performance).

Current FEMA P-58 guidelines provide more sophisticated performance based design procedures to achieve desired seismic performance with higher levels of reliability. These guidelines can facilitate design for higher levels of performance, with less damage and downtime. They utilize more complex methodologies based on probabilistic hazard analysis and probabilistic non-linear analysis of structural and non-structural systems.

PBD looks at the environmental demands on the building and designs it to perform desirably in these events. There are several pathways for using performance-based design methodologies to decrease the environmental impact of a building as outlined below.

(1) Use PBD to justify additional up-front structure costs in order to achieve a higher performance level and reduce overall life-cycle costs
(2) Use PBD to decrease structural materials without decreasing building life. LCA is not necessary to prove the decrease in environmental impacts, as this can be ascertained qualitatively
(3) Use PBD to extend life-cycle of existing building

The recent white paper "Disaster Resilience and Sustainability" by the ASCE Structural Engineering Institute's Sustainably Committee and the SEAONC Sustainable Design Committee paper (Kneer, Maclise 2008) discuss the importance of considering disaster resilience when designing structures as well as the environmental impact of designing resiliently.

Mass Timber Systems

A wood technology that is gaining a lot of momentum in the US in part because of its carbon footprint story is mass timber. When used in place of concrete or steel, mass timber offers the potential for significant carbon savings. Based on data from 21 different LCA studies it was found that on average there was an average displacement factor of 2.1 meaning that for every ton of carbon (tC) stored in the wood products substituted in place of a non-wood product, there is an average GHG reduction of 2.1 tC.

North American forest growth is currently exceeding harvest and forest land cover remains relatively constant. Forest health is at risk with the increase in density and changing climate patterns, suffering from wildfire, pestilence and disease. Mass timber heralds an opportunity to use our natural resources instead of lose them. Over 176,000 CLT structures on the scale of Stadhaus project pictured in figure 10 could be built annually in addition to current demands from light frame projects and still not have harvest exceed growth of North American forests.

We are starting to see heavy timber buildings being permitted and built. The tallest heavy timber building permitted in the US is the Framework building in Portland, which is a 12-story mixed use building. This building utilizes CLT for its floors as well as for its lateral system.

Figure 10. Stadhaus CLT Project, London UK
(WoodWorks - Photography by Will Pryce)

Cross Laminated Timber (CLT) is referenced in the 2015 IBC and NDS which has recently been adopted by California, the use of CLT as a shear wall requires an alternative means of compliance approach with the permitting jurisdiction.
As designers we should be aware of these newer materials and should consider them as a structural option for a building that would typically be constructed out of steel or concrete. We should be educating our architects about this material and highlighting it as the structural option with the least environmental impact

Conclusion

Sustainability is now a mainstream consideration on projects and structural engineers have the power to make decisions that will help reduce the environmental embodied impacts of the structures they design. By considering material and structural system selection, specifications, designing for future adaptability or deconstruction, the performance/resilience of the structure in a natural or man-made disaster, among others, structural engineers can incorporate sustainability into their projects every day.

Many may remember when recycling your garbage was not a standard household practice. In the 1970's the US began curbside collection programs for recycling and many felt like it was a hassle; separating and cleaning their trash for no direct financial incentive for them as an individual. Fast forward to today and most of us don't even think twice about it. It's a given that we would invest in our future resources without demand for personal gain. We are now transitioning into the era when sustainable design becomes the default standard of practice for structural engineers.

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