SEI Sustainability Committee – Wood Construction

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Introduction

Wood, the most widely used structural building material in the world, is the only one that is renewable and bio-based. Powered by solar energy collected by a tree's leaves, carbon dioxide extracted from the atmosphere is combined with water and nutrients absorbed through the tree's roots to form a composite of hollow cellulose fibers bound in a matrix of lignin by photosynthesis. The result is an extremely versatile lightweight structural material that is easily shaped and fastened with common hand tools.

Figure 1 Wood products begin their life as trees. *Photo by DeStefano & Chamberlain*

As mature trees are harvested they are replaced by younger trees and the wood resource is renewed. In a well managed forest this natural renewal can continue indefinitely as long as there is an ample source of water, carbon dioxide and sunlight.

Scientific evidence suggests that increasing levels of carbon dioxide in the atmosphere from the consumption of fossil fuels is the prime cause of accelerated climate change. The only practical technology currently available for extracting carbon dioxide from the atmosphere is the cultivation and harvesting of trees and other crops.

A well managed forest or woodlot will extract a considerable amount of carbon dioxide from the atmosphere. For every pound of wood grown, 1.47 pounds of carbon dioxide is removed from the atmosphere and replaced with 1.07 pounds of oxygen. However, if a forest is not managed and trees are not thinned and harvested, the forest will mature to a point where the carbon dioxide returned to the atmosphere by the decay of dead trees and forest fires balances that extracted from the atmosphere. To effectively remove carbon dioxide from the atmosphere on a sustainable basis, mature trees must be periodically harvested and milled into building products that will endure for many decades. This is referred to as "carbon sequestration" since carbon becomes a permanent and integral part of the building products. When trees are harvested for short duration uses such as paper pulp or in the construction of buildings with a relatively short service life, the carbon dioxide may soon be returned to the atmosphere with less sustained environmental benefit. One key to effective carbon sequestration is building wood structures that will endure for many decades, or even centuries, with wood products.

Studies have shown that wood has low embodied energy compared to most other structural materials. The energy consumed in managing forests, harvesting trees, milling timber and transporting lumber to job sites is relatively small. Wood fares exceptionally well when comparing the manufacturing impacts of building materials such as solid waste generation, air and water quality impacts, and greenhouse gas creation.

Sustainable Forestry

Responsible forest management is the key to preventing potential adverse environmental impacts associated with the extraction of timber from forests. In the past there have been instances of environmental degradation of forests from irresponsible logging practices. In recent decades forest owners have become more environmentally sensitive and there has been a trend towards managing forests in a more sustainable manner. Foresters have gained a better understanding of the forest environment. Forest management has evolved into not just maximizing timber yield, but also protecting streams and rivers, minimizing erosion, protecting natural ecosystems, and enhancing wildlife habitats. Modern harvesting practices and equipment enable forest owners to remove timber with less long-term impact on the forest ecosystem.

Figure 2 Damage to understory plants can be minimized by performing logging operations in winter. *Photo by DeStefano & Chamberlain*

Figure 3 Riparian fringe adjacent to a woodland stream. *Photo by DeStefano & Chamberlain*

For example, it is important to maintain a riparian fringe of vegetation immediately adjacent to rivers and streams. The vegetated fringe serves as a natural bio-filter that traps nutrients and eroded soil that would otherwise degrade the waterway. The plant roots stabilize stream banks, the tree canopy provides essential shade for the water, and trees fall into the streams to create stream flow conditions important to many fish and other riparian species.

The science of forest ecosystems and cultivating trees is referred to as *Silviculture*. Every forest has a unique combination of species, soil type, elevation, climate, and terrain. For this reason, individual forests require a specifically tailored management strategy to keep the forest healthy, maximize forest growth, and protect against environmental degradation. Foresters have developed a variety of silvicultural tools to assist them in responsible forest management.

Timber may be harvested by selection where individual mature trees are marked and cut. This allows the younger trees to grow more vigorously when competition for water, soil nutrients, and sunlight is reduced. Selection is the preferred harvesting method for tree species that can propagate in the shade of surrounding trees.

Timber may also be harvested by clearcutting, also referred to as even-age forestry. While the practice of clearcutting has often been vilified by environmental groups, when done responsibly considering size, shape, adjacency, water quality protection, erosion control, and wildlife needs, clearcutting can have many environmental benefits. It can be very effective in enhancing wildlife habitat since it creates a forest fringe ecosystem that is essential to deer, wild turkey, and many other species of wildlife. It allows for the growth of many plant species that can only propagate in full sun and better mimics natural stand clearing disturbances such as fire and windstorms. Even-age forestry requires that effective erosion control measures be implemented including the proper disposal of tree crowns and limbs (referred to as "slash") from the harvested trees. In general, shade intolerant species such as Douglas fir, some Pine species and Oaks are best managed by using even-age forestry practices.

Figure 4 Small-scale sustainable timber harvest. *Photo by DeStefano & Chamberlain*

Biodiversity must be considered in forestry management. It is efficient to plant a single species of tree and to grow the stand to harvest at the same age, while maintaining opportunities for diverse wildlife habitat. Conscientious forest managers will also typically also maintain a certain amount of their forest in natural stands comprised of multiple tree and plant species of varying age.   They will also maintain a diverse understory of plants, and maintain other tree species that seed naturally among the planted trees.

The most important aspect of sustainable forestry is keeping forests healthy and available as a long-term resource. When forest lands are displaced by shopping centers or housing developments, that forest resource is lost forever. Development pressure is by far the biggest threat to forests globally. The economic value generated from sustainable timber harvesting provides woodland owners with an incentive to maintain their forest.

So how does a structural engineer know if the lumber on his or her project came from a responsibly managed forest? There are certification programs that verify that wood products are linked to forests managed under specific sustainable forestry criteria.

The two best-known forest certification programs in the U.S. are the *Forest Stewardship Council (FSC),* the *Sustainable Forestry Initiative® (SFI).*

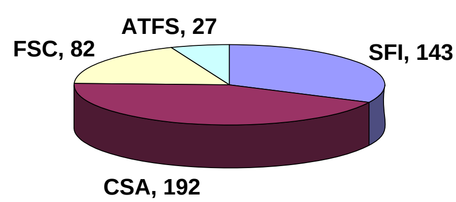
The *Forest Stewardship Council (FSC)*, originally created by the World Wildlife Fund, is a non-profit environmental organization devoted to encouraging the responsible management of the world's forests. FSC standards are intended to ensure that forestry is practiced in an environmentally responsible, socially beneficial, and economically viable way. It was originally created to protect tropical hardwood forests in developing nations and has evolved into an umbrella certification program that endorses national and regional FSC programs with emphasis on the protection of ecosystems. Criteria for FSC certification vary by country, and even by region within a country. Much of the FSC certified woods available in the US are tropical hardwoods imported for millwork and other non-structural uses

The *Sustainable Forestry Initiative® (SFI)* standard was initially developed by the US wood products industry as a code of conduct for responsible forest management. It has evolved into a fully independent non-profit organization. The SFI standard is designed to address sustainable forestry issues found in the specific forest conditions of North America. Almost all of the SFI certified wood products available are domestically harvested softwoods for structural applications.

Two other widely-known forest certification programs in North America are *American Tree Farm System (ATFS) and Canadian Standards Association (CAN/CSA-Z809)* sustainable forest management standard.

Founded in 1941, the *American Tree Farm System (ATFS)* is the oldest sustainable forestry program in North America. ATFS covers predominately family owned forestland and has nearly 70,000 certified tree farmers.

Figure 5.
Certified Forests in North America
(millions of acres)



The *Canadian Standards Association (CAN/CSA-Z809)* sustainable forest management standard was developed for publicly owned forests in Canada.

While there has been considerable debate over which certification program is best, all four are recognized and credible programs. The CSA, FSC, and SFI programs currently have criteria for on-product labeling of certified wood products. Each has a system for manufacturing facilities to track the percentage of fiber that originates from certified forests.

Less than 20% of the structural wood products available today come from certified forests. Wood that is not certified by one of the four sustainable forestry programs may not necessarily have been grown and harvested in the most sustainable manner. While the LEED rating system only recognizes FSC certification of wood products, the Green

Globes and NAHB rating systems recognize all four prominent North American certification programs.

Wood Product Selection

Each type of wood product available to the specifier will have its own environmental advantages and disadvantages that need to be considered.

Solid sawn lumber, and particularly dimension lumber, is commonly used in building construction. A major advantage of sawn lumber is its extremely low embodied energy. Specifying kiln-dried lumber rather than green or air-dried lumber will result in an increase in its embodied energy.

Transportation impacts and the associated embodied energy can be minimized by specifying locally or regionally grown species. Typically the dominant structural wood species in various regions of North America are: Douglas fir in the West, Southern Yellow Pine in the Southeast, and Spruce-Pine-Fir (SPF) in the Northeast and Midwest.

The popularity of *Engineered Wood Products (EWP)* for structural applications has grown significantly in recent decades. EWPs include:

- Structural composite lumber (SCL) including LVL, LSL and PSL
- Plywood
- Oriented Strand Board (OSB)
- Wood I-joists
- Glued laminated timbers (Glulam)

Figure 6. Engineered wood products utilize wood efficiently. *Photo by DeStefano & Chamberlain*

The primary advantage of EWPs is their ability to efficiently use smaller trees and underutilized species with very little manufacturing waste. For example, Aspen is often used in the manufacture of OSB and some SCLs. Aspen is a fast growing species that has the ability to naturally regenerate from its live root system after harvest.

Another advantage of EWPs is their ability to span further and use fiber more efficiently. For example, a typical wood I-joist requires only 65% of the fiber to support the same structural load as a solid section. Offsetting these advantages for EWPs is their somewhat higher embodied energy when compared to solid sawn lumber.

EWPs are manufactured using petro-chemical based adhesives and resins. There are valid toxicity and air-quality concerns related to off-gassing from urea-formaldehyde resin in non-structural wood products used in indoor applications such as cabinets and furniture. Interior use urea-formaldehyde resins have not been historically used in the manufacture of structural EWPs since they do not perform as well as exterior-use resins when exposed to the weather. EWPs primarily utilize phenol-formaldehyde resins which are not subject to any significant detectable off-gassing. Reduced quantities of urea-formaldehyde at acceptable emission levels are still commonly used in non-structural wood products used for architectural millwork.

Precut and prefabricated building components are assembled more efficiently and with less waste than site-built construction. Prefabricated components include:

- Metal plate connected wood trusses
- Panelized framing
- Structural Insulated Panels (SIPs)
- Timber framing

Fabricating wood building components in a factory environment, unimpeded by adverse weather conditions has proven to result in greater efficiency and productivity which translates into reduced embodied energy.

Structural Insulated Panels

Structural Insulated Panels (SIPs) have a rigid foam core sandwiched between OSB skins. Expanded Polystyrene (EPS) and urethane are the most common core materials. SIPs can be used as a cladding system on a timber frame structure or as a stand alone structural system. The panels can be engineered to meet a wide range of structural spans.

Figure 7. SIP roof and wall cladding over structural steel on a school in Cherokee, NC. *Photo by Panelwrights*.

SIPs result in a very energy efficient structure. They have a high R-value and provide a very low air infiltration rate. With proper sealing of the panel joints, infiltration rates are typically less than 0.10 air changes per hour. As with any “tight” structural system, SIP enclosed structures must be mechanically ventilated to prevent indoor air quality problems.

Timber Framing

Timber framing, sometimes referred to as post and beam construction, utilizes heavy timbers connected with mortise and tenon style joints that are secured with hardwood pegs. This type of construction has been around for thousands of years and has experienced a resurgence in popularity in recent decades for architecturally exposed structures.

Timber frame structures tend to have a long service life due to the substantial nature of their construction and aesthetic appeal.
These structures can be easily deconstructed and re-erected on another site. This is commonly done with old barn frames and antique house structures.

Figure 8 Timber framing has experienced a revival in popularity. *Photo by DeStefano & Chamberlain*

Timber frame structures are commonly clad with SIP roof and wall panels resulting in very energy efficient structures.

Recycled and salvaged timbers are often used in timber frame structures. Older timbers from demolished structures can be used in their whole dimension but they are more often recycled by re-sawing into new timbers.

Some timber harvested from standing dead trees is valued for its dimensional stability, although it may contains defects such as excessive shake. There is a significant supply of standing dead timber which has been killed by fires or by parasites. In the western states, large stands of Pines have been decimated by the Pine Bark Beetle. In the northeast, Hemlocks have been killed off by the Wooly Adelgid. While an individual standing dead tree, referred to as a snag, within a healthy forest provides shelter for wildlife, when an entire stand of trees is killed off, wildlife habitats are severely impacted. Harvesting this standing dead timber allows the forest to be rejuvenated.

Advanced Framing

Advanced framing techniques, also referred to as *Optimum Value Engineering (OVE)*, involves framing structures with less lumber than would be used with traditional wood framing methods. Advanced wood framing uses wood most effectively when wall studs, joists and rafters are spaced at 24 inches on center rather than the more common spacing of 16 inches on center. Joists and rafters are aligned with wall studs and wall studs are aligned from floor to floor. This alignment of horizontal framing members with studs allows the use of single member top plates. Headers are sized for actual loading conditions at structural and non-structural walls and redundant studs and floor joists are eliminated on typical details.

Advanced framing allows for more effective insulation of exterior walls with fewer studs to interrupt the insulation.

Advanced framing results in fewer pieces of lumber, but often an increase in lumber size. For instance, when wall stud spacing is increased from 16” to 24”, the stud size will usually increase from 2x4 to 2x6. The wall sheathing and drywall will also often increase in thickness from ½” to 5/8”.

Implementing advanced framing techniques requires some retraining of carpentry crews. It has been estimated that it takes framing as many as ten house structures for a framing crew to become proficient at executing advanced framing techniques.

Advanced framing results in a more efficient structure than a conventionally framed wood structure. It also results in a less redundant structure which can be a disadvantage when a structure is altered or adapted to a different use. Additionally, the advantages of advanced framing can be limited by other design concerns such as fire and draft stopping, or floor vibrations due to reduced mass.

Design for Durability

All efforts to design an efficient structure are of limited sustainable value if the structure has a short service life and is demolished or destroyed after a few decades. If a wood frame structure does not stand for as long a time as it took the trees that went into its construction to grow, then it can be hardly classified as a sustainable building. Sometimes a robust structure that can be easily adapted to new building uses and loading conditions will be the most sustainable design.

The natural durability of wood has been proven by the multitude of buildings that have stood for centuries. While wood’s natural bio-based attributes make it a sustainable building material, those same attributes mean that proper design, installation and detailing are critical to ensure long-term durability.

When wood is used in exposed applications, or in areas where it is subjected to moisture and insects, it must be protected with mechanical barriers, coatings and, in some instances, preservative treatments. Proper design details such as roof overhangs, drip edges and flashing around window and door openings can also protect wood from excessive moisture intrusion.

Preservative Treatment

Figure 9 Borate treatment is an effective non-toxic preservative. *Photo by DeStefano & Chamberlain*

Wood can be impregnated with preservative chemicals to protect it from decay and insect damage. Many preservative compounds are toxic and protect the wood by poisoning decay fungi and insects. Common preservative treatment compounds such as CCA, ACQ, Copper Azole and pentachlorophenol, require special handling during manufacture and disposal after use. Designers should note that CCA, while available for commercial or industrial applications, is no longer available for residential applications. The advantage of an extended service life must be balanced against chemical toxicity concerns. Although in most case the chemicals are fixed within the wood (i.e., they do not leach during exposure to weather), preservative-treated wood can result in adverse environmental impacts if not properly handled and disposed of.

Borates are not toxic to humans and other mammals although they are toxic to termites and decay fungus. Most borate treatments are susceptible to leaching and are not suitable for applications where they are exposed to the weather. Their use is limited to applications such as sill plates, crawlspace framing, and other protected framing. There are some borate treatments which are non-leaching that can be exposed to the weather but are not suitable for ground contact.

An emerging preservative technology uses sodium silicate which seems to combine the benefits of non-toxicity with non-leachability.

Naturally decay resistant species contain extractives in their heartwood that are resistant to decay and wood eating insects. Redwood, Cedar and Cypress are commonly used when natural decay resistance is desired.

Deconstruction and Recycling

Within the manufacturing environment, wood waste is either recycled into the production process or used as process fuel.

At the jobsite, wood waste along with drywall scraps can be processed into landscape mulch. Studies have shown that mulch made from engineered wood products is suitable for landscape use. Mulch is beneficial to plantings due to its ability to retain moisture in the soil and retard weed growth. Eventually the mulch decays and contributes organic material to the soil.

Figure 10 Wood construction waste is converted to landscape mulch in a tub grinder. *Photo by DeStefano & Chamberlain*

Demolition debris can be sorted and recycled. Larger structural timbers can be salvaged during deconstruction for re-use in other structures. Sorting and nail removal from light wood framing can be very labor intensive and impractical unless specialized tools are used.

Wood waste can also be used as a boiler fuel. Jobsite waste, demolition debris, manufacturing scraps and slash from logging operations can all be chipped and used as bio-fuel, displacing the consumption of fossil fuels.

SUMMARY

A structural engineer endeavoring to design responsibly with wood should consider the following sustainable initiatives:

- Specify wood products that come from sustainably managed forests.
- Specify wood species that are grown in the same region as the project.
- Utilize wood efficiently. Consider using prefabricated building components, engineered wood products and advanced framing techniques.
- Design durable structures that are resistant to deterioration and can be altered and adapted to new uses and loading conditions.
- Specify non-toxic preservative treatments when appropriate.
- Require that construction site waste and demolish debris be sorted and recycled or used as biofuel.

References

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2. APA-The Engineered Wood Association – Mulching Engineered Wood Products: An Alternative to landfills
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8. U.S. Department of Agriculture – Successful Approaches to Recycling Urban Wood Waste, 2002
9. U.S. Department of Energy – Advanced Wall Framing, 2000

Website Resources:

APA – The Engineered Wood Association: www.apawood.org

ATFS – American Tree Farm System: www.treefarmsystem.org
Canadian Standards Association (CSA): www.csa-international.org

Forest Stewardship Council (FSC): www.fscus.org

Sustainable Forest Initiative (SFI): www.sfiprogram.org

Structural Insulated Panel Association (SIPA): www.sips.org

Consortium for Research on Renewable Industrial Materials (CORRIM): www.corrim.org