People making wooden buildings

A chapter in: *Trees of the People*, by Alan R. Walker

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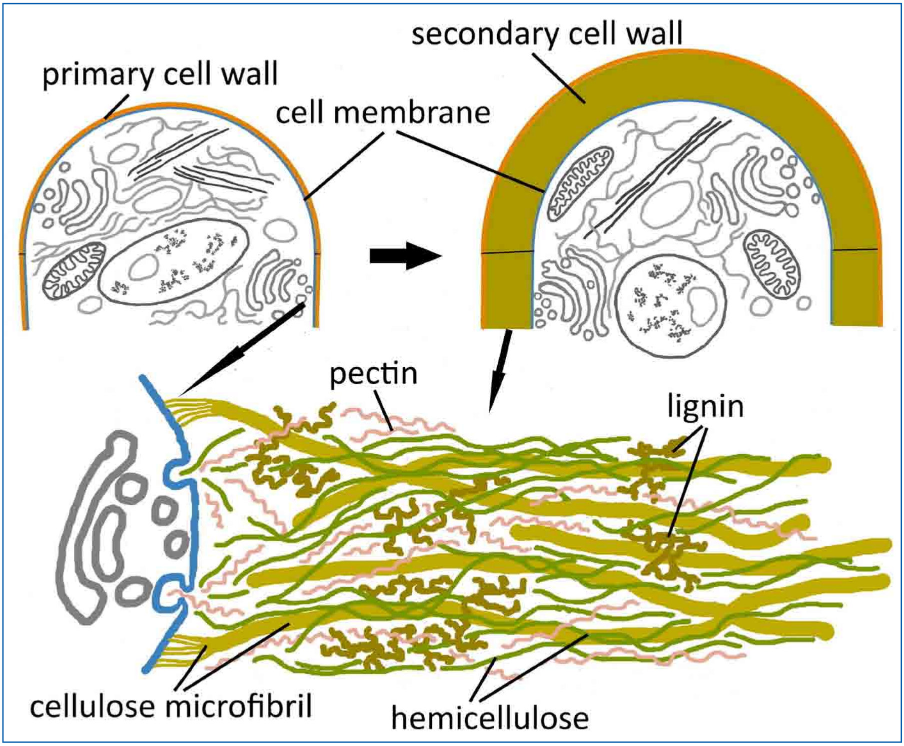
Wind caught the wing of a seed from its cone and blew it amongst grass and heather. This propagule, this embryonic pine tree, carried scarce resources. Its life and future were precarious but promptly it transformed into root and a shoot topped with a few narrow leaves. Towering above was a dense thickness of larger and longer leaves of grasses and woody stems and branches of heather, all shading the seedling. Later, as the competing vegetation died back with the approach of winter the ever-green seedling gained sufficient energy from the sun to establish itself in the soil. Organic nutrients flowed down from is leaves and minerals flowed up from its fine network of roots. The stem of the seedling grew taller: that was its singular task in the future life of this tree. Stems, thick and tall, evolved as the adaptation making trees the co-dominant plant life-form on Earth. If the seedling's stem can outcompete that other dominant life-form – grasses – it will survive and grow tall.

Pine seedling, *Pinus sylvestris*, establishing itself amongst grass and heather, soon to rise on its central stem above this competition for light.

Structure of wood.
Most species of trees grow with a single, central, stem. This robust structure is their crucial adaptation for successful growth to maturity and spread of their next generation. Stems raise trees above non-tree vegetation and with luck of where an individual seed landed a stem will rise above trees nearby, gaining more sunlight. Tall stems however are at risk of wind-throw, lightning strike, and many species of trees evolved amid the hazard of demolition by various types of tree-eating large herbivores, now represented by elephants. The wood of stems and branches evolved as a material with extraordinary properties for something composed almost entirely of carbon, hydrogen, oxygen and nitrogen that are assembled into polymer molecules by minute and softly fragile living cells. Some species of trees grow thick branches extending horizontally for many metres. The torsion stress, the leverage, at the junction with the stem demonstrates the enormous strength of wood that develops as stem and branch grow by the minute and discrete activity of cambium stem cells just below the bark. The secret of this strength with flexibility and resistance to rupture lies at many levels of the fine structure of wood. Levels scaled from nanometres as huge molecules, to millimetres as individual cells that make up wood (1 billion nanometres = 1 millimetre).

Mature oak tree, with typical massive branches extending far from stem and exerting great leverage stress at junction.

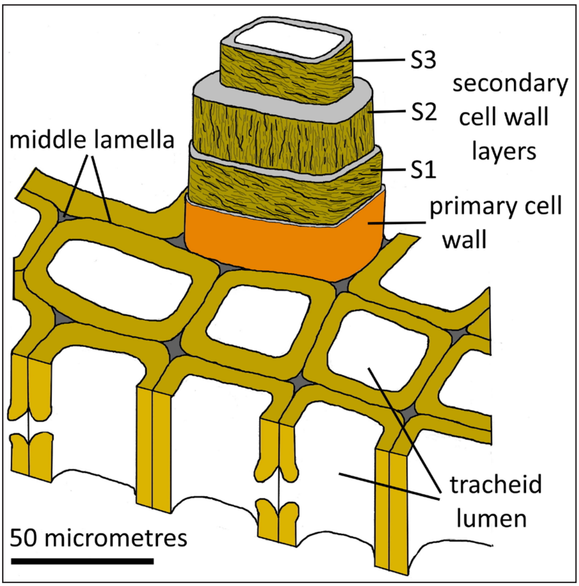
Xylem cells construct wood. They build up the woody stem so that leaves above are bathed in sunlight, but up there the leaves need water and nutrients from the soil. So the stem also must grow as a vascular system to transport liquids both up through the thick layers of xylem and down through the thin layer of phloem cells. A young xylem cell starts like a sphere that has been stretched from opposite poles, then rapidly elongates to fit the orientation of stem, branch or leaf vein.



Structure and growth of a generalized woody cell.

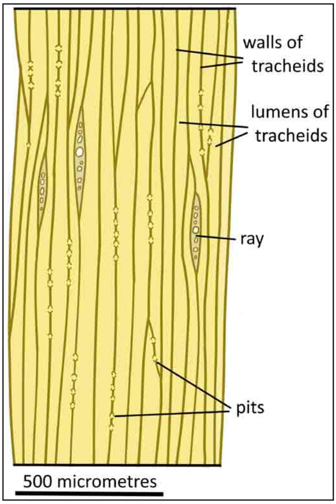
This cell works through an array of membranous structures to synthesize precursors of wood. It secretes these molecules out through its thin live outer membrane into a volume where the non-living walls of the cell build up. These materials will coalesce and bind around the major component, cellulose, of the non-living walls. Cellulose, formula $(C_6H_{10}O_5)n$, is secreted directly from enzyme complexes embedded in the xylem cell's outer membrane. Long polymer molecules of cellulose bundle together, about twenty of them, to form microfibrils, which in turn may bundle together as macrofibrils. Within these fibrils there develop lengths of crystalline structure of extra strong molecular bonding.

Also secreted from a live xylem cell are long molecular chains of hemicelluloses of various molecular types. These chains align closely with numerous microfibrils of cellulose, both along the fibrils and crossing between them. Hemicellulose bonds to the cellulose, creating a dense three dimensional meshwork. Into the watery space between this mesh the tracheid cell secretes pectin molecules. As this space fills densely with elongated intertwined molecules the pectin becomes a matrix packing the developing wood together. Pectin also fills small spaces that remain between adjacent cells: the middle lamella that will allow materials to pass from cell to cell. As the woody multiple outer walls of the tracheid cells are laid down they become infiltrated with lignin. This is the material that gives wood its characteristic hardness and colour. Lignin molecules are hugely and variedly complex, they weave with the mesh of cellulose and hemicellulose fibres in the finally dense interlocked network that is wood.



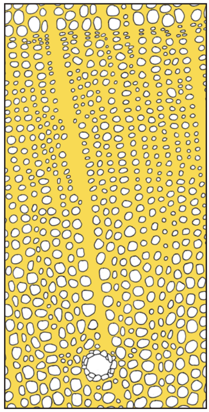
Fine structure of the walls of tracheid cells that have transformed into non-living xylem components.

The tracheid cells thus squeeze and elongate together as a coherent mass of living tissue. All this secretory activity of the live cell first creates the primary cell wall. This is woody, and as the growing cells are produced from the cambium layer of the stem the tracheid cells compact together as roughly rectangular in cross-section and greatly elongated relative to the diameter of the inner cell.



Left: a tangential section of a softwood stem to show alignment of tracheids with the pits that connect them, and the rays.

Right: a similar softwood in cross section showing lumens of tracheids and the amount of wood relative to lumens of tracheids (from 'Leaf-fall')



As the transformation into wood continues more woody material is laid down by the live cell. These layers form the secondary cell wall, in three layers. The first produced has its macrofibrils oriented at about 20° to the long axis of the cell. The next, middle layer has macrofibrils laid down parallel to the cell's long axis, whilst the innermost layer, the last to be formed, has macrofibrils orientated the same way as the outermost layer. Wood evolved millions of years ago as a three-ply cross-laminated structure, composed on the scale of nanometres.

Live cells of xylem tissue, accompanied by a layer of phloem cells, continue elongating to form tubes capable of carrying water and sap. Connections between these cells are created as sculpted pores. Various types of cell differentiate to form xylem depending on type of tree. Softwood needle-leaf trees (gymnosperms) have xylem as tracheid cells with pore connections between the side walls of the cells. Hardwood broad-leaf trees (angiosperms) have these tracheid cells and also a smaller proportion of cells of a type called vessel elements. These are specialized for rapid water transport up the stem through additional pore connections at their ends. Finally in the growth of wood the live wood-forming cell disposes of itself neatly – it actively shrinks then deconstructs its cellular materials for further use by the tree in a process called apoptosis. Such recyling is an adaptation of multi-cellular organisms from long ago. To function, the cells of the xylem become tubes filled with water that moves up the stem mainly because of suction force of transpired water vapour from leaves. In this discrete cellular way xylem self-assembles into scaffolding, walls, floors, and roofs of the construction that becomes a tree stem towering toward the sun.

From tipis to tower-blocks.

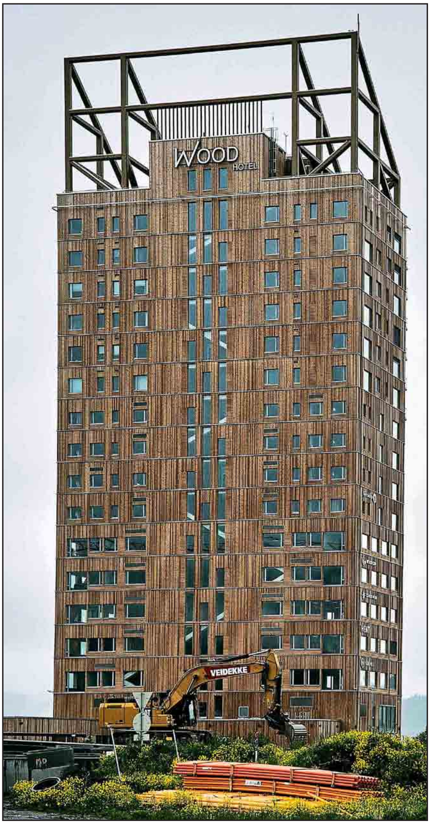
People have made dwelling places and tools with wood for thousands of years. Tipis as erected by the peoples of Siberia and North America are illustrated in 'History' chapter; each supported by ten to fifteen stems of young trees. Multi-storey wooden buildings using log-cabin technique of roundwood interlocked at the four corners remain commonplace, retaining extra value in villages and towns visited by tourists.

Family and their home built of logs, winter in Minnesota, USA, during the 1890s. Credit: Wikimedia

Until about the 1870s, when iron-hulled sailing ships were introduced, the only method for shipbuilding needed continuous supplies of good quality stem wood, usually grown and managed for that purpose. In many countries any building site where ordinary residential houses are constructed will reveal much wood in use as the timber (lumber) of roof trusses and rafters, as floor joists, and often as sheets of laminated wood for inner walls. The predominant materials however remain concrete or brick for foundations, and stone, brick or concrete for load bearing walls that are inherently weatherproof. Similarly, nearly all blocks of apartments or offices will be built up as layers of concrete and steel, often with large sheets of structural glass as walls that also let in the light. Only a small proportion of the material of these buildings will be wooden: doors, furniture and some decorative internal walls.

Stadthaus: a nine storey wooden apartment block in London. Upper left is a concrete and steel apartment tower; lower left is an old brick built apartment block of low cost accommodation.

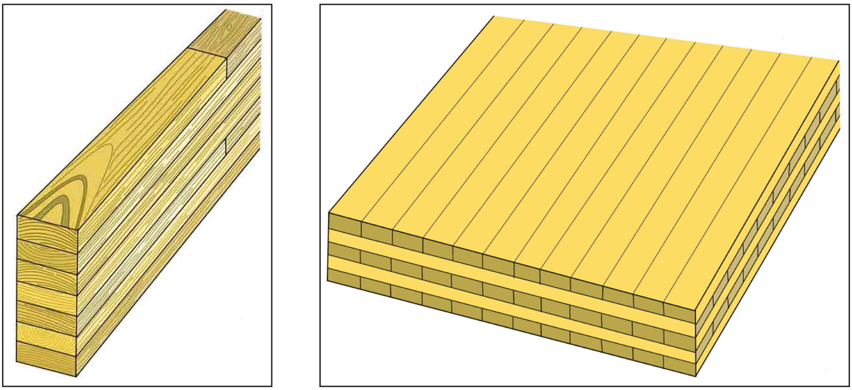
Now there grows a radical trend for greater use of wood for buildings: small houses to tall apartment blocks and offices. These may have the internal structure and most load-bearing parts made of specially manufactured forms of lumber (timber), generically known as engineered wood. Often these new buildings are finished with a weatherproof and decorative outer layer of brick or a cladding layer of some composite sheet material that shields the internal wood. More radical still are buildings made conspicuously of wood, both inner and outer surfaces, with the wood as the main load-bearing element. This building type may be supported also by a central lift-shaft and stairwell constructed conventionally of steel-reinforced concrete. Many combinations exist of experimental forms of these buildings, in the sense of testing the acceptability of both potential purchasers and users and to meet building and fire safety codes and regulations.



Mjøstårnet building, Brumunddal, Norway (during construction) with 18 storeys for mixed use. Credit: Wikimedia, Oyvind Homstad.

Some of these buildings are enthusiastically promoted by their architects, who design them also to include inherent economic and environmental benefits. The wood that was trees in a forest has incorporated carbon by the tonne from the atmosphere into its molecular structure. The same wood as timber for buildings will continue to store, sequester, that carbon in the body of the building during its life of many decades.

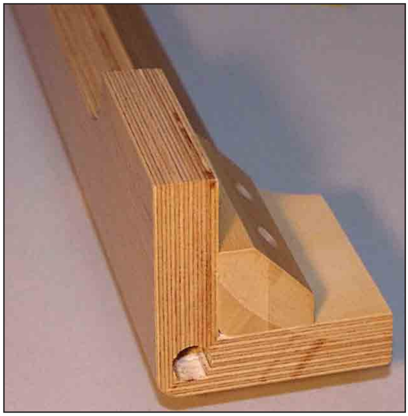
Engineered wood as beams and sheets is made to precise specification for a particular building in a distant factory, then transported on trucks to the building site. Wood is light for its volume, much less dense than brick, concrete or steel. So these light-weight components are simpler to lift and position floor by floor by a team of joiners for final bolting into place. Whatever external surfacing is used, the internal surfaces can remain as bare wood revealing its pleasurable look and feel to the occupants. At end-of-life for the building these wood components are much easier to take apart and recycle than buildings of concrete and steel, specially so if originally designed for de-construction and re-use rather than simple demolition. At the least, the woody material returns to factories for manufacture of lower grades of construction wood or to timber-yards as fuel to generate electricity and useful heat.



Left: formation of a beam using glulam technique.
Right: formation of a sheet of cross laminated timber.

Types of engineered wood.

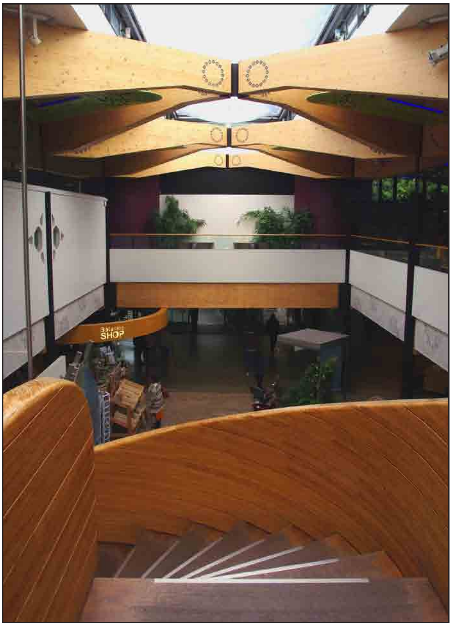
The concept and manufacture of engineered wood has a deep history. Plywood has long been made using a combination of a massive lathe to rotate entire stems against a blade sharp enough to slice off thin layers as veneers. These are combined as a minimum of three, to ten or more, with their orientation of grain alternating crossways to give great strength and stability. The glue binding it all in one large piece is now likely to be a synthetic organic resin that is inherently waterproof and rot-proof. Modern versions of this method, using thicker veneers are known as laminated veneer lumber, LVL. This can be used as load bearing walls when thick enough.



Left: floorboards surfaced with oak upon softwood laid across the grain and forming interlocking tongue & groove. Right: top of a leg of a self-assembly table, constructed of engineered wood to fit together precisely.

Similarly an engineered wood know as glulam or gluelam has been available for about one hundred years. This is formed of long pieces of timber precisely cut along the grain and with a rectangular cross-section. These are built up as a minimum of three layers at one cross-section wide, or as many more layers and several cross-sections wide. Ends of the long pieces of timber are butt jointed or finger jointed for greater strength. These beams of glulam can be assembled in curved shapes and delivered to the building site in precise dimensions specified by the architect or civil engineer. Large cutting machines can perform this task with high accuracy and consistency whilst under computer numerical control, CNC, or robots in plain language.

Sheet-wood assembled in a way similar to glulam is called cross laminated timber, CLT. The pieces of timber are cut along the grain and are small in cross-section compared to manufacture of glulam. They are laid up cross ways as a minimum of three, but more when the sheets are designed for load supporting walls. The sheets can be as wide as will fit in the factory, with the long pieces of timber usually butt jointed together. Many types of sheet-wood are manufactured from fibres, strands and sawmill waste: chip-board, fibre-board, medium density fibre-board or MDF, are some of the familiar generic names for these lower grades of engineered wood. They are widely used for many non load-bearing fittings and furniture in apartments and office blocks.



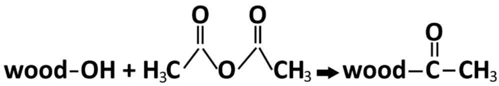
Glulam beams and a spiral staircase formed by glulam technique for the visitor centre of a botanic garden.

Floor-boards have long been a major component of conventional buildings as lengths of solid softwood or hardwood cut with edges to form simple matching grooves and tongues. Now a popular floorboard is available as an engineered wood. The top layer is a veneer of hardwood that resists wear by foot tread. This is supported by softwood laid on with its grain at right angles to the top veneer and with a groove and tongue cut so precisely that the boards click together (using a strong pull!) and need no fixings to hold them in place. The bottom layer is a veneer of softwood with grain parallel to the top layer. Another woody material used for floorboards comes from large species of bamboo, such as *Phyllostachys edulis* (moso bamboo) These plants are in the grass family but nevertheless make excellent material for building work as scaffolding poles and for some styles of complete building. Bamboo can be used to make floorboards with a fine-grained surface that is particularly hard wearing. Either thin strips of the wood are cut and laid up as the top layer of engineered floor boards, or large sections of the thickest stems can be flattened under wet heat to make whole-wood floor-boards. Such floor-boards reveal the seasonal growth nodes of the bamboo.

Wooden bridge over an autoroute in the Netherlands constructed with 'Accoya' treated glulam beams. Credit: Wikimedia.

Modern synthetic glues have greatly enabled this revolution toward engineered wood. They are complex organic compounds, applied hot or cold to the wood to then set hard by spontaneous polymerization as the layers of wood are pressed together. The liquid monomer resin initially penetrates into the porous grain of the wood so that the set bond is as strong as the wood. Furthermore the glues are resistant to water and microbial decay. Another advantage of newer formulations of these glues is that they produce low or negligible amounts of volatile organic compounds as gas that can be irritating or harmful to people if the gas accumulates in buildings (the phenomenon known as sick building). Phenol formaldehyde creates a strong bond suitable for exterior applications. A similar glue is phenol resorcinol formaldehyde which is more reactive than phenol formaldehyde so it will readily set faster when cold. These two glues are often used together as a mixture. The amount of glue in a typical item of engineered wood is about two percent by weight.

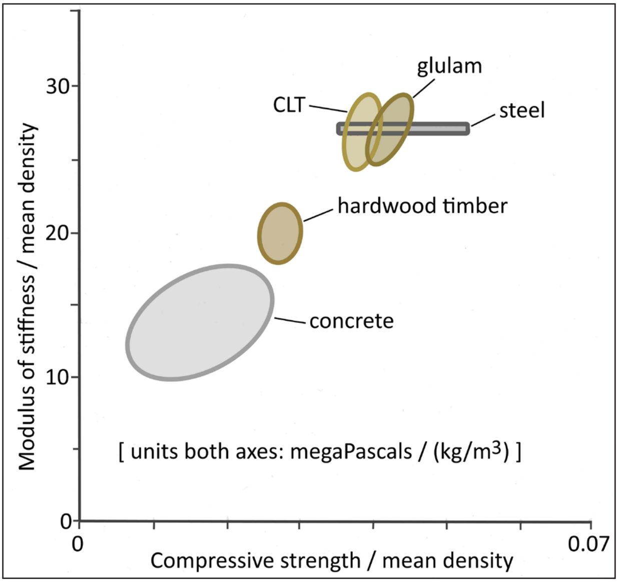
Proofing wood that faces the exterior of a building against the seemingly slight but powerful effects of damp, frost and ultra-violet light is difficult and options include charring the outer surface to leave resistant carbon with its dreary dull blackness. Another treatment that greatly reduces the wettability of wood is known as acetylation. Large pieces of timber are soaked in an aqueous solution of acetic anhydride, a chemical of numerous industrial processes. The acetyl group in solution reacts with wood to replace its hydroxyl group, OH, and thus make the wood less hydrophobic, less easy to wet.



Sheet engineered wood treated by acetylation is available and massive glulam beams constructed from acetylated wood are used for large bridges with novel visual impact of civil engineering design combined with the colour and texture of wood. One commercial brand is promoted as “Accoya” wood.

Advantages of wood to architects and builders.
There are attractive commercial advantages in building with wood to add to wood’s environmental benefits. These are best described relative to the costs and constraints of building with stone, brick, concrete and steel in various combinations. Plain timber is strongest as hardwood such as oak. This is superior to concrete in strength measured as stiffness and resistance to compression. Softwood as glulam and cross laminated timber becomes similar to steel for these characteristics of strength. (Comparisons with concrete are complicated by the use of steel reinforcing rods and grids.) Engineered wood as beams and sheets are lighter than the inorganic materials.

However, the lightness is both asset and problem. Less weight allows less material to support vertically the storeys of the building compared to use of concrete or steel. But a tall building that is too light will bend more with the wind so its tendency to sway may need to be damped by incorporation of concrete. If this is done by using reinforced concrete to construct floors with inherent resistance to fire a good compromise can be reached. A significant advantage of building with wood is the ease of delivery and handling of pre-formed wood elements to reduce the nuisance of the typical building site to people nearby. Also the time to topping out, with the building at full height of its roof, is much reduced. Most examples of modern wooden buildings are designed as a simple rectilinear layout, this being simplest and cheapest. More complex shapes are possible by intricate adjustments to the basic rectilinear form and large complex developments for housing or office space are feasible if cost of construction can be kept low. The more that beams and panels are fabricated off-site exactly to the architect's design the faster the building can be completed.

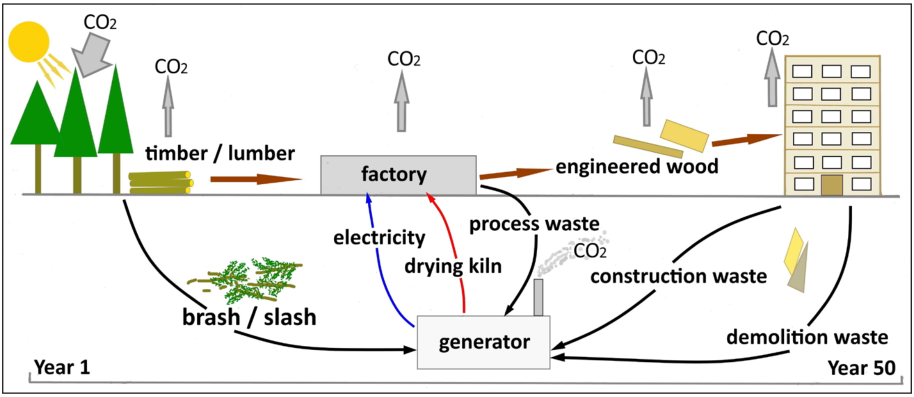


Strength properties of wood, concrete and steel.

Concrete has a poor environmental reputation for one particular reason. Dry, set concrete consists of approximately 80% gravel and sand with 20% of cement as the matrix binder. Manufacture of cement starts with quarried limestone, crushing that, then mixing in clay and similar mineral materials. Intense heat transforms this mixture into cement as a powder and this will react with water to transform into a hard solid. Carbon dioxide is a waste product of chemical reactions as the limestone is heated. This gas is vented out of the kiln into the atmosphere: about half a tonne of it for every one tonne of manufactured cement. Also vented out of the kiln is much CO_2 from the burning fuel, the flame of which roars up the rotating metal kiln. Otherwise, concrete has a modest environmental impact in terms of energy needed to make it compared to that of steel. Also the furnaces burn hot enough to have waste such as worn vehicle tyres added to the fuel mix. Manufacture of cement needs 730 megajoules (MJ) of energy per tonne of concrete, whilst for steel 14,700 MJ per tonne is needed. Currently nearly all of this vast energy is supplied by burning fossil fuels and there are no cheap alternatives.

Plain timber for construction is usually kiln dried and the kilns consume 3420 MJ per tonne of dried wood. Engineered wood such as glulam has a higher overall energy cost at 5890 MJ per tonne and partly this is due to the glue that requires elaborate chemical processes that consume 9,800 MJ per tonne of glue. However, comparisons between these data require care. For drying wood a sawmill integrated with an electricity generator fueled with waste wood will have available much of the energy it needs within its own operation. (Data from Gustavsson *et al*. 2010; with conversion here to joules where 1 kilowatt hour = 3.6 megajoules.)

As with most analysis involving financial budgets much depends on the scale of the process – on what its boundaries are in space and time. So a budget to compare the environmental characteristics of a wooden building with one made of concrete and steel involves a complete life-cycle that starts with mature trees in a plantation. Analysis ends with energy and carbon that was incorporated in the trees being used to generate electricity and heat to feed back into the manufacturing process. Only a small proportion of difficult waste wood is disposed into landfill, and even from there some of the methane from decomposition may be returned to this life-cycle to generate elecricity. However: what was the energy cost of planting, managing and harvesting the trees? The only part of such a life-cycle as trees to buildings to recycled wood that comes free is the sunlight. As 'Photosynthesis' chapter explained, photosynthesis extracts a minute fraction of this energy. Hence the vast number of leaves lifted up into the sunshine to support all that wood. So sunshine as a free energy source would be a deceptive starting point for such a budget.



Sawmill, factory for wood products, electricity generator.

Environmental advantages of building with wood.
The life-cycle diagram here summarises the flows of energy and carbon over a standard life-span of fifty years for a typical tall apartment block built mainly of wood. The quantification of this cycle is complex and currently available data are difficult to generalize. It is the pathways that are most important for understanding these flows. Carbon with its inherent energy is gained from air by photosynthesis. Then losses of carbon occur when it is consumed by the respiration of the trees and by burning of diesel fuel in forestry machines. The sequence of wood processing factory to building construction to maintenance of the building and its eventual end-of-life recycling all release carbon dioxide. They also consume energy derived from fossil fuels and renewable sources. Along these life-cycle pathways there is efficient recovery of carbon as the brash (slash) at the forest harvesting site, followed many years later by woody material coming into the factory from construction and demolition waste. Woody material as difficult as the large mounds of

tangled branches and stem loppings can be gathered and ground into chips by special machines at the forest. The chips spew out from the machine directly into a bulk-carrier truck for delivery to a biofuel generator of electricity sited next to the sawmill and factory.

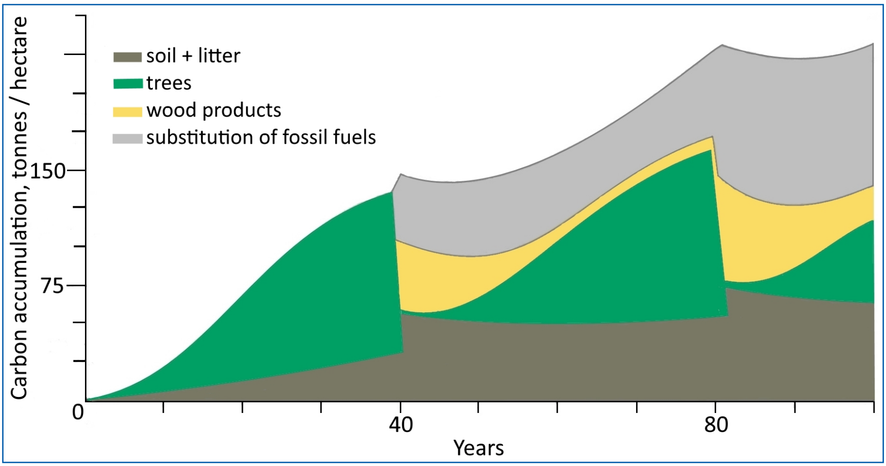
Electricity generator fueled with waste wood, on site of a sawmill.

A comparison of the overall energy balance during the life-cycle of four storey apartment buildings as concrete frame or wood frame constructions with projected life spans of one hundred years gave: concrete frame +260 gigajoules (GJ), wood frame –1110 GJ. This negative energy balance for the wood frame building was because of the energy made available to the life-cycle of the wood materials in the form of waste wood to burn in elecricity generators. (Data here are from Gustavvson & Sathre, 2006.)

Another comparison is of the material carbon footprint, or in other words the global warming potential, during the sixty year working life of wooden three-storey building against equivalent buildings constructed as concrete frame or steel frame gave ratios of the tonnes of CO_2 equivalent per square metre of building as concrete frame to steel frame to wood frame of 1: 0.89 : 0.59. (CO_2 equivalent, or CO_2e, is a measure that includes other greenhouse gases, specially methane with its much greater absorption of heat in the atmosphere.) Data here are from Buchanan *et al*. 2012.

Similar information for this global warming potential of essential materials used in construction of a wooden building , comparing by the square metre of material used, showing steel as the highest at 35kgCO_2e; insulation materials second at 24kgCO_2e; cross laminated timber third at 14kgCO_2e. Also, further down the list were other forms of wood: particle board at 7kgCO_2e and sawn timber at 5kgCO_2e. The high value for CLT is due to its complex manufacturing process. Data here are from Al-Najar & Dodoo, 2023.

Overall, a typical figure for reduction in global warming potential through building with wood rather than concrete is 25%. This level of difference for potential mitigation of climate heating has the potential for incorporation into procedures, regulations and laws for carbon trading and carbon offsets of the sort that are important for plantation forestry and its ability to sequester, to store, large amounts of carbon (see 'Carbon'). The same timber that soaks up carbon dioxide in a forest is easier to count, evaluate and incorporate into a rigorous accounting of carbon trading as large buildings close by rather than trees doing their slow work in remote planations.



Carbon accumulation of conifer plantation with harvesting and replanting every 40 years; light grey is carbon as fuel-wood for power generation.

However, most of the energy used and greenhouse gases emitted during the life span of a building as wood framed, concrete framed or steel framed is for the maintenance of the completed buildings. The needs for heating, cooling, electrical power, refurbishments and so on, are both large and closely similar for these three types of building. Only wooden buildings constructed to the specifications for very low energy use, the *passivhaus* method, will perform significantly better than conventional buildings.

Free-standing wooden roof built for World Expo 2000, Hannover, Germany. Credit: Wikimedia.

A perspective for the energy efficiency of building with wood is known as the displacement factor for emission of greenhouse gas, otherwise known as substitution factor. This is described in 'Carbon' where a chart showed the sequence of growth and harvesting of a plantation forest over repeated cycles of forty years from planting to harvest. A large component, repeated at each cycle, was the energy value of the fossil fuels that would not be burnt within the general industrial economy where the forestry was conducted. This saving was because of various forms of woody material that ended up in the furnaces of the biofuel generators of electricity. Stark examples are semi-redundant electricity generators, formerly coal-fired but now partially fired with wood pellets substituting for coal. The energy available in one tonne of dried wood ranges from 15 to 20 gigajoules (GJ), depending on factors such as the varying composition of wood: cellulose, lignin, resin, wax . . .

Attitudes of builders and public to safety, costs and novelty.
Apartment and office blocks are made for sale or lease in the private or public sectors at a profit for the builders. If the potential potential purchases make a reasonable and sensible association between wood and fire they may be reluctant to buy a house made of wood. Hideously dramatic fires of apartment blocks have killed too many people for there to be anything but suspicion, of outer cladding materials in particular, and also of claims that wood is a safe building material in general.

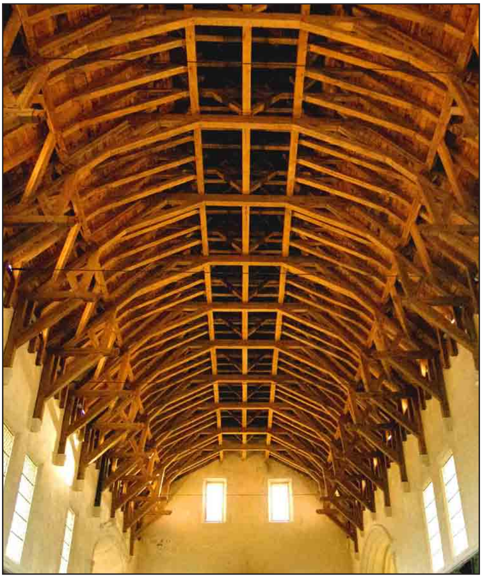
Nevertheless, building regulations and codes for general and fire safety are adhered to as these wooden buildings are designed, constructed, then inspected and certified safe for use. Engineered wood as load bearing beams of glulam or thick panels of cross laminated timber are fitted at dimensions that allow for substantial charring of the outer layers to form a barrier to further combustion, whilst sufficient intact wood remains to support the building. Fire safety regulations typically specify that under severe test conditions in a laboratory the wood structures remain intact and operational for sixty minutes to allow for evacuation of the building. Wood beams and floors are protected by the long established practice of sheathing, typically with layers of gypsum sheet (dryliner board), or a concrete layer as the floors. Sprinkler systems that will automatically shower water onto a starting fire can be installed, but the need for massive water tank at the top of a tall wooden building make this safety feature difficult, specially in relation to resistance to earthquakes.

Fire safety specifications are in the context that the imminent danger to occupants of any building on fire is toxic smoke from burning furniture and appliances. These are also the most likely starting point of a building fire: a cigarette on a sofa; a faulty electrical connection within a refrigerator.

Wooden buildings have gained over many years a good reputation for resistance to earthquake. Their light weight, slight flexibility and potential for highly trussed, triangulated, design all help to make them more resistance to seismic shock than concrete or brick based buildings. But the slight flexibility of a wooden building as a whole, derived from the nature of wood, can obscure the crucial need for the metal joints between very numerous wooden components to be sufficiently ductile. That is the metal must be able to deform considerably without breaking, whilst retaining its structural function. Speciality steels are needed for manufacture of the joints and the design of the joints should include the ability to replace them during repair work after an earhquake. The possibility of such repair is largely inherent in the fundamental style of construction of these wooden buildings

Wood as a material has acoustic properties that make it ideal for making many musical instruments, but anyone who has lived in a traditional apartment block with bare wooden floors will be aware of the clattering noise that may issue from their neighbours above. If wooden houses gain a reputation for being noisier than brick or concrete ones they will not become as popular as their architects hope. Most home-owners will be familiar with the lively responses of wood to variations in ambient moisture and temperature, and some of them will be familiar with how much better window frames made of plastic perform. These limitations of wood remain a design problem with continuing need for research.

Builders in most countries have a reputation for caution and continuation with existing methods: they need to spend much money long before customers pay, also customers may be more conservative than builders. New skills are needed for building in wood and there may be the worry of fewer jobs for builders in this new method. An important driver of change, slow as it is, might be that many people enjoy the look and feel of the wood they experience as trees in parks and forests, as their furniture, and now increasingly as the wood they see as pleasingly aligned and curved forms as staircases, beams and trusses supporting roofs and external surfaces revealing the texture and colour of wood. Although some wooden buildings have their woody nature invisible beneath cladding material that resembles ordinary mineral based composites or a complete outer layer of brick. This may be to provide both a robust solution to the problems of waterproofing, also to gradually introduce the idea of building medium height apartment blocks in wood. Purchasers need to make that initial conceptual move whilst confident that their new wooden home can be re-sold readily.



Roof of the Great Hall of Stirling Castle, rebuilt in recent times using traditional hammerbeam construction with oak.

Other types of buildings, a single storey visitor centre with restaurant in a public park, or a sports stadium, can be designed to a freer, experimental, concept where strong visual impact is greatly valued. Another example is maintaining traditional, cultural and aesthetic values. At Stirling Castle in Scotland there stands the ceremonial Great Hall with its splendid hammerbeam supported roof. The original roof was built five hundred years ago as then the best way to support a long wide roof span. But this castle is a real fortress, under siege many times, and was still occupied as a barracks into the calm times of the 1960s. The Hall was poorly cared for then, allowing the roof beams to deteriorate. When Historic Scotland took over the management of the castle they began renovation of the Great Hall. Three hundred mature oak trees were felled in a region where such trees are scarce. There was no other aesthetically and culturally appropriate option to renew the roof other than its original style and materials Visitor's eyes are drawn upward in the way that frescoe and tiling on the ceiling of a place of religious observance inspire awe. The joiners who renewed the roof of this hall can show off their splendid handiwork to their grandchildren, whilst the timbers will store their carbon for another five hundred years.

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