The Age of Timber: How Engineering Is Bringing Back an Ancient Material

Danann De Alba

Abstract

In the past few years, mass timber has been gaining traction in the architectural community. Architects and engineers tout wood as the sustainable material of the 21st century, envisioning a future dominated by timber construction. Yet the renewed interest in wood construction seems counterintuitive. We built out of timber in the past, and we still build our houses out of wood today. What sets this new “mass” timber apart? And how did we overcome the problems that lead to its declining use? The answer is engineering. Innovations in manufacturing have enabled us to build stronger, better wood materials for cheaper. Once again, engineering has pushed construction into a new era, but this time, by giving a new twist to an ancient material.

About the Author

Danann De Alba is a fourth-year at the USC School of Architecture. Driven by the pursuit for sustainable, responsible and beautiful design, he is always exploring the possibilities that lie at the intersection of technology, engineering, nature and design.

Introduction

Imagine you were asked to rebuild the Empire State Building today. How would you go about doing it? Perhaps you would build it just as the original: using steel and concrete —the trusted way to build skyscrapers as much today as a hundred years ago— or perhaps you might consider some alternate, more modern material, like, say, wood. It sounds ridiculous, but that is exactly what Michael Green Architects and the timber products company Metsä Wood proposed in 2015 [1]. Thanks to a number of innovations in timber manufacturing, we can now envision a future in which skyscrapers, airports, and stadiums are built not of concrete and steel, as in the last century, but of wood, a natural, sustainable and elegant material befitting the 21st century.

Rebuilding the Empire State Building out of wood - Michael Green Architects [1].

A History of Wood

As a construction material, wood is as old as it gets. It has been the material of choice for log cabins and pagodas, for the roofs of cathedrals and palaces, for the foundations of piers, bridges and houses. Throughout most of our history, wood was everywhere. Today, that is not so much the case. In the last couple hundred years, the development of other materials, particularly concrete and steel, have left wood in the dust.

Historical examples of wood architecture: Mănăstirea Bârsana Monastery in Romania (left) [2] and Pagoda in Osaka, Japan (right) [3].

The decline in wood construction was due to a few different factors [4]. One of those factors was deforestation [4]. The loss of wood resources, especially old-growth forests, in addition to the environmental cost of logging, mean it is nearly impossible to source the quality and sizes of wood required to build anything big. Another factor is fire, which has naturally driven designers and builders away from large-scale wood construction [4]. The final factor is that wood has some natural inconsistencies—such as bending, knots and other such defects, sensitivity to decay, response to moisture, among others— that are not present in “modern” materials, which were a headache for engineers, designers and manufacturers [4]. The advantages of steel and concrete proved too enticing for most architects in the 20th century, and wood construction was relegated to small residential construction [4] [5]. Yet today, thanks to a number of critical innovations in manufacturing, combined with concerns over the sustainability of concrete and steel, wood is quickly returning to prominence as a building material in large-scale construction.

Glue, Computers, and a Little Creativity

Imagine, once again, that you were tasked with designing a skyscraper out of wood. You know wood is strong; after all, redwoods can be over a hundred meters tall. But because of deforestation, the kinds of large, mature trees once used to make large structures are rare, and take centuries to grow. Today, we rely on harvested conifer trees, which are abundant and fast growing, but are also smaller and have more defects —such as knots or holes— in the wood [4] [5]. Because of this, most wood construction today is made up of small wood members [5]. We need much bigger structural members for a skyscraper. Logically, we can do this by joining together smaller pieces of wood into a single structural element, but that is easier said than done. Nails are not strong enough and mechanical fastening is expensive and complex [6]. We need something else.

Comparison of wood studs, found in most American houses [7], and the massive beams of a large structure [8]

The secret to modern wood construction lies not in the wood but in the glue. Wood glue is nothing new of course; glues made from casein —a protein found in milk— have been used to make beams from smaller pieces of wood since at least the 19th century [6]. However, casein glues are not very strong, and they are also water-soluble, meaning they cannot be used in exteriors. Therefore, since the 1930s, resin glues —made of synthetic polymers— have taken the place of casein glues. Resin glues are much stronger, and best of all, they are water and decay resistant [6]. In fact, resin glues are stronger than the very wood they hold together. This means that structural elements made of glued parts are functionally indistinguishable from solid wood elements [6]. Glue allows us to make larger, stronger and safer structures using the same small, affordable pieces of wood used in residential construction. We call these wood and glue composites *engineered wood* [4] [5].

However, glue works best when the surfaces it's attaching match perfectly, with enough contact area for the glue to hold together. That means pieces of wood need to be cut to match each other perfectly, like pieces of a jigsaw puzzle. Naturally, this requires a high degree of precision. Skilled craftsmen can do it, but they are hard to find, and expensive. On the other hand, machines are just as precise, but faster, more consistent, and much cheaper. Add in a computer to tell the machine exactly how to cut and you got what is known as a *Computer Numerical Control*, or CNC system [4].

With CNC milling, a whole new world opens up. With precise computer control, you can design any structural element on the computer and the machine will give you exactly what you asked for —A process known as *computer-aided manufacturing*, or CAM— [6]. This means we can now design a whole host of unique, structurally efficient shapes, including those that don't exist in nature (arches, panels, etc.) repeatedly and at low cost [4] [6]. Additionally, engineers can now better understand and respond to the unique properties of wood thanks to computer simulations and updated construction codes [4].

CNC milling lets designers play with very unusual shapes [9].

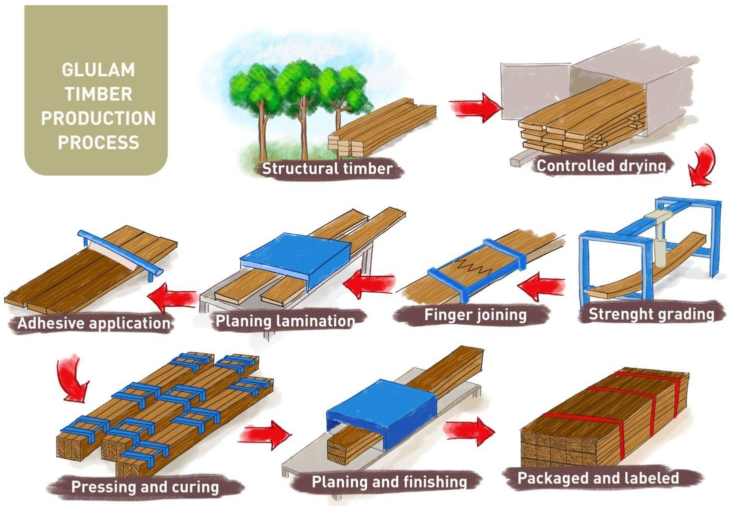
Computational design & CNC milling enable architects to create complex organic shapes with ease [10]. Shown is the BUGA Wood Pavilion, designed by the University of Stuttgart, in Heilbronn, Germany.

Engineered Wood and Mass Timber

By exploiting woods' properties, engineers have created engineered wood products suitable for many different applications —from the feeble particle board used for furniture, to the massive beams of sports arenas— by exploiting wood's properties to improve material use and strength [5]. For example, wood has a direction of strength that corresponds to its natural grain pattern. This means it is much more difficult to break a piece of wood along the grain than across it. By exploiting this property and aligning glued layers of wood —and thus its grain— at different angles, affordable materials like plywood can actually be stronger than solid wood [5].

But plywood isn't going to build a skyscraper. For that, we need *Mass Timber*. Mass timber simply refers to large-scale wooden structures, particularly those made of engineered wood [4]. Because very large structures require incredibly large and strong structural members, numerous engineered wood products have been developed to meet those extreme requirements.

Perhaps the most common one is Glue Laminated Timber —or Glulam for short. Glulam is made by joining together precisely cut strips of wood along the same direction [4][5]. This makes glulam members very strong in one direction, which is ideal for structural elements such as beams, columns and arches [4]. Because glulam is made of many small and standard pieces of wood (see first image below), it can be scaled to fit the size requirements of large structures, and pieces can be spliced together using precisely machined *finger* or *scarf* joints whose interlocking edges maximize the surface area for glue to cover between spliced sections (See fourth image below) [5] [6]. Additionally, using modern machinery, glulam beams can be bent or shaped precisely into arches, which make for economical long-span structures [5] [6].



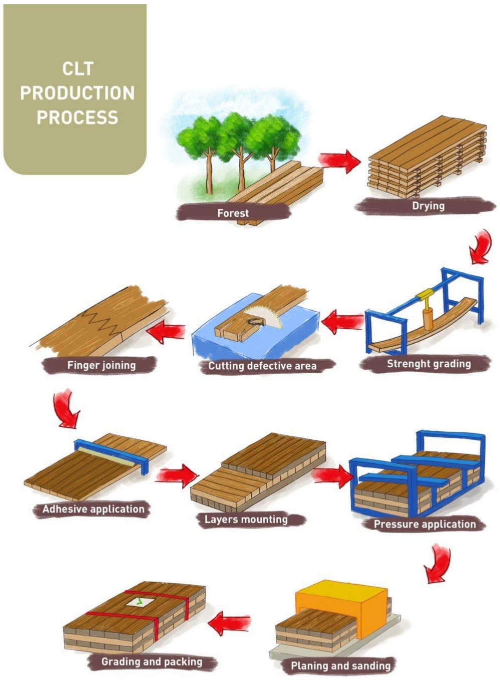
Glulam production process [11]. A precise and mechanized production process produces large, high quality structural members from small pieces of wood.

Large-scale glulam structure (The Wooden Sphere in Stenberg am See, by HESS Timber) [12].

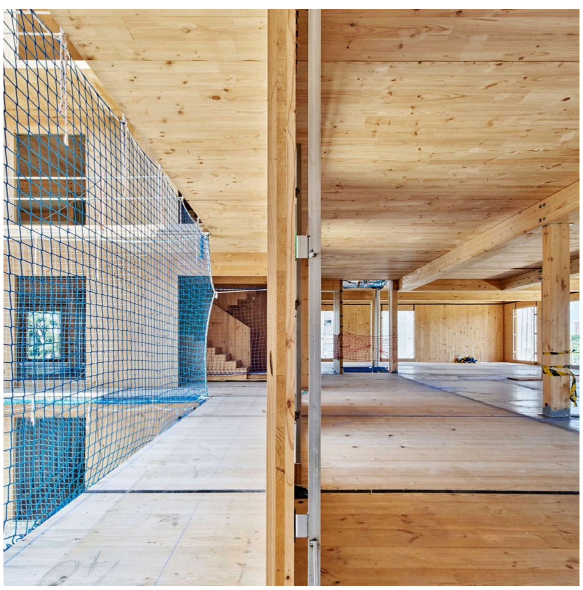
Glulam closeups showing individual wood strips (known as lamella) in cross section [24].

Finger joints (used in both Glulam and CLT). Cutting the ends of beam segments this way maximizes the contact area between them, allowing glue to hold together as much material as possible, maximizing strength [25].

More recently, Cross-Laminated Timber —or CLT for short— is seeing wider use. CLT uses multiple layers of wood, joined and pressed together, and oriented at right angles to maximize strength and stability in all directions [4] [5] [6]. Like glulam, it uses solid pieces of wood joined at their ends with finger joints [5]. This produces thick panels that can be used for walls and floors just as they are. The promise of CLT lies in its simplicity. Panels are made in a factory, and quickly put in place at the site. CLT is capable of holding up multiple stories without additional structure. CLT also takes full advantage of computer-aided manufacturing. Each panel can be designed to a very particular specification or shape [4] [5] [6].



CLT production process [11]. Notice how after adhesive is applied, layers are aligned perpendicularly and then pressed together. This is what makes CLT efficient and stable in all directions.



As seen here, CLT can be used for all kinds of elements, such as walls, floors and even staircases [13].

Possibilities of Mass Timber

Mass timber has several advantages over other construction materials that make it particularly attractive to architects and engineers. For example, with mass timber you can build components off-site and assemble them quickly on-site. This means less time on a chaotic construction site and more time in a controlled indoor environment, which saves time and increases reliability, thus saving costs. When the time comes to assemble, construction workers can put the building together more quickly and reliably [5] [6].

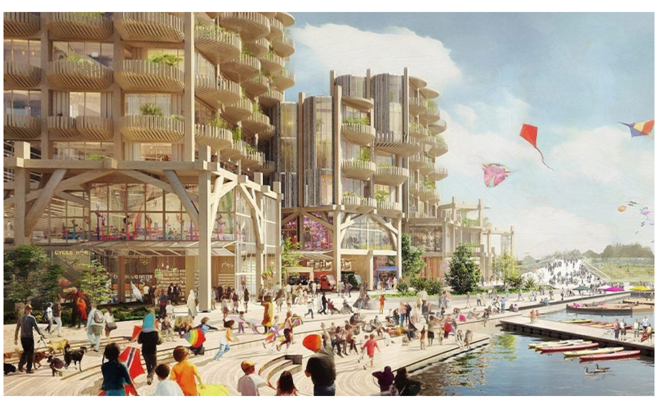
Mass timber is ideal for prefab modular construction [14]

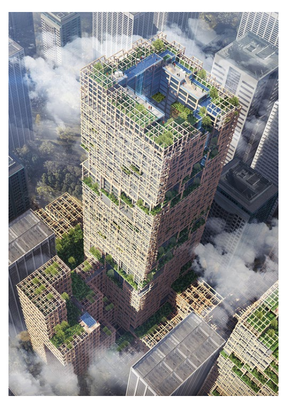
Environmental concerns are the main driver for the adoption of mass timber. The construction sector accounts for 13.8% of global emissions, with 3% from cement production alone [15] [16]. Wood, on the other hand, stores carbon and keeps it locked away in the structure. Additionally, we can save energy in transportation and construction with the aforementioned improvements in construction efficiency and weight.

Architects also appreciate wood's pleasing qualities. Wood is warm, inviting and beautiful, and it "gives mother nature fingerprints in our buildings" [27]. Engineered wood can retain the pleasing qualities of wood while greatly improving its properties. Driven by its benefits, architects have embraced mass timber. Vancouver-based Michael Green Architects —who proposed the aforementioned thought experiment of rebuilding the Empire State Building with wood— have shifted their practices to build almost entirely in mass timber [1]. Ambitious firms are competing to build the tallest timber building, with the current record held by Norway's Mjøstårnet tower [17]. Looking forward, Japanese company Sumitomo Forestry proposed building a 350 meter timber skyscraper in Tokyo by 2041 [18]. At the urban scale Google's Sidewalk Labs has proposed using modular timber construction in their future smart city [19].

Wood employed for its beauty [20]

Norway's tallest timber building, the Mjøstårnet tower [17]





Google’s vision for a smart city built with mass timber [19]   Proposed timber skyscraper in Japan [18]

Challenges

Surely these people must be insane. Have they forgotten wood catches fire? Surprisingly, this is not an issue. That is because wood burns slowly and predictably. Fire takes a long time to reach the interior of such large wood members, and is slowed down by a non-combustible protective layer that forms on the charred surface. So even in a worse case scenario, mass timber buildings can survive long enough to evacuate everyone inside [4] [21]. And that is if you can even set the building alight. If you’ve ever tried to start a campfire you would know that setting a large log on fire is not that easy. Add in all the usual fire prevention measures, and it becomes extremely difficult to set a mass timber building on fire. In fact, when compared directly with steel and concrete structures, timber is surprisingly safe. In serious fires, steel and concrete can lose their structural integrity [4]. Concrete and steel buildings are not immune from fire, as demonstrated by the Grenfell Tower fire in 2017, in which a flammable cladding allowed fire to spread rapidly along the building’s facade, taking the lives of 72 people [26]. Still, fire prevention is a challenge for mass timber construction, as it increases costs and complexity [4].

Mass Timber protects itself. The outer layers are charred, slowing the penetration of fire [21].

The infamous Grenfell Tower fire demonstrates that a concrete building is not immune from fire [26].

It is also important to understand that mass timber cannot exist in isolation. Concrete and steel construction will still be an essential component in any mass timber building, whether as structure, or in a secondary role, such as with steel joints. We have to recognize that concrete and steel cannot be fully replaced and that mass timber is not a panacea for environmental issues in construction.

Most mass timber structures still require extensive use of concrete and steel [23].

Another challenge we face with mass timber is simply that it is so new. So far, the potential savings of mass timber have not been verified, and still don't know much about its long term economic viability. We also don't know how mass timber products will age, and what kinds of issues we might encounter in the long-term, particularly in terms of decay, which has historically been a problem for wood construction [4] [22]. Additionally, we must be vigilant about the sourcing of mass timber products and ensure that logging is done sustainably.

Conclusion

Despite its challenges, mass timber is the new frontier of architecture, and it is no wonder there is so much hype around it. Perhaps in a couple of decades we will see skylines filled with wooden skyscrapers, towering over wooden apartment blocks, libraries, malls and stadiums. Will wood be the material of the twenty-first century? If engineers can continue to crack the code of this ancient material, as they have done before, then it just might be.

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