Cross Laminated Timber Building Performance

Current standard construction techniques play an increasing role in greenhouse gas emissions, so the need for exploration into alternative methods are a requirement for future products and construction. 47% of the CO_2 emissions delivered into our atmosphere are due to building construction and materials. Cross-laminated timber (CLT) and other varied wood products are an emerging, viable source of sustainable, alternative building methods. The presented body of research explains the benefits of utilizing CLT, and other wood products, by expressing their embodied energy calculations and how that is determined by a process known as "Cradle-to-Gate".

The cradle-to-gate process offers a step-by-step analysis of the energy used in the harvest, manufacture, and transportation of constructive products. From this calculation, the overall embodied energy calculation (see: carbon footprint) is surmised. Though much research is still needed, there has been a large volume of research on CLT and other wood building products. Though this research does exist, the United States construction industry (as well as city, county, and federal code systems) is reticent to jump into any type of supportive role for heavy timber (HT) construction. These overseeing bodies cite several concerns, due to lack of information and investigation, but the research does, as mentioned, exist.

In the analyses performed, it became important to expand on the research available and to express the overwhelming benefits of heavy timber construction, especially when it comes to the sustainability and carbon-reducing effects of the material(s). Theory dictates the construction industry will save countless building dollars, man hours, and erection time, etc., with the implementation of sustainable construction practices. As more sustainable methods for building construction are introduced and research is becoming solidified, this theory is becoming reality. Architect Michael Green, an ambassador for building with HT, references the hurdles faced, in the guise of building codes and lack of education, in many of his published articles and informative lectures. Mr. Green acknowledges there is uncertainty, at a base level, about HT construction, yet his firm is pioneering a 'pushing of the envelope', so to speak, by building taller and larger wood buildings and simplifying the methods used.

The research statistics for CLT were initially achieved using Athena software as a comparative tool. The same volumetric scenarios for CLT/HT, steel, and concrete constructions were input, separately and comparatively, and Athena dictated the overall embodied energy calculation. This information was utilized, later, for a cradle-to-gate life cycle analysis. This analysis helps to express the actual, real cost over a material's life cycle from the cradle to the delivery. Other analyses, called "Cradle-to-Grave", analyze the real cost over the entire lifetime of a material. This analysis is not applicable to the project, at hand, due to possible discrepancies in the available information and, in some cases, a suitable lack of information. Ultimately, the intent of the research is to explain the cost-effectiveness and benefits, environmentally and sustainably, of building with HT materials.

Initially, the basis for the research was based in the desire to push the Oregon building code to allow for HT structures taller than 6 stories. In conjunction with Sarah Post-Holmberg and the THA architectural firm, the course of research was meant to outline a comparative model of a structure comprised of 3-ply (6.66") CLT floor plates with structural glu-lam beams and columns (1'4" x 1') and a structure comprised of post-tensioned concrete formulated with 30% fly ash – considered 'best sustainable practice' for concrete. To keep the analysis parameters similar, additive construction materials – screws, rebar, etc. – were excluded from the volumetric calculations.

In the course of the research, it became evident it was detrimentally important to show the actual benefits of HT construction, rather than just stating it was something that 'needs to happen'. The exploration into the sustainable aspects of HT construction became tantamount to the desired end result, so the direction was partially diverted to encompass this idea. As research became the focal point, it was noted there is a severe lack of experienced information funneling into the smaller governmental bodies, regarding HT construction. It should be noted the International Building Code, 2015, has approved CLT/HT as a viable building material and Scot Horst, of LEED, is a champion of bringing HT construction to the forefront of the US building industry. Eventually, the calculations were converted into the cradle-to-gate model for a more discerning understanding of cost structure.

The cradle-to-gate model, which looks at the amount of energy consumed up to delivery to the transport factory, takes into account two main consumption components: 'operational energy' and 'embodied energy'. The 'primary (potential) energy' cycle is comprised of the energy used over the total life span of a material and helps to define the real cost of operation. The operational energy and embodied energy are inclusive of this model, yet there are other costs that may arise and can be included in the primary energy cycle; cost of worker transportation (to and from work), worker services (health, etc.), and food to feed workers (transport, etc.) are a few pieces that can be added into an endless calculation cycle. For the research at hand, the focus was on the theoretic primary energy cycle and the 'delivered energy' cycle. The conclusions, broken down, create the embodied energy calculation. To be fair to this specific project, the embodied energy calculations include primary resource extraction, transportation of unfinished product, and processing and manufacturing, yet do not include final product transport, assembly, maintenance, or demolition/recycling.

An important piece of research noted, across the board, is wood's unmistakable ability for carbon sequestration. Many of the other materials calculated do not perform as well and, often, release more carbon than they are capable of sequestering. A key factor in the embodied energy calculation of wood is the ability to sequester carbon it is harvested with, while keep energy production cost down. Many other materials display the opposite qualities, producing more carbon and energy costs. According to Michael Green, 1 cubic meter of wood will sequester 1 metric ton of carbon within itself, after harvest.

The presentation of analysis, via Athena software, is comprised of a series of information sets needed for end result data. Athena relies on geographic information, building life and type(s), projected occupancy, and other, optional information, such as annual operational costs. Other input needed for calculation include explanation of different building assemblies, including width and span of stated assemblies, and live load of floor assemblies. From this theoretical model, a conceptual building model can be formed for the calculation of embodied energy. These calculations, again, can be used in the cradle-to-gate modeling, for a better understanding of actual, real cost.

In conclusion the research of embodied energy and the cradle-to-gate model, it is surmised that CLT/HT construction is, markedly, a more sustainable construction practice than steel or concrete construction. This seems an obvious assertion, yet the building industry, at large, is wary of taking a leap into the realm of HT construction, due to lack of information. CLT/HT construction is a viable containment process for carbon sequestration and keeps a lower energy cost, during manufacture, therefore creates a valuable case for responsible sustainability practice in a cost-driven market. The research conducted shows incredible potential for use of HT in construction, at minimal environmental and monetary cost, so it is now a matter of adjusting building codes for the allowance of CLT/HT construction. As greenhouse gas emissions from standard building practices become more and more of an issue, cross-laminated timber and other emerging technologies require a push to the forefront of alternative building materials. Lack of information and education may be what is standing in the way of these technologies, so it is important to push the ongoing research further, in order to ascertain inconclusive results of the benefits of CLT/HT construction and other alternative building materials. In pushing further, what is now considered alternative may become the 'norm.'

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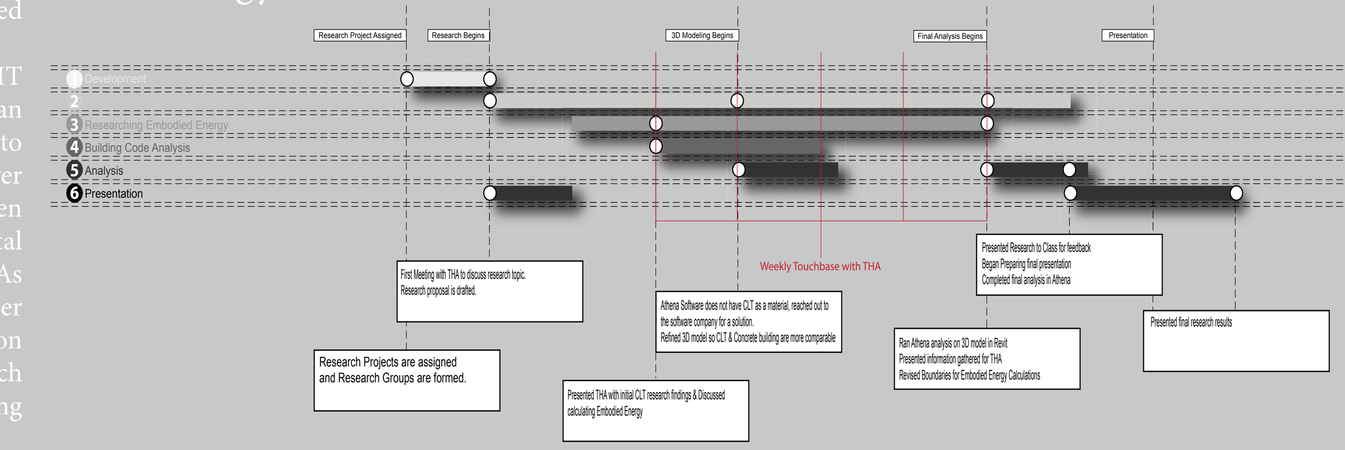
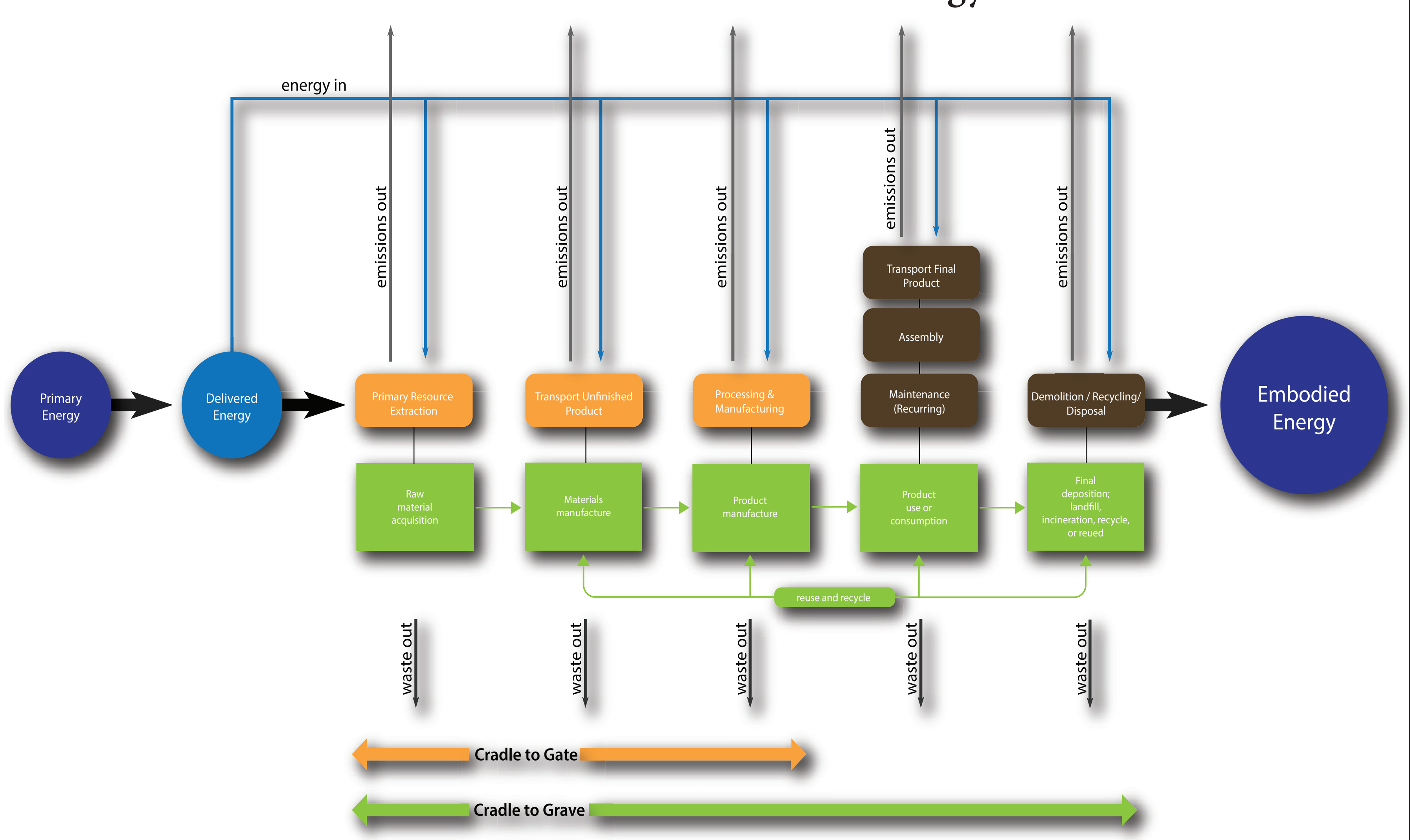
Methodology Timeline



How Cradle to Grave is Used to Calculate Embodied Energy



For the purposes of this comparative embodied energy analysis between CLT and Concrete we used a "cradle to gate" boundary. It is also worth noting that a more in depth analysis could be possible with using a wider boundary of "Cradle to Grave", but this wider boundary starts to create challenges as how to set boundaries and to determine the building operational energy. Also, it is important to note that care should be taken to ensure that primary energy consumption is calculated, not delivered energy, which will understate the real energy cost. (Haynes, 2013)

Panel Properties

Maximum Panel Size	10' x 40'
Maximum Planed Panel Size	8' x 40'
Maximum Thickness	12.18"
Production Widths	8' and 10'
Panel Edges:	1/4" chamfer on long edges
Moisture Content	12% (+/-2%) at time of production
Glue Specifications	Purbond polyurethane adhesive
Wood Species	SPF No.1/No. 2, other species available upon request
Squareness	Panel face diagonals shall not differ by more than 1/8th
Straightness	Deviation of edges from a straight line between adjacent
Dimensional Tolerances	
Thickness:	+/- 1/16" or 2% of the CrossLam thickness whichever is greater
Width:	+/- 1/8" of the panel width
Length:	+/- 1/4" of the panel lenght (40ft panel)

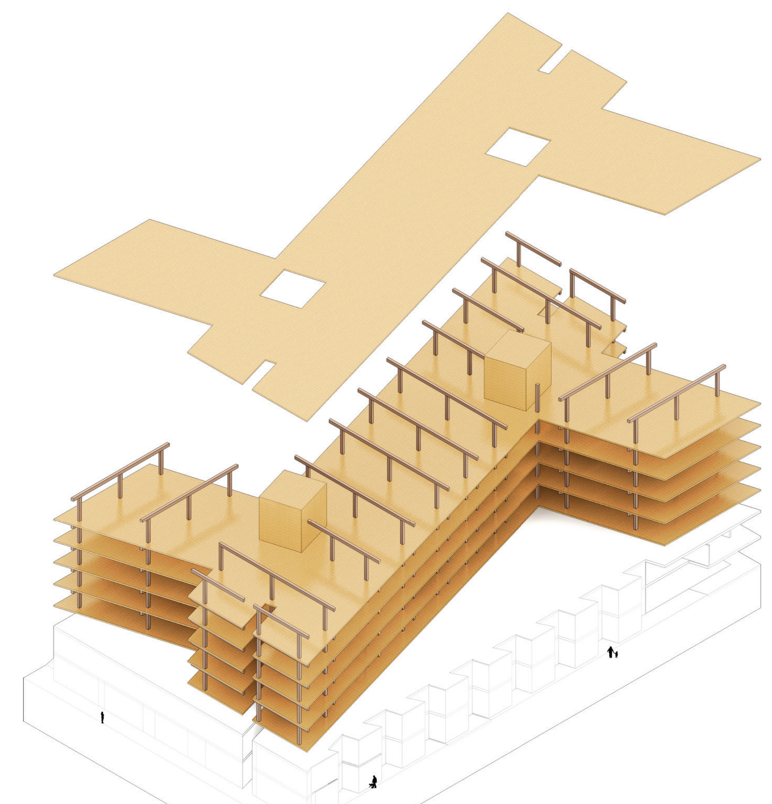
FLOOR SLAB COMPARISON CROSSLAM VS. CONCRETE

MAX SPANS	CrossLam PANEL THICKNESS (in)	SLAB THICKNESS REQUIRED (in)	RATIO CLT/CONC THICKNESS (%)	VIBRATION CONTROLLED SPAN (ft)	CONCRETE SLAB ONE END CONT dx24 (ft)
SLT3	3.90	5.91	66	10.67	7.32
SLT5	6.66	7.87	85	14.94	12.50
SLT7	9.42	10.24	92	18.90	17.68
SLT9	12.18	12.20	100	22.56	22.56

"NORTH AMERICAN FORESTS GROW ENOUGH WOOD EVERY 13 MINUTES FOR A 20 STORY BUILDING"

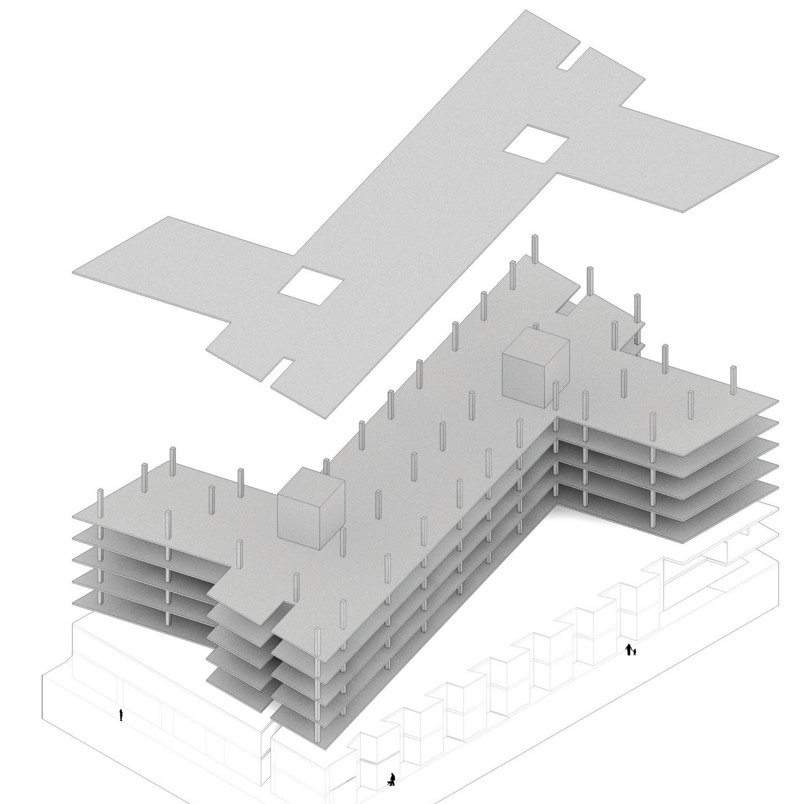
Michael Green

Comparative Study Between CLT and Post-Tension Concrete Construction



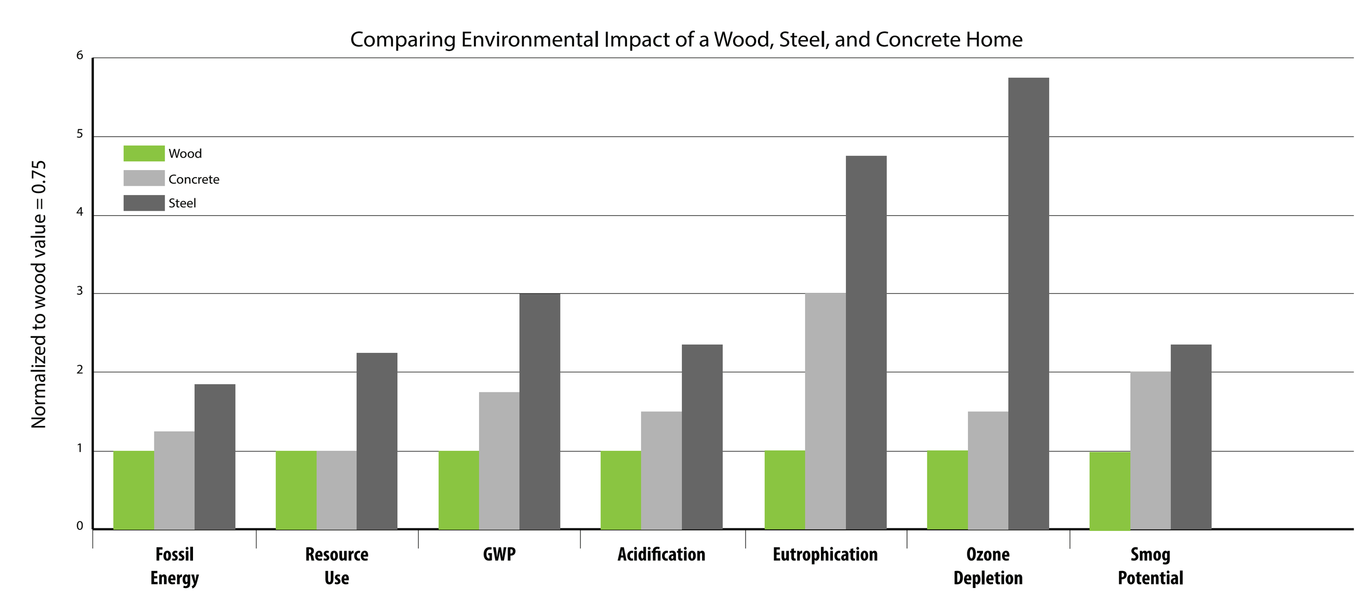
CLT ASSEMBLIES

5 FLOORS 1 ROOF	SLT 5 (5 PLY) CrossLam Panel 6 2/3 inches thick 5 Floors 1 roof each with 11367 cubic feet =68202 cubic feet
COLUMNS	8'2" (1'3" x 1'1/4") 210 columns of 10.3508 ft^3 2173.668 ft^3 11'2 (1'3" x 1'1/4") 42 columns of 14.789 ft^3 621.138 ft^3 =3571.227 cubic feet
BEAMS	1'4 x 1'3/4 278.1464 + 77.4618 + 83.376 + 51.9134 + 432.83 + 102 + 79.5 =6631.3656 cubic feet
	TOTAL = 77628.1716 ft^3



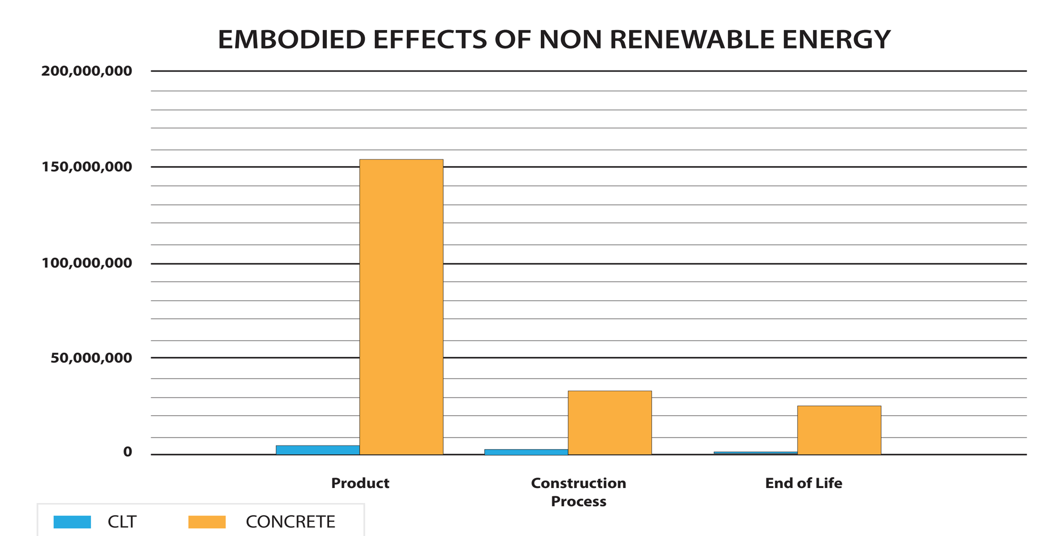
PT CONCRETE ASSEMBLIES

5 FLOORS 1 ROOF	Post Tension concrete 30% fly-ash 8 inches thick 5 Floors 1 roof each with 13596.4309 ft^3 =81579.5854 ft^3
COLUMNS	9'4" (1'6" x 1'6") 156 columns with 21 ft^3 3276 ft^3 11'2" (1'3" x 1' 1/4") 39 columns with 27.75 ft^3 1082.25 ft^3 =4358.25 ft^3
BEAMS	
	TOTAL = 85937.8354 ft^3

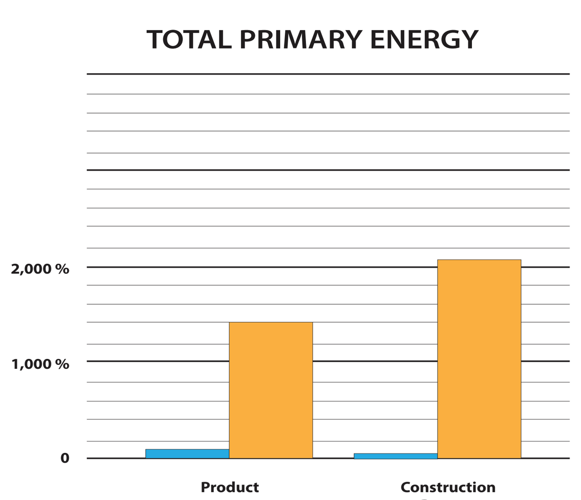


In the graph below, three hypothetical buildings (wood, steel, and concrete) of identical size and configuration are compared. Assessment results are summarized into seven key measures covering fossil energy consumption, weighted resource use, global warming potential, and measures of potential for acidification, eutrophication, ozone depletion, and smog formation. In all cases, impacts are lower for the wood design. Source: Dovetail Partners using the Athena Eco-Calculator (2014)

Results:



Project Name	Unit	Product (A1-A3)	Construction Process (A4 & A5)	End of Life (C1 to C4)	Total
CLT	MJ	4.03E+03	1.55E+06	5.71E+05	6.15E+06
PT Concrete	MJ	1.54E+08	3.30E+07	2.49E+07	2.12E+08



Product	Construction Process
100 %	100 %
1,511 %	2,061 %

Speed and Efficiency of Installation

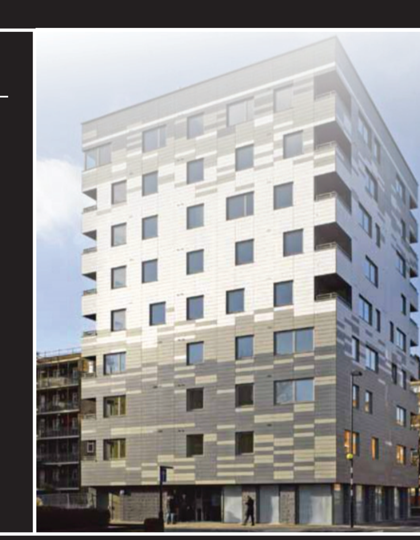
Project: Bridport House
Location: Hackney (London), UK
Architect: Karakusevic Carson Architects
Completed 2011
Description: 8 story Residential
Construction: Platform-based CLT system

Developers chose to use wood for the Bridport House to optimize the structural capabilities of CLT, its speed of construction, and environmental advantages.

CLT panels were prefabricated off site and then craned into place. On-site assembly took just 12 weeks. EURBAN, the timber engineer for the project estimates assembly time to be 50 percent faster than conventional reinforced concrete. (Bryan 2014)

CONSTRUCTION BENEFITS

- Off site fabrication
- Shorter construction programs
- Reduced man hours
- Less waste
- Clean and dust free



Project: Murray Grove
Location: London, England
Architect:
Completed 2008
Description: 8 story residential

On site construction to a crew of four carpenters 3 days per floor totaling

It is estimated the choice to use CLT saved 22 weeks vs. concrete. (KLH)

ASSEMBLIES

Exterior wall
- 3-ply CLT
- Exterior insulation
- Gypsum board on furring
- Internal insulation

Separation walls
- 2 x 3-ply CLT
- Insulation
- Gypsum on furring both sides

Partition walls
- 3-ply CLT
- Gypsum on furring both sides
- *Wood stud partitions are economical in non load bearing walls.

Floors
- 3 to 7 ply CLT
- Insulation
- Suspended ceiling
- *T-shaped Glulam beams can be used together with thinner panels

Roof
- 3 to 5 ply CLT
- Covering
- Insulation

HEAVY TIMBER BUILDINGS AS A CARBON STORAGE BANK

20 STORY BUILDING

CONCRETE EMITS	1,215 TONNES CO2
WOOD SEQUESTERS	3,150 TONNES
NET DIFFERENCE	4,360 TONNES

Equivalent to removing 900 cars from the road each year