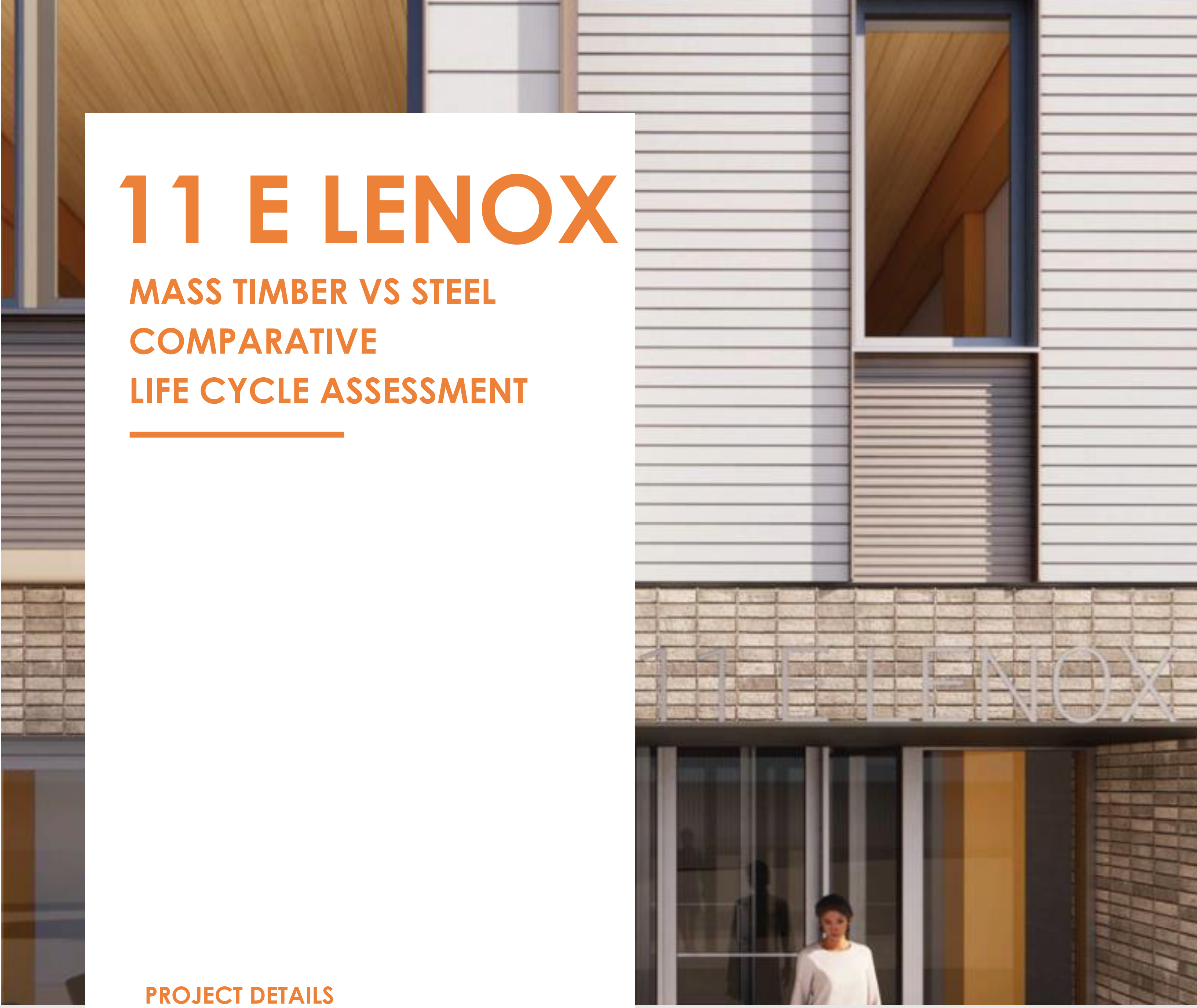

# 11 E LENOX

## MASS TIMBER VS STEEL COMPARATIVE LIFE CYCLE ASSESSMENT

**PROJECT DETAILS**

34-unit Multifamily Residential
Passive House
7-story Type IV- C construction
Boston, Massachusetts

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Study funding provided by WoodWorks

# Table of Contents

# Executive Summary

With the increase in global carbon emissions and a shift to spending more time indoors, sustainable construction systems are gaining an increasing recognition in the building sector. Measuring the environmental impact of a building is starting to become a standard practice rather than a special request. The integration of life cycle assessment (LCA) in the early stages of design can help designers to understand the environmental impact of their choices and make informed decisions. This impact is expressed as Global Warming Potential (GWP) in units of kg of $CO_2$ equivalent.

Building professionals are shifting to more efficient and sustainable building systems, one of them being mass timber. Interest in mass timber is surging along with concern about the greenhouse gas emissions associated with concrete and steel. The production of construction materials such as steel, cement, and glass accounts for 10% of global energy-related $CO_2$ emissions, according to a United Nations report.[1] In an attempt to reduce the greenhouse gas (GHG) emissions of the built environment, professionals often focus only on the operational energy and neglect the embodied carbon impact of the materials used. Embodied carbon refers to the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials.[2] Unlike operational carbon, which can be reduced throughout a building's lifetime, embodied carbon is locked in as soon as a building is constructed.[3] By 2060, the buildings sector total floor area is expected to double, accounting for more than 230 billion square meters globally in new construction.[4] Therefore, it is crucial to address the embodied carbon emissions of buildings.

Sustainably sourced mass timber buildings offer a low embodied carbon alternative to traditional concrete and steel structural systems. Along with this mass timber buildings can capture or sequester carbon dioxide in the forest and subsequently in service. This study demonstrates the value that whole building LCA (WBLCA) provides as a primary driver for structural system design and architectural development of mass timber buildings, rather than single material comparisons using environmental product declarations (EPDs).

This study presents a comparative cradle-to-grave LCA conducted by Haycon Building LLC using Athena Impact Estimator (Athena) software. The baseline mass timber building is currently under construction in Boston and is compared to a functionally equivalent steel building, both of which are structurally designed by H+O Structural Engineering Firm. Both buildings have a gross floor area of 43,564 square feet. Operational energy is excluded from this LCA, as the focus of this LCA is to analyze and quantify the lower embodied carbon impacts of mass timber.

## Key results:

- The steel alternative has a 405% higher GWP (kg of $CO_2$ eq) impact compared to the mass timber structure.
- Total reduced carbon emissions from the mass timber building accounts to 581,870 kg of $CO_2$ eq which is equal to the greenhouse gas emissions from 125 gasoline-powered passenger vehicles driven for one year.[5]
- Construction stage (A4-A5) has increased emissions associated with transportation of mass timber, but they were insignificant compared to the lower manufacturing emissions and carbon storage.

## The Challenges:

- Exporting an accurate and detailed bill of materials (BOM) to Athena.
- Post processing the Revit take-off of BOM for baseline building to maintain consistency with the structural design take-off of steel building.
- Accounting for model omissions, e.g., structural connections, exterior insulation, interior finishes, and partitions.
- Identifying the appropriate material types and readjusting the material quantities for proxy materials.

## Lessons Learned:

- Build the Revit model to accurately reflect material quantities for all elements.
- Develop in-house procedures and tools to integrate LCA with building modelling at schematic design level.
- Use the same approach to estimate quantities when making comparisons between alternatives.

## Future Scope:

- Add more materials (e.g., gypcrete) to Athena database.
- Update Athena methodology to account for biogenic carbon flows within the correct life cycle stages, in alignment with ISO 21930.
- Refine the process for creating BOM.
- Develop a percent estimate for the mass timber structural connections.

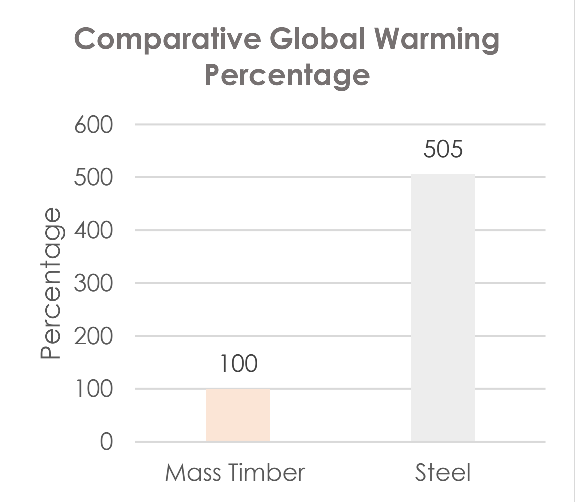


*Figure 1 – Comparative GWP percentage*

# Introduction

The purpose of this study is to conduct a Whole Building Life Cycle Assessment (WBLCA) comparing the embodied carbon impacts of a mass timber building against a functionally equivalent steel building using Athena Impact Estimator software (IE4B). The study is based on a seven story, Type IV-C, 69'-6 ¾" tall, mass timber, multifamily residential project, which is under construction at 11 E Lenox St, in Lower Roxbury, Boston, Massachusetts. The in-progress building is pre-certified to PHIUS+2018 standards. Haycon Building LLC serves as the general contractor of the project and the structural design is done by H+O Structural Engineering. The alternative steel building is Type IB with an identical footprint, similar height, and equivalent acoustical performance and is also designed by H+O Structural Engineering.
The report starts with a brief description of embodied and biogenic carbon followed by the building description and LCA analysis.

# Embodied Carbon: The Big Picture

Operational carbon is the amount of carbon emitted during the use of a building.[6] This includes the energy used to power, heat and cool the building. Embodied carbon refers to the GHG emissions of the building materials themselves- from extraction of raw materials, manufacture and refinement of materials, transportation, and construction, through to the deconstruction and disposal of materials at the end of life.[6]

In the last several decades, there has been a significant focus on reducing the operational carbon footprint of buildings. Building codes and government policies have pushed builders and designers towards more sustainable practices and products. Net-zero energy buildings are the best examples of that effort. However, without a new and comparable focus on reducing the embodied carbon of construction materials, that work will not lead to GHG reductions necessary to mitigate climate change.

Architects have recently established voluntary targets for embodied carbon reductions, through the Architecture 2030 program. Those targets are an immediate reduction of 40 percent, then 65 percent reduction by 2030, and zero emissions from materials by 2040.[7] Structural engineers have a similar challenge, SE 2050, which aims to reach net zero embodied carbon structural systems by 2050.[8]Achieving these results will not be easy and will require a holistic approach in the design process and innovations in the material technology. Choosing materials with low carbon footprint has become extremely important and this is where mass timber comes into play. Mass timber works to reduce the carbon footprint of the building in two ways: first, it has low embodied carbon during the product stage – from harvest to manufacture. Additionally, mass timber acts as a carbon sink by storing carbon that was sequestered by the tree from the atmosphere during its growth. This biogenic carbon continues to be stored in the wood for the lifetime of the building and beyond.

One of the goals of the 11 E Lenox project was to meet PHIUS+2018 requirements to reduce the operational energy of the building. PHIUS+2018 is a high-performance building standard that challenges the building industry to construct buildings that can maintain a comfortable indoor environment with very low operating energy. The project team successfully met the requirements of this standard for operational energy. To take the carbon analysis a step further, though, the project team was motivated to evaluate how their use of mass timber as a building system led to embodied carbon reductions, as well. The goal of this study is to quantify these embodied carbon reductions.

## Biogenic Carbon

In the context of wood construction products, biogenic carbon is the carbon sequestered by the tree as it grows that continues to be stored in the wood product over its lifetime.[9] ISO 21930, the international standard that guides product-level environmental declarations, allows biogenic carbon to be counted in a LCA analysis if the wood was sourced from sustainably managed forests[10]. Based on national reporting as required by the IPCC, both the U.S. and Canada meet the requirements for stable or increasing forest carbon stocks, allowing all products sourced from North American forests to be considered sustainably sourced. In recognition of this, and in alignment with the PAS 2050 carbon footprint standard, Athena Impact Estimator includes biogenic carbon by default in its LCA methodology.[11] [12] The amount of carbon stored in the product serves as the initial credit from which the end-of-life emissions are deducted.[13] However, while ISO 21930 states that biogenic carbon flows should be reported in the life cycle stages where they occur, Athena only reports the net biogenic carbon flows (that is, the initial credit minus end-of-life emissions) in Module D.[13]

When buildings are deconstructed or demolished, the wood products generally have four possible fates: direct reuse (i.e., a beam from the original building is used in a new building), recycling (i.e., a beam from the original building is chipped and used in a new engineered wood product), incineration for energy recovery (i.e., a wood product is used as biofuel as a renewable source of energy), or landfilling (typically with landfill gas capture and energy recovery). Current practices in the U.S. and Canada result in the majority of wood products ending in a landfill, although this can be expected to shift more toward direct reuse and recycling as mass timber gains traction in North America. To reflect the current reality, however, Athena assumes that 80% of wood products are landfilled. 10% are assumed to be incinerated for energy recovery while the remaining 10% are recycled.[13] (Athena does not currently have an option for direct reuse.)

When wood products are incinerated for energy recovery, the biogenic carbon they stored is released back to the atmosphere as an emission. When wood products are reused or recycled, the biogenic carbon they stored is considered to be an "emission," even though the carbon is not released to the atmosphere, because they leave the building's life cycle system boundary. When wood products go to a landfill, they partially decay, releasing a portion of their biogenic carbon back to the atmosphere. However, a significant portion does not decay, leading to permanent biogenic carbon storage within the landfill. Of the 80% wood products that go to the landfill, Athena assumes 77% does not decay. This results in 61.6% permanent biogenic carbon storage in the landfill; this is the net value that is reported in Module D – after end-of-life impacts have been considered.[13] It is important to note that this value, which represents the amount of biogenic carbon permanently stored in the landfill is less than the amount of biogenic carbon stored in the wood products for the life of the building.

Module D is meant to capture impacts and benefits beyond the life cycle. Therefore, it is typically excluded when performing a WBLCA to ensure only those impacts that are related to the life cycle of the building are included.

However, because this is also where Athena reports biogenic carbon, it is necessary to include Module D in the assessment of wood products to capture the biogenic carbon benefits. In this study, a full A-C analysis was performed for all building materials (excluding Module D, as is typical). Then, an A-D analysis was performed for the wood materials only, for the purpose of obtaining the net biogenic carbon effects reported in Module D. Note that Module D effects for all other products were excluded, per ISO 21930.

# Building Description

The study compares two multifamily residential building systems: mass timber and steel.

## Mass Timber System:

The baseline building is a new construction multifamily Passive House residential building in Boston, Massachusetts. It is a seven-story, Type IV-C, mass timber structure, standing at 69'-6 ¾" tall with a total gross area of 43,564 square feet. It uses 5-ply, 6' 7/8" thick cross-laminated timber (CLT) slabs, glue-laminated "glulam" columns, and double glulam beams. Prefabricated modular concrete cores are used around stairs and elevator shafts and serve as the lateral support system. CLT floor panels are topped with two inches of gypcrete, to meet acoustical performance requirements, and finish floor (LVT, tile, carpet tile).

CLT remains as the exposed finished ceiling in large portions of each residential unit, except common corridors where a dropped ceiling with 3 inches of fiberglass insulation and 5/8" of gypsum wall board finish is used. At the second floor, twelve steel transfer beams are used, supported by steel posts below in order to accommodate parking at the first floor. The first floor consists of two thermally broken 5" slabs on grade design with foamed glass gravel as sub-slab insulation. Structural stem walls and footings are beneath the exterior walls and structural columns, with a mat slab beneath each stair core. The exterior walls are 2x6 fire-treated wood stud wall (16" O.C.) with batt cavity insulation, 5/8" Gypsum Wall Board (GWB) on the interior and an ArmorWall™ Plus sheathing system for the continuous exterior insulation.

The ArmorWall™ Plus system, by DuPont, is a high strength, fire resistant, structural insulated sheathing system that is ICC listed.[14] Two types of cladding systems are used on this project: Terracotta and Fiber Cement. For this study we have assumed only one type of cladding, i.e., fiber cement. The building's height is below the 70-foot height threshold, so does not trigger additional "high-rise" provisions under the Massachusetts State Building Code.

## Steel System:

The alternative steel building, also designed by H+O Structural Engineering group, is intended to be functionally equivalent to ensure equivalent performance and functionality to the baseline building.

As such, it is a seven-story, Type IB steel structure, with an overall building height of 71'-0 ¼" and the same gross area of 43,564 square feet as the baseline building. The alternative building uses composite concrete-on-metal deck floors (6 ¼" total thickness) supported by wide-flange steel beams and columns. The grid layout is similar to the baseline design but uses fewer columns due to the spanning capability of the steel beams.

Prefabricated modular concrete core walls matching those of the baseline design serve as the lateral system. The concrete-on-metal deck floor assembly requires a dropped ceiling and 3 ½" batt insulation to match the acoustical performance of the baseline building and meet the minimum requirements of the code. Steel transfer beams are used at the second floor, similar to the baseline design. The first floor is also consistent with the mass timber design, using two thermally broken 5" slabs on grade design with foamed glass gravel as sub-slab insulation. Structural stem walls and footings are beneath the exterior walls and structural columns, with a mat slab (same as baseline) beneath each stair core. The steel design requires fewer but larger footings as compared to the mass timber. The exterior walls remain the same as baseline. However, due to the increased depth of the floor-ceiling assembly, and to maintain floor-to-ceiling clear heights consistent with the mass timber building, the overall height of the alternative steel design increases to 71' 0-1/4". The extra height of exterior wall and core wall material is accounted for in this LCA. This height (over 70 feet) also pushes the building into the high-rise category under the Massachusetts State Building Code. However, this provision is not expected to affect the LCA results.

*Figure 2 – Mass Timber System*

# LCA Scope

The scope of this comparative LCA study includes all structural elements which are part of the building system, i.e., foundations, columns, beams, floors, roofs, steel reinforcement, core walls and exterior walls, as well as architectural elements that are critical to the performance of the building, such as ceiling gypsum board and insulation and exterior wall insulation and cladding.

Because the intent of this LCA is to compare structural systems, nonstructural building components that do not affect the performance and functionality of the building and are expected to be the same for both buildings, are not modeled to be part of the LCA analysis. This includes architectural finishes not listed above, such as interior partitions, floor and interior wall finishes (e.g., LVT, tile, carpet), fixtures, furniture and appliances, paints, stains and sealers, as well as site, civil, mechanical, electrical, and plumbing scope. Similarly, materials common in the roof assemblies of both designs, like the roofing membrane and tapered insulation, are not modelled. Structural exclusions from the LCA scope are the structural connections of framing members and miscellaneous metals. This exclusion is expected to be conservative for wood since steel connections required for the steel framing and composite slab design are expected to be greater than that for a typical mass timber building. The estimation of structural connections for a mass timber system could be considered as a future scope of work by the wood industry.

Operating energy is excluded from this LCA but is assumed to be equivalent between the two designs.

The results are intended to support future decisions about using mass timber as the structural material for construction in lieu of more traditional building materials in order to reduce the environmental impacts associated with construction of new buildings.

# LCA Methodology & Material Assumptions

This comparative cradle-to-grave study is performed using Athena Environmental Impact Estimator software. Athena allows user to “build” a simulation of their project by defining a set of architectural and construction assemblies.[13] The model provides a cradle-to-grave Life Cycle Inventory (LCI) profile for a whole building over a user-selected building service life. The chosen service life for our comparison is 60 years.

The IE supports the following life cycle impact assessment measures based on the US EPA Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI v2.1 (2012)) and in accordance with ISO 21930/31:

- Global Warming Potential (kg $CO_2$ eq)
- Acidification (air) Potential (kg $SO_2$ eq)
- Eutrophication (air & water) Potential (kg N eq)
- Smog (air) Potential (kg $O_3$ eq)
- Fossil Fuel Consumption (MJ)

Given the current goals to reduce GHG emissions and limit global warming, the focus of the study is to quantify the GWP impact.

# Methodology

The software is able to import a "bill of materials" for a said design (from CAD/BIM based tools) and uses this information to provide a detailed environmental footprint for the building. A 'Bill of Materials' was created for both the designs. For the mass timber building, Revit take-offs, structural drawings and submittals are used to estimate the material quantities. For the steel building, the structural drawings provided by H+O team is used to estimate the material quantities. Proxy materials are used when the original material wasn't available in the software. One of the examples is gypcrete, it is substituted with 8" lightweight concrete blocks. A full accounting of the assumptions for each major material category is included in Table 1.

Table 1 shows a summary of material quantities of both the designs distributed by assembly groups (columns and beams, floor, roof, foundation, walls, and extra materials). Materials which were not available directly in the Athena database are entered as proxy materials as indicated by the "Athena Entry" column.

The standard life cycle stages and the modules that make up those stages are represented in Figure 3. The scope for this comparative whole building LCA is cradle-to-grave. The modules excluded from the assessment are B1(installed product in use), B3 (repair), B5 (refurbishment), B6 (operational energy use), B7 (operational water use), and D (benefits and loads beyond system boundary). The life for all structural materials is assumed to be the same as the assumed building life, which is 60 years; therefore, Modules B2 & B4: maintenance & replacement are included within the scope but have minimal impact in this study. Further discussion of the modules that are excluded and the impacts measured in each remaining module are in the section that follows.

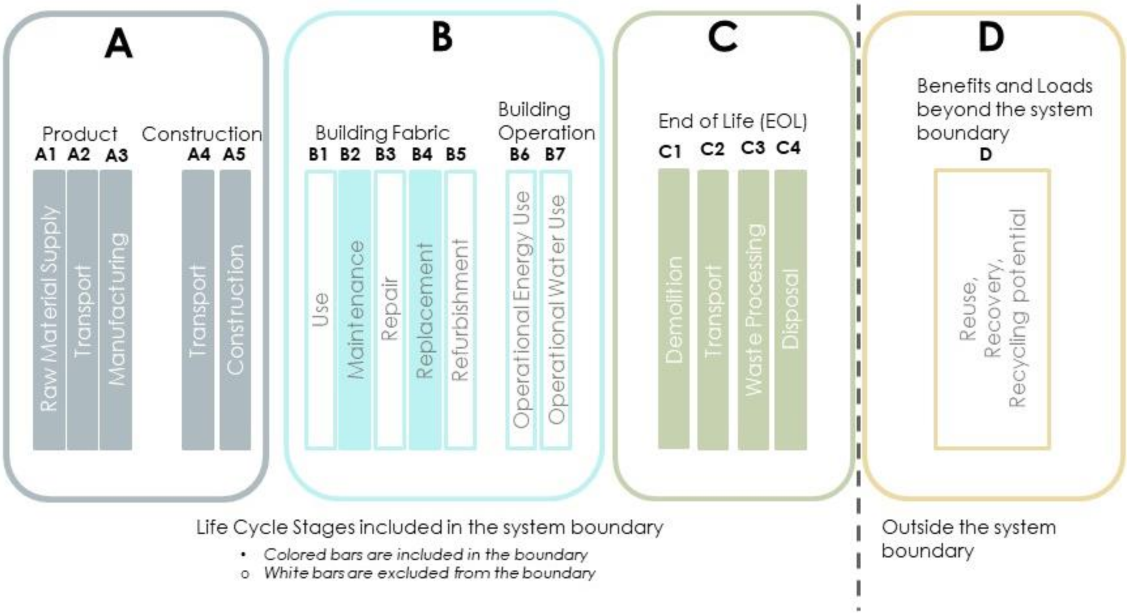


*Figure 3 – Life Cycle Product System Boundary*

| | CLT Building (69'- 6 3/4") | Steel Building (71'- 0 1/4") | Unit of Measurement | Athena Entry |
|---|---|---|---|---|
| **Columns & Beams** | | | | |
| Glulam Columns | 2949 | 0 | ft$^3$ | Glulam Sections |
| Glulam Beams | 6871 | 0 | ft$^3$ | Glulam Sections |
| Steel Columns | 2.09 | 29.6 | tons | Wide Flange Sections |
| Steel Beams | 4.03 | 84.1 | tons | Wide Flange Sections |
| **Floor** | | | | |
| Concrete - Level 1 Slab on Grade | 88.9 | 88.9 | yd$^3$ | Concrete Benchmark USA 5000 psi |
| Metal Floor Deck | 0 | 37.8 | tons | Galvanized Decking |
| Concrete Fill | 0 | 504.5 | yd$^3$ | Concrete Benchmark USA 4000 psi |
| CLT Floor | 19663 | 0 | ft$^3$ | Cross Laminated Timber |
| Gypcrete Topping | 23427 | 0 | blocks | 8' Lightweight Concrete Blocks |
| Ceiling Gypsum Board | 3737 | 34320 | sf | 5/8" Fire Rated Type-X Gypsum Board |
| Ceiling Fiberglass Insulation | 5605 | 120120 | sf | FG Batt R11-15 |
| **Roof** | | | | |
| Metal Roof Deck | 0 | 6.87 | tons | Galvanized Decking |
| CLT Roof | 3372 | 0 | ft$^3$ | Cross Laminated Timber |
| Roof Lumber | 0.585 | 0 | 1000 board feet (mbf) | Large Dimensional Softwood Lumber, kiln-dried |
| Roof Plywood | 0.728 | 0 | 1000 square feet (msf) | Softwood Plywood |
| Ceiling Gypsum Board | 1456 | 6249 | sf | 5/8" Fire Rated Type-X Gypsum Board |
| Ceiling Fiberglass Insulation | 3367 | 3367 | sf | FG LF Cavity fill R15 |
| **Foundation** | | | | |
| Concrete Piers | 9.76 | 0 | yd$^3$ | Concrete Benchmark USA 5000 psi |
| Haunch Beams | 3.26 | 3.26 | yd$^3$ | Concrete Benchmark USA 5000 psi |
| Column Footings | 26.29 | 78.1 | yd$^3$ | Concrete Benchmark USA 5000 psi |
| Wall Footings | 169.7 | 169.7 | yd$^3$ | |
| **Walls** | | | | |
| Concrete: Exterior & Core Walls | 341.3 | 343.5 | yd$^3$ | Concrete Benchmark USA 5000 psi |
| Fiber Cement Panels | 20266 | 20704 | sf | Fiber Cement |
| Armorwall Sheathing (1/2" layer of Magnesium Oxide) | 20266 | 20704 | sf | ½" Gypsum Fiber Gypsum Board |
| Armorwall Insulation | 45592 | 46576 | sf | Polyisofoam Board (unfaced) |
| Batt insulation | 111478 | 113884 | sf | FG Batt R11-15 |
| Gypsum Wall Board | 20266 | 20704 | sf | 5/8" Fire-rated type X Gypsum Board |
| **Extra Materials** | | | | |
| Rebar | 9.4 | 15.8 | tons | Rebar, rod, light sections |

*Table 1 – Bill of Materials*

# LCA Comparative Results & Discussions

The results of the comparative cradle-to-grave whole building LCA are summarized in this section, focusing on the GWP. Figure 4 shows the embodied carbon impact of both the systems for each life cycle stage of the system boundary (A-C). Because of the way Athena reports the biogenic carbon, the net biogenic carbon for the mass timber building is not included in each life cycle stage but is instead reported separately.

The product stage (A1 to A3) includes raw material extraction from nature, transportation to manufacturers, and product manufacturing. For both systems the product stage has the highest GWP impact. Wood impacts during the manufacturing phase are low compared to concrete and steel, which are made from substances that must be mined and heated to extremely high temperatures.[15] Production of a ton of steel generates almost two tons of $CO_2$ emissions, and each pound of concrete releases 0.93 pounds of $CO_2$.[16] [17] Alternatively, the wood industry accounts for only 0.2% of global greenhouse gas emissions.[18] By using wood in place of higher emitting materials, the overall GWP of the built environment can be reduced significantly.

In addition to low embodied carbon impacts during manufacture, mass timber has the potential to offset a considerable percentage of the product stage emissions by storing the carbon when the building is in use, thus, making it a better choice compared to steel and concrete.

The construction stage includes the transportation of materials from factory to construction site by truck or rail (A4) and construction work, such as product installation and groundwork (A5). We can see that the mass timber building has higher emissions for this stage. This is largely due to increased transportation distances for CLT over more locally available steel. As market adoption of CLT increases and more manufacturers come online, a reduction in A4 transportation impacts can be expected.

The use stage of the life cycle includes installed product in use (B1), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), and operational energy and water use (B6 and B7, respectively). Athena excludes B1 due to lack of consensus on an appropriate methodology. Since B1 is meant to be a placeholder for any impacts not reported in B2-B5, this exclusion is appropriate. B2 maintenance impacts include things like repainting. Due to the scope of materials included in this study, there are no B2 impacts reported. Athena excludes B3 due to lack of robust data on building repairs.

Replacement impacts, reported in B4, are based on the expected lifespan of each material relative to the lifespan of the building. All structural materials are expected to last for the lifetime of the building. However, a few non-structural materials like fiber cement panels of the exterior walls might need to be replaced over the life span of the building, resulting in minimal carbon emissions from use stage. Athena excludes B5, refurbishment, since this is not typical for most buildings and should be handled on a case-by-case basis. Operational impacts (B6 and B7) are excluded from the scope of this LCA, as previously mentioned.

The end-of-life stage includes the

impact of demolition (C1), transportation of those materials from site to waste processing (C2), waste sorting and processing (C3), and final disposal (C4). Carbon emissions in this stage from both the buildings are only slightly different, indicating that both consumed a similar amount of energy at the end of building life cycle.

The “Beyond the Building Life Cycle” Stage (Module D) is not a part of our system boundary and is only used to calculate the permanent biogenic carbon storage of wood products at the end of their life, as mentioned earlier. Note that the amount of permanent biogenic carbon storage, (378,000 kg $CO_2$ eq) nearly offsets the emissions seen in the product stage (400,000 kg $CO_2$ eq) of mass timber building.

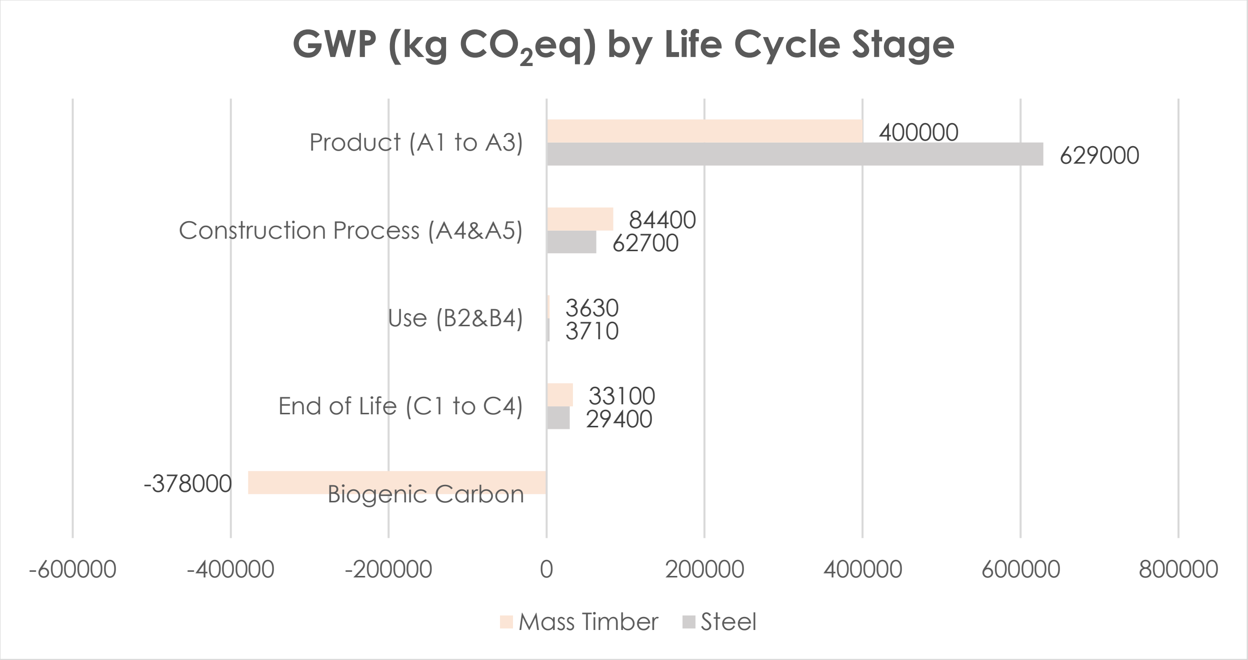
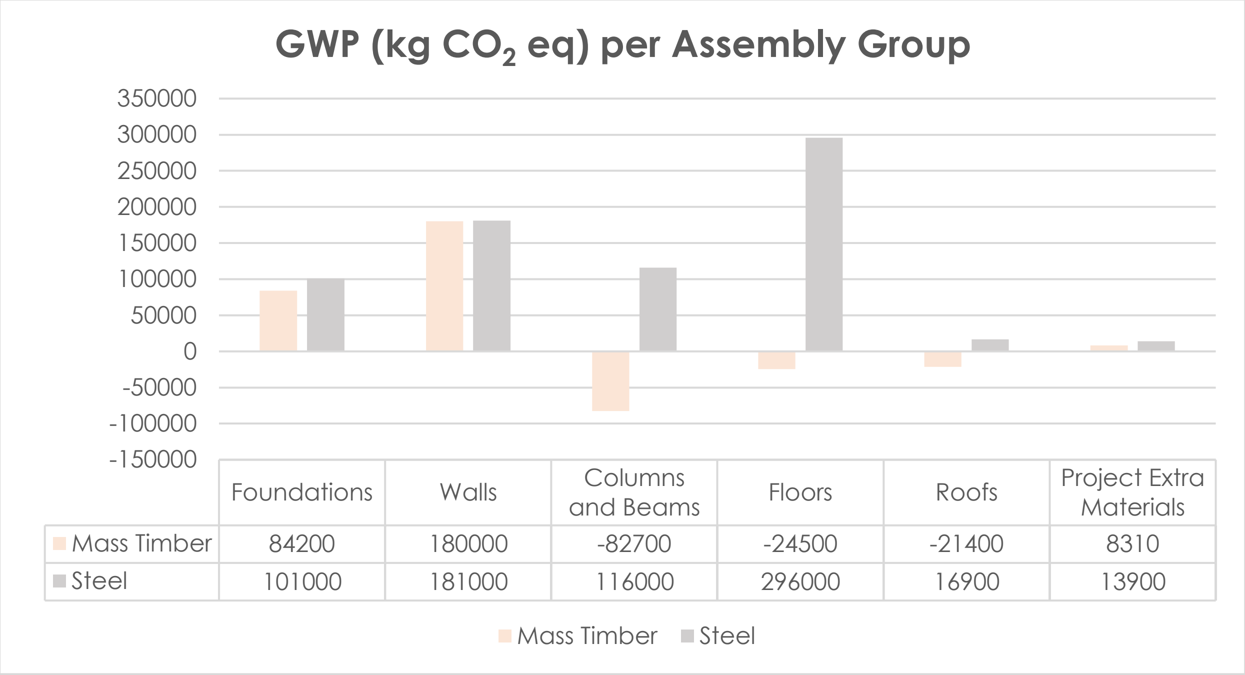


*Figure 4 – Global Warming Potential by Life Cycle Stage*

The life cycle stage analysis provides an understanding of the overall embodied carbon of the two structural systems and when emissions happen over the life cycle of the building. Figure 5 gives an insight on the embodied carbon emissions of each assembly group.

The assembly group with the largest difference in GWP between the steel and the mass timber designs is the floor system. Floors in the mass timber building are comprised primarily of CLT panels and gypcrete topping with batt insulation and gypsum board ceilings in limited areas. Floors in the steel building are comprised of lightweight concrete over metal deck with batt insulation and gypsum board ceiling across entire footprint. Note that for both buildings, the “floor” category also includes the concrete used at the first-floor slab on grade. The large difference in GWP between these two systems can be attributed to a few factors:



| | Foundations | Walls | Columns and Beams | Floors | Roofs | Project Extra Materials |
|---|---|---|---|---|---|---|
| Mass Timber | 84200 | 180000 | -82700 | -24500 | -21400 | 8310 |
| Steel | 101000 | 181000 | 116000 | 296000 | 16900 | 13900 |

*Figure 5 – Global Warming Potential by Assembly Groups*

- CLT floor panels have low embodied carbon plus biogenic carbon storage which results in net carbon storage (represented by the negative value shown in Figure 4).
- The CLT floor assembly uses 2" of gypsum concrete topping. The steel floor assembly uses 3 ¼" concrete over a 3" metal deck, resulting in an average of 4 ¾" inches of concrete over the floor area. In addition to the fact that the steel building system uses more than twice as much cementitious material at the floors, light weight concrete generally has a higher GWP than normal weight concrete of an equivalent strength while early studies have shown gypsum concrete to have a lower GWP than typical normal weight concrete mixes, due to its lower strength.
- The CLT floor system is largely exposed. Dropped ceilings were only provided in the corridors to hide MEP systems, reducing the amount of material required. To achieve equivalent fire and acoustical performance, the steel system required dropped ceilings everywhere.

The next most impactful assembly group in terms of GWP is the framing system itself (i.e., beams and columns.) In the mass timber building, the framing is comprised primarily of glulam beams and columns, with a limited number of steel beams and columns as previously noted. In the steel building, the framing is comprised entirely of wide flange beams and columns. The difference in the embodied carbon impact of steel versus wood is highlighted here, with wood again showing net carbon storage.

Roof assemblies show a similar pattern where the CLT roof system results in negative GWP values due to net carbon storage by the wood. However, the steel roof system consists primarily of an untopped metal deck with dropped ceiling similar to those at the floor. The low GWP relative to the GWP at the concrete-on-metal deck floor system further reveals the impact of the concrete topping on the overall GWP.

Walls show only a minor difference in the GWP. The small increase (18 inches) in the building height doesn't have much impact on the emissions.

The alternative steel building uses more concrete for the column footing and thus has slightly higher emissions for the foundation than the mass timber design. However, the difference between the two foundation systems was minor, so the difference in GWP for the two designs were minimal.

The total amount of concrete used for the steel building is higher than mass timber building (Table 1) which results in increased quantity of rebar and related emissions from reinforcement material. This increase is mainly due to the reinforcement required for the lightweight concrete floor slabs of the alternative building.

The GHG emissions from steel building are considerably higher because of the use of steel and concrete as structural system. It is fair to say that the use of mass timber as a construction material in the baseline building, showed significant environmental savings as compared to the traditional building materials. It is a viable substitute for steel and concrete which make up majority of the embodied carbon emissions as seen in this study.

# Summary and Outlook

In this study, a seven-story mass timber new construction building in Boston is compared to an alternative steel building in a whole-building LCA using Athena Impact Estimator tool.

The study investigates the key benefits of mass timber as a sustainable construction material compared to the traditional products like concrete and steel. The mass timber building achieved a better environmental performance and showed significant carbon reductions, providing insight to construction and design professionals on the impact of integrating more timber-based solutions into their projects.

Several limitations and challenges of the study should be mentioned. One of the limitations was the accuracy of material take-off. The mass timber building had a set of structural drawings and a detailed Revit model to export a BOM. The material take-off of the steel building was largely calculated manually using just the structural drawings. Additionally, the BOM for both buildings did not include material quantities that were not explicitly modelled, for e.g., metal deck edge closures, other miscellaneous metals and structural connections. Another limitation was the exclusion of the impact of certain assemblies like internal partition walls, windows, and certain façade materials like brick and terracotta from our scope.

Another limitation within the tool itself was the ability to map the designed construction products to the appropriate material due to the limited set of materials available within Athena. As a result, several proxy materials were used, as shown in Table 1. For example, gypcrete was replaced by 8" lightweight concrete blocks while lightweight concrete was replaced by normal weight concrete of the same strength. Armor wall sheathing which comprises of ½" layer of Magnesium Oxide (MgO) was replaced by ½" layer of gypsum fiber gypsum board.

For the materials that were available in Athena, the data represented national averages rather than regional or product-specific data. In some cases (i.e., dimensional lumber), this is appropriate based on the procurement process for these materials. In other cases, however, such as CLT where a specific manufacturer is used, the inability to select a specific manufacturer will impact the results in module A4, transportation of materials from factory to construction site.

Another challenge was accounting for the biogenic carbon of mass timber building. Because Athena reports biogenic carbon in module D, this required running three simulations in order to account for the credit within the system boundary (A-C).

Future research may include estimating the percentage of structural connections required for mass timber products. Future research may also focus on the effects of different design decisions on many aspects, e.g., variations in the column spacing, beam depth, change the amount of material, and thus life-cycle environmental impact.

The next steps could also involve including the operational energy of the building in the study of embodied carbon emissions and comparing a mass timber passive building to an alternative steel or concrete non-passive building.

This LCA study highlighted the environmental benefits of using mass timber as a construction material. As the construction industry continues to grow in the high-performance building sector, there is also a need to focus on the embodied carbon impact of these systems. A holistic approach is required to reduce the carbon emissions of the built environment.

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