Nez Perce-Clearwater Office

Comparative Life Cycle Assessment Study

Author: KL&A Engineers & Builders

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Executive Summary

How does mass timber compare to traditional structural systems? Is mass timber sustainable? What are the associated dollar cost premiums?

This study of the Nez Perce-Clearwater National Forests Supervisor's Office endeavors to answer these questions. It compares two functionally equivalent[1] structural systems—a mass timber/light-frame wood hybrid (MT/LF hybrid) and an alternate designed in steel—and the associated architectural systems in terms of global warming potential (GWP), dollar cost, and construction schedule. It is part of the *Mass Timber Comparative Life Cycle Assessment Series* comparing functionally equivalent structural systems across a variety of building types and geographical locations in the United States, and should be read together with the *Mass Timber Comparative Life Cycle Assessment Series Introduction* (Feitel & Kingsley, 2024).

The Nez Perce-Clearwater project is a government office building in Kamiah, Idaho built with the MT/LF hybrid structural system. The design team included Mosaic Architecture, structural engineer Morrison-Maierle, and general contractor Quality Contractors, LLC. Construction of the 18,540-gross-ft^2 (1,722 m^2), Type V-B, two-story building was completed in 2021. Due to a sloping site, the lower level is partially below grade. The structure consists of shallow spread footing foundations, full-height and partial-height concrete foundation walls with slab-on-grade at the lower level, wood sheathing on wood floor trusses and glulam beams at the upper level, cross-laminated timber (CLT) core walls, interior and exterior light-frame wood stud walls, and CLT panels on glulam beams at the roof. The term "mass timber/light-frame hybrid system" in this report is used to represent the combination of mass timber and traditional light-frame wood components. The alternate steel system is typical for office buildings in Idaho. Also Type V-B, the alternate structure is identical at the lower level, with concrete slab-on-metal deck on non-composite wide-flange steel beams at the upper level, and metal deck on open-web steel bar joists and wide-flange beams at the roof. In the alternate system, light-frame wood exterior walls are replaced with cold-formed steel (CFS) walls, and CLT elevator core walls are replaced with fully grouted reinforced concrete masonry (CMU) walls.

Key results of the study, which incorporates a whole building life cycle assessment (WBLCA) by KL&A Team Carbon and construction cost estimates by Quality Contractors and KL&A's construction management group, include the following:

Global warming potential (cradle-to-grave): The total GWP of the MT/LF hybrid building is 159 kgCO_2eq/m^2, a 43% reduction compared to the steel building GWP, which is 277 kgCO_2eq/m^2 (Figure 1). The 118 kgCO_2eq/m^2 savings equates to 203 metric tons of CO_2eq, which is equivalent to 48 gas-powered passenger vehicles driven for one year or the electricity needed to power 40 homes for one year (United States Environmental Protection Agency, 2023). The major contributor to GWP in the MT/LF hybrid system is the concrete foundation and slab-on-grade. The contribution of wood material is net negative due to the natural ability of wood to store carbon; this type of carbon (derived from material of biological origin) is termed biogenic carbon.[2]

Construction duration: The steel system superstructure was estimated to take 65 days to erect compared to 48 days for the MT/LF hybrid superstructure. This project shows that, even at a small scale, a MT/LF hybrid superstructure can be erected faster than steel—in this case 26% faster. This time savings benefits both the dollar cost and embodied carbon impact of the MT/LF hybrid system.

Construction cost: It is common for initial cost estimates to show a significant material premium for mass timber over traditional structural materials and the Nez Perce-Clearwater office was no different. Comparing only the structural material costs for the superstructure above the concrete foundation walls, the MT/LF hybrid system was estimated to cost 7.7% more than the steel system. However, when considering the whole building construction cost, including savings associated with the shorter construction duration, the MT/LF hybrid system premium was reduced to 2.7% (Figure 2).

Photo Heidi Long, Longview Studios

The construction industry has a significant opportunity and responsibility to address climate change by virtue of its outsized 42% contribution to global greenhouse gas (GHG) emissions (Architecture 2030, 2024). The most immediate way for the building industry to reduce GHG emissions is to reduce embodied carbon—i.e., the emissions associated with physical building materials, through their raw material extraction, production and manufacturing, transportation, installation, and end-of-life scenarios. Mass timber and wood hybrid structural systems are one potential strategy for embodied carbon reduction due to the materials' relatively low manufacturing GWP impacts and natural ability to store biogenic carbon for the life of a building (and potentially indefinitely).

This building study demonstrates that implementation of an MT/LF hybrid structural system for small-scale buildings like the Nez Perce-Clearwater office can present a viable, cost-competitive approach to significantly reducing and minimizing a building's embodied carbon impact (Figure 2), with the understanding that building life expectancy, material sourcing,[3] and end-of-life pathways influence cradle-to-grave results.[4]

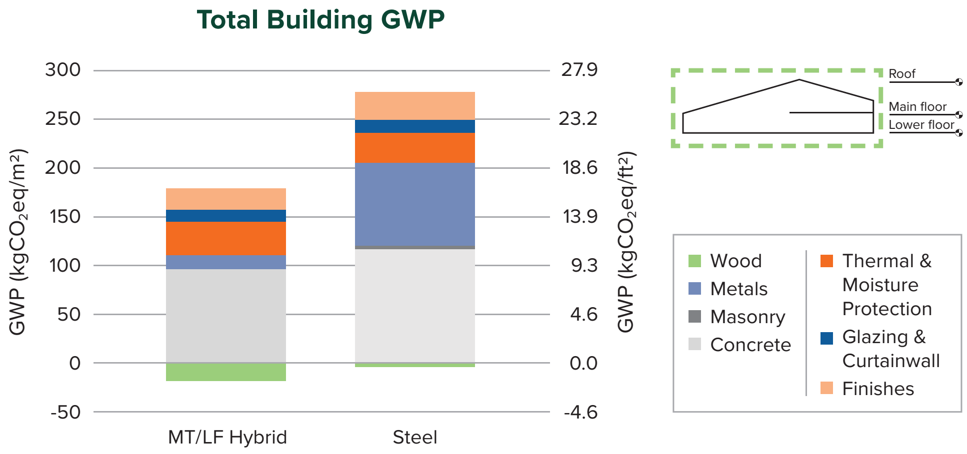


FIGURE 1: Total building (structure and architecture) GWP comparison and material contributions

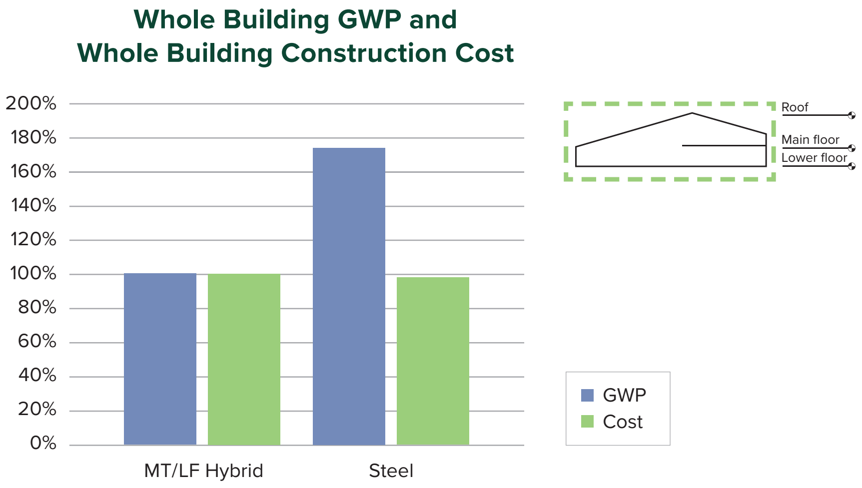


FIGURE 2: Total building GWP (structure and architecture, including the enclosure, fire resistance-rated assemblies, acoustic assemblies, and interior ceiling finishes) and whole building construction cost comparison of the building systems, normalized to the GWP and cost of the MT/LF hybrid system

Introduction

The purpose of this building study is to use whole building life cycle assessment (WBLCA) and cost estimates to understand the embodied carbon and dollar cost differences between functionally equivalent[1] mass timber/light-frame wood hybrid (MT/LF hybrid) and steel structural systems.

The study examines how an MT/LF hybrid building—the Nez Perce-Clearwater National Forests Supervisor's Office, located in Kamiah, Idaho (hereafter abbreviated to "Nez Perce-Clearwater office")—compares to a functionally equivalent building designed in steel. In the reference project, mass timber elements include a cross-laminated timber (CLT) roof and glued-laminated timber (glulam) beams and columns; light-frame wood components include 2x bearing walls and floor trusses with plywood sheathing. Construction of the reference building was completed in 2021. Comparisons between the two structural systems are made in terms of embodied carbon, construction dollar cost, and speed of construction. The variations between architectural designs (construction type, enclosures, fire protection, acoustic performance, and ceiling finishes) are included in the analyses.

This report starts with an overview of the reference building, followed by a description of the alternative design and scope of the study, and then the results of the comparative life cycle assessments (LCAs), dollar cost, and speed of construction analyses. It is part of WoodWorks' *Mass Timber Comparative Life Cycle Assessment Series*, and is intended to be read together with the *Mass Timber Comparative Life Cycle Assessment Series Introduction* (Feitel & Kingsley, 2024). The series introduction details aspects common to all studies in the series, including methodology, approach, scope, and code compliance of the comparative designs, LCA, and dollar cost analyses, and the importance of embodied and biogenic carbon[2] as part of the building industry's strategy to address climate change and environmental degradation. This study details information specific to the Nez Perce-Clearwater office and variations from the series introduction.

Project Background and Alternative Designs

This section describes the reference building, the alternate building's design considerations, and the structural and architectural design results.

The Nez Perce-Clearwater office is a Type V-B, two-story building in Kamiah, Idaho owned by the U.S. Forest Service (USFS). The Architect of Record is Mosaic Architecture, the Structural Engineer of Record is Morrison-Maierle, and the general contractor is Quality Contractors, LLC. The USFS chose an MT/LF hybrid system because of its alignment with their values and sustainability goals, as described in the WoodWorks case study of this project (WoodWorks, 2022). The CLT was designed and supplied by SmartLam North America from their Columbia Falls, Montana plant, which also supplied the glulam. The wood trusses were designed by The Truss Company and supplied by Early Bird Supply. The authors of this study utilized information from completed construction documents and shop drawings from the built project.

A steel system was chosen for the alternate design based on local construction practices. It is commonly used for buildings of this scale in this part of the country.

> WoodWorks' case study of the Nez Perce-Clearwater office estimates the potential carbon benefit of using wood instead of a more traditional steel or concrete structural system, considering both the carbon stored in the wood and avoided greenhouse gas emissions associated with wood's lower embodied carbon. The estimated impact varies from this building study for several reasons, including different component scopes, level of detail related to materials, assumed service life, and embodied carbon data.

Comparative Building Systems

The two structural systems compared in this study are illustrated in Figure 3. The MT/LF hybrid reference building was designed by the project's original design team. KL&A designed the alternative steel building in collaboration with Mosaic Architecture.

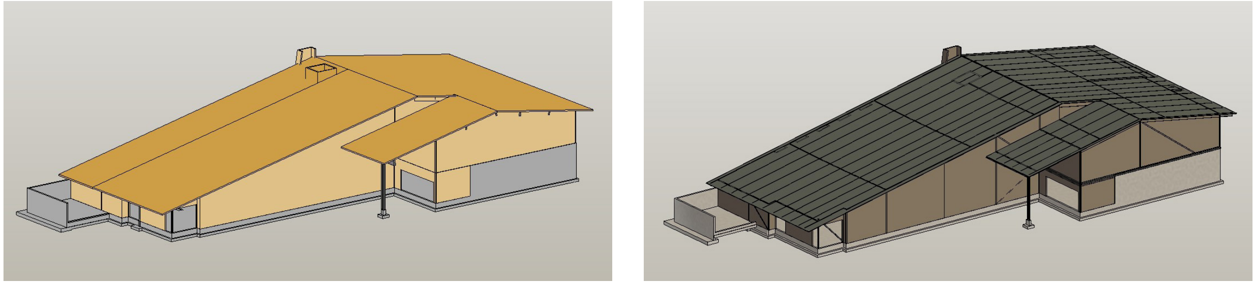


FIGURE 3: Schematic 3D images of the two alternate buildings—MT/LF hybrid (left) and steel (right)

Reference Building – Mass Timber/Light-Frame Hybrid

The MT/LF hybrid building has a total gross floor area of 18,540 ft^2 (1,722 m^2) and includes a lower level partially below grade and one partial story above grade at the main level. The lower level is mixed-use, with a café, storage, and office space, while the main level includes office space, conference rooms, open work areas, and mechanical rooms. The MT/LF structural system can generally be described as a post-and-beam framing system with locations of load bearing walls. A schematic section drawing of the reference building is shown in Figure 4.

The east portion of the building consists of a two-story open space extending from the lower level to the roof. The floor assembly for the partial main level at the west half of the structure consists of floor finishes on 3/4-in. plywood sheathing over prefabricated wood trusses, dimensional lumber joists, and wood I-joists (Figure 5). Typical floor truss depths are 18 in. and 24 in. and span to exterior and interior wood bearing walls or glulam beams, which range in size from 6-3/4 in. x 12 in. to 6-3/4 in. x 18 in. The glulam beams are supported by glulam columns, which range in size from 6-3/4 in. x 7-1/2 in. to 8-3/4 in. x 9 in. In the cavities between the floor framing, there is 6 in. of sound batt insulation. Kinetic wave hangers suspend two layers of gypsum board below the insulation with acoustic ceiling tiles suspended below the gypsum board.

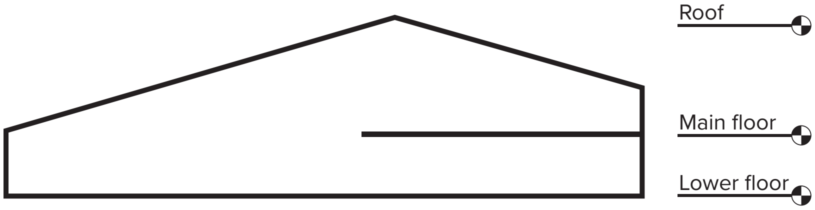
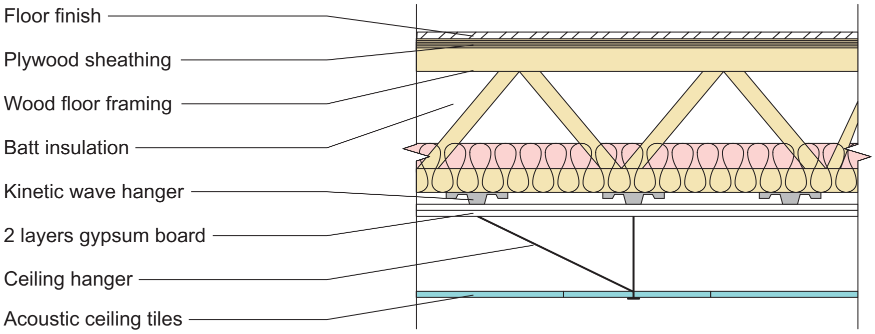


FIGURE 4: Schematic building section of Nez Perce-Clearwater office



Note: Floor finish is considered architectural finish and excluded from the LCA.
Kinetic wave hangers are excluded from the LCA due to lack of available data.

FIGURE 5: MT/LF hybrid system floor assembly

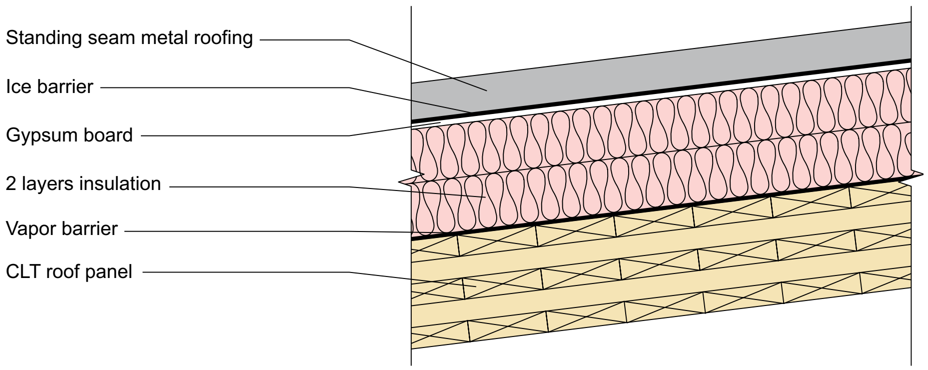


FIGURE 6: MT/LF hybrid system roof assembly

The single gabled roof consists of 4-ply[5] (5-1/2-in.-thick) and 5-ply (6-7/8-in.-thick) CLT panels spanning to glulam beams. The CLT roof panels are visually exposed at the interior and are topped with a vapor barrier, two layers (8 in. total) of insulation, gypsum board, ice barrier, and standing seam metal roofing (Figure 6). The CLT panels directly support 4,400 ft² of photovoltaic panels. Typical glulam roof beam widths are between 5-1/2 in. and 8-3/4 in., with depths ranging between 15 in. and 33 in. The glulam beams span to glulam columns, which typically vary from 5-1/2 in. to 6-3/4 in. wide by 6 in. to 9 in. deep. In the two-story space on the east side of the building, double glulam columns are utilized to maintain a consistent column size throughout.

The typical interior bearing wall assembly includes 2x framing, batt insulation in the wood stud cavities and one layer of 5/8-in. gypsum board on both faces of the wall. There is a single moveable partition wall, supported by a wide-flange steel beam and HSS steel columns, hidden within interior partition walls.

Light-frame wood bearing walls enclose the perimeter of the building, some of which are used for lateral force resistance. Steel wind girts and columns are utilized within the exterior bearing walls to frame large openings, such as the main entry and windows. The exterior bearing wall system (Figure 7) consists of several exterior finishes, including glass, wood lap siding, and engineered board and batten siding. Finishes are typically backed with a weather barrier over structural plywood sheathing on wood studs. The spaces between the studs are filled with batt insulation for thermal and acoustic control. The interior finish is 5/8-in. gypsum board.

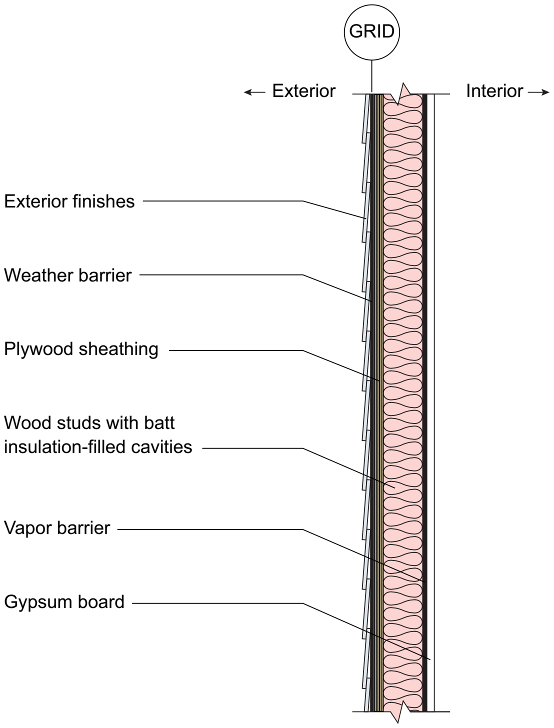


FIGURE 7: MT/LF hybrid system exterior wall assembly

The four-sided, 7-ft-5-in. x 8-ft-4-in. elevator core is comprised of 5-ply CLT walls, supported by a 12-in.-thick concrete mat slab foundation. The core supports gravity loads and is not used for lateral force resistance. It also includes steel elevator hoist beams.

The foundations consist of cast-in-place concrete foundation walls including full-height basement, retaining, and partial-height walls on spread footings. Most foundation walls are 8-in. thick, with a 12-in.-thick wall in one location. Continuous spread footings vary in size between 2-ft wide x 1-ft thick and 7-ft-6-in. wide x 1-ft-4-in. thick. Isolated footings vary in size between 3-ft x 3-ft x 1-ft thick and 7-ft x 7-ft x 1-ft-6-in. thick. The lowest level consists of slab-on-grade; most is 4-in. thick but there is a small thickened 6-in. portion.

Kamiah, Idaho is in Seismic Design Category C and the ultimate design wind speed is 105 mph. Seismic loads govern the lateral design. The lateral system is comprised of light-frame wood shear walls sheathed with wood structural panels at the building perimeter.

The structural framing for the stairs includes steel HSS stringers supporting glulam treads.

The fully sprinklered MT/LF hybrid building is Type V-B. The primary structural frame, floors, and walls (interior, exterior, and CLT cores) are allowed to have 0-hour fire-resistance ratings (FRRs), allowing the structural members to be exposed. While structural components are permitted to be visually exposed, some are not due to requirements for acoustics, insulation, and building envelope design.

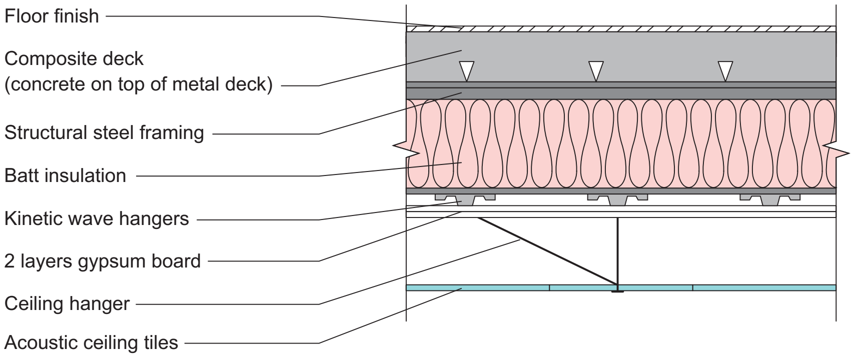
Photo Heidi Long, Longview Studios

Steel Building System

The alternate building is functionally equivalent and meets the same design criteria as the reference MT/LF hybrid building, meaning equivalent floor area, site orientation, programmatic layout, geographic location, load criteria, and performance requirements, following ISO 14044 4.2.3.7 and ASTM E2921. Although the steel system has no interior load bearing walls, it can generally be described as a post-and-beam framing system with locations of load-bearing walls, like the MT/LF system.

The floor assembly for the partial main level at the west half of the structure consists of floor finishes on 5-1/2-in.-thick composite deck comprised of 3-1/2-in. normal-weight cast-in-place concrete over a 2-in. 20-gauge steel deck (Figure 8). The deck spans to exterior load bearing cold-formed steel (CFS) bearing walls and non-composite wide-flange steel beams and girders, which are supported by HSS steel columns.

The roof is a 2-in. acoustic metal deck supported by open-web, K-series steel bar joists, wide-flange girders, exterior CFS bearing walls, and HSS steel columns (Figure 9). The steel joists support 4,400 ft^2 of photovoltaic panels. The alternate building's roof differs in terms of its acoustic and soundproofing assembly. The steel building roof assembly utilizes a 2-in. acoustic metal deck with insulation-filled cavities. On top of the deck is a vapor barrier, insulation, and gypsum board with wood slats above to isolate the standing seam metal roofing from the metal roof deck and thus reduce sound transmission. To maintain a comparable acoustic performance to the MT/LF hybrid system, the steel structure includes acoustic ceiling tiles hung from the roof framing with ceiling hangers (Figure 9).



Note: Floor finish is considered architectural finish and excluded from the LCA.
Kinetic wave hangers are excluded from the LCA due to lack of available data.

FIGURE 8: Steel system floor assembly

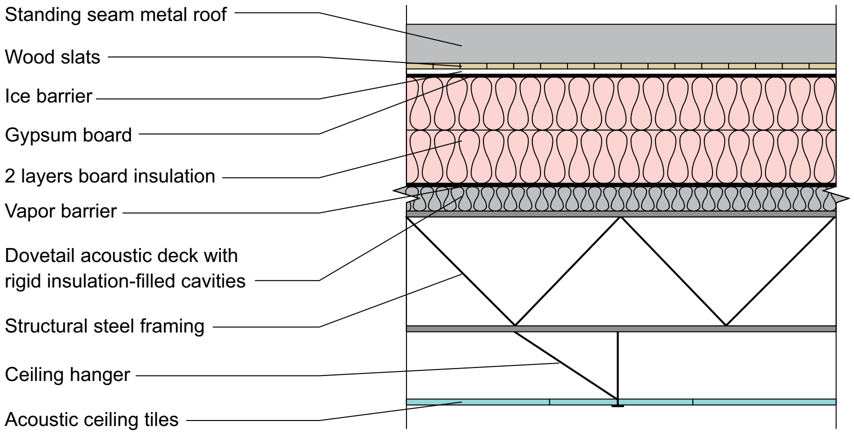


FIGURE 9: Steel system roof assembly

The interior partition wall layout is the same as the MT/LF hybrid building; however, since steel columns support the floor and roof framing of the steel building, interior load-bearing walls are not required. The structural framing that supports the moveable partition wall is the same as for the MT/LF hybrid system.

The building perimeter consists of load-bearing CFS walls. In collaboration with Mosaic Architecture, it was determined that the exterior walls required additional thermal and acoustic assembly components to maintain the functional equivalency of the light-frame wood walls used in the MT/LF hybrid system. Batt insulation is used in the metal stud cavities and a 2-in. layer of continuous mineral wool insulation is included on the exterior side of the wall (Figure 10).

The lateral system for the steel alternative consists of steel ordinary concentrically braced frames supported by concrete spread footings. The braced frames are located within the exterior walls, replacing the wood shear walls in the MT/LF hybrid system. The steel building is approximately 10% heavier than the MT/LF hybrid, with an associated increase in seismic lateral forces. To account for this increase, the elevator core is also used as part of the lateral force-resisting system. The CLT elevator core in the MT/LF hybrid is replaced with 8-in., fully grouted reinforced concrete masonry walls supported by a concrete mat foundation.

The foundation components are the same as the MT/LF hybrid system, with slight size increases due to the increased weight of the steel building, resulting in a 3% increase in concrete volume in the foundations. Some continuous and isolated footing widths increase by 6 in. to support the increased weight of the structure, and to provide lateral foundations under steel braced frames. The mat foundation under the elevator core increased in thickness by 4 in.

The stair structural framing is similar to the MT/LF hybrid system, utilizing steel HSS stringers; however, the glulam treads are replaced with steel channels filled with concrete.

The steel building, like the MT/LF hybrid building, is classified as Type V-B, which is permitted to have a 0-hour FRR. Therefore, changes to the MT/LF hybrid system assemblies related to fire resistance are not required for the steel system assemblies.

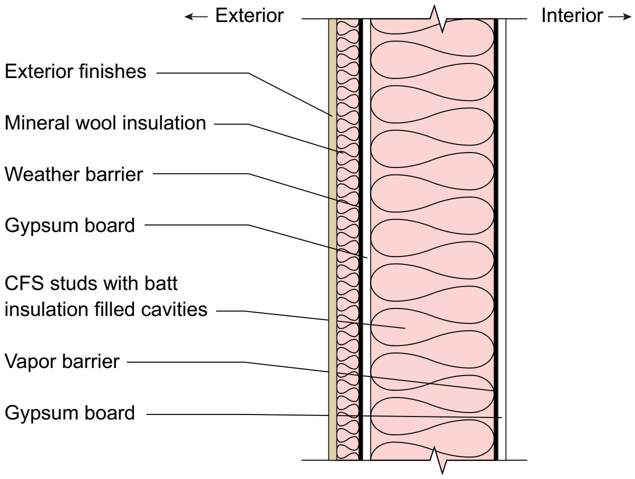


FIGURE 10: Steel system exterior wall assembly

Building Floor-to-Floor Heights

The main level floor assembly is 3-in. shallower for the steel system than the MT/LF hybrid system and the roof assemblies have equivalent thicknesses. In theory, the steel system's main level could be lowered by 3-in. while maintaining the same floor-to-ceiling height. However, because the roof assemblies have equivalent thicknesses in the two systems, the roof elevation should remain the same to maintain the floor-to-ceiling height at the open, two-story portion. Therefore, the height of all vertical components was kept the same for both building systems.

Concrete Mix Designs

Concrete is a high-embodied carbon material and its GWP often dominates a building's total GWP. A significant portion of concrete GWP is due to the cement content. GWP reductions can be achieved by substituting supplemental cementitious materials (SCM) for cement. As explained in the series introduction, TallyLCA's concrete mix design data references the 2019 National Ready Mixed Concrete Association (NRMCA) *Industry-Average Environmental Product Declaration* (EPD), plus supplemental life cycle inventory (LCI) data.

Table 1 lists the concrete mix designs' 28-day strength and SCM content for components used within the two building LCAs. The mix designs selected for this study reflect the specified 28-day strengths in the construction documents for the Nez Perce-Clearwater office; however, the SCM content (and thus cement content) deviated from the construction documents with the intention that the selected mixes be as optimistic regarding the GWP impact of concrete as could reasonably be assumed for material availability, finish-ability, and speed of construction for the particular elements.[6] The SCM was fly ash (noted as FA in Table 1).

Concrete Mix Property Assumptions	
Element	**Concrete (psi, SCM%)**
SOG	4000, 20% FA
Pilasters	5000, 20% FA
Mat Slab	5000, 20% FA
Footings	5000, 20% FA
Foundation Walls	5000, 20% FA
Slab on Metal Deck	4000, 20% FA

TABLE 1: Concrete mix design assumptions for both buildings


Photo Heidi Long, Longview Studios

Life Cycle Assessment Methodology

The methodology, approach, and code compliance of the individual life cycle assessments (LCAs) and their comparisons are detailed in the series introduction. Major methodology and assumptions are described in this section, along with variations from the general series.

Life Cycle Assessment Material Scope

The component and material scope of the LCAs includes primary structure, vertical and horizontal enclosures, fire resistance-rated assemblies (if any), acoustic assemblies, and interior ceiling finishes as they are described in the section, Comparative Building Systems; this is considered a whole building life cycle assessment. Material quantities are based on the designed quantities and do not consider the final bill of materials or construction waste estimates.

The primary structure includes substructure (foundations and slab-on-grade) and superstructure components (floors, roofs, framing, columns, bearing walls, and lateral systems). The slab-on-grade concrete and steel reinforcement quantities and resulting GWP impact are the same for the two building systems and are therefore itemized as part of the substructure as opposed to the superstructure, which varies from the series introduction. The purpose of this variation is to isolate the alternate structural systems of the superstructure and avoid dilution of their GWP impact comparison.

Reinforcing steel within concrete components is included.[7] Stair structural framing (stringers and treads) is included due to the large footprint of the stairs relative to the gross floor area. The structural framing that supports the moveable partition wall is included. Connections and accessory structural components such as elevator support, handrails, and guardrails, are excluded from the LCA. An exception to this scope is the inclusion of the suspended ceiling attachment for acoustic ceiling tiles.

The vertical enclosure includes the exterior finishes, windows and curtain wall systems, waterproofing, insulation, wall framing, plywood sheathing, and gypsum board. The horizontal enclosure includes the exterior finish, waterproofing, insulation, framing, and acoustic materials. For this study, the exterior wall wood studs and plywood sheathing in the MT/LF hybrid system are considered structural because they are necessary for the building's gravity and lateral system. In the steel system, cold-formed studs are considered structural, while all other components of the assemblies, including the exterior gypsum board, which replaces the structural plywood sheathing in the MT/LF hybrid system, are categorized as architectural.

Interior load-bearing walls in the MT/LF hybrid are included in the LCA, as are their entire assemblies. In the steel building, there are no interior bearing walls. All non-load-bearing interior partition walls are excluded from the LCA, and unrated interior partition walls are excluded from the LCAs of both buildings. Similarly, all architectural finishes (floor finishes, interior wall finishes, furnishing, paints, stains, sealers, etc.) are excluded from the LCA.

Other exclusions are site work, civil, landscape, mechanical, electrical, plumbing, and all interior furnishings. Although the photovoltaic panels are an important aspect to the sustainable qualities of the Nez Perce-Clearwater office, the LCA excludes the panel impacts due to lack of available data.

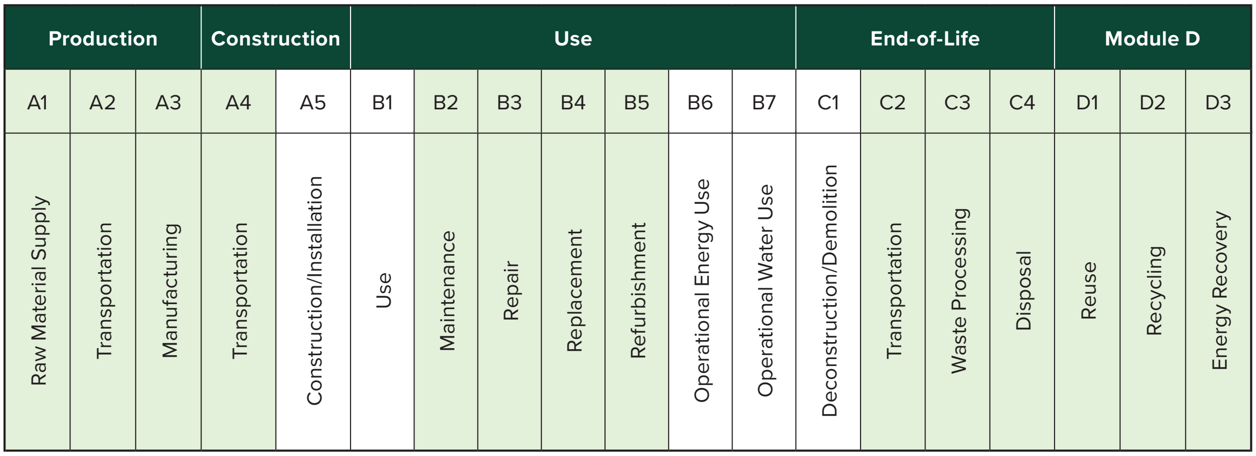
Life Cycle Assessment System Boundary

The LCA system boundary is cradle-to-grave (A-C plus D), inclusive of stages A1-A3, A4, B2-B5, C2-C4, and Module D (Figure 11). The building's service life is 75 years, representing the reference study period. The service life for all materials and components matches that of the buildings, except roof enclosure finishes and windows, which are assigned a 40-year service life.

Concrete carbonation is excluded.

Biogenic carbon is included. The methodology in TallyLCA dictates the end-of-life mix allocation assumptions. See the series introduction for more details.

Life Cycle Stages:
Cradle-to-Grave + Module D



Production			Construction		Use							End-of-Life				Module D		
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D1	D2	D3
Raw Material Supply	Transportation	Manufacturing	Transportation	Construction/Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	Deconstruction/Demolition	Transportation	Waste Processing	Disposal	Reuse	Recycling	Energy Recovery

Note that the stages and information modules shown here deviate slightly from the naming convention used in ISO 21930 (ISO, 2017). However, this series generally uses terminology consistent with ISO 21930.

FIGURE 11: LCA life cycle stages; scope inclusions in light green

Life Cycle Assessment Data Methodology

For the LCA data methodology, assumptions, data uncertainty, software limitations, and end-of-life methodology, reference the series introduction. The Supplemental Life Cycle Assessment Results section of this report addresses the data limitations identified for glulam and CLT within TallyLCA. See the Appendix for specific material quantities and EPD and LCI data selections used to perform the individual LCAs.

Comparative Results and Discussion

The LCA, cost, and speed of construction results of the building study are described in this section. The LCA results focus on GWP, measured in kilograms of carbon dioxide equivalent (kgCO$_2$eq). The results are presented in terms of kgCO$_2$eq/m^2 (kgCO$_2$eq/ft^2) based on the gross floor area of the building, which is the industry standard.

Life Cycle Assessment Results

Table 2 summarizes the WBLCA results, providing the GWP impact of the total building, isolating superstructure and substructure, and breaking each down by structural and architectural component impacts.

“Total building” refers to all building components, including the substructure and superstructure. Overall, when considering the total GWP impact of the building, including architectural and structural systems, the MT/LF hybrid building GWP is 43% less than the steel building (Figure 12). Figure 13 provides further detail on the total GWP impacts by reporting the contributions of each material category and the breakdown between structural and architectural components for each building.

GWP Summary Table								
	Total Building			**Superstructure**			**Substructure**	
	Total	Structure	Architecture	Total	Structure	Architecture	Total	Structure
MT/LF Hybrid kgCO$_2$eq	273,870	156,863	117,008	88,152	-28,855	117,008	185,718	185,718
Steel kgCO$_2$eq	476,371	351,711	124,659	284,918	160,259	124,659	191,452	191,452
MT/LF Hybrid kgCO$_2$eq/m^2 (kgCO$_2$eq/ft^2)	159 (15)	91 (8)	68 (6)	51 (5)	-17 (-2)	68 (6)	108 (10)	108 (10)
Steel kgCO$_2$eq/m^2 (kgCO$_2$eq/ft^2)	277 (26)	204 (19)	72 (7)	165 (15)	93 (9)	72 (7)	111 (10)	111 (10)

TABLE 2: Summary of GWP of the total building, superstructure, and substructure with contributions from structural and architectural systems

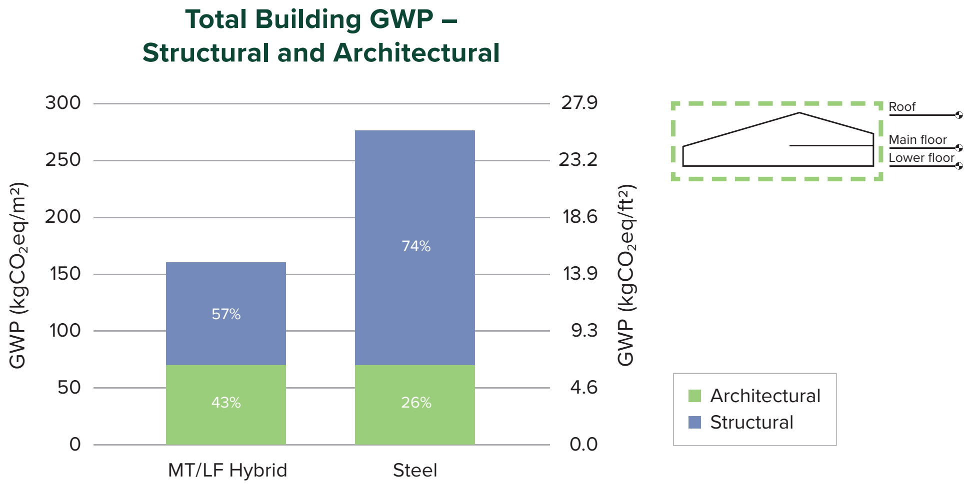


FIGURE 12: Total building GWP (structure and architecture) comparison of both buildings

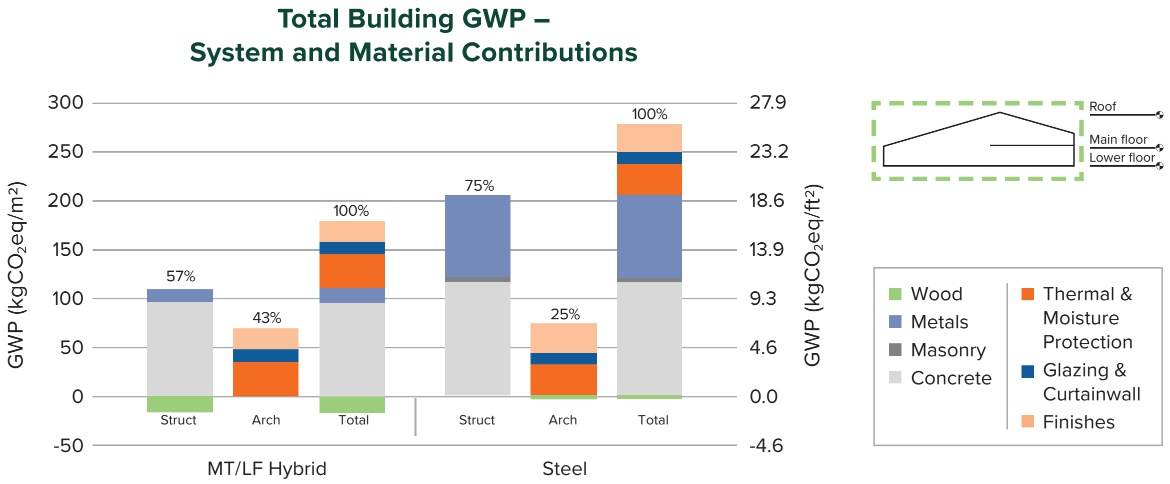


FIGURE 13: Total building GWP comparison of the buildings by structural and architectural components and their material contributions

Isolating the structural components, the MT/LF hybrid system has 55% less GWP than the steel system. This is largely due to the wood and mass timber components compared to steel components. The wood and mass timber components contribute a net negative impact due to their stored biogenic carbon, offsetting their positive GWP impact. Structural wood components are not present in the steel structural system; however, there are wood slats in the architectural roof assembly and both buildings have wood siding.

The concrete material is a significant contributor to the GWP impact of both buildings. One reason is the high GWP intensity of concrete. Another is that concrete substructure (foundation and slab-on-grade) components make up 80% of the total building material quantities by mass in the MT/LF hybrid building and 38% in the steel building. The MT/LF hybrid building has 26% less concrete compared to the steel building due to the steel building's increase in foundation sizes and concrete in the main level floor assembly. While floor systems in wood-frame buildings can include a concrete topping slab, the MT/LF hybrid building does not, which is noteworthy for the embodied carbon impact.

It is helpful to separate the LCA results of the superstructure and substructure because the concrete in the substructure has an overwhelming impact on material volumes and GWP. "Substructure" as defined here refers to the foundation system and slab-on-grade. "Superstructure" refers to all other components (Figure 14).

Figure 15 illustrates the superstructure's total GWP impact (structure and architecture) and material contributions for both systems. The MT/LF hybrid system's superstructure has 69% less GWP compared to the steel system.

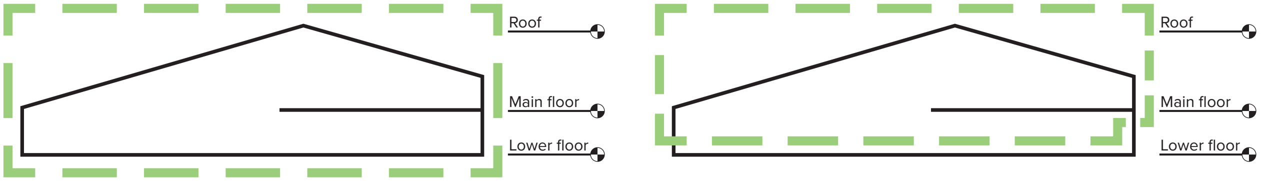


FIGURE 14: Schematic sections defining the meaning of "total building" (substructure and superstructure) (left) and "superstructure" (right)

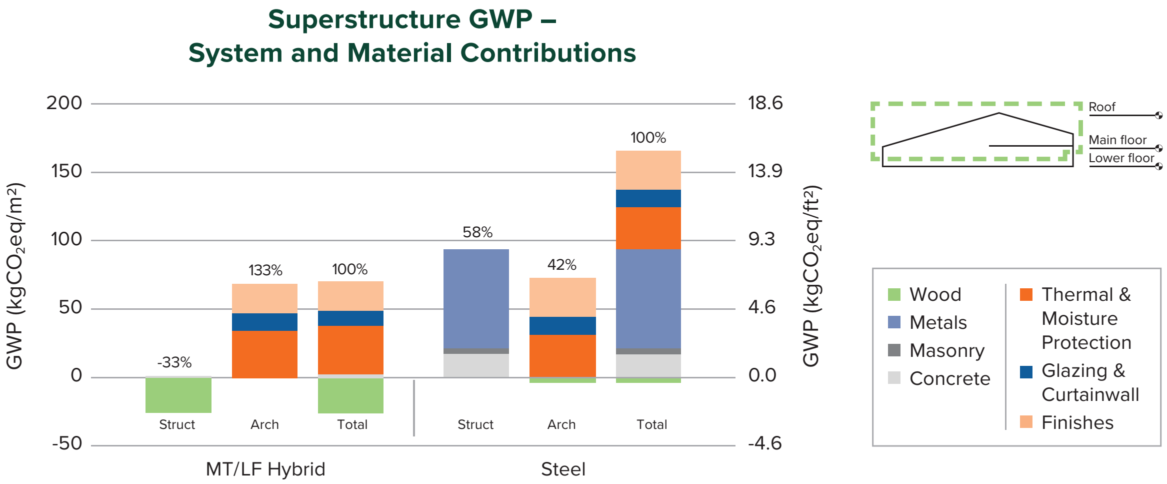


FIGURE 15: Superstructure GWP comparison of the systems by structural and architectural components and their material contributions

Figure 16 isolates the structural component GWP impact of the two superstructure systems. When considering only the structural components, the MT/LF hybrid system's superstructure has 118% less GWP than the steel system. The wood components (light-frame and mass timber) contribute a net negative impact due to their stored biogenic carbon, resulting in a net -17 $kgCO_2eq/m^2$ impact for the system.

Figure 17 illustrates the relative percentages of each structural material's mass compared to its relative GWP contribution for both superstructure systems. For the MT/LF hybrid system, wood dominates the mass, while steel dominates the GWP. The contribution of metals in the MT/LF system is attributed to the steel wind girts, movable partition wall support, and elevator hoist beams. The wood material's GWP contribution in the MT/LF system is net negative and therefore does not show as a contributor to the superstructure's GWP. Steel contributes the most to both the mass (55%) and GWP (76%) of the steel system, with concrete contributing 36% of the mass and 19% of the GWP, and masonry contributing 9% of the mass and 4% of the GWP.

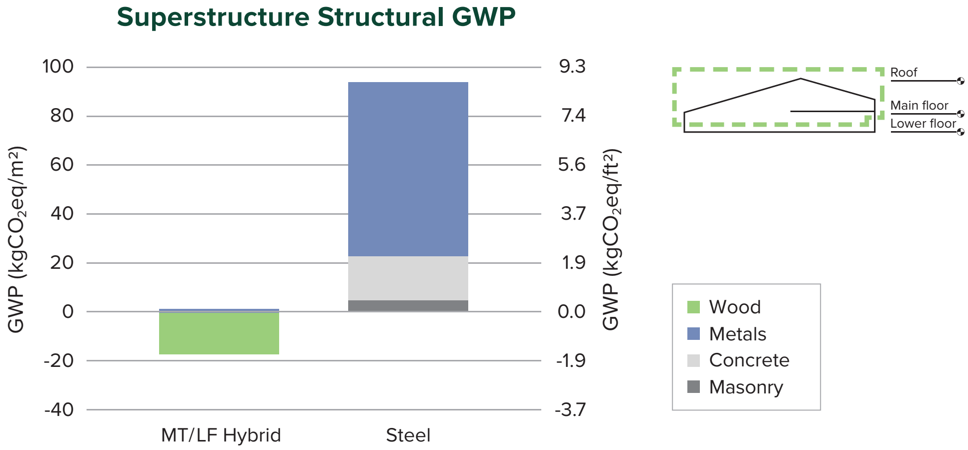


FIGURE 16: Superstructure structural GWP comparison of the two systems and material contributions

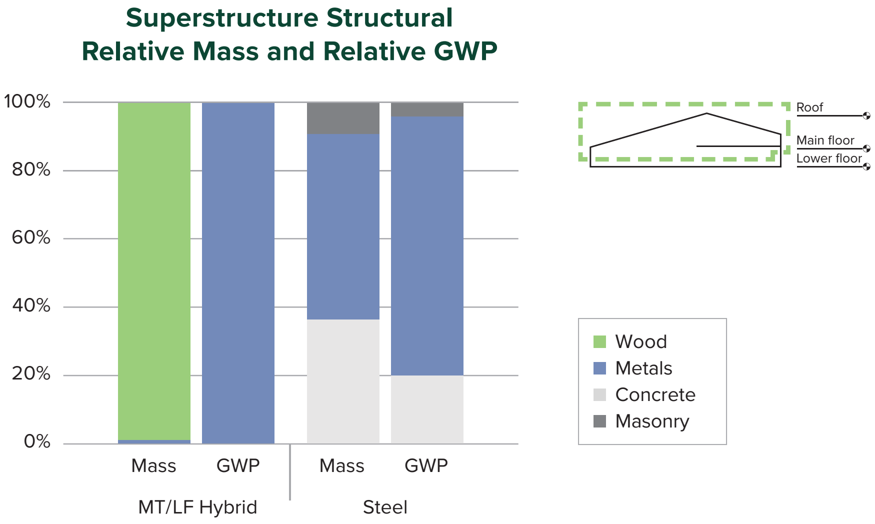


FIGURE 17: Superstructure structural GWP comparison of the systems and material contributions

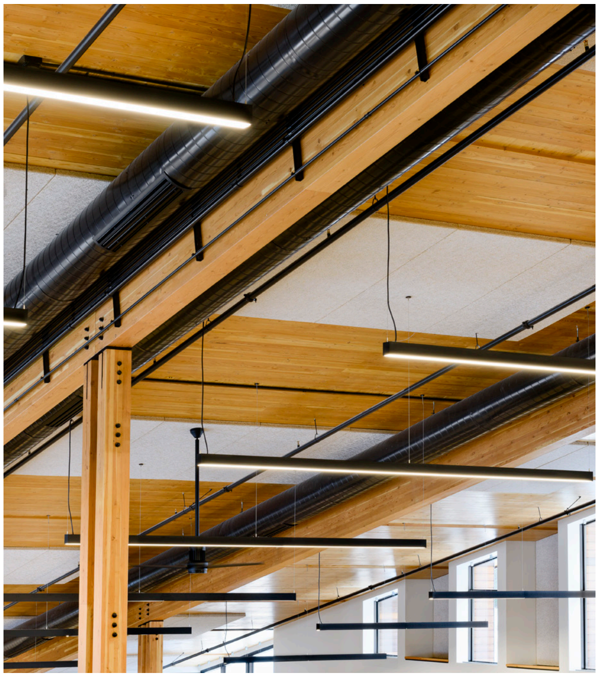


Photo Heidi Long, Longview Studios

Figure 18 shows the GWP impact of the architectural components for the superstructure, separated into four categories: vertical enclosure, horizontal enclosure, interior walls, and ceilings. The GWP impact of the architectural components of the MT/LF hybrid system is 6% less than the steel system, mainly due to the impacts of the additional materials in the vertical and horizontal enclosures. The GWP impact of the MT/LF hybrid system's vertical enclosure is 6% less than the steel system. The steel system's exterior wall assemblies include additional insulation. The steel system's exterior walls also include a layer of architectural gypsum board versus the MT/LF system's layer of structural plywood sheathing (and are categorized as such). The GWP impact of the MT/LF hybrid system's horizontal enclosure is 10% less than the steel system. The steel system's roof assembly utilizes insulation-filled cavities in the metal deck and acoustic panels hung from steel framing to achieve the same acoustic performance as the MT/LF system, increasing the system's GWP. The MT/LF hybrid system has a minimal GWP impact attributed to insulation and gypsum board at the interior load-bearing walls, while the steel system has no interior bearing walls and therefore no GWP impact. Note that in the MT/LF hybrid system, the interior wall wood stud framing is included in the structural impacts. The GWP impact of the ceiling systems is 10% less for the MT/LF hybrid versus steel. This is due to the addition of dropped ceilings at the steel system's roof assembly.

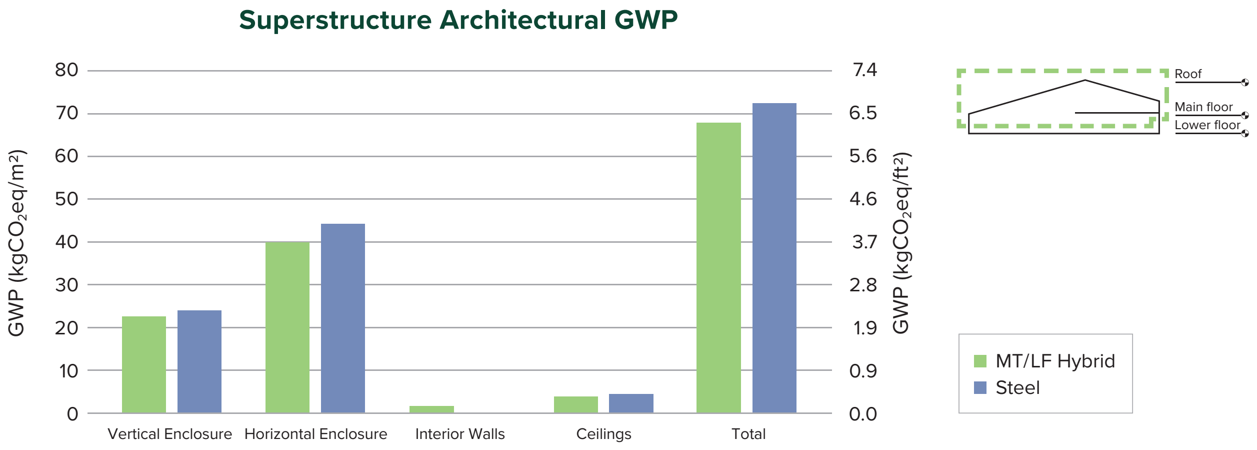


FIGURE 18: Superstructure architectural GWP comparison of the systems by use category

The substructure (foundation and slab-on-grade) GWP impacts are similar for the two systems (Figure 19). The steel system substructure has a roughly 3% greater GWP, which correlates to an increase in size and thickness of some foundation components compared to the MT/LF hybrid foundations.

Figure 20 illustrates the life cycle stage contributions to the total building GWP. The dominant stage for embodied carbon in both buildings is the Production Stage (A1-A3). While the MT/LF hybrid building appears to have a near net zero A1-A3 impact, the value includes the negative GWP effects of stored biogenic carbon entering the system, offsetting most of the positive GWP impacts.

Transportation (A4) has a minimal impact on both buildings. The transportation distances are typically set to TallyLCA's default distance, based on U.S. averages. However, for the CLT and glulam in the reference building, the LCA considered the 275-mile (443 km) distance from the supplier, SmartLam in Columbia Falls, Montana, to Kamiah, Idaho. The total A4 transportation impact of the MT/LF hybrid system is equivalent to only 3% of the stored biogenic carbon within the mass timber material (CLT and glulam). The A4 transportation impact is also equivalent to only 3% of the total A-D impact of the MT/LF building and 1% of the steel building. This is due to the relatively short travel distance and illustrates that transportation impacts are much less significant than the carbon storage impact of wood materials.

The Use Stage (B2-B5) has minimal impact as only the roof finishes and windows are assumed to be replaced at 40 years, before the end of the building's service life. The steel and MT/LF buildings have identical B2-B5 impacts because the roof finishes and windows are the same.

The End-of-Life Stage (C2-C4) has a greater impact on the MT/LF hybrid building due to the release of stored biogenic carbon from the mass timber and wood products. The LCA assumes 31.75% of the biogenic carbon is permanently stored. Reference the series introduction for a description of TallyLCA's end-of-life assumptions and mix allocation.

Finally, Module D has a net negative impact for both building systems. For both designs, this is primarily due to the recyclability of steel material, crediting the system for recycling their respective portions of net scrap.

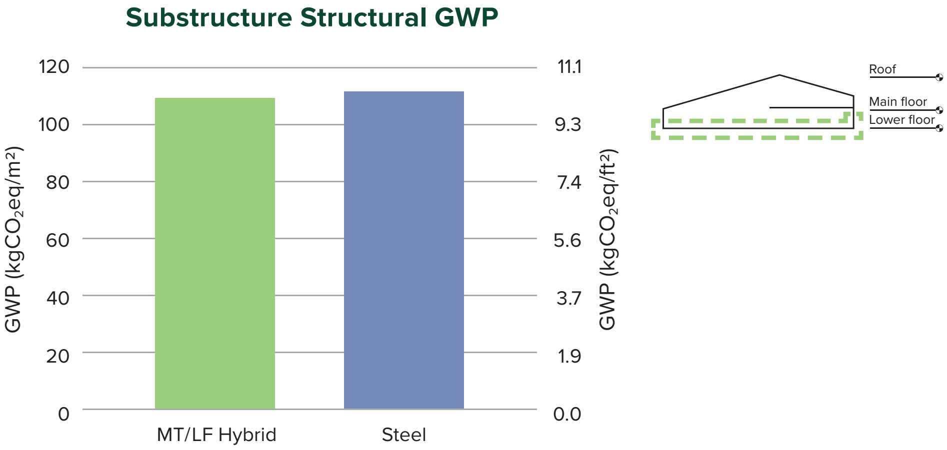


FIGURE 19: Substructure structural GWP comparison of the systems

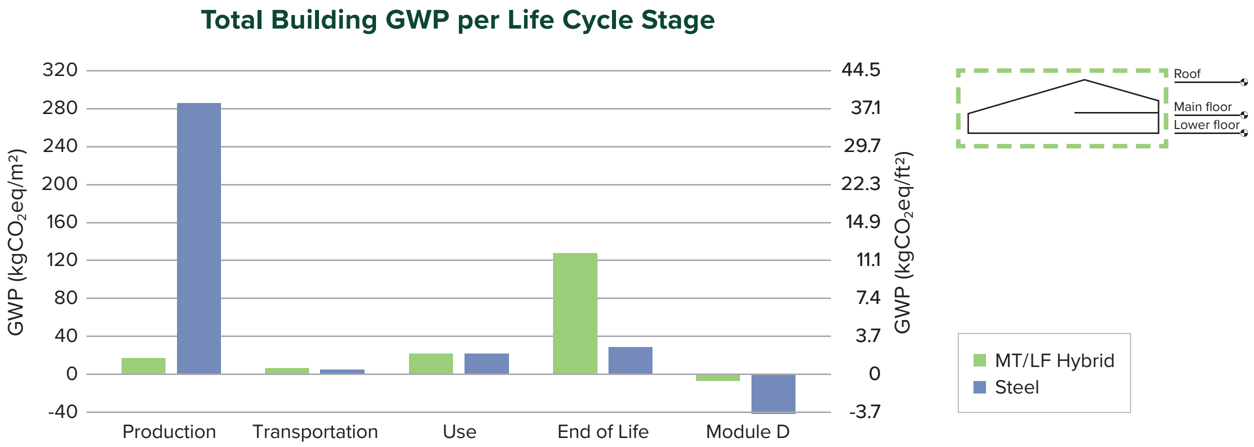


FIGURE 20: Total building GWP per life cycle stage comparison of the buildings

Photo Morrison-Maierle

Module D is considered outside of a building's system boundary (A-C) and its benefits and burdens ultimately belong to the next system, such as another building or physical product. However, TallyLCA does not allow the proper exclusion of Module D from the analysis. Therefore, as discussed in the series introduction, Module D is included for all materials in this report.

The steel building system receives the largest relative benefit by the inclusion of Module D, due to the high amount of steel material and assumption that 98% of steel is recycled and the net scrap is credited as avoided burden. This means that the more virgin material used to manufacture the product (Stage A1-A3), the greater the benefits (credits) to the material in Module D, as is the case for HSS, metal deck, and CFS studs (Figure 21). If the percentage of recycled content of the product exceeds the percent allocated to recycling at end-of-life, the product will have a net burden in Module D. This is the case with wide-flange and steel reinforcement. Although the composite metal deck has a negative GWP contribution for Module D, it presents a challenge for end-of-life recovery and recycling when interlocked with concrete material. Reinforcing bars, which already have a positive GWP contribution for Module D due to their high recycled content, present the same challenge.

Figure 21 illustrates the life cycle stage percentage contribution of the major materials in this study. Stage A1-A3 dominates the GWP contribution of all materials. Materials with a replacement period in Stage B have nearly equal impacts in Stage A and Stage B.

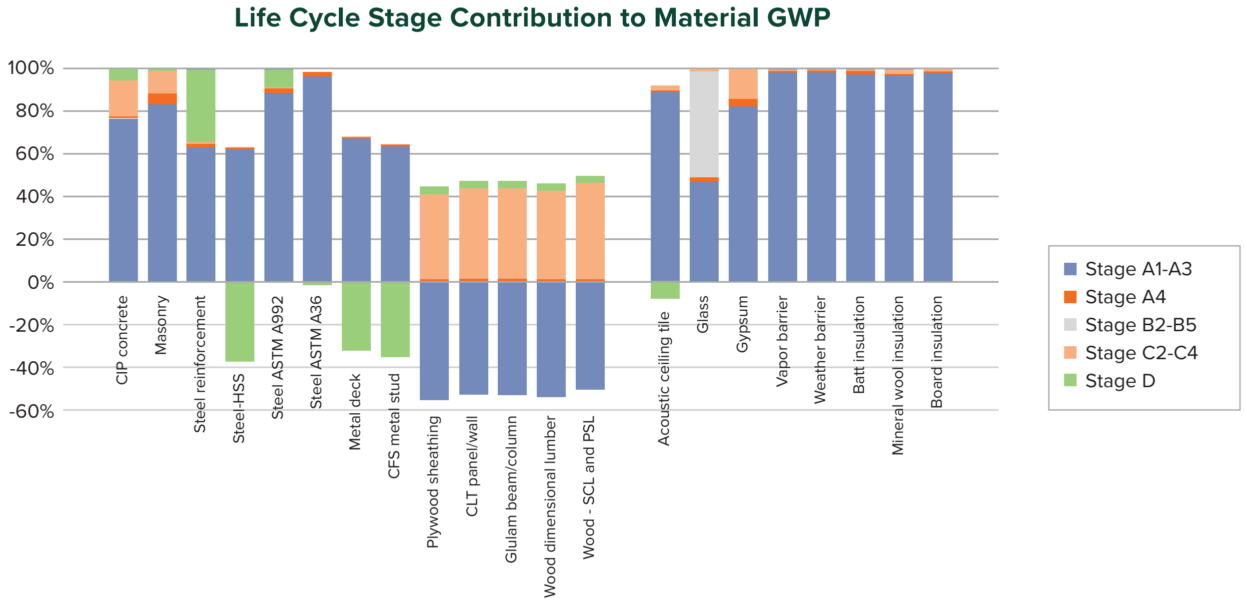


FIGURE 21: Life cycle stage GWP contributions per material

Assumptions regarding the wood products' end-of-life disposition are an important consideration for biogenic carbon and any potential embodied carbon advantages. The LCA results in this building study are based on TallyLCA's end-of-life mix allocation assumptions, which presume that the majority of the biogenic carbon is released back into the atmosphere via incineration or decomposition at landfill, while 31.75% is permanently stored (Feitel & Kingsley, 2024).

To illustrate the biogenic carbon content of the MT/LF hybrid system, Figure 22 shows the stored biogenic carbon of each wood product (at Stage A1-A3). The combined total stored biogenic carbon is -127 $kgCO_2/m^2$ for only the mass timber components (CLT and glulam). This negative GWP impact is significant when compared to the total GWP impacts of 159 $kgCO_2eq/m^2$ for the MT/LF hybrid system and 277 $kgCO_2eq/m^2$ for the steel system. The best-case scenario at end-of-life is that the mass timber and wood material store all the biogenic carbon content indefinitely, through deconstruction, recovery, and direct reuse, or the building service life reaches 100 years, at which point the biogenic carbon is considered to be permanently stored (Biotechnology Innovation Organization, n.d.).

GWP is the impact category discussed primarily in this study as it represents all greenhouse gas (GHG) emissions in proportion to their relative influence in creating the conditions for global temperature rise. GHG emission impacts "can be reported with clarity, as they have a high degree of global agreement on reporting methods [...] The emissions of GHGs anywhere in the world results in the same global impact on climate change" (Simonen, 2014). In contrast, the effects and risks of other environmental impacts are locally and regionally dependent. Table 3 shows all impact categories calculated in the LCAs. This study's results show that the MT/LF hybrid system has a lesser impact on GWP, smog formation potential, primary energy demand, and non-renewable energy demand, but the steel system has a lesser impact in the other four categories.

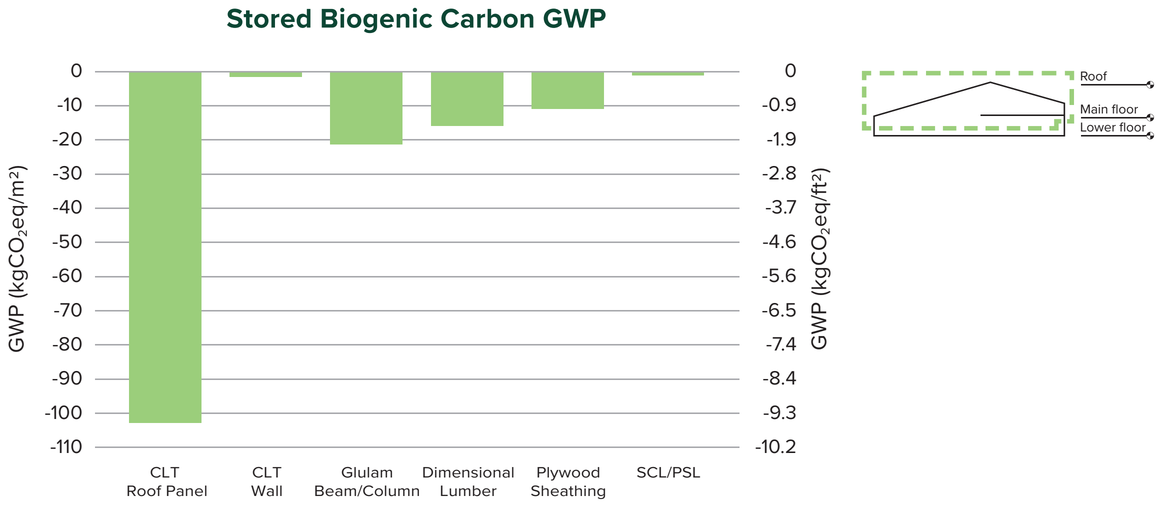


FIGURE 22: Stored biogenic carbon GWP of the MT-LF hybrid building

Environmental Impact Categories					
Impact Category	**Unit**	**Mass Timber**		**Steel**	
Acidification Potential	$kgSO_2eq/m^2$	1.23E+00	100%	1.49E-01	12%
Eutrophication Potential	$kgNeq/m^2$	1.15E+01	100%	7.21E-02	6%
Global Warming Potential	$kgCO_2eq/m^2$	1.59E+02	100%	2.77E+02	174%
Ozone Depletion Potential	$CFC\text{-}11eq/m^2$	5.65E-06	100%	2.96E-06	52%
Smog Formation Potential	kgO_3eq/m^2	1.56E+01	100%	1.72E+01	110%
Primary Energy Demand	MJ/m^2	3.65E+03	100%	3.79E+03	104%
Nonrenewable Energy Demand	MJ/m^2	2.56E+03	100%	3.46E+03	135%
Renewable Energy Demand	MJ/m^2	1.10E+03	100%	3.26E+02	30%

TABLE 3: Total Stages A-C plus Module D environmental impact categories for both buildings

Supplemental Life Cycle Assessment Results

As discussed in the series introduction, the results of the two LCAs are dependent on the data available within the TallyLCA database and its methodology at the time of analysis. The purpose of this section is to compare some of TallyLCA's data with currently available industry information and discuss the potential effects on the comparative LCA results.

Glued-Laminated Timber (Glulam)

Glulam data within TallyLCA is based on the American Wood Council and Canadian Wood Council's (AWC/CWC's) 2013 *Industry-Average EPD for Glued-Laminated Timbers*, which expired in 2019 and was selected to represent all glulam within the MT/LF hybrid building LCA as described in the series introduction. The current EPD version, issued in 2020, was not available within TallyLCA at the time of this analysis.[8]

The 2020 glulam EPD has roughly 30% less A1-A3 GWP impact compared to TallyLCA and the 2013 EPD. Based on current industry average data, TallyLCA overestimates the GWP impact of the glulam material. If the TallyLCA A1-A3 GWP data is replaced with the 2020 AWC EPD data, the GWP impact of the glulam beams and columns would decrease by 2,367 $kgCO_2eq$ in the MT/LF hybrid system. This would result in a negligible 0.8% reduction of the superstructure structural cradle-to-grave (A-C plus D) GWP, and a 0.6% reduction of the total building cradle-to-grave (A-C plus D) GWP impact.

Cross-Laminated Timber (CLT)

SmartLam North America's Columbia Falls, Montana plant was the CLT manufacturer for this building. Their 2021 *Environmental Product Declaration Cross-Laminated Timber (CLT)* has a roughly 2% lower A1-A3 GWP impact than the CLT data in TallyLCA. This translates to a 0.2% reduction in the structural cradle-to-grave (A-C plus D) GWP impact and a 0.1% reduction in total building cradle-to-grave (A-C plus D) GWP of the MT/LF hybrid building.

Cost and Speed of Construction Results

This building study focuses primarily on WBLCA and embodied carbon impact implications of design choices. Obviously, building material and system selections also have costs in terms of dollars and time. This section endeavors to answer the question: *What is the dollar cost of lower embodied carbon systems and material choices?*

This cost study is based on the Nez Perce-Clearwater office reference building compared to a functionally equivalent steel alternative. The construction costs of the MT/LF hybrid building were provided by the General Contractor, Quality Contractors LLC, based on actual costs at the time of construction in 2021.[9] KL&A's independent construction management (CM) group prepared a construction cost estimate for the steel building system described in this study, normalized to regional 2021 costs for material and labor. The steel cost estimate referenced Quality Contractors' original estimate for concrete and steel unit prices to provide a more accurate historical comparison.

The comparative cost analysis performed for this study includes all substructure, superstructure, architectural, and structural components as described in the previous sections, plus all other building components, such as site work, MEP, and interior finish components.

It is typical for the initial pricing of MT/LF hybrid systems to show a dollar cost premium over conventional systems, and this building was no different. The total structural raw material cost is less expensive for the steel system, resulting in an 8% premium for the MT/LF hybrid system.

While there might be greater schedule savings on larger, multi-story structures with more repetition, there were still schedule savings on this project that helped bring down the overall cost of the MT/LF hybrid system. KL&A's CM group estimated that the superstructure, excluding foundations, of a steel system would take 65 days to erect compared to 48 days for an MT/LF hybrid system, a 26% time savings. The dollar cost analysis took the schedule reduction into account by considering general conditions (labor), general requirements (equipment and waste), crane costs, site logistics, and costs associated with variations in finishes, such as gypsum covering and acoustic panels, and is termed "total structure construction." With these compounding considerations, the steel system is still less expensive. However, the cost premium of the MT/LF hybrid system is reduced from 7.7% to 5.4%. When considering the "whole building construction cost"[10] the wood premium drops further, to just 2.7% over steel. These relative cost comparisons and premiums are illustrated in Figure 23.

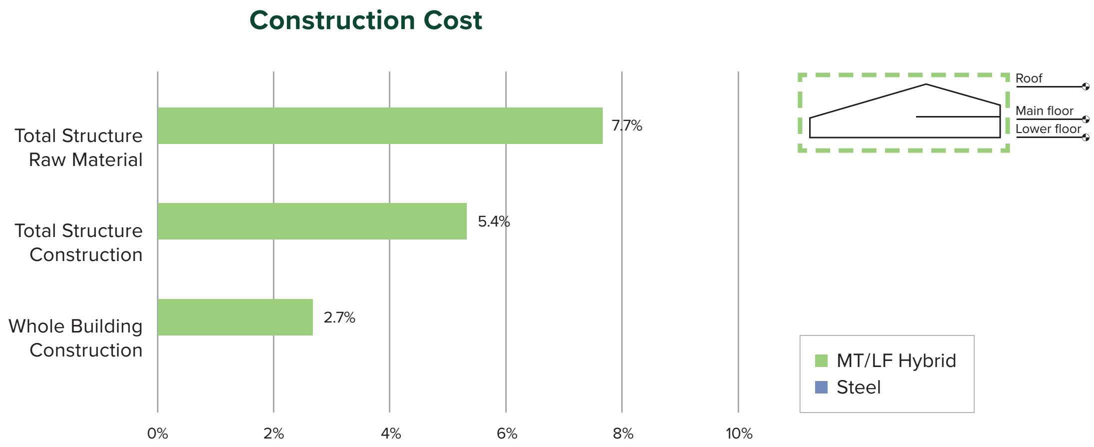


FIGURE 23: Construction cost premiums of both building systems, relative to the steel building cost (illustrating progression of the cost analysis)

Photo Heidi Long, Longview Studios

Conclusion

This comparative building study endeavors to answer the questions: *How does mass timber compare to traditional structural systems? Is mass timber more sustainable? What are the associated dollar cost premiums?*

The LCA and dollar cost results presented in this building study illustrate that an MT/LF hybrid system, for a building of this construction type and occupancy, can have significant embodied carbon savings with a small total cost premium, along with construction schedule benefits, when compared to a functionally equivalent conventional structural steel system (Figure 24).

Specifically:

- Considering the buildings' total GWP impact, the MT/LF hybrid system GWP is 43% less than the steel system.
- Considering only the structural components, the MT/LF hybrid system GWP is 55% less than the steel system.
- Considering only the superstructure (structure and architecture), the MT/LF hybrid system's GWP is 69% less than the steel system.
- Excluding foundations, the MT/LF hybrid superstructure can be erected 26% faster than the steel superstructure.
- Material pricing showed a dollar cost premium of 7.7% for the MT/LF hybrid system. However, when considering the whole building construction cost, including schedule savings, the wood premium drops to 2.7%.

Despite clear material cost premiums, relative mass timber costs are reduced when considering impacts to the construction schedule and architectural assemblies added to the steel building for thermal, moisture, and acoustic performance. Economical solutions are achievable with thoughtful design, material optimization, designing for constructability, and thorough, holistic cost-estimating that includes schedule and labor savings as a real component of construction cost.

The Nez Perce-Clearwater office building was included in this building study series to represent a smaller building designed specifically to be economical, efficient, and sustainable. The dollar cost for the MT/LF hybrid building was shown to be moderately greater than the alternate design, but the embodied carbon cost of the MT/LF hybrid building is considerably less.

The building industry has a significant opportunity and responsibility to address climate change and environmental impacts due to its outsized global greenhouse gas emissions impact. This study explores a mass timber and light-frame wood structural system as one potential embodied carbon reduction strategy, due to the materials' relatively low manufacturing GWP impacts and natural ability to store biogenic carbon. However, the building design and construction industry will also need to consider bolder, innovative, multifaceted reduction opportunities for all systems, including both design and material strategies. The implementation of an MT/LF hybrid system should be considered as a viable approach to minimizing a building's embodied carbon impact with the understanding that a building's life expectancy, material sourcing,[3] and end-of-life pathways[4] also influence cradle-to-grave results.

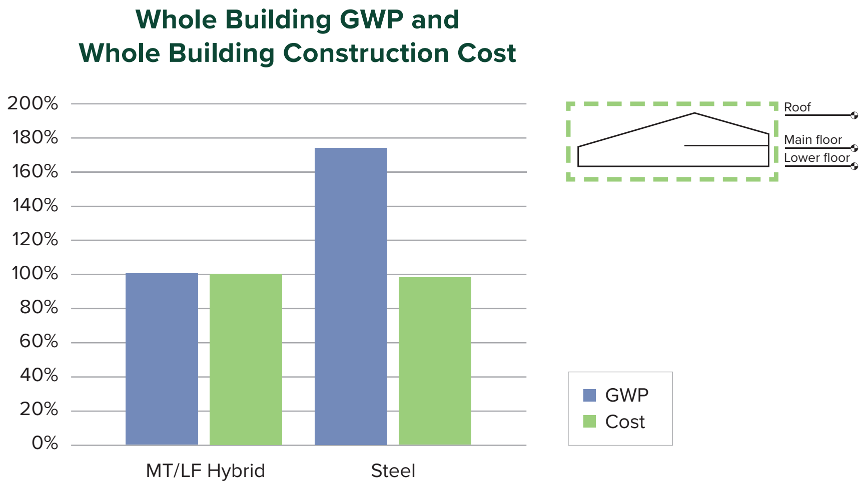


FIGURE 24: Total building GWP (structure and architecture, including the enclosure, fire resistance-rated assemblies, acoustic assemblies, and interior ceiling finishes) and whole building construction cost comparison of the building systems, normalized to the GWP and cost of the MT/LF hybrid system

End Notes

1. Functionally equivalent means the same design criteria as the reference system—i.e., equivalent floor area, site orientation, occupancy, general programmatic layout, geographic location, load criteria, and performance requirements, in accordance with ISO 14044 4.2.3.7 and ASTM E2921.
2. For more information on biogenic carbon, see the *Mass Timber Comparative Life Cycle Assessment Series Introduction* (Feitel & Kingsley, 2024).
3. Wood products sourced from North American forests meet the definition of sustainable sourcing per ISO 21930 Section 7.2.1.1. For more information, see the *Mass Timber Comparative Life Cycle Assessment Series Introduction*.
4. End-of-life considerations are included in the cradle-to-grave LCA results and are based on TallyLCA's end-of-life allocation assumptions, as described in the *Mass Timber Comparative Life Cycle Assessment Series Introduction*.
5. In some portions of the roof assembly, a 4-ply CLT layup consisting of two interior minor direction laminations was used to achieve the necessary spans.
6. The construction documents originally specified that fly ash be used as a cement replacement. However, during construction, mix designs containing fly ash were not utilized, reportedly due to cost premiums in the Kamiah, Idaho market at the time of construction. Therefore, the embodied carbon impact of the concrete in this report is less than it was for the actual building. The 20% SCM cement replacement for all concrete components in the LCA analysis was selected to balance the local conditions with a desire to be fair and optimistic about the GWP impact of concrete.
7. Primary concrete reinforcing steel is included, such as typical and additional reinforcement in slabs, walls, and footings, and vertical bars and ties in pilasters. Secondary reinforcing steel such as lap splices, dowels, connections, drag bars, and corner detailing are excluded.
8. After the LCA's were performed for this building study, TallyLCA added the AWC/CWC 2020 *Environmental Product Declaration North American Glued Laminated Timber* to its database.
9. The reported construction costs do not include the costs associated with the lower embodied carbon concrete mix designs for either building system, as described in the section, Concrete Mix Designs.
10. Whole building construction cost includes the material and installation of the foundation substructure, floor, and roof superstructure, all architectural, mechanical, electrical, plumbing, and civil costs, as well as schedule-related costs like general conditions, labor, equipment, waste, and site logistics. As noted in the series introduction, costs such as developer liability insurance premiums and financial benefits or losses to the developer associated with the time-value of money or any market value sale of the building are omitted.

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Appendix

TallyLCA® Data Selection[1]	Total Mass (kg)	
	MT/LF Hybrid	Steel
Acoustic ceiling tile (ACT), mineral fiber board	2,736.56	9,964.04
Adhesive, acrylic	1,283.06	760.94
Adhesive, polychloroprene (neoprene)	267.84	0
Aluminum curtain wall system, YKK AP - EPD	1,021.86	1,021.86
Aluminum suncontrol system, YKK AP, ThermaShade - EPD	214.68	214.68
Aluminum window wall system, YKK AP - EPD	527.12	527.12
CLT (Cross laminated timber)	107,029.49	0
Coated steel deck, SDI - EPD	0	17,984.93
Cold formed structural steel	0	36,343.45
Composite wood I-joist, AWC - EPD	64.59	0
Concrete masonry unit (CMU), hollow-core	0	17,106.55
Contruction steel, light structural shapes, CMC - EPD	0	4,961.44
Domestic softwood, US, AWC - EPD	21,213.77	5,629.17
EPDM, non-reinforced membrane, 60 mils, SPRI - EPD	5,703.37	2,253.43
Exterior grade plywood, US	10,940.84	0
Fasteners, galvanized steel	373.70	792.86
Fasteners, stainless steel	222.90	423.78
Fluid applied elastomeric air barrier	0	490.62
Galvanized steel support	2,343.58	4,687.17
Glass wool unfaced batt, Knauf, EcoBatt - EPD	1,399.50	1,399.50
Glazing, double, insulated (air)	9,326.42	9,326.42
Glue laminated timber (Glulam), AWC - EPD	20,754.09	0
Hot rolled structural steel, AISC - EPD	368.34	30,363.71
Mineral wool, low density, NAIMA - EPD	0	1,368.05
Mortar type N	0	2,181.02
Parallel strand lumber (PSL)	1,657.47	0
Polyethelene sheet vapor barrier (HDPE)	1,077.47	1,851.79
Polyisocyanurate (PIR), board	9,948.75	9,948.75
Softwood veneer	0	4,045.75
Steel joist, SJI - EPD	0	6,288.18
Steel tube, Bull Moose Tube - EPD	2,087.40	16,799.99
Steel, concrete reinforcing steel, CMC - EPD	14,492.41	16,304.53
Steel, sheet	13,391.91	13,391.91
Structural concrete, 4000 psi, 20% fly ash	266,404.13	413,424.50
Structural concrete, 5000 psi, 20% fly ash	436,423.90	455,512.42
Suspended grid	581.58	2,117.59
Thickset mortar	0	18,472.12
Wall board, gypsum, fire-resistant (Type X)	38,039.33	51,147.13
Wall board, gypsum, natural	25,295.70	25,295.70
Window frame, wood, fixed	1,085.57	1,085.57

1. The TallyLCA® Data Selection name reported is the TallyLCA® formal data entry terminology and represents the LCI and EPD data set for a given product type and specification

Photo Gabe French

WW-LCA-03 – Nez Perce-Clearwater Office Comparative Life Cycle Assessment Study

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