North American Hybrid Steel and Mass Timber Structural Systems – Design and Construction Considerations

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Table of Contents

Executive Summary

The purpose of this report is to provide project stakeholders (developers, contractors, architects, engineers and other construction professionals) with a background on the critical items which should be considered when comparing, evaluating or selecting a hybrid steel and mass timber structural system verses typical steel construction. These items include building code fire resistance requirements, acoustic performance, vibration performance, embodied carbon comparisons, costs and construction advantages of these systems.

For this report a hybrid system consists of a steel framing system, with a Cross Laminated Timber (CLT) panel spanning the secondary framing supports and the appropriate concrete topping. Although Dowel Laminated Timber (DLT) and Glued-Laminated Timber (GLT) are not specifically addressed in this report, similar considerations should be made with these products. This type of hybrid system allows for many of the advantages of mass timber buildings while providing for larger clear spans. These advantages include aesthetics, biophilia, reduced embodied carbon and increased biogenic carbon storage, reduction in on-site labor, and increased construction speed. However much like mass timber buildings there are several disadvantages that must be accounted for in design to achieve a successful project. These disadvantages can include increased structural cost, increased influence of floor vibration on design, reduced acoustic performance, limitations on building size, lateral diaphragm design limitations and increased fire ratings.

A previous study conducted by Vulcraft and KL&A compared this type of hybrid steel and wood system in floor and roof assemblies with conventional steel assemblies[1]. It documented where each system was most advantageous in terms of embodied carbon, estimated structural cost, and structural depth over a range of bay sizes common in both residential and commercial construction. This paper expands upon the results of that study and extends it by providing guidance into other aspects of design which are important to understand when developing hybrid steel and mass timber buildings.

Ideal applications for hybrid steel and mass timber structures were identified, and include buildings which:

- Do not require a fire rating.
- Exposed steel and timber meet the desired aesthetic.
- Have low to moderate acoustic requirements.
- Have stated sustainability goals.
- Benefit from reduction in on-site labor or construction duration.

[1] Hohmann, J. "North American Steel & Hybrid Steel and Mass Timber Structural Systems: A comparative study of embodied carbon, structural depth, and approximate cost." Nucor, 2024.

Introduction

The popularity of mass timber structures continues to grow throughout the United States due to benefits which include lower embodied carbon, greater biophilia, aesthetics, and faster construction. However, limitations of full mass timber systems compared to more conventional structural systems include shorter beam/joist and girder spans, increased floor depth, the limited number of manufacturers, and material cost premiums. For these reasons hybrid systems which combine mass timber components with other structural materials have the potential to balance the advantages of mass timber while circumventing possible shortcomings.

The intent of this report is to give the reader a background on the critical items which should be considered when comparing and evaluating a hybrid steel with CLT panel structural system with conventional steel systems and which building or site types may be best suited for a hybrid structure. The proper selection of a structural system needs to include numerous non-structural factors including fire rating, acoustic performance, building systems integration, construction cost, and construction schedule. For conventional structural systems, involved parties typically understand the advantages and disadvantages of each system and there is a long history of potential solutions for each. The general knowledge of these structural systems allows each party to operate independently with less coordination, especially during early design phases. When dealing with new or unconventional systems close coordination between all parties is more critical, as solutions to system disadvantages or advantages may require each party to deviate from their typical process.

In a previous analytical study, hybrid systems that utilize Cross-laminated Timber (CLT) panels supported by steel framing were investigated and compared with conventional steel framing in terms of Global Warming Potential (GWP), system depth, and construction cost. The study included floor and roof framing with hot rolled steel sections (wide flange (WF) beams) and open web steel joists (OWSJ). The results of this study are utilized to provide recommendations for system types which are most likely to be economical in the current construction market. The previous study found that while hybrid structures did often result in reduced embodied carbon as compared to conventional structures, only by accounting for stored biogenic carbon were significant carbon reductions achievable. The study also found a significant cost premium for steel and mass timber hybrid structures. In nearly all bay sizes studied OWSJ floor and roof systems contained less embodied carbon than systems utilizing WF secondary beams. This was true for both hybrid and conventional assemblies. For commercial bay sizes (30 feet or larger) OWSJ hybrid assemblies were generally lower in cost than hybrid assemblies using WF secondary framing.

Another comparable variable is composite verses non-composite construction. Composite construction utilizes additional connections, typically headed stud anchors, to enforce deformation compatibility (“composite action”) between the steel beams (OWSJ or WF) and the concrete or CLT slab after the slab is placed and cured. This generally results in more efficient steel beam design at the expense of additional connector cost. Generally, composite construction, both OWSJ and WF, has reduced steel and in turn lower GWP values.

Steel and Mass Timber Hybrid Structure Basics

The primary form of steel and mass timber hybrid structure under consideration in this report consists of mass timber panels, typically Cross-Laminated Timber (CLT), supported by a steel frame. This system can be utilized in roof and/or floor construction, and the steel frame can be comprised of hot rolled steel shapes, typical wide flanges, or open web steel joists (OWSJ). This hybrid system allows for many of the benefits of a mass timber structure, but with a greater ability to support larger beam and girder spans.

Common reasons for considering steel and mass timber hybrid systems are as follows:

- Aesthetics: Exposed wood and steel is a desirable look and can pay homage to the look of historic industrial or manufacturing buildings common in urban areas. Many of these historic buildings have been successfully reused as residential or commercial spaces and command premium lease rates.
- Embodied carbon: In recent years there has been a rapidly growing focus on the importance of embodied carbon – generally expressed as Global Warming Potential (GWP) – in the built environment. This newly focused attention has been inspired by the fact that materials used in the construction industry account for over one third of worldwide annual global greenhouse gas emissions. The urgency of climate change together with commitments made to reduce embodied carbon by such organizations as the ASCE Structural Engineering Institute (SE 2050 Challenge) and federal and state governments are encouraging design and construction professionals to explore innovative designs and materials to reduce GWP at a rapid pace.
  Also to note, unless sustainable harvest sourcing for the wood has been documented, the combining of embodied carbon (GWP) with wood biogenic carbon (GWPbio) is still not advantageous in most LCA evaluations. Industry standard of care, without more project specific material sourcing and detailed LCA analysis, is moving to report GWP and GWPbio separately.
  It is clear, though, when materials are used in their most efficient ways (steel for tension, compression, and long spans; wood for decking floor areas), and when responsible wood sourcing is verified, that optimal, least carbon design solutions are being achieved.
- Biophilia: This is the human tendency to desire to interact or be closely associated with nature. There is a current trend to increase the amount of exposed natural materials (wood, bamboo, natural textiles, etc.) within buildings to increase the desirability of the buildings and the happiness of the occupants.
- Limited on-site labor availability: In many areas there is a shortage of labor for skilled trades. Steel and mass timber hybrids can be a solution to reduce the amount of on-site labor required.
- Short construction durations: The prefabricated nature of large mass timber panels combined with steel can allow for a reduction in construction duration, allowing difficult schedules to be maintained and reducing general condition and finance costs.

Typical assemblies for both conventional steel framing systems and for hybrid framing systems are illustrated in Figure 1, following page.

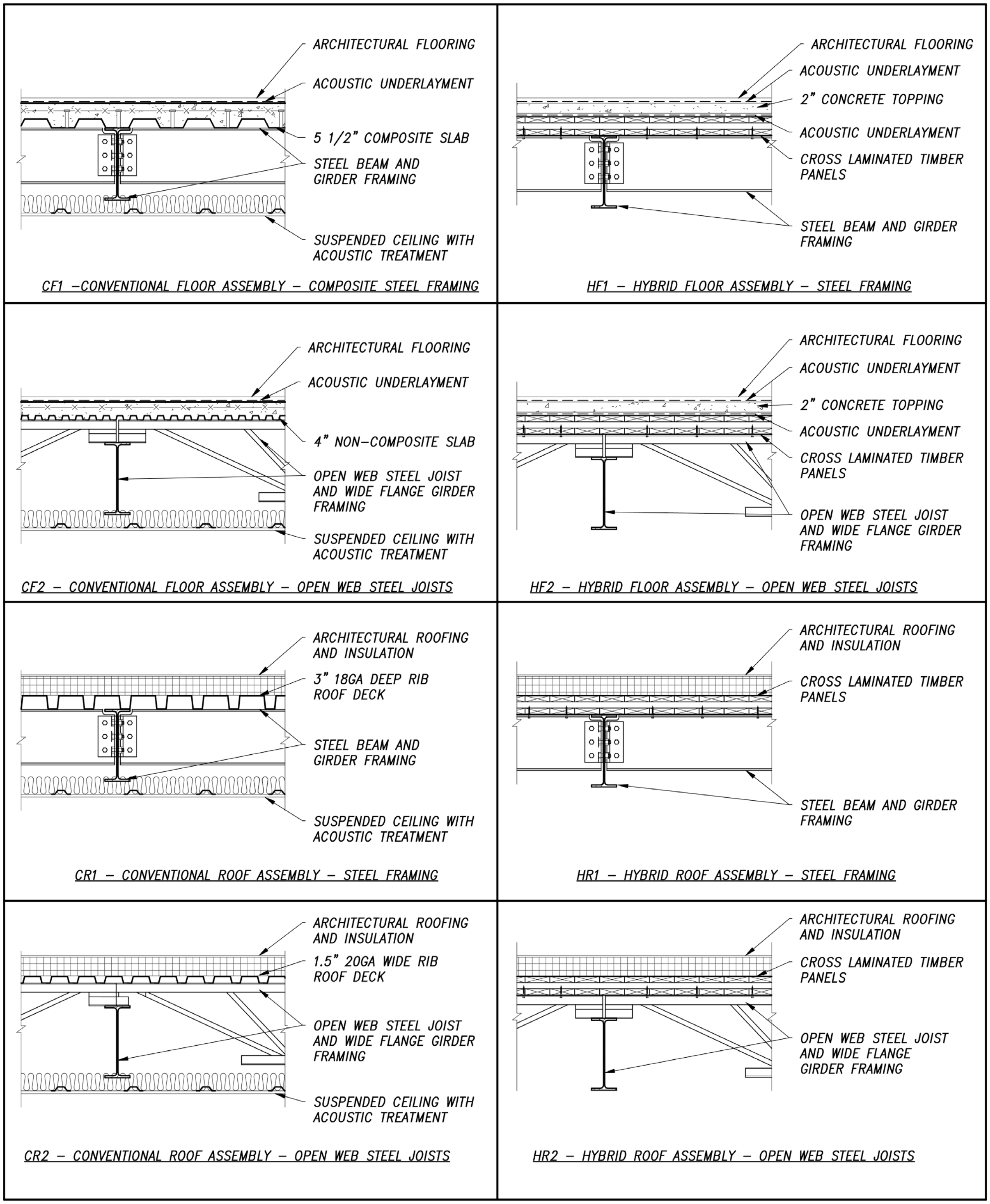

Figure 1 - Conventional and Hybrid Assemblies

Structural Design

The structural design of a hybrid steel and CLT structure requires the engineer to be knowledgeable in both steel and mass timber analysis and design. The American Institute of Steel Construction (AISC) has published a Design Guide[2] to assist structural engineers in this design. The intent of this paper is to focus on a larger group of stakeholders (engineers, architects, contractors, and developers), while the AISC Design Guide primarily addresses structural engineering design and case studies. Ultimately both documents complement each other, with the AISC guide focusing on technical structural engineering and this paper providing a broader view of cost, market viability, and sustainability.

The selection of the CLT panel thickness will drive beam or joist spacing. Given the relatively high cost of CLT, the thinnest panel which meets the required fire and acoustic ratings generally results in the lowest total cost even though a thinner panel may require closer beam spacing and therefore a higher steel piece count.

Required Fire Rating	CLT Thickness, inch	Typical Span, ft
None	3.5 - 4.125	7-12
1 Hour FRR	4.125 - 5.5	6-15
2 Hour FRR	6.875 +	13-20

Table 1 - Typical CLT Panel Spans as a function of fire rating

One significant difference in the design of hybrid steel and CLT structures in comparison to conventional steel structures is in the analysis of the behavior of the floor and roof diaphragms. Traditionally concrete filled steel deck diaphragms have been analyzed assuming rigid diaphragm behavior and bare metal roof deck diaphragms have been analyzed assuming flexible diaphragm behavior. A CLT floor or roof diaphragm tends to fall in between these two assumptions, and as such may require analysis as a semi-rigid element. This can require a more robust structural model is utilized in analysis, or that the diaphragm be analyzed as both a rigid and flexible member and the results are enveloped. Specific design requirements and limitations are included in the Wood Lateral Design Code[3]. In addition, a design guide[4] is available to assist engineers in the analysis and design of CLT diaphragms.

[2] Barber et all, “Design Guide 37: Hybrid Steel Frames with Wood Floors”, AISC, 2022
[3] “2021 Special Design Provisions for Wind and Seismic”, American Wood Council, 2021
[4] Breneman et all, “CLT Diaphragm Design Guide”, Woodworks, 2023

Steel and Mass Timber Hybrid Advantages and Disadvantages

Code Limitations for Hybrid Structures:

In the United States, building construction is commonly required to be in accordance with the International Building Code (IBC)[5]. For the purposes of this report, the 2024 edition of this code is utilized.

Allowable Building Types for Hybrid Structures

Chapter 5 of the IBC outlines limitations to building height in feet, height in stories, and area based on Construction types. Construction types I and II do not allow combustible building elements and are therefore not applicable to hybrid structures as CLT is combustible. The tables below outline these limitations.

Non-Rated Assemblies

Type III B (load bearing exterior walls to be rated)	**Type V B**
A-Occupancy (Retail/Restaurant) Height: 75' Stories: 3 Area: 28,500 sf per floor	**A-Occupancy (Retail/Restaurant)** Height: 60' Stories: 2 Area: 18,000 sf per floor
B-Occupancy (Office) Height: 75' Stories: 4 Area: 57,000 sf per floor	**B-Occupancy (Office)** Height: 60' Stories: 3 Area: 27,000 sf per floor
R-Occupancy (Residential) Height: 75' Stories: 5 Area: 48,000 sf per floor	**R-Occupancy (Residential)** Height: 60' Stories: 3 Area: 21,000 sf per floor

Notes:

1. height, story, and area limitations assume a sprinklered building.
2. IBC 711.2.4.3 requires a 1HR FRR assembly between dwelling units. R-Occupancy not an option with an unrated floor assembly.
3. Type II B does not require rated assemblies but does require non-combustible construction and is not an option for the Hybrid System.
4. R-Occupancy in Type IIIB and VB buildings rely on IBC Section 708.4, Exception 1, which allows the FRR of supporting construction to be less than that of the Fire Partition it supports.

[5] "2024 International Building Code", International Code Council, 2023

Fire-Resistance Rated Assemblies

Type III A	**Type V A**
(load bearing exterior walls to be rated) 1HR FRR Primary Structural Frame 1HR FRR Floor Assembly **A-Occupancy (Retail/Restaurant)** Height: 85' Stories: 4 Area: 42,000 sf per floor **B-Occupancy (Office)** Height: 85' Stories: 6 Area: 85,500 sf per floor **R-Occupancy (Residential)** Height: 85' Stories: 5 Area: 72,000 sf per floor	1HR FRR Primary Structural Frame 1HR FRR Floor Assembly **A-Occupancy (Retail/Restaurant)** Height: 70' Stories: 3 Area: 34,500 sf per floor **B-Occupancy (Office)** Height: 70' Stories: 4 Area: 54,000 sf per floor **R-Occupancy (Residential)** Height: 70' Stories: 4 Area: 36,000 sf per floor

Type IV A	**Type IV B**	**Type IV C**
3HR FRR Primary Structural Frame 2HR FRR Floor Assembly **A-Occupancy (Retail/Restaurant)** Height: 270' Stories: 18 Area: 135,000 sf per floor **B-Occupancy (Office)** Height: 270' Stories: 18 Area: 324,000 sf per floor **R-Occupancy (Residential)** Height: 270' Stories: 18 Area: 184,500 sf per floor	2HR FRR Primary Structural Frame 2HR FRR Floor Assembly **A-Occupancy (Retail/Restaurant)** Height: 180' Stories: 12 Area: 90,000 sf per floor **B-Occupancy (Office)** Height: 180' Stories: 12 Area: 216,000 sf per floor **R-Occupancy (Residential)** Height: 180' Stories: 12 Area: 123,000 sf per floor	2HR FRR Primary Structural Frame 2HR FRR Floor Assembly **A-Occupancy (Retail/Restaurant)** Height: 85' Stories: 6 Area: 56,250 sf per floor **B-Occupancy (Office)** Height: 85' Stories: 9 Area: 135,000 sf per floor **R-Occupancy (Residential)** Height: 85' Stories: 8 Area: 76,875 sf per floor

Notes:

1. height, story, and area limitations assume a sprinklered building.
2. Type II A&B require non-combustible construction and is not an option for the Hybrid system.
3. Type IV Fire Resistance Ratings (FRR) are achieved through Calculated Fire Resistance in IBC Section 722.

Type I and II Conventional Steel Structures for Reference

Steel structures that do not utilize a Hybrid CLT system can be classified as Type I or II construction. These have a range of allowable geometries, from unlimited in Type I A to limitations in Type II B that are less than that in Type IV C. These are outlined in the tables below.

Type I A	**Type I B**
3HR FRR Primary Structural Frame 2HR FRR Floor Assembly	2HR FRR Primary Structural Frame 2HR FRR Floor Assembly
A-Occupancy (Retail/Restaurant) Height: Unlimited Stories: Unlimited Area: Unlimited sf per floor	**A-Occupancy (Retail/Restaurant)** Height: 180' Stories: 12 Area: Unlimited sf per floor
B-Occupancy (Office) Height: Unlimited Stories: Unlimited Area: Unlimited sf per floor	**B-Occupancy (Office)** Height: 180' Stories: 12 Area: Unlimited sf per floor
R-Occupancy (Residential) Height: Unlimited Stories: Unlimited Area: Unlimited sf per floor	**R-Occupancy (Residential)** Height: 180' Stories: 12 Area: Unlimited sf per floor

Type II A	**Type II B**
1HR FRR Primary Structural Frame 1HR FRR Floor Assembly	NR FRR Primary Structural Frame NR FRR Floor Assembly
A-Occupancy (Retail/Restaurant) Height: 85' Stories: 4 Area: 46,500 sf per floor	**A-Occupancy (Retail/Restaurant)** Height: 75' Stories: 3 Area: 28,500 sf per floor
B-Occupancy (Office) Height: 85' Stories: 6 Area: 112,500 sf per floor	**B-Occupancy (Office)** Height: 75' Stories: 4 Area: 69,000 sf per floor
R-Occupancy (Residential) Height: 85' Stories: 5 Area: 72,000 sf per floor	**R-Occupancy (Residential)** Height: 75' Stories: 5 Area: 48,000 sf per floor

Notes:

1. height, story, and area limitations assume a sprinklered building.

Fire-Resistance Ratings and Potential Pathways to Solve

The IBC construction type and resulting required fire-resistance ratings can be significantly more impactful for the design of a steel and mass timber hybrid structural system as compared to a conventional structural system and can greatly affect the structural design and cost of a steel and mass timber hybrid system. Buildings that do not require a fire-resistance rating can utilize exposed steel framing and thinner CLT, where buildings that require a fire-resistance rating must utilize fire protective strategies to achieve compliance.

Mass timber is combustible, therefore without fire protective materials to provide a fire-resistance ratings (FRR) the Construction type is limited to Types IIIB and VB. Building height and area are most restrictive in these construction types.

When fire protective materials are utilized, Types IIIA, IVA, IVB, IVC, and VA are applicable. Building height and area are less restricted with these construction types, allowing for larger buildings.

Fire protective strategies to achieve the required fire-resistance rating include char layer development or gypsum board covering for timber and Spray Applied Fire Resistive Materials (SFRM), intumescent coatings, and gypsum board enclosure for steel. Each steel protection strategy carries its own design, engineering, construction sequencing, and aesthetic considerations outlined below.

- Spray Applied Fire Resistive Materials (SFRM) are the least expensive option but are generally not acceptable to leave exposed to view in finished areas. They are most often used with a dropped ceiling assembly, which negates many of the advantages of a timber floor panel.
- Intumescent coatings maintain the aesthetic appeal of exposed steel framing while providing fire protection. Intumescent coatings are a more expensive option and there are durability concerns in high-wear areas.
- A gypsum board enclosure conceals and protects the steel structure. Construction sequencing can be a challenge with gypsum board enclosures as pre-rocking can complicate on-site logistics and penetrations in the enclosure require a fire rating.

For Type IV-HT building construction types, the fire-resistance rating of the horizontal floor panels is achieved through providing minimum thickness dimensions based on IBC Table 2304.11. The thicker CLT panel required to achieve higher fire-resistance ratings can have a significant impact on the structural design and the cost of a hybrid system. A design approach can be utilized to optimize the thickness of CLT floor panels based on FRR requirements and structural span capacities.

Selection of an IBC building construction type and resulting fire-resistance requirements early in the design process is critical for a successful steel and CLT hybrid system. In general, higher fire-resistance requirements will result in an increase in GWP and cost.

Hybrid Structure Acoustics:

Structure Acoustics Background

Sound Transmission Class, or STC, is a single-number rating of the airborne sound transmission loss performance of a construction. The higher the STC rating, the more efficient the construction will be in reducing sound transmission. This metric is used to determine how effective an assembly is at mitigating noise such as conversation, TV speakers, music, etc.

Impact Isolation Class, or IIC, is a single-number rating of the impact sound transmission loss performance of a construction. The higher the IIC rating, the more efficient the construction will be in reducing impact noises. This metric is used to determine how effective an assembly is at mitigating noise such as footfall, rolling carts, dropped objects, moving furniture, etc.

For residential buildings, there is a minimum code rating from unit to unit of STC 50 and IIC 50. At these ratings, a "moderate" amount of sound would be blocked. An assembly is considered "high-end" when the STC and IIC ratings are above 60. Other building types do not have code minimums associated with them, and the targeted ratings should be based on the desired performance.

Floor to Floor STC/IIC Ratings for Assemblies

Composite Steel Deck assembly ratings:

Assembly	STC	IIC
CF1	61-63	60-61
CF2	58-60	~59
CR1	53-56	NA
CR2	52-55	NA

Hybrid assembly ratings:

Assembly	STC	IIC
HF1	~54	~44
HF2	~53	~51
HR1/HR2	31-34	NA

The presented assembly ratings are extrapolated based on available test reports for similar assembly configurations[6,7], computer prediction using INSUL software, and interpretation/extrapolation of the two.

CLT Assembly Sound Isolation Challenges

Most CLT projects desire an exposed ceiling for the aesthetic benefits from using this structure type. Acoustically upgrading CLT assemblies is difficult, as most products used to increase performance require a ceiling to function. Conventional products like spring hangers, neoprene hangers, isolation clips, and resilient channel all cannot be used in this application. Instead, the only way to upgrade these assemblies is to increase the topping slab thickness, increase the sound mat thickness beneath the topping slab, or to include an acoustical underlayment beneath the finished floor. These add to the cost and GWP of the structure.

[6] "Woodworks Mass Timber Acoustic Assemblies Database", Woodworks, retrieved April 2025 from www.woodworks.org

[7] "Compilation of Acoustics Information for Concrete Construction and Other Materials", National Ready Mixed Concrete Association and the Ready Mixed Concrete (RMC) Research & Education Foundation, July 2022, retrieved July 2025 from www.nrmca.org

The current highest performing 5-ply CLT assembly tested without a ceiling contains a 50mm (2 inch) thick sound mat, a 4-inch thick topping slab, and an acoustical underlayment beneath the finished floor. The same level of acoustical performance can be easily achieved by a traditional composite deck assembly with conventional upgrade methods.

Interior Acoustics Challenges

Another challenge with CLT assemblies, especially for commercial/office uses, is the severe reduction in available surface area to acoustically treat a room for reverberations. Since CLT is visually appealing, there is a reluctance to cover any of it with an acoustical product. This eliminates some of the most popular ways to add acoustical treatment into a room, including acoustical ceiling tiles, acoustic clouds, etc. This makes the walls the only available surface area to add acoustical treatment, which both limits the types of products available and the ability to evenly spread out any treatment. If not planned for properly, this could lead to more reverberant rooms than typically desired for commercial and office spaces.

Floor Vibration

Floor vibration can be a controlling limit state for hybrid steel and mass timber structures. The longer spans combined with the light weight of the assembly can result in poor floor performance if not specifically included in design. Three design guides[8,9,10] are available to assist structural engineers. It is generally assumed that the CLT panels are fully composite with the steel framing, but a concrete topping slab separated from the CLT by a soundmat is assumed to behave as non-composite.

Floor vibration performance is dependent on the mass, stiffness, and dampening of the system. Conventional composite steel floors generally have adequate vibration performance or require minor increases in member sizes to obtain adequate performance. Historically conventional OWSJ floors performed reasonably, but for certain joist spans (typical between 25 – 35 feet) a greater increase in member size was required to provide adequate vibration response. Newer advances in flush-framed OWSJ systems, in which the girders are flush with the bottom of the slab or CLT in lieu of dropped, result in improved vibration response and limit the increase in member sizes needed to meet vibration requirements. The vibration response of hybrid floor assemblies is generally worse than conventional assemblies if dampening is assumed to be constant. This is due to the lighter weight (reduction in mass) and reduced composite stiffness (wood is softer than concrete).

The influence of vibration on member size can be expressed as a ratio between the steel weight per unit area of a floor designed for adequate vibration response and a floor designed for code required strength and deflection requirements only. A resulting ratio of 1 indicates that vibration did not control the design, while a ratio of 1.2 indicates a 20% increase in steel weight was required to provide adequate vibration response. This resulting vibration influence is

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[8] Breneman et all, “U.S. Mass Timber Floor Vibration Design Guide”, Woodworks, 2023
[9] Murray et all, “Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity, 2nd ed.”, AISC, 2016
[10] Davis and Murray, “Technical Digest 5: Vibration of Steel Joist-Concrete Floors”, Steel Joist Institute, 2015

shown graphically in Figure 2 through Figure 5 for conventional and hybrid assemblies using flush framing for OWSJ assemblies. These figures only consider interior framing bays of relatively large floor plates (floor width equal to 100 feet, floor length equal to 150 feet) and assume constant dampening of 2.5% for all assemblies.

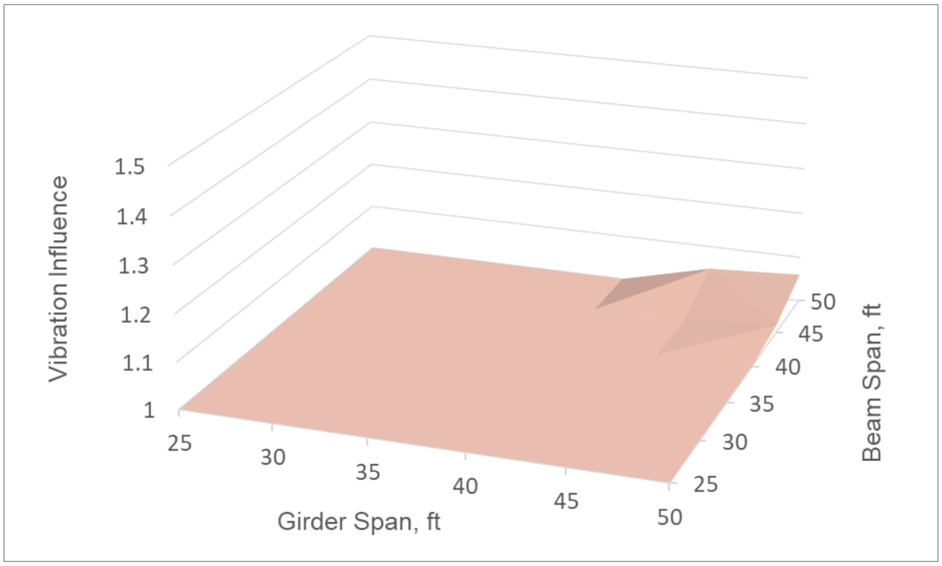

Figure 2 - CF1 - Composite Steel Vibration Influence

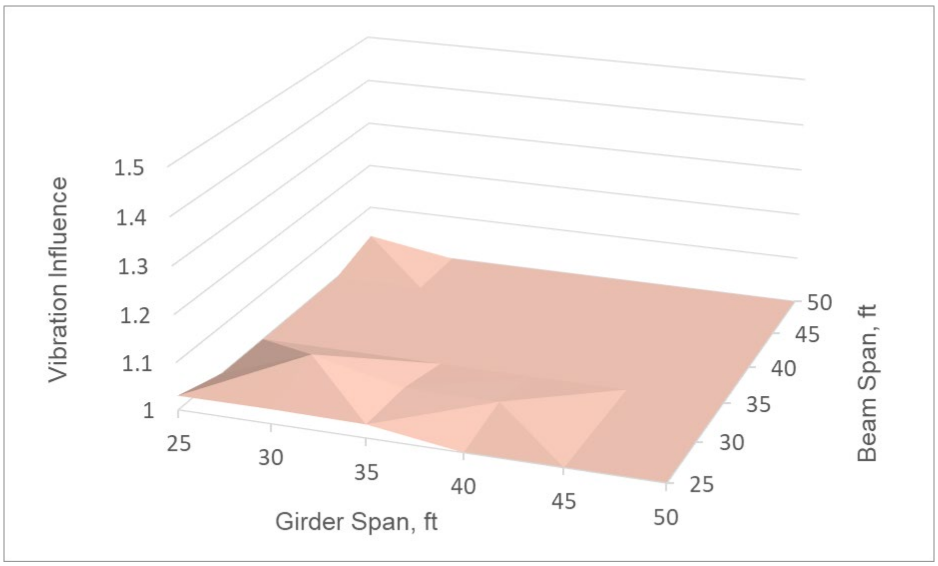

Figure 3 – CF2, Flush Framed - Conventional OWSJ Vibration Influence

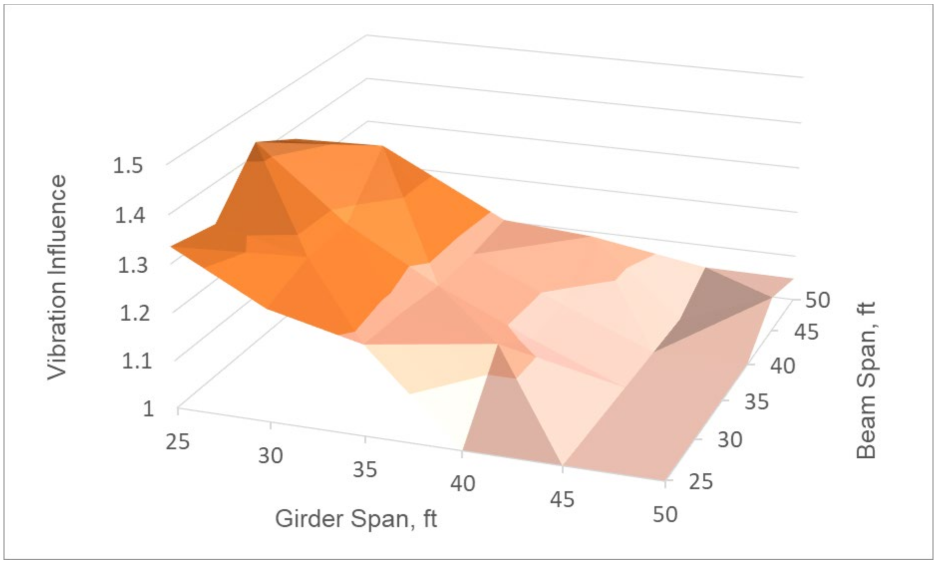

Figure 4 - HF1 - Hybrid Steel Floor Vibration Influence

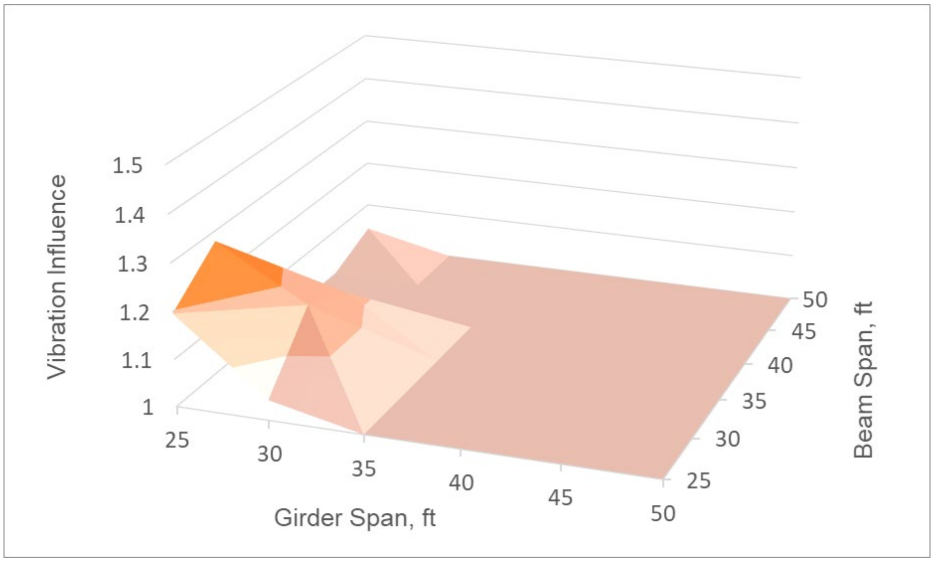

Figure 5 - HF2, Flush Framed - Hybrid OWSJ Vibration Influence

These figures illustrate the increased vibration response (decreased performance) of hybrid assemblies as compared to conventional assemblies. The HF1 assembly has the largest vibration influence, and in most of the bays member sizes were required to be increased to achieve adequate vibration performance. The hybrid OWSJ assembly (HF2) did require increases in member sizes for short spans, but for common office joist spans of 40-45 feet did not require any increase in member sizes.

Embodied and Biogenic Carbon

One common reason to select a steel and mass timber hybrid system is the desire to reduce carbon emissions. As the construction industry moves towards decarbonization, understanding both operational and embodied carbon has become essential. Operational carbon refers to emissions from the energy used to run buildings—such as heating, cooling, lighting, and equipment—and has traditionally been the focus of sustainability efforts.

However, as buildings become more energy efficient, embodied carbon—the emissions from material extraction, manufacturing, transportation, construction, and end-of-life disposal—is gaining increased attention. Unlike operational carbon, which can be reduced over time, embodied carbon is locked in from the start making early design and material choices critical to minimizing a building's total emissions.

A specific consideration of timber is its biogenic carbon content. Wood naturally sequesters carbon dioxide during tree growth, storing about 50% of its dry weight as carbon, which makes it a unique building material capable of acting as a carbon sink. This stored biogenic carbon can help offset emissions from other materials and supports immediate carbon reduction goals. However, the long-term benefit of this carbon storage depends on end-of-life scenarios—whether the wood is reused, decomposed, burned, or remains stored in long-term applications. If wood is decomposed or burned, the biogenic carbon is released in the atmosphere at the end-of-life of the product.

Vulcraft and KL&A have previously studied the ability of hybrid structural systems to reduce embodied carbon and provide stored biogenic carbon. Table 2, below, indicates the embodied and biogenic carbon content of each structural material studied in the previous study. For Cross Laminated Timber (CLT), biogenic carbon content is directly related to panel thickness. Standard U.S. CLT panels using 1.375" laminations store:

- 96 $kgCO_2eq/m^2$ for 3-ply CLT,
- 160 $kgCO_2eq/m^2$ for 5-ply CLT,
- 224 $kgCO_2eq/m^2$ for 7-ply CLT.

Environmental Product Declarations (EPDs) current as of June 2023 were used to estimate global warming potential (GWP) impacts, as shown in Table 1. All EPDs are third-party verified, Type III declarations compliant with ISO 14025 and ISO 21930; industry averages were used for non-Nucor products. GWP estimates include structural materials—steel framing, steel deck or CLT panels, and topping slabs—but exclude steel reinforcement, fireproofing, acoustic materials, and finishes. Fireproofing was excluded due to the assumption of an unrated structure, and reinforcement was excluded due to minimal impact.

Structural Component	EPD Name	EPD Owner	A1-A3 Total GWP (kgCO2e/Declared Unit)	Maximum Potential Biogenic Carbon (kgCO2e/Declared Unit)	EPD Date
Steel Decking	Fabricated Steel Roof and Floor Deck	Nucor	1740 / 1000kg	0	June 29 2023
Steel Joists	Fabricated Open Web Steel Joists and Joist Girders	Nucor	839 / 1000kg	0	December 21 2022
Steel WF Beams	Fabricated Hot-Rolled Structural Steel Sections	Nucor	1220 / 1000kg	0	Januray 1 2021
Concrete	Industry Average EPD For Ready Mixed Concrete, 4000 psi with 0% SCMs	NRMCA	383 / 1m^3	0	January 3 2022
CLT	Cross Laminated Timber (CLT)	Average of (6) referenced CLT EPDs	135 / 1m^3	0	Varies
CLT Biogenic Carbon	Biogenic Carbon in Cross Laminated Timber (CLT)	Average of (6) referenced CLT EPDs	0	-868 / 1m^3	Varies

Table 2 - EPDs used for embodied carbon estimates.

The study computed embodied carbon for a range of structural bay sizes for each floor and roof assembly. The results indicate that for embodied carbon, hybrid systems do not always result in the lowest embodied carbon. See Figure 6 for embodied carbon as a function of beam or joist span for a constant girder span of 30 feet for floor assemblies. The figure demonstrates several key results of the study as follows:

1. OWSJ floor assemblies, both conventional (CF2) and hybrid (HF2), generally contain less embodied carbon than composite steel (CF1) or hybrid steel (HF1) assemblies.
2. Embodied carbon content of OWSJ floor assemblies, conventional or hybrid, are least affected by increased span.
3. Embodied carbon content of Hybrid steel floor assemblies (HF1) is most affected by increased span.
4. The stored biogenic carbon, -96 kgCO2e/m2 for assemblies HF1 and HF2, may be sufficient to offset all or most of the embodied carbon present in the floor assembly depending on how accounted for and the assumed end-of-life scenarios for the CLT panels.

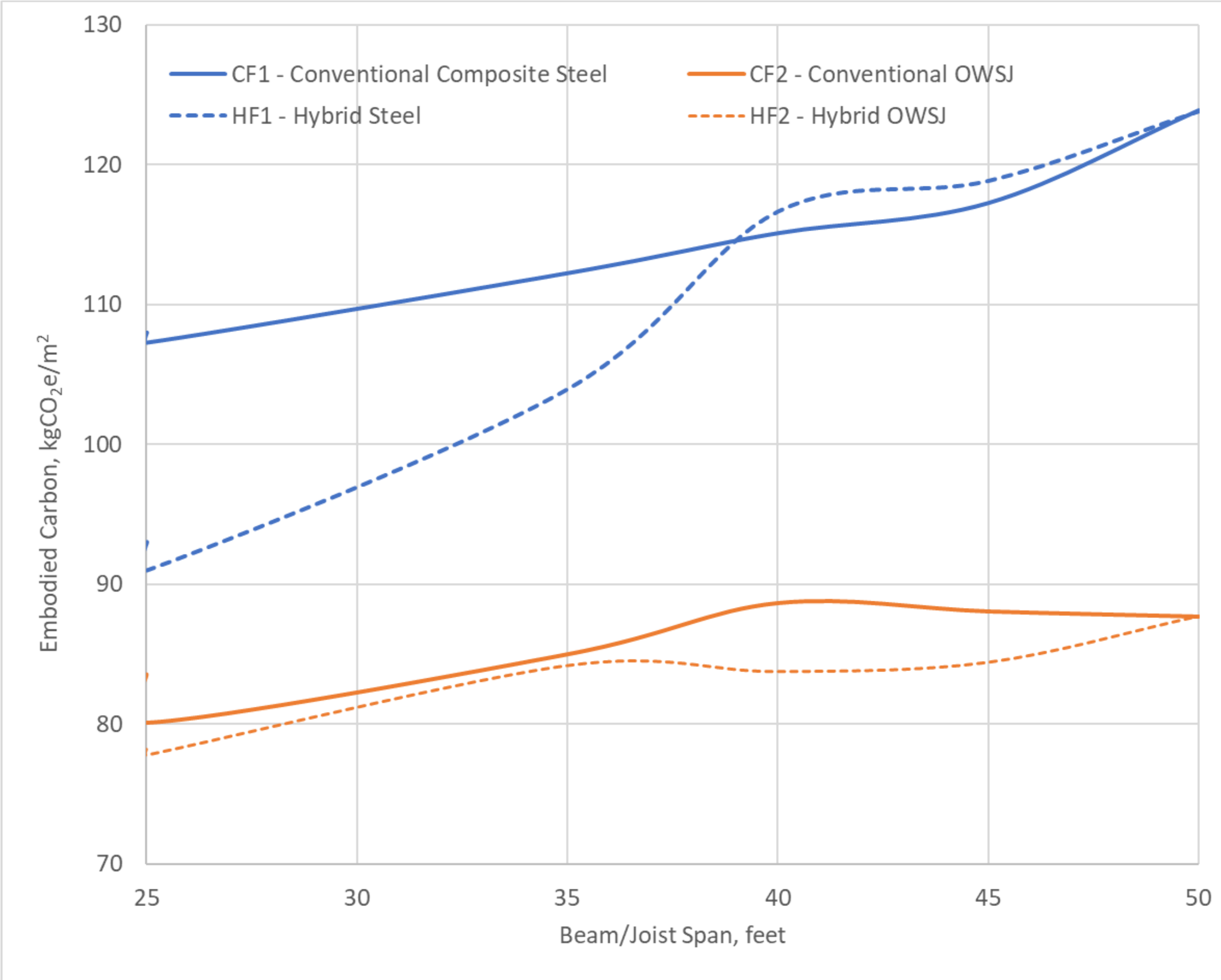

Figure 6 – Floor Beam/Joist Span vs Embodied Carbon - 30ft Girder Span

See Figure 7 for embodied carbon as a function of beam or joist span for roof assemblies, also for a constant girder span of 30 feet. The figure demonstrates several key results of the study as follows:

1. OWSJ roof assemblies, both conventional (CR2) and hybrid (HR2), generally contain less embodied carbon than composite steel (CR1) or hybrid steel (HR1) assemblies.
2. Embodied carbon content of OWSJ roof assemblies, conventional or hybrid, are least affected by increased span.
3. Embodied carbon content of conventional and hybrid steel floor assemblies are similarly affected by increased span.
4. The stored biogenic carbon, -96 kgCO2e/m2 for assemblies CR2 and HR2, may be sufficient to offset all or most of the embodied carbon present in the roof assembly depending on how accounted for.

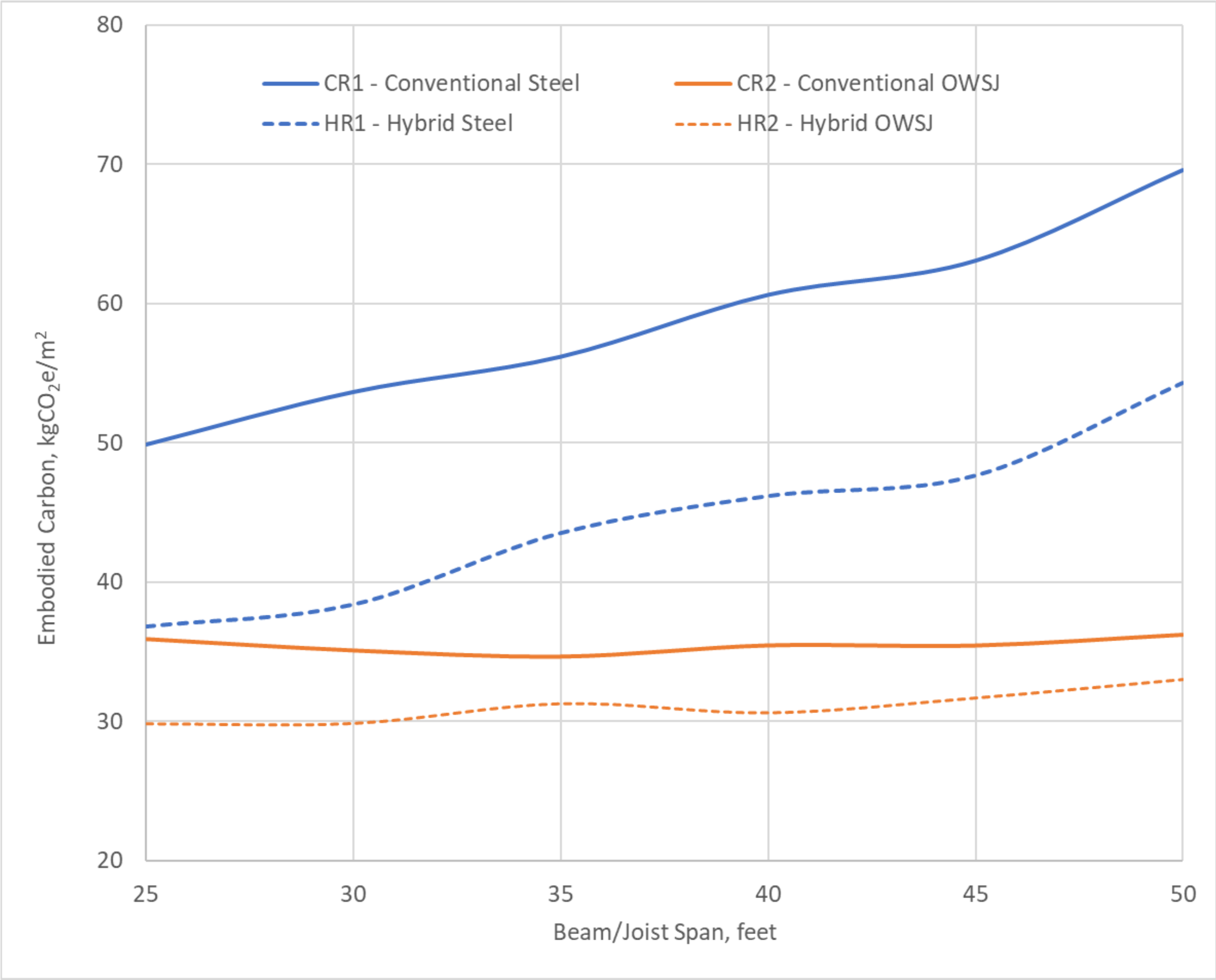

Figure 7 - Roof Beam/Joist Span vs Embodied Carbon - 30ft Girder Span

Approximate Structure Cost

One concern with steel and mass timber hybrid systems (or full mass timber systems) is the potential for increased cost. This was previously studied by Vulcraft and KL&A over a range of potential bay sizes using approximate cost metrics. The cost metrics used were based on 2023 subcontractor costs in the Denver, Colorado market for a 60,000 square foot building of moderate complexity. Actual costs may vary significantly from these costs depending on project location, size, complexity, and time and it is recommended a knowledgeable contractor or cost consultant is contracted to review and adjust as required on a project specific basis.

System Component	Installed Cost	Unit
Structural Steel	$ 6,000.00	ton
Open Web Steel Joists	$ 6,500.00	ton
Steel Deck - 1.0C22	$ 7.50	sf
Steel Deck - 2VLI18	$ 9.20	sf
Steel Deck - 3N18	$ 9.45	sf
Steel Deck - 1.5B20	$ 8.00	sf
Concrete Fill - 3 1/2" NWT over 2" deck w/ WWF	$ 14.25	sf
Concrete Fill - 3" NWT over 1" deck w/ WWF	$ 13.75	sf
Concrete Fill - 3" NWT over CLT w/ WWF	$ 12.75	sf
Reduced GWP Concrete Fill - 3 1/2" NWT over 2" deck w/ WWF	$ 17.10	sf
Reduced GWP Concrete Fill - 3" NWT over 1" deck w/ WWF	$ 16.50	sf
Reduced GWP Concrete Fill - 3" NWT over CLT w/ WWF	$ 15.30	sf
Cross Laminated Timber - 3-Ply 4.125"	$ 22.75	sf
Cross Laminated Timber - 5-Ply 6.875"	$ 29.75	sf
Cross Laminated Timber - 7-Ply 9.625"	$ 37.75	sf

Table 3 - Approximate Cost Metrics

The study computed approximate structural cost for a range of structural bay sizes for each floor and roof assembly. The results indicate that hybrid assemblies generally have a significant post premium as compared to conventional assemblies. See Figure 8 for approximate cost as a function of beam or joist span for a constant girder span of 30 feet for floor assemblies. The figure demonstrates several key results of the study as follows:

1. Hybrid floor assemblies had a cost premium of $13-$30 over conventional assemblies.
2. The cost premium for hybrid steel assemblies increases with beam span.

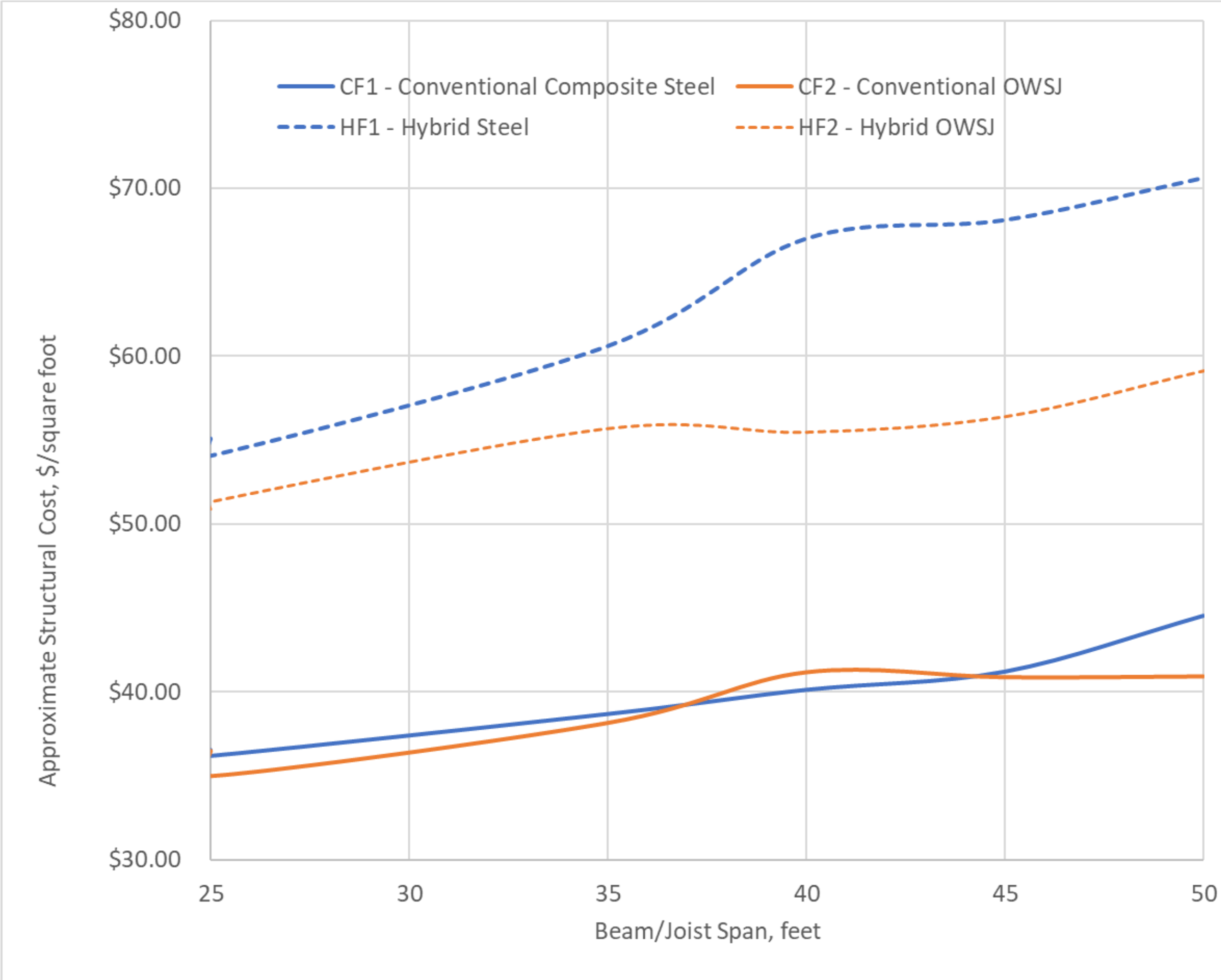

Figure 8 – Floor Beam/Joist span vs Approximate Cost, 30ft girder span

The approximate cost results for roof assemblies are presented in Figure 9. The cost premium for hybrid roof assemblies was less than that of floor assemblies and ranged from $12-$16 per square foot. The cost premium was relatively constant for both steel wide flange and OWSJ assemblies and was not greatly affected by beam or joist span.

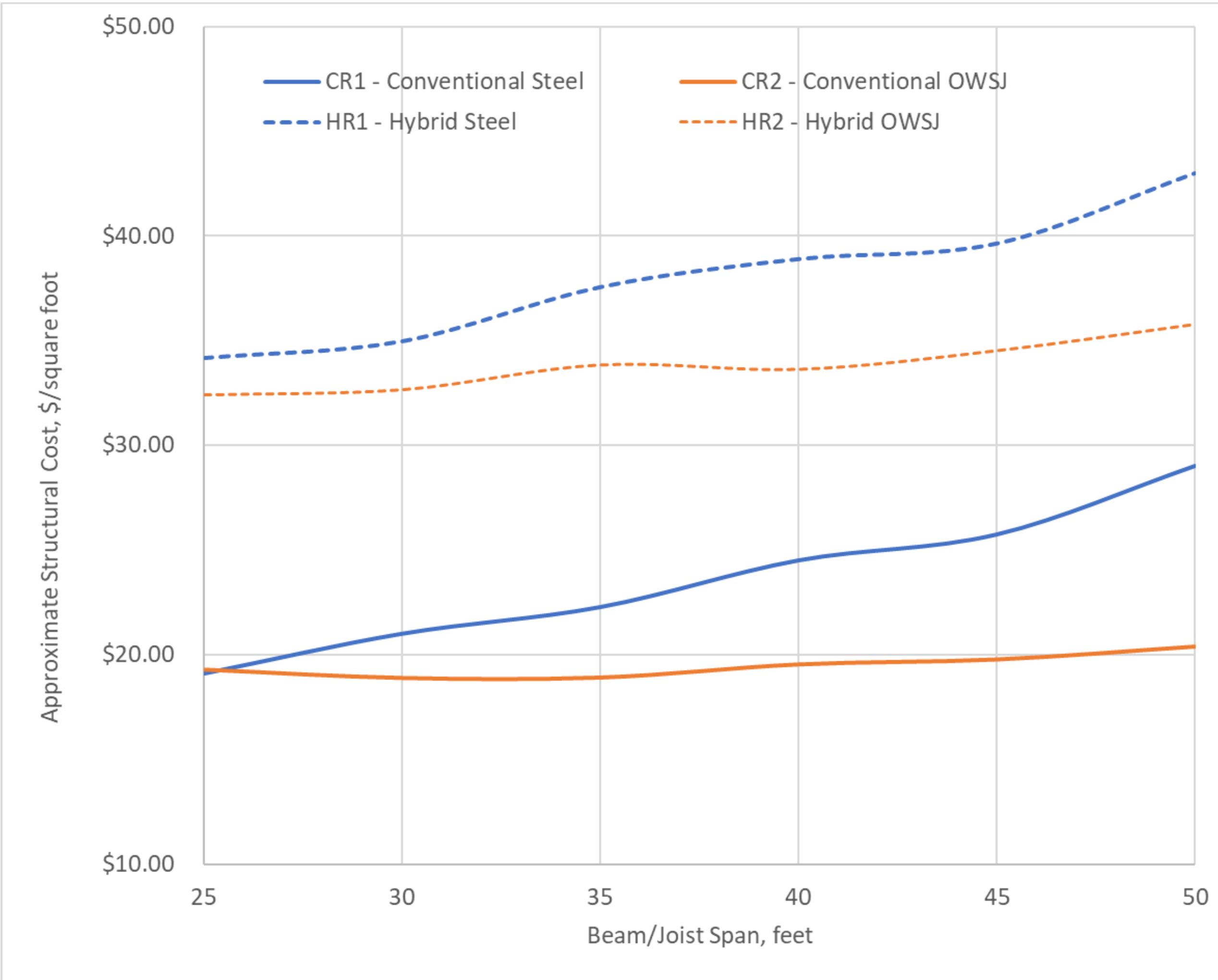

Figure 9 – Roof Beam/Joist span vs Approximate Cost, 30 ft girder span

Structural Depth

Structural system depth was computed for each bay size studied to quantify if hybrid assemblies would differ significantly from conventional assemblies in depth. It should be noted that the solutions selected for each bay size were based on minimizing the weight of the steel beams and joists utilized, and therefore system depth was not optimized for. Steel weight is generally directly proportional to the approximate structural cost and embodied carbon. A different set of results would be obtained if structural system depth was optimized for in lieu of steel weight. The results are presented in Figure 10 for floor assemblies and Figure 11 for roof assemblies. The results are less conclusive than the embodied carbon or structural cost results, but the following general trends were identified:

1. OWJS floor assemblies were generally very similar in depth between hybrid and conventional systems.
2. Conventional composite steel floor assemblies were often, but not always, shallower than hybrid assemblies. This is primarily due to the advantages of composite action in conventional assemblies.
3. Roof assemblies can generally be similar in depth between conventional and hybrid assemblies. While the chart presented indicates hybrid OWSJ assemblies have greater depth than conventional assemblies, this is driven largely by the choice of optimization for minimum steel weight and not depth.
4. OWJS assemblies, while often deeper than WF assemblies, offer the advantage of allowing building systems to easily pass through the open webs in lieu of being located below the beams.

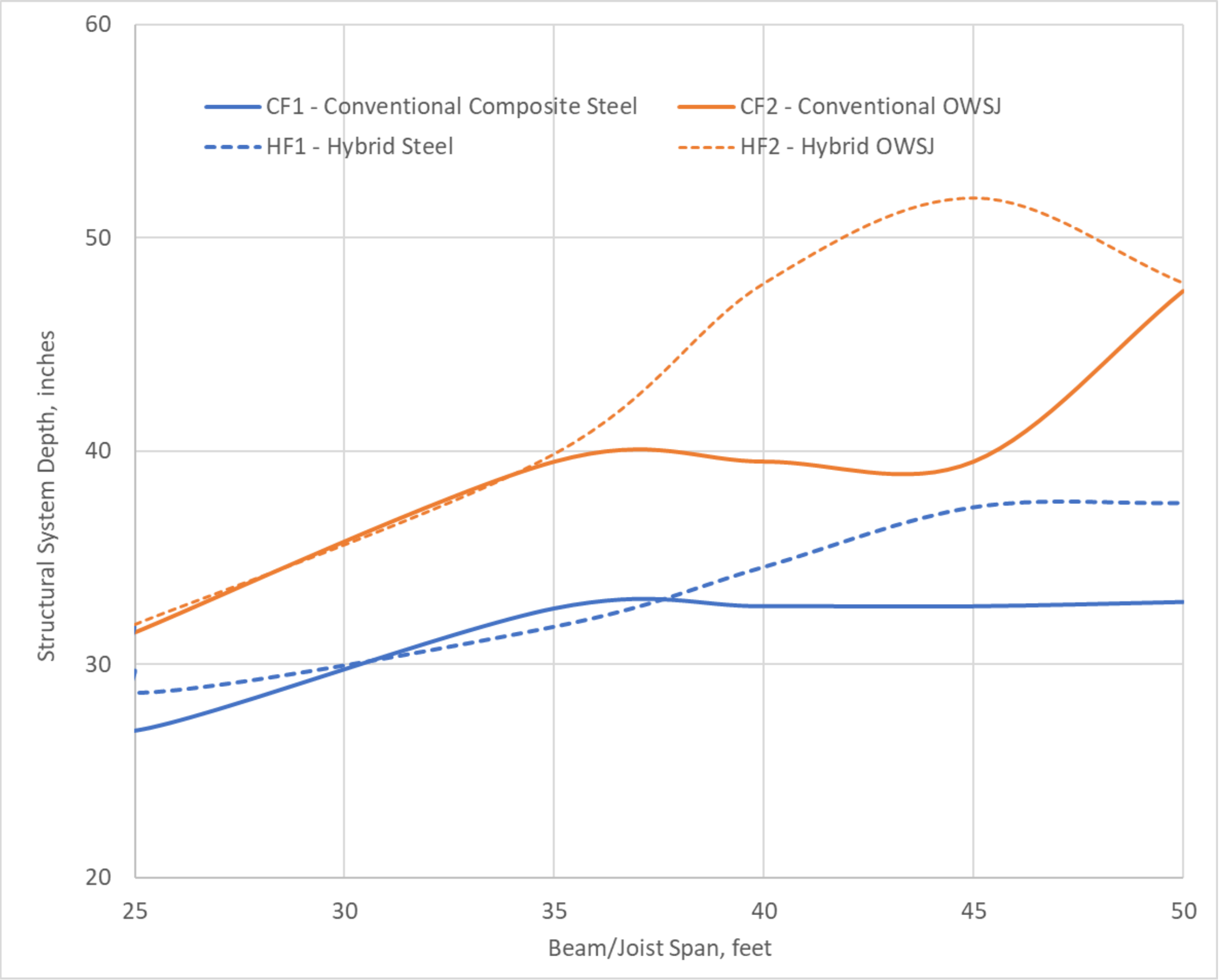

Figure 10 - Floor Beam/Joist span vs Structural Depth, 30 ft Girder span

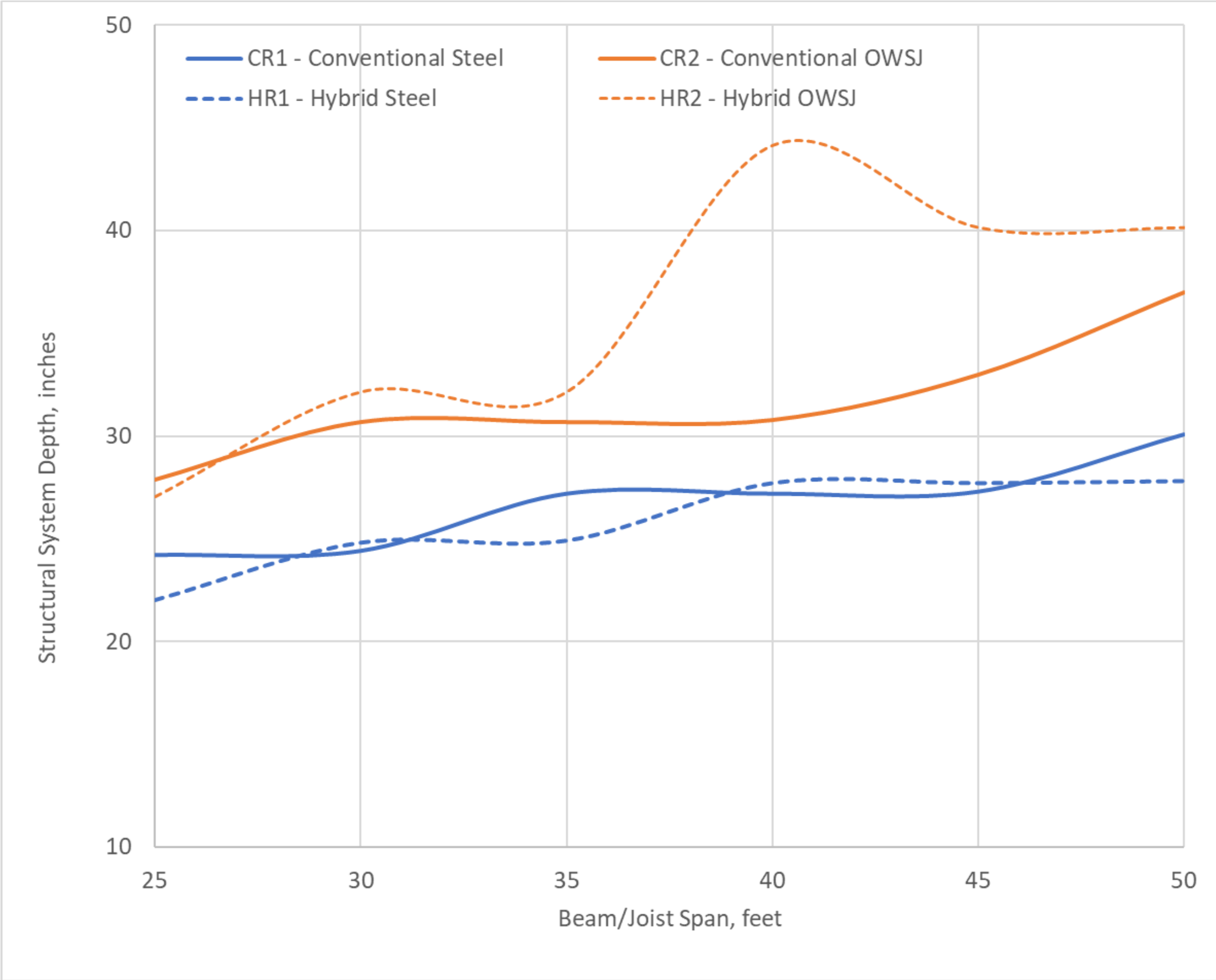

Figure 11 - Roof Beam/Joist span vs Structural Depth, 30 ft Girder span

Conclusion

Steel and mass timber hybrids structures are suitable for many types of building structures. A holistic design approach, especially during early design phases, is important to capture the advantages of a steel and mass timber hybrid structure while limiting the potential challenges. Key ideas that should be incorporated early in design include:

- Programing space utilization to minimize required fire ratings.
- Minimizing CLT thickness to reduce cost premium.
- Establish acoustic targets early and identify methods to control sound, both between spaces and within a space.
- Expanding carbon accounting to include a cradle to grave or cradle to cradle LCA or WBLCA so biogenic carbon can be properly accounted for.
- Identifying construction phase efficiencies, including erection speed and labor savings, that a prefabricated structural system can achieve.

Larger buildings with more restrictive code provisions are more challenging to develop as steel and mass timber hybrid. Some building types (i.e. IBC Type I, II) do not allow combustible materials within the structure except for limited applications. Other building types (i.e. IBC III-A, IV, V-A) allow the use of combustible materials but require a fire rating is provided. These types could be suitable for hybrid construction. However, solving the fire rating may negate some advantages of a hybrid structure or limit their cost effectiveness.

Buildings with high acoustic performance targets may also be more difficult to develop as a hybrid structure. Many acoustic solutions rely on in-ceiling elements, which would require the timber to be concealed. This negates several of the advantages of a hybrid structure.

Ideal Applications for Steel and Mass Timber Hybrid Structures

While every building and site is unique, the following general situations will likely be ideal candidates for a steel and mass timber hybrid structure.

- Buildings which do not require a fire rating.
- Occupancies which require low to moderate acoustic demands.
- Sites which pose construction challenges including:
    - High labor costs
    - Reduced construction durations or seasonal limitations on exterior construction.
    - Challenging access for other construction materials (remote sites, sites in undeveloped areas)
- Building owners with stated carbon reduction objectives.
- Buildings targeting a green rating (i.e. Green Globes, BREEAM, LEED, etc.)