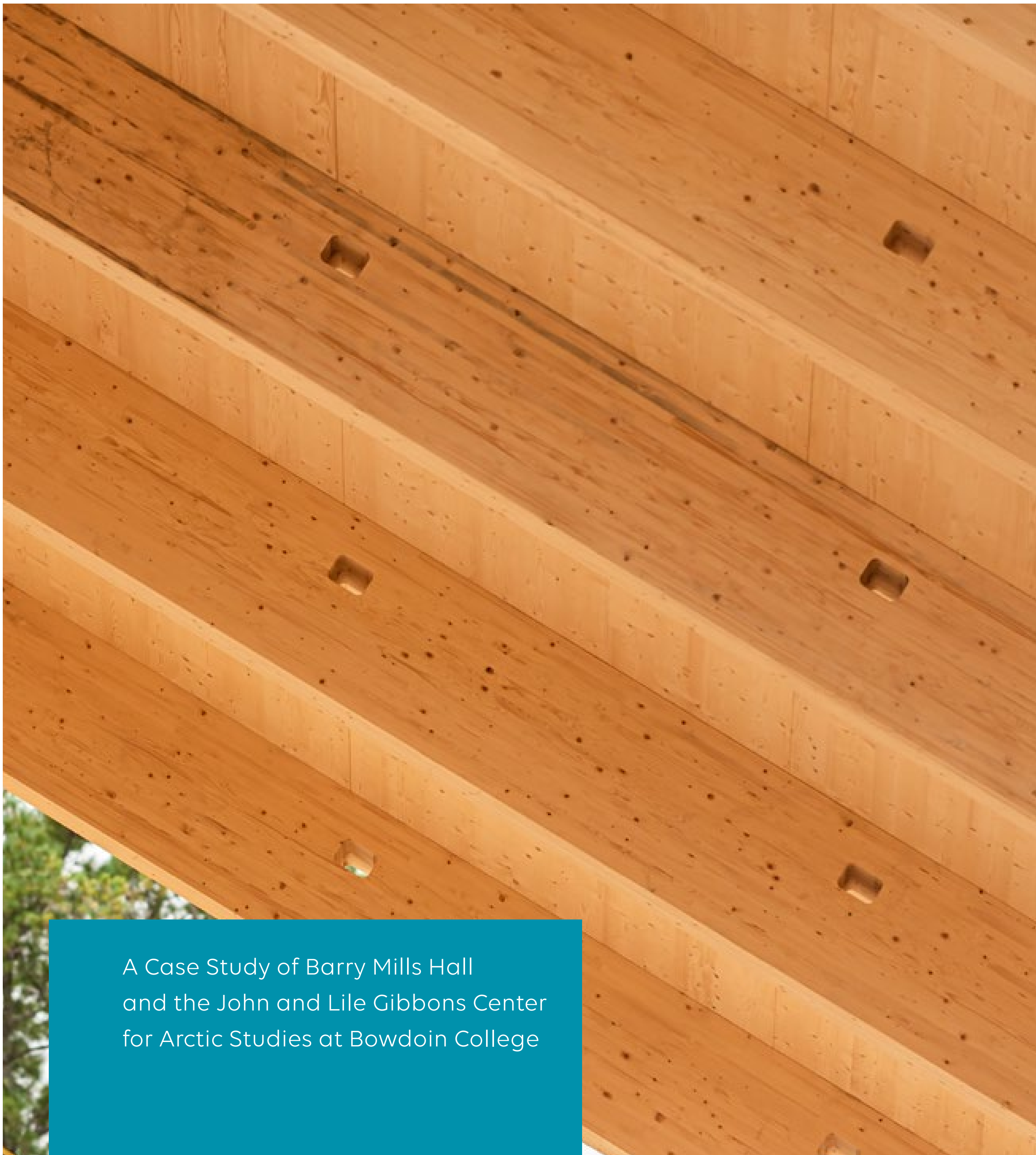
HGA

FURTHERING MASS TIMBER CONSTRUCTION



A Case Study of Barry Mills Hall
and the John and Lile Gibbons Center
for Arctic Studies at Bowdoin College

JULY 2022

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1 EXECUTIVE SUMMARY

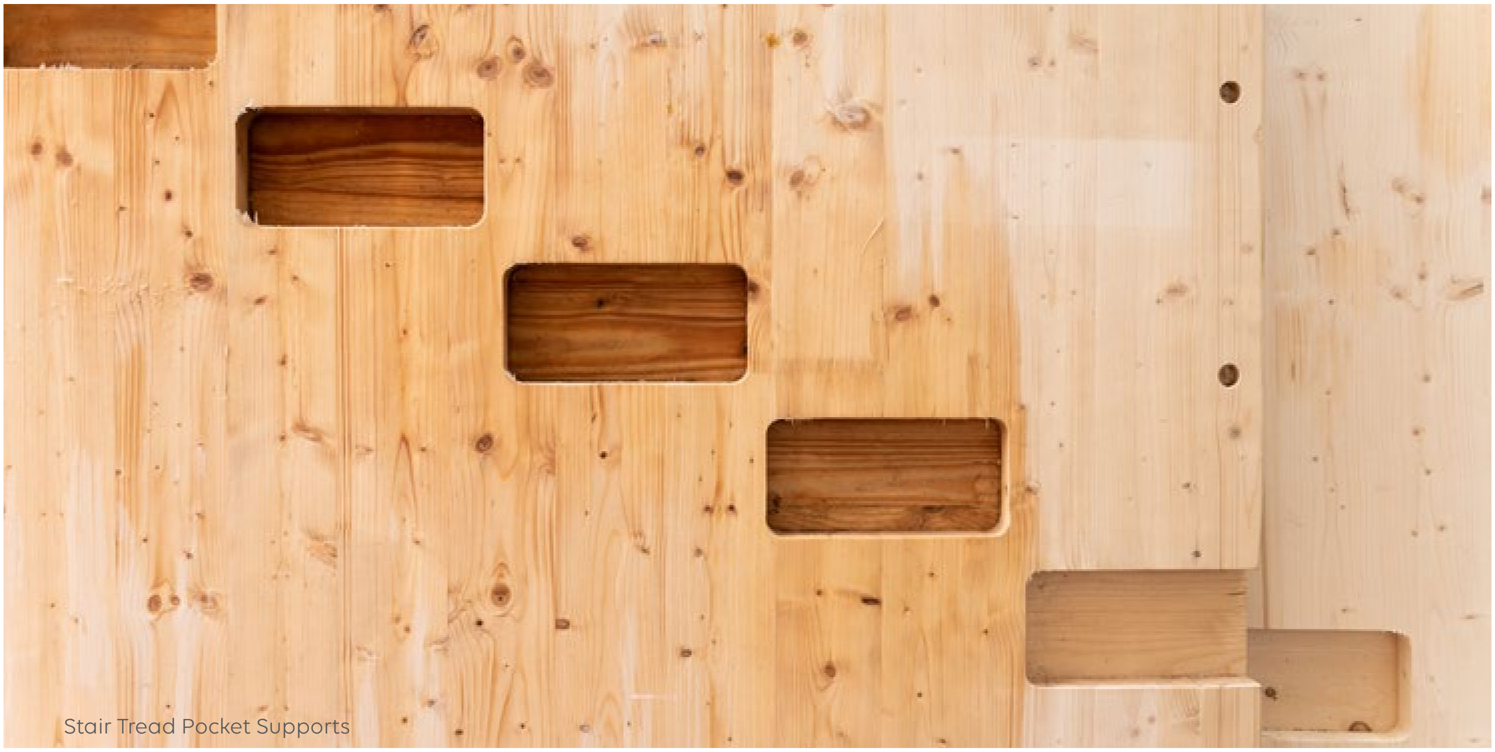
Exterior Rendering

The Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies buildings are the newest additions to Bowdoin College's campus in Brunswick, Maine. The pair of buildings are, fittingly, the first commercially-scaled mass timber project in the state of Maine. From the College's commitment to carbon-neutrality, to its location among a grove of pine trees, to the timber-rich history of Maine, the project setting seemed well-suited for a mass timber structure. In order to prove mass timber could be economical and practical as well, the project team worked to thoroughly vet the idea of using mass timber over a more traditional structural system, starting early in design.

In order to confirm that mass timber was a cost-effective and sensible solution, the design team explored two structural systems in the beginning phases of design: mass timber and steel. For both options, structural framing was developed and compared for cost, schedule, and embodied carbon impacts. This early investigation showed that, while the cost of the two systems was similar, the mass timber option was projected to save approximately three weeks of construction time, and 80% of the embodied carbon when compared to the steel option. With this information, the College decided to pursue a mass timber structure.

The final structural design incorporated glue-laminated timber beams and columns, cross-laminated timber floor and roof decking, and cross-laminated shear walls. In finalizing the design, the team addressed and solved a number of challenges unique to the mass timber structure, including species selection, the fire rating of the structure, and the protection of the timber during construction. The design team also undertook extensive coordination with the timber supplier and mechanical trades to ensure all building services were strategically incorporated into the exposed structure. Through extensive research and careful design and construction practices, the project team found mass timber to be an economical structural design solution that was also true to the College's mission and history.

2 MASS TIMBER OVERVIEW



Stair Tread Pocket Supports

Although it is recognized as one of the world's oldest building materials, wood construction has only recently been revitalized and reinvented to serve a new class of building types, thanks to mass timber construction. The use of mass timber structural systems brings opportunities to explore new ways to provide a built environment that offers improved sustainability metrics, more efficient construction methods, and a multitude of occupant benefits. While mass timber structures have been widely used in Europe for decades, recent code changes and the expansion of the mass timber market into mid-rise, high-rise, and non-residential applications has opened the door for wide-spread use in the United States. With the construction of two new buildings on campus, Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies, Bowdoin College has taken full advantage of the multiple benefits that mass timber has to offer, while remaining true to their commitment of environmental stewardship.

WHAT IS IT?

The term "mass timber" is used to describe a variety of timber products that combine laminations of dimensional lumber into larger structural members or panels. This lamination approach allows manufacturers to put the highest quality pieces where they have the largest impact, and to avoid defects (knots, etc.) at critical locations.

By combining these layers, mass timber structural members can achieve strengths and spans far larger than traditional dimensional lumber. Those capabilities open the doors for mass timber to be used where dimensional lumber falls short, such as museums, long-span event spaces, and more.

BENEFITS

Mass timber offers a long list of benefits, making it an appealing and effective structural solution for many project types.

- Aesthetics – Perhaps the most easily recognizable advantage of mass timber is the beauty of wood. Wood has long been used as finish material in commercial construction. However, mass timber enables the design team to integrate this beauty into the structure of a building. This has additional embodied carbon benefits if less finish materials can be used.
- Reduced construction time – Because mass timber building elements are largely prefabricated offsite, they typically require smaller crews and less erection time. Prefabrication can reduce erection time by up to 25% compared to a concrete building.[1]
- Reduced building weight – Wood is noticeably lighter than steel or concrete. Compared to a concrete alternative, a mass timber structure can reduce the overall building weight by up to 65%[1], resulting in significant foundation savings. In regions of high seismicity, lower building weight can also lead to significant reduction in seismic loads.
- Proven fire resistance – Many mass timber assemblies have tested fire ratings up to 2 hours.[1] This is due to a protective char layer that forms around mass timber elements during a fire event. Depending on the governing code and building type, it is possible to achieve the required fire rating using the timber itself, without additional protection.
- Reduced embodied carbon – Arguably one of the most important benefits of mass timber construction is its potential to reduce a building's embodied carbon footprint. Trees naturally sequester carbon as they grow. This carbon is retained in the wood when a tree is harvested, allowing it to offset some of the carbon required to fabricate, transport, and erect the final product. Depending on the product type, production techniques, and project location, this can result in structural elements that have net negative embodied carbon. That is, the carbon sequestered by the wood during its growth is greater than the carbon required to harvest, produce, fabricate, transport, and install the final product. The exact numerical impact can be evaluated on a project-by-project basis using life cycle analysis. Life cycle analysis, including its use on this project, is discussed further in the Life Cycle Analysis section.

DRAWBACKS

- Availability in the U.S. – While capacity in the United States is increasing, certain mass timber elements can still be difficult to procure in some markets.
- Industry knowledge base – As is true with any new construction technology, it will take time for design teams, contractors, and other industry partners to widely adopt mass timber as a construction material.
- Code limitations – Current codes in many jurisdictions preclude mass timber from being a cost-effective solution for certain project types. The addition of construction types IV-A, IV-B, and IV-C to the 2021 IBC removes some of these limitations.

Mass timber may not be a perfect option for all project types. However, given the multitude of benefits it offers, mass timber is clearly an effective solution for many projects, and should be considered as a viable structural system.


Roof Panel Eave

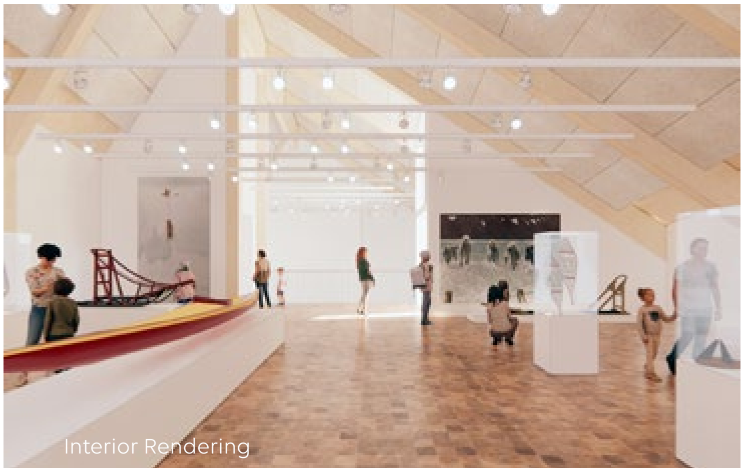
MASS TIMBER PRODUCTS

While there are several different products that fall under the mass timber umbrella, the design and construction of Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies employed two products, specifically: Glue-laminated timber and Cross-laminated timber.

Glue-laminated Timber (Glulam)
Typically used in beam and column applications, glulam is formed by stacking and laminating parallel boards to form linear members.

Cross Laminated Timber (CLT)
CLT is formed by stacking and laminating boards in layers that are perpendicular to each other. It is panelized, and typically used in roof, floor, and wall applications.

3 PROJECT OVERVIEW


Interior Rendering


Interior Rendering

BOWDOIN COLLEGE | BARRY MILLS HALL AND THE JOHN AND LILE GIBBONS CENTER FOR ARCTIC STUDIES

BACKGROUND

The John and Lile Gibbons Center for Arctic Studies and Barry Mills Hall sit on the south side of Bowdoin's campus in Brunswick, Maine. Together, the buildings provide over 45,000 square feet of space. Barry Mills Hall offers two stories to house staff and faculty offices, state-of-the-art educational facilities, and a large event space. The John and Lile Gibbons Center for Arctic Studies will provide a new home for Bowdoin's storied Peary-MacMillan Arctic Museum, along with offices and classrooms in three stories. The museum includes two new galleries, allowing space for temporary exhibitions, events, travelling artifacts, and student installations. While separated into two distinct buildings above grade, Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies also share a common basement, used for building support space, storage space, and some research laboratories.


Site Plan

Fittingly, the project site sits among a grove of pine trees, common on campus and in the surrounding areas. Many of these pine groves were originally planted to serve Maine's long-standing logging industry, and they have become a defining symbol of the College. Utilizing a mass timber structural system was an excellent way to pay homage to the State's history and to naturally integrate the building into the surrounding landscape.

Bowdoin College also prides itself on a strong commitment to environmental stewardship. In 2018, Bowdoin achieved carbon neutrality on campus as part of the American College and University Presidents' Climate Commitment, making it only the third college in the nation to do so. It was critical that the team integrate this dedication into the design and operation of Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies

Design of the two buildings spanned from early 2019 to spring 2020. Construction began in spring 2021, and the buildings are expected to be occupied by the beginning of the spring 2023 semester.

4 STRUCTURAL SYSTEM SELECTION

Glulam and CLT Framing in the John and Lile Gibbons Center for Arctic Studies

Mass timber was identified early in design as a desirable structural strategy due to Maine's rich logging history and Bowdoin's long-standing relationship to the surrounding forests. In addition to the aesthetic and cultural benefits, mass timber provided an opportunity to align with Bowdoin's commitment to environmental stewardship. To validate the use of a mass timber structure, and to confirm it could be done within the project budget, the design team investigated two structural systems early in design: mass timber and structural steel. Both systems were evaluated for design, function, cost, and embodied carbon content before a selection was made.

MASS TIMBER

The mass timber structural option consisted of glulam beams and columns supporting the above-grade floors. The gable roofs were supported by custom glulam trusses or ridge beams and rafter beams, allowing for column-free spaces in the event space and museum galleries. Columns were placed at a 10′ spacing in one direction to minimize the structural depth and eliminate girders in that direction. Floor decks were 5-ply CLT panels topped with a 3″ concrete topping slab over an acoustic mat. Both the deck assemblies and the glulam framing members were sized to achieve an inherent 1-hour fire rating.

The basement level was framed using traditional steel and composite slab construction. Steel hollow structural section (HSS) columns were aligned with glulam columns above and supported composite steel beams at grade-level. Basement walls and footings were designed as concrete elements.

Steel and concrete construction was chosen for the basement for three primary reasons. For construction and schedule, it was deemed advantageous to create a "podium" structure that could be erected and backfilled in preparation for the timber, which was expected to be a longer lead item. Second, because the basement houses the primary mechanical, electrical, and plumbing systems for the building, the shallower structural depths offered by a steel system were useful in keeping ceiling spaces open for ductwork and piping. Finally, the spaces housed in the basement are largely out of public view, meaning the aesthetic benefits of the timber structure were not as necessary.

STEEL FRAMING

The steel structural option consisted of steel beams and columns supporting the above-grade floors. Floor decks were 3.5″ concrete slabs on 3″ composite deck (6.5″ total thickness). Again, a 3″ concrete topping slab over an acoustic mat was utilized.

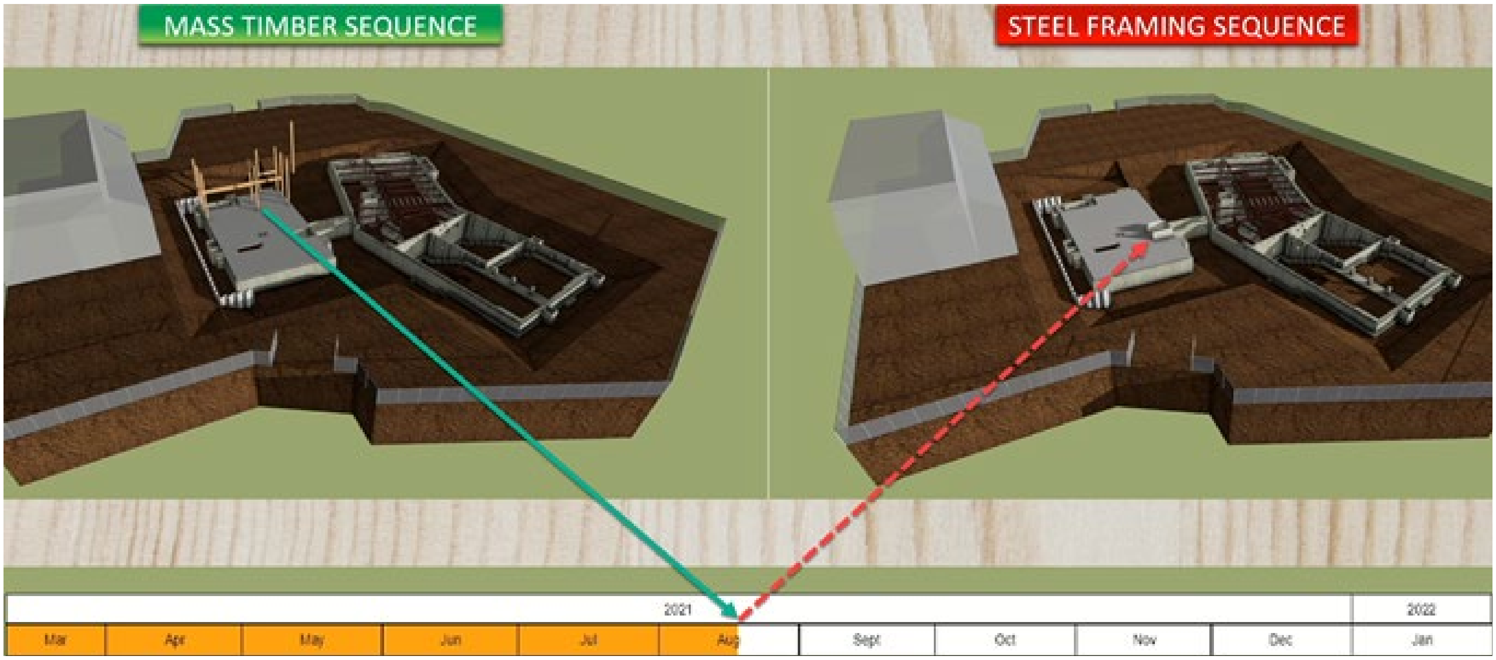
Because closely spaced columns were not required to reduce the structural depth, columns were placed at roughly a 30′ spacing. In most locations, the gable roofs were steel roof deck supported by steel ridge beams and rafter beams. At the event space, Architecturally Exposed Structural Steel (AESS) trusses supported exposed timber roof decking. All structural steel was spray fireproofed to achieve a 1-hr fire rating, aside from the exposed trusses at the event space, which were painted with intumescent paint.

The basement level was framed using the same steel and composite deck strategy as the mass timber option.

View of the Barry Mills Hall Event Space Under Construction

EARLY COST AND SCHEDULE EVALUATION

Cost comparisons considered two different structural systems that each addressed the project requirements for gravity and lateral loads, addressed program requirements (column spacing and open long span assembly spaces) along with architectural appearance. The entire structural framing system above the first level (excluding the basement) was the focus of the analysis, as it was assumed that the first floor (grade level) and foundation systems would be constant across systems. The variation in costs considered for the two systems is summarized on the next page.



STEEL, CONCRETE AND MASONRY STRUCTURE

A steel, concrete and masonry system was considered as the baseline option, whereby Consigli utilized a quantity-based measurement of all structural elements and applied historical unit prices along with vendor quotes for specialty items such as AESS. Concrete Masonry Unit (CMU) walls were chosen for the lateral system, whereby CMU was assumed for shafts for the elevator and stairs along with CMU shear walls constructed between columns at the ends of the building. Structural Steel wide flange columns were utilized in the baseline, composite steel wide flange beams supporting composite metal deck were the primary floor framing systems. Architecturally Exposed Structural Steel trusses were assumed for the long span roof framing at assembly spaces. Where columns were within the space of the program, the baseline cost model included light gauge framed and drywall column wraps. Additionally, intumescent paint was included on the exposed steel elements of the superstructure where 1-hour fire protection was required, along with cementitious fire proofing on the balance of the concealed structural steel.

PRICING ASSUMPTIONS

At the time of preparation of the two cost comparisons, Consigli predicted the costs of steel at the current erected price of $3,400 per ton (2019 pricing) and an AESS unit cost for exposed steel at the trusses of $6,000 per ton. The unit prices for CMU shafts and shear walls were carried at $25/square foot of wall.

The trade cost of the two systems resulted in an approximately equivalent installed costs of all elements that were considered variable between the two options (Consigli did not price in a cost advantage due to the shorter structural installation).

MASS TIMBER STRUCTURE

The mass timber option utilized a more closely spaced column grid that was optimized for the wood material. Quantity measurements for the volume of glue laminated timber beams and columns were completed along with quantifying the volume of cross laminated timber floor plates, roof plates, stair and elevator shafts and shear walls. Consigli solicited budgets for the mass timber supply from two vendors (one in the United States and one from Europe). Additionally, the installation of the mass timber structure was priced by Consigli's self-perform installation division.

PRICING ASSUMPTIONS

At the time of the initial project budgeting / options analysis (2019), the timber cost estimates were quoted at the then current-market for lumber of $400/ thousand board feet. The initial budgets received for fabrication and delivery translated to quotes of approximately $45/cubic foot for glulam and $35/cubic foot for CLT elements which included manufacturing, fabrication and delivery. The installation costs inclusive of general conditions, mobilization, crane and rigging were priced based on historical crew sizes, and quotes on crane rental. The installation cost of the timber structure based on the production rates turned out to be approximately 35% of the total cost of the mass timber fabrication and delivery pricing.

4D CONSTRUCTION MODEL

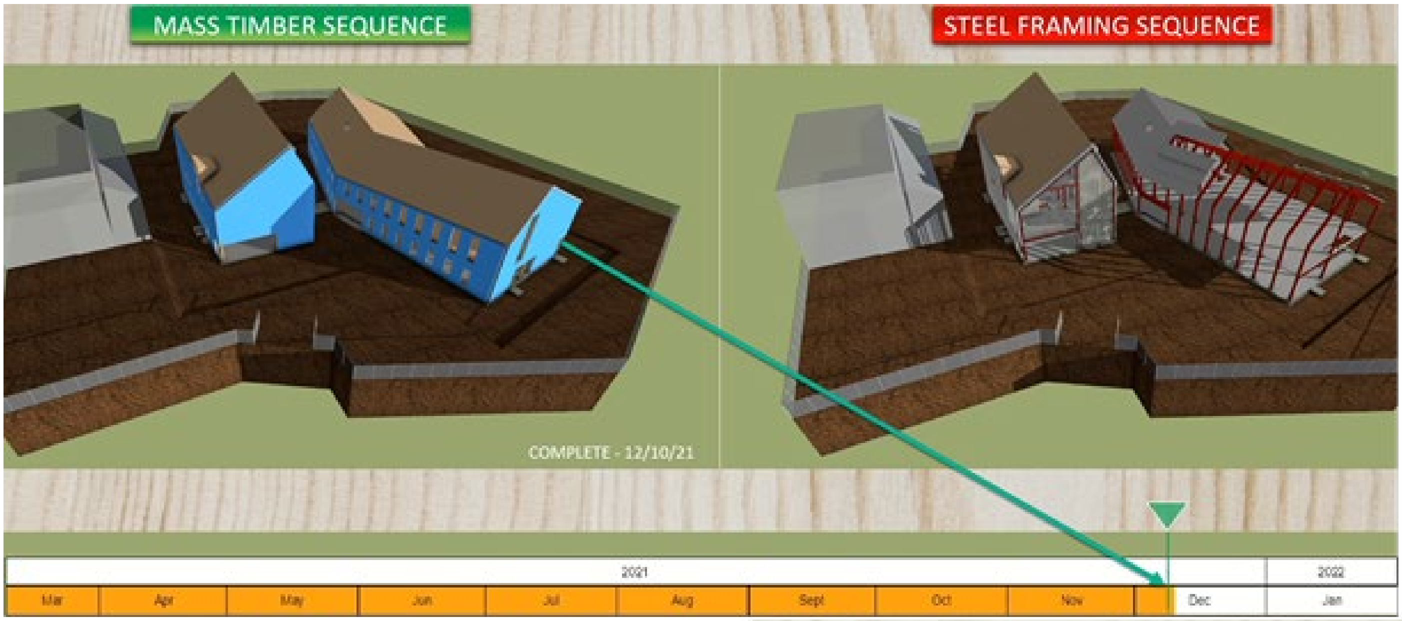
Finally, in order to complete a total cost evaluation of the two systems, Consigli prepared a schedule for each system inclusive of the building envelope, consisting of light gauge metal exterior framing, air vapor barrier on walls and a primary roof vapor barrier, along with exterior roof insulation and a secondary water barrier. Consigli ran both schedules utilizing historical piece-count installation production rates, along with known production rates for the CMU installation utilizing historical production rate history from previously self-performed CMU shaft and shear wall projects. As scheduling efforts progressed, the project management and self-perform team of Consigli spent significant time iterating through the many options of sequencing the steel, concrete, and CMU system installation and determined that numerous sequences could be implemented. When each option both for the steel and CMU were contemplated, the sequencing of handoffs between trades presented risks and potential trade flow inefficiency. Regardless of the potential risk of the handoffs between trades, the schedule for the steel and CMU option did not build in any contingency for these stop and start risks, and a continuous operation between trades was modeled (which was likely optimistic, but was seen as the correct method to evaluate the comparison to the timber option).

Predicted through the scheduling exercise there were very few instances where trade flow risk was evident with a single installer / erector for the timber option. This was noted as an advantage during the modeling of the schedule. The assumption was that a single installer would be responsible for the glue laminated timber columns, beams, CLT floors and CLT roof plates, along with the lateral systems consisting of the CLT elevator, stair and shear walls.

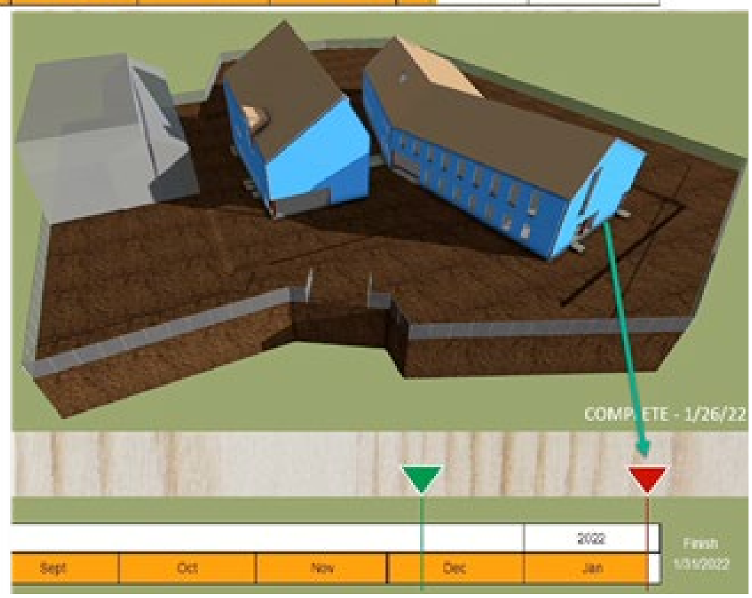
The timber option presented in the preconstruction scheduling showed a six-week advantage (without any penalties applied to the steel and CMU option for the risk of trade flow interruptions at handoffs). In order to communicate the schedule advantage of the timber option, since visualization of schedule benefits via a Gannt chart is very difficult, a graphical comparison of the superstructure installation for both options was created. The design team's 3D model was tied to each of the CPM schedule activities, and the installation sequence was animated in a video called a "4-D model". In the animations, the structural sequence is modeled from foundations through installation of the envelope. The schedules for each option were predicted to be the same from the start of foundations through the completion of the first building's first floor concrete slabs (see image below). On August 15 the schedules diverged, with the start of the timber column installation, and for the steel option the start of the CMU elevator began, which were required to be in place to support the second floor steel (note that the scaffolding that would be in place for the CMU shafts is not modeled for clarity).

Click HERE for link to 4D Construction Model Video

View of the Composite Steel Floor in Barry Mills Hall



For the purposes of the schedule comparison, "completion" was defined as the date on which the air vapor barrier on the insulated roof was completed. Neither option could be predicted to have a completed envelope by the ideal completion date of November 15 (the date Consigli uses to indicate when winter condition risks begin for the central Maine region). Consigli typically predicts the additional costs for temperature sensitive work such as slab placements that are scheduled to start after November 15. Temporary blankets, and heat are included beyond this date due to the risk of below freezing temperatures. The timber option predicted an envelope complete date of December 10, whereas the steel option did not complete envelope work until January 2023.



Although the six-week schedule advantage could be theoretically predicted in the initial modeling, there still remained many risks in the project at the early schematic design phase, so only 1/3 of the schedule/cost reduction was modeled in the cost comparison. Two weeks advantage was costed due to the unknowns that were still remaining in terms of coordination, permitting, final sizing of timber, material sourcing and most importantly buy in from other involved trades. The significant advantage that the construction team was that with a completed CLT floor plate, follow on trades could advance earlier. Additionally, the timber option allowed the earlier advancement of exterior enclosures and rough-in and provided an advantage for enclosing the building as the project advanced into the winter months.

For the Steel and Concrete option, a disadvantage was that the placement of concrete elevated slabs would have occurred in December and January and would require significantly more temporary heat and temporary enclosures in order to place the concrete decks, in addition to needing to hold off on installation of MEP trades for rough-in.

ASSUMPTIONS / ANALYSIS DETAIL USED DURING THE INITIAL SCHEDULE ITERATIONS

- Site mobilization of March 16, 2020 (Unfortunately COVID shut down the project on March 13, 2020 and we did not mobilize in 2020 – The project was back on track in late 2020 and actual mobilization occurred on March 21 2021)
- The work at the grade level up to the first-floor concrete slab on deck is the same for both timber and steel options. The CAS building would be complete to the first deck by August 15, 2021 and Barry Mills Hall first-floor concrete would be completed by August 25, 2021
- One week mobilization for timber installer to allow for layout of the timber structure and organizing of the deliveries and preparation of the site for erection.
- Install of timber beams, columns and floor plates (15 pieces) per day
- Installation of the second building was initially assumed to start prior to the completion of the first structure (This assumption did not prove to be possible due to shipping / supply chain problems occurring at the port receiving the mass timber.)

ASSUMPTIONS MADE FOR THE STRUCTURAL STEEL AND CONCRETE SCHEDULING

- In order to complete the structural steel second and third level framing, the mason would need to start work and advance shafts ahead of the steel erector to provide support for deck support steel and floor framing members.
- Shear walls designed to be built between columns and tight to the beams above could not start until after the concrete floors were placed.
- Four trade contractors required sequencing / hand offs (plus the requirement of General Conditions installation of temporary enclosures for slab placements).
    - Mason must install CMU shafts prior to the start of steel erection
    - Steel erector lays steel deck, and finishes the installation of the steel frame prior to the elevated slab reinforcing or in-floor conduit being started.
    - Concrete place and finish of elevated floor slabs must be complete before the mason can return to install second floor level shear walls between steel columns.
    - Concrete place and finish activities must be complete prior to the framing of the balloon framed light gauge metal exterior walls, due to anticipated deflection in the steel after slab placement.
    - Temporary protection walls at exterior were required to allow for cold weather concrete placement.
    - Flatwork subcontractor places reinforcing mesh and places concrete topping and finishes the elevated concrete slabs.

An advantage for the timber option that was not obvious at the time of the schedule modeling was that the electrical contractor was more productive with the installation of "in-floor" conduit that was laid out on the CLT decks prior to the placement of the concrete topping slabs. Traditionally, the electrical contractors need to walk on the surfaces of irregular metal deck in order to run in-slab conduit. In retrospect, we were likely predicting a faster installation of the steel and concrete option due to the lack of information available at the schematic design phase that was ultimately required for the in-slab conduit. The electrical scope had not yet been detailed for the numerous floor boxes, and in-slab power runs across the open second and third floors at the time of modeling.

EARLY LIFE CYCLE ANALYSIS

With Bowdoin's commitment to a carbon free campus, the potential carbon impact of using mass timber was a very important element in the decision-making process. To confirm the extent of the carbon benefits of mass timber, if any, an early-phase Life Cycle Analysis (LCA) was conducted for both the mass timber and steel options. Further discussion of the LCA approach and methodology are included in the Appendix.

Because this study was done early in the design process, during Schematic Design, it was not realistic to perform a full-scale LCA on the entire building extents for each option. Many pieces of the design were still falling into place, and the results from such a large model would likely not be practical or informative. Rather, the decision was made to study a representative section of the building structure in order to quantify the relative difference between the two structural options. A 30-foot-long section of the design for Barry Mills Hall was modelled for each option in Revit, and the Tally plug-in was used for this comparison. It should be noted that, because suppliers and subcontractors had not yet been selected for any of the structural elements, industry average values were used in the study to determine embodied carbon content and travel distances.

The results of the LCA indicated the mass timber structure offered significant embodied carbon savings over the steel structure, nearly an 80% reduction. While this comparison was early and approximate, it offered confirmation that a mass timber structure would help to further the environmental mission and goals of Bowdoin College.

> With the thorough study of costs, schedule, embodied carbon impacts, and aesthetics done with the two early design concepts, mass timber was clearly an excellent structural solution for Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies . The approach for the final design is discussed in the following sections.


CLT Shear Wall Base Connection

5 STRUCTURAL DESIGN APPROACH

View of Mass Timber Framing Under Construction in the John and Lile Gibbons Center for Arctic Studies

Once mass timber was deemed as an appropriate structural solution, the design team began finalizing the details of the glulam and CLT structure.

SYSTEM DESCRIPTION

The final mass timber structure is constructed from glulam beams and columns, typically 300 mm wide. Above grade floor decks are 130 mm thick, 5-ply CLT panels, with a 3" concrete topping slab over an acoustic mat. The topping assembly was primarily driven by the location of the event space over an acoustically-sensitive cinema classroom. In other areas that did not require the same acoustic barrier, the topping slab was decreased to 2" thick, or the acoustic mat was removed.

The roof structure in the north wing of Barry Mills Hall consists of rafter beams supported by building columns. In the south wing, the roof is supported by custom, asymmetrical glulam trusses with steel tension rods to allow for a column-free event space. The roof structure in the CAS consists of a center ridge beam supporting rafter beams on each side. Roof decks are 130 mm thick, 5-ply CLT panels.

Columns are located at a 10' spacing in the north / south direction to minimize the structural depth and eliminate girders in that direction, allowing for more unobstructed routing of mechanical and electrical systems across the width of the building. Column and grid spacing in the east/west direction varies. In nearly all spaces, the glulam columns, beams, and CLT decking are exposed to view.

CLT shear walls comprise the building's above-grade lateral system. These shear walls are 175 mm thick, 5-ply panels, oriented vertically. Walls are placed strategically throughout the building, and around elevator cores. In most cases, at least one face of the wall is left exposed to view.

The structural analysis of the mass timber structure was completed using the RISAFloor and RISA3D modeling platforms. Gravity beams and columns were modeled and sized in RISAFloor, while RISA3D was used for lateral analysis and design of the custom roof trusses.

View of Mass Timber Framing Under Construction in John and Lile Gibbons Center for Arctic Studies

SUPPLIER COORDINATION

The mass timber supplier, producer, and connection engineer were all brought onto the project team at the beginning of the Construction Documents phase of design. This allowed for coordination and collaboration between the design and construction team during the final stages of design. As a result, the design team was able to issue a more streamlined set of construction documents, rather than spending time during construction working through details. The early involvement of the supplier, producer, and connection engineer were especially valuable because all of the mass timber elements were being sourced from Austria.

Sourcing the timber from Austria posed one main challenge: the wood species supplied by KLH and Wiehag was to be Austrian Spruce. Not only was this species different from the original, structural design assumptions, but it was specified to a different grading system than is typically used in the United States. Reference strength and stiffness values had to be converted and adjusted to align with NDS design standards. Furthermore, the timber elements coming from KLH and Wiehag would be of metric dimensions.

The ability to redesign all of the timber elements based on the design properties and dimensions of Austrian Spruce allowed the design team to fine tune coordination items prior to the onset of construction, such as finalizing partition wall locations, and making adjustments to mechanical, electrical, and plumbing routing around new beam sizes.

> Collaboration with the supplier and connection engineer was also valuable, as it allowed HGA to tailor the construction documents to better align with the erector's preferences for hardware and sequencing, saving valuable coordination time during construction. With an understanding of hardware and detail preferences, the design team was able to incorporate these preferences into the documented construction details, and coordinate opportunities to conceal connections where necessary ahead of time.

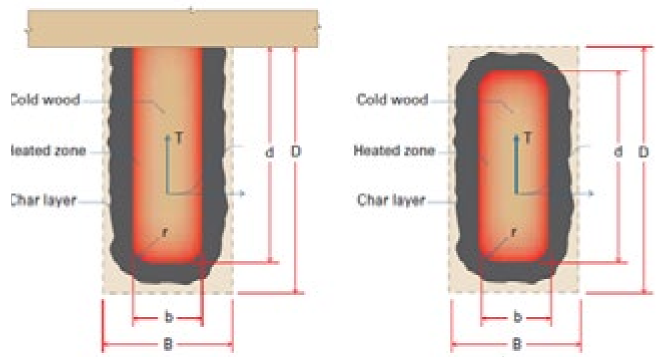
FIRE RATING

Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies were designed under construction Type V-A. As such, the primary structural frame (columns, floor and roof beams, and floor and roof deck) are required to hold a 1-hour fire rating.[2] As previously noted, this rating typically comes from a sacrificial layer of timber that chars and acts as an insulator, protecting the structural portion of the member from heat and fire.

A number of mass timber suppliers have undergone testing to prove and quantify the fire rating for various assemblies.[3] Where data exists, these test may be used to justify a fire rating. However, the exact thickness of this protective char layer is more often calculated with analytical methods, which have been developed using third-party testing data, material properties, and engineering principles.[4]

Most frequently, building codes will allow for this char thickness to be calculated using the provisions in Chapter 16 of the National Design Specification for Wood Construction (NDS). These provisions allow the engineer to determine a char thickness based on the required rating and the thickness of the laminations comprising the timber member. Once the thickness is determined, the engineer must then account for this additional thickness on all exposed sides of the member in question.

Though the char method detailed in Chapter 16 of the NDS is accepted by most jurisdictions, the Maine State Fire Marshal also required that the provisions of National Fire Protection Association 220 (NFPA 220) were met for this project. NFPA 220 requires that fire resistance ratings of structural elements and building assemblies be determined in accordance with NFPA 5000 or NFPA 101. Instead of NDS Chapter 16, these provisions reference the char calculation method in American Society of Civil Engineers (ASCE) 29. The method specified in ASCE 29 is based on similar principles as the NDS method. However, ASCE 29 relies on member dimensions and a defined load factor[5] rather than the thickness of the individual laminations.



GRAPHIC DEPICTING CHAR METHOD[6]
CLT Handbook, FPInnovations & Softwood Lumber Council

Glulam Column Splice

6 FULL-BUILDING LIFE-CYCLE ANALYSIS

View of Mass Timber Framing Under Construction in the John and Lile Gibbons Center for

Life Cycle Analysis (LCA) has become a widespread tool used by designers and engineers to measure the embodied carbon impact of a building structure. Until recent years, sustainability efforts in the building environment have focused on operational carbon: the carbon required to operate a structure, such as mechanical and electrical equipment, etc. Improved operational efficiency over the last few decades has led design professionals to look for other ways to address sustainability in projects, namely, embodied carbon. Embodied carbon refers to the carbon required to produce, transport, install, and recycle building components. Given that embodied carbon in the construction industry accounts for 11% of CO_2 emissions worldwide,[7] it is a worthwhile effort to reduce embodied carbon in our buildings.

Mass timber has been purported to offer significantly lower embodied carbon than other traditional construction materials. Just how much of a reduction is project specific. To quantify this reduction, life cycle analysis is used to measure the total embodied carbon for the materials and processes used on a project. An LCA reflects embodied carbon for each life cycle stage in the building process, from extraction, to manufacturing and construction, to recycling and disposal. This "Cradle-to-Grave" approach gives the design team a complete accounting of the embodied carbon of the structure throughout its expected lifespan, measuring the Global Warming Potential (GWP) of the building in equivalent kilograms of equivalent CO2 or kg CO2 eq.

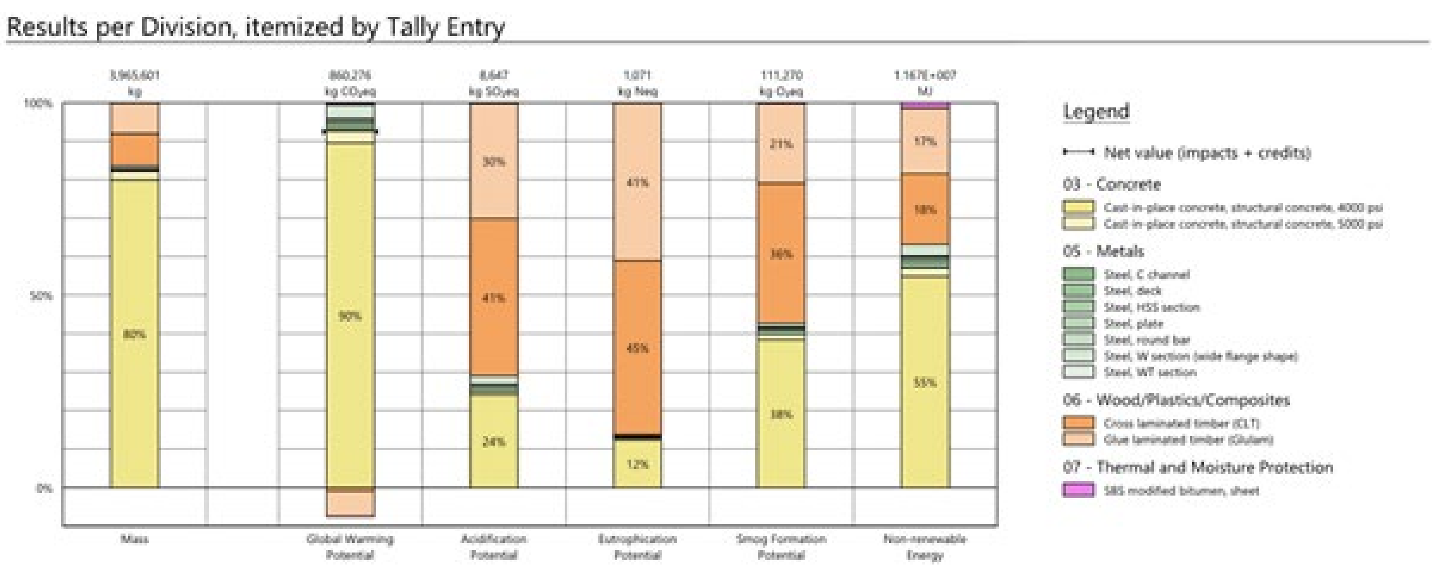
As discussed earlier, the design team employed life cycle analysis early in the project to gain a qualitative understanding of how a mass timber structure would impact the carbon footprint of the building, compared to a steel structure. With the design completed and construction underway, a full-scale LCA of the final building structure was completed. Methodology for this LCA and the complete report can be found in the Appendix.

RESULTS

The full-building LCA report contains an analysis of the carbon required to produce, transport, install, and recycle all of the structural building components used in both Barry Mills Hall and the John and Lile Gibbons Center for Arctic Studies . While this report examines a number of sustainability metrics, the Global Warming Potential (GWP) was the team's primary focus, as this value is a measure of the embodied carbon required for the project.

As seen in the complete report, the primary contributor to structural GWP on the project was concrete (foundations, basement walls, floor slabs, etc.), contributing 800,531 kg CO2eq. The structural steel used on the project accounted for 55,868 kg CO2eq, and the timber accounted for -64,738 kg CO2eq. Note that, like the early design LCA, the embodied carbon value assigned to the timber is negative, meaning that the timber has sequestered more carbon than was required to fabricate and install it in its final application.

In the early design model, it was estimated that the timber would remove approximately 4.2 kg CO2eq per square foot of structure. In the full building analysis, however, the timber removed approximately 1.4 kg CO2eq per sqft, significantly lower than what was seen in the results of the early design LCA. This difference can be attributed to two main factors.



LCA Results per Division (Full Building Analysis) – HGA

First, the early design LCA was performed in a section of the building that did not have a basement. Thus, the additional embodied carbon due to the concrete basement walls and steel floor framing was not accounted for. This decision to exclude the basement was made intentionally during schematic design. As discussed earlier, the early design LCA was done with the express purpose of comparing the embodied carbon values of a steel structure to that of a comparable mass timber structure. Given the basement framing was to be the same in either scheme, the decision was made to perform the LCA in a bay that did not have a basement, allowing for a clearer comparison between the superstructure options. Removing the basement square footage from the full building LCA results in a value of approximately 2 kg CO2eq per sqft removed by the timber. This is closer to the early estimate, but still noticeably lower, which leads to the second factor.

The early design LCA was based on a schematic-design-level building and industry-average emission data. At the early stages of design, when construction logistics and subcontractors are typically far from settled, this was deemed an appropriate avenue for estimating embodied carbon values. Once construction was underway, the analysis for the full building LCA was adjusted to include specific data from selected manufacturers, where available, and specific shipping methods and travel distances. This was especially impactful for the timber, which was sourced from Europe. During construction, the exact travel distances and modes for the timber transportation (i.e. how many miles were traveled each by truck, rail, and ocean freight) were determined with information from the supplier. Understandably, these distances were much further than those included in the early LCA, where a North American supplier was assumed. This is illustrated in the results for both LCAs. In the early design LCA, transportation of wood elements accounted for approximately 0.3 kg CO2eq per sqft, while in the full building analysis, transportation for timber accounted for approximately 1.7 kg CO2eq per sqft.

Despite the increase in embodied carbon due to transportation of the timber, the mass timber elements of the structure still reduced the overall embodied carbon by nearly 10%. The contribution of the timber elements, -64,738 kg CO2eq, is equivalent to removing 15 passenger vehicles from the road for a year, or saving 7,833 gallons of gasoline.[8] With the arrival of new mass timber suppliers to the North American market, it is expected that these values will improve.


View of Mass Timber Roof Framing in the Center for Arctic Studies

7 CONSTRUCTION PLANNING & EXECUTION

View of Mass Timber Framing Under Construction in the John and Lile Gibbons Center for Arctic Studies

At the time of writing of this report, all structural and weatherproofing work is complete, and the project is four months from completion. Although not complete during the grant period, the construction team learned a number of lessons that will be carried forward to future projects.

During the preconstruction planning phase, the Construction Manager (CM) is focused on risk management for the project. It is the CM's responsibility to manage cost and schedule risk along with planning for a safe and high-quality construction installation. On any project, where a product or a construction methodology that is new to a market (in this case the Northeast), the level of scrutiny and time spent planning and evaluating risks related to pricing, manufacturing schedule and quality control is intensified.

With higher levels of scrutiny for new products, cost and schedule contingencies tend to be placed on the new material or process. However, the advantages that the new product or process may bring to the project may be under-weighted, and may not be fully recognized in the schedule. When there are experienced professionals on all parts of the project team and a high level of trust across owner, designer, and contractor, the advantages of a new system can be taken and risks can be mitigated.

For this project, the team spent considerable time evaluating two different structural systems and the Construction Manager focused on the pricing, availability, fabrication and scrutinized the critical path of the schedule advantages and disadvantages of each of the structural options. At the pre-schematic design phase, the design team, client, and construction manager communicated about the potential risks and rewards of each, and together put in place a plan to mitigate many of the cost and schedule risks. One of the risk mitigation methods implemented early on, was the decision to engage the mass timber supplier at the end of the Design Development phase. Integrating the Mass Timber supplier within the team after the Design Development phase allowed the team to eliminate cost, schedule, and many coordination concerns while the final design documents were being created. A key to enabling this early procurement was the willingness of the client to allow the Construction Manager to issue a procurement RFP for the mass timber supplier on a reimbursable "Design Assist" basis ahead of the finalization of design and prior to the CM establishing a Guaranteed Maximum Price for the overall project.

The CM and Design team generated a list of design decisions and risks that needed to be established so that the iterative process of design could progress through the completion of Construction Documents. One of the most significant unknowns early was the range of performance characteristics, appearance and size availability of the elements and cross laminated timber plates, their delivery schedule, price and detailing of the connections.

Since the Structural Engineer and the Construction Manager had sufficient information about the available size strength and stiffness range of available mass timber elements that would be available from the vendors being considered for the project, a basis of Design scope of work was defined in the Design Development package and was issued to mass timber suppliers, fabricators and integrators via an RFP. Proposals were reviewed from five proposing teams and a commitment was made to the mass timber supplier at the end of Design Development. The selection of South County Post and Beam included the commitment to a CLT manufacturer (KLH), a Glulam Manufacturer (Wiehag) and a delegated connection design engineer (Fire Tower Engineering).

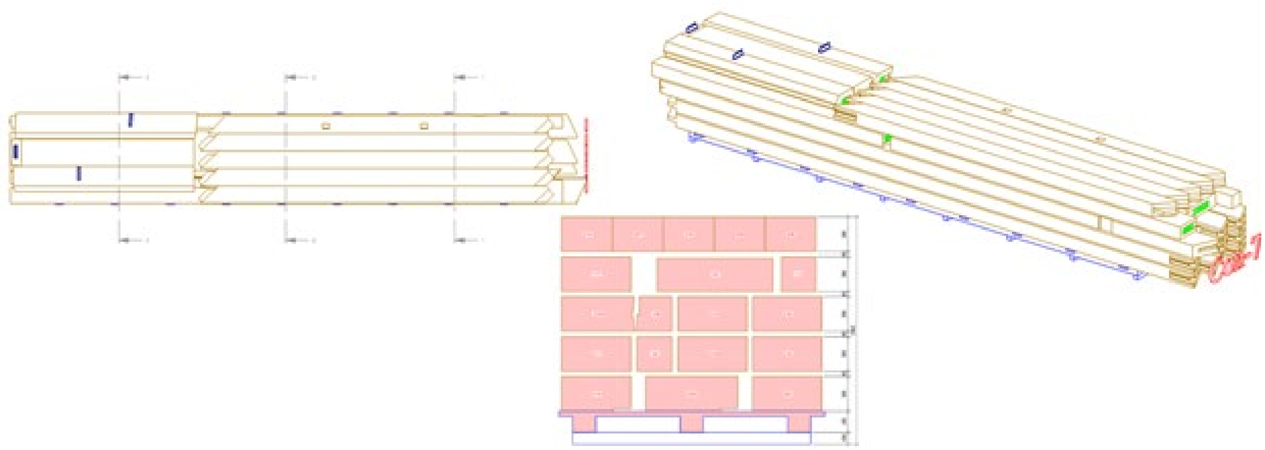
With the highly variable size availability of structural elements and a limited market of local CLT and Glulam manufacturers, it was necessary to integrate the selected manufacturer's product sizes into the detailing of the final construction documents. Numerous design, fabrication, logistical and installation details were evaluated and integrated into the final design. Some of the decisions and activities that were able to be completed during the Construction Documents phase included the following:

Species / Finish Selection: Selection of Austrian Spruce for the CLT and Glulam: Many species options were considered in the RFP, samples were received and strength parameters of the species were considered. Through the selection of the Austrian manufacturer, Austrian Spruce was integrated into the final design including use of the same species in the millwork and custom door slabs.

Structural Detailing: Commitment to the types of connections for all superstructure elements were reviewed and exchanged between the Delegated Design Engineer and the Engineer of Record. Additionally, the team evaluated numerous options for connecting the superstructure to the foundation. The selection of column base assemblies, anchor bolt and lateral restraining details were determined. Identifying all of the foundation connection details allowed the Construction Manager to clearly delineate the ownership of the scope of work assigned to other trades including the concrete foundation subcontractor and the miscellaneous metals supplier. The selection of economical base plate / column base products that the fabricator and delegated design structural engineer had experience with, allowed those specific details to be integrated in the Construction Documents.

Engineering / Conversion from European Glulam Standards: Glulam manufactured in Austria conforms to a European standard that requires conversion to U.S. standards under the American Society for Testing and Materials (ASTM). The utilization of a European glulam product and standard metric sizes available from the Glulam vendor required the conversion of the strength standards to be converted from European standard to ASTM in order to finalize sizing for the superstructure. This required an iterative process between HGA and the Design/Assist engineering team led the Delegated Connection Design Engineer.

Cross Laminated Timber Shipping Plan



Glue Laminated Timber Shipping Plan

Optimizing Sizing of Mass Timber Elements: Sourcing the material from a European supplier presented a number of design constraints on the project. At initial pricing, elements that were larger than the size of a standard shipping container presented a cost premium for shipping. Through the Design Assist effort, we were able to incorporate splicing and connection details to optimize the cost of shipping. The modifications focused on limiting the sizes to fit within shipping container. Many of the longer roof beams and connections were refined to accommodate splicing and connection details that made for a more economical shipping solution. (See above for the shop drawing created for the loading and sequencing container packing).

Logistics Planning: Mass timber installation requires more careful handling, protection and therefore more planning for erection efficiency than what would be required for a steel framed structure. The timber beams, columns and CLT plates are the final exposed finished elements and therefore required minimizing handling and planning for laydown and protection. A detailed laydown plan was created for the project and the sequencing and loading of containers was incorporated into the planning.

Currency / Exchange Rate Volatility: The RFP issued to the mass timber suppliers included vendors located in the United States, Canada, Austria and Germany. It was recognized that the price of the supply contract was dependent on the currency exchange rate between the U.S. Dollar and the Euro. The RFP requested the proposers from Canada and Europe to peg the supply price to an exchange rate on the date of the RFP response and adjust the final contract value at the completion of Construction Documents and establishment of the Guaranteed Maximum Price.

All of the above were risks that were known at the beginning of design that were mitigated through the early procurement of the mass timber vendor. During the preconstruction phase, a global pandemic occurred, forcing the shutdown of the project and resulting in numerous global supply chain anomalies that were significant disruptions to many construction projects. We have since generated a number of additional risk-mitigating strategies to handle these new challenges.

Source: www.tradingeconomics.com - "Chicago Lumber Futures"

Commodity Price Risk Management Lesson Learned: Prior to the recent highly variable an unpredictable price volatility in the lumber market (see chart above) Mass Timber suppliers were asked to fix prices at the time of engagement on a project. The time between engagement and when the raw material for the project is procured can vary widely across projects. The price volatility has caused most fairly handle the fixing of pricing of a manufactured product such as mass timber. With changes in the highly variable commodity markets future projects will be procured with a reference commodity price that the pricing is established on. For instance, in RFPs going forward, a reference commodity price for the lumber will established along with a request for mass timber vendors to identify how the commodity price will affect the overall project price given the quantity and grade of lumber included in the price proposal and a method and timing for final adjustment to the supply price of the project.

Logistics and Shipping / Timing of Deliveries: The critical path of the construction schedule runs through the erection of the superstructure. The construction team planned for a start of erection of the superstructure 12 months prior to the delivery of the material. Focus was placed on the delivery date, the quantity of pieces installed per day. The completion of the superstructure erection drove the date that the "weather tight" milestone. However, even with this intensive planning, changes outside the control of the construction team can cause changes to the planned installation. Two major issues occurred that dramatically affected the planned installation

- A global container shortage prevented the mass timber manufacturer from being able to deliver the mass timber in shipping containers. In early 2021, a disruption in the global shipping industry caused the logistics company that the mass timber vendor was relying on for transporting the Glue Laminated Timber from Austria cancelled their contract for delivering containers. The entire project had been planned around a sequence of container deliveries and all of the beams, columns and floor and roof plates were organized in a container sequence and packing plan that aligned with the erection sequence. In order to deliver the mass timber, the manufacturer decided to Ship the project via a different method of "break bulk shipping" which changed the way the mass timber was delivered as palletized components. The palletized material was packed on "Roll on Roll Off" ships. This changed the method of delivering the project and resulted in a two-week delay in the start of erection. However, the erection duration for the project proceeded faster than was originally planned and the two weeks were made up during the erection sequence.

Shipping and Delivery Lesson Learned: When ordering material being delivered from international vendors, there are more factors that can come into play with the delivery of a critical path / schedule critical component**. Manufacturing / final fabrication of elements require more float in the schedule need to be planned for. Although this could be seen as an issue for mass timber being delivered from European vendors, there was a similar structural steel supply chain disruption that occurred in a similar time window related to delays at border crossings between the U.S. and Canada.

**NOTE: Even though a two-week delay was incurred by the change in shipping method, it was mitigated by a faster erection duration. There were two additional factors that affected the installation of the building envelope (which was the true measure the construction team was focused on, as it triggered the ability for follow-on subcontractors to begin work). In March of 2021 a supply chain disruption in raw materials that were critical to the manufacturing of polyisocyanurate insulation, along with a significant demand increase for the material extended lead times from four weeks to eight months for the nail board product (bonded polyisocyanurate and sheathing material). This issue was mitigated through a change in the roof insulation product specification from Polyisocyanurate Nail Board to Extruded Polystyrene along with a change in the fastening methods and the choice to change the method of installing the insulation and roof sheathing to be individually in built up layers. The roof insulation disruption caused a delay in the completion of the roof envelope and was a more significant factor than any of the superstructure impacts from the shipping container and delivery delays.

8 CONCLUSION


View of Mass Timber Framing Under Construction in the Center for Arctic Studies

MASS TIMBER

80%

REDUCTION OF EMBODIED CARBON VS STEEL CONSTRUCTION

3

WEEK REDUCTION IN SCHEDULE

The recent revitalization of mass timber presents the building industry with a unique opportunity for creating beautiful, inviting spaces while simultaneously addressing schedule restraints, occupant safety, and the impact of buildings on the environment. While there are numerous benefits that come with the use of this structural system, mass timber is an option that should be weighed carefully and implemented diligently. In the case of The John and Lile Gibbons Center for Arctic Studies and Barry Mills Hall at Bowdoin College, the benefits strongly outweighed the drawbacks, proving that mass timber has a place in the built environment. With engineers and project teams continuing to advocate for mass timber, the industry will evolve to better support this economical, sustainable building system.

There are challenges in all projects with managing numerous suppliers, vendors and installers. The use of Mass Timber as a superstructure solution merely poses different challenges that those of multi-trade steel, concrete and CMU structures. There were significant benefits reaped through the offsite pre-fabricated CLT Floor Plates that were integrated and installed by a single supplier / installer. The speed of erection utilizing the mass timber shear walls as the lateral force resisting system presented one of the more significant schedule benefits. The precision manufacturing of openings in floor plates and in the beams and wall panels forced the construction team to accelerate coordination and make decisions earlier in the construction phase and resolve issues before they occurred in the field.

Forces outside of the control of design team and Construction Manager and unrelated to the selection of superstructure caused more challenges for the construction phase than anything that was planned or related to the type of structural solution chosen.   As of June 2022, the project remains on schedule and is anticipated to be completed on the original contract completion date, in large part due to the team put in place at the inception of the project when the Design team and Construction Manager were chosen by the client and provided the goals of the project and the requirements of the users of the building.

Appendix available upon request

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