George Brown Polytechnic

# Limberlost Place

## Life Cycle Assessment

Final Report

8 June 2026

Moriyama Teshima ARCHITECTS

# CONTENTS

# INTRODUCTION

LIMBERLOST PLACE

Limberlost Place is a new addition to George Brown Polytechnic's waterfront campus, and stands as a landmark tall wood, low-carbon building featuring ecological innovation across its entire life cycle. A model for 21st century smart, sustainable, green building innovation throughout Canada, the net-zero building also has a Made-in-Canada structural solution, where all the mass wood components have been sourced nationally. The large span, beam-less structure will enable demising walls to expand and contract, providing flexibility of sizes for a variety of learning spaces, and the angled apex of the roof structure speaks to future advancements of tall wood technologies as well as the development of net-positive and low carbon building methodologies.

This Life Cycle Assessment provides a unique opportunity to examine the carbon emissions of an as-built project and provide some insight into the 'reality' of the embodied carbon of a building beyond the design stage. The results allow us to validate where we are being successful in reducing carbon emissions and learn where improvements should be made.

# RESULTS SUMMARY

# RESULTS SUMMARY

Below is a summary of the overall results of the LCA. Further detail is presented in subsequent sections of this report

## PROJECT INFORMATION

| | |
|---|---|
| **Project Name** | Limberlost Place |
| **Architect** | Moriyama Teshima Architects |
| **Location** | Toronto ON, Canada |
| **Use** | Education |
| **Date of Assessment** | September 5th, 2025 |
| **Software** | OneClick LCA, Version: 1.16.0 |
| **Project Life** | 60 Years |
| **Assessment timing** | As-built |
| **GFA** | 18,900 m2 |
| **No. Storeys above grade** | 10 |
| **No. Storeys below grade** | 1 |

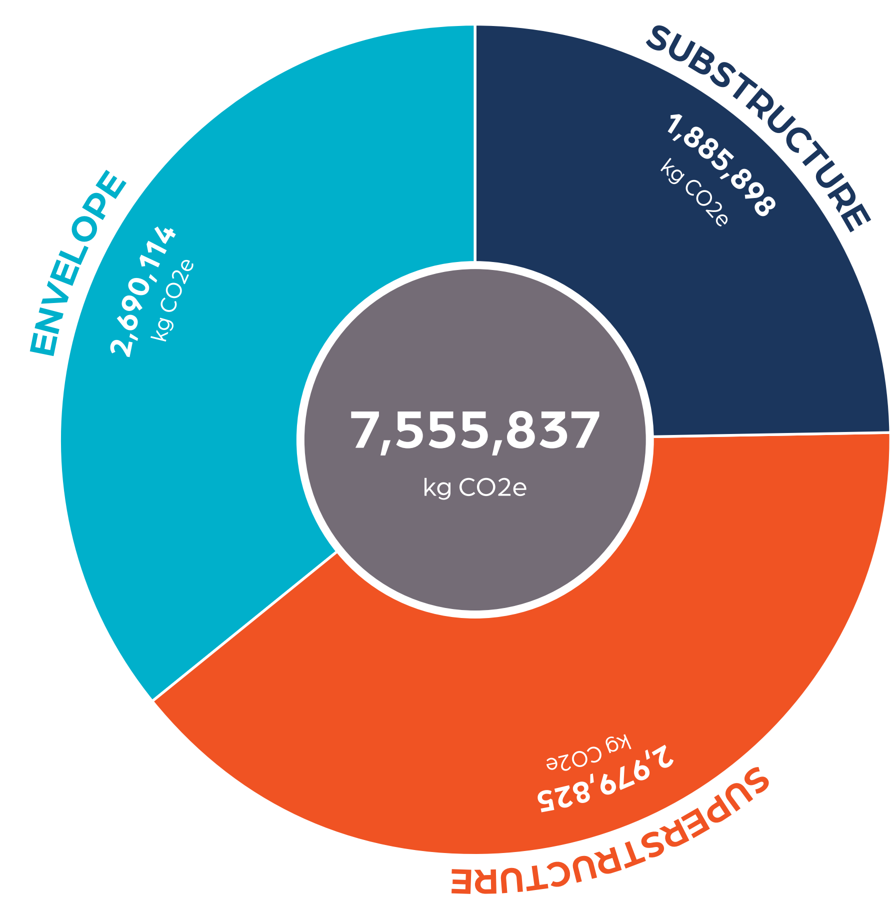
Total Embodied Carbon A-C (kg CO2e)

**7,555,837**

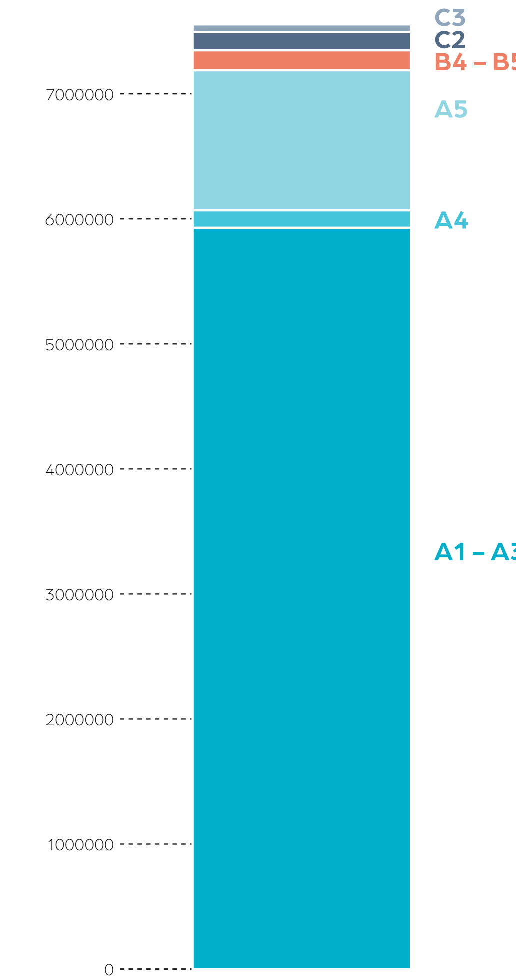
Total Embodied Carbon Intensity (kg CO2e/m2)

**399.78**

Embodied Carbon breakdown by building element




Embodied Carbon breakdown by stage

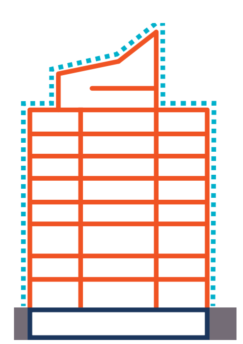



## INCLUSIONS

GWP

GLOBAL WARMING POTENTIAL

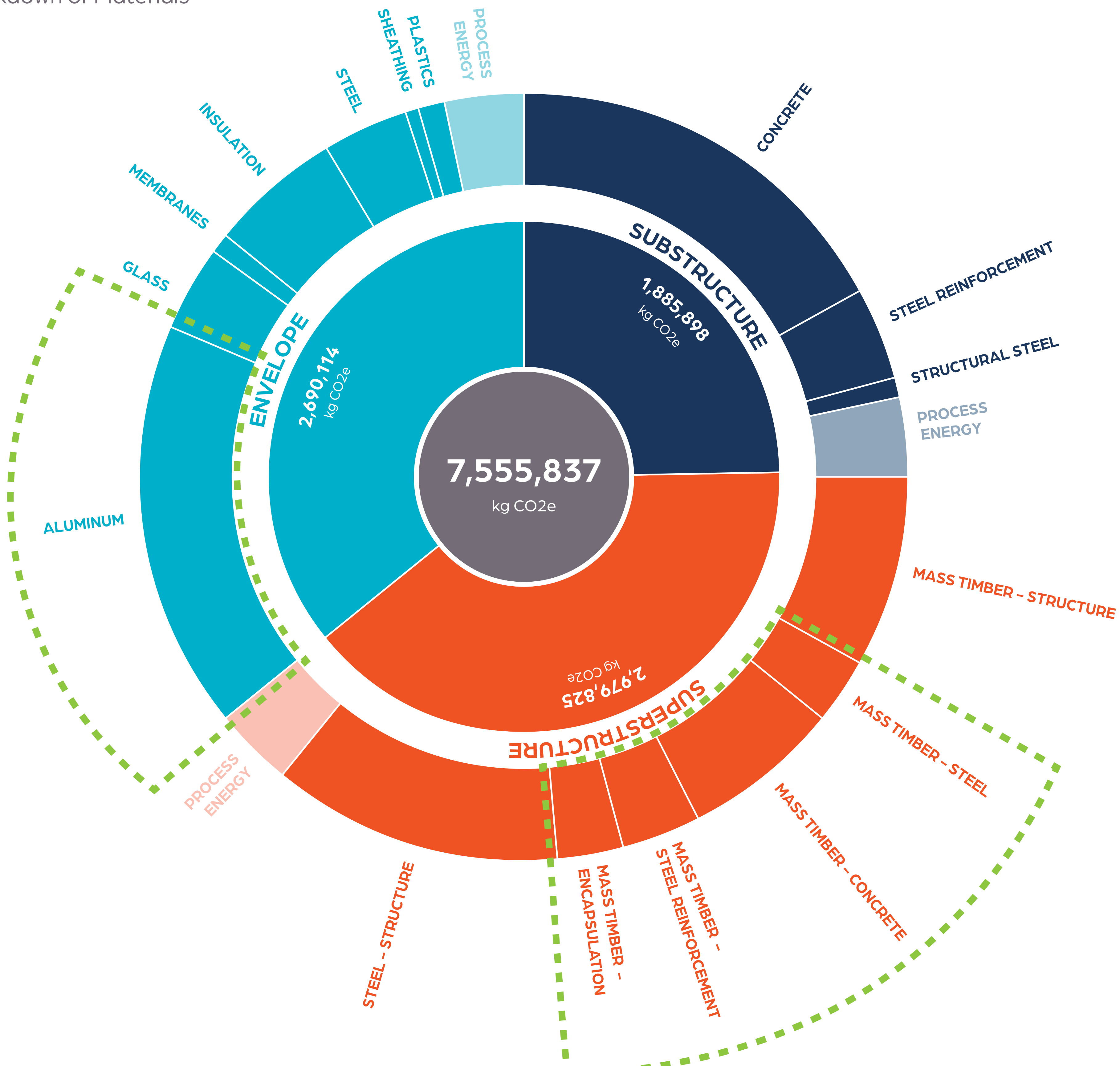

A1 - C4
CRADLE TO GRAVE



SUBSTRUCTURE
SUPERSTRUCTURE
ENVELOPE

Embodied Carbon Structure Comparison

Breakdown of Materials




In the chart to the left, the results have been further broken down providing more insight into the impact of materials on the overall embodied carbon of the building.

## ALUMINUM

The building envelope includes aluminum in the frames for the glazed elements as well as the cladding. As expected, the results for the envelope show that the aluminum contributes a significant amount of embodied carbon to the building.

## MASS TIMBER

The mass timber structure includes not only the wood for the mass timber elements but also steel connections, concrete column bases, concrete slab toppings and encapsulation required by codes. The results show that these elements contribute a larger amount of embodied carbon than the wood itself.

## CONSTRUCTION PROCESS ENERGY

Further explanation of the process energy is provided later in the report. For the sake of simplicity, it has been equally divided between the substructure, superstructure and envelope.

## BIOGENIC CARBON

The total biogenic carbon for this building was calculated to be 4,233,548 kgCO2e. Standards for how biogenic carbon can be included into embodied carbon calculations vary from place to place and as such, for this report, it has been shown as a separate value and was not included in the total embodied carbon calculation.

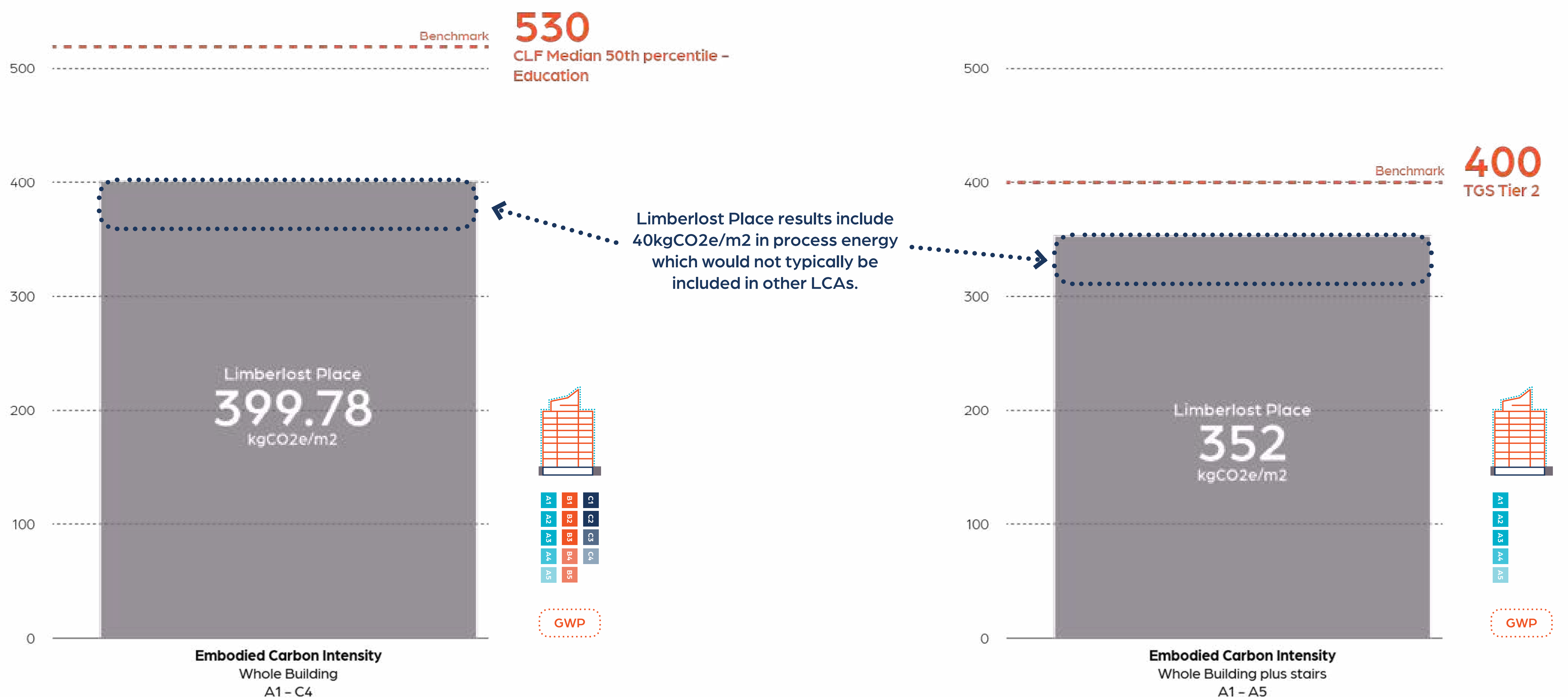
Total Biogenic Carbon (kgCO2e)

**4,233,548**

Reported separately and not factored in to total embodied carbon results

# RESULTS SUMMARY | METRICS COMPARISON

Comparison of results to other metrics




## CARBON LEADERSHIP FORUM

**WBLCA Benchmark Study V2**

The Whole Building LCA Benchmark Study V2 from the Carbon Leadership Forum provides embodied carbon benchmarks for buildings broken down into various different uses and includes the same metrics to calculate ECI as this report. The metric used for comparison was the 50th percentile for **education** buildings and the results of this LCA are significantly lower than the benchmark of 530 kgCO2e/m2.

## TORONTO GREEN STANDARD

**TGS Version 4**

In order to provide a comparison of the results to the Toronto Green Standard Version 4, the results were adjusted to be in line with the requirements of the standard. The embodied carbon for the **stairs** was added and only stages **A1 to A5** were included. The results shows that the Embodied Carbon Intensity for Limberlost Place was below the requirement for Tier 2 of 400kgCO2e/m2 for institutional buildings.

# 1.0 METHODOLOGY

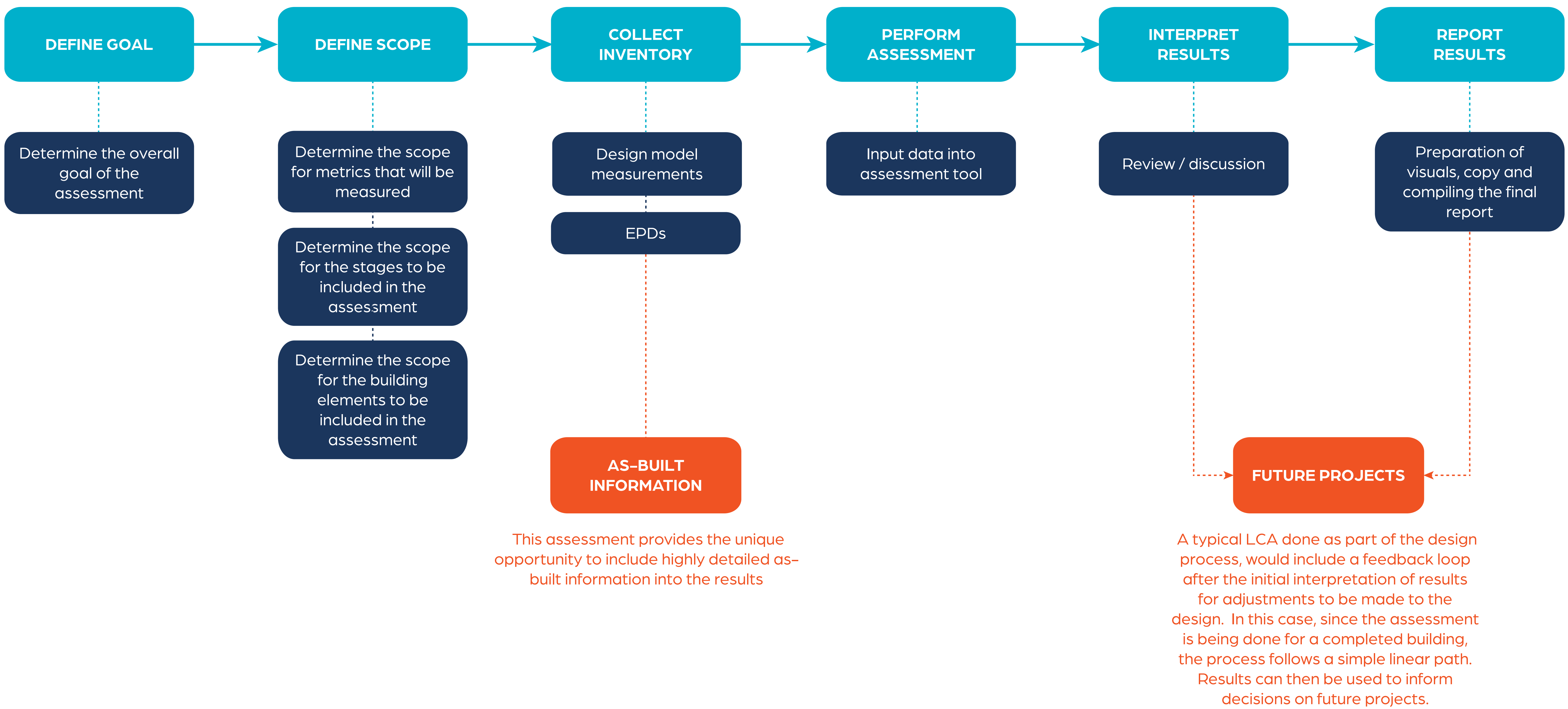
This section introduces the process of undertaking a Life Cycle Assessment

# 1.1 INTRODUCTION

Description of the process followed for preparing the life cycle assessment

## AS-BUILT PROJECT

The process used for this LCA follows a similar process outlined in the LCA Practice Guide published by The Carbon Leadership Forum. Since this LCA will be for an as-built project, the interpretation of the results will be used to inform future projects rather than as a tool to inform design decisions.



# 1.2 ASSESSMENT GOAL

Definition of the goal or goals of the life cycle assessment

## MASS TIMBER AND PREFABRICATION

It is tempting to try and have an all encompassing goal for a life cycle assessment however, especially for an as-built scenario, well defined goals are critical. The goals help guide both what is calculated and included in the assessment as well as what is ultimately reported.

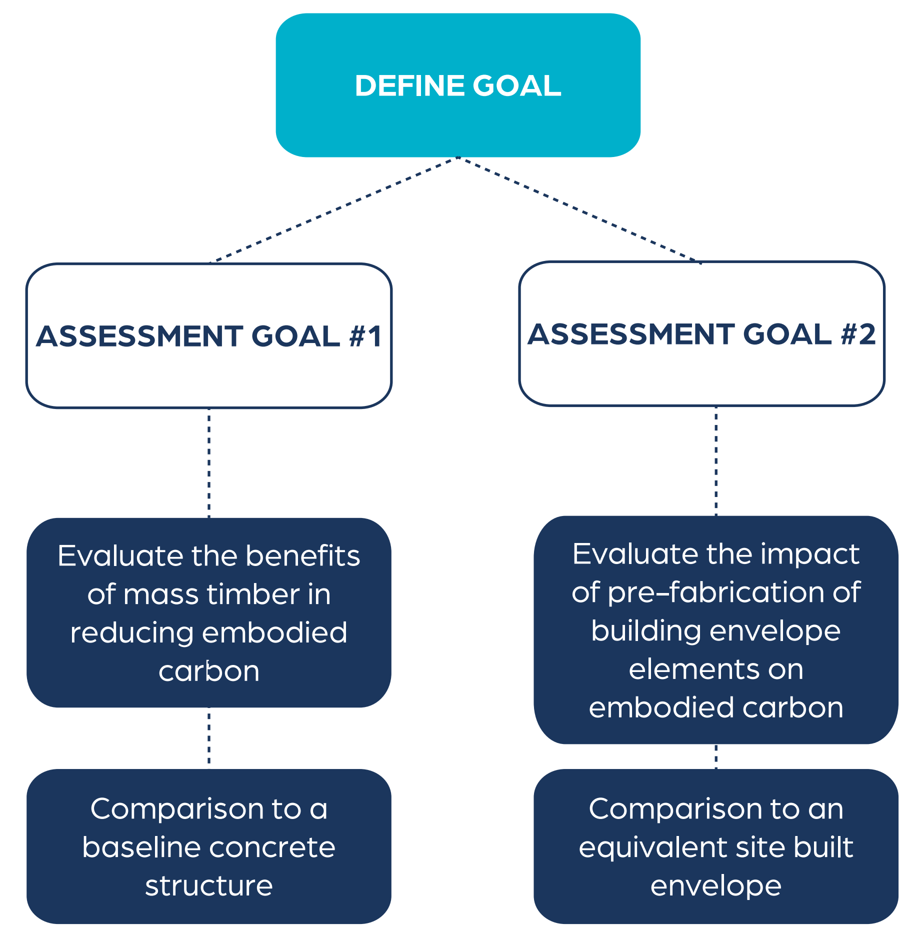
For this assessment, two goals were identified:

**1) Evaluation of the benefits of Mass Timber in reducing embodied carbon.**

As the adoption of mass timber as a replacement for concrete and steel structures increases, it is important to clearly evaluate whether this shift in the industry is in fact helping reduce the embodied carbon emissions of our buildings and if so, by how much. For this assessment, a baseline concrete structure was used as a comparison to the as-built hybrid mass timber and steel structure.

**2) Evaluation of the impact of prefabrication of the building envelope on the embodied carbon.**

Prefabrication of the building envelope is becoming a more popular choice especially for mass timber. The intention is that by prefabricating the panels off-site, they can be quickly installed shortly after the mass timber structure is erected, enclosing the building and protecting the wood from the elements. Prefabrication does require different elements and processes than a site built envelope and this assessment seeks to explore the impact of those on the embodied carbon of the envelope.

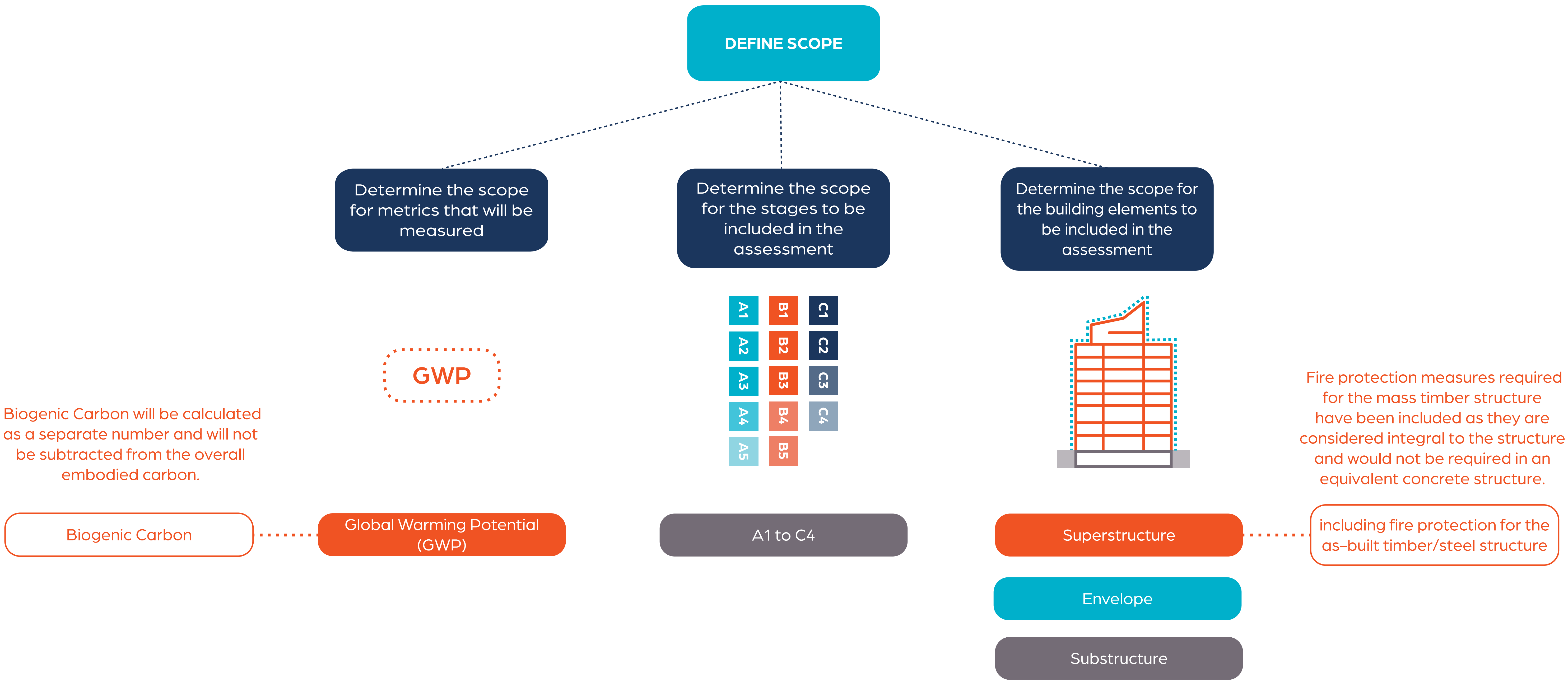


# 1.3 ASSESSMENT SCOPE

Establishment of the scope for the metrics, stages and building elements to be included in the life cycle assessment

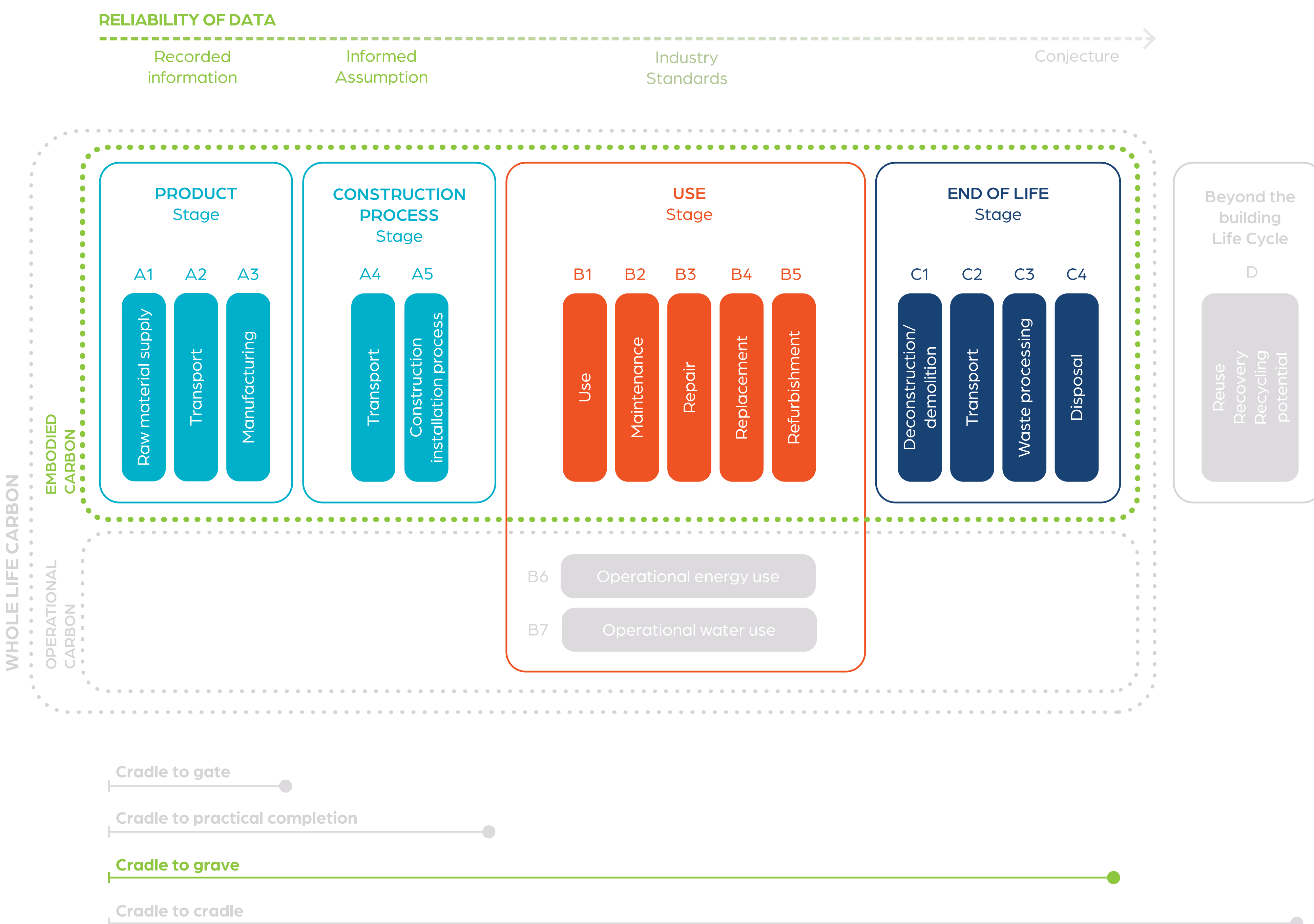
## GWP | A1 to C4 | SUBSTRUCTURE, SUPERSTRUCTURE, ENVELOPE

The scope of this LCA will measure total Global Warming Potential (GWP) for the substructure, superstructure and envelope of the building and will include stages A1 to C4. Fire protection measures required as a result of the mass timber will also be included in the GWP for the superstructure so as to provide a more accurate comparison to the baseline concrete structure. Biogenic carbon will be calculated as a separate figure and will not be incorporated into the total embodied carbon result.



# 1.3a ASSESSMENT SCOPE | STAGES

Further details on the stages included in the assessment




## ASSESSMENT STAGES

The intention of this study was to be as all-encompassing as possible and to take advantage of as-built data that could be incorporated into the assessment. However, there are still some areas where reliable data was not available and assumptions had to be made. Certain stages were also not always relevant given the scope of the analysis.

**A1–A3 – Product Stage**
The product stage of the assessment contains the most reliable data that was collected from quantity take-offs from as-built models, EPDs, shop drawings and bills of material.

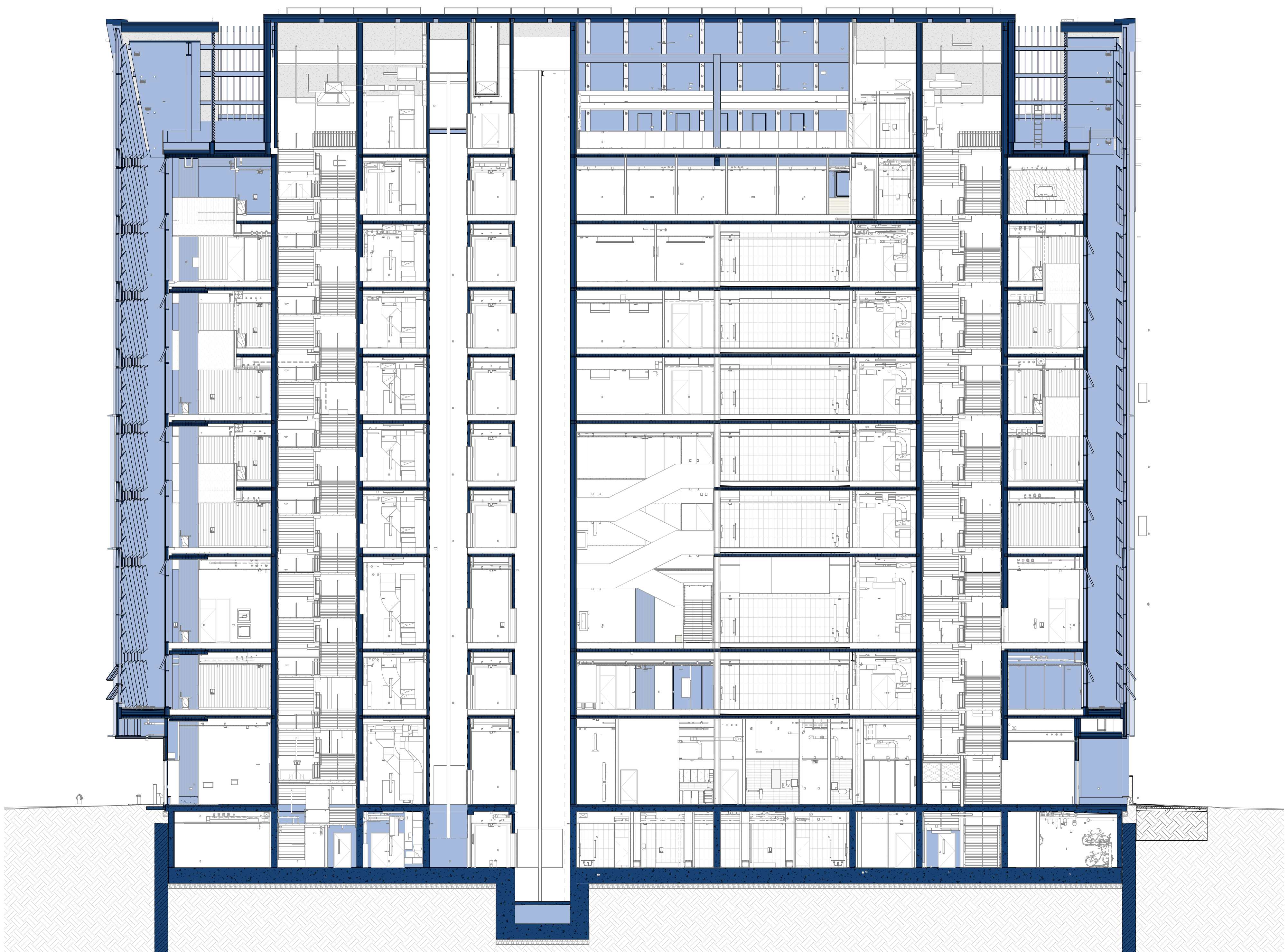
**A4–A5 – Construction Processes Stage**
We endeavored to incorporate as much transportation data as possible from available delivery records and purchase orders. Transport distances were adjusted according to suppliers' facility locations where known, and multi-leg trips were accounted for. Construction installation process energy proved more difficult to quantify accurately despite having interviewed the contractors. The electrical draw from the construction site was not separately metered and diesel fuel invoices for equipment were not available.

**B1–B5 – Use Stage**
The use phases rely on default values included in the LCA calculation platform and on the expected life span of materials identified in product EPDs. Phase B1 was deemed not relevant to scope of the project. Phases B2 & B3 were also not included due to absence of reliable data.

**C1–C4 – End of Life Stage**
End of Life Stages are based on current material disposal practices and rely heavily on assumptions. Standard EOL scenarios were assumed for all building materials, however data for this stage is considered theoretical, especially for mass timber. Future studies will benefit from more real-world references for these stages.

# 1.3b ASSESSMENT SCOPE | BUILDING ELEMENTS

Further details on the building elements included and excluded from the assessment



## SCOPE OF BUILDING ELEMENTS STUDIED

Life cycle analysis frameworks can vary in scope, both in what phases of the life cycle are required, and what elements of the building are included and excluded in the study, especially throughout the broader international community.

As is more typical in North America, the scope of this life-cycle analysis was intentionally limited to only the structure and envelope of the building. Historically, these two categories are the largest contributors of embodied carbon among architectural elements, and many regulatory and performance standards only require accounting for these major components.

As illustrated in the diagram on the left, the building elements which were included in the study were the **substructure (including below grade shoring), superstructure, and the building envelope, including the roof, solar chimneys, and all exterior soffits**.

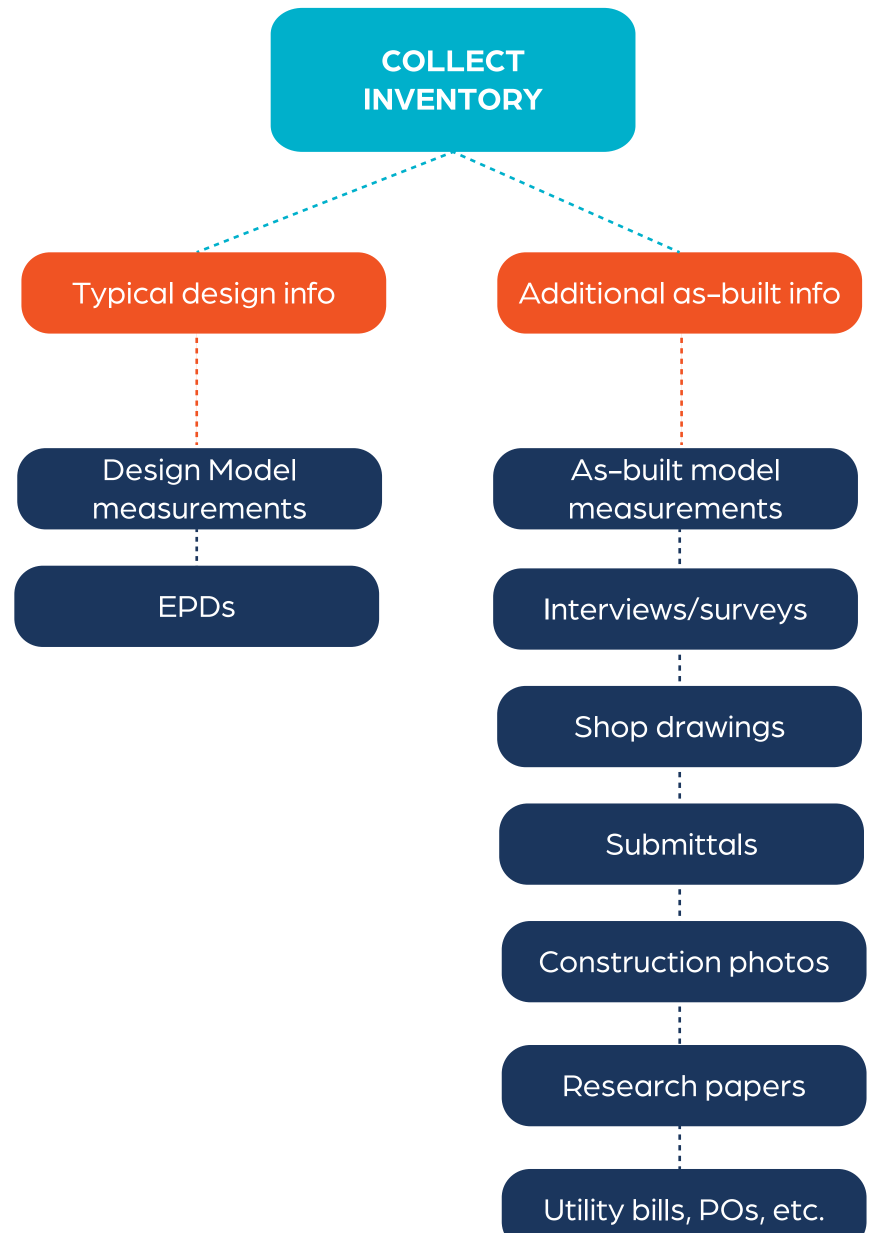
All interior partitions, millwork, fixtures, and finishes are excluded from this LCA study. Further information on the excluded elements can be found later in this report.

# 1.4 INVENTORY COLLECTION

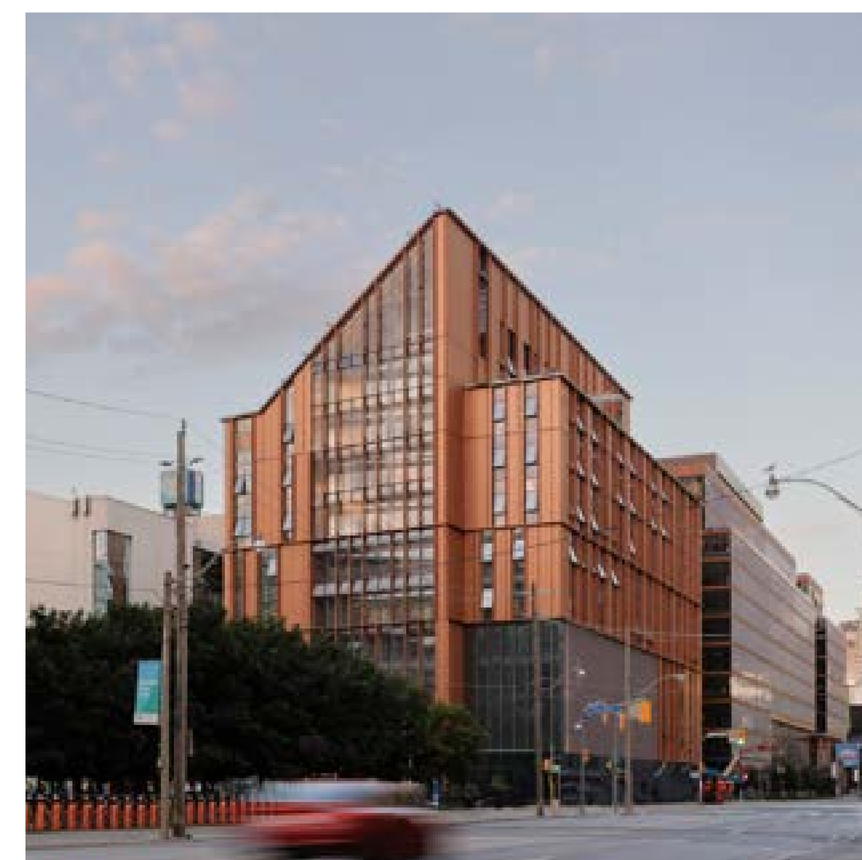
Description of the inventory collection process and what is collected

## WHAT WE COLLECTED

The life cycle analysis process relies on the collection of accurate data. In a typical design-phase LCA, the study will use quantity take-offs from design documents and environmental product declarations for the products specified or selected. In order to provide more detail for this study, we incorporated additional as-built information to collect more accurate quantity take-offs, including as-built models provided by the constructors, and shop drawings of the building elements. Submittals allowed us to source product-specific EPDs where available. If EPDs for elements were not available, we used reasonable product substitutes or EPDs of industry averages. Interviews with the Construction Manager and Contractors provided further detail on means and methods, time frames for completing certain scopes of work, and information on material sourcing and delivery. The Construction Manager also provided useful insight in comparing site-built versus prefabricated construction efficiencies. Construction photos were an important resource for confirming construction sequencing and execution. While we attempted to collect utility bills to more accurately calculate process and construction related emissions, the reality of how energy was supplied to site made this approach difficult. Research papers provided additional guidance in terms of methodologies and case studies.




Limberlost Place - Concept rendering



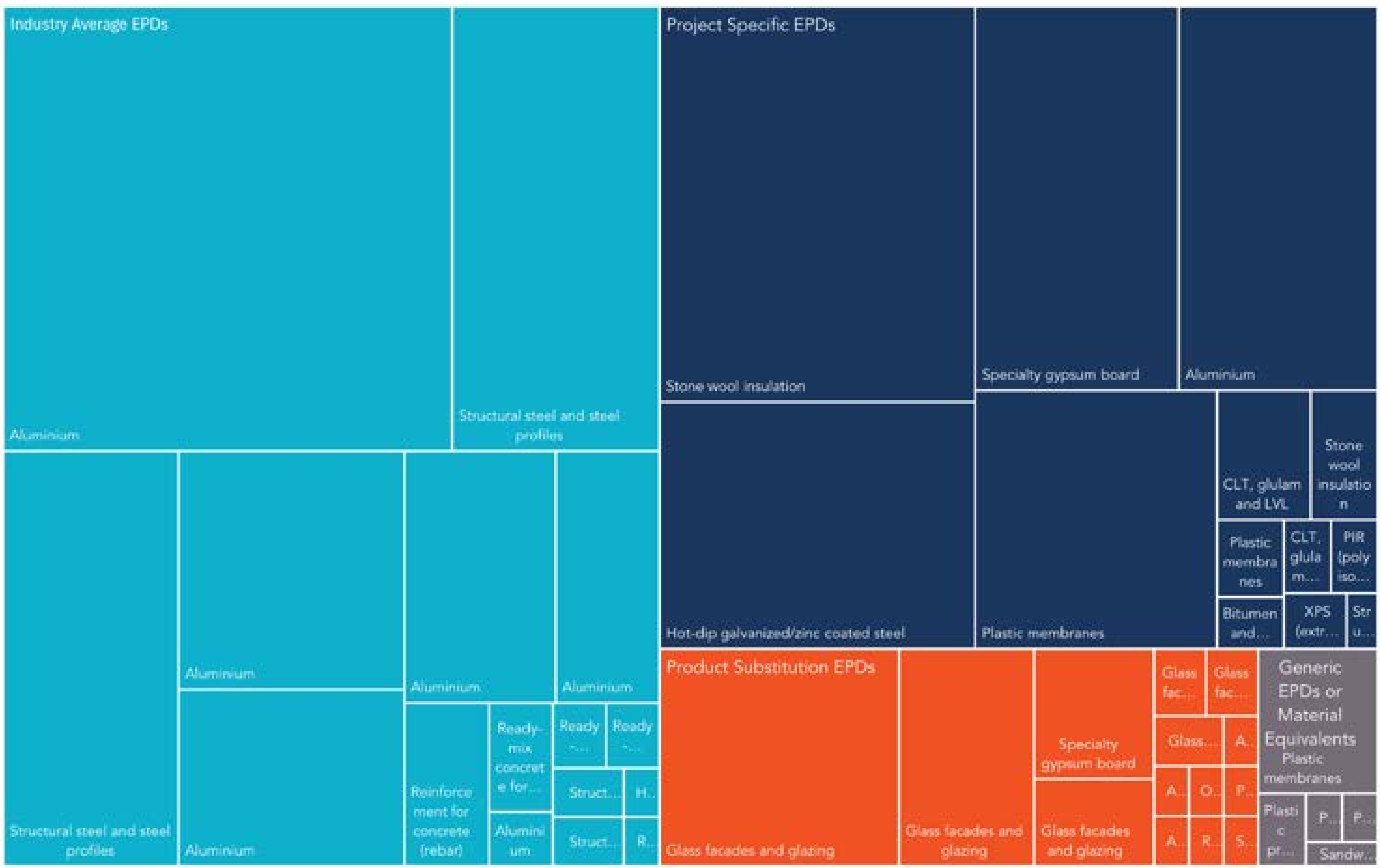
Limberlost Place - As-built photo

# 1.4a INVENTORY COLLECTION | DATA INTERPRETATION

How the inventory collected is used

**INDUSTRY AVERAGE EPDs**

**PROJECT SPECIFIC EPDs**




**PRODUCT SUBSTITUTION EPDs**

**GENERIC EPDs or MATERIAL EQUIVALENTS**

## DATA QUALITY

This assessment was performed using One Click LCA software using the Life Cycle Carbon – North America tool. One Click LCA has been third party verified by ITB for compliance with the following LCA standards: EN 15978, ISO 21931–1 and ISO 21929, and data requirements of ISO 14040 and EN 15804. All of the datasets in the tool comply with ISO 14040/14044 and for the most part also EN 15804 standard. LCA results are obtained using methodology called characterization, which describes environmental impact of a given emission. One Click LCA implements multiple characterization methodologies, but in North America, the TRACI 2.1. methodology defined by United States Environmental Protection Agency is applied.

Careful interpretation of the data collected is a critical part of the process and requires decisions to be made around what is included or excluded and how to quantify global warming impacts where data is not available. The chart to the left represents the quantity of each type EPD used in this assessment. Ideally, all EPDs would be **Project Specific** and reflect the products utilized on the project, but not all manufacturers provide GWP information at this time. Where **Industry Average EPDs** have been used, we attempted to localize them to the appropriate geography of manufacture. **Product substitution** and **Generic EPDs** were used where no product-specific or industry average data was available. In some instances, product specific EPDs were available, however they were not compatible with our assessment method and could not be used.

# 1.4b INVENTORY COLLECTION | CONSTRUCTION PROCESSES

Construction Installation Process emissions


## PHASE A5.2 PROCESS ENERGY

As previously mentioned, accurate calculation of Phase A5 – Construction Installation emissions was not as successful as we had originally hoped.

**The default method for A5 emissions in the LCA platform used, is to calculate emissions associated with material waste during construction (phase A5.3), but it does not include emissions associated with the actual assembly and erection process (A5.2).**

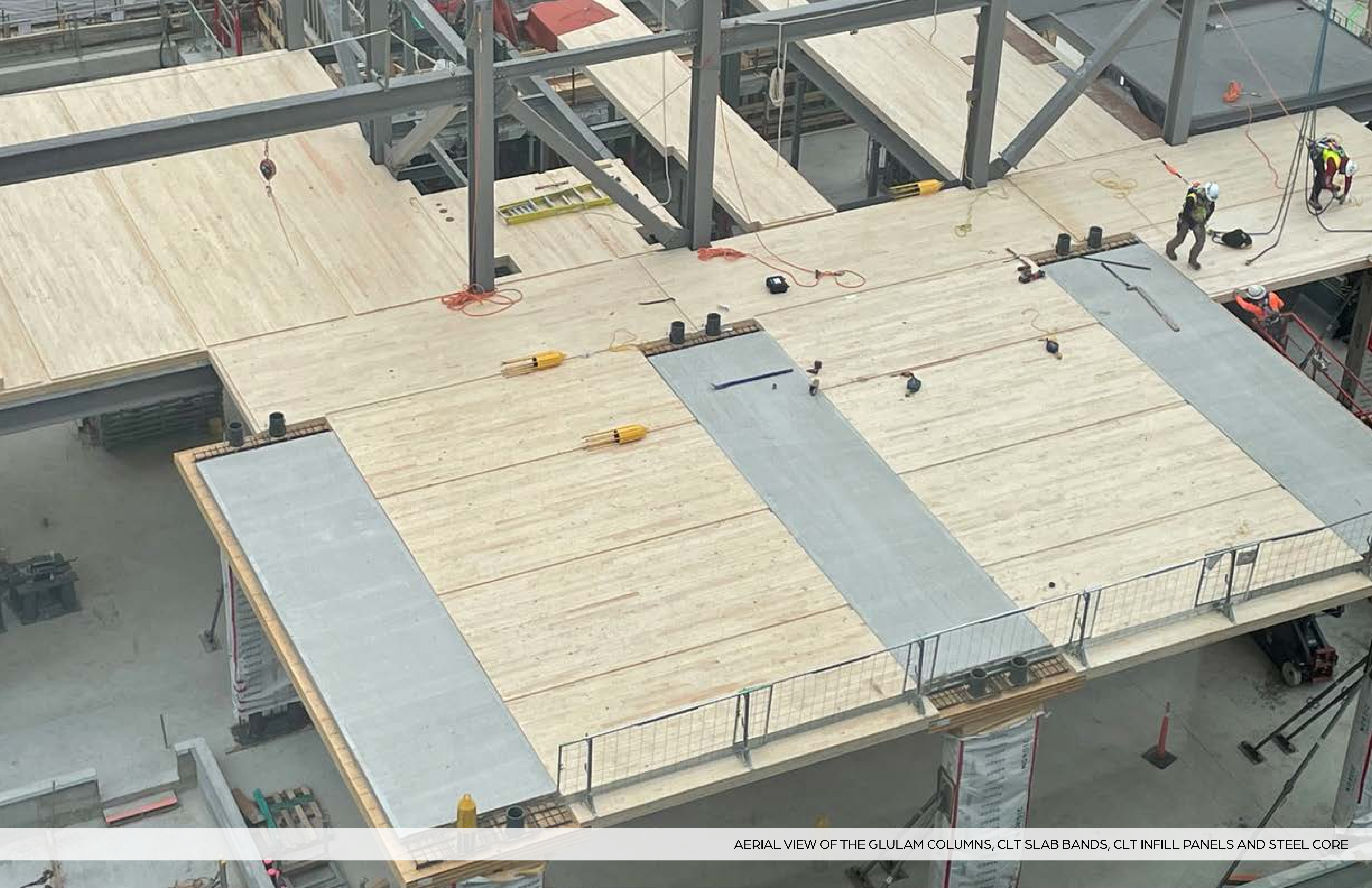
The team explored multiple methods of capturing global warming potential associated with construction. Methods considered included using construction photos to develop an inventory of equipment used on site and their relevant energy demand; and applying hourly energy use intensity values from previous construction case studies to the life span of construction. Due to the reliability of the data, the team ultimately decided to use the method described in the forthcoming ASHRAE / ICC Standard 240P for calculating A5.2 emissions that uses a calculation of **40 kgCO2/m2**. This is consistent with embodied carbon benchmarking studies performed by the Carbon Leadership Forum. We expect this is a conservative estimate; the Limberlost construction site relied heavily on electric-powered equipment with power supplied from Ontario's relatively clean grid, and site heating tapped into the district heating network in downtown Toronto. Both of these approaches should significantly lower construction emissions from a standard baseline.

Process Energy Calculation

**18,900m2 GFA x 40 kgCO2/m2 = 756,000 kgCO2**

# 2.0 STRUCTURE

This section focuses on the embodied carbon for the structure of the building including the comparison of the as-built structure to the baseline concrete structure.



AERIAL VIEW OF THE GLULAM COLUMNS, CLT SLAB BANDS, CLT INFILL PANELS AND STEEL CORE

# 2.1 STRUCTURE | INVENTORY – AS-BUILT

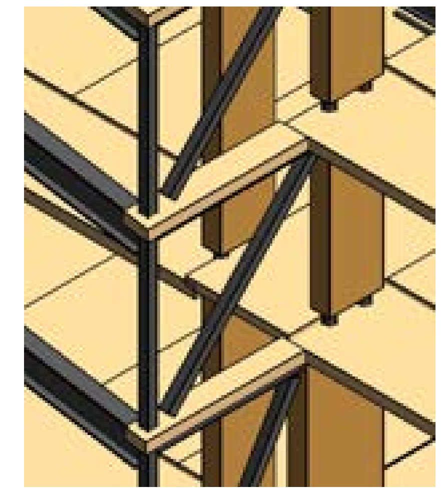
Quantity take-offs of as-built structure

As-built information in today's BIM world provides us with the opportunity to use detailed 3D models for quantity take-offs. Apart from the concrete, we had detailed as-built 3D models for the entire structure which included the steel model from Walters Steel and the Mass Timber model from Nordic Structures including all the steel connection, kerf plates, etc.

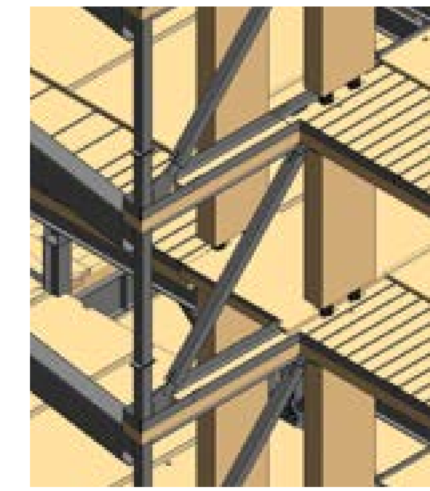
## INCLUSIONS & EXCLUSIONS

- Calculations only include elements integral to structural support of overall building
- Gypsum partitions that provide fire protection to the stair cores and the steel frames are included in the As-Built structure material takes offs
- The below-grade steel piles and the concrete secant pile wall are included in the material take offs
- Steel elements in the As-Built structure provided for support of building overhangs are not included as structural elements; where relevant, they will be included in the Envelope calculations
- The Bridge is not included
- Stairs, including concrete stairs and all steel elements providing support and formwork, are not included

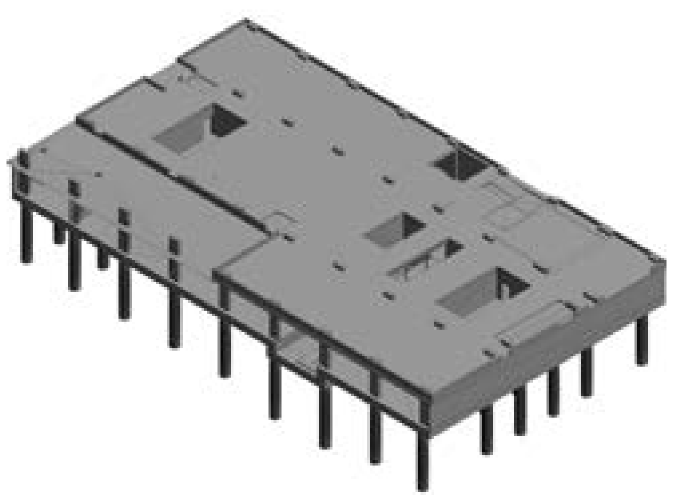
It is interesting to note the difference in the level of detail available between the design model and the as-built model. The images below show a significantly higher amount of steel in the as-built model compared to the design model.



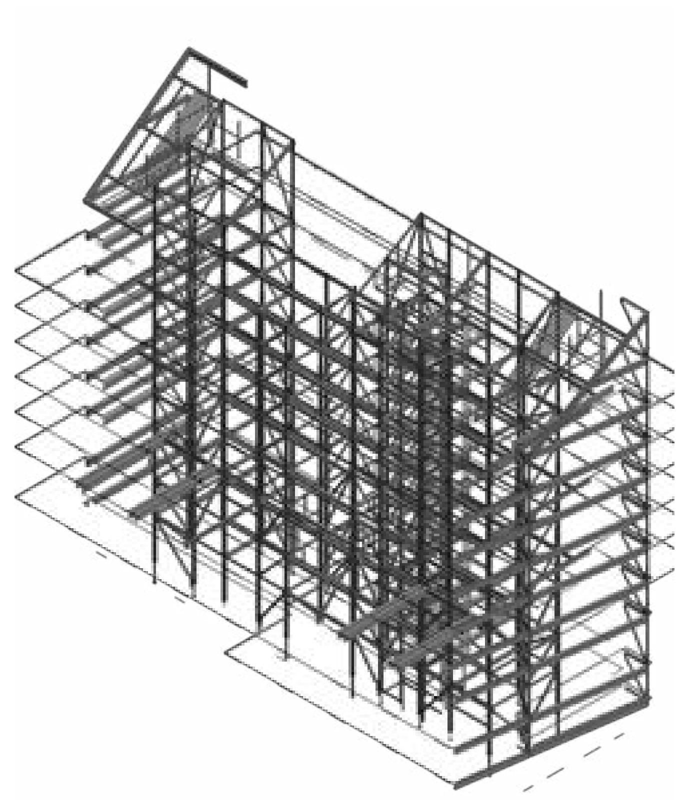
Design Model Level of Detail



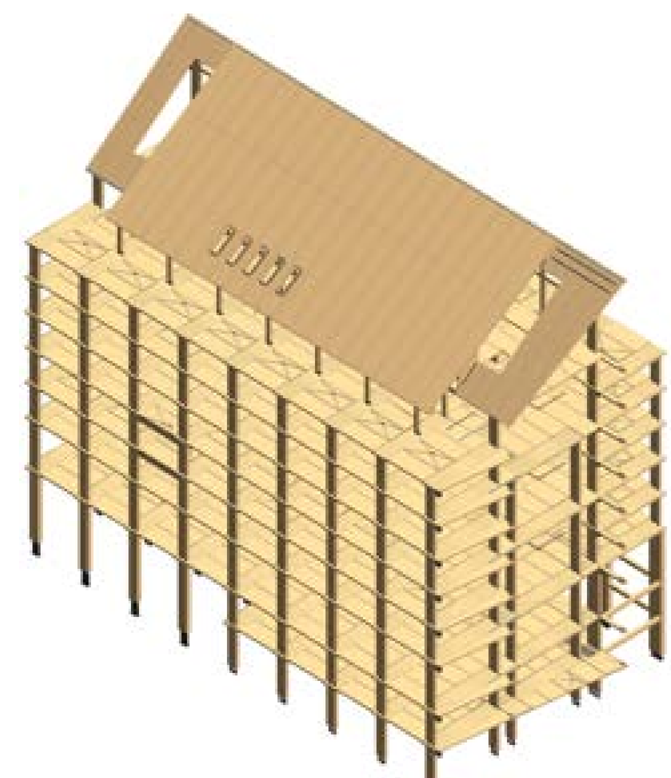
Construction Model Level of Detail



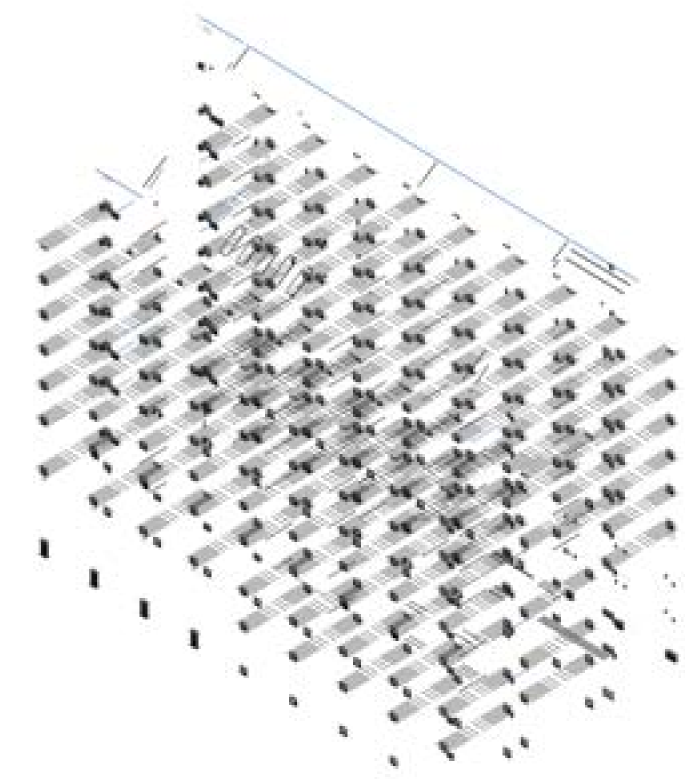
Concrete – Design Model



Steel – Walters As-Built Model



Mass Timber – Nordic As-Built Model

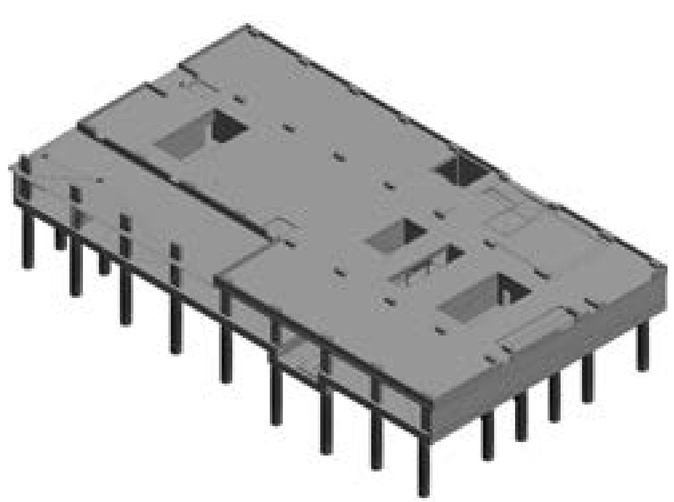


Mass Timber Connections – Nordic As-Built Model

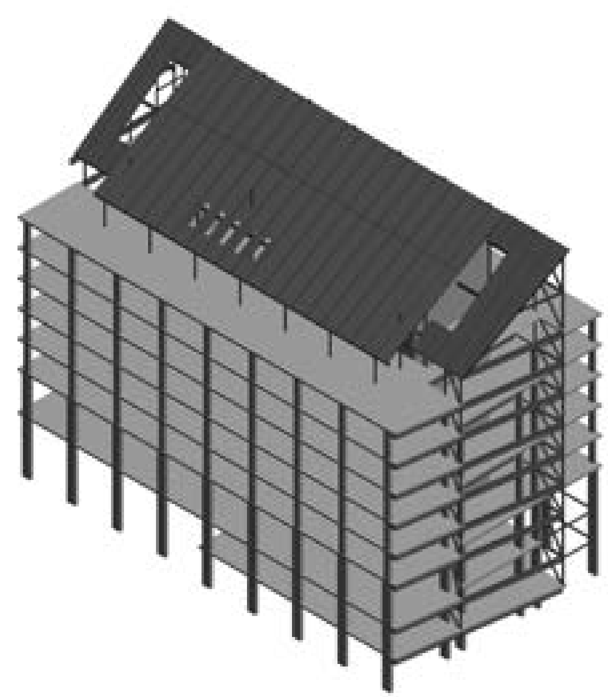
# 2.2 STRUCTURE | INVENTORY – CONCRETE BASELINE

Quantity take-offs of baseline concrete structure


Concrete – Design drawings



Concrete – Design Model



Concrete baseline – 3D model based on Bluebeam mark-up

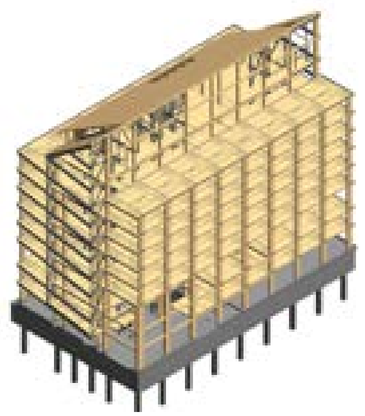
For the baseline concrete structure, Fast+ Epp, the structural engineers for the project, provided design drawings for a comparative concrete structure. This was used as the basis for the quantity take-off for the concrete, reinforcement and structural steel and was modeled in 3D for greater clarity of the visuals.

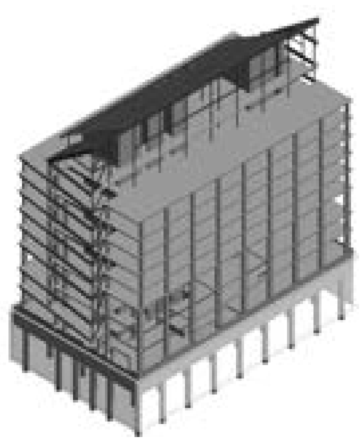
## INCLUSIONS & EXCLUSIONS

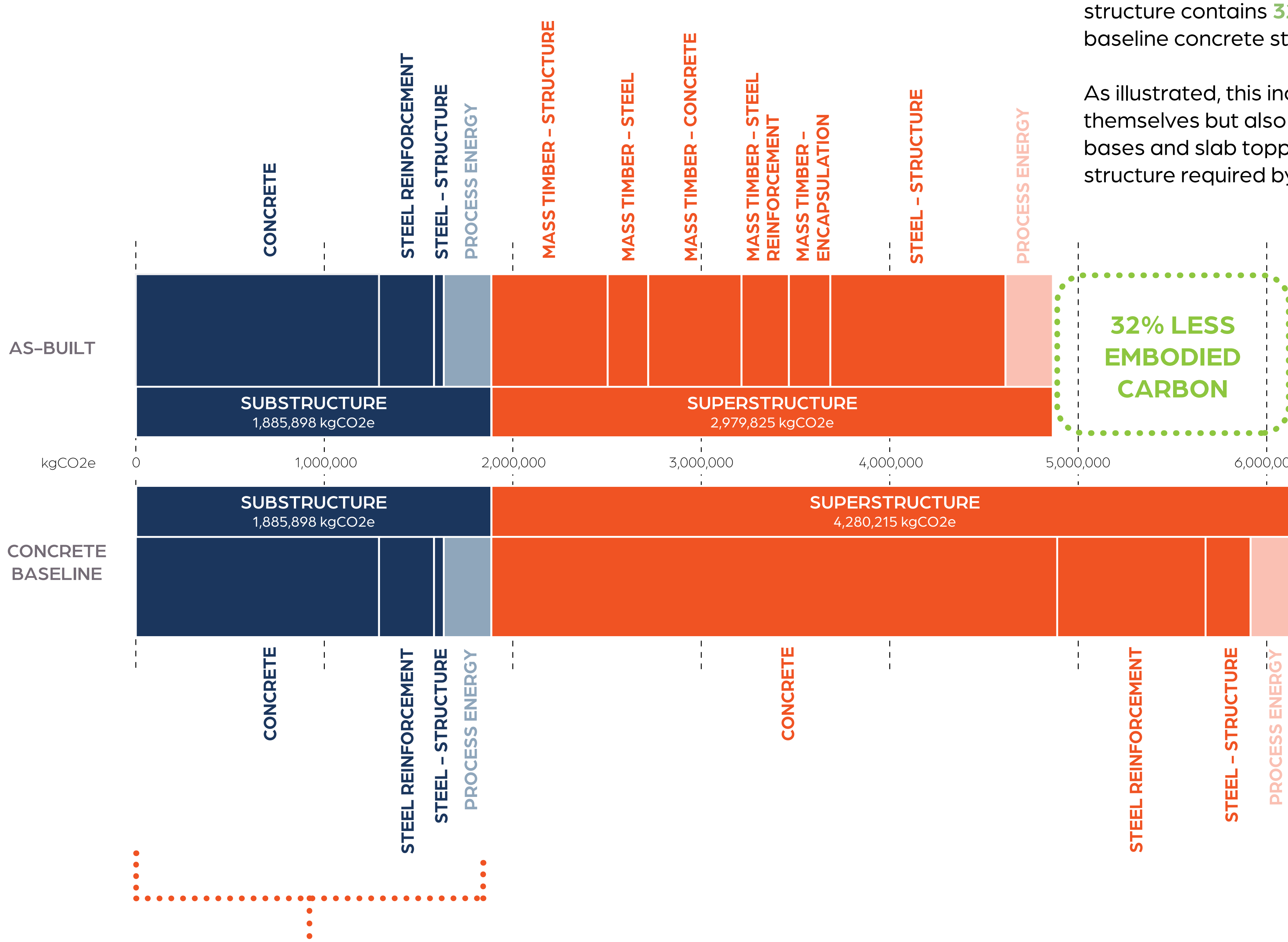
- Calculations only include elements integral to structural support of overall building
- Gypsum partitions that provide fire protection to the stair cores and the steel frames previously included in the as-built option are not required due to the inherent fire resistance of the concrete
- The below-grade steel piles and the concrete secant pile wall are included in the material take offs
- Steel elements in the structure provided for support of building overhangs are not included as structural elements; where relevant, they will be included in the Envelope calculations
- The Bridge is not included
- Stairs, including concrete stairs and all steel elements providing support and formwork, are not included

# 2.3 STRUCTURE | RESULTS – BUILDING ELEMENTS

Comparative results between the as-built and concrete baseline structures







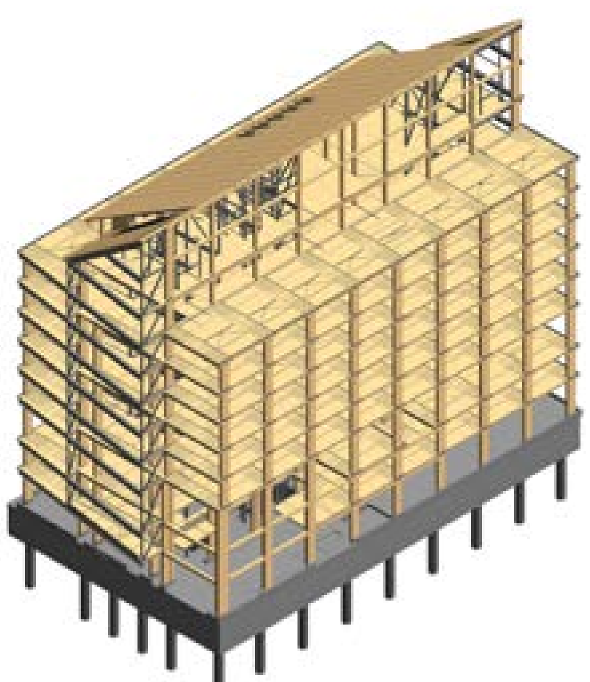

The overall results show that the as-built hybrid mass timber/steel structure contains **32% less embodied carbon** as compared to a baseline concrete structure.

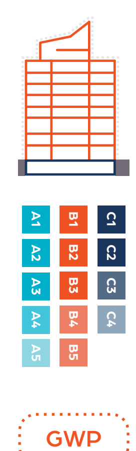
As illustrated, this includes not only the mass timber elements themselves but also all the steel connections, concrete for column bases and slab toppings and all the encapsulation and core steel structure required by the codes at the time.

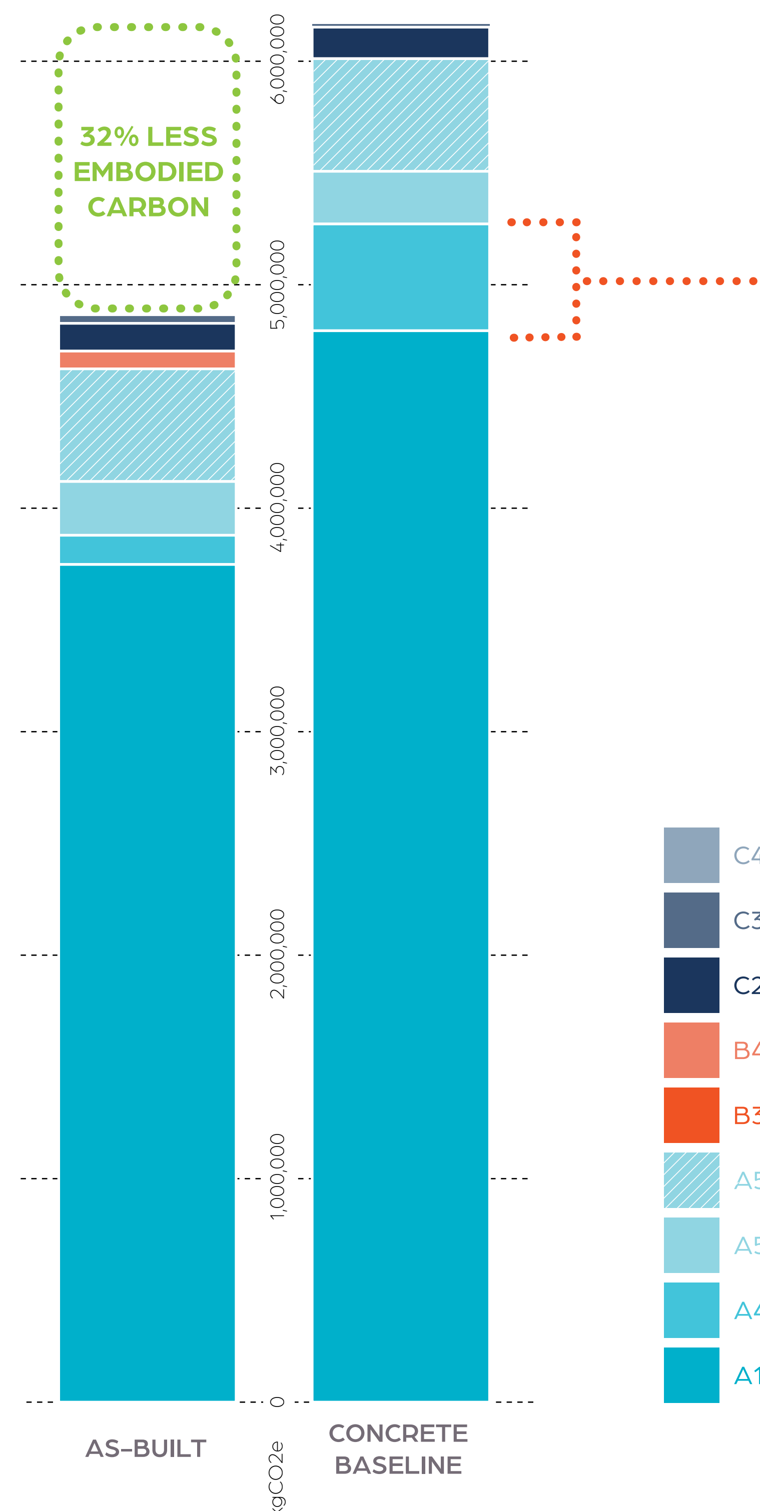

In theory, the substructure required for the as-built mass timber structure could have been smaller since it would be supporting a lighter superstructure. In reality, due to site conditions, deep piles and a secant wall were required and the substructure had to be designed to suit the size of the machinery used for the piles resulting in the same design for both scenarios.

# 2.4 STRUCTURE | RESULTS – ASSESSMENT STAGES

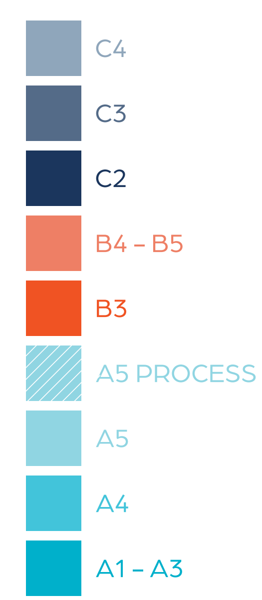
Comparative results between the as-built and concrete baseline structures

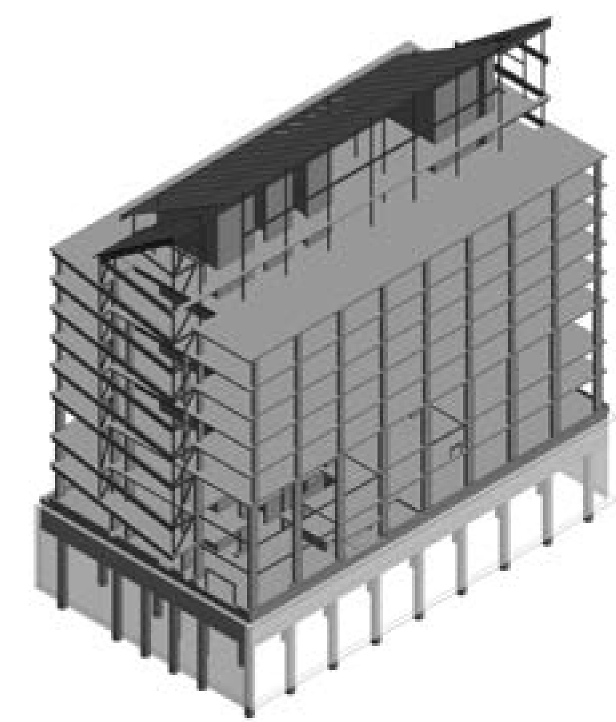




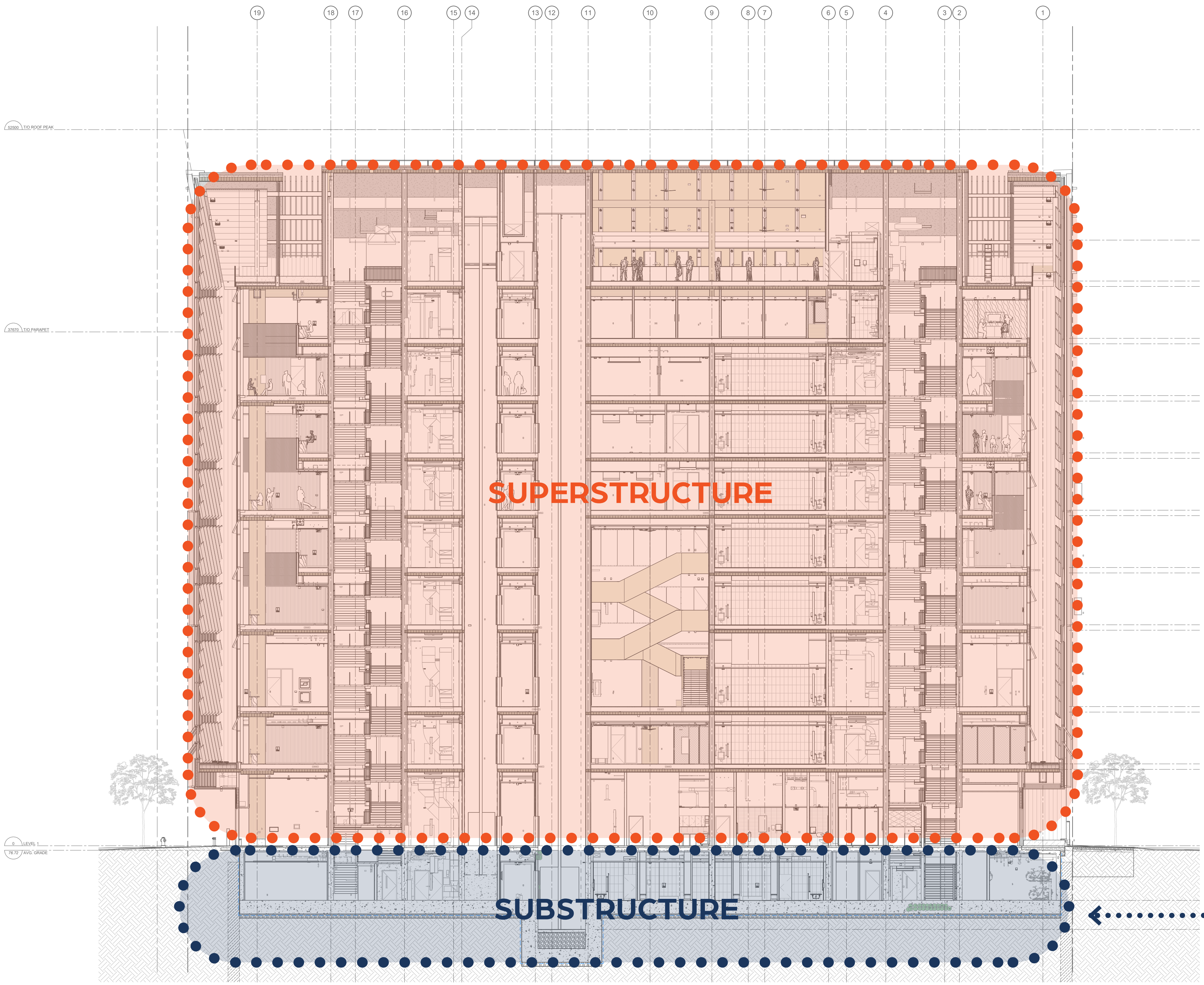

The assessment stages graphs show results that are fairly consistent with each other except for the A4 transportation results. The concrete baseline structure shows higher transportation numbers presumably due to the number of concrete mixer trucks that are required to provide concrete to the site.



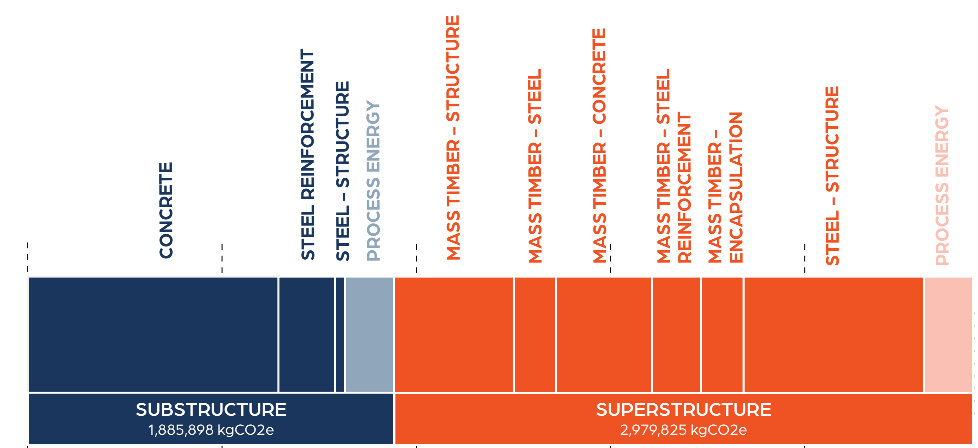
# 2.5 STRUCTURE | ANALYSIS – SUBSTRUCTURE vs SUPERSTRUCTURE

The impact of below grade structure




Much of the focus of this LCA is on the mass timber structure. It is important to remember that the industry has yet to find suitable low carbon solutions for below grade structure and the use of concrete is still prevalent.

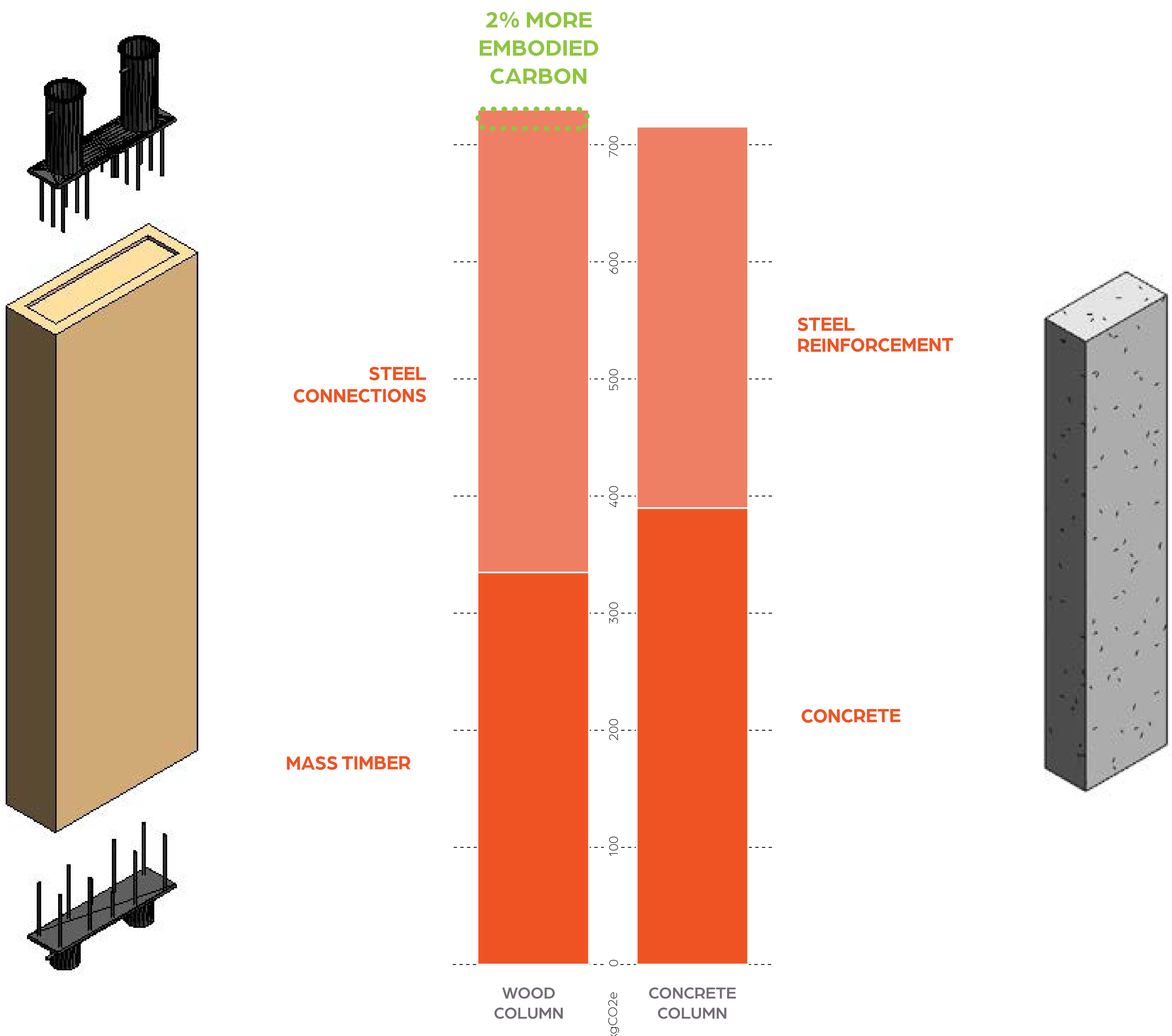
The substructure for Limberlost Place contains **38.8% of the total embodied carbon of the structure**. Low carbon alternatives for below grade structures will be an important step forward in further reducing the impact of buildings on the environment.




**38.8% OF TOTAL EMBODIED CARBON OF THE STRUCTURE**

# 2.6 STRUCTURE | ANALYSIS – MASS TIMBER vs CONCRETE COLUMN

Comparison between a single mass timber column and a baseline concrete column




Due to code restrictions, Limberlost Place was constructed as a hybrid structure with mass timber and steel for the core of the building. As we worked through the data for this assessment we were interested in understanding what the results might be for a full mass timber structure. In order to do so we decided to assess a single column and a single typical mass timber structural bay which would exclude the required steel structure in the core of the building.

For the column comparison the mass timber column included the mass timber as well as the steel connections. It was surprising to see that the results showed that this as-built column has **2% more embodied carbon** than the baseline concrete column. The biggest contributing factors to this result are the steel connections.

STEEL CONNECTIONS FOR THE MASS TIMBER COLUMNS DELIVERED TO THE SITE

# 2.7 STRUCTURE | ANALYSIS – MASS TIMBER vs CONCRETE STRUCTURAL BAY

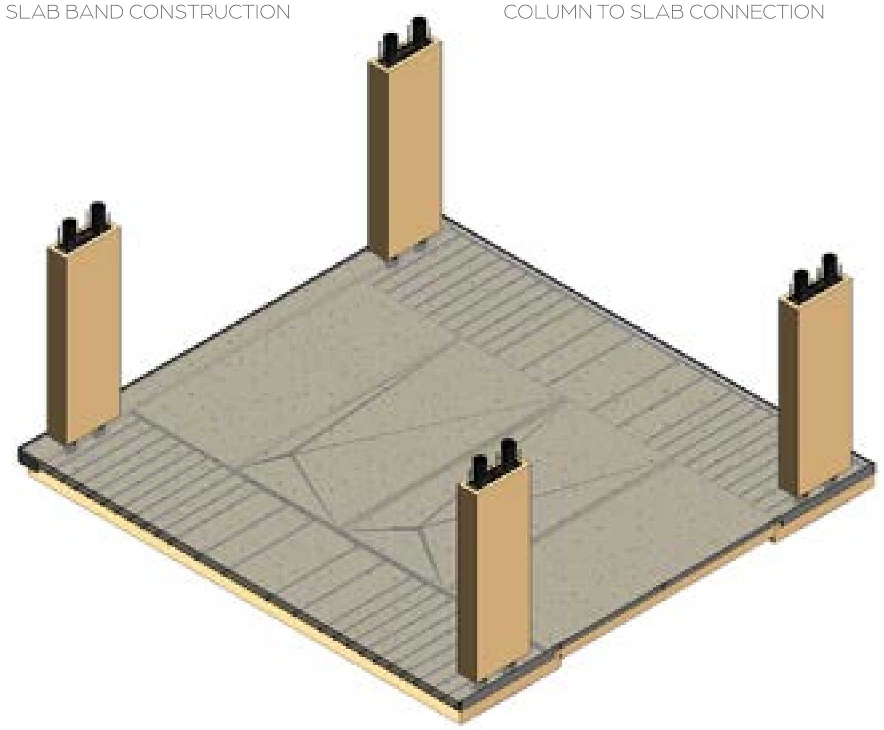
Comparison between a mass timber structural bay and a baseline concrete structural bay

The same assessment was then expanded to a typical structural bay and included all the steel and concrete toppings required for the mass timber. The results for this comparison showed that the as-built mass timber structural bay had **39% less embodied carbon** than the baseline concrete structure.

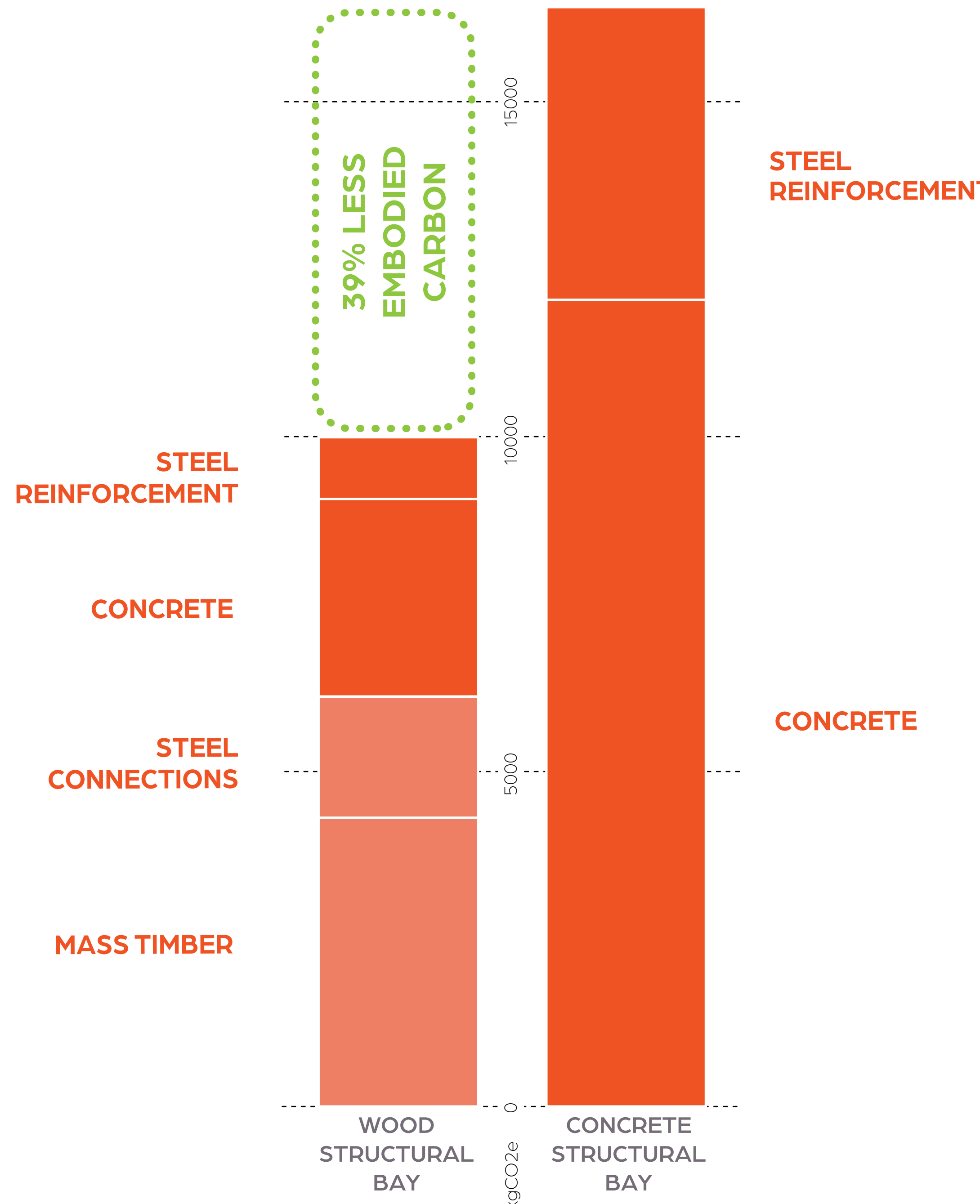
These results support our previous understanding that the use of mass timber for slabs provides the most significant savings in embodied carbon.

SLAB BAND CONSTRUCTION

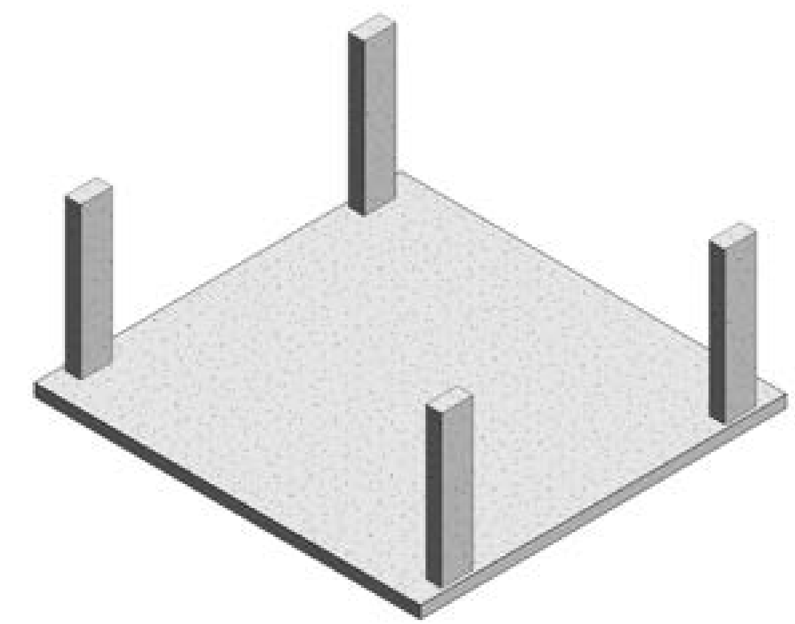
COLUMN TO SLAB CONNECTION



TYPICAL MASS TIMBER STRUCTURAL BAY




COLUMN TO SLAB CONNECTION



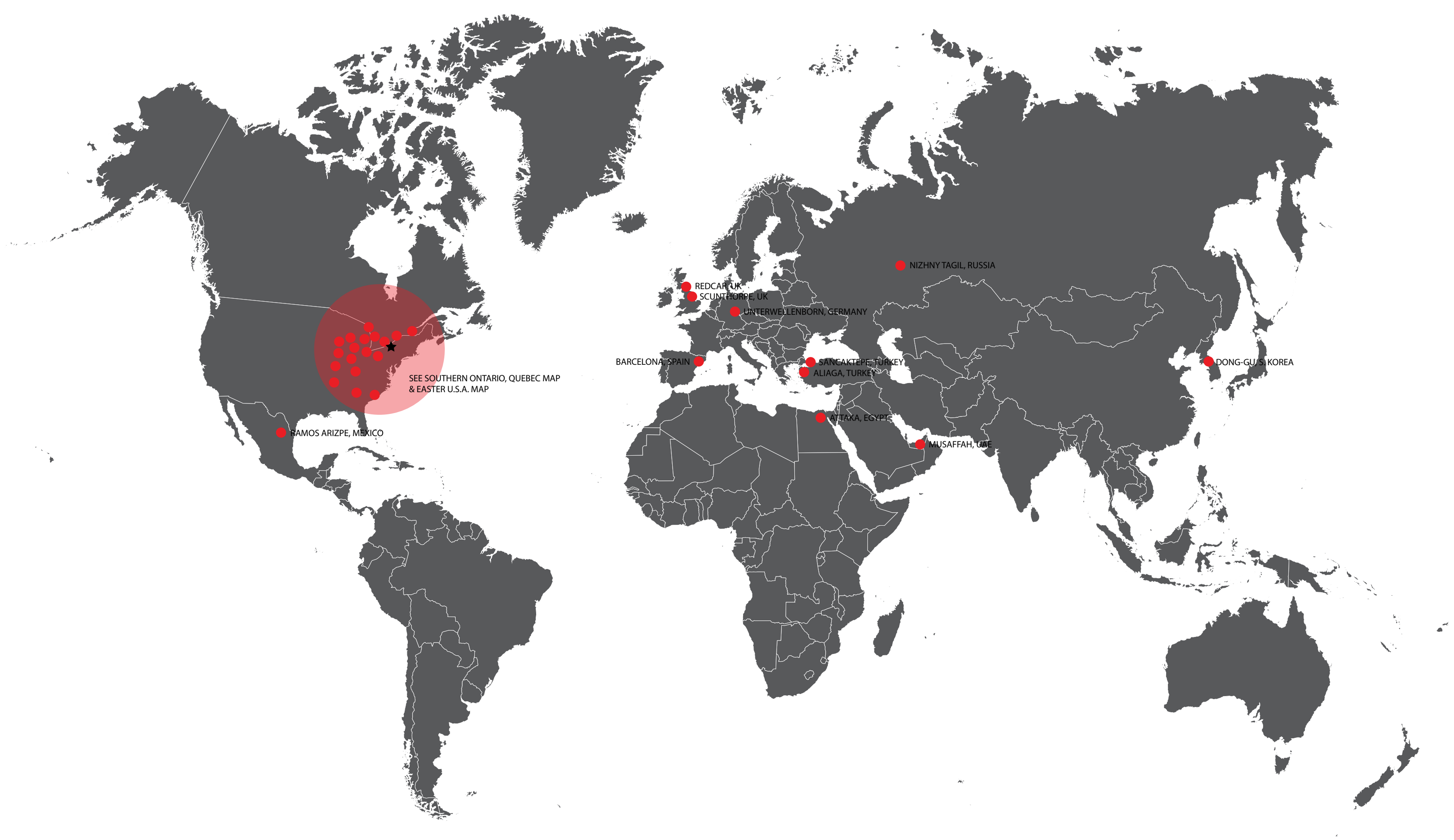
TYPICAL BASELINE CONCRETE STRUCTURAL BAY

# 2.8 STRUCTURE | ANALYSIS – STEEL TRANSPORTATION

Steel Sourcing

While attempting to understand more about the impact of transportation on the total emissions for the project, we were surprised by the data we received for the steel structural members. Steel testing certificates, containing the addresses for each of the steel mills, revealed that the steel was sourced from over 50 different places including places as far away as Korea, Abu Dhabi and Russia.

There was not enough time within the scope of this assessment to include the data for the transportation emissions for all the steel however it is an important factor to note and be mindful of for future projects.



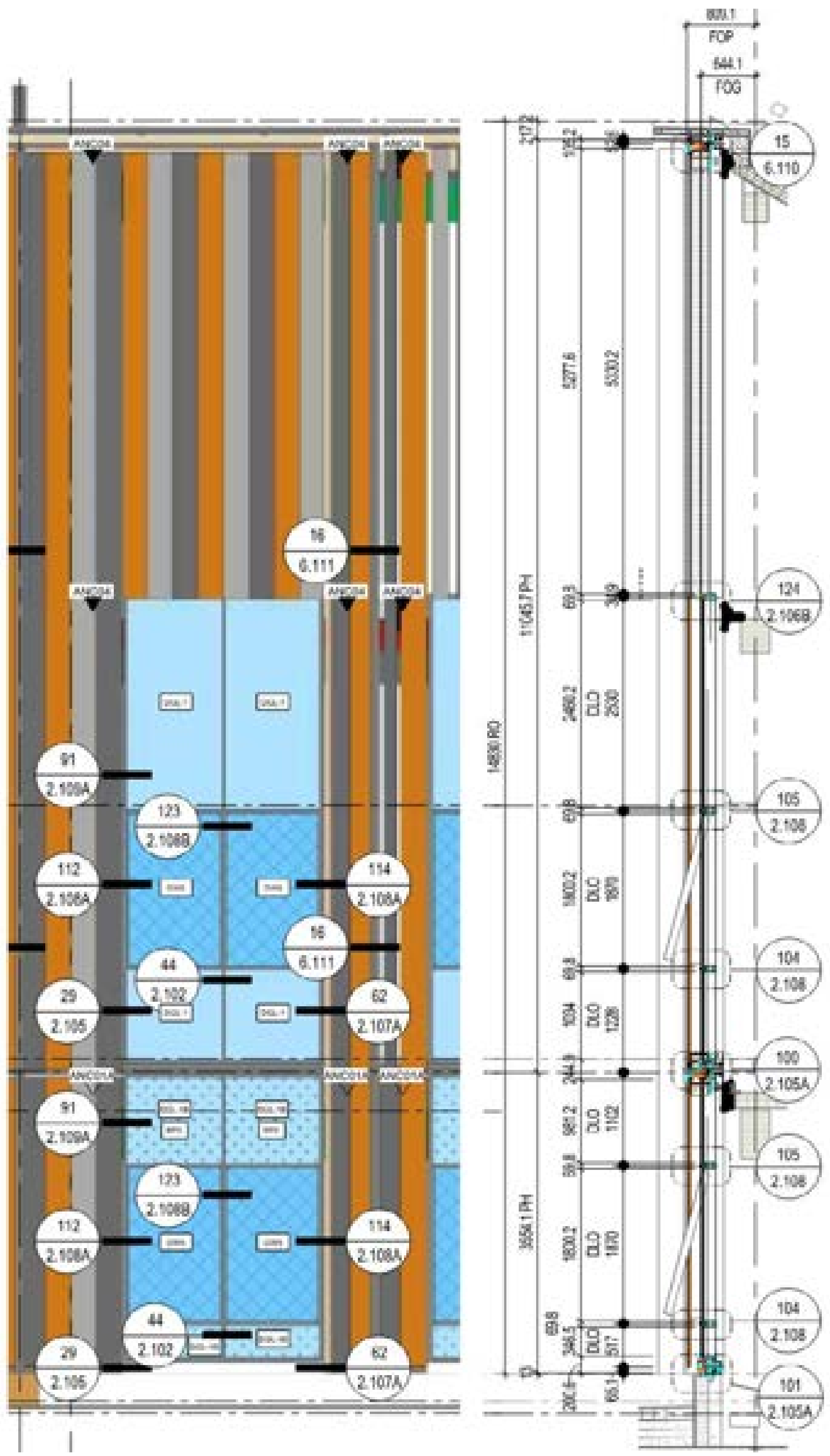

# 3.0 ENVELOPE

This section summarises the results for the envelope of the building including the comparison of the prefab portion of the envelope to an equivalent site built option.

FIRST PREFAB ENVELOPE PANELS BEING INSTALLED ON SITE

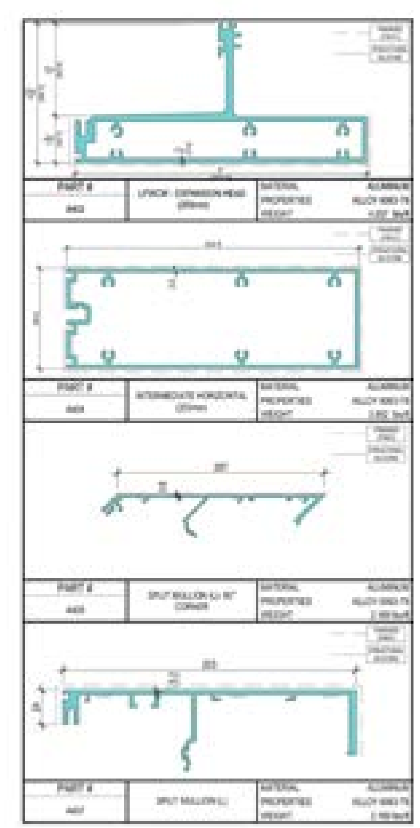
# 3.1 ENVELOPE | INVENTORY

Quantity take-offs for the prefab envelope comparison

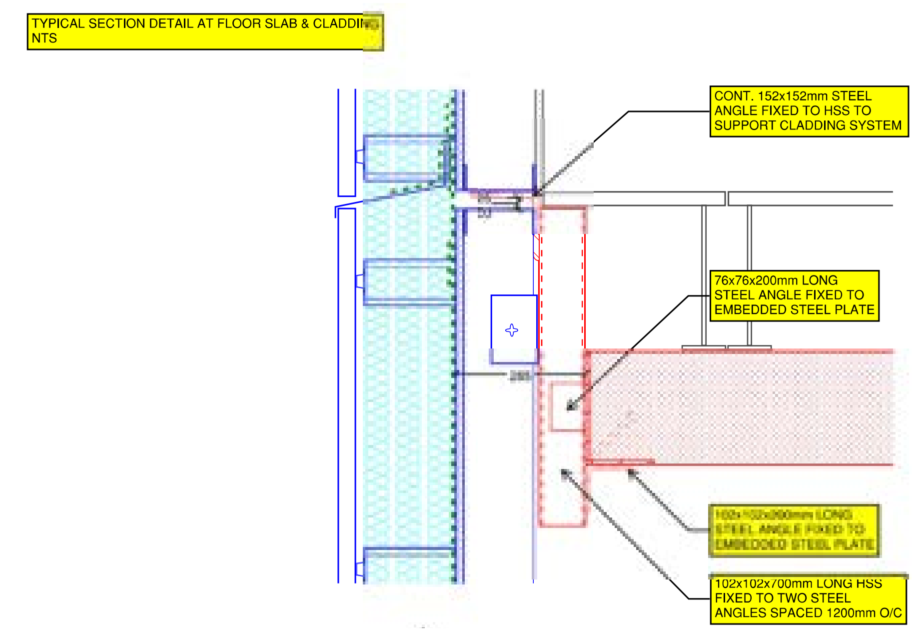


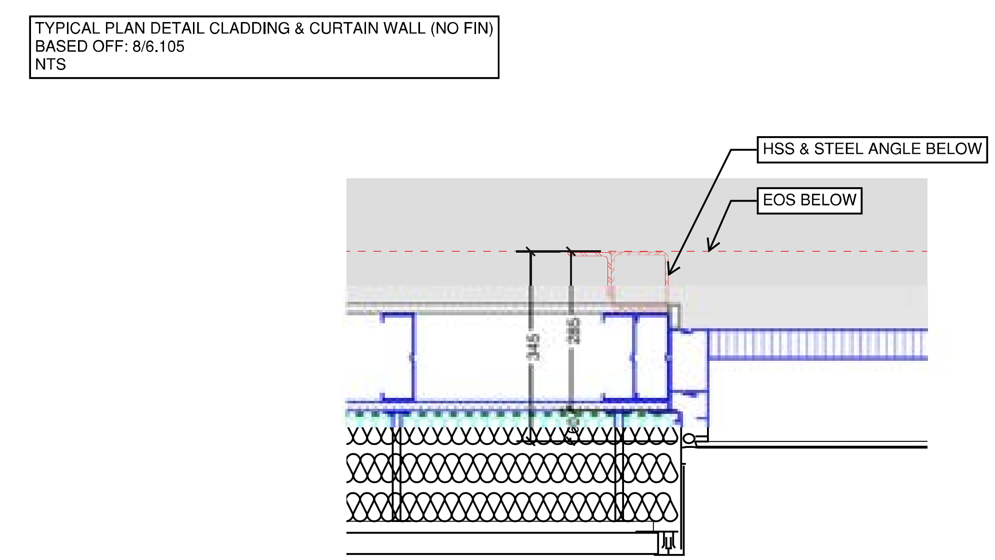
The prefabricated envelope panels for Limberlost Place were designed as large vertical sections most of which spanned multiple floors. Everything from the back-up wall to the exterior aluminum cladding and curtain wall as well as the perimeter connections and steel supports were prefabricated off site and delivered to site in one piece.

Access to shop drawings and site photos for the panels provided very detailed documentation for the quantity take-offs. A comparative site built envelope was designed to match the design of the as-built panels based on the shop drawings provided. It is important to note that, had the project called for site built envelope from the beginning, it is possible that the design of the envelope would have been quite different.



DETAILED SHOP DRAWINGS FOR THE AS-BUILT PREFAB PANELS




COMPARATIVE SITE BUILT ENVELOPE DESIGN DRAWINGS

# 3.2 ENVELOPE | ANALYSIS – PREFAB PANEL COMPARISON

Embodied carbon intensity per panel

The first step we took in assessing the impact of the prefabrication of the envelope panels was to analyze panels individually. Since the panels varied in size, the analysis was done on a **per square meter** basis giving us a comparison for the **Embodied Carbon Intensity (ECI)** for each panel. This allowed us to understand how the various sizes and glazing options impacted the embodied carbon. The results below show that some of the smallest panels had the highest embodied carbon intensity.

**Panel Type A5**

155.3 $kgCO_2e/m^2$

**Panel Type A1/A4**

165.9 $kgCO_2e/m^2$

**Panel Type C5**

170.1 $kgCO_2e/m^2$

**Panel Type A2/A3**

225.8 $kgCO_2e/m^2$

**Panel Type C1/C4**

236.5 $kgCO_2e/m^2$

**Panel Type C2/C3**

287.0 $kgCO_2e/m^2$

# 3.3 ENVELOPE | ANALYSIS – PANEL MATERIALS

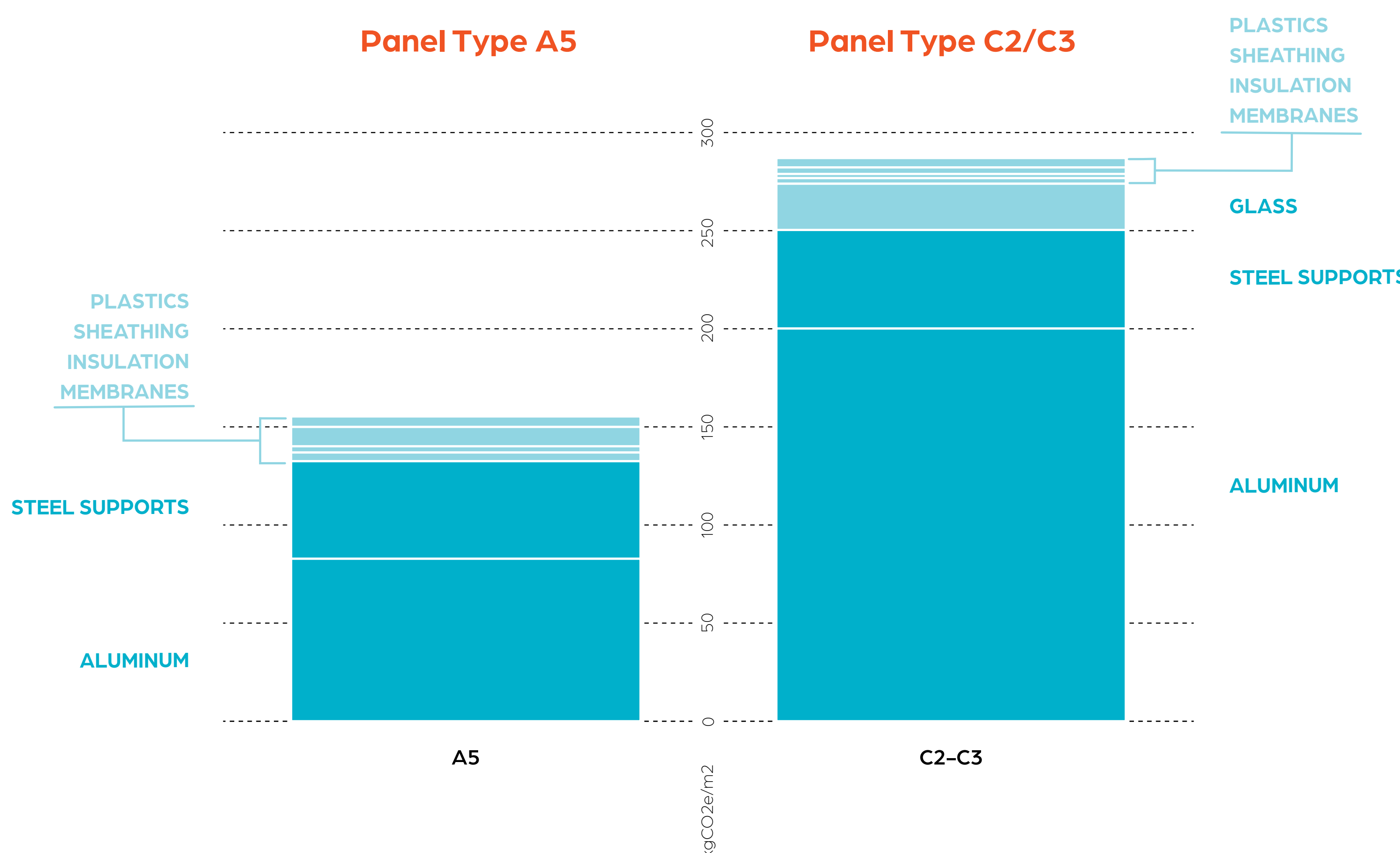
Impact of the steel and aluminum

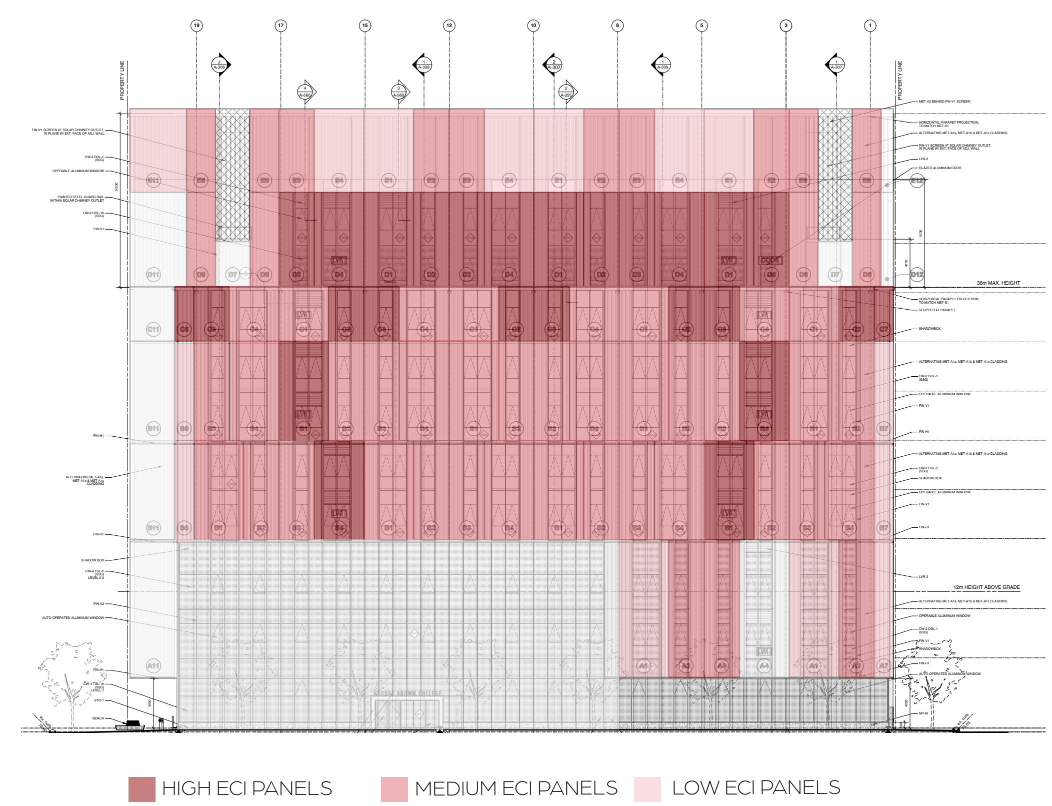
A further breakdown of the materials was done for the panel types with the highest and lowest embodied carbon intensity (Panel Type A5 and Panel Type C2/C3) so as to gain an understanding of which materials and elements were having the greatest impact. The results show the **steel** and **aluminum** as the largest contributing materials to the ECI for these panels. Panel type C2/C3 has the highest ECI since it is the smallest and contains aluminum framed glazing.

The heat map below of the north elevation also helps us to understand how often the higher intensity panels are used which then affects the overall embodied carbon of the envelope.

**Panel Type A5**

**Panel Type C2/C3**



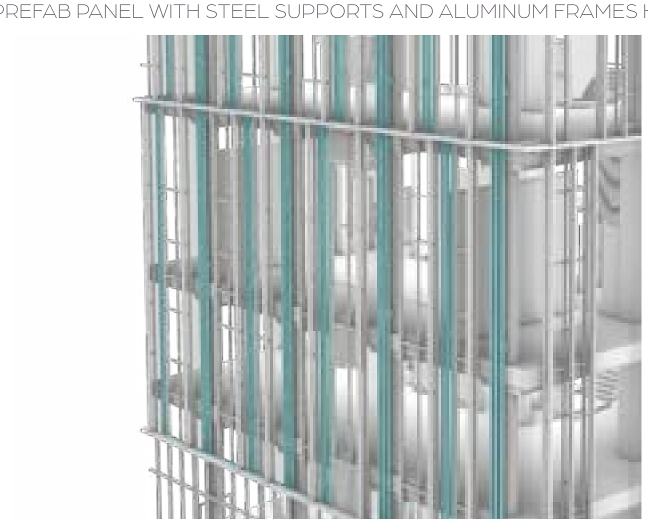

NORTH ELEVATION HEAT MAP SHOWING THE ECI OF THE PANELS

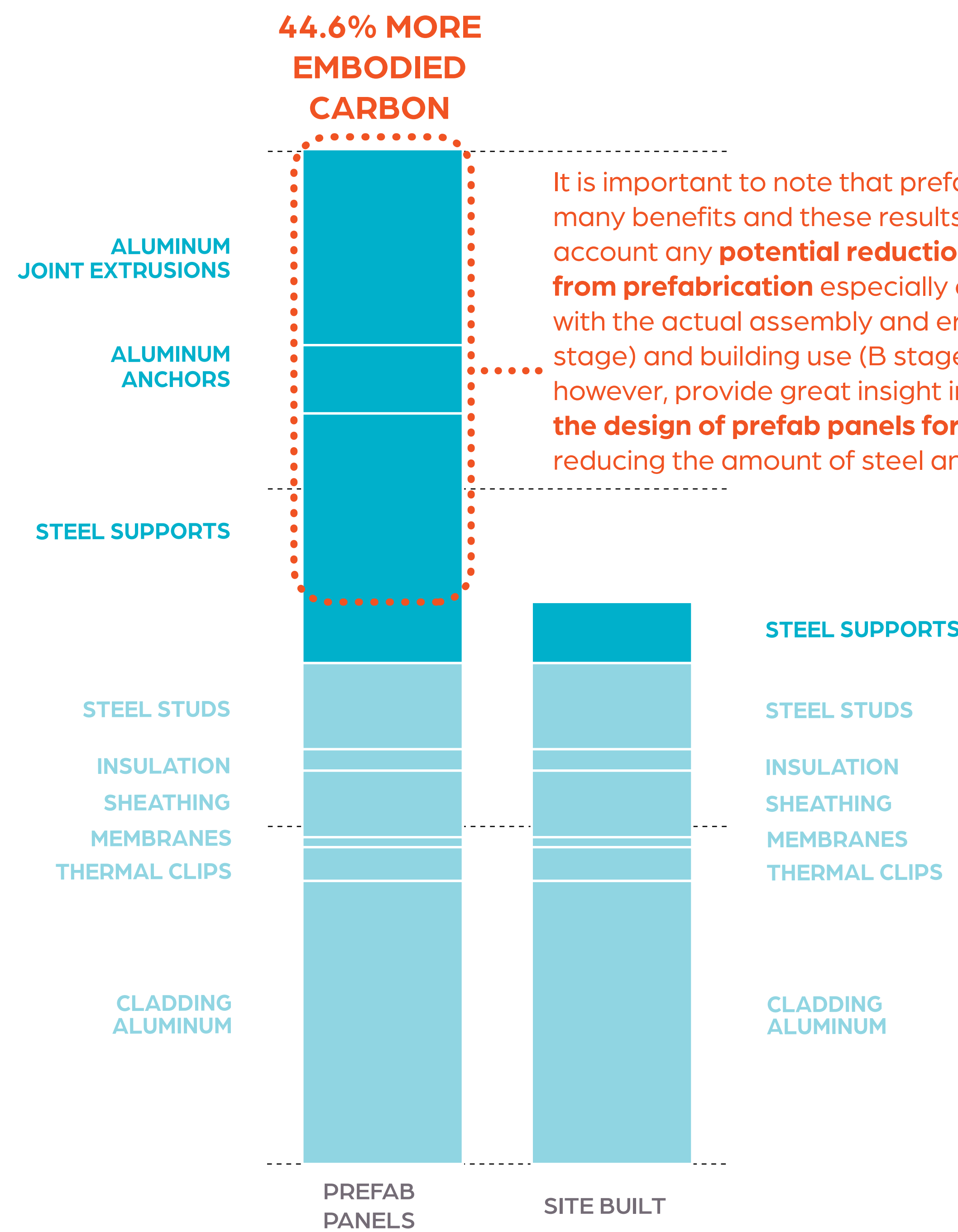
# 3.4 ENVELOPE | RESULTS – PREFAB vs SITE BUILT

Breakdown of envelope elements

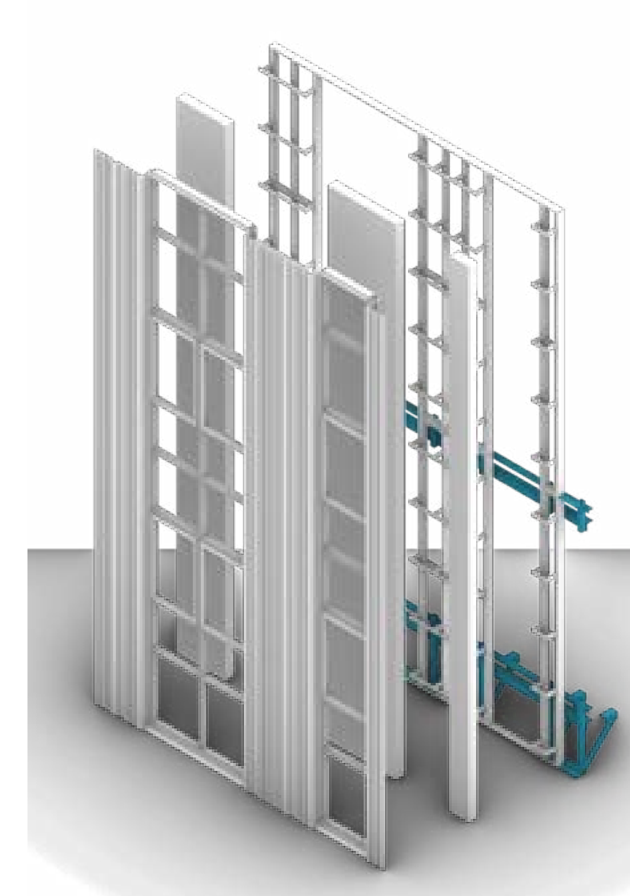
To compare the results for the individual panels to the site built option, we used an average embodied carbon intensity of all **the solid portions of the prefab panels**. The chart below shows that the cladding aluminum, thermal clips, membranes, sheathing, insulation, glazing, and steel studs were identical for each option. The most significant difference lies again in the larger steel supports and the aluminum perimeter frames and anchors required for the prefab panels. The steel frames provide rigidity allowing the panels to be transported and to span across multiple levels. The aluminum frames provide the required connection between panels allowing them to easily click into place and create an airtight seal. The results show that because of these additional requirements, the as-built prefab panels contain **44.6% more embodied carbon** than the comparative site built option.

PREFAB PANEL WITH STEEL SUPPORTS AND ALUMINUM FRAMES HIGHLIGHTED

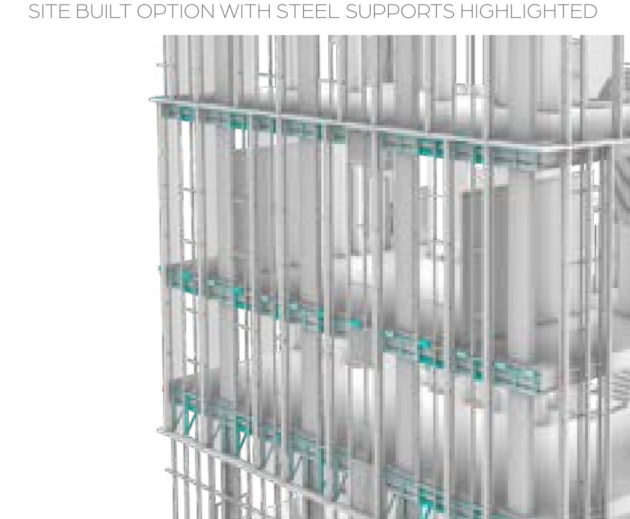





It is important to note that prefabrication provides many benefits and these results do not take into account any **potential reduction in embodied carbon from prefabrication** especially emissions associated with the actual assembly and erection process (A5.2 stage) and building use (B stage). These results do however, provide great insight into **how we can improve the design of prefab panels for future projects** by reducing the amount of steel and aluminum.



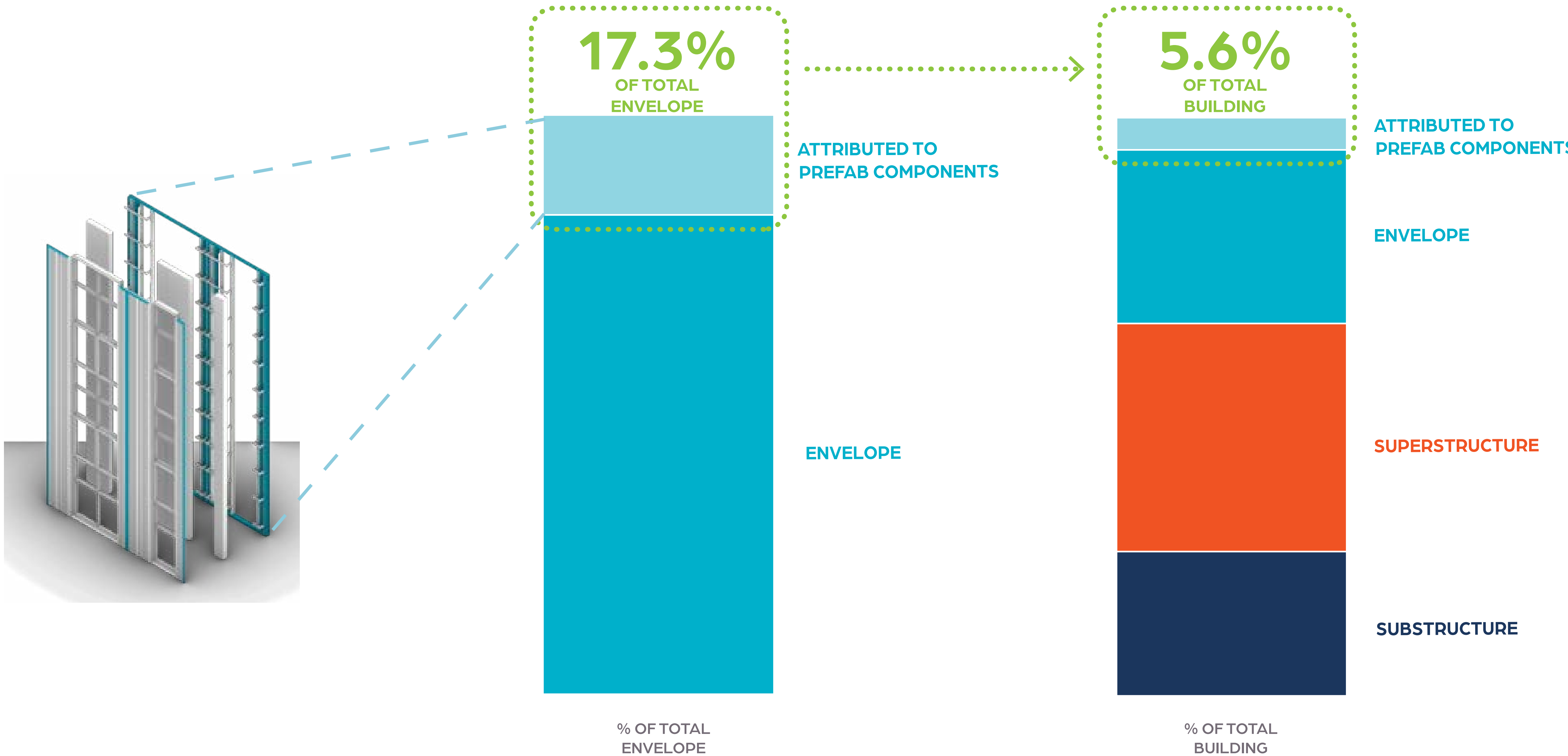
SITE BUILT OPTION WITH STEEL SUPPORTS HIGHLIGHTED



# 3.5 ENVELOPE | RESULTS – OVERALL IMPACT OF PREFAB PANELS

Results within the larger context

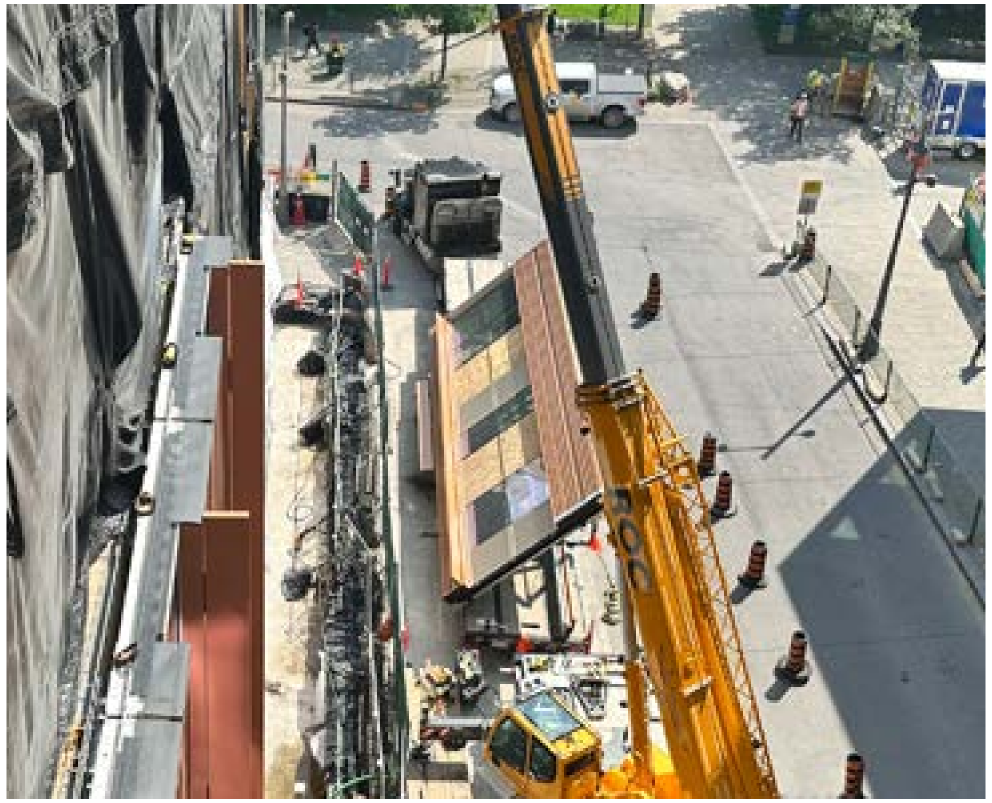
Reviewing the results from the previous page in a broader context shows that the prefab components account for **17.3% of the total envelope** and **5.6% of the total building's** embodied carbon. This better illustrates how potential embodied carbon savings in stages A5.2 and B, combined with refinements to the panel design that reduce steel and aluminum use, could allow prefabricated panels to achieve similar or even lower embodied carbon than comparable site-built options.

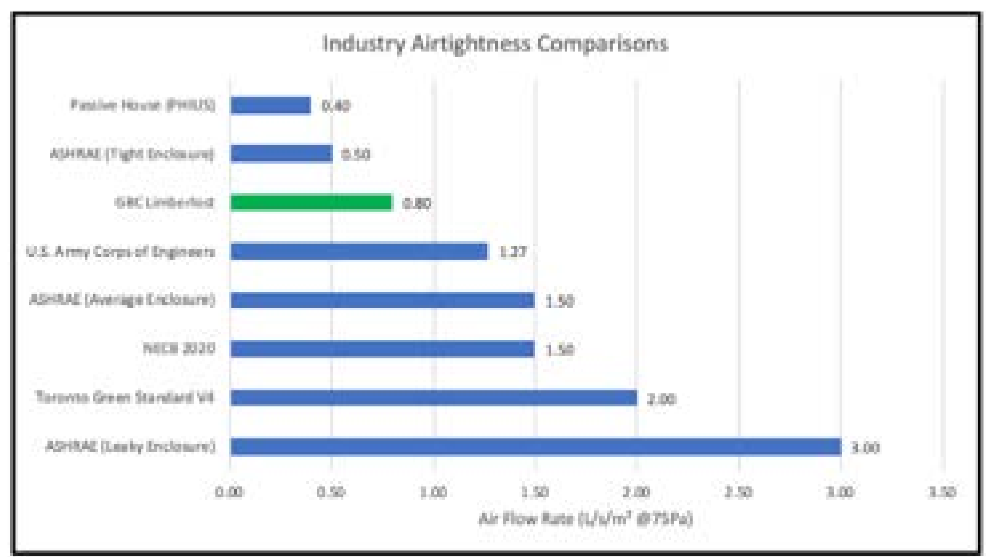


# 4.0 LESSONS LEARNED & FURTHER STUDY

# 4.1 LESSONS LEARNED | IMPACT OF DESIGN ON PREFAB PANEL

Considerations for prefab systems






Limberlost has a unique and striking vertically-oriented cladding design, achieved through large-format wall panels that often span across multiple floors. The final result is a highly polished look with great thermal performance, but the process of building the system revealed some valuable lessons that will inform future prefabricated designs.

The scale and orientation of the panels resulted in some unanticipated challenges in their delivery and installation. The width and length of the largest panels meant that many of them needed to be placed on a delivery truck in an angled position to meet height restrictions. This limited delivery to one panel per truck for the largest elements, and went up to four for the smallest ones. This reduced transportation efficiency and produced supply chain challenges that slowed the envelope installation.

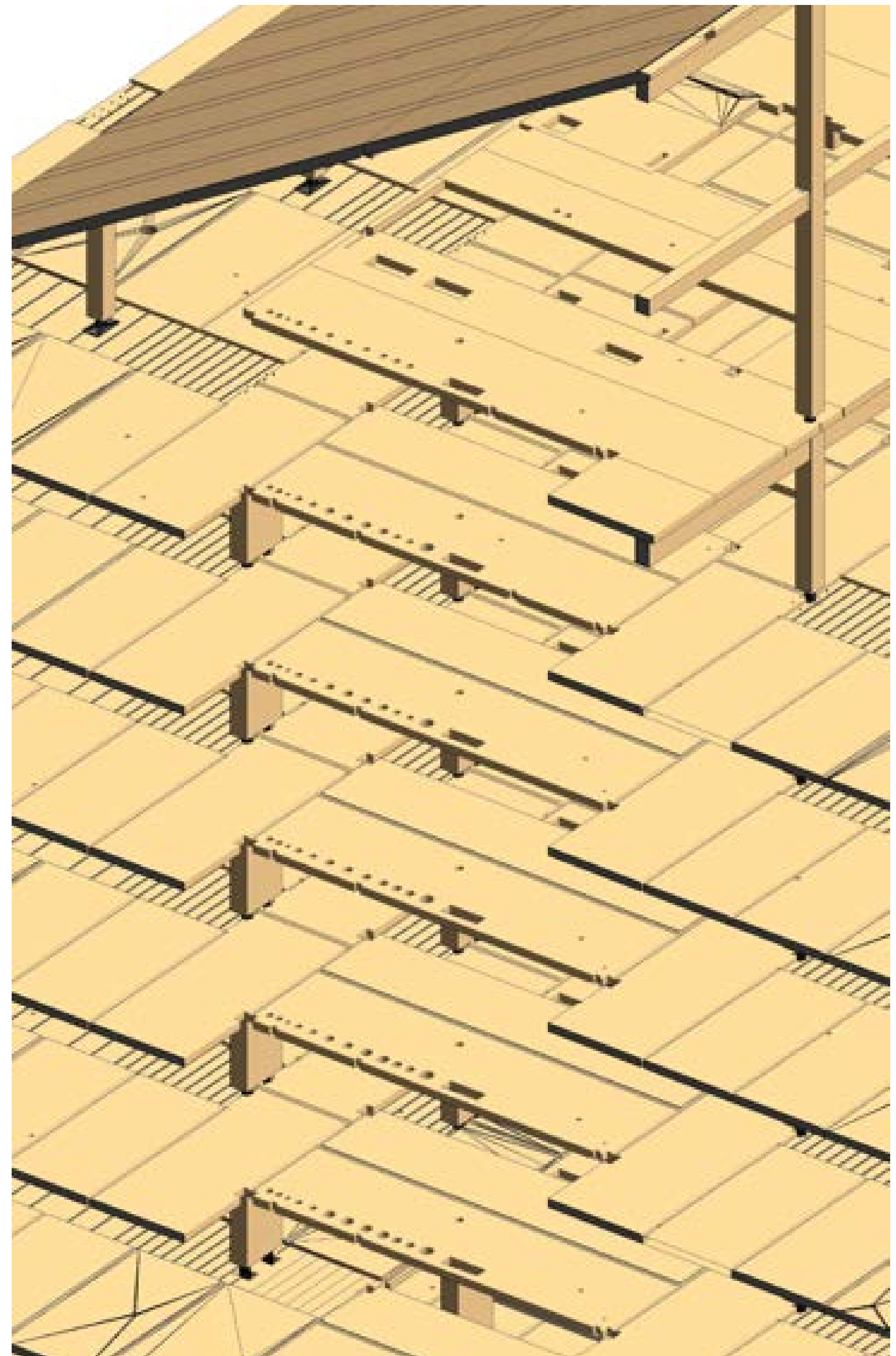
Panels were delivered to site horizontally and angled on trucks. They had to be hoisted off the truck and rotated in the air before being moved into position for installation. This operation could only be done with two cranes or using one highly specialized crane, again impacting the speed of construction. Additionally, spanning vertically between floors limited the number of anchor points for each panel, requiring an increase in framing and structural elements in the panels to ensure their rigidity.

Despite the challenges of this specific prefabricated panel system, the envelope at Limberlost demonstrated exceptional performance, particularly in air tightness as seen in the chart at left. This level of performance of this scale of building would be much more challenging to achieve with site-built systems.

In the future, we will work closely with our envelope manufacturers to ensure our designs account for material and transport efficiency, and to reduce the embodied carbon of the materials used in all components.

# 4.2 LESSONS LEARNED | CONSTRUCTION TOLERANCES

Planning for precision

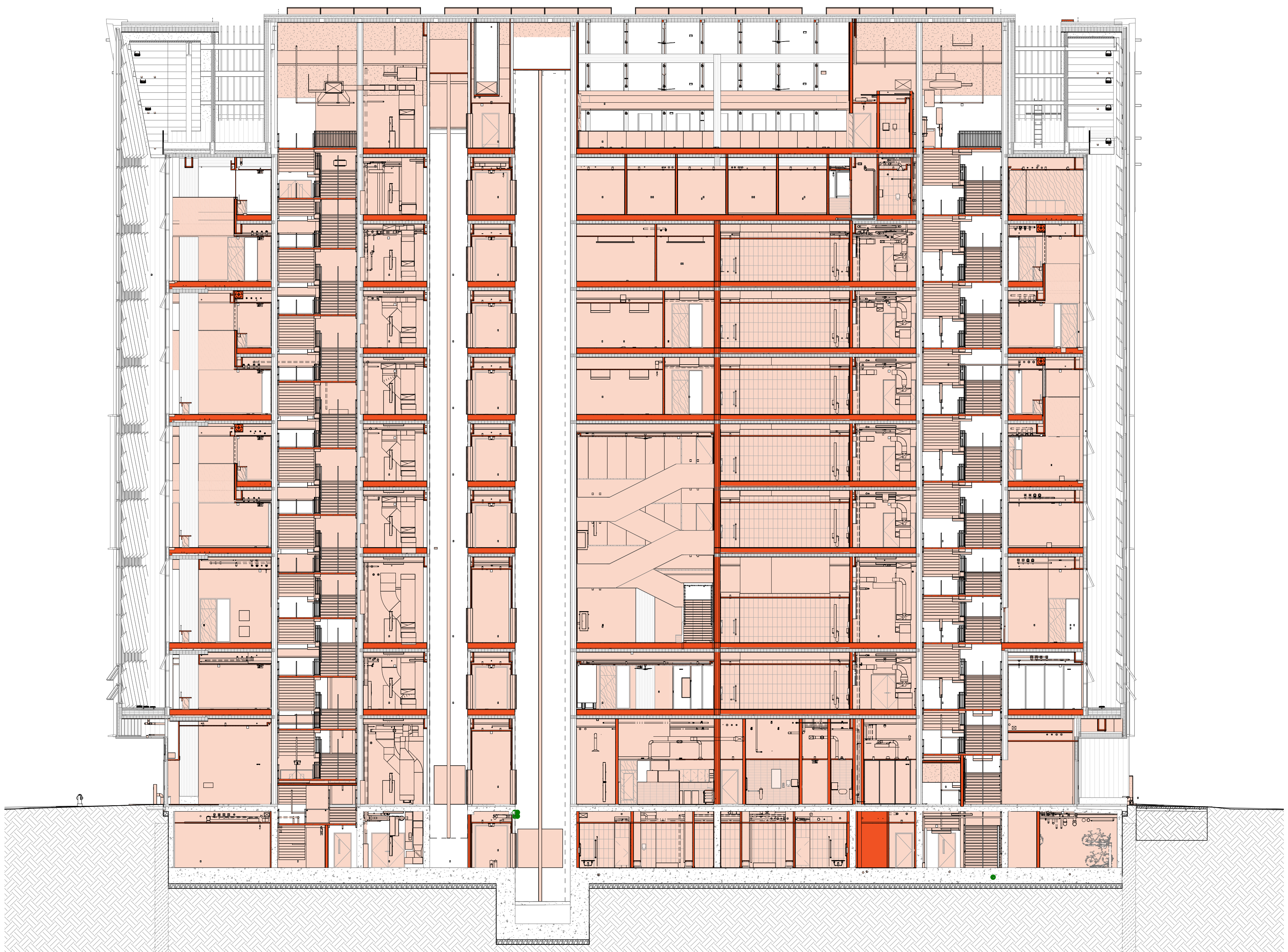



Prefabricated systems allow for tight tolerances in assemblies, improving assembly performance and the quality of finishes. However, close coordination is required to ensure that the design tolerances can be met by all systems, especially where two come in close contact. As an example, any openings in the mass timber floor structure had to be cut in the factory prior to shipping. The design team worked together closely to coordinate all of the building infrastructure services and ensure all routing was fully planned prior to project bid. This coordination was continued through construction to capture any changes required when the Construction Manager came on board.

Coordination is also required when considering the interface of envelope systems with the interior. The prefabricated panels were originally designed to accept a flush layer of finish drywall after they were installed. However, unexpected connectors that extended past the interior stud face and slight misalignments of panels made the installation of drywall impossible. A layer of furring strips, as shown at the far left, had to be added to all perimeter walls, increasing material usage and slowing the construction process. In future projects, we will consider tolerance more carefully to avoid unintended consequences.

# 4.3 FURTHER STUDY | EXCLUDED BUILDING ELEMENTS

Expanding the scope for future analysis



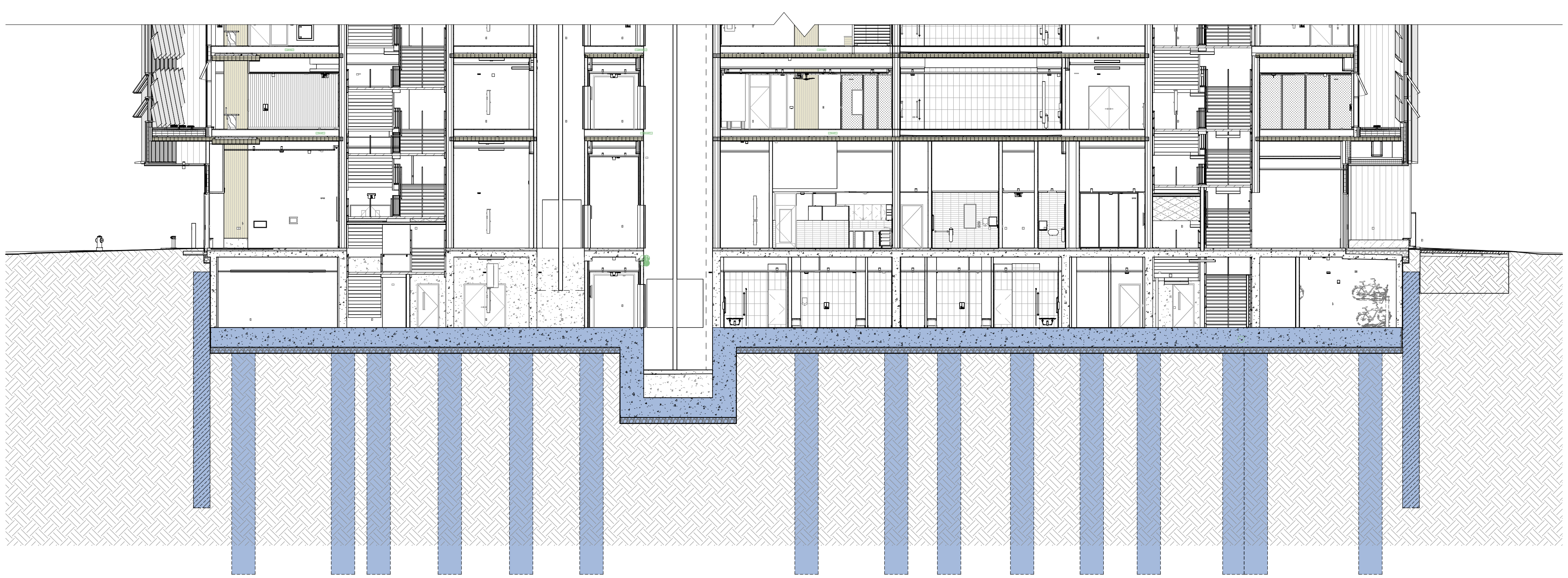
As previously highlighted, the scope of this life-cycle analysis was intentionally limited to only the structure and envelope of the building. While this practice is fairly standard, it does mean that large quantities of material are not accounted for in the overall embodied carbon of the building, in particular, **interior partitions and finishes, as well as mechanical, electrical and plumbing (MEP) systems**. The diagram on the left indicates how much of the building material is excluded from the LCA calculations.

Limberlost Place was designed with extremely efficient Mechanical and Electrical systems to reduce operational carbon. While there is a lot of discussion around the energy use of MEP systems during building operation, accounting for the embodied carbon in the materials for these systems is not typical in North America. These systems are materially-intensive and some studies have indicated that MEP components can contribute close to 30% of a building's overall embodied carbon, similar in magnitude to the building envelope.

As tools and data for life-cycle analysis become more accessible, extending studies to include the full building scope will provide a better picture of the environmental impact of our designs. Limberlost Place, with its unique natural-ventilation driven mechanical system, would be an excellent candidate for further study.

# 4.4 FURTHER STUDY | SITE SELECTION

Soil conditions impact on embodied carbon



Project teams often do not have much flexibility on the location for building, as the functional requirements are constrained by many conditions, including ownership, accessibility, servicing, and beyond. But the conditions of a selected site can have profound impacts on the embodied carbon of the entire project. As noted earlier, the substructure accounts for 37% of the embodied carbon of the entire building's structure, despite only accounting for one floor of usable space.

Toronto's Waterfront, where Limberlost is located, is largely composed of landfill, and the soil has incredibly poor bearing quality. A large portion of the carbon is consumed by a network of 1.2 meter diameter piles that extend 11 meters into the ground to provide adequate support for the building in this poor soil. A high water table also required continuous dewatering during construction, which continued until Level 6 was complete. While we were unable to calculate the specific emissions created from the dewatering, it would contribute to an increase in the overall A5 phase emissions.

The Limberlost site has many advantages for the long-term sustainability of the building, including access to public transit and bike networks and adjacency to the existing campus, so we are not proposing that another site would be more appropriate. Rather, we are identifying that understanding the constraints and challenges of specific sites is important when establishing embodied carbon targets for projects.

# 4.4 FURTHER STUDY | PROCESS ENERGY

Data collection concurrent with construction versus post construction

By default, many life-cycle analyses only consider the embodied carbon of the manufactured materials, accounting for A5 emissions just in the waste created on the construction site. But design decisions do have impacts on energy consumption during construction. Whether it's reduced winter heating from enclosing a building faster with a prefab envelope or reduced transport and equipment time from foregoing shoring and concrete form work, we believe utilizing modern means of construction can produce a significant reduction in the total carbon footprint of realizing a building.

One of the objectives of this study was to better understand exactly this impact. While our discussions with the contractors and manufacturers provided good qualitative information about the construction conditions, we were not able to collect reliable data to help us prove the difference. We think the limitation comes from trying to source the necessary information at the end of project. The workload to forensically compile years of utility bills, diesel fuel invoices, and equipment rental information is significantly higher after a project is finished. Implementing techniques of collecting relevant data while work is progressing would lower the barriers to doing analysis on process energy and provide consultants, clients, and constructors with valuable feedback on where carbon consumption can be reduced. We look forward to working with teams in the future to track process energy live so we can help fill this gap in available information.

# ACKNOWLEDGEMENTS

This study was completed with the support of George Brown Polytechnic. We would like to thank many people from the project team, including Nerys Rau and Pietro Ferrari from George Brown Polytechnic, Brian Fowler from PCL Constructors, Simon Gallagher from Nordic Structures, Mohammed Dawoud from Contract Glaziers, and Arthur Brito from Walters Inc for providing project information and background. We would also like to acknowledge the contributions of Sina Bagheri, Luna Cho, and Abbey Gagnon, students of George Brown Polytechnic, to this research.