Towards **Zero Carbon** Buildings

Design guidelines to achieve low embodied carbon buildings

Manual for architects, engineers and project managers

AR3B025 Sustainable Design Graduation Preparation
Department Architectural Engineering + Technology
Master track Building Technology

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Preface

The building industry accounts for almost 40% of the total carbon emissions that are directly responsible for climate change. The buildings are now deploying energy-efficient solutions to lower carbon emissions from the operational phase. This adversely affects the share of embodied carbon emissions of building materials. The graduation thesis aimed to study and compare the life cycle impact of different materials in building applications. The life cycle assessment method was adapted using certain assumptions to account for circular design approaches. End-of-life scenarios for all the materials were formed and compared using the assessment method. The analysis of materials in different building applications presented a significant difference in embodied carbon emissions.

This manual explains the step-by-step approach to integrate the carbon footprint aspect in building design. The assessment method and results from graduation thesis are used to derive guidelines for this manual. The defined approach covers the stages from project inception until material finalization. The goal to reduce embodied carbon emissions is thus achieved by careful selection of materials and recommended strategies.

Contents

Limitations

The guidelines in this manual are based on the graduation thesis- 'Towards Zero Carbon Buildings'. Some limitations of the design guidelines are:

- The research focused only on the Global Warming Potential (GWP) indicator of the building materials, i.e. CO_2 equivalents of Greenhouse gases. It does not consider other impact indicators such as acidification, eutrophication potential etc.

- There are limited number of materials studied in the research representing broad material families. These guidelines are based on the findings from the research and thus, do not show results of materials beyond the scope.

- Alternate materials proposed in the guidelines have equivalent structural properties. However, other properties such as thermal or acoustic are not considered, but attempted to be similar.

- The demonstrated end of life scenarios are assumed to have 100% conditions of incineration/ reuse/ recycle/ landfill. However, due to limited technology, the current practical conditions do not allow that. Therefore, the guidelines must be used as target goals while designing.

- The guidelines are broadly defined for a typical construction. There may be more conditions in this flowchart of design that are not acknowledged. Closest resembling solutions in the defined steps can still be followed to achieve estimated results.

- The use of alternate materials may cause a consequential need for other solutions, such as fireproof coating or heavier scaffolding. Therefore, reassessment of design while detailing could lead to more accurate results.

The material data used in the research are extracted from third-party verified EPDs and other published literature.

Overview

0 Building definition

- Type of building
- Structurally and economically feasible materials
- Other building components and material quantities

1 Determining material family

Based on research, determining lowest carbon footprint material family

2 Determining material and service life of component

Choosing lowest carbon footprint materials based on specific parameters, and determining the appropriate service life of component based on building life

3 Defining the end of life

Using the results from defined scenarios, defining an appropriate EOL

0

Building Definition

The type of construction has a huge influence on the embodied carbon emissions of the project. A clear definition of building is important to assess its carbon emissions and compare it with other benchmark projects.

The definition of building includes:

- Type of construction
  - New construction/ Renovation
  - Educational/ Commercial/ Residential/ Office/ Other
  - High-rise/ Mid-rise/ Small scale construction
- Built-up Area
- Anticipated Life Span

In this section, the importance of building life span and construction type is explained along with other necessary steps for assessment.

Important recommendations:

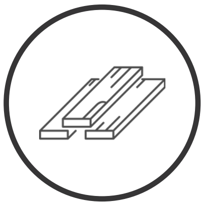
- Adaptive reuse of a construction must be preferred if possible. Existing buildings are a representation of existing carbon emissions in the atmosphere.
- Low/Mid-rise construction must be preferred if possible. This allows design for disassembly and light-weight timber construction.
- The type of construction must not dictate the design completely to allow adaptive reuse in future.

a. Anticipated life span

The life span of a construction plays an important role in defining the carbon emissions over its life. Besides an impact on the operational emissions, it impacts the embodied emissions too. The replacement and maintenance of building materials contribute considerably towards the total emissions.

The substructure and superstructure of a building contributes to an average of 60% embodied carbon emissions. Therefore, the life span of a construction must be designed as long as possible with adaptive design strategies for flexible use in future.

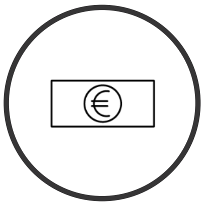
From the research, timber structure may have a life span of more than 120 years and results in the lowest embodied carbon emissions. A construction using similar materials, but with shorter life span may also have lower carbon emissions if designed with circular strategies.



b. Economic and structural feasibility

The concept building design must be studied with different building materials to understand structural and economic feasibility of construction.

An estimate of quantity of building materials is useful to further assess the carbon footprint.

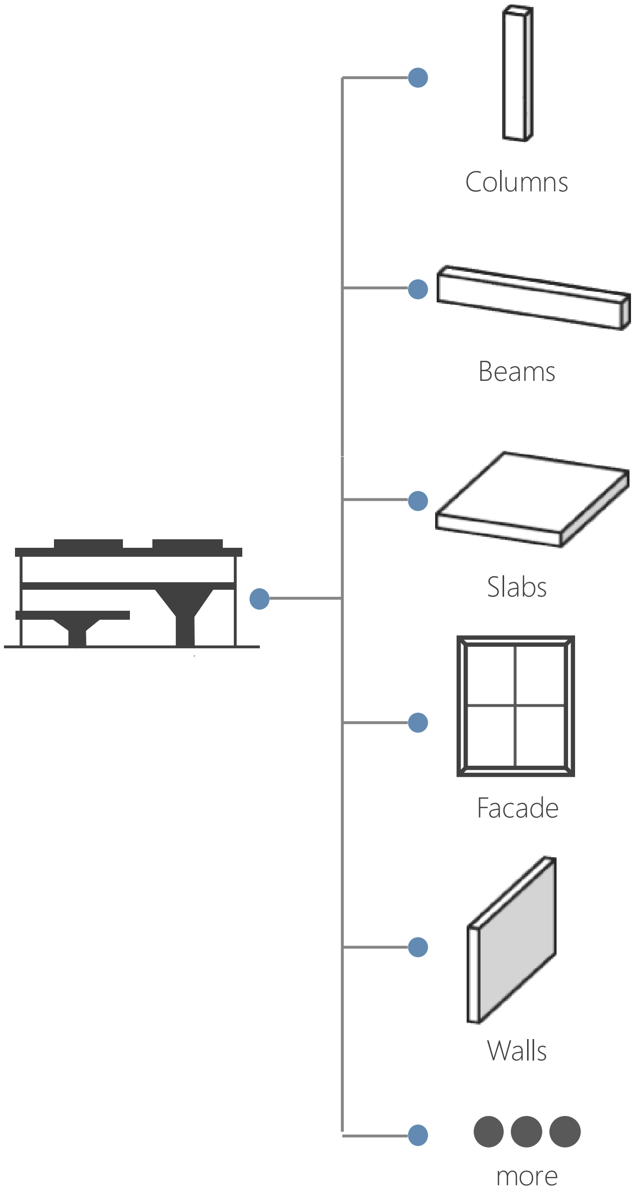


Important recommendations:

- The role of structural consultant at an early design stage is important for the feasibility study of different structural materials.

c. Determining other building components and quantities

The building must be further divided into separate components for assessment along with the estimated quantities.



Important recommendations:

- Use of some BIM or other tools (carbon designer in One Click LCA) allows estimation of material quantities for concept building design.

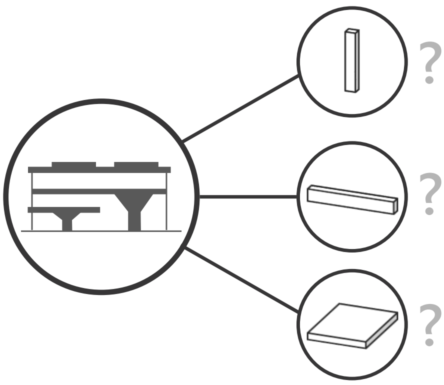
1

Determining material family

The structural and economic feasibility study of the building may result in material options other than all-wood construction. This may be due to structurally unfeasible wood columns in high-rise construction or its economic unfeasibility in some countries.

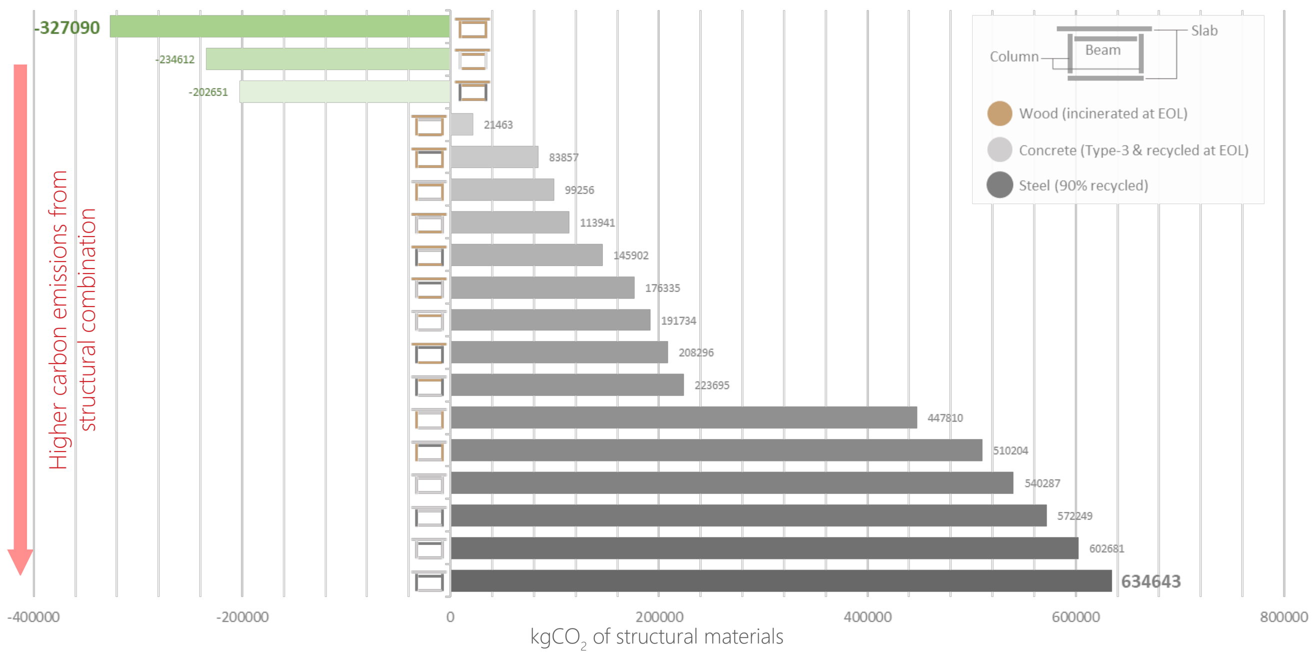
In such cases, the structure of the building may be reiterated with other combinations of columns, beams and slabs to lower the carbon footprint. The results from research may be used as basic guidance tool to choose the feasible option with lowest carbon emissions.

In the bar chart shown below, the icons next to each bar depict the combination of material type used in each structural element- column, beam and slab. The carbon emissions reduce as we go down in the bar chart.

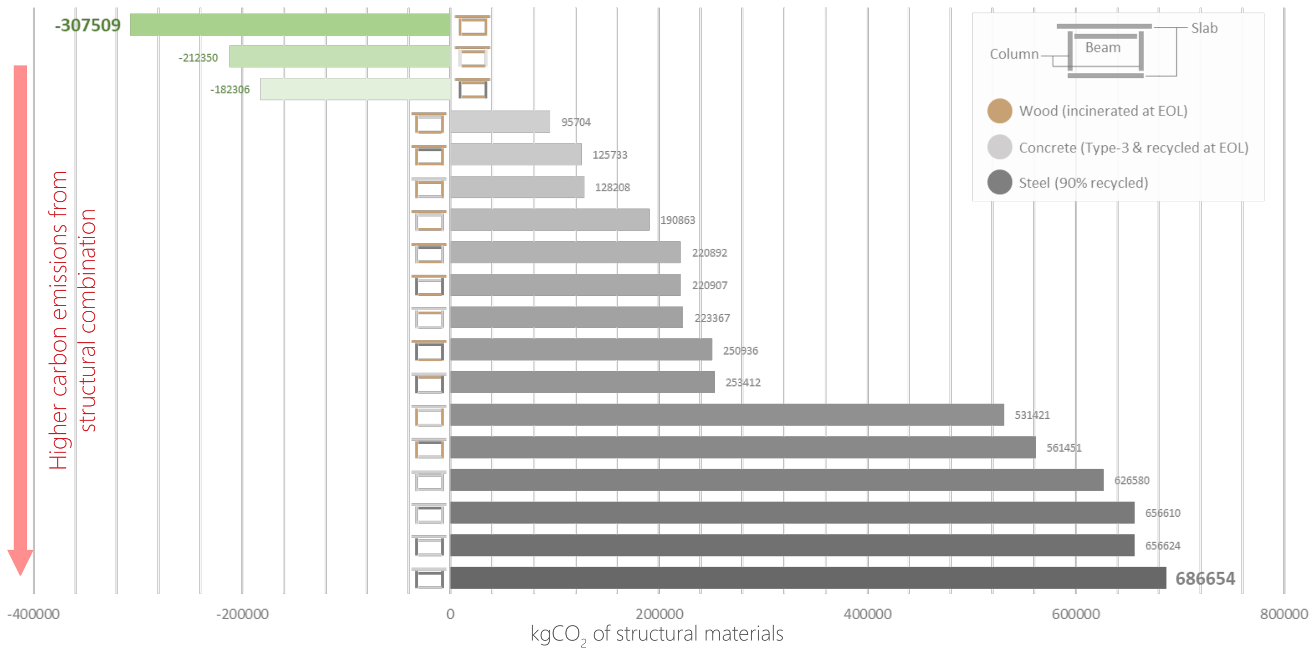


Important recommendations:

- Based on results, using wooden slabs have higher impact in reducing the total carbon emissions than its use in beams or columns.



Combinations for structure with anticipated life span of 120 years.



Combinations for structure with anticipated life span of 60 years.

2

Determining material and service life of building component

To determine a suitable material and its service life, some parameters must be checked from the declarations such as EPD by manufacturers. These are mentioned below in order of their importance:

- GWP_{A1-A3}: declared carbon footprint (A1-A3) (kgCO_2eq./ est. material quantity)
- Service life
- Energy recovery potential (if any upon incineration at EOL) (in kgCO_2eq./ est. material quantity)
- Local availability
- Biogenic carbon stored (if any) (kgCO_2eq./ est. material quantity)

a. Parameters influencing the environmental impact of materials

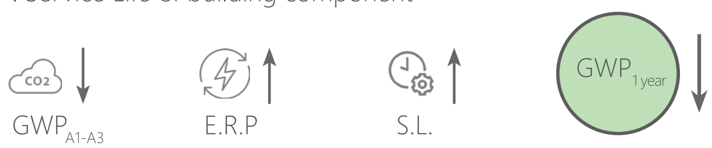
The environmental impact of materials is most influenced by the GWP_{A1-A3}, service life and energy recovery potential. It cannot be interpret individually by any one parameter. The rest of the life cycle stages (maintenance, demolition etc) are insignificant as compared to the GWP_{A1-A3} and are also similar for different materials in most cases. Energy recovery potential (E.R.P) from incineration is estimated to be between 200-500 $kgCO_2eq./m^3$ of material.

Therefore, a basic formula to compare the impact of materials is derived as:

$$GWP_{1\,year} = \frac{GWP_{A1-A3} - E.R.P.}{S.L.}$$

where

$GWP_{1\,year}$: Global warming potential (GWP) per 1 year of service life
GWP_{A1-A3} : Total carbon footprint ($kgCO_2eq.$/ est. material quantity)
E.R.P. : Energy recovery potential (if any) ($kgCO_2eq.$/ est. material quantity)
S.L. : Service Life of building component



The other parameters (local availability and biogenic carbon stored) are also important while determining the material, but does not have a lot of influence on the results. Materials with the closest proximity to the building site must be preferred to lower the transportation carbon emissions. The bio-based materials with highest biogenic carbon stored must also be preferred to increase the carbon stored in technosphere.

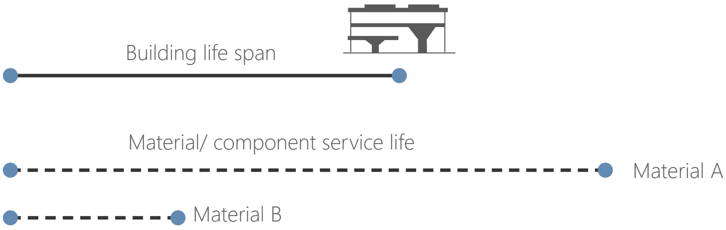
The materials with **lowest $GWP_{1\,year}$ value** in each building application shall provide the suitable material option.

Important recommendations:

- Materials/ building components with highest service life must usually be preferred to allow circular use even after building life.
- Bamboo has a higher carbon sequestration potential than wood

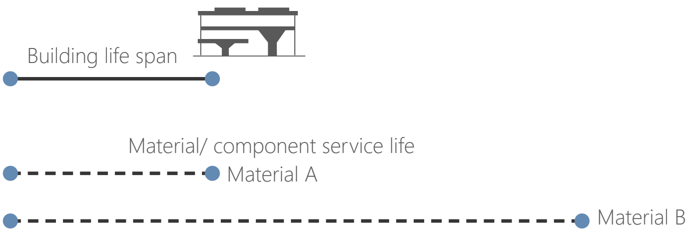
b. Determining the service life of materials/ building components

The service life of materials are declared by the manufacturers and must always be taken into consideration while choosing materials. The choice of suitable material life is explained with an example below:



- The materials with service life equal to or greater than the building life span (Material A) are commonly the preferred choice. This choice is justified if the $GWP_{1\ year}$ of material A is lesser than material B.

- However, if $GWP_{1\ year}$ of material B is considerably lesser than material A, material B must be preferred to achieve lower environmental impact. This may result in higher price. Therefore, a considerate approach is needed.



The materials used in building application must always be compared with other possible materials having longer service life and lower $GWP_{1\ year}$. This allows a circular use of materials even after building life.

Defining the end-of-life

3

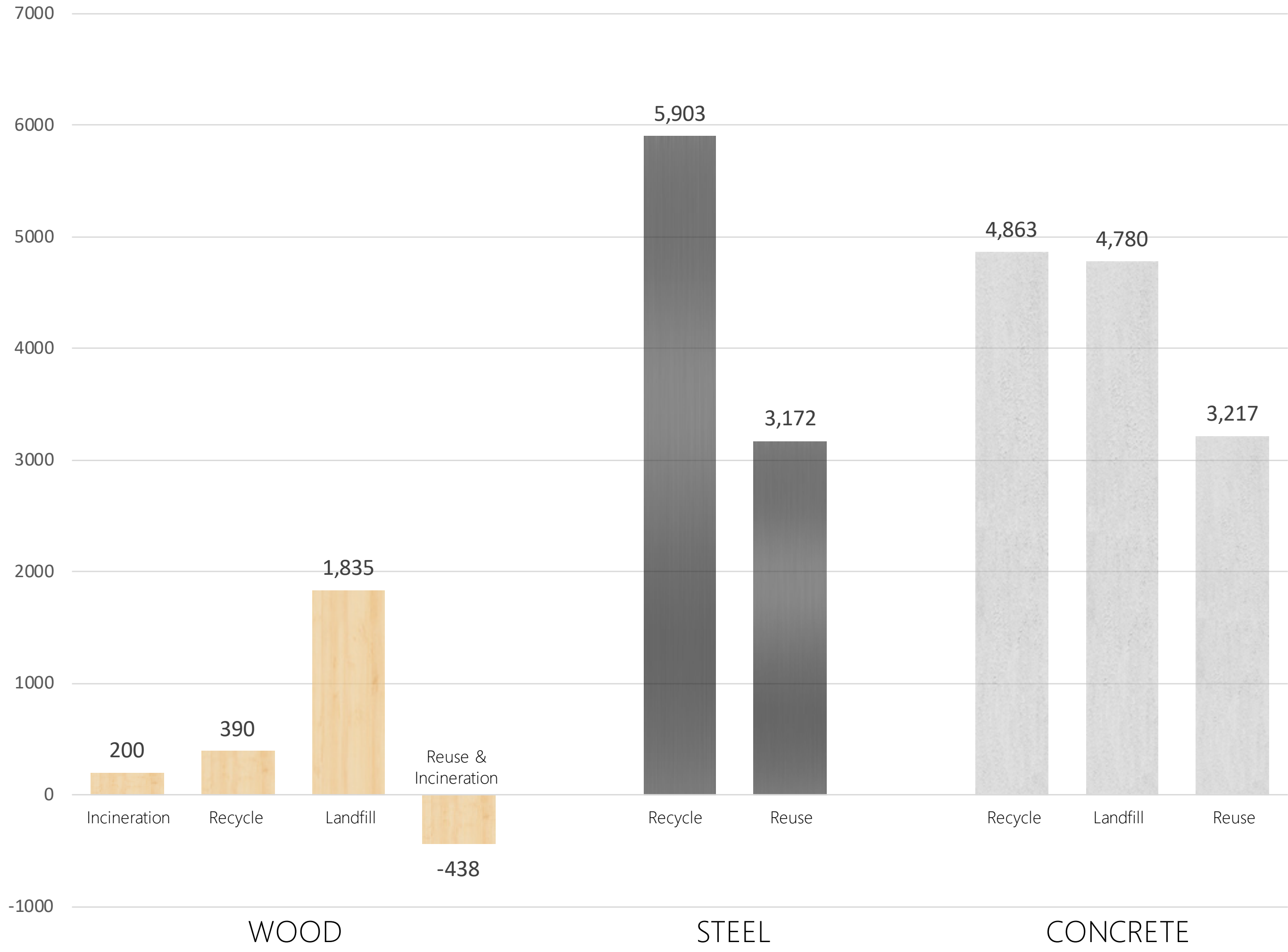
The research to assess several end-of-life scenarios for materials was conducted for each building component. While the impact varied between the building components, the trend of best and worst end-of-life scenarios remained similar due to the assumptions.

An example of results for beam is shown comparing the $GWP_{1\ year}$ values of wood, steel and concrete including the end-of-life carbon emissions. The results are simplified to show the comparison of carbon footprint per year by assuming

- the service life of all the materials are 120 years
- the end-of-life for incineration/ recycle/ landfill occurs at 60 years
- the reuse scenario shows the materials being used until end of service life
- concrete with the lowest carbon footprint from research is shown

Important recommendations:

- The design strategies must be governed by the anticipated end-of-life for the building materials
- Module D/ benefits from end-of-life must be carefully accounted (only once), to understand the holistic picture of life cycle impacts



The results from above illustration must be interpret as:

- Bio-based material incineration and reuse

Incineration scenarios of wood, bamboo, wood fiber insulation, etc has the lowest carbon emissions. However, the use of such materials for longer period results in even lower carbon footprint as shown in 'reuse & incineration'.

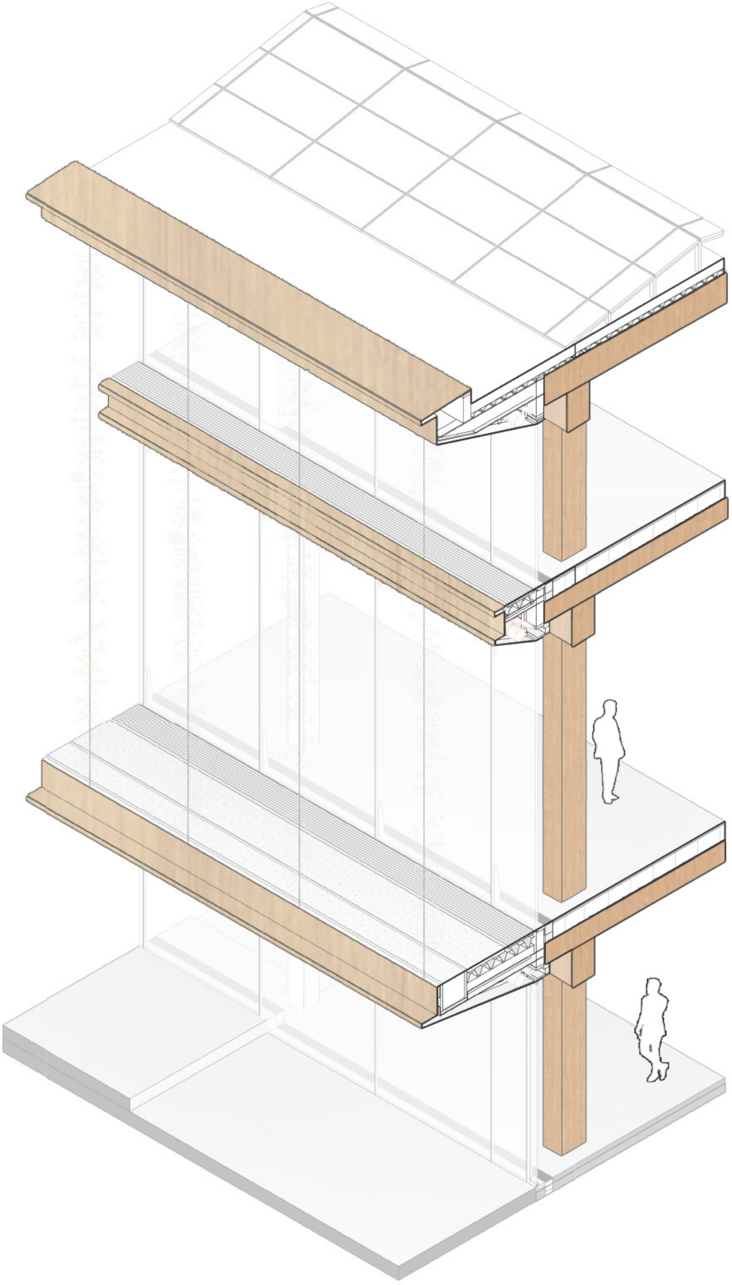
- Reuse and Recycle

In all the materials, reuse scenario results in almost half the carbon emissions as of recycle. This is due to energy intensive recycling processes that has higher carbon equivalent as compared to negligible carbon emissions involved in reuse.

- Landfill

Landfill of wood presents higher carbon emissions due to release of carbon dioxide in soil. It is also an energy intensive process with almost no energy recovery and therefore, must not be practiced. Landfill of other materials such as concrete, PVC, etc may also be harmful for the environment.

Summary



~120% lower
embodied carbon
emissions

An estimated result from assessment of a mid-rise educational building by appropriate choice of materials, end-of-life and other variables

Reduced carbon offset
period of almost
30 years

Based on the potential energy positive design of the case example

Increased role of
buildings in mitigating
climate change

By reducing the carbon emissions from construction sector, climate change mitigation is foreseeable.