

Reducing Emissions through Low-Carbon and Biomaterials: The Case of Green Office Enjoy, Paris

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Article Info:

Submitted: May 16th, 2025

Reviewed: June 15th, 2025

Accepted: July 25th, 2025

Keywords:

biomaterial;
embodied carbon;
fly ash replacement.

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Abstract

Drastic transformation in the construction industry is required to achieve global net-zero targets while accommodating the continuing need to build to anticipate the growing population. With the increase implementation of energy efficient building, the significant of embodied carbon becomes higher. The use of biomaterial has great potential to reduce building emissions. This paper presents a case study that has been built with engineered timber components, and examines to what extent, a further reduction of embodied emissions can be performed. Three material replacements were proposed to further decarbonize the building emissions, and the embodied carbon reductions resulted by changing the timber specification and fly ash use in concrete mixture were assessed quantitatively with embodied carbon assessment. Results show that by replacing the building materials with lower carbon options, the embodied carbon of the case study can be reduced from 52 to 242 tons of CO₂e or 2.82 to 12,99 kgCO₂e/m².

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INTRODUCTION

Due to the climate crisis, there has been a raised awareness on the urgency of sustainable development. The changes of land use, from agricultural or forestry to the built environment have contributed roughly 21% of global greenhouse gas emissions, showing that the building and construction industry plays a major role in climate change (EPA, 2021). As of 2022, buildings accounted for 34% of the global energy consumption and 37% of global energy and process-related carbon emissions (UNEP, 2024). Built environment has grown significantly in accommodating the continuing increase of global and urban populations. With the increase of population by 10% from 2010 to 2018, floor area has grown by 20%, causing 10% increase in energy and emissions (UNEP, 2021). Realizing the negative environmental impacts of the construction industry, the way buildings are constructed should be changed, and sustainable development should be implemented. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability in architecture refers to the methods, materials, and design strategies that minimize environmental impact and promote resource efficiency throughout a building's life cycle (Ghodsian, 2024).

Looking into the future, the challenge of today's construction industry is to develop new floor spaces or buildings, while reducing greenhouse gas emissions. While the global climate target is to be net-zero carbon emissions by 2050, it was predicted that by 2060, more than 230 billion square meters of new floor area will be required to accommodate the global population. To satisfy this demand, new floor area should be created, equal to building the area of Japan every year for forty years (Ness, 2020). To achieve net-zero targets, while accommodating the new space demand, transformation in the construction industry is crucial, and thus, life cycle perspective should be implemented.

The whole carbon emissions of buildings comprise operational carbon emissions and embodied carbon emissions (WGBC, 2019). While operational emissions are related to daily use of a building, including carbon emissions due to lighting and HVAC, embodied emissions are carbon emissions produced in material production, construction process, maintenance, and end-of-life of the building (demolition, deconstruction). Hence, embodied emissions are closely related to building construction. In the past, the focus of sustainable architecture was to reduce

energy and carbon emissions in operational phase, by applying energy-efficient design and passive systems, such as daylighting, natural ventilation, etc. As a result, energy efficiency of new buildings has commonly increased, causing embodied carbon emissions to have higher percentage in the whole-life carbon emissions (Röck et al., 2020; Schmidt et al., 2020). It is believed that for buildings constructed now until 2050, the embodied emissions will be the majority of building emissions (Simonen et al., 2017) Therefore, for drastic reduction of carbon emissions, the mitigation of embodied carbon emissions becomes crucial.

Sustainable construction focuses on reducing embodied carbon emissions. It prioritizes the technologies and methodologies implemented during the material production and construction processes. Sustainable construction is designed to save energy and resources, to minimize waste, to harmonize with the local climate, tradition, culture, and surrounding environment, and to be able to sustain and improve the quality of human life, by increasing the efficiency of the construction process, using eco-friendly materials, and applying innovative construction techniques to reduce carbon footprint of buildings (Ghodsian, 2024). There are four building strategies for mitigating embodied carbon in construction (Beama, 2022; WGBC, 2019): build nothing, build less, build clever, and build efficiently, as shown in Figure 1.

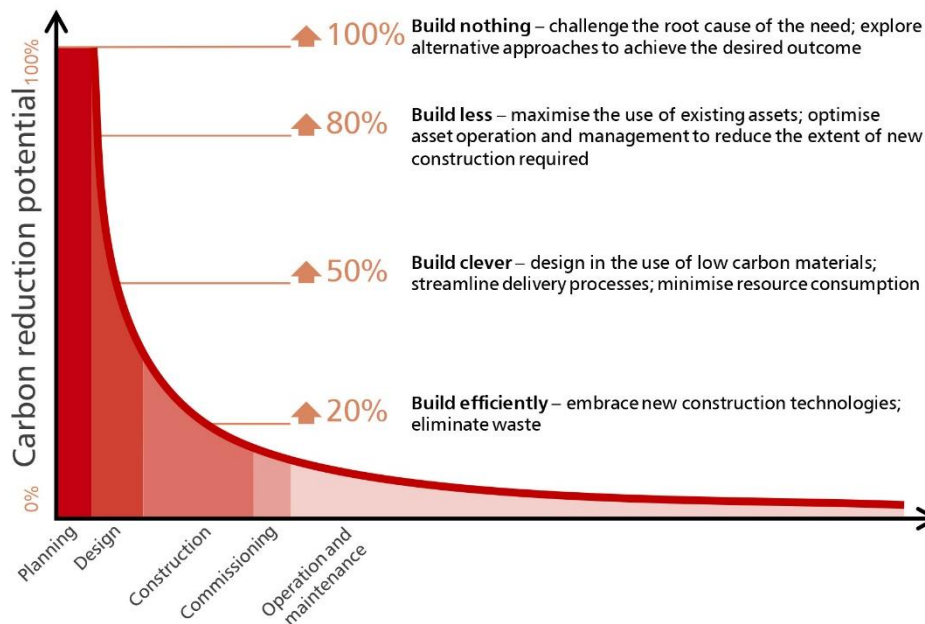


Figure 1. The four building strategies (Source: Green Construction Board in HM Treasury, 2013).

To build efficiently, it is essential to choose construction methods that minimize material usage and reduce construction impacts on the environment. Here, increasing the use of prefabricated elements and off-site construction can significantly lower waste, improve quality control, and speed up the building process. Off-site construction also plays an important role in reducing material waste on-site and offers more precise construction techniques; also known as modular construction. Local sourcing of materials reduces transportation emissions and supports the local economy, further enhancing construction efficiency. By building efficiently, 20% carbon reduction can be achieved.

Building clever, on the other hand, can produce 50% carbon reduction, but should be planned early during the design phase of the project. This includes using low carbon materials and minimizing resource consumption. The use of materials with low embodied energy and carbon helps reduce the overall environmental impact of construction. The use of local materials, reused and/or recycled materials, and sustainable resources further supports a more eco-friendly built environment. In the past the construction industry relied on carbon-intensive materials, such as concrete and steel. To reduce embodied carbon, the use of carbon-intensive materials should be limited, and replaced with alternative lower-carbon material alternatives. Another application is by prioritizing structural efficiency to reduce structural weight and minimize material use.

Further reduction of embodied carbon can be achieved by building less and building nothing, with an estimated of 80% and 100% carbon reduction respectively. Here, the concept is maximizing the use or occupation of existing buildings to limit the need for new construction to be built, or prioritizing alternatives to constructing new structures. For instance, in the case of office buildings, the question arises whether building new spaces are necessary, especially when some offices are still vacant/not fully occupied. In this context, adaptive reuse is a beneficial strategy, where existing buildings/structures are repurposed to extend their lifespan.

Material selection and production has an important role in implementing ‘build clever’. Using materials that can be reclaimed, recycled, or repurposed from other construction sites helps reduce the need for new resources. Renewable, bio-based building materials have the potential to reduce atmospheric carbon, if they are sustainably sourced and managed. Currently, there has been a shift to use biomaterials and low-carbon alternatives. Using biomaterials can reduce up to 40% carbon emissions by 2060 (UNEP, 2023).

Timber is a leading biomaterial, timber production and use offer opportunities for embodied carbon reduction. Timber is exceptional materials when it comes to their contribution to sustainability, primarily because they are recyclable, reusable, and renewable (Evison, 2018). When sourced and used responsibly, timber plays a vital role in creating sustainable construction systems and reducing the environmental impact of building projects. Of the conventional building materials, sustainably harvested timber has the potential to be the most environmentally friendly since it typically has the lowest emissions of greenhouse gases of any conventional building material (UN Habitat, n.d.). Timber also has carbon sequestration potential, meaning that it can store carbon and contributes to offsetting carbon emissions during the building’s lifecycle. Hence, by using timber in building construction, it is believed that buildings can act as carbon sinks, as illustrated in Figure 2, to reduce the concentration of atmospheric greenhouse gases (Churkina et al., 2020).

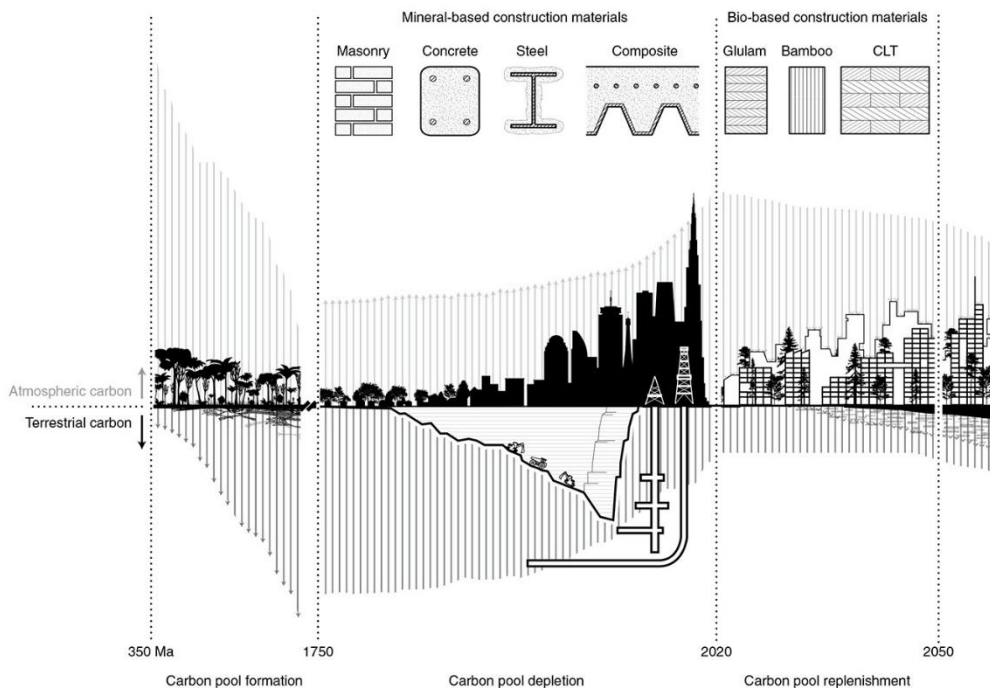


Figure 2. Building as carbon sinks (Source: Churkina et al., 2020).

In the last two decades, engineered timber has become an attractive alternative to concrete and steel, due to its potential for sustainability, strength, and flexibility, as well as its suitability for incorporation into fast, modular off-site construction techniques (UNEP, 2023). Among engineered timber products, glue-laminated timber (glulam) and cross-laminated timber (CLT) are two most frequently used products, with application varied from low up to high-rise buildings. Glulam is a structural timber produced by at least two parallel laminations of 6-45 mm timber layers, glued together, while CLT is made of a minimum of three timber layers stacked on top of each other at right angles and glued to form a thickness ranging 50-500 mm (Ramage et al., 2017). CLT has in-plane and out-of-plan carrying capacity, making it suitable for many structural elements, including floor slabs, walls, and roof elements (Brandner et al., 2018; Jelec et al., 2018). First developed in Europe in the 1990s, CLT has become an attractive alternative to concrete and steel, due to its potential for sustainability, strength, and flexibility, as well as its suitability for incorporation into fast, modular off-site construction techniques (Mallo & Espinoza 2014; Brandner et al. 2016). As a timber product, it is a low embodied carbon material, has various end-of-use potential, decomposes naturally or can be recycled, and has carbon sequestration potential, hence, it has low whole-life environmental impacts (Lehmann, 2013; Younis & Dodoo, 2022).

This paper aims to study and analyze the implementation of sustainable construction principles in an existing building that was built with a biomaterial, then discusses whether additional improvement strategies can be implemented to reduce further its embodied carbon emissions. Since the use of biomaterials, such as timber, already has many environmental benefits, how to improve further the building’s environmental performance? This is the

research question to be answered in this paper. The case study chosen for this research is a green office building, called Green Office Enjoy, in Paris. This building was first analyzed to identify the sustainable construction features that were implemented, especially related to embodied carbon mitigation strategies. Then, an improvement plan was made to reduce further its carbon emissions, and carbon assessment was performed to calculate the resulted embodied carbon reduction.

METHODOLOGY

This research was designed with a mixed-methods approach, combining qualitative literature review and case study analysis, with quantitative carbon assessment. Mixed-methods research collects and analyses data quantitatively and qualitatively to obtain comprehensive understanding of the research problem (Creswell, 2014). The exploratory mixed methods were implemented, starting with qualitative literature review and case study analysis, and then continued with quantitative carbon calculation. The methodology consists of four phases, as illustrated in Figure 3.

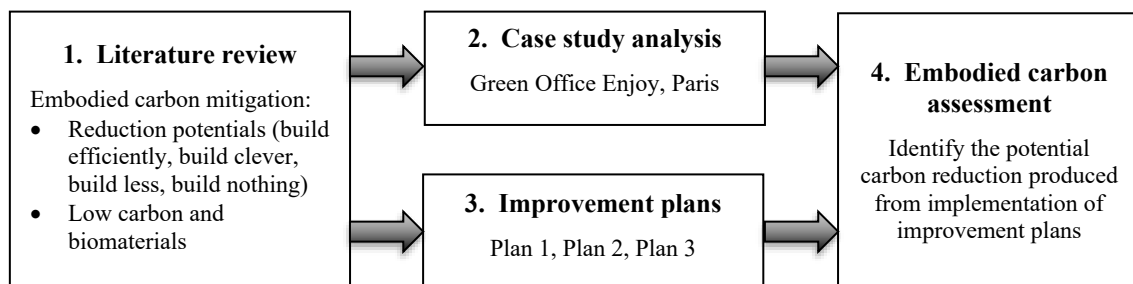


Figure 3. Four phases of the research methodology (Source: authors).

1. Literature review

This research started with a literature review, where existing literature about sustainable construction principles, specifically embodied carbon mitigation strategies, low-carbon and biomaterials was collected and reviewed. This review is necessary to understand the fundamental principles of sustainable construction, which will be used to analyze and evaluate a vertical building case study.

2. Case study analysis

To look at the implementation of sustainable construction principles in vertical buildings, a case study has been selected to be analyzed. The case study was taken from a real project that was recognized for incorporating various sustainable construction features. The use of biomaterials becomes one main criterion in selecting the case study, since the purpose of the research is to examine the possibility to reduce further the carbon emissions of buildings constructed with biomaterials. The case study selection process was performed through observing digital resources of building projects. As a result, Green Office Enjoy in Paris was chosen as the case study. Multiple documentary research was performed to collect building information, then the sustainable construction features of this building were identified, based on embodied carbon mitigation strategies coined during literature review.

3. Improvement plan

In this phase, more exploration to sustainable construction principles and precedents were undertaken to propose an improvement plan of the selected case study. This includes the exploration of alternative methods and materials that could further reduce the environmental impact of the building. Here, the embodied carbon mitigation strategies, especially ‘build efficiently’ and ‘build clever’ (Beama, 2022; WGBC, 2019) become the reference.

4. Embodied carbon assessment

Calculations of the embodied carbon resulted in building construction is necessary to compare the embodied carbon of the existing case study and how the improvement plan proposed can reduce further carbon emissions. This embodied carbon calculation provides evidence or confirmation towards the effectiveness of the improvement plans in reducing carbon emissions.

The embodied carbon calculations were directed by Life Cycle Assessment (LCA) framework in ISO 14040 (ISO, 2006). The objective of the calculation was to compare the existing construction with the proposed improvement in terms of embodied carbon, hence, the scope of the calculation focuses solely on embodied carbon, specifically upfront embodied carbon related to material production (A1–A3), which accounts for roughly 50% of whole-life carbon emissions (Gibbons et al., 2022), as shown in Figure 4. Other phases were excluded from the analysis. For inventory analysis, as the case study is located in France, embodied carbon factors for calculating (A1–A3) (ECF_{A13}) were sourced from the Inventory of Carbon and Energy (ICE), Version 3.0 (Craig & Hammond, 2019). The calculation methodology followed guidance from the Institution of Structural Engineers (Gibbons et al., 2022) and the Royal Institute of Chartered Surveyors (RICS, 2017). The value of (A1–A3) for each building component was calculated by multiplying the building component’s quantity (volume/mass) with embodied carbon factor for (A1–A3), symbolised by ECF_{A13} . The formula is as follows:

$$(A1-A3) = \text{material quantity} \times ECF_{A13}$$

where (A1–A3) = upfront embodied carbon due to material production (kgCO₂e)
 material quantity = volume (m³) or mass (kg)
 ECF_{A13} = embodied carbon factor for (A1–A3) (kgCO₂e/m³ or kgCO₂e/kg)

For the impact assessment, the reduction in embodied carbon was evaluated by comparing the global warming potential (GWP) of the existing construction and the proposed improvement, expressed in kgCO₂e/m² (kilogram carbon dioxide equivalent per square meter). Here, emission values (kgCO₂e) were normalized by the gross floor area (GFA) of the building.

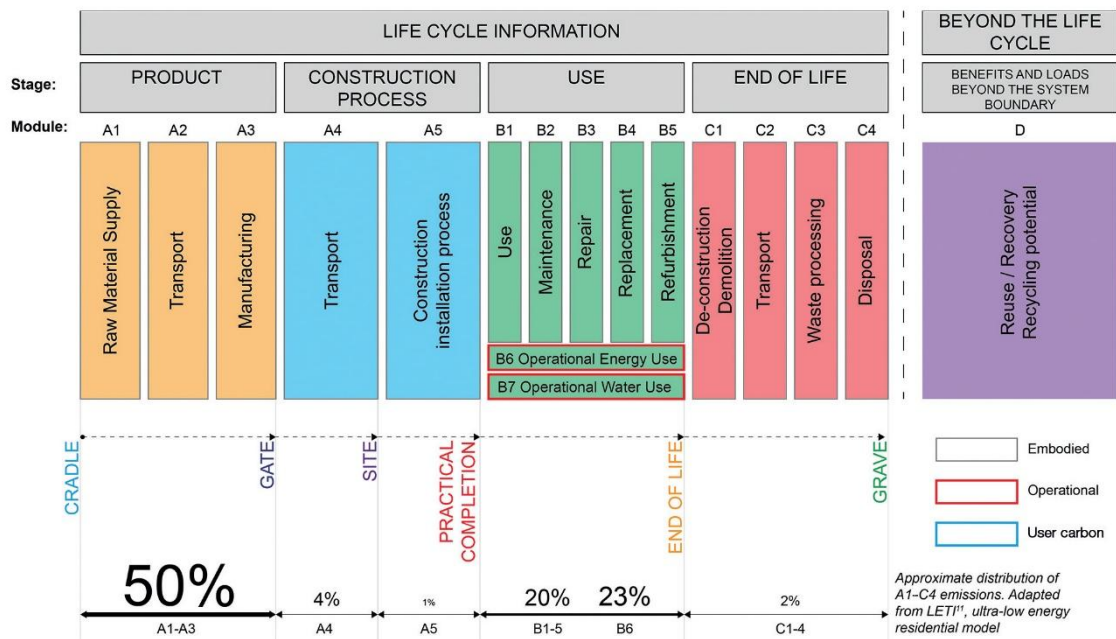


Figure 4. Building’s whole life cycle based on EN 15978 (Source: Gibbons et al., 2022).

CASE STUDY DESCRIPTION

The case study, Green Office Enjoy in Paris, France (Figure 5), was designed by Baumschlager Eberle Architekten. The planning phase of this building was started in 2013, and the construction process occurred between 2015 and 2018. The building consists of seven levels, with a total floor area of 16,970 m² (Baumschlager Eberle Architekten, 2018). Green Office ENJOY is the first office block in Paris to produce more energy than it consumes. This building uses renewable energy sources such as solar panels and geothermal energy to achieve net-zero energy status. The construction followed ISO 14001 standards with a strong emphasis on waste management, 80% of the construction was recycled. Additionally, this building used sustainable materials including certified timber and low-

VOC paints, which were used throughout the building's construction (Austria-architects, 2019). This building has received ISO 14001 and BREEAM EXCELLENT certificates, as well as BBKA Certificate Award for low-carbon building in 2016.



Figure 5. Green Office Enjoy (Source: Baumschlager Eberle Architekten, 2018).

With today's increased awareness of the finite nature and scarcity of resources, timber as a biomaterial has a great potential to be a sustainable construction material. Decision to use timber was also supported by the architect's long experience in timber buildings and expertise in BIM planning (Austria-architects, 2019). This building has a frame structure system, made of engineered timber, which rises above a concrete base. Standing atop a railway underpass in Paris's Clichy-Batignolles quarter, the site demanded the lightest-weight construction method possible. This is why the engineered timber was chosen, being a lightweight structural material, with weight a third less than concrete. Concrete was used only for the base to anticipate the vibrations from the passing trains underneath (Austria-architects, 2019; Arquitectura Viva, n.d.).

The building incorporates innovative techniques to achieve its low-carbon goals for its construction materials, particularly the structural system. Above the building's concrete base, which is 10-m above the rail tracks, stands a frame structure made of glued spruce and pine laminate (Austria-architects, 2019). The floor slabs are made of a hybrid system of pine CLT and concrete (Arqa, 2019). The CLT panels used were prefabricated off-site. The innovative use of CLT panels in conjunction with concrete not only reduces the environmental impact of the building but also enhances its energy efficiency, acoustic comfort, and overall durability. The facades were constructed using a solid timber frame, sterling board (OSB) and mineral wool and finished with aluminum cassettes (Arquitectura Viva, n.d.). Figure 6 presents the 3D structure of the building, while Figure 7 listed detailed description of the structural components.

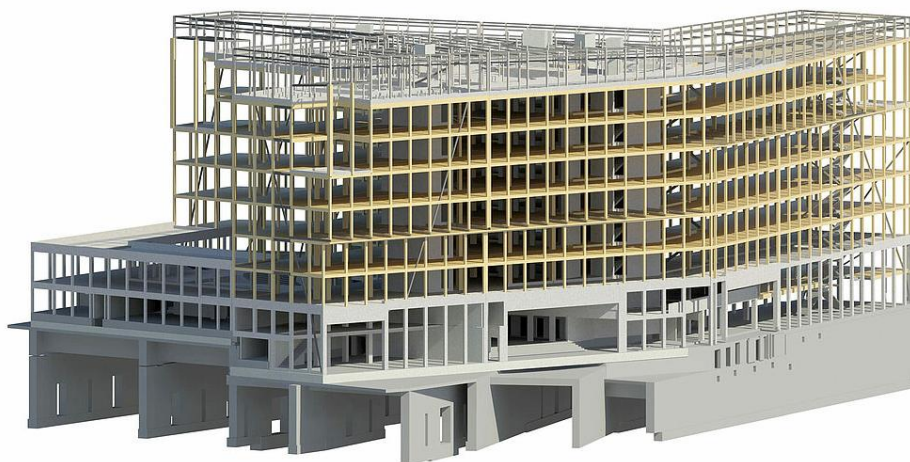


Figure 6. 3D structural model of the case study (Source: Baumschlager Eberle Architekten, 2018).

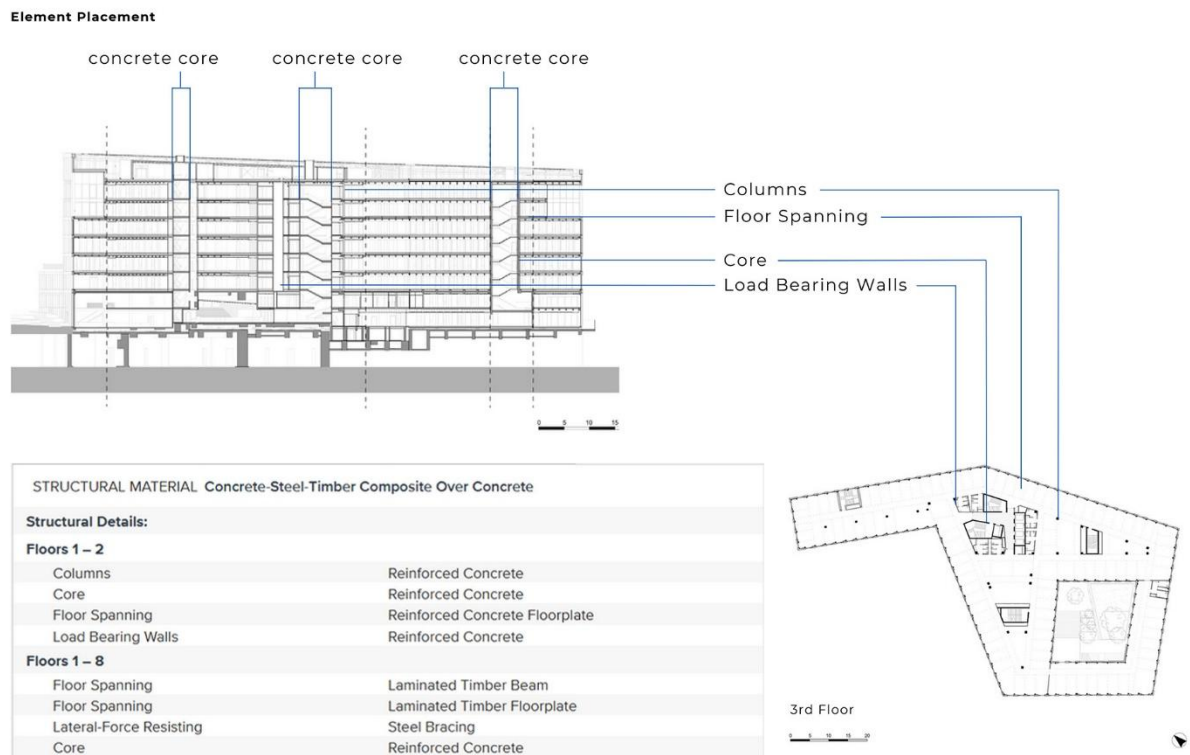


Figure 7. Description of structural components (Source: authors).

RESULTS AND DISCUSSION

1. Sustainable Construction Features

After examining the case study through the lens of sustainable construction principles, particularly embodied carbon mitigation strategies, several key sustainable construction features can be identified, including:

- **The use of timber as biomaterial**

The case study uses engineered timber as its main structural material, alongside concrete. Glulam and CLT, embody the character of timber as a biomaterial, which is biodegradable and recyclable. As a natural material, the processing of timber requires less energy and produces less carbon emissions, and at the end-of-life of the building, timber will decompose naturally or can be reused or recycled. Hence, it produces lower environmental impact over a building's life cycle (Stora Enso, 2018). Additionally, by using timber in the building, due to its carbon sequestration potential, the 2,700 m³ of building structure stores 520 tons of CO₂ (Arqa, 2019).

- **Structural efficiency**

The building structure was designed with structural efficiency in mind. By combining concrete construction with engineered timber (glulam and CLT), the overall structural weight can be reduced (Austria-Architects, 2019; Foster & Reynolds, 2018). By using timber columns, the structural weight can be reduced up to a third. The hybrid floor slab system combines the lightweight nature of CLT with the load-bearing capacity of concrete, which allows for thinner floor slabs compared to using just timber or concrete alone.

- **Off-site construction**

Engineered timber components are produced and prepared off-site, in a controlled factory environment, to ensure their accuracy and quality (Falk, 2013). These components are then transported to the site for assembly. The benefits include less on-site waste and disruption, faster construction timelines, more precise manufacturing with lower material errors. Flat-pack modular system applied (Figure 8), was designed for easy assembly on-site, reducing the time and labor required during the actual construction process. They also allow for future disassembly and re-use, contributing to circular construction practices (BuildInWood, 2020).

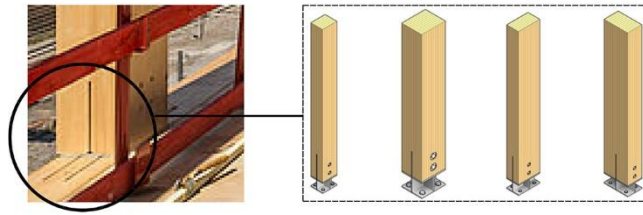


Figure 8. Flat-pack modular system (Source: Brown, 2017).

- **Low-carbon construction**

By employing timber for most structural components, including columns, girders, slabs and interior facades, low-carbon construction can be achieved. As a result of this innovative design, the building saves 2,900 tons of CO₂, as compared to a traditional concrete construction, equal to planting 1,500 trees (Arqa, 2019).

- **Efficient construction process and waste management**

The ISO 14001 environmental management system was applied during construction to systematically reduce the environmental impact. This standard helps in managing aspects such as waste disposal, material selection, and site impact monitoring, ensuring sustainable practices are followed during the build phase (Baumschlager Eberle Architekten, 2018). Moreover, during construction, over 80% of the construction debris was recycled, ensuring minimal waste was sent to landfills. This effort was critical to achieving both ISO 14001 and BREEAM standards.

All above features show that the case study has been designed as a sustainable building with the implementation of sustainable construction principles. As discussed in the Introduction Section, there are four building strategies with varied carbon reduction potentials – build efficiently, build clever, build less, build nothing (Beama, 2022; WGBC, 2019). Build clever with up to 50% carbon reduction potential involves using low carbon materials, streamline delivery process, and minimizing resource consumption, while ‘build efficiently’ with up to 20% carbon reduction involves applying efficient construction techniques and minimizing construction waste (Figure 1). Therefore, by using timber as a biomaterial, by designing structural efficiency, and by using low-carbon construction, the case study has implemented the ‘build clever’ strategy. Likewise, by employing off-site construction, efficient construction process, and waste management, the ‘build efficiently’ strategy has been adopted.

Additionally, the building has specifically been designed with waste management in mind during material selection and the construction process. By using a biomaterial which can be reused and recycled, the building adopts circular thinking, to minimize waste and prolong material’s lifespan (Domenech, 2014). By applying off-site construction and efficient construction techniques, construction waste on site can be reduced, while 80% of the construction debris was recycled.

2. Improvement Plan

The case study already has great environmental performance in terms of the operational and embodied carbon emissions, shown by the certificates and awards that the building has gained. This raises the question of whether further decarbonization is possible. To simulate the possibility to reduce further building emissions, improvement plans were developed to explore the potential of reducing embodied carbon emissions, through material replacement. Here, it was assumed that the improvement plan was made during the planning phase of the building, where the construction process has not been started. Three material replacements were proposed, related to the specification of timber, the concrete mixture, and the building facade.

- **Plan 1: Replacement of structural timber material**

The case study uses pine and spruce glulam for its columns and beams, and softwood CLT for the floor slabs (Stora Enso, 2018). Timber from angiosperms, such as oak, beech, is called hardwoods, while timber from gymnosperms, such as pine is called softwood (Ramage et al., 2017). Hardwoods tend to grow slower in time, causing hardwoods to have greater density and strength (Duffield Timber, 2021). The embodied carbon factor (ECF_{A13}) for hardwood (0.306 kgCO_{2e}/kg) is smaller compared to softwood CLT (0.437 kgCO_{2e}/kg) in ICE database (Craig & Hammond, 2019). Hence replacing softwood with hardwood can reduce further carbon emissions.

• **Plan 2: The use of fly ash in concrete**

Another improvement plan that was proposed is the use of fly ash to replace cement in concrete. Concrete is the most-used material in the building sector, and therefore, cement as the binding agent in concrete, has contributed to 7% of the global carbon emissions. For achieving net-zero targets, the use of cement, alongside steel and aluminium, the three carbon-intensive materials, should be limited (UNEP, 2023). By replacing cement in a traditional concrete mixture with fly ash, the carbon footprint of concrete can be reduced. Fly ash is a byproduct of coal combustion, which is non-cementitious in its natural form, but it can form cementitious compound when it is reacted with calcium hydroxide and water, making it more environmentally friendly material compared to conventional Portland cement. Fly ash offers several environmental benefits, including reduced heat of hydration, better frost resistance, energy and carbon-saving, and economic benefit (Muñoz-Pérez et al., 2022; Nayak et al., 2022). Additionally, concrete with fly ash mixture has several benefits, including better mechanical and physical properties, such as strength, workability, and durability (Muñoz-Pérez et al., 2022).

• **Plan 3: Replacement of glass facade**

Double glass was originally used in the facade of the case study. Despite the fact that double glass already has low embodied carbon, there are still some lower carbon options to reduce embodied carbon of the building construction. Laminated glass has lower embodied carbon (1.56 kgCO₂e/kg), as compared to double glass (1.75 kgCO₂e/kg), based on values on ICE database (Craig & Hammond, 2019). However, both have different performances. While double glass can save energy cost and budget friendly, laminated glass offers safety and security, and improves privacy (Veka, 2023). Hence, it is unfair to compare the two, without calculating whole life emissions, including different operational carbon caused by the two products.

3. Embodied Carbon Assessment

Embodied carbon assessment was performed to examine to what extent each improvement plan can contribute to reducing carbon emissions of the case study. Among the three improvement plans proposed, two out of three plans were undergone embodied carbon assessment, where the upfront embodied carbon for material production (A1-A3) was calculated and compared with the existing building. Improvement Plan 3 – replacement of glass facade, was not assessed, since to measure carbon reduction potential of this plan requires whole life-cycle assessment, not just embodied carbon emissions.

Embodied carbon assessment of Plan 1 is shown in Table 1. Here, the use of hardwood is compared with the existing softwood CLT. Calculation results show that with the existing condition, where softwoods CLT was employed, the normalized embodied carbon emissions (A1-A3) due to timber components were 22.32 kgCO₂e/m². If the softwood CLT were replaced with hardwood, the embodied carbon emission will be reduced to 15.63 kgCO₂e/m². This will cause a 6.69 kgCO₂e/m² reduction of embodied carbon emissions, which is equal to roughly 30% reduction. This shows that the use of hardwood could significantly reduce the embodied carbon emissions.

Table 1. Embodied carbon assessment of Improvement Plan 1.

Existing Building (GFA 18,600 m ²)					
Building part	Material	Quantity		ECF _{A13} (kgCO ₂ e/kg)	[A1-A3] (kgCO ₂ e)
		m ³	kg		
Main structure	Softwood CLT	1,900.00	950,000.00	0.437	415,150.00
TOTAL					415,150.00
TOTAL/m ²					22.32
Improvement Plan (GFA 18,600 m ²)					
Building part	Material	Quantity		ECF _{A13} (kgCO ₂ e/kg)	[A1-A3] (kgCO ₂ e)
		m ³	kg		
Main structure	Hardwood	1,900.00	950,000.00	0.306	290,700.00
TOTAL					290,700.00
TOTAL/m ²					15.63
Reduction of Carbon Emissions					
Total reduction (kgCO ₂ e)	124,450				
Total reduction (kgCO ₂ e/m ²)	6.69				
Percentage	29.98%				

Embodied carbon calculations for Improvement Plan 2 are presented in Table 2, where the comparison between regular concrete and concrete with fly ash mixture are shown. Calculations show that the use of traditional concrete with cement mixture resulted the normalized embodied carbon emissions (A1–A3) of 29.96 kgCO₂e/m². If the cement in concrete were replaced with 30–40% fly-ash, the embodied carbon emissions will be lower, ranging from 23.67 to 27.14 kgCO₂e/m². This will cause a reduction of embodied carbon emissions, ranging from 2.82 to 6.29 kgCO₂e/m², equal to roughly 9–21% reduction, meaning that the integration of fly-ash concrete to building construction could provide a lower carbon construction. It should be noted that as shown in Table 2, embodied carbon cannot be reduced if only 15% fly ash replacement was done.

Table 2. Embodied carbon assessment of Improvement Plan 2.

Existing Building (GFA 18,600 m ²)									
Building part	Material	Quantity		ECF _{A13} (kgCO ₂ e/kg)			[A1-A3] (kgCO ₂ e)		
		m ³	kg						
Main structure	32/40 MPa concrete	1,682.68	4,038,432.00	0.138			557,303.62		
TOTAL							557,303.62		
TOTAL/m ²							29.96		
Improvement Plan (GFA 18,600 m ²)									
Building part	Material	Quantity		ECF _{A13} (kgCO ₂ e/kg)			[A1-A3] (kgCO ₂ e)		
		m ³	kg	15%*	30%*	40%*	15%*	30%*	40%*
Main structure	32/40 MPa concrete w/fly ash	1,682.68	4,038,432.00	0.139	0.125	0.109	561,342.05	504,804.00	440,189.10
TOTAL							561,342.05	504,804.00	440,189.10
TOTAL/m ²							30.18	27.14	23.67
Reduction of Carbon Emissions									
Fly ash replacement		15%*	30%*	40%*					
Total reduction (kgCO ₂ e)		-4,038.43	52,499.62	117,114.52					
Total reduction (kgCO ₂ e/m ²)		-0.22	2.82	6.29					
Percentage		-0.72%	9.42%	21.01%					

Table 3. Embodied carbon assessment of Improvement Plans 1 and 2 combined.

Existing Building (GFA 18,600 m ²)							
Building part	Material	Quantity		ECF _{A13} (kgCO ₂ e/kg)		[A1-A3] (kgCO ₂ eq)	
		m ³	kg				
Main structure	32/40 MPa concrete	1,682.68	4,038,432.00	0.138		557,303.62	
	Softwood CLT	1,900.00	950,000.00	0.437		415,150.00	
TOTAL						972,453.62	
TOTAL/m ²						52.28	
Improvement Plan (GFA 18,600 m ²)							
Building part	Material	Quantity		ECF _{A13} (kgCO ₂ e/kg)		[A1-A3] (kgCO ₂ eq)	
		m ³	kg	30%	40%	30%	40%
Main structure	32/40 MPa concrete w/fly ash	1,682.68	4,038,432.00	0.125	0.109	504,804.00	440,189.10
	Hardwood	1,900.00	950,000.00	0.306		290,700.00	290,700.00
TOTAL						795,504.00	730,889.10
TOTAL/m ²						42.77	39.30
Reduction of Carbon Emissions							
Fly ash replacement		30%	40%				
Total reduction (kgCO ₂ e)		176,949.62	241,564.52				
Total reduction (kgCO ₂ e/m ²)		9.51	12.99				
Percentage		18.20%	24.84%				

Additional analysis was performed combining Improvement Plans 1 and 2, to understand to what extent the carbon emissions can be reduced if the two scenarios were to be implemented together. Calculation and results are presented in Table 3. Here, the 15% fly ash replacement in concrete mixture is excluded, since this will not cause any carbon reduction. Result in Table 3 shows that if Plans 1 and 2 were applied together, there will be a potential to reduce embodied carbon emissions from 9.51 to 12.99 kgCO₂e/m², equal to roughly 18–25 % of reduction.

CONCLUSION

This paper explores the application of sustainable construction principles in an existing building constructed with biomaterials. While biomaterials like timber already offer significant environmental advantages, this paper presents opportunities to enhance the building's overall environmental performance even further. The case study – Green Office ENJOY, is a prime example of mid-rise sustainable office development, achieving a balance between cutting-edge green technologies and practical, energy-efficient construction. With its ISO 14001 and BREEAM Excellent certifications, this building sets a strong precedent for net-zero energy office buildings that combine environmental responsibility with high functionality for its occupants. In terms of its construction, several embodied carbon reduction strategies have been implemented contributing to its sustainability. This includes the use of timber as a biomaterial, designing hybrid construction of concrete and timber for structural efficiency, implementing off-site construction, efficient and low-carbon construction, and minimizing construction waste. By using timber, the building saves 2,900 tons of CO₂.

Three improvement plans were proposed to reduce further the case study's embodied carbon emissions: 1) replacing the specification of timber, 2) using fly ash to replace cement in concrete, and 3) replacing the specification of glass facade. Of the three suggested material replacements, two were assessed quantitatively with upfront embodied carbon assessment, considering embodied carbon due to material production [A1–A3]. Results show that as much as 53–242 tons of CO₂e can be reduced through the two plans. Replacing softwood CLT with hardwood can reduce up to 30% of embodied carbon or 6.69 kgCO₂e/m². Applying 30–40% fly ash replacement in concrete mixture can reduce 2.82–6.30 kgCO₂e/m², or roughly 9–21% reduction of embodied carbon. If the two replacements are combined, embodied carbon reduction ranging from 9.51 kgCO₂e/m² to 12.99 kgCO₂e/m² can be achieved, equal to 18–25% carbon saving.

The embodied carbon calculations have confirmed the potential to further decarbonize an already sustainable building design, through replacing the materials with lower carbon alternatives. This research focuses on improving building environmental performance through embodied carbon reduction, considering that with the current net-zero climate targets, embodied carbon has greater significance in the whole life cycle emissions. Consequently, improvement plans were designed to specifically reduce embodied emissions, *not* operational emissions. In embodied carbon assessment, this research only calculated upfront embodied carbon (A1–A3) which commonly contributes to around 50% of carbon emissions in highly energy efficient buildings, as shown in Figure 4. For material replacement which will influence the operational energy/carbon emissions of the building, i.e. improvement plan 3, a whole life cycle assessment should be undertaken to measure the possible carbon saving. Thus, this should be accommodated in future work.

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