University of Westminster
College of Design, Creative and Digital Industries
School of Architecture and Cities
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Sem 3 - Thesis Project

The Impact of Material Selection and Construction Strategies on Embodied Carbon

A Case Study Analysis of W3 King's Cross

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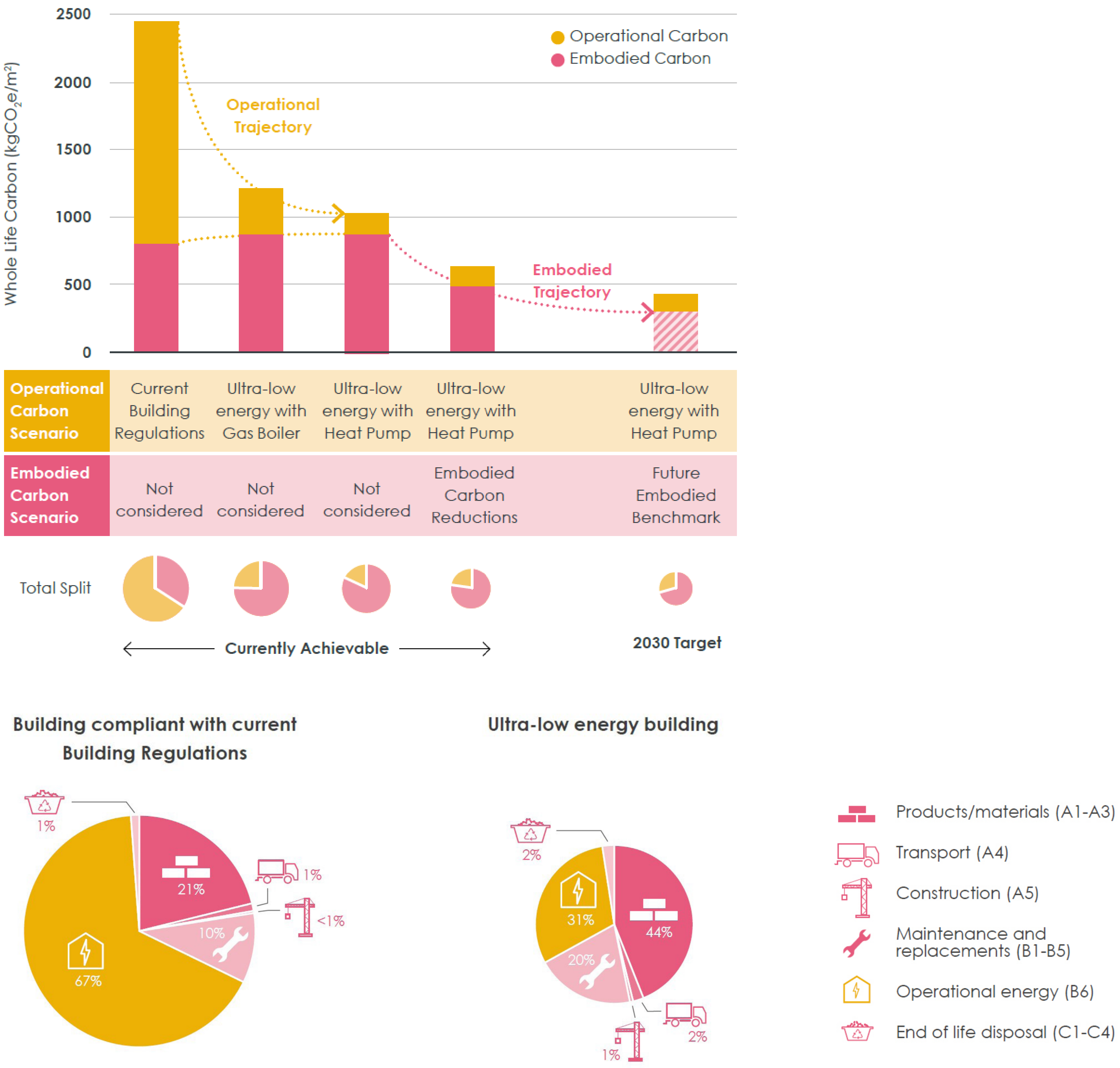
Introduction

The effects of climate change are projected to be adverse for the environment and societies globally. Today, the objective is to prevent further increasing temperatures caused by carbon emissions to mitigate the impacts of this change. Global warming is attempted to be limited below 2°C and if possible, it is bound to 1.5°C (IPCC, 2018). To achieve this goal, carbon emissions linked to built environment must be drastically reduced. Considering that in the UK, the built environment influenced GHG emissions are attributed to 42%, the construction industry has a clear obligation to cut emissions (UKGBC, 2021).

Currently, for a typical school archetype compliant with current building regulations, breakdown of Whole Life Carbon suggests that 67% account for operational energy. Thus, reducing operational energy has been the predominant method of combating climate change. New buildings, however, are expected to have a remarkable decrease in operational energy due to the energy efficiency improvements. Therefore, it is possible for embodied carbon to account for a larger proportion of Whole Life Carbon than it did previously. In an ultra-low energy office building, carbon emissions related to operational energy are projected to be decreased down to 31%. With future trajectory demonstrating the increasing impact of embodied carbon, it is imperative to understand the value of embodied carbon calculations (LETI, 2020).



Whole Life Carbon Breakdown, School Archetype [LETI]

Aims & Objectives

Embodied carbon is an important component of Whole Life Carbon assessment, and because new buildings are projected to have a significant drop in operational energy, embodied carbon is predicted to account for an even larger share.

The breakdown of product stage embodied carbon demonstrates the structure's substantial influence, implying that the materiality of the structural system is a critical component in reducing emissions. Due to their structural and carbon sequestration qualities, timber structures have been advocated for lowering carbon impact and achieving net zero goals. Timber buildings have been studied numerous times, and their impact in carbon reduction is irrefutable.

This study aims to go beyond the timber structure and analyze the next generation of mass timber construction by means of exploring further reduction methods. While doing so, various questions were posed to cover different issues of material selection and construction strategies. Two key areas were discussed to undertake a structured study: The main part of the study focuses on embodied carbon, while the other part focuses on operational aspects to reach a more wholesome approach.

The study was done on a case study building, and through the case study building the possible impacts of material selection is understood. Through the analysis of different scenarios, various impacts and influences of the design choices are quantified; as a result an improved version is proposed. The outcome of this study aims to highlight those variables, and even though there are variables subjective to the case study, various optimization can be made as the results can be broken down to building element scale.

Theoretical Background
WLC Assessment Guide

RICS distributes building elements into categories in which Substructure and Superstructure categories should be mandatorily considered during whole life carbon assessment, while others could be avoided as per requirement. In the whole life cycle assessment of any building, first, all the building elements have to be distributed in their respected categories, then life cycle carbon emission will be calculated. According to BREEAM new construction, the life span of non- domestic buildings will be considered as 60 years for any calculation.

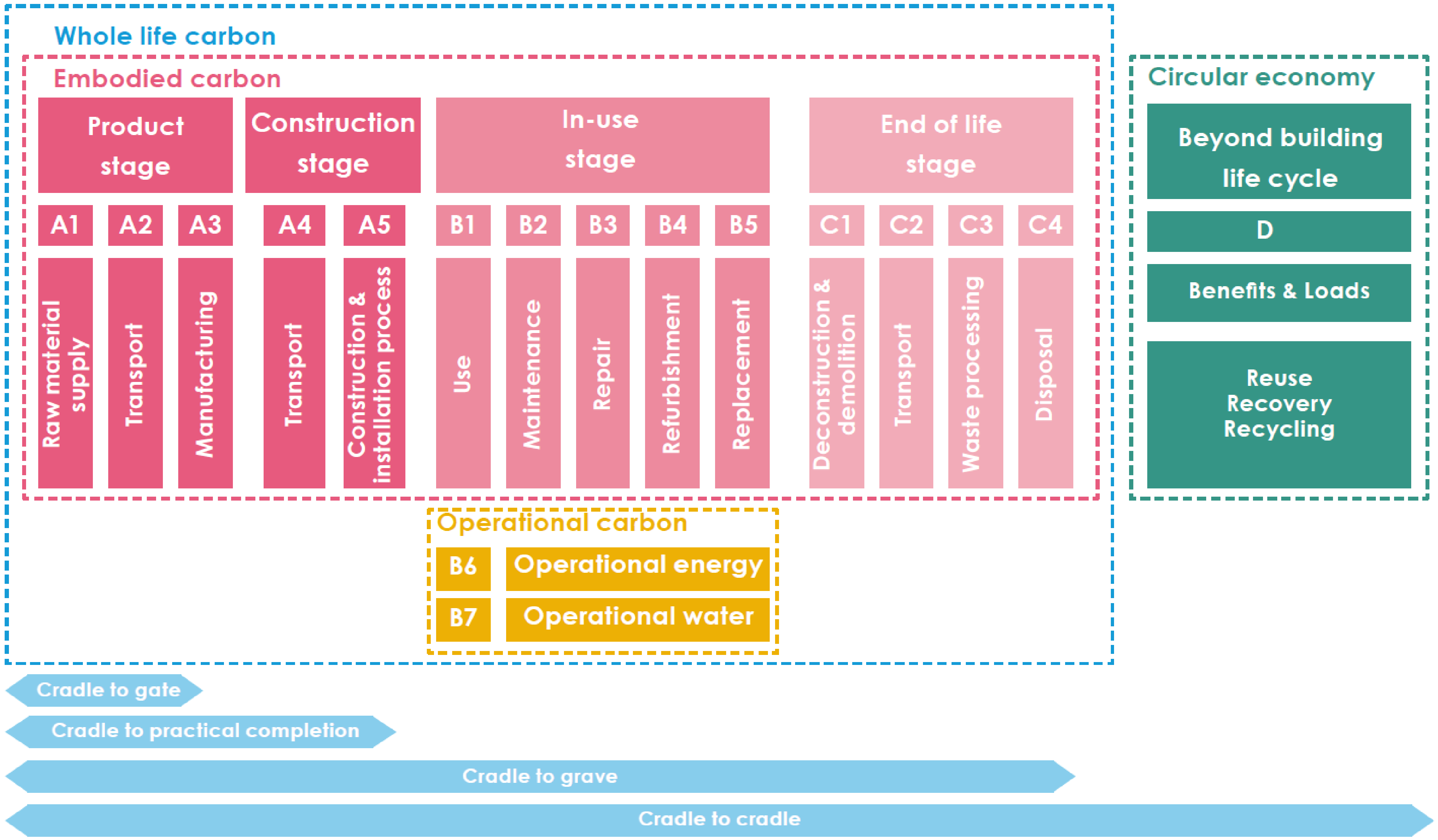
Product stage (A1-A3) The process in this stage is recognized as 'cradle to gate'This stage includes raw material extraction, transportation to the manufacturing plant location, and manufacturing process This value differs from manufacturer's company to company as per their plant location and manufacturing process type

Construction stage (A4-A5) material transportationto the site (A4) and construction and installation process (A5). The process till end of this stage is recognized as 'cradle to practical completion', which refers end of construction and commencement of building usage.

In-use stage (B1-B7) B 1 -B 5 stands for embodied carbon from usage, maintenance, replacement, repair and refurbishment during the building use. While B6 and B7 stands for operational carbon emission during building occupation, which includes operational energy and water usage. The process till end of this stage is considered as 'cradle to End of life'

End of life stage (C1-C4) This stage includes demolition of the building, waste transportation, waste processing and disposal of the waste. This stage concludes whole life carbon emission and the values till end of this stage is 'cradle to grave' values

Beyond the life cycle (D) This additional stage identifies the potential of recycling and reusage of the materials



Whole Life Cycle Stages [LETI]

Theoretical Background
Potential to Reduce Carbon

Biobased materials are derived from living organisms such as plants, which have been processed into a functional product. Biobased construction refers to the application and use of such materials in construction. As a means of decarbonizing the building industry, it is increasingly considered effective.

One major benefit of biobased materials is that the plant may absorb carbon dioxide (CO_2) while growing. This sequestered CO_2, also referred to as biogenic carbon, is then trapped in the material when it is harvested. When the biogenic CO_2 sequestered by a biomaterial is greater than the fossil CO_2 expended in its harvest and processing, the biomaterial can be considered carbon negative.

The images ilustrate the various biobased materials that are currently/ soon to be in the market. Apart from the strcutural timber and wood fibre insulation, rest of the materials are UK based.

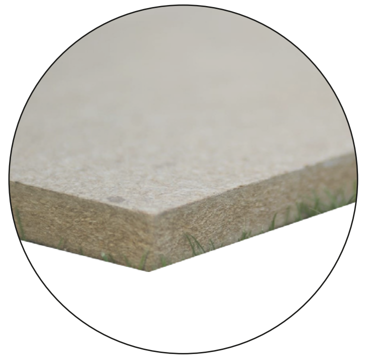
STRUCTURE

Structural Timber

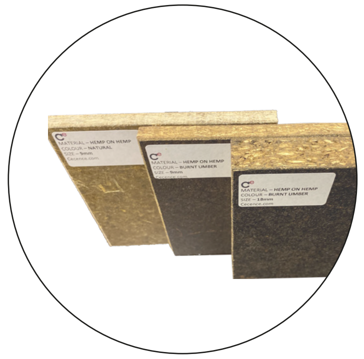
LINING

Wood Wool Boards
[Celenit]

Hemp Lime Boards
[Adaptavate]



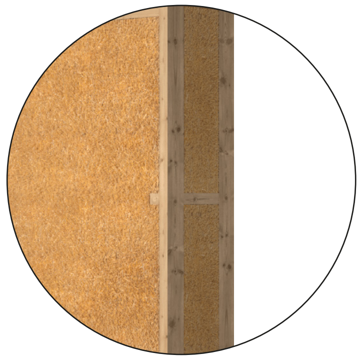
Compressed Straw Boards
[Stramit]



Hemp OSB
[Cecence]

INSULATION

Hempcrete
[IsoHemp]



Straw Panels and Boards
[Modcell]

Hemp Fibre Batts
[Indinature]

Sheep's Wool
[thermafleece]

Wood Fibre
[Steico]

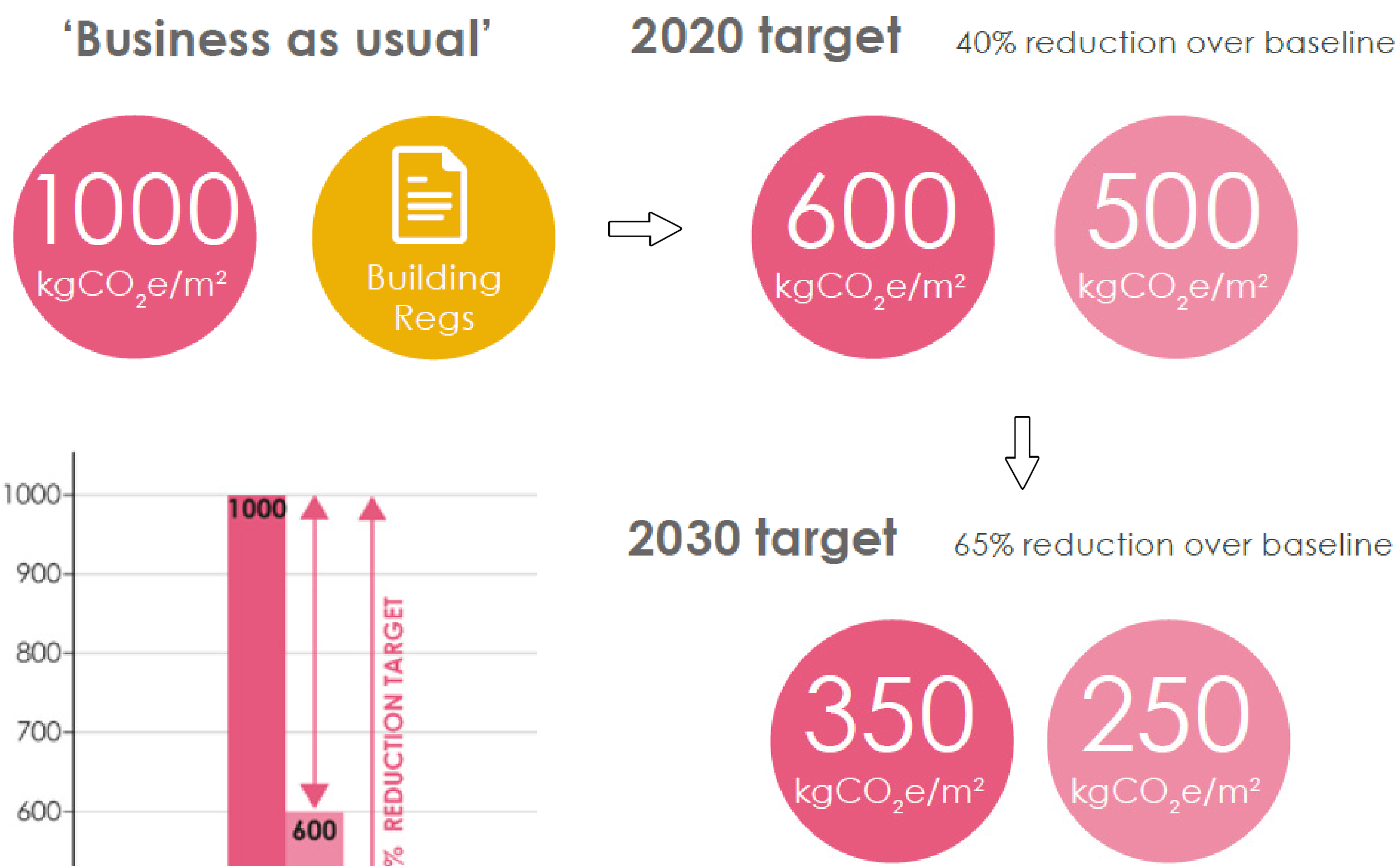
Theoretical Background
Targets & Benchmarks

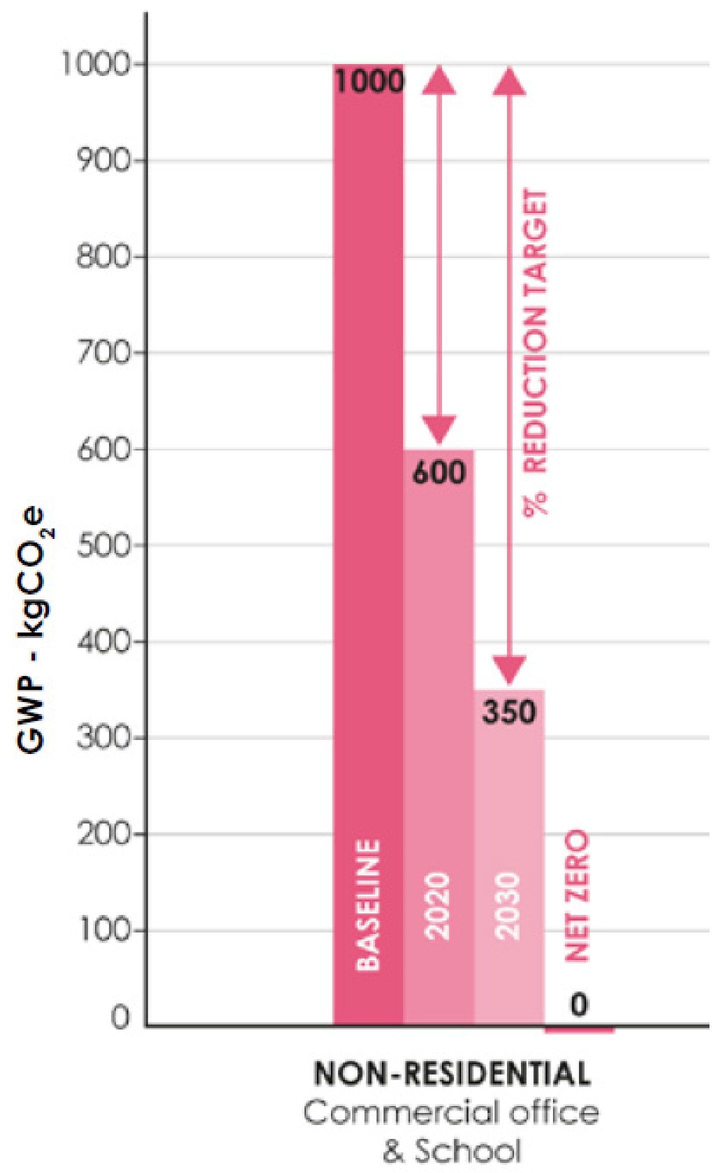
London Energy Transformation Initiative (LETI) has published a number of design guidance documents that set out a trajectory of embodied carbon and operational energy targets required to address the Climate Emergency. The WLCA scope associated with their targets is limited to stages A1-A5 cradle to Practical Completion.

The 'business as usual' figures give an estimate of embodied carbon in buildings that are built without implementing embodied carbon reductions.

For schools, LETI suggests 40% embodied carbon reduction over the baseline to 600 $kgCO_2/m^2$ by 2020. It suggests 65% reduction of 350 $kgCO_2/m^2$ by 2030 (excluding sequestration). The targets set including sequestration are 500 $kgCO_2/m^2$ by 2020 and 250 $kgCO_2/m^2$ by 2030.

Additionally, fabric U-value recommendations were given for different building archetypes. The diagrams showcases values for school archtype.





Fabric U-values (W/m².K)	
Walls	0.13 - 0.15
Floor	0.09 - 0.12
Roof	0.10 - 0.12
Windows	1.0
Doors	1.2

Embodied Carbon Reduction Targets [LETI]

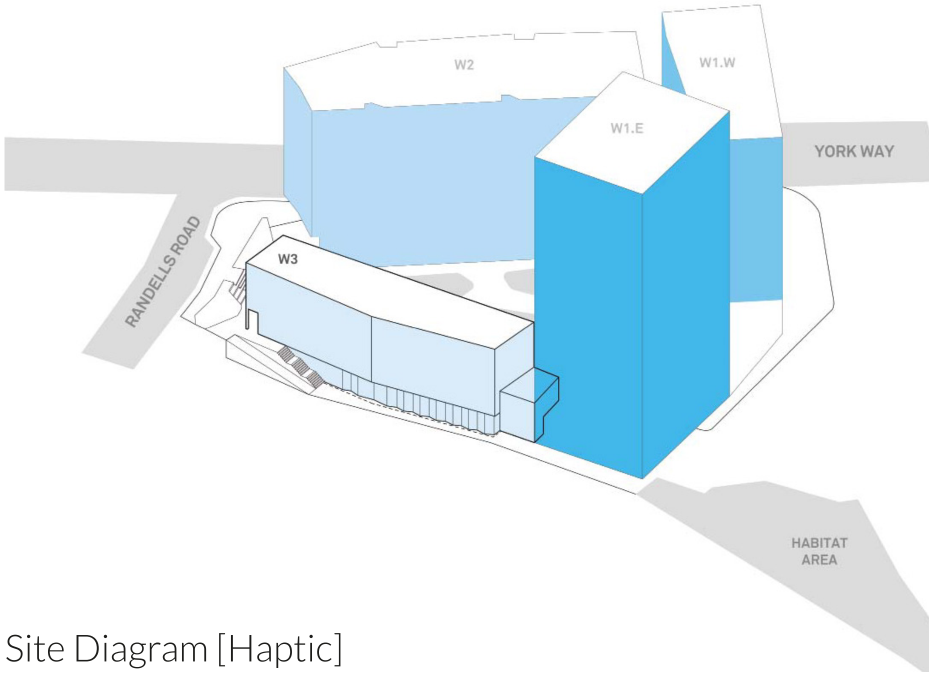
Overview
The Case Study: W3 King's Cross

W3 King's Cross is community building comprising of a cafe, gym and creche. The site is part of the Triangle Site of the Kings Cross Central masterplan and complements the surrounding residential uses. The massing of Building W3, as a leisure centre, differs from that of its immediate neighbors, which are residential buildings.

By complementing the prominent presence of Buildings W1 and W2, W3 acknowledges the various and complementary functions of the buildings in the Triangle Site, both in terms of their urban environment and internal uses.

Building W3's mass creates a buffer between the public and the railway while reducing the scale of the proposed building. Creating transparency through these design decisions strengthens the sense of place, maximising the views across the site to surrounding areas in both Camden and Islington boroughs, as well as through Building W3. (Haptic, 2018)

W3 Elevation [Haptic]



Site Diagram [Haptic]

designed by

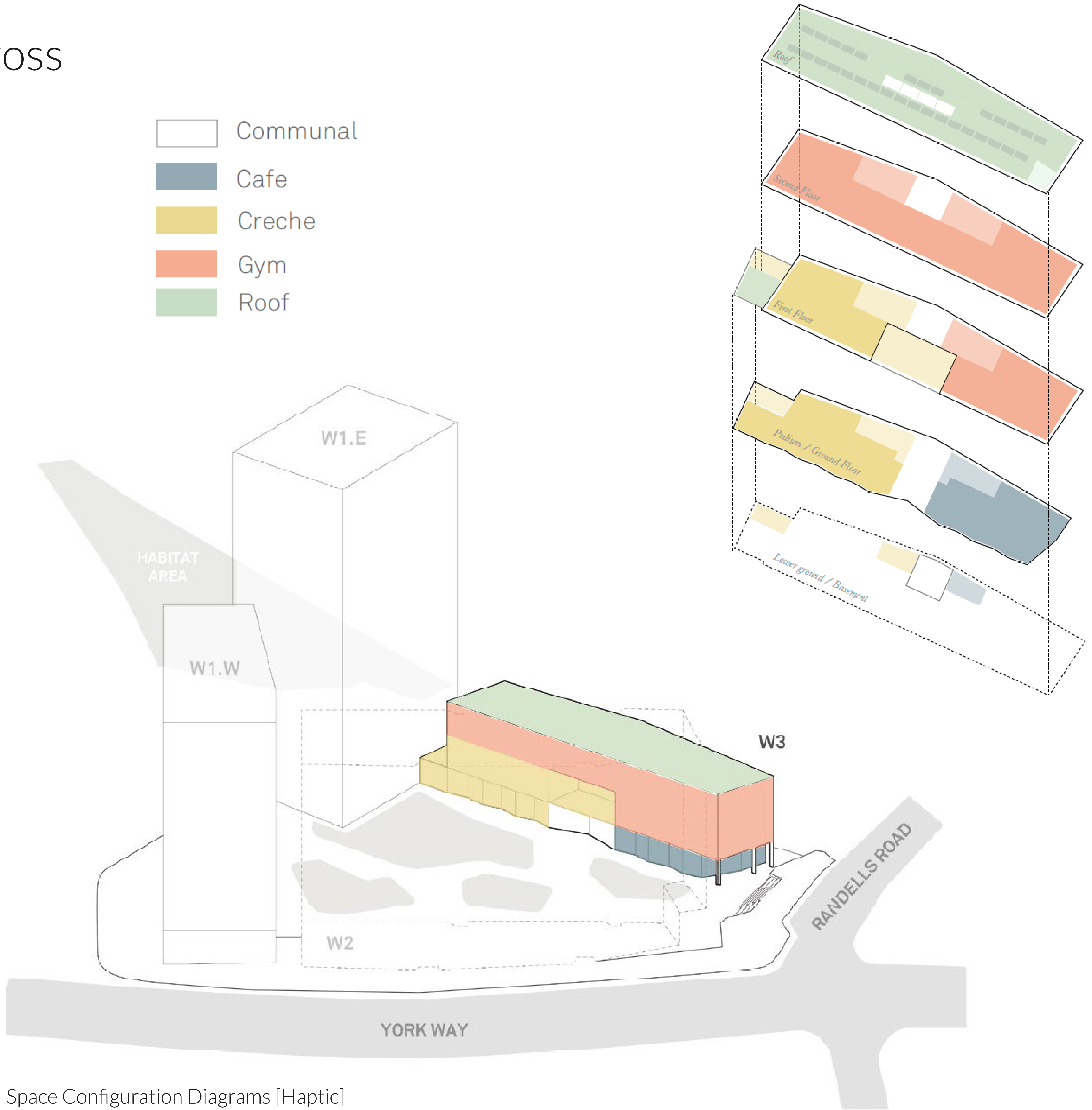
HAPTIC

Overview

The Case Study: W3 King's Cross

A clear understanding of space distribution can be gained through the diagrams. An east-facing core is positioned at the center of the floorplate of the building. As a result of this arrangement, the floorplate is divided symmetrically into two zones, each with equal access to the shared core. In the central core, there are two sets of staircases, one on either side of the passenger lift, each with its own lobby. For the different possible tenants and uses, service areas are located adjacent to both staircases in the core to provide plant rooms and stacked wet areas.

The ground floor consists of a creche and cafe; the first floor is shared between a creche and gym, and the second floor is entirely devoted to the gym. (Haptic, 2018)



Space Configuration Diagrams [Haptic]

Analytical Work

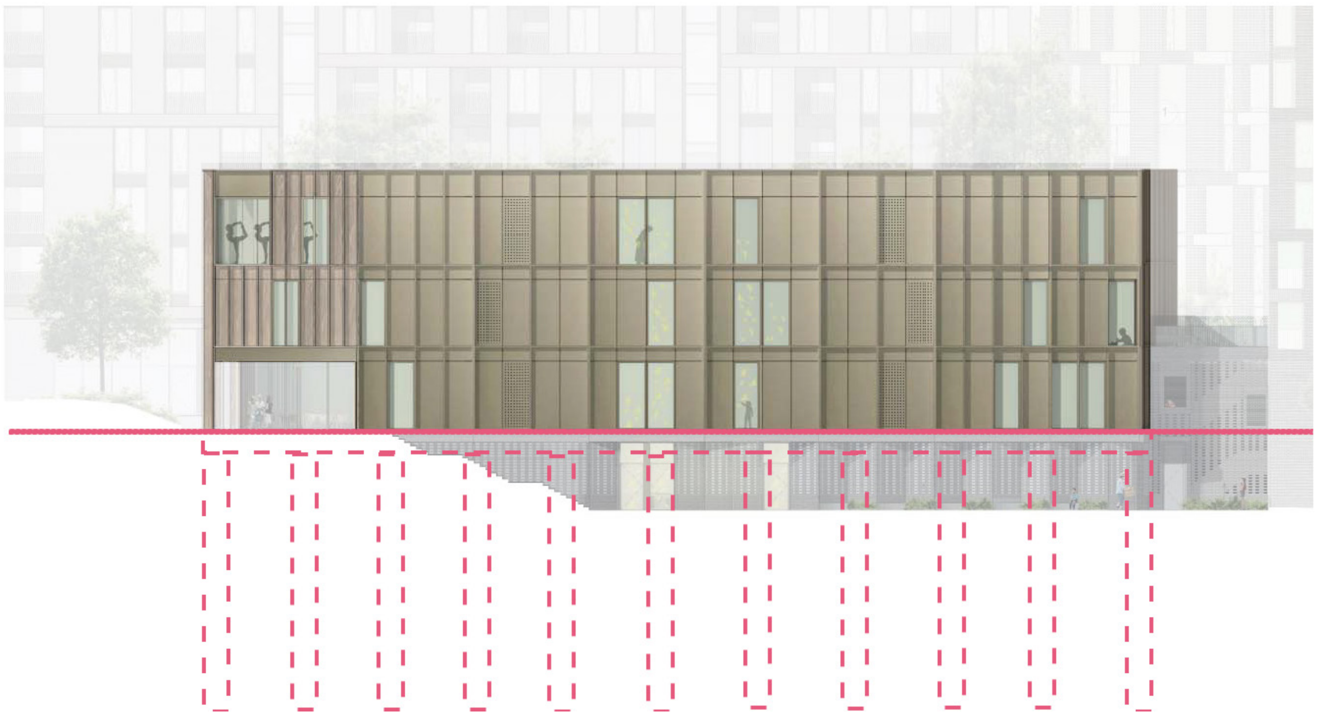
Methodology, Assumptions & Limitations

With respect to the RICS guide, analyses was done on Substructure, Superstructure and Finishes categories. Basement floor was not included in the analysis since it is a shared space between all three buildings. Due to the similar reasons, the external staircase of the nursery was excluded from the analysis. Foundation base and piling quantities were assumed with respect to the as built building build up.

OneClick LCA was the lifecycle assessment software used to model the different constructions. The components considered within the building functional unit were input into OneClick. Where products were known environmental product declaration certificates for those products or the closest equivalent product with an EPD in the OneClick database were used. For this reason, limitations for material selection occured due to the deficiencies in OneClick LCA database.

For unknown transportation distances, RICS default scenarios were used. For A5 construction/installation process, default construction site scenario within OneClick was chosen: Average site impacts - temperate climate (North) (per GFA).

The operational energy calculations were performed using EDSL TAS. For internal conditions such as occupancy gains, lighting gains NCM database was used and each zone was assigned in correspondence with the closest NCM internal conditions.



Analysis Area

1	Substructure	1.1 Substructure
2	Superstructure	2.1 Frame 2.2 Upper floors incl. balconies 2.3 Roof 2.4 Stairs and ramps
2	Superstructure	2.5 External Walls 2.6 Windows and External Doors
2	Superstructure	2.7 Internal Walls and Partitions 2.8 Internal Doors
3	Finishes	3.1 Wall finishes 3.2 Floor finishes 3.3 Ceiling finishes

Categories Analysed [RICS]

Transport scenario	km by road*	km by sea**
Locally manufactured e.g. concrete, aggregate, earth	50 [1]	-
Nationally manufactured e.g. plasterboard, blockwork, insulation	300 [1]	-
European manufactured e.g. CLT, façade modules, carpet	1,500 [2]	-
Globally manufactured e.g. specialist stone cladding	200 [3]	10,000 [3]

Default Transport Scenarios for UK Projects [RICS]

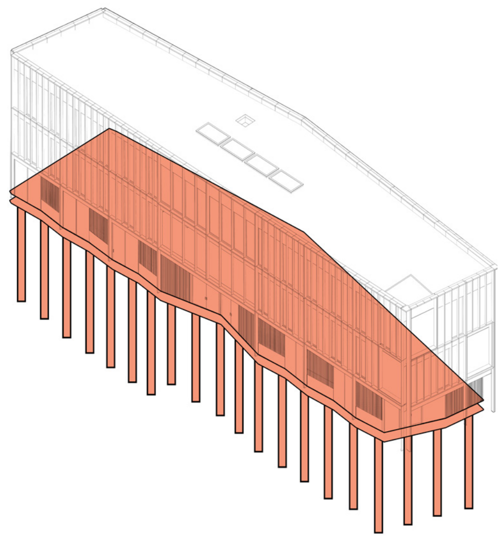
Analytical Work
Building Elements

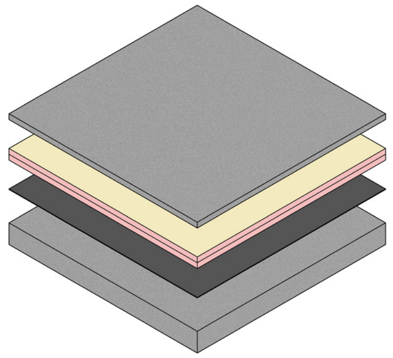
A study of the as-built building was the first step in the analytical process. Each building element is visualized through diagrams. For analysis, volumes and kgs of each building element was calculated, afterwards logged into OneClick. Ground floor/foundation consists of C40/50 concrete, which has 0% recycled binders. The insulation that is used in ground floor is phenolic insulation, which is a type of plastic foam board, following by cement screed with epoxy finish. The overall U-value is calculated as 0.11 which correlates with LETI guidelines.

The structural frame of the building is hybrid consisting of glulam column and beams, S235 steel columns and and concrete main core. Again, similar to the substructure the concrete within the main core has 0% recycled binders.

In upper floor slabs CLT was used, which was left exposed throughout the ceilings. Two different finishes were used throughout the design. In circulation areas and service spaces epoxy finish was used. For thermal insulation in intermediate floors, 5 layers of cementboard was placed in between plywoods.

Ground Floor / Foundation

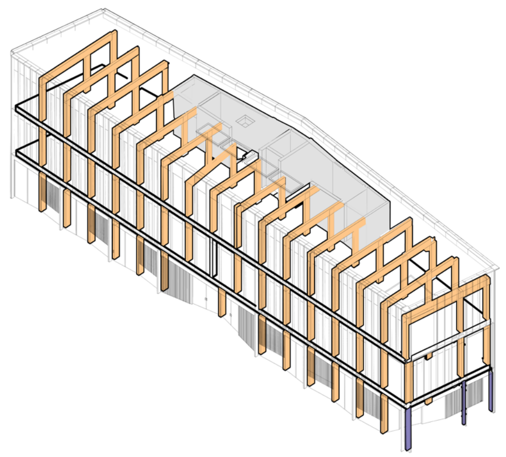




1- Cement Screed [72mm] + Epoxy [3mm]
2- 2 x Phenolic Insulation [160mm]
3- Damp Proof Membrane
4- Foundation Base, 0% recycled binders [300mm]

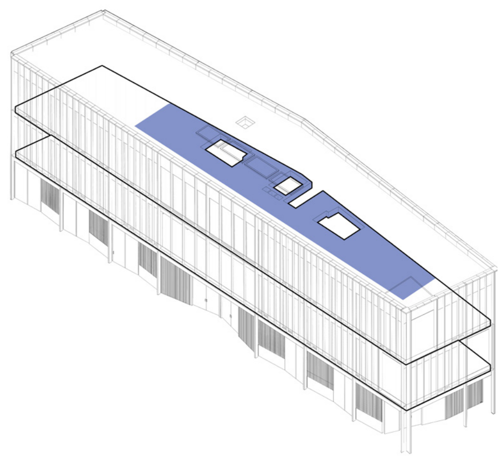
U Value: 0.11 W/m²K

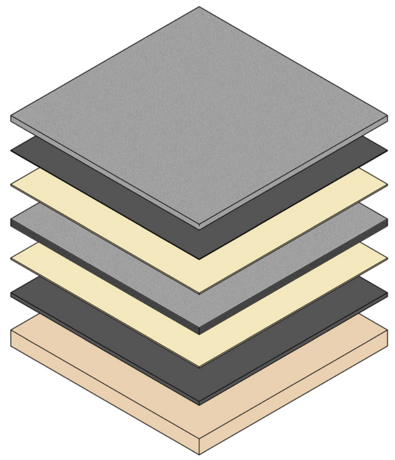
Frame / Stairs



1- Glulam Column & Beams
2- Steel Columns
3- Concrete Main Core [300mm]

Upper Floors





1- Cement Screed [72mm] + Epoxy [3mm]
2- Fitness Floor Covering [8mm]
3- Plywood [19mm]
4- 5 x 12mm Cementboard [60mm]
5- Plywood [19mm]
6- Floating Floor System [50mm]
7- CLT Floor Slab [220mm]

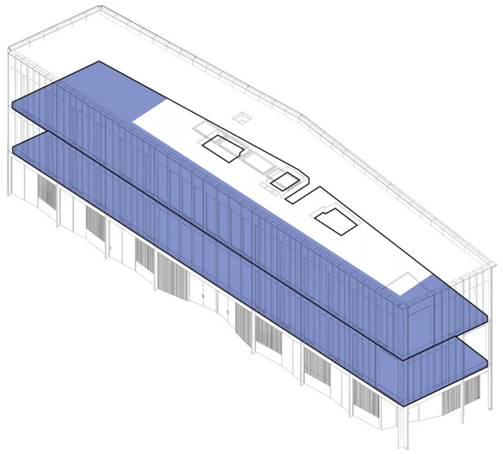
U Value: 0.28 W/m²K

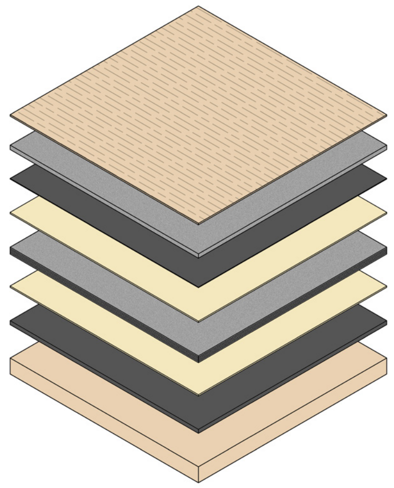
Analytical Work
Building Elements

The other finishing used in the upper floors are timber flooring. In which 20mm allowance was left for timber finishing. The U-value is 0.27.

The roof consists primarily of a green roof structure. CLT was used in the slab. For insulation, XPS was used. The U-value achieved is 0.12 which is in correlation with LETI.

Apart from the green roof, the roof structure consists of concrete pavings. Again, similar to the green roof structure XPS is used as the insulation. However, the overall U-value achieved fails to meet the LETI standard.

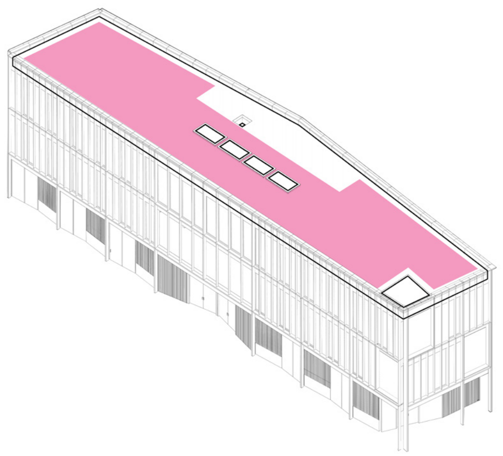


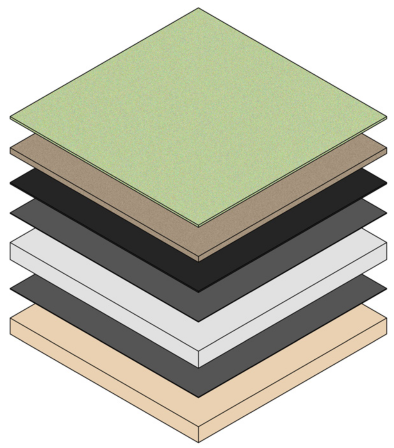


1- Timber Flooring [20mm]
2- Cement Screed [55mm]
3- Fitness Floor Covering [8mm]
4- Plywood [19mm]
5- 5 x 12mm Cementboard [60mm]
6- Plywood [19mm]
7- Floating Floor System [50mm]
8- CLT Floor Slab [220mm]

U Value: 0.27 W/m²K

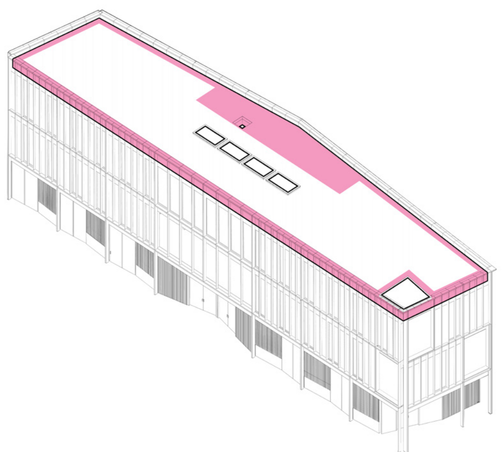
Roof

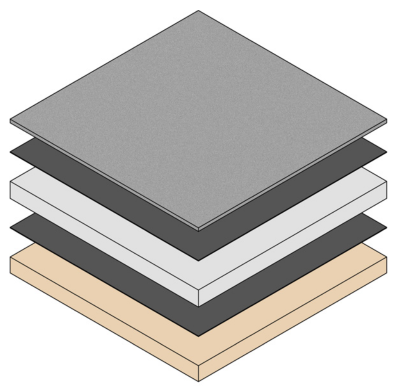




1- Wildflower Mat [30mm]
2- Green Roof Substrate [80mm]
3- Drainage Board + Filtration Fleece [20mm]
4- XPS Waterflow Reducing Layer
5- XPS [235mm]
6- Rubberised Membrane
7- CLT Floor Slab [220mm]

U Value: 0.12 W/m²K





1- Concrete Paving [600x600x50mm]
2- XPS Waterflow Reducing Layer
3- XPS [235mm]
4- Rubberised Membrane
5- CLT Floor Slab [220mm]

U Value: 0.13 W/m²K

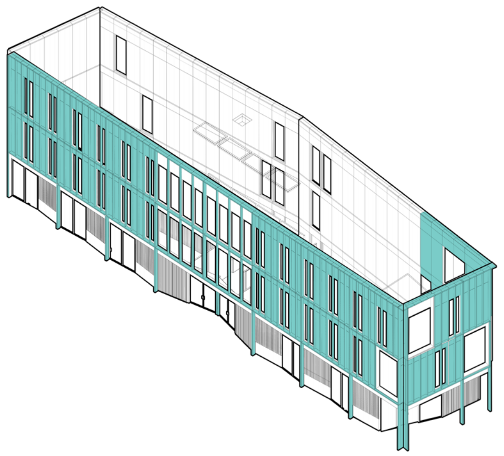
Analytical Work
Building Elements

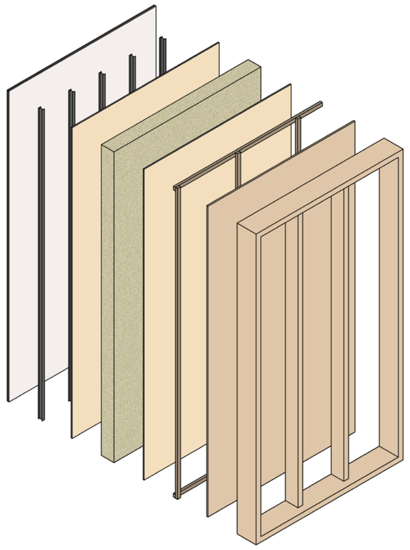
The external walls consist of two different type of finishes. Timber (accoya) and aluminium. The lining consists of two layers of plasterboard, For insulation, mineral wool was chosen to be placed in between OSB boards. The finishing thicknesses vary according to different cladding types; aluminium cladding is set to have 40mm thickness; whereas timber is 20mm. The U-values for timber and aluminium external walls are 0.15 and 0.14 respectively which meets the U-value criteria.

In internal walls a basic plasterboard buildup was used. In which 70mm of mineral wool insulation was placed in between 2 layers of plasterboard.

Th external windows and door are aluminum frame, with double glazing, where the U-value of the overall structure was calculated as 0.92.

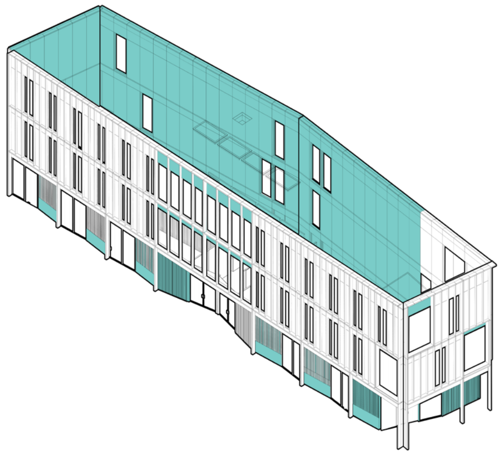
External Walls

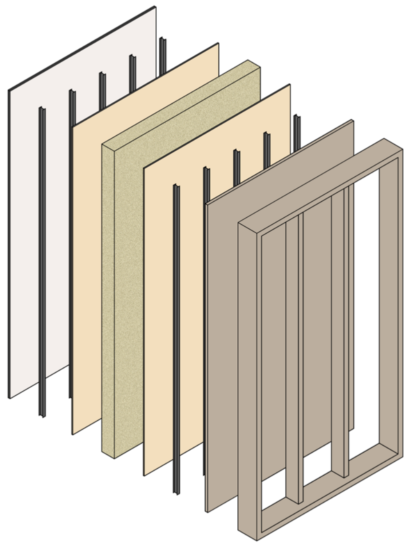




1- Accoya Fins [Radiata Pine]
2- Accoya Cladding [20x115mm]
3- Timber Studs
4- OSB
5- Mineral Wool [200mm]
6- OSB
7- I Stud [60mm]
8- 2 x Plasterboard

U Value: 0.15 W/m^2K

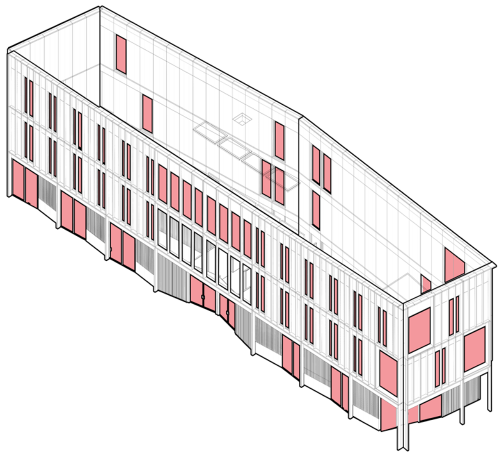


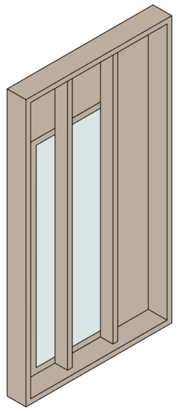


1- Aluminium Fins
2- Aluminium Cladding [40mm]
3- Aluminium Panel Fixing System
4- OSB
5- Mineral Wool [200mm]
6- OSB
7- I Stud [60mm]
8- 2 x Plasterboard

U Value: 0.14 W/m^2K

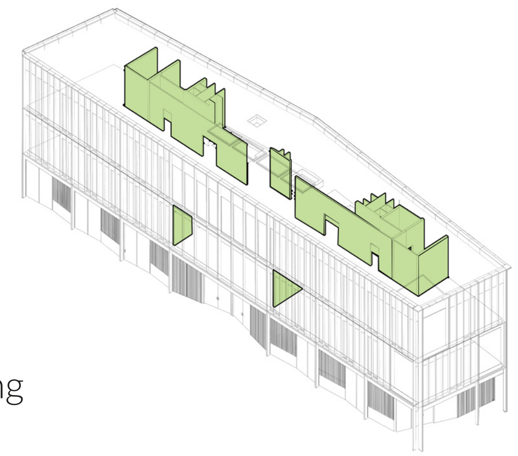
Windows & External Doors

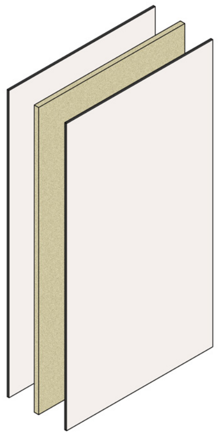




Aluminium Frame + Double Glazing
U Value: 0.92 W/m^2K

Internal Walls





1- 2 x Plasterboard
2- Mineral Wool Insulation [70mm]
3- 2 x Plasterboard

U Value: 0.4 W/m^2K

Analytical Work
Results & Discussion

The results showcase the embodied carbon measuresement for each building element for each LCA stage. As mentioned previously the analysed RICS elements are substructure, superstructure and finishes. To be able to make comparioson with the benchmark, first embodied carbon of MEP must be added to the calculations. According to LETI, for non-domestic buildings MEP account for 13% of the overall embodied carbon. Thus, through this ratio it can be concluded that through the A1-A5 stage the overall embodied carbon without sequestration is 562.48 kg CO_2e/m^2

The embodied carbon accounting sequestration is 177.88 kg CO_2e/m^2 (A1-A5)

Both of the values meet LETI's 2020 target, however fail to meet the 2030 target without sequestration.

The embodied carbon results accounting other stages of lifecycle suggest the total embodied carbon values of (A1-C4) 326.78 kg CO_2e/m^2 with sequestration.

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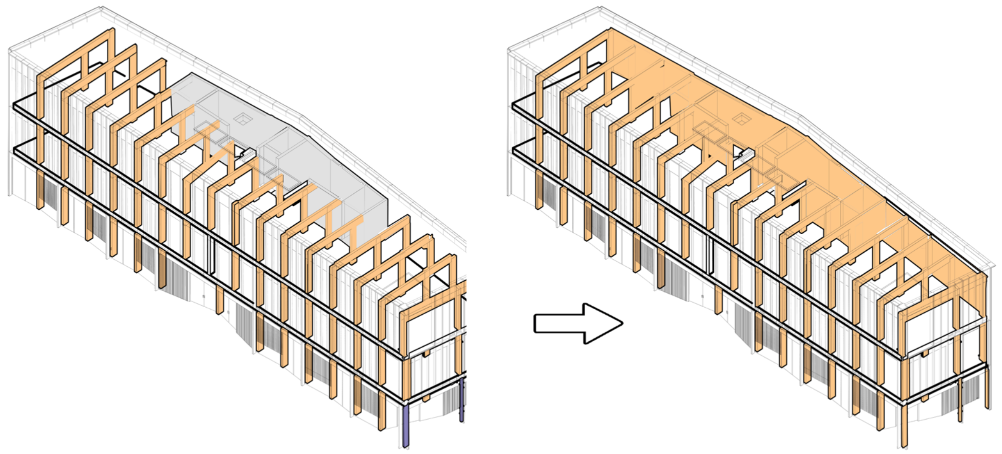
	A1-A3 Construction Materials	A4 Transportation to the Site	A5 Construction/ installation process	B1-B5 Material replacement and refurbishment	C1-C4 End of life	Biogenic Carbon Storage
Foundation	163 775					
Ground Floor	63387					
Frame	67666					112472
Stairs	1393					
Upper Floors	82428					290,046
Roof	25785					76999
External Walls	136633					34656
Internal Walls	5 323					
Windows	34476					
Doors	300					524
TOTAL kg CO2e	581 169	49430	46334	65683	209318	514 697
TOTAL kg CO2e/m2	**434.36**	**36.94**	**34.63**	**49.09**	**156.44**	**384.68**
TOTAL kg CO2e/m2			**711.46**			**384.68**

Analytical Work

Timber

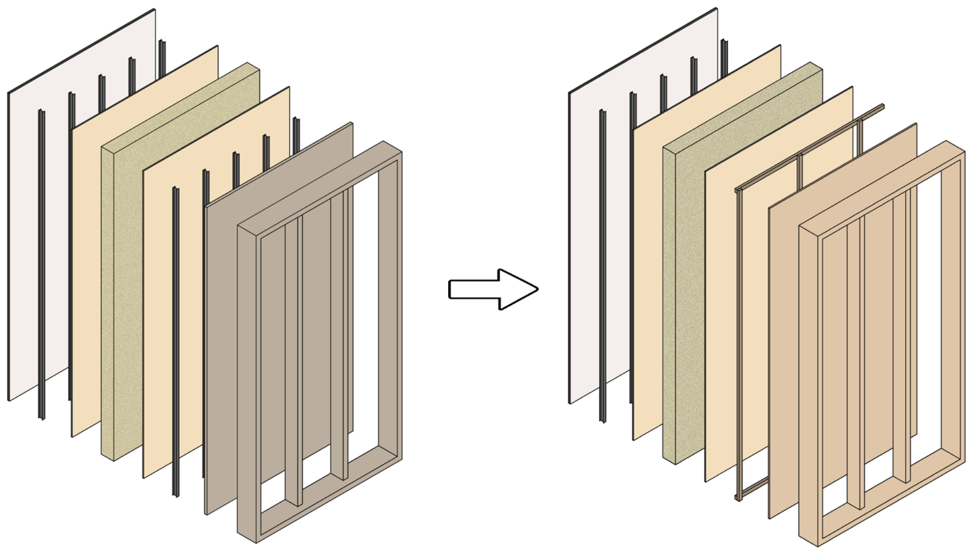
As mentioned in the beginning, the thesis aims to analyze and improve the mass timber building, thus in order to create the full timber building, modifications were made to the as built building. Three areas were the focused: The hybrid structure was transformed into a full timber version consisting of glulam column, beams and CLT shear walls. Secondly, the aluminium elements in the facade were transformed into timber. Moreover, the aluminium window frames were transformed into timber frames.

Frame



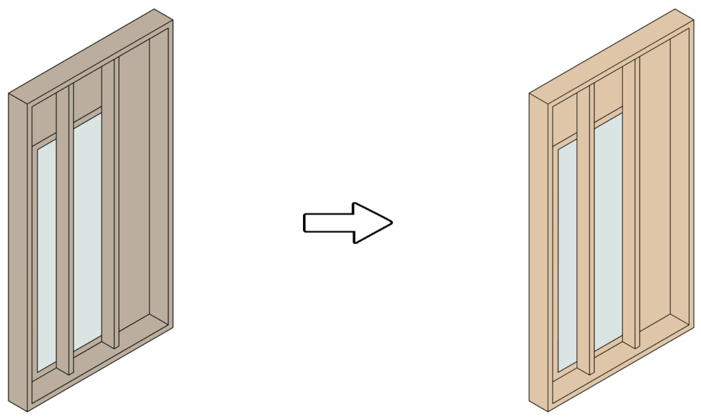
Glulam Column & Beams
CLT Shear Walls [200mm]

External Walls



Timber Cassette Panels

Windows / External Doors



Timber Frame Window
Double Glazing

U Value: 1 W/m²K

Analytical Work
Results & Discussion

With the improvements made only to the structure, facade and windows the results obtained show that lower embodied carbon values were achieved with the treatments.

Due to timber products having less durability compared to aluminium, emissions related to material replacement and refurbishment have increased.

By accounting 56 kg CO_2e/m^2 MEP emissions, the total embodied carbon in A1-A5 is calculated as 470.2 kg CO_2e/m^2.

Including sequestration, embodied carbon has a value of -23.37 kg CO_2e/m^2.

Cradle to grave (A1-C4) embodied carbon assessment results in 163.9 kg CO_2e/m^2.

	A1-A3 Construction Materials	A4 Transportation to the Site	A5 Construction/ installation process	B1-B5 Material replacement and refurbishment	C1-C4 End of life	Biogenic Carbon Storage
Foundation	163775					
Ground Floor	63387					
Frame	11386					209001
Stairs	146					2777
Upper Floors	82428					290,046
Roof	25785					76999
External Walls	69691					70527
Internal Walls	5323					
Windows	30742					11029
Doors	300					524
TOTAL kg CO2e	452 966	54 903	46 334	122 615	202 879	660404
TOTAL kg CO2e/m2	**338.54**	**41.03**	**34.63**	**91.64**	**151.63**	**493.57**
TOTAL kg CO2e/m2			**657.47**			**493.57**

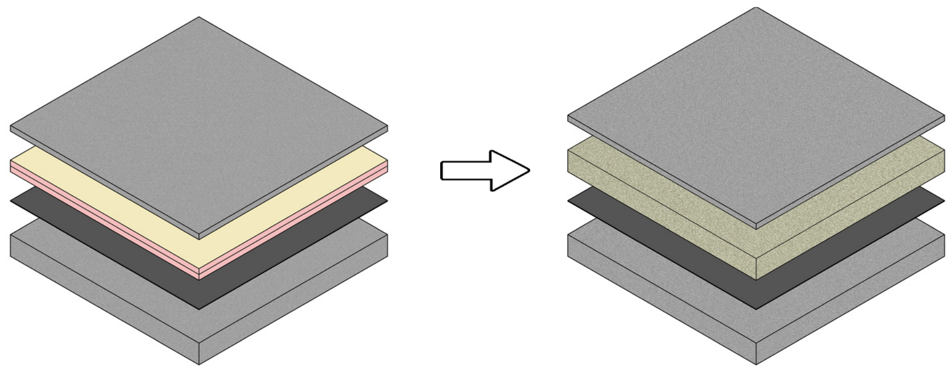
Analytical Work
Next Generation of Mass Timber

The next assessment of the analytical work considers all the other elements within the building. First, substructure is reanalyzed. As mentioned previously the 0% recycled binders were used in the concrete, this is substituted with 50% recycled content. Cement screed is replaced with calcium sulphate screed, as it consists of recycled content, is a more sustainable option. For insulation, biobased options are explored and phenolic insulation is replaced with hemp fibre. However, in order to achieve the required U value insulation thickness had to be increased.

In upper floors, for both epoxy and timber flooring finishes, cementboard + plywood thermal insulation was replaced with hemp fibre. Again, the insulation is thicker than the base case scenario.

In internal walls, wood wool board was introduced to replace plasterboards. As they are an effective lime render substrate that can be used as an alternative to plasterboard. They are made of wood strands, bound together with Portland cement. For insulation, similar to the previous strategies mineral wool was replaced with hemp fibre.

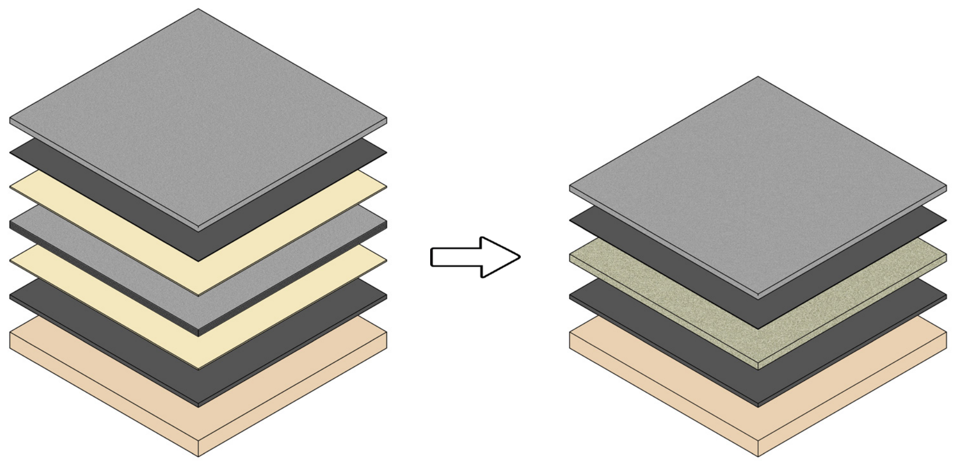
Ground Floor / Foundation



1-Calcium Sulphate Screed [72mm] + Epoxy [3mm]
2- Hemp Fibre Insulation [300mm]
3- Damp Proof Membrane
4- Foundation Base, 50% Recycled Content [300mm]

U Value: 0.13 W/m²K

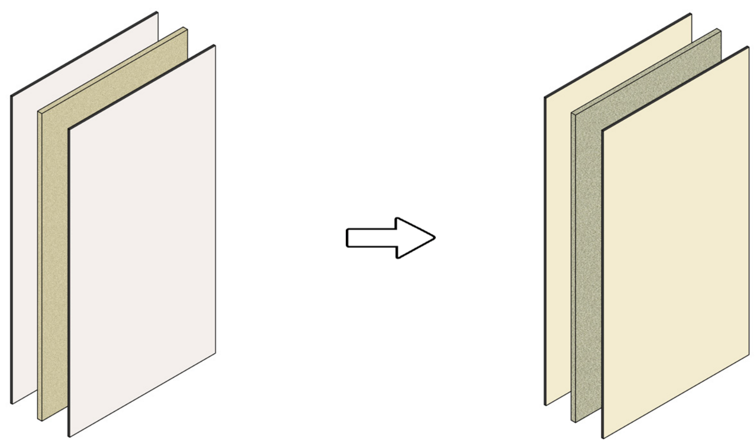
Upper Floors



1- Calcium Sulphate Screed [72mm] + Epoxy [3mm]
2- Fitness Floor Covering [8mm]
3- Hemp Fibre Insulation [100mm]
4- Floating Floor System [50mm]
5- CLT Floor Slab [220mm]

U Value: 0.18 W/m²K

Internal Walls



1- 2 x Wood Wool board
2- Hempfibre Insulation
3- 2 x Wood Wool board

U Value: 0.38 W/m²K

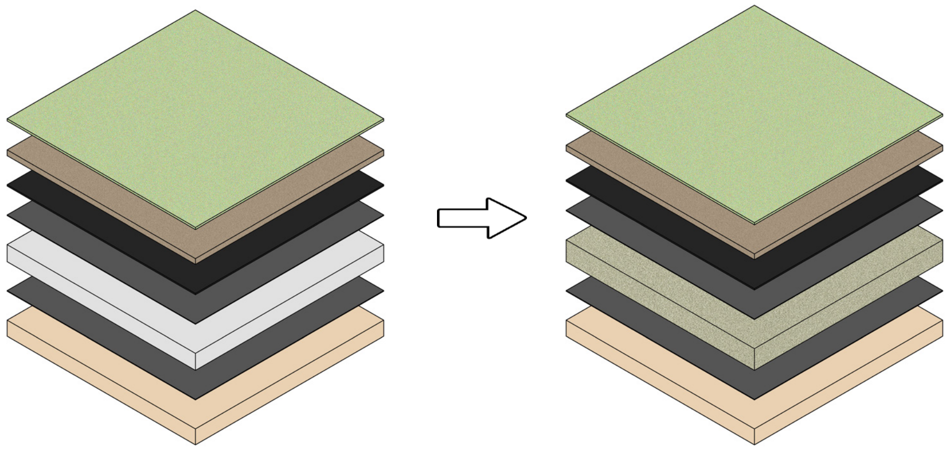
Analytical Work
Next Generation of Mass Timber

For roof constructions, XPS was replaced for a biobased option. However, by doing so the insulation thickness increased to 235mm to 300mm.

The existing concrete paving roof wasn't meeting the U-value benchmarks, with the insulation criteria was met.

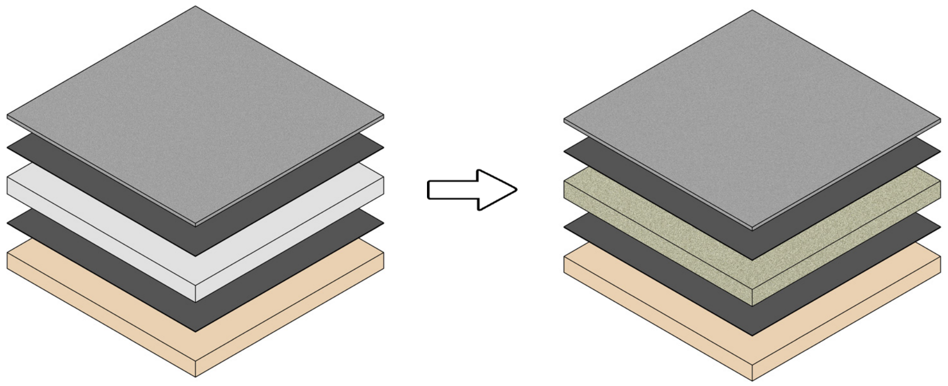
The cladding material used in the original construction is Accoya, Even though it is a sustainable, durable material compared to other timber claddings, it has to be imported from New Zealand. To tackle the emissions related to transportation, Radiata Pine was swapped with Scots Pine, which can be transported from Scotland. Moreover, hemp fibre and wood wool board is included in the new scenario.

Roof



1- Wildflower Mat [30mm]
2- Green Roof Substrate [80mm]
3- Drainage Board + Filtration Fleece [20mm]
4- Waterflow Reducing Layer
5-Hemp Fibre Insulation [300mm]
6- Rubberised Membrane
7- CLT Floor Slab [220mm]

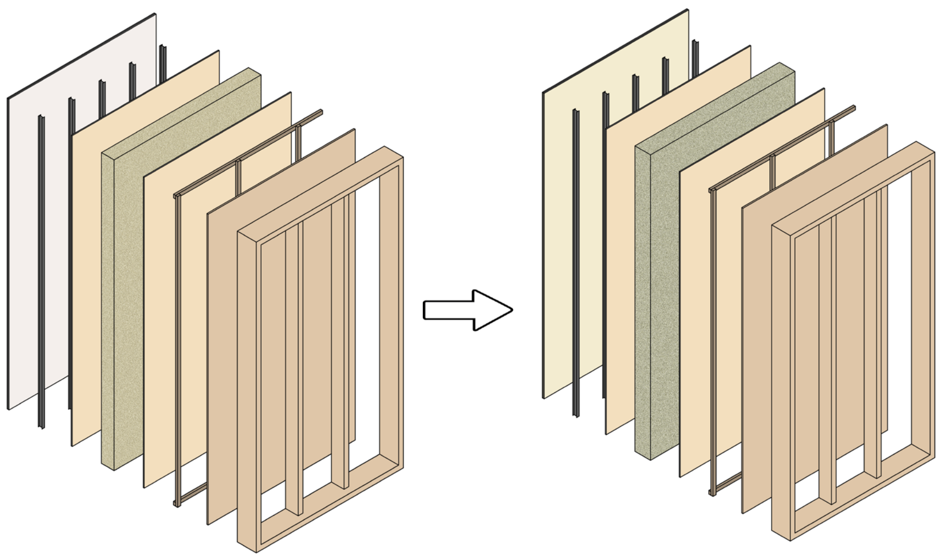
U Value: 0.11 W/m²K



1- Concrete Paving [600x600x50mm]
2- Waterflow Reducing Layer
3- Hemp Fibre Insulation [300mm]
4- Rubberised Membrane
5- CLT Floor Slab [220mm]

U Value: 0.12 W/m²K

External Walls



1- Accoya Fins [Scots Pine]
2- Accoya Cladding [20x115mm]
3- Timber Studs
4- OSB
5- Hemp Fibre Batts [250mm]
6- OSB
7- I Stud [60mm]
8- 2 x Wood Wool Board

U Value: 0.13 W/m²K

Analytical Work
Results & Discussion

The results show an visible decrease for different building element categories.

The A1-A5 embodied carbon results indicate a value of 290 kg CO_2e/m^2, without sequestration, which fulfills the benchmarks set for both 2020 and 2030. With sequestration the results for A1-A5 -206 kg CO_2e/m^2

Cradle to grave (A1-C4) embodied carbon assessment results in -17.3 kg CO_2e/m^2.

	A1-A3 Construction Materials	A4 Transportation to the Site	A5 Construction/ installation process	B1-B5 Material replacement and refurbishment	C1-C4 End of life	Biogenic Carbon Storage
Foundation	81900					
Ground Floor	36294					2024
Frame	11386					209001
Stairs	146					2777
Upper Floors	43362					267206
Roof	17140					79,023
External Walls	40331					91559
Internal Walls	32					773
Windows	30742					11029
Doors	300					524
TOTAL kg CO2e	263153	41852	46334	86167	200257	663916
TOTAL kg CO2e/m2	**196.7**	**31.3**	**34.63**	**64.4**	**149.69**	**496.2**
TOTAL kg CO2e/m2			**478.9**			**496.2**

Analytical Work
Results & Discussion

By EDSL TAS, calculations were done to see how different scenarios perform against each other. The results were quite similar, as expected, since similar U-values were achieved in every scenario. Operational energy calculations indicate the best case scenario to be alternative material, following by the as built and all timber scenarios. The results show high lighting and auxilary gains as NCM database was used, in reality the building is expected to be perform better. Moreover, cooling gains can be improved as no passive ventilation strategies was implemented when creating the scenarios. Heating emissions are lowest for alternative scenario, while cooling emissions are lowest for as built scenario.

The CO_2 emission results show that scenario with biobased materials not only performs the best in terms of embodied carbon, it also is the best performing in the operational energy aspect.

	As Built	Timber	Alternative
Heating	10.78	11.47	6.91
Cooling	4.98	4.96	5.54
Auxiliary	42.63	42.65	42.25
Lighting	24.89	24.89	24.89
Hot water	84.55	84.55	84.55
Equipment*	48.02	48.02	48.02
TOTAL**	**167.82**	**168.52**	**164.14**

Energy Consumptions by End-Use [kWh/m^2]

	As Built	Timber	Alternative
Cooling (kgCO2/m²)	2.58	2.57	2.87
Auxiliary (kgCO2/m²)	22.13	22.14	21.93
Lighting (kgCO2/m²)	12.92	12.92	12.92
DHW (kgCO2/m²)	43.88	43.88	43.88
Displaced Electricity (kgCO2/m²)	-2.41	-2.41	-2.41
Equipment (kgCO2/m²) *	*24.92*	*24.92*	*24.92*
Total (kgCO2/m²)	84.69	85.05	82.78

CO_2 Emissions [kgCO_2/m^2]

Conclusions

The study shows how a well performing building in correlation with the most up to date guidelines can further improved.

Through the results; it can be summed up that bio-based materials can be implemented to the design not only in structure and facade treatments but also in insulation and linings. However it should be taken into consideration that in some scenarios material quantities should be increased to achieve the required U-values. In embodied carbon aspect, this is not an issue due to sequestration aspect, however this may lead to increased costs.

It is inevitable that cement-based products will be used in some parts of the building: foundations and substructures can be improved through recycled content to reduce embodied carbon.

Also, the impact of transportation should not be ignored especially considering the huge amount of timber products are imported. Careful consideration must be made while material selection. As seen in external Accoya claddings; between two types due to transportation emissions a considerable difference was achieved.

The conclusions indicate the next generation of mass timber constructions, the possible hotspots, means of improvement in both embodied and operational carbon to reach the net zero building.