Reimagining the ‘Home’ Project

Holistic Technical Report

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1. Construction

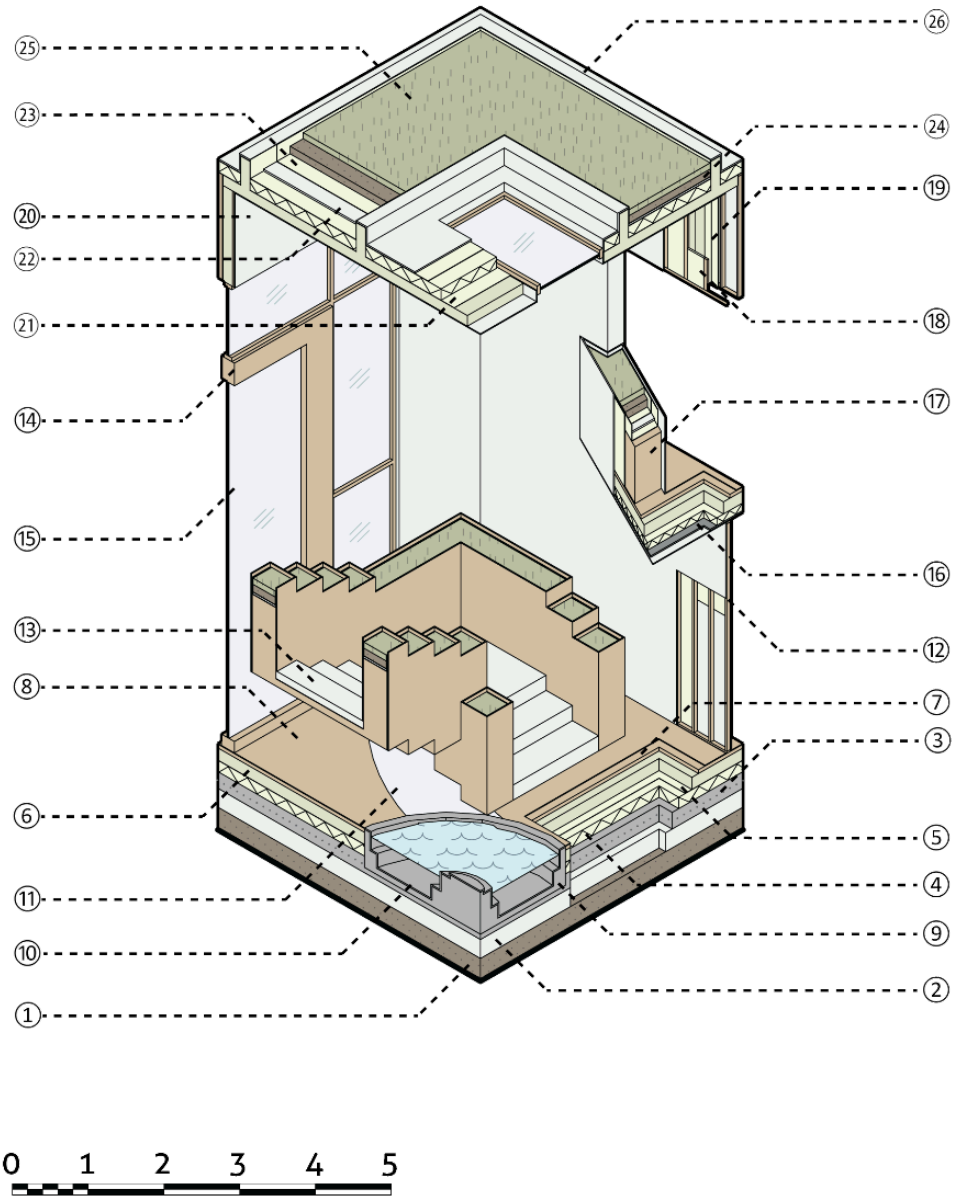


Figure 1.1. Isometric detail 1:100

Final CLT construction design depicted after revisions to the initial steel and concrete design revised throughout the report.

1. Natural ground
2. 250 mm Recycled MOT type 1 (compacted in-situ)
3. 220 mm GGBS low-carbon concrete slab (cast on-site)
4. 150 mm Wood-fibre compressive insulation (prefabricated)
5. 3 mm Damp proof airtight membrane (prefabricated)
6. 160 mm CLT floor panel, 140 mm used for walls and roof (prefabricated)
7. 50 mm Dry screed boards (prefabricated)
8. 10 mm Reclaimed timber flooring (prefabricated)
9. 80 mm GGBS concrete shell (cast on-site)
10. 20 mm Low-carbon concrete finish (cast on-site)
11. 50 mm Laminated structural glass (prefabricated)
12. 25 x 50 mm Timber stud frame (site-assembled)
13. 100 mm Ceramic tiles on 10 mm adhesive bed (prefabricated)
14. 200 mm Solid timber door with 1 mm natural oil finish (prefabricated)
15. 32 mm Triple glazing (prefabricated)
16. 0.8 x 25 mm Steel resilient bars (prefabricated)
17. 400 x 750 mm Internal planter wall glulam body structure, also for stairs (prefabricated)
18. 50 x 25 mm Service void timber batten structure with 25 mm insulation (site-fixed)
19. 0.5 mm Breathing membrane with 12 mm wood-fibre sheathing (prefabricated)
20. 15 mm Internal clay plaster (site-applied)
21. 1 mm Vapour control membrane (prefabricated)
22. 25 mm Drainage layer on 5 mm root resilient membrane (prefabricated)
23. 5 mm Filter fleece (prefabricated)
24. 100 mm Growing medium (placed in-situ)
25. 80 mm Vegetation (planted and grown in-situ)
26. 20 mm External clay plaster (site-applied)

Figure 1.2. Isometric detail key

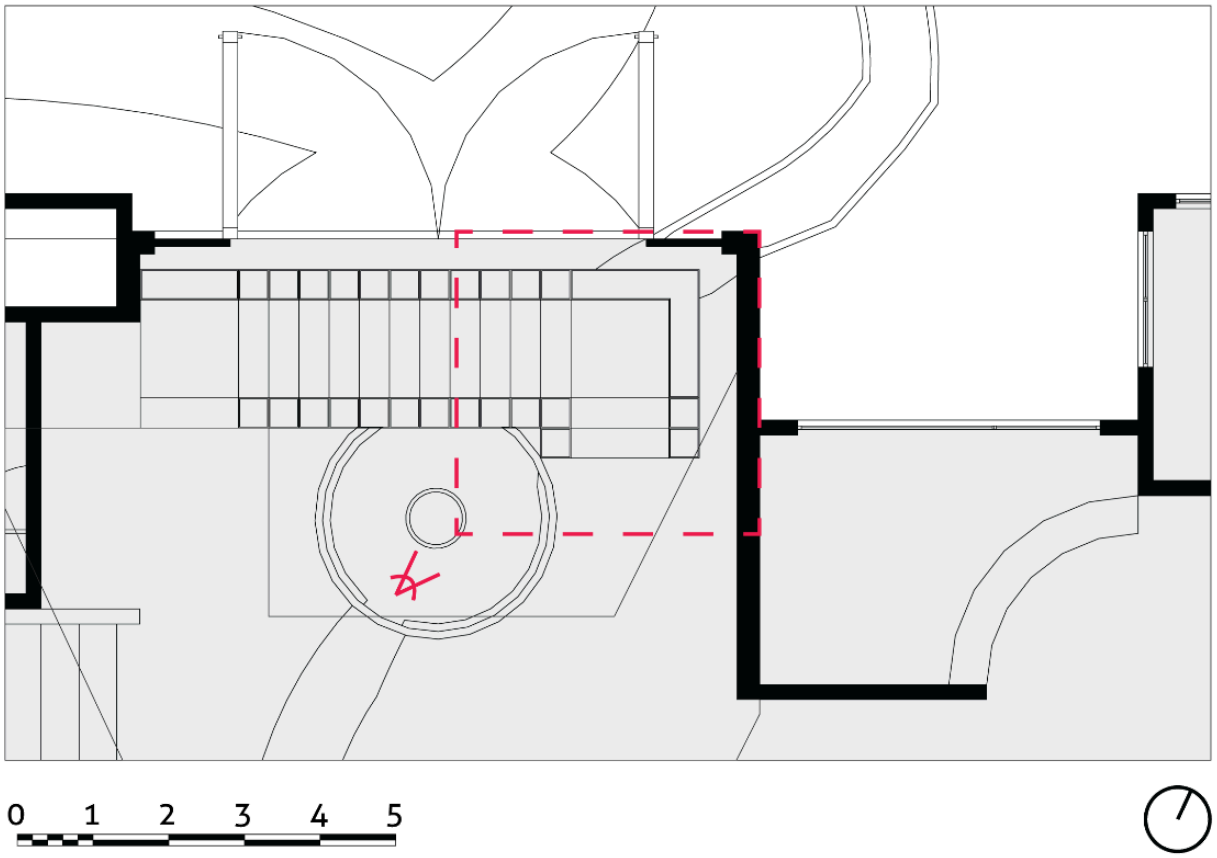


Figure 1.3. Isometric detail location plan scale 1:100

1.1 Construction Risks and Challenges

The structure sits atop a sloped rural site intersected by an active stream which presents flood and erosion risk. Heavy rainfall or channel blockage could cause both internal and external flooding, leaving foundations vulnerable to being undermined. Temporary stream diversion will therefore be required during slab casting, increasing complexity and erosion exposure of other site locations. Prefabricated CLT panels must be protected prior to enclosure to prevent moisture-induced damage. The initial design steel and concrete construction imposed high dead loads, elevating settlement risk, whereas the lighter final CLT structure reduces ground pressure but increases moisture sensitivity at ground interfaces.

In regards to structure, the eastern cantilever poses high bending moments and deflection risk, therefore it requires temporary support during construction. While the initial steel frame provided efficient tensile resistance, the final CLT solution requires deeper sections or concealed reinforcement which increase in sensitivity throughout the structure's life. Similarly, the western primary column supporting the suspended master bedroom represents a collapse risk due to disproportionate load-path concentration. Construction tolerances and connection detailing are critical to avoid any failure.

The green roof and internal planter systems introduce variable saturated loads and potential drainage blockage. The initial concrete roof tolerated moisture and mass, however the final CLT roof demands rigorous waterproofing and root-barrier detailing to prevent long-term degradation.

Post-construction, durability and maintenance of drainage infrastructure are critical. Overall, the final design reduces structural mass and embodied carbon but increases reliance on precise detailing, moisture control and long-term resilience strategies. The final design is therefore of improved environmental performance, but reduced resilience and requires more care.

1.2 Construction Methods

The final design adopts a hybrid prefabricated and in-situ strategy, combining off-site manufactured CLT and glulam elements with limited cast-on-site low-carbon concrete where structurally necessary. This approach minimises environmental disturbance while maintaining structural reliability, taking great care with the biophilic and sustainable approach.

Primary structural components, CLT wall, floor and roof panels, glulam planter/stair elements, triple glazing, laminated glass and timber doors are prefabricated off-site. Off-site fabrication ensures quality assurance, dimensional accuracy, improved airtightness tolerances and limits material waste, while significantly reducing construction duration. On a rural site intersected by a stream, this decreases heavy vehicle movements, ground compaction, noise pollution and ecological disruption, directly supporting the project's biophilic and low impact ambitions.

Cast-on-site elements are limited to the essentials, such as the GGBS low-carbon concrete slab and shell. Concrete is therefore used only where compressive strength, durability and water resistance are structurally required. Incorporating high GGBS content reduces embodied carbon while maintaining performance.

Preassembled layered systems, such as green roof build-ups, service voids and timber stud infill frames allow staged installation, facilitating maintenance access and future adaptability. This layered construction enhances disassembly potential and long-term life cycle circularity.

Locally sourced timber and aggregates were prioritised to reduce transport emissions, although specialised elements such as high-performance glazing and membranes required wider procurement due to technical performance constraints and limited local suppliers.

Overall, prefabrication is the most appropriate method for this project as it reduces environmental impact, improves construction precision, shortens on-site duration, enhances safety through controlled assembly, and aligns with the structural logic and sustainability objectives of the final CLT biophilia-centric design.

1.3 Construction Process

Construction begins with site preparation, temporary stream diversion and excavation to formation level. The natural ground is stabilised and compacted (①), followed by placement of 250 mm recycled MOT Type 1 sub-base (②) to distribute loads and prevent differential settlement. A 220 mm GGBS low-carbon concrete slab (③) is then cast in-situ, forming the primary foundation and ground-bearing structure.

Once cured, prefabricated CLT floor panels (⑥) are craned into position and mechanically fixed, establishing the structural platform. Primary vertical structure is erected next, including the glulam planter/stair structural core (⑰) and load-bearing CLT wall panels (⑥). The first-floor CLT panels forming the eastern cantilever are craned into position and temporarily propped until stability is achieved and permanent mechanical connections are secured. On the western elevation, the overhanging upper volume is installed onto the primary glulam beam and supporting column, with temporary bracing provided until structural load paths are fully stabilised. Timber stud infill framing (⑫) is installed where non-loadbearing partitions / internal walls are required. Service void battens (⑱) are fixed internally to protect membranes and allow mechanical, electrical and plumbing installation.

The roof structure follows, with CLT roof panels (⑥) installed and sealed. The low-carbon concrete shell (⑨) and external concrete finish (⑩) are set in preparation for flow of the stream. Waterproofing layers are then installed: vapour control membrane (⑪), root-resistant membrane and drainage layer (⑭, ⑮), followed by filter fleece (⑲), growing medium (⑳) and vegetation planted (㉕), completing the green roof system.

Before enclosure works are finalised, the stream channel undergoes stringent water tightness, flow rate and erosion testing. Following successful inspection and certification, the stream is gradually reinstated under controlled flow conditions to verify performance and prevent scour or leakage. Stream diversion is no longer necessary.

Building enclosure is completed with installation of triple glazing units (⑮), laminated structural glazing (⑪), and solid timber doors (⑭). Breather membranes (⑲) and clay plaster finishes (⑳, ㉖) are applied internally and externally under dry, mild weather conditions to ensure appropriate setting, airtightness and moisture control.

Finally, internal finishes including dry screed boards (⑦), reclaimed timber flooring (⑧), ceramic tiles (⑬) and clay plaster (⑳) are completed. Services are commissioned, drainage systems tested, and the stream channel reinstated. The building is then inspected, certified, and delivered as a fully enclosed, structurally complete and environmentally integrated dwelling.

2. Environmental

2.1 Baseline Environmental Performance Assessment

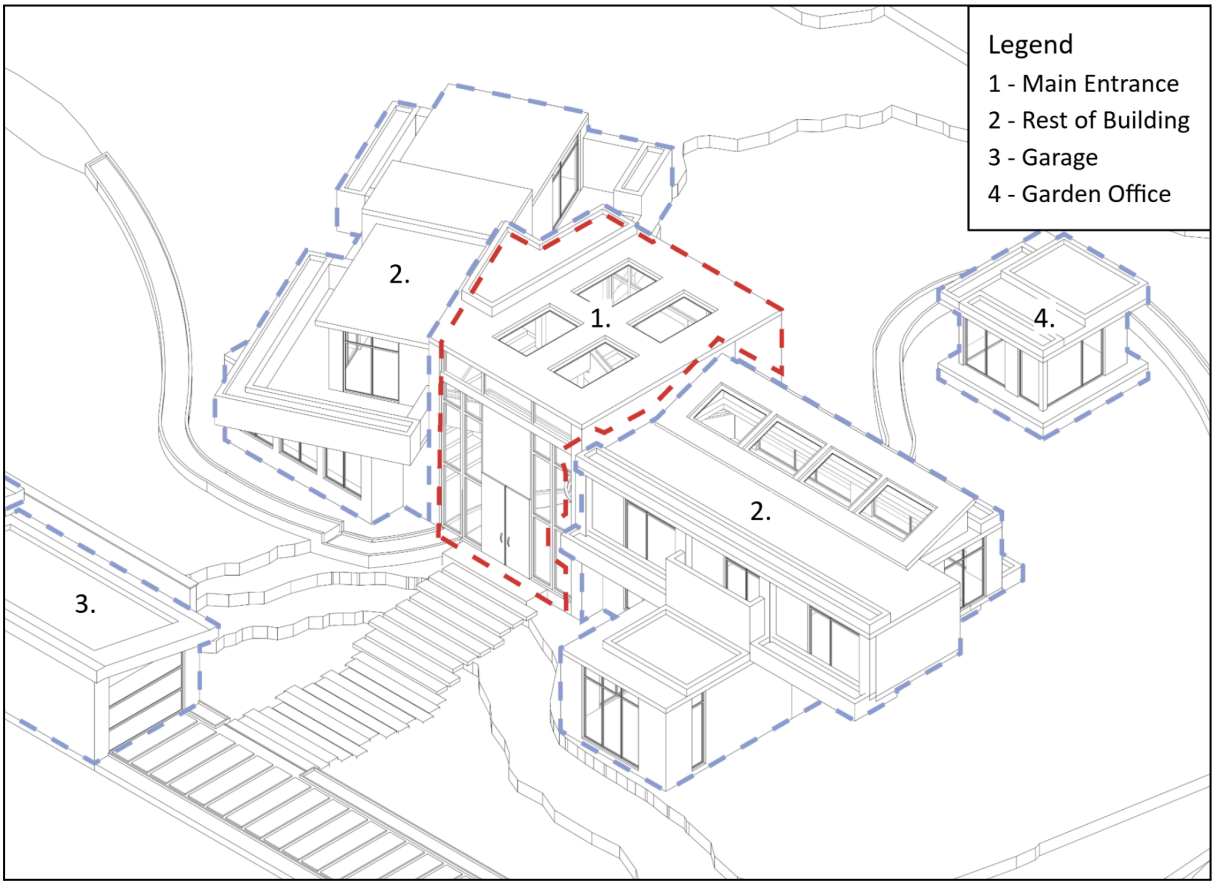


Figure 2.1. Environmental assessment building zoning

Architecturally, the initial design demonstrates a strong biophilic and experiential ambition, most clearly expressed through the central entrance space. From an environmental perspective, however, baseline performance is uneven and can be understood by separating the building into two distinct components: the large, highly glazed entrance volume (red) and the remainder of the building (blue), as shown in Figure 2.1. While the rest of the building adopts forms consistent with conventional UK domestic construction and is therefore expected to perform at UK norms, the entrance space introduces environmental vulnerabilities that are likely to dominate overall energy demand and thermal comfort outcomes.

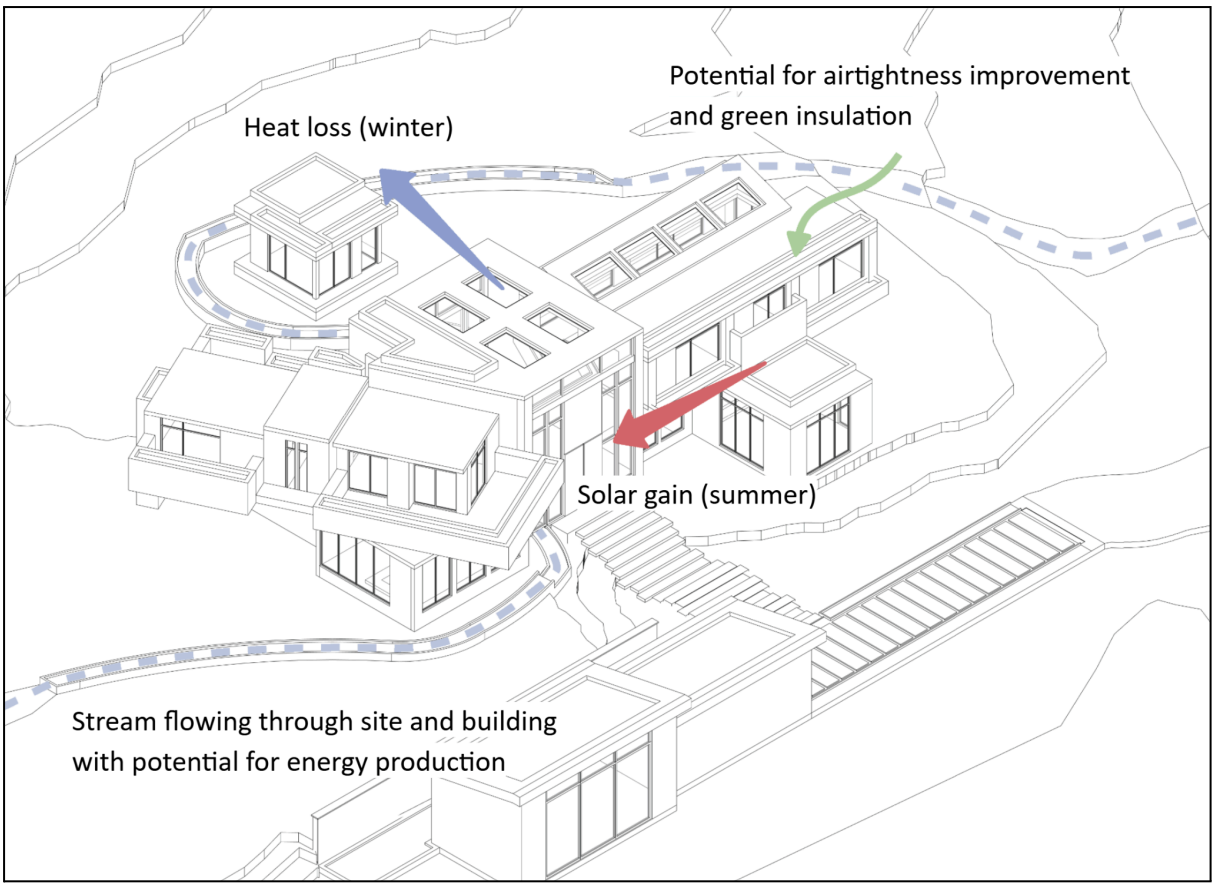


Figure 2.2. Baseline environmental performance issues and missed opportunities

The building is composed of a majority of smaller rooms with moderate window to wall ratios and standard insulated envelopes, being broadly consistent with typical UK housing. Therefore, operational energy demand, winter heat loss and summer overheating risks of these spaces are expected to remain close to UK standards, supporting stable year-round thermal comfort.

In contrast, the entrance volume represents a clear thermal weak point. Extensive south facing glazing, a large single volume space and lower insulation levels increase winter heat loss and thus, heating demand under a gas boiler system, raising operational carbon relative to the rest of the building. In summer, high solar gains and limited shading increase overheating risk. However, opposing openable facades and rooflights enable cross and stack ventilation (Figure 2.2), improving summer performance. As a result, thermal behaviour is highly seasonal, with winter performance being significantly weaker than summer.

Overall, baseline performance is driven by elevated heating demand from the poorly performing entrance space. Missed opportunities include enhanced airtightness, expanded green roof potential and wall insulation, low temperature systems such as underfloor heating, and potential on-site renewables generating power from the stream, which could reduce grid dependence and strengthen the environmental strategy.

2.2 Ventilation Strategy and Airflow Geometry Analysis

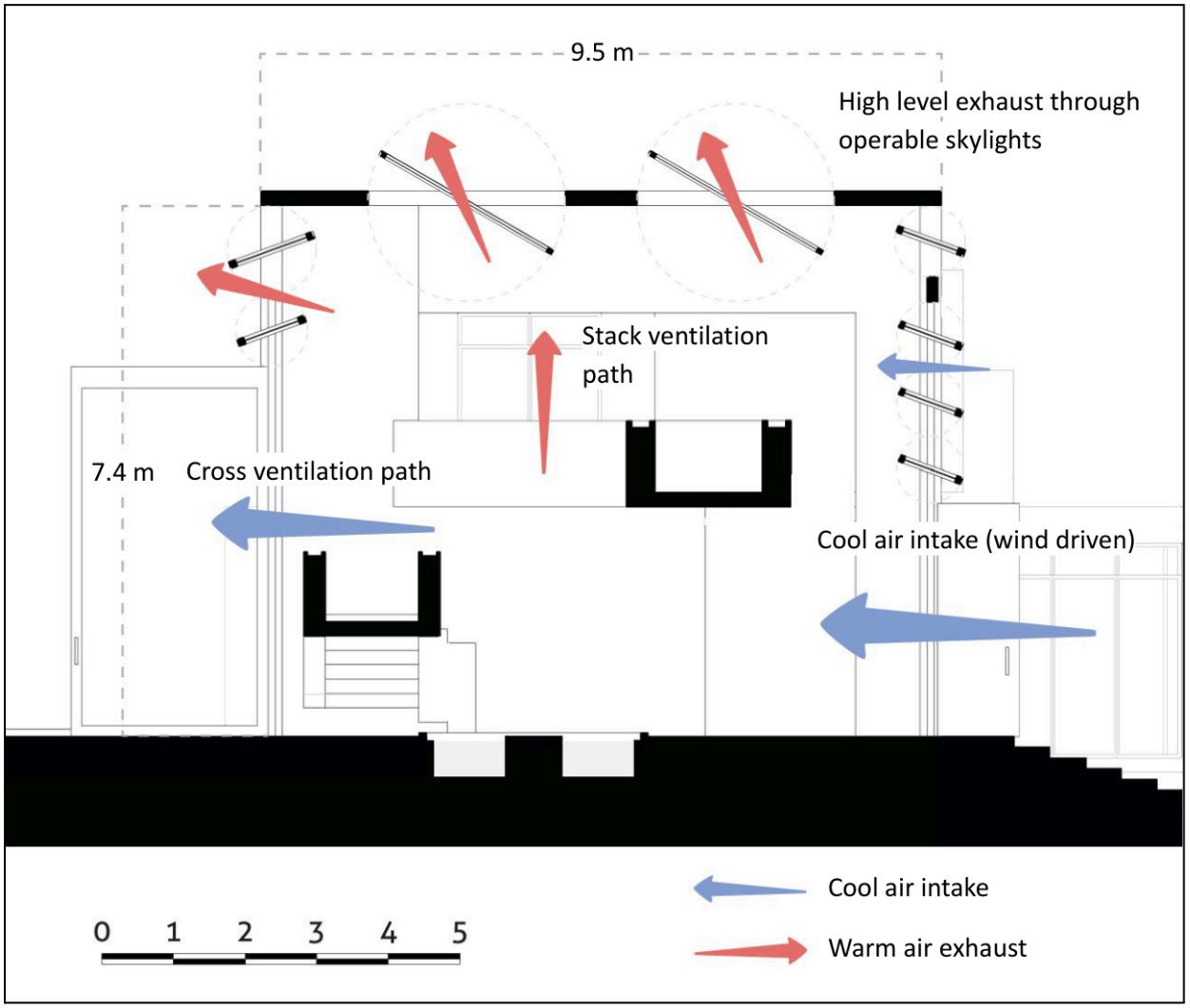


Figure 2.3. Ventilation strategy of entrance

Ventilation Type	Cross ventilation	Stack ventilation
Rule of Thumb Formula	$D_{max} = 5 \times H$	$H > 3$ m
Depth, D (m)	9.5	N/A
Height, H (m)	7.4	7.4
Calculations (m)	$D_{max} = 5 \times 7.4 = 37$ $9.5 \leq 37$	$7.4 > 3$
Pass or Fail	Pass	Pass

Figure 2.4. Entrance rule-of-thumb calculations

The entrance relies on cross ventilation through large openable glazed facades on opposing sides, enabling wind-driven airflow across the space. In the exposed rural context, sufficient wind pressure differentials can be assumed, and the tall, unobstructed volume supports high air change rates in summer. However, performance depends on wind direction, speed and user control. During low wind conditions, cross ventilation becomes less reliable despite the vast opening areas.

Rooflights provide stack ventilation. At a height of 7.4 m, the volume exceeds the 3 m rule-of-thumb threshold for buoyancy-driven flow (Figure 2.4), allowing warm air to rise and exhaust at high level whilst drawing cooler air in from below. The combination of cross and stack ventilation significantly improves robustness compared to a single strategy.

Performance remains seasonal. Summer conditions benefit from effective heat removal, while winter heat loss is amplified by the large volume, high skylight exhausts and extensive glazing, making the entrance the weakest environmental element. Future refinement should moderate rather than increase ventilation, through a buffer lobby, improved airtightness and insulation, and smart automatically controlled openings. Reducing ceiling height or subdividing the space could improve thermal stability but would compromise spatial openness and biophilic intent.

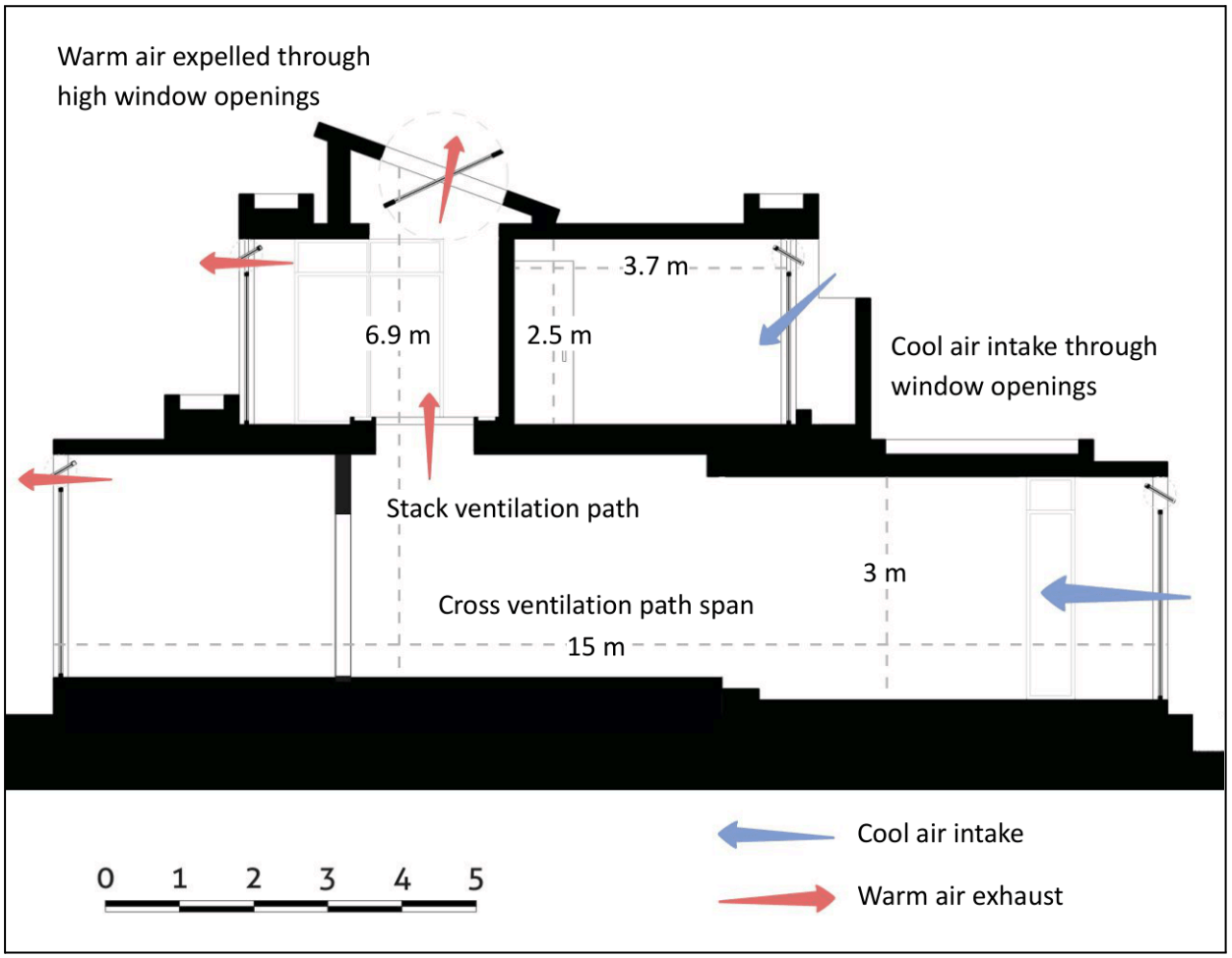


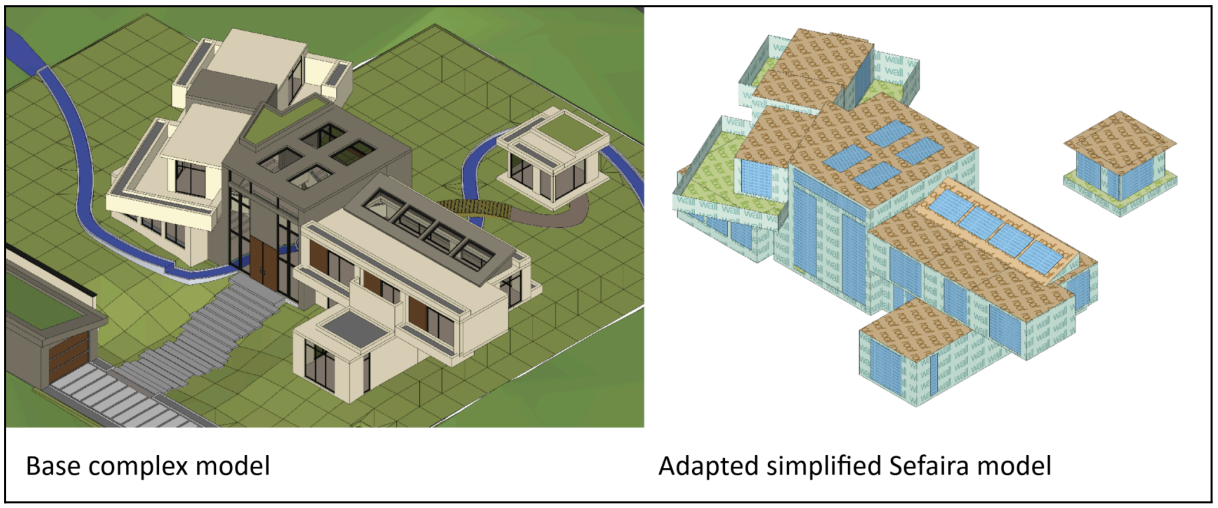
Figure 2.5. Ventilation strategy of rest of building

Ventilation Type	Single-sided Ventilation	Cross Ventilation	Stack Ventilation
Rule of Thumb Formula	$D \leq 2 \times H$	$D_{max} = 5 \times H$	$H > 3$ m
Depth, D (m)	3.7	15	N/A
Height, H (m)	2.5	3	6.9
Calculations (m)	2 x 2.5 = 5m 3.7 ≤ 5	D_{max} = 5 x 3 = 15 15 ≤ 15	6.9 > 3
Pass or Fail	Pass	Pass	Pass

Figure 2.6. Rest of building rule-of-thumb calculations

The rule-of-thumb assessments indicate that the remainder of the building performs well under natural ventilation criteria (Figure 2.6). Single-sided ventilation is effective where room depths remain shallow, cross ventilation operates at the maximum acceptable depth-to-height ratio, and stack ventilation is supported by a tall void with a skyflight, increasing reliability when wind flow is reduced. While both tables confirm that the ventilation strategy is successful overall, this consistency highlights the contrast with the entrance space. The rest of the building represents a stable and an enhanced UK domestic condition, whereas the entrance remains a deliberate yet vulnerable environmental outlier. Future refinement should be concentrated on the entrance volume, where geometric exaggeration amplifies both ventilation benefits and thermal risks.

2.3 Energy Modelling and Annual Demand Evaluation



Base complex model Adapted simplified Sefaira model

Figure 2.7. Preparing Sefaira model

This section uses Sefaira to evaluate the initial design and test targeted improvements (Figure 2.7) to be carried forward to the final design. Only conditioned spaces are modelled, hence the exclusion of the uninsulated garage but inclusion of the heated home office. Results are benchmarked against the UK Part L 2010 notional building to identify weaknesses and guide evidence-based refinements.

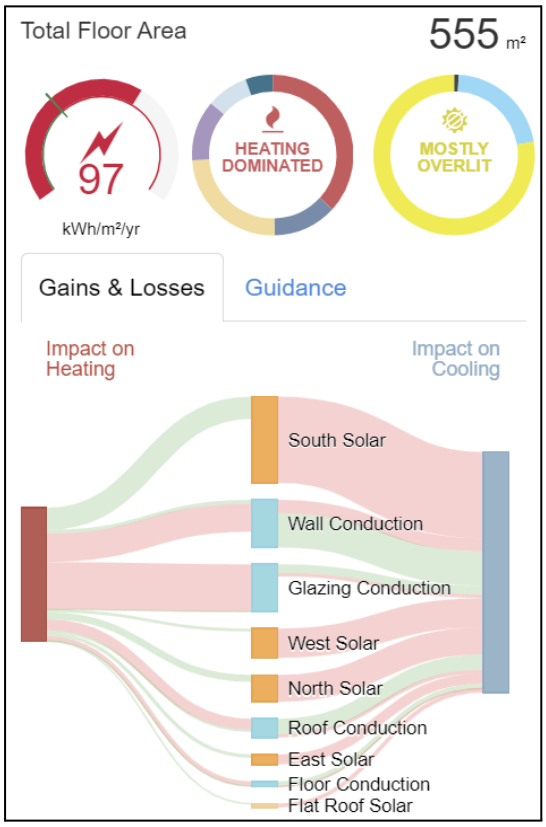


Figure 2.8. Initial design Sefaira simulation results

Energy Segment	Annual Energy Demand (kWh/yr)	Share of Total (%)
Heating	19,829	37%
Cooling	6,883	13%
Lighting	13,105	24%
Equipment	6,552	12%
Fans	4,529	8%
Pumps	2,939	5%
Total	53,837	100%
Energy Use Intensity (EUI)	97 kWh/m²/yr	N/A

Figure 2.9. Tabulating initial Sefaira results

The Sefaira simulation in Figure 2.8 with tabulated results in Figure 2.9, shows an energy use intensity of 97 kWh/m2/yr, approximately 50% lower than a typical UK benchmark (180-200 kWh/m2/yr). This indicates strong efficiency relative to standard UK dwellings, while still revealing targeted performance weaknesses.

Despite this success, the results identify glazing as the primary limitation. Extensive glazing leads to 78% of spaces being overlit, driving high summer solar gains and cooling demand while causing significant winter heat loss. These effects are concentrated in the large entrance volume, which dominates variability of the building's thermal behaviour.

Performance issue	Evidence from model	Implication	Design response
Excessive Glazing Solar Gains (Summer)	43,615 kWh/yr Gains in cooling hours 78% of spaces overlit	Elevated cooling demand and overheating risk	- Reduce glazing size - Introduce overhangs for solar control - Consider adaptive electrochromic glazing to balance daylight and solar gains
Excessive Glazing Heat Loss (Winter)	23,959 kWh/yr Losses in heating hours	Elevated heating demand and energy waste	- Upgrade glazing specification with lower U-value - Reduce glazing size - Improve airtightness at window edges
Wall Heat Loss	14,312 kWh/yr Losses in heating hours	Significant envelope inefficiency contributing to high heating demand	- Improve insulation and airtightness to achieve lower U-values - Add green wall systems to provide thermal buffering and microclimate moderation - Add permeable barrier for stream running through entrance - Introduce a partially enclosed lobby to break up the large entrance volume and reduce volumetric heat loss
Lighting energy demand	13,105 kWh/yr demand despite high daylight availability	Unnecessary electrical demand where daylight levels are already sufficient	- High-efficiency LED lighting replacements
Roof Heat Loss	5,557 kWh/yr Losses in heating hours	Moderate but reducible losses	- Improve roof insulation to reduce U-value - Add green roof systems (natural insulation)

Figure 2.10. Initial design weaknesses and design responses

A refined design targets the most energy-intensive elements identified in Figure 2.10, focusing on reducing glazing related heat transfer. South facing glazing is reduced where possible and supplemented with external overhangs to limit summer gains whilst still maintaining daylight.

Glazing performance is improved through lower U-values and enhanced junction airtightness to reduce winter heat loss, while wall and roof build-ups are upgraded with improved insulation and airtightness. The entrance volume is partially divided with a lobby to reduce volumetric heat loss and stabilise inconsistent internal temperatures.

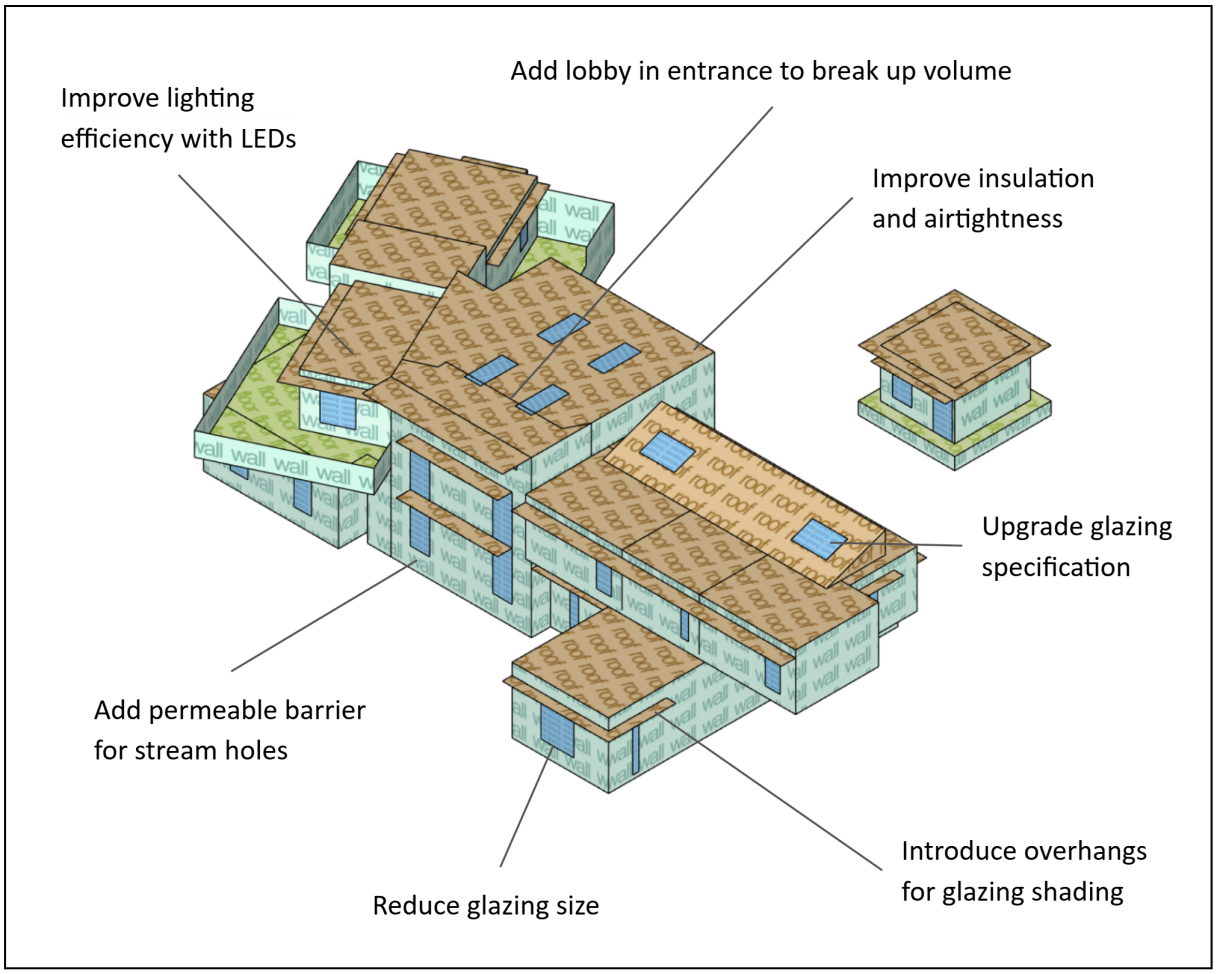


Figure 2.11. Refined design Sefaira model

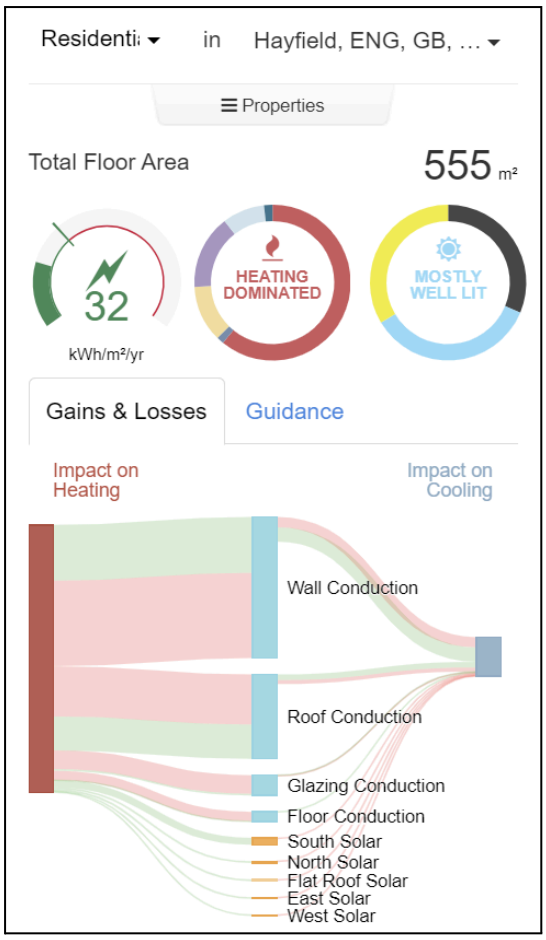


Figure 2.12. Refined design Sefaira simulation results

	Initial		Refined		Annual Energy Demand Reduction	
Energy Segment	Annual Energy Demand (kWh/yr)	Share of Total (%)	Annual Energy Demand (kWh/yr)	Share of Total (%)	(kWh/yr)	(%)
Heating	19,829	37%	10,928	61%	8,901	44.89%
Cooling	6,883	13%	269	2%	6,614	96.09%
Lighting	13,105	24%	2,097	12%	11,008	84.00%
Equipment	6,552	12%	2,752	15%	3,800	58.00%
Fans	4,529	8%	1,573	9%	2,956	65.27%
Pumps	2,939	5%	314	2%	2,625	89.32%
Total	53,837	100%	17,933	100%	35,904	66.69%
Energy Use Intensity (EUI)	97 kWh/m²/yr	N/A	32 kWh/m²/yr	N/A	65 kWh/m²/yr	67.01%

Figure 2.13. Tabulating refined Sefaira results

The refined Sefaira results in Figure 2.12 show an energy use intensity of 32 kWh/m2/yr, representing an approximate 67% reduction compared to the initial design in Figure 2.13. This reflects an absolute best case performance scenario, demonstrating the effectiveness of targeted glazing reduction, improved fabric performance, and solar control strategies under perfect conditions, hence the drastic difference.

As shown in Figure 2.13, substantial reductions occur across all end uses, particularly in cooling (-96%) and lighting (-84%). Although the refined design remains heating dominated, the increased heating share (61%) stems from greater reductions elsewhere rather than increased heating demand,

reinforced with absolute heating energy being reduced by approximately 45%. These improvements significantly enhance environmental performance but hinder the project's biophilic architectural approach, highlighting a trade-off between spatial ambition and energy efficiency.

While on-site energy generation does not reduce demand, photovoltaics and a small-scale hydro turbine within the on-site stream could offset a substantial proportion of the remaining energy use, supporting a highly self-sufficient, potentially fully off-grid design, reinforcing the project's sustainable, biophilic narrative that has been otherwise undermined by energy efforts.

3. Materials

3.1 Material Layers and Alternatives

Layers are listed outside to inside, internal walls are room to room.

Building Component	Material Layer	Material Thickness (mm)	Critical Reflection	Material Alternative	Initial Comparison to Alternative
Foundation	Reinforced concrete ground-bearing slab	200	Primary load-bearing element, high embodied carbon	Low-carbon concrete (GGBS)	40-70% embodied carbon reduction with equivalent strength
	Damp proof membrane (DPM)	0.3	Prevents ground moisture ingress	Bio-based polyethylene membrane	Comparable moisture resistance, lower fossil fuel content
	Rigid PIR insulation board	150	High thermal performance, poor circularity, high embodied carbon.	Foam glass	Lower carbon, durable, recyclable
	Sand blinding	50	Level substrate, no structural role	Recycled aggregate blinding	Reduced new material extraction
	Compacted hardcore sub-base	150	Load distribution and drainage layer	Recycled concrete aggregate (MOT Type 1)	Structurally equivalent, lower environmental impact
External Wall	Clay rainscreen / clay tile cladding	25	Durable biophilic finish, high mass and secondary substructure required	Clay plaster on timber substrate	Maintains aesthetic with lower mass and embodied carbon
	Ventilated cavity	50	Promotes drainage and drying, reduces internal condensation risk	Reduced cavity with hygroscopic materials	Relies on vapour permeability. simpler construction
	Cement-based sheathing board	12	Provides weather protection, moderate embodied carbon	Wood fibre sheathing board	Lower carbon and improved vapour permeability
	Breather membrane	1	Wind and water-resistant, vapour-open	Bio-based vapour-open membrane	Similar performance, reduced fossil fuel content
	Steel frame studs with mineral wool insulation	140	Structurally efficient, thermal bridging, high carbon.	Timber frame / CLT wall panel	Significantly reduced carbon and improved thermal continuity

	Vapour control layer (VCL)	1	Limits internal moisture migration	Intelligent vapour membrane	Increased hygrothermal robustness
	Service void (timber battens)	25	Protects VCL, increases build-up depth	Integrated CLT service zone	Reduced layers and construction complexity
	Internal plasterboard lining	12.5	Fire resistance and finish, low moisture buffering	Clay plaster finish	Improved hygrothermal regulation and biophilia
Internal Wall	Internal plasterboard lining (both sides)	12.5 x 2	Fire resistance and finish, low moisture buffering	Clay plaster finish	Improved hygrothermal regulation and durability
	Steel stud frame	1	Lightweight, high embodied carbon	Timber stud frame	Lower carbon, improved environmental performance
	Mineral wool acoustic insulation	50	Improves acoustics, moderate embodied carbon	Wood fibre insulation	Comparable acoustics, lower carbon
Floor / Ceiling	Ceramic floor tiles	10	Durable finish, high embodied carbon	Reclaimed tiles	Reuse/circular option
	Tile adhesive bed	5	Necessary bond layer, limited disassembly	Lime-based bedding	Improved reversibility
	Cementitious levelling screed	50	Flat substrate, added mass	Dry screed boards	Lower carbon. faster install
	Reinforced concrete topping (composite slab)	130	Stiffness, fire resistance, acoustic separation	Low-carbon concrete (GGBS)	Major carbon reduction
	Profiled metal deck (steel decking)	1	Enables long spans, rapid construction	CLT floor panel	Major carbon reduction
	Acoustic insulation	100	Airborne sound insulation	Wood fibre insulation	Similar acoustics, lower carbon
	Resilient bars / decoupling layer	20	Reduces vibration transfer	Acoustic mat	Equivalent performance, simpler construction
	Ceiling lining (plasterboard)	12.5	Fire protection and finish	Clay plaster	Improved hygrothermal performance
Roof	Green roof vegetation	80	Improves biodiversity and runoff control	Biodiverse wildflower roof	Higher ecological value
	Growing	100	Retains moisture	Lightweight	Reduces load with similar

	medium			recycled substrate	performance
	Filter fleece	5	Prevents drainage blockage	Recycled geotextile	Lower new plastic content
	Drainage layer	25	Manages excess water	Recycled HDPE board	Improved circularity
	Root-resistant waterproof membrane	5	Critical waterproofing	Recycled membrane	Similar durability, lower carbon
	Rigid insulation	150	Low U-value	Wood fibre insulation	Lower carbon, thicker build-up
	Vapour control	1	Limits internal condensation	Intelligent vapour membrane	Greater moisture robustness
	Steel roof deck	1	Increased structural spanning	CLT roof panel	Major carbon reduction
	Internal ceiling lining	12.5	Fire protection	Clay plaster	Improved IEQ and biophilia aligned
Windows	Aluminium frame	30	Good durability and thermal performance	Timber-framed glazing	Lower embodied carbon, similar U-values
	Double glazing	24	Limits heat gain but fixed performance	Electrochromic smart glass	Adaptive solar control reduces overheating, glare, and cooling demand

Figure 3.1. Structural components and alternative comparison

3.2 Embodied Carbon Calculation

		Dimensions							Environmental Data	
Structure		Length	Width	Surface Area	Thickness	Volume	Density	Mass	Carbon Coefficient	Embodied Carbon
Type	Materials	(m)		(m2)	(m)	(m3)	(kg/m3)	(kg)	(kgCO2e/kg)	(kgCO2e)
Foundation										
	Reinforced concrete ground-bearing slab	16.00	13.70	219.20	0.2000	43.84	2,400	105,216.00	0.198	20,832.77
	Damp proof membrane (DPM)	16.00	13.70	219.20	0.0003	0.07	950	62.47	2.540	158.68
	Rigid PIR insulation board	16.00	13.70	219.20	0.1500	32.88	32	1,052.16	4.260	4,482.20
	Sand blinding	16.00	13.70	219.20	0.0500	10.96	1,600	17,536.00	0.005	87.68
	Compacted hardcore sub-base	16.00	13.70	219.20	0.1500	32.88	2,000	65,760.00	0.005	328.80
External Wall										
	Timber cladding (bedrooms)	6.00	2.50	15.00	0.0500	0.75	600	450.00	0.200	90.00
	Clay rainscreen / clay tile cladding	55.14	11.73	646.79	0.0250	16.17	1,900	30,722.63	0.480	14,746.86
	Ventilated cavity	8.42	12.73	107.19	0.0500	5.36	0	0.00	0.000	0.00
	Cement-based sheathing board	55.14	11.73	646.79	0.0120	7.76	1,300	10,089.96	1.090	10,998.05
	Breather membrane	55.14	11.73	646.79	0.0010	0.65	950	614.45	2.600	1,597.58
	Steel frame studs	8.27	1.76	14.56	0.0010	0.01	7,850	114.26	1.530	174.82
	Mineral wool insulation	44.87	9.97	447.35	0.1400	62.63	60	3,757.77	1.280	4,809.95
	Vapour control layer (VCL)	55.14	11.73	646.79	0.0010	0.65	950	614.45	2.600	1,597.58
	Service void (timber battens)	8.42	12.73	107.19	0.0250	2.68	600	1,607.80	0.200	321.56
	Internal plasterboard lining	44.91	10.18	457.18	0.0125	5.71	800	4,571.84	0.390	1,783.02
Internal Wall										
	Internal plasterboard lining	60.36	3.00	181.08	0.0125	2.26	800	1,810.80	0.390	706.21
	Steel stud frame	6.04	3.00	18.12	0.0010	0.02	7,850	142.24	1.530	217.63
	Mineral wool acoustic insulation	60.36	3.00	181.08	0.0500	9.05	60	543.24	1.280	695.35
	Internal plasterboard lining	60.36	3.00	181.08	0.0125	2.26	800	1,810.80	0.390	706.21
Floor / Ceiling										
Floor	Ceramic floor tiles	37.34	17.90	668.39	0.0100	6.68	2,300	15,372.88	0.780	11,990.84
	Tile adhesive bed	37.34	17.90	668.39	0.0050	3.34	1,900	6,349.67	0.221	1,403.28
	Cementitious levelling screed	37.34	17.90	668.39	0.0500	33.42	2,000	66,838.60	0.182	12,164.63
	Reinforced concrete topping (composite slab)	37.34	17.90	668.39	0.1300	86.89	2,400	208,536.43	0.198	41,290.21
	Profiled metal deck (steel decking)	33.10	17.90	592.49	0.0010	0.59	7,850	4,651.05	1.540	7,162.61
Ceiling	Acoustic insulation	17.95	15.97	286.66	0.1000	28.67	60	1,719.97	1.280	2,201.56
	Resilient bars / decoupling layer	0.23	15.97	3.67	0.0200	0.07	7,850	576.68	1.530	882.32
	Ceiling lining (plasterboard)	17.95	15.97	286.66	0.0125	3.58	800	2,866.62	0.390	1,117.98

Roof										
	Green roof vegetation	17.61	5.40	95.09	0.0800	7.61	300	2,282.26	0.000	0.00
	Growing medium	22.01	5.40	118.85	0.1000	11.89	900	10,696.86	0.024	256.72
	Filter fleece	22.01	5.40	118.85	0.0050	0.59	950	564.56	3.430	1,936.43
	Drainage layer	22.01	5.40	118.85	0.0250	2.97	950	2,822.78	3.190	9,004.68
	Root-resistant waterproof membrane	22.01	5.40	118.85	0.0050	0.59	1,200	713.12	3.190	2,274.87
	Rigid insulation	19.42	18.90	367.04	0.1500	55.06	32	1,761.78	4.260	7,505.19
	Vapour control	19.42	18.90	367.04	0.0010	0.37	950	348.69	2.600	906.58
	Steel roof deck	19.42	18.90	367.04	0.0010	0.37	7,850	2,881.25	1.540	4,437.12
	Internal ceiling lining	17.48	18.90	330.37	0.0125	4.13	800	3,303.72	0.390	1,288.45
Fixtures										
Windows	Aluminium frame	43.50	0.90	39.15	0.0300	1.17	2,700	3,171.15	9.080	28,794.04
	Double glazing	43.50	7.65	332.78	0.0240	7.99	2,500	19,966.50	0.910	18,169.52
External Doors	Aluminium handle	2.96	0.05	0.15	0.0010	0.00	2,700	0.40	9.160	3.66
	Polyurethane coating	7.60	3.30	25.08	0.0001	0.00	1,200	3.01	3.000	9.03
	Solid timber door	7.60	3.30	25.08	0.2000	5.02	600	3,009.60	0.240	722.30
Internal Doors	Aluminium handle	4.80	0.05	0.24	0.0010	0.00	2,700	0.65	9.160	5.94
	Solid timber door	7.20	2.20	15.84	0.0350	0.55	600	332.64	0.240	79.83
Miscellaneous										
Stairs	Concrete fill	18.36	1.20	19.56	0.3000	5.87	2,400	14,083.20	0.107	1,506.90
	Ceramic floor tiles	8.58	1.90	10.48	0.0100	0.10	2,300	241.04	0.780	188.01
	Tile adhesive bed	8.58	1.90	10.48	0.0050	0.05	1,900	99.56	0.221	22.00
Outdoor Shower	Ceramic floor tiles	4.63	2.70	12.50	0.0100	0.13	2,300	287.52	0.780	224.27
	Tile adhesive bed	3.50	2.70	9.45	0.0050	0.05	1,900	89.78	0.221	19.84
Planters	Green roof vegetation	14.80	6.00	88.80	0.0800	7.10	300	2,131.20	0.000	0.00
	Growing medium	18.50	6.00	111.00	0.1000	11.10	900	9,990.00	0.024	239.76
	Filter fleece	18.50	6.00	111.00	0.0050	0.56	950	527.25	3.430	1,808.47
	Drainage layer	18.50	6.00	111.00	0.0250	2.78	950	2,636.25	3.190	8,409.64
	Root-resistant waterproof membrane	18.50	6.00	111.00	0.0050	0.56	1,200	666.00	3.190	2,124.54
	Concrete shell	20.00	7.50	150.00	0.1000	15.00	2,400	36,000.00	0.107	3,852.00
Garden Bridge	Oak	4.47	1.33	5.95	0.0700	0.42	700	291.31	0.240	69.91
Garden Path	Stone slabs	27.53	3.30	90.85	0.1500	13.63	2,600	35,431.11	0.079	2,799.06
Stream Channel	Aluminium finish	79.87	1.80	143.77	0.0020	0.29	2,700	776.34	9.160	7,111.24
	Concrete shell	79.87	1.80	143.77	0.0200	2.88	2,400	6,900.77	0.107	738.38
Totals								**715,399.04**		**247,056.76**

Figure 3.2. Spreadsheet of embodied carbon calculations

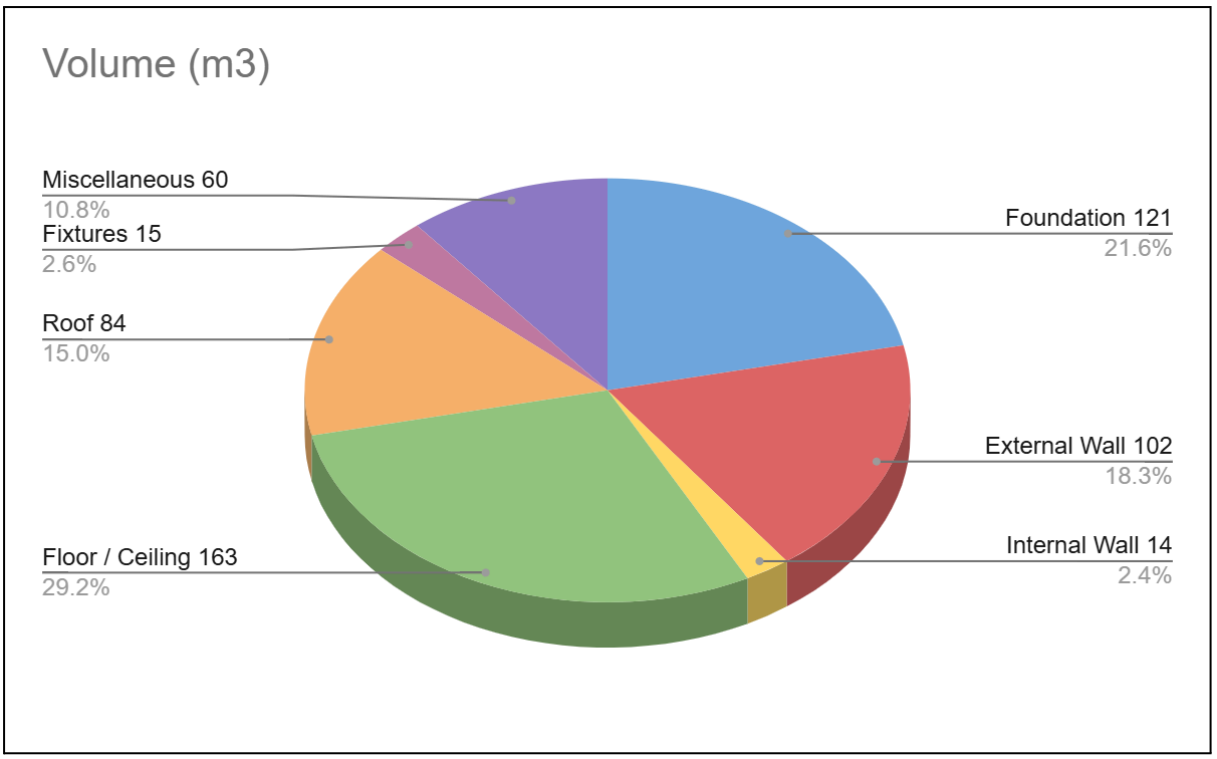


Figure 3.3. Distribution of volume of structural components

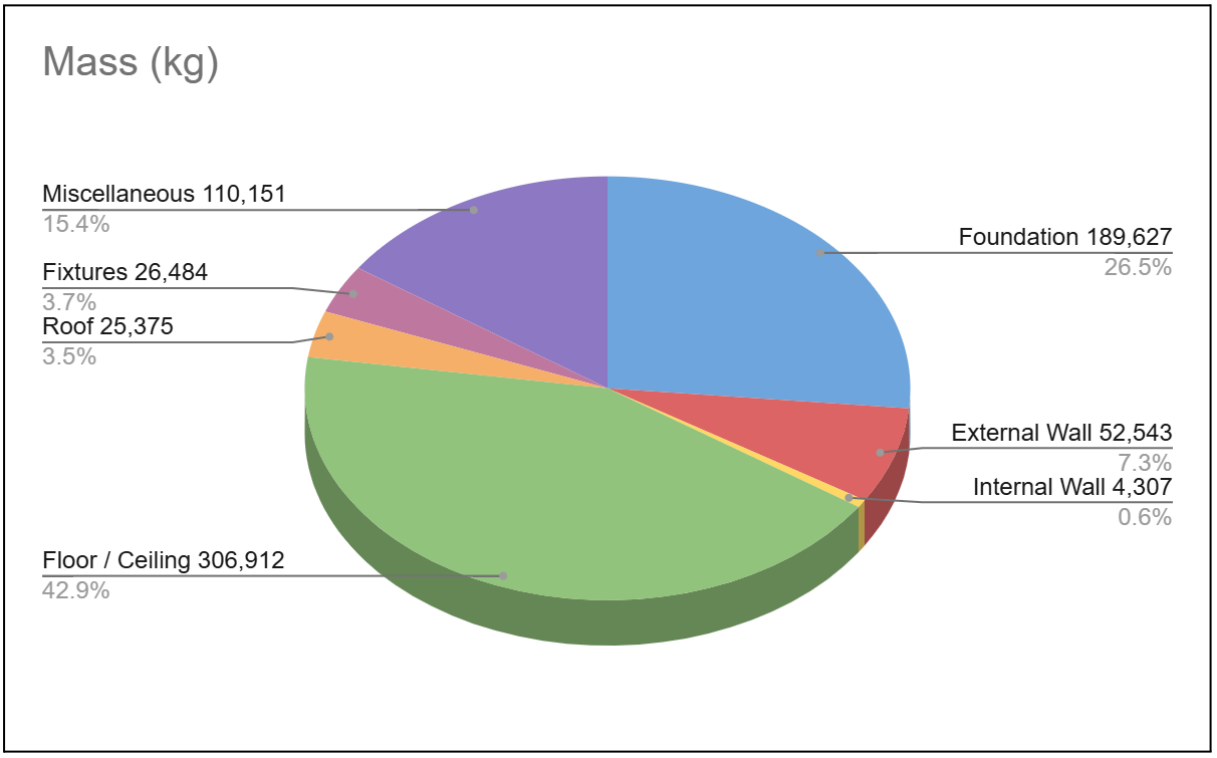


Figure 3.4. Distribution of mass of structural components

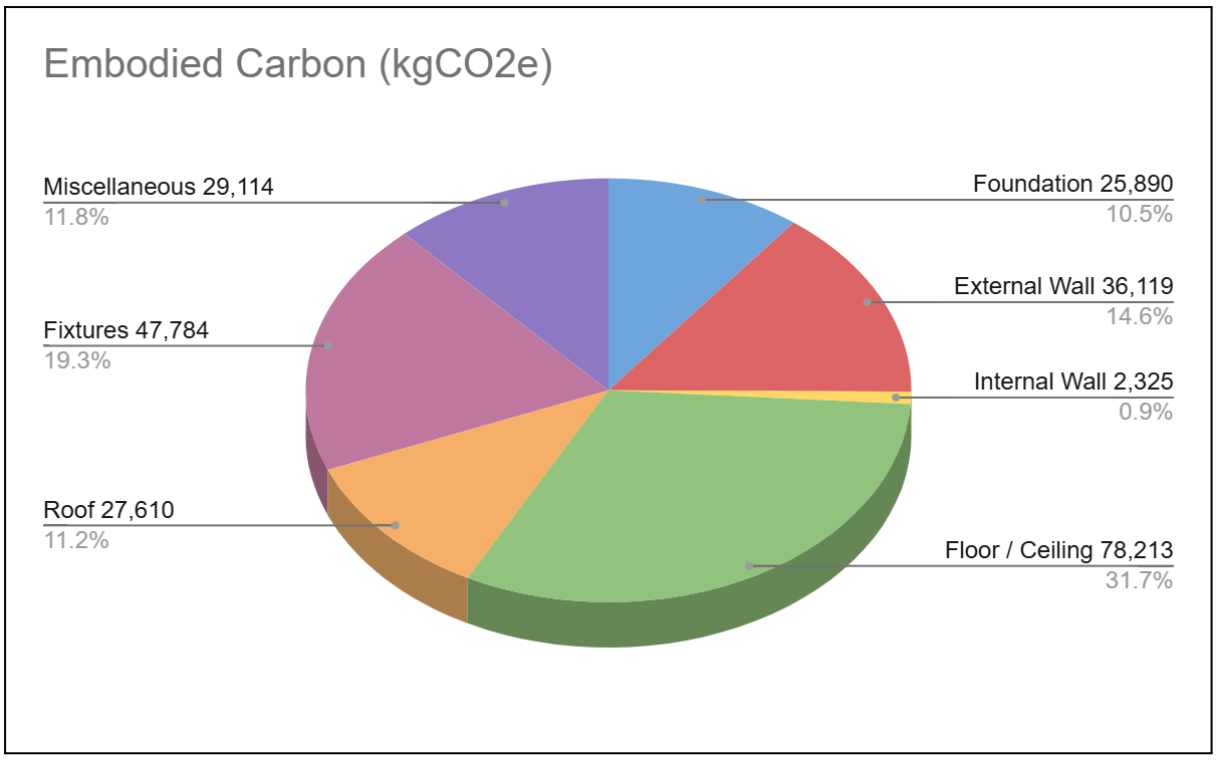


Figure 3.5. Distribution of embodied carbon of structural components

The initial design contains 247,056.76 kgCO2e, which equals 247 tCO2e. This amounts to 403 kgCO2e for every square metre across 612.8 m2 (Figure 3.2). Many of the impact comes from structural mineral and metal parts, not from finishes. The main sources are the layered floor plus ceiling assembly and the aluminium glazing systems.

Figures 3.3-3.5 confirm the structural dominance. The floor and ceiling account for 29.2% of volume, 42.9% of mass and 31.7% of embodied carbon, identifying the composite slab as the primary hotspot. Fixtures represent only 3.7% of mass yet 19.3% of carbon, demonstrating the high intensity of aluminium glazing. Foundations contribute 26.5% of mass but only 10.5% of carbon, while internal walls are negligible. Decarbonisation should therefore focus on structural substitution, such as replacing steel and composite slabs with CLT, rather than minor material adjustments.

Figures 3.3-3.5 confirm the structural dominance, with the floor and ceiling occupying 29.2% of the volume, 42.9% of the mass and 31.7% of the embodied carbon with the composite slab being the main hotspot. Fixtures contribute to only 3.7% of the mass but 19.3% of the carbon, revealing the high impact of aluminium glazing. Foundations equate to 26.5% of the mass but only 10.5% of the carbon, while internal walls are almost negligible. Decarbonisation should aim at replacing structural elements, like substituting steel and composite slabs with CLT, instead of tweaking minor materials.

3.3 Life-Cycle Assessment (LCA)

				Waste			Transport to Site			Replacement			End of Life						
Structure		Mass	Embodied Carbon		Carbon	Updated Embodied Carbon	Distance	Carbon Conversion Factor / km	Carbon	Expected Lifespan	Churn Rate	Replacement Emissions				Landfill Waste Mass	Transport Emissions	Waste Processing Emissions	Landfill Emissions
Type	Materials	(kg)	(kgCO2e)	Material Factor	(kgCO2e)	(kgCO2e)	(km)	(kgco2e/kg)	(kgCO2e)	(Years)	(RSP of 60 / Years)	(kgCO2e)	EOL Scenario	Revcovery Rate	Disposal Rate	(kg)	(kgCO2e)	(kgCO2e)	(kgCO2e)
Foundation																			
	Reinforced concrete ground-bearing slab	105,216.00	20,832.77	0.053	1,104.14	21,936.91	50	0.00007524	395.82	60+	0	0.00	Recycled	0.938	0.062	6,523.39	49.08	438.74	0.00
	Damp proof membrane (DPM)	62.47	158.68	0.060	9.52	168.20	300	0.0001065	2.00	60+	0	0.00	Landfill	0.000	1.000	62.47	3.99	0.00	0.81
	Rigid PIR insulation board	1,052.16	4,482.20	0.060	268.93	4,751.13	300	0.0001065	33.62	30	2	4,751.13	Landfill	0.000	1.000	1,052.16	67.23	0.00	13.68
	Sand blinding	17,536.00	87.68	0.030	2.63	90.31	50	0.00007524	65.97	60+	0	0.00	Stay / reused on site	0.938	0.062	1,087.23	8.18	1.81	0.00
	Compacted hardcore sub-base	65,760.00	328.80	0.030	9.86	338.66	50	0.00007524	247.39	60+	0	0.00	Stay / reused on site	0.938	0.062	4,077.12	30.68	6.77	0.00
External Wall																			
	Timber cladding (bedrooms)	450.00	90.00	0.050	4.50	94.50	50	0.0001065	2.40	30	2	94.50	Recycled	0.800	0.200	90.00	0.96	1.89	193.50
	Clay rainscreen / clay tile cladding	30,722.63	14,746.86	0.060	884.81	15,631.67	300	0.0001065	981.59	30	2	15,631.67	Recycled	0.938	0.062	1,904.80	121.72	312.63	0.00
	Ventilated cavity	0.00	0.00	0.000	0.00	0.00	0	0	0.00	60+	0	0.00	N/A	0.000	1.000	0.00	0.00	0.00	0.00
	Cement-based sheathing board	10,089.96	10,998.05	0.030	329.94	11,327.99	300	0.0001065	322.37	30	2	11,327.99	Landfill	0.000	1.000	10,089.96	644.75	0.00	131.17
	Breather membrane	614.45	1,597.58	0.030	47.93	1,645.51	300	0.0001065	19.63	30	2	1,645.51	Landfill	0.000	1.000	614.45	39.26	0.00	7.99
	Steel frame studs	114.26	174.82	0.010	1.75	176.57	300	0.0001065	3.65	60+	0	0.00	Recycled	0.960	0.040	4.57	0.29	3.53	0.00
	Mineral wool insulation	3,757.77	4,809.95	0.060	288.60	5,098.55	300	0.0001065	120.06	30	2	5,098.55	Landfill	0.000	1.000	3,757.77	240.12	0.00	8,079.21
	Vapour control layer (VCL)	614.45	1,597.58	0.000	0.00	1,597.58	300	0.0001065	19.63	30	2	1,597.58	Landfill	0.000	1.000	614.45	39.26	0.00	7.99
	Service void (timber battens)	1,607.80	321.56	0.050	16.08	337.64	50	0.0001065	8.56	30	2	337.64	Recycled	0.800	0.200	321.56	3.42	6.75	691.35
	Internal plasterboard lining	4,571.84	1,783.02	0.290	517.08	2,300.10	300	0.0001065	146.07	30	2	2,300.10	Recycled	0.938	0.062	283.45	18.11	46.00	0.00
Internal Wall																			
	Internal plasterboard lining	1,810.80	706.21	0.290	204.80	911.01	300	0.0001065	57.86	30	2	911.01	Recycled	0.938	0.062	112.27	7.17	18.22	0.00
	Steel stud frame	142.24	217.63	0.010	2.18	219.81	300	0.0001065	4.54	60+	0	0.00	Recycled	0.960	0.040	5.69	0.36	4.40	0.00
	Mineral wool acoustic insulation	543.24	695.35	0.060	41.72	737.07	300	0.0001065	17.36	30	2	737.07	Landfill	0.000	1.000	543.24	34.71	0.00	1,167.97
	Internal plasterboard lining	1,810.80	706.21	0.290	204.80	911.01	300	0.0001065	57.86	30	2	911.01	Recycled	0.938	0.062	112.27	7.17	18.22	0.00
Floor / Ceiling																			
Floor	Ceramic floor tiles	15,372.88	11,990.84	0.040	479.63	12,470.47	1500	0.0001065	2,455.82	30	2	12,470.47	Recycled	0.938	0.062	953.12	304.52	249.41	0.00
	Tile adhesive bed	6,349.67	1,403.28	0.030	42.10	1,445.38	300	0.0001065	202.87	30	2	1,445.38	Landfill	0.000	1.000	6,349.67	405.74	0.00	82.55
	Cementitious levelling screed	66,838.60	12,164.63	0.053	644.73	12,809.36	50	0.00007524	251.45	30	2	12,809.36	Recycled	0.938	0.062	4,143.99	31.18	256.19	0.00
	Reinforced concrete topping (composite slab)	208,536.43	41,290.21	0.053	2,188.38	43,478.59	50	0.00007524	784.51	60+	0	0.00	Recycled	0.938	0.062	12,929.26	97.28	869.57	0.00
	Profiled metal deck (steel decking)	4,651.05	7,162.61	0.010	71.63	7,234.24	300	0.0001065	148.60	60+	0	0.00	Recycled	0.960	0.040	186.04	11.89	144.68	0.00
Ceiling	Acoustic insulation	1,719.97	2,201.56	0.060	132.09	2,333.65	300	0.0001065	54.95	20	3	4,667.31	Landfill	0.000	1.000	1,719.97	109.91	0.00	22.36
	Resilient bars / decoupling layer	576.68	882.32	0.030	26.47	908.79	300	0.0001065	18.42	20	3	1,817.58	Recycled	0.950	0.050	28.83	1.84	18.18	0.00
	Ceiling lining (plasterboard)	2,866.62	1,117.98	0.290	324.21	1,442.19	300	0.0001065	91.59	20	3	2,884.39	Recycled	0.938	0.062	177.73	11.36	28.84	0.00
Roof																			
	Green roof vegetation	2,282.26	0.00	0.000	0.00	0.00	50	0.00007524	8.59	0	0	0.00	Stay / reused on site	0.938	0.062	141.50	1.06	0.00	0.00
	Growing medium	10,696.86	256.72	0.030	7.70	264.42	50	0.00007524	40.24	30	2	264.42	Stay / reused on site	0.938	0.062	663.21	4.99	5.29	0.00
	Filter fleece	564.56	1,936.43	0.030	58.09	1,994.52	300	0.0001065	18.04	30	2	1,994.52	Landfill	0.000	1.000	564.56	36.08	0.00	7.34
	Drainage layer	2,822.78	9,004.68	0.030	270.14	9,274.82	300	0.0001065	90.19	30	2	9,274.82	Landfill	0.000	1.000	2,822.78	180.38	0.00	36.70
	Root-resistant waterproof membrane	713.12	2,274.87	0.030	68.25	2,343.12	300	0.0001065	22.78	30	2	2,343.12	Landfill	0.000	1.000	713.12	45.57	0.00	9.27
	Rigid insulation	1,761.78	7,505.19	0.060	450.31	7,955.50	300	0.0001065	56.29	30	2	7,955.50	Landfill	0.000	1.000	1,761.78	112.58	0.00	22.90
	Vapour control	348.69	906.58	0.030	27.20	933.78	300	0.0001065	11.14	30	2	933.78	Landfill	0.000	1.000	348.69	22.28	0.00	4.53
	Steel roof deck	2,881.25	4,437.12	0.010	44.37	4,481.49	300	0.0001065	92.06	60+	0	0.00	Recycled	0.960	0.040	115.25	7.36	89.63	0.00
	Internal ceiling lining	3,303.72	1,288.45	0.290	373.65	1,662.10	300	0.0001065	105.55	20	3	3,324.20	Recycled	0.938	0.062	204.83	13.09	33.24	0.00
Fixtures																			
Windows	Aluminium frame	3,171.15	28,794.04	0.010	287.94	29,081.98	1500	0.0001065	506.59	30	2	29,081.98	Recycled	0.960	0.040	126.85	40.53	581.64	0.00
	Double glazing	19,966.50	18,169.52	0.053	962.98	19,132.50	300	0.0001065	637.93	35	2	19,132.50	Recycled	0.938	0.062	1,237.92	79.10	382.65	0.00
External Doors	Aluminium handle	0.40	3.66	0.010	0.04	3.70	1500	0.0001065	0.06	30	2	3.70	Recycled	0.960	0.040	0.02	0.01	0.07	0.00
	Polyurethane coating	3.01	9.03	0.030	0.27	9.30	300	0.0001065	0.10	10	6	46.50	Landfill	0.000	1.000	3.01	0.19	0.00	0.04
	Solid timber door	3,009.60	722.30	0.050	36.12	758.42	50	0.0001065	16.03	30	2	758.42	Recycled	0.800	0.200	601.92	6.41	15.17	1,294.13
Internal Doors	Aluminium handle	0.65	5.94	0.010	0.06	6.00	1500	0.0001065	0.10	30	2	6.00	Recycled	0.960	0.040	0.03	0.01	0.12	0.00
	Solid timber door	332.64	79.83	0.050	3.99	83.82	50	0.0001065	1.77	30	2	83.82	Recycled	0.800	0.200	66.53	0.71	1.68	143.04
Miscellaneous																			
Stairs	Concrete fill	14,083.20	1,506.90	0.053	79.87	1,586.77	50	0.00007524	52.98	60+	0	0.00	Recycled	0.938	0.062	873.16	6.57	31.74	0.00
	Ceramic floor tiles	241.04	188.01	0.040	7.52	195.53	1500	0.0001065	38.51	30	2	195.53	Recycled	0.938	0.062	14.94	4.77	3.91	0.00
	Tile adhesive bed	99.56	22.00	0.030	0.66	22.66	300	0.0001065	3.18	30	2	22.66	Landfill	0.000	1.000	99.56	6.36	0.00	1.29
Outdoor Shower	Ceramic floor tiles	287.52	224.27	0.040	8.97	233.24	1500	0.0001065	45.93	30	2	233.24	Recycled	0.938	0.062	17.83	5.70	4.66	0.00
	Tile adhesive bed	89.78	19.84	0.030	0.60	20.44	300	0.0001065	2.87	30	2	20.44	Landfill	0.000	1.000	89.78	5.74	0.00	1.17
Planters	Green roof vegetation	2,131.20	0.00	0.000	0.00	0.00	50	0.00007524	8.02	60+	0	0.00	Stay / reused on site	0.938	0.062	132.13	0.99	0.00	0.00
	Growing medium	9,990.00	239.76	0.000	0.00	239.76	50	0.00007524	37.58	30	2	239.76	Stay / reused on site	0.938	0.062	619.38	4.66	4.80	0.00
	Filter fleece	527.25	1,808.47	0.030	54.25	1,862.72	300	0.0001065	16.85	30	2	1,862.72	Landfill	0.000	1.000	527.25	33.69	0.00	6.85
	Drainage layer	2,636.25	8,409.64	0.030	252.29	8,661.93	300	0.0001065	84.23	30	2	8,661.93	Landfill	0.000	1.000	2,636.25	168.46	0.00	34.27
	Root-resistant waterproof membrane	666.00	2,124.54	0.030	63.74	2,188.28	300	0.0001065	21.28	30	2	2,188.28	Landfill	0.000	1.000	666.00	42.56	0.00	8.66
	Concrete shell	36,000.00	3,852.00	0.053	204.16	4,056.16	50	0.00007524	135.43	60+	0	0.00	Recycled	0.938	0.062	2,232.00	16.79	81.12	0.00
Garden Bridge	Oak	291.31	69.91	0.050	3.50	73.41	50	0.0001065	1.55	30	2	73.41	Recycled	0.800	0.200	58.26	0.62	1.47	125.26
Garden Path	Stone slabs	35,431.11	2,799.06	0.111	310.70	3,109.76	1500	0.0001065	5,660.12	30	2	3,109.76	Recycled	0.938	0.062	2,196.73	701.85	62.20	0.00
Stream Channel	Aluminium finish	776.34	7,111.24	0.010	71.11	7,182.35	1500	0.0001065	124.02	30	2	7,182.35	Recycled	0.960	0.040	31.05	9.92	143.65	0.00
	Concrete shell	6,900.77	738.38	0.053	39.13	777.51	50	0.0001065	36.75	60+	0	0.00	Recycled	0.938	0.062	427.85	4.56	15.55	0.00
Totals		**715,399.07**	**247,056.76**		**11,536.10**	**258,592.86**			**14,391.34**			**180,431.59**				**77,739.64**	**3,853.79**	**3,884.41**	**12,094.02**

Figure 3.6. Whole life carbon calculation spreadsheet

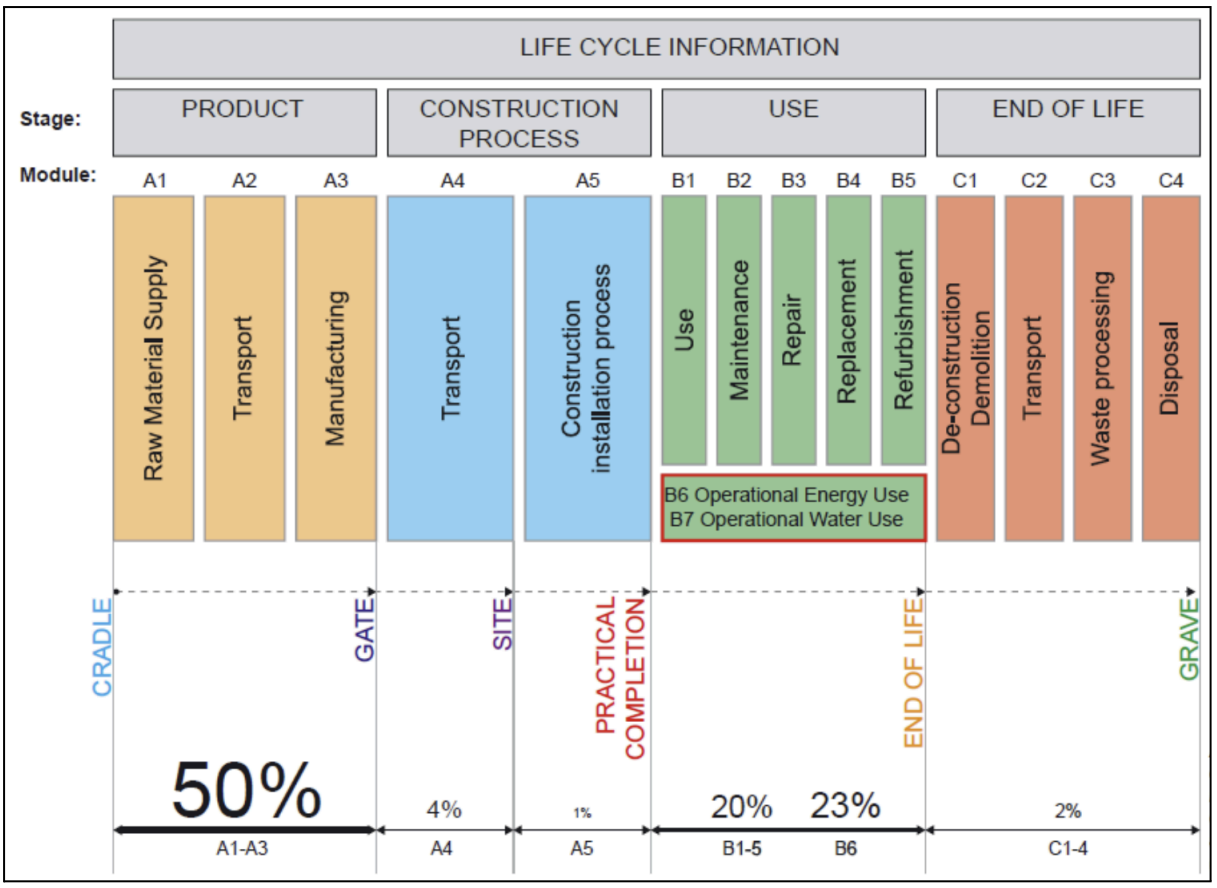


Figure 3.7. Whole life carbon calculation structure

Stage	Description	Formula	Calculations	Result (kgCO2e)
A1-A3	Product stage including waste	EC_total + Waste factor	247,056.76 + waste allowance - see figure 3.6	258,592.86
A4	Transport to site	Material mass x Transport distance x Carbon conversion factor	See figure 3.6	14,391.34
A5	Construction process	1400kgCO2e / £100k of construction cost	Construction cost = £2,340/m2 x GIA GIA = 612.8m2 2,340 x 612.8 = £1,433,952 1,433,952 / 100,000 = 14.34 14.34 x 1,400	20,076.00
B1-B3+B5	No major refurbishment anticipated, only minor furniture updates	5% of embodied carbon (258,592.86)	0.05 x 258,592.86	12,929.64
B4	Replacements	Embodied carbon of material x (Churn rate - 1)	See figure 3.6	180,431.59

B6	Electricity - Lighting	(Demand / COP) × EF × RSP	Lighting COP = 1 13,105 / 1 = 13,105 kWh/yr Lighting energy consumption = 13,105 kWh/yr Electricity carbon emission factor = 0.233 kgCO2e/kWh 13,105 × 0.233 × 60 = 183,195.90 kgCO2e	183,195.90
	Gas - Boiler heating	(Demand / COP) × EF × RSP	Gas boiler + radiator COP = 0.9 19,829 / 0.9 = 22,032.22 kWh/yr Gas energy consumption = 22,032.22 kWh/yr Gas carbon emission factor = 0.203 kgCO2e/kWh 22,032.22 × 0.203 × 60 = 268,321.48 kgCO2e	268,321.48
	Total operational carbon	Electricity + Gas	183,195.90 + 268,321.48	451,517.38
B7	Operational water	Total daily water demand x Operational days x Water supply carbon coefficient x RSP	Daily water demand = 120 l/person x 4 people = 480l Operational days = 365 Water supply carbon coefficient = 0.000344 kgCO2e/liter RSP = 60 480 x 365 x 0.000344 x 60	3,616.13
C1	Deconstruction	3.4 x GIA	GIA = 612.8m2 3.4 x 612.8	2,083.52
C2	Waste transport	Mass of waste to be transported x Transport carbon factor x Distance to disposal site	See figure 3.6	3,853.79
C3	Recycling	2% of embodied carbon of recycled materials	See figure 3.6	3,884.41
C4	Disposal	Non-organic materials = 0.013 per kgCO2e/kg waste Organic materials = 2.15 per kgCO2e/kg waste	See figure 3.6	12,094.02

Figure 3.8. Whole life carbon calculation table

Stage	Module	Carbon Emissions (kgCO2e)
Product	A1 to A3 - Product	258,592.86
	A4 - Transport	14,391.34
	A5 - Construction Installation Process	20,076
Use	B1 to B3 + B5 - Use, Maintenance, Repair and Refurbishment	12,929.64
	B4 - Replacement	180,431.59
	B6 - Operational Energy Use	451,517.38
	B7 - Operational Water Use	3,616.13
End of Life	C1 - Deconstruction + Demolition	2,083.52
	C2 - Transport	3,853.79
	C3 - Waste Processing	3,884.41
	C4 - Disposal	12,094.02
	Total	**963,470.68**

Figure 3.9. Whole life cycle carbon total

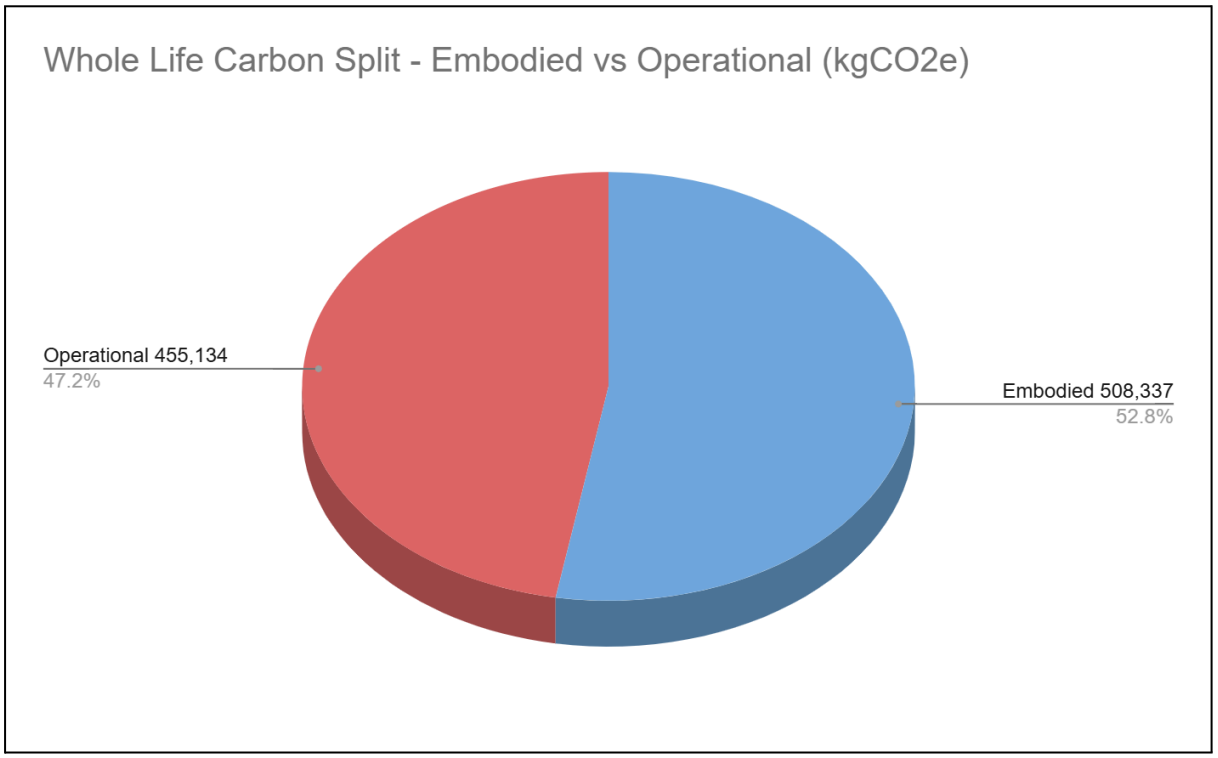


Figure 3.10. Distribution of whole life carbon

Total whole-life carbon is 963,471 kgCO2e, or 1,572 kgCO2e/m2 over 60 years. Embodied carbon accounts for 53% and operational 47%, indicating a relatively balanced profile compared to typical UK housing where operational impacts dominate. The largest contributors are A1-A3 and B4, confirming structural concrete, facade systems and replacement cycles as key hotspots. B6 reflects moderate energy demand but remains significant, while end-of-life stages contribute less than 3%.

3.4 Environmental Impact Evaluation and Redesign

		Dimensions							Environmental Data	
Structure		Length	Width	Surface Area	Thickness	Volume	Density	Mass	Carbon Coefficient	Embodied Carbon
Type	Materials	(m)		(m2)	(m)	(m3)	(kg/m3)	(kg)	(kgCO2e/kg)	(kgCO2e)
Foundation										
	CLT floor panel	16.00	13.70	219.20	0.1600	35.07	500	17,536.00	0.110	1,928.96
	DPM / airtight membrane	16.00	13.70	219.20	0.0003	0.07	950	62.47	1.900	118.70
	Wood-fibre compressive insulation	16.00	13.70	219.20	0.1500	32.88	160	5,260.80	0.130	683.90
	GGBS low-carbon concrete slab	16.00	13.70	219.20	0.1500	32.88	2,400	78,912.00	0.107	8,443.58
	Recycled MOT Type 1 sub-base	16.00	13.70	219.20	0.1500	32.88	2,000	65,760.00	0.005	328.80
External Wall										
	Clay plaster finish	55.14	11.73	646.79	0.0200	12.94	1,700	21,990.93	0.220	4,838.01
	Ventilated cavity (battens)	8.42	12.73	107.19	0.0500	5.36	500	2,679.67	0.110	294.76
	Wood-fibre sheathing board	55.14	11.73	646.79	0.0120	7.76	160	1,241.84	0.130	161.44
	Breather membrane	55.14	11.73	646.79	0.0010	0.65	950	614.45	1.900	1,167.46
	CLT wall panel (primary structure)	55.14	11.73	646.79	0.1400	90.55	500	45,275.45	0.110	4,980.30
	Service void (timber battens)	8.42	12.73	107.19	0.0250	2.68	500	1,339.83	0.110	147.38
	Internal clay plaster finish	44.91	10.18	457.18	0.0150	6.86	1,700	11,658.19	0.220	2,564.80
Internal Wall										
	Clay plaster finish	60.36	3.00	181.08	0.0150	2.72	1,700	4,617.54	0.220	1,015.86
	Timber stud frame	6.04	3.00	18.12	0.0010	0.02	500	9.06	0.110	1.00
	Wood-fibre acoustic insulation	60.36	3.00	181.08	0.0500	9.05	160	1,448.64	0.130	188.32
	Clay plaster finish	60.36	3.00	181.08	0.0150	2.72	1,700	4,617.54	0.220	1,015.86
Floor / Ceiling										
Floor	Low-carbon finish layer - reclaimed timber	37.34	17.90	668.39	0.0100	6.68	500	3,341.93	0.110	367.61
	Dry levelling layer (dry screed boards)	37.34	17.90	668.39	0.0500	33.42	800	26,735.44	0.240	6,416.51
	CLT floor panel (primary structure)	37.34	17.90	668.39	0.1600	106.94	500	53,470.88	0.110	5,881.80
Ceiling	Acoustic insulation wood fibre	17.95	15.97	286.66	0.1000	28.67	160	4,586.58	0.130	596.26
	Resilient bars / decoupling	0.23	15.97	3.67	0.0200	0.07	7,850	576.68	1.400	807.35
	Ceiling lining clay plaster	17.95	15.97	286.66	0.0125	3.58	1,700	6,091.56	0.220	1,340.14
Roof										
	Green roof vegetation	17.61	5.40	95.09	0.0800	7.61	300	2,282.26	0.000	0.00
	Growing medium	22.01	5.40	118.85	0.1000	11.89	900	10,696.86	0.024	256.72
	Filter fleece	22.01	5.40	118.85	0.0050	0.59	950	564.56	3.190	1,800.94
	Drainage layer	22.01	5.40	118.85	0.0250	2.97	950	2,822.78	3.190	9,004.68
	Root-resistant waterproof membrane	22.01	5.40	118.85	0.0050	0.59	1,200	713.12	3.190	2,274.87
	Wood-fibre insulation	19.42	18.90	367.04	0.1500	55.06	160	8,808.91	0.130	1,145.16

	Vapour control / airtight membrane	19.42	18.90	367.04	0.0010	0.37	950	348.69	1.900	662.50
	CLT roof panel	19.42	18.90	367.04	0.1400	51.39	500	25,692.66	0.110	2,826.19
	Internal ceiling lining	17.48	18.90	330.37	0.0125	4.13	800	3,303.72	0.240	792.89
Fixtures										
Windows	Timber frame	43.50	0.90	39.15	0.0300	1.17	500	587.25	0.110	64.60
	Glazing	43.50	7.65	332.78	0.0240	7.99	2,500	19,966.50	0.850	16,971.53
External Doors	Stainless steel handle	2.96	0.05	0.15	0.0010	0.00	8,000	1.18	6.150	7.28
	Natural oil finish	7.60	3.30	25.08	0.0010	0.03	900	22.57	2.500	56.43
	Solid timber door	7.60	3.30	25.08	0.2000	5.02	500	2,508.00	0.110	275.88
Internal Doors	Stainless steel handle	4.80	0.05	0.24	0.0010	0.00	8,000	1.92	6.150	11.81
	Solid timber door	7.20	2.20	15.84	0.0350	0.55	500	277.20	0.110	30.49
Miscellaneous										
Stairs	Glulam stair structure	18.36	1.20	19.56	0.1600	3.13	500	1,564.80	0.110	172.13
	Ceramic tiles	8.58	1.90	10.48	0.0100	0.10	2,300	241.04	0.780	188.01
	Adhesive bed	8.58	1.90	10.48	0.0050	0.05	1,900	99.56	0.221	22.00
Outdoor Shower	Ceramic tiles	4.63	2.70	12.50	0.0100	0.13	2,300	287.52	0.780	224.27
	Adhesive bed	3.50	2.70	9.45	0.0050	0.05	1,900	89.78	0.221	19.84
Planters	Green roof vegetation	14.80	6.00	88.80	0.0800	7.10	300	2,131.20	0.000	0.00
	Growing medium	18.50	6.00	111.00	0.1000	11.10	900	9,990.00	0.024	239.76
	Filter fleece	18.50	6.00	111.00	0.0050	0.56	950	527.25	3.190	1,681.93
	Drainage layer	18.50	6.00	111.00	0.0250	2.78	950	2,636.25	3.190	8,409.64
	Root-resistant waterproof membrane	18.50	6.00	111.00	0.0050	0.56	1,200	666.00	3.190	2,124.54
	GGBS low-carbon concrete shell	20.00	7.50	150.00	0.1000	15.00	2,400	36,000.00	0.107	3,852.00
Garden Bridge	Oak	4.47	1.33	5.95	0.0700	0.42	710	295.47	0.110	32.50
Garden Path	Stone slabs	27.53	3.30	90.85	0.1500	13.63	2,600	35,431.11	0.080	2,834.49
Stream Channel	Low-carbon concrete finish	79.87	1.80	143.77	0.0200	2.88	2,400	6,900.77	0.107	738.38
	GGBS low-carbon concrete shell	79.87	1.80	143.77	0.0200	2.88	2,400	6,900.77	0.107	738.38
Totals								**540,187.18**		**100,748.63**

Figure 3.11. Refined design for reduced embodied carbon

	Mass (kg)			Embodied Carbon (kgCO2e)		
	Initial	**Refined**	**Decrease**	**Initial**	**Refined**	**Decrease**
Foundation	189,626.63	167,531.27	11.65%	25,890.13	11,503.94	55.57%
External Wall	52,543.16	84,800.37	-61.39%	36,119.41	14,154.15	60.81%
Internal Wall	4,307.08	10,692.78	-148.26%	2,325.40	2,221.04	4.49%
Floor / Ceiling	306,911.88	94,803.07	69.11%	78,213.43	15,409.66	80.30%
Roof	25,375.02	55,233.56	-117.67%	27,610.05	18,763.95	32.04%
Fixtures	26,483.95	23,364.63	11.78%	47,784.32	17,418.01	63.55%
Miscellaneous	110,151.32	103,761.52	5.80%	29,114.03	21,277.87	26.92%

Figure 3.12. Comparison of refined and initial design

Figure 3.11 displays how the steel frame and composite slab are replaced with CLT wall, floor and roof panels. Concrete is reduced through GGBS mixes, and the aluminium stream channel is substituted with low-carbon concrete. Figure 3.12 indicates the resulting major embodied carbon reductions: foundation -55.57%, external wall -60.81%, and floor / ceiling -80.30%. Although some

elements increase in mass, carbon falls, confirming that intensity, not weight, drives impact. Fundamental structural substitution delivers far greater savings than minor material changes.

	Energy Demand (kWh/yr)		Coefficient of Performance COP		Energy Consumption (kWh/yr)		Carbon Coefficient (kgCO2e/kWh)		Operational Carbon (kgCO2e/yr)		
Energy Segment	Initial	Refined	Initial	Refined	Initial	Refined	Initial	Refined	Initial	Refined	Reduction
Heating	19,829	10,928	0.90	3.50	22,032	3,122	0.203	0.233	268,352	43,650	224,703
Cooling	6,883	269	2.50	4.00	2,753	67	0.233	0.233	38,490	940	37,550
Lighting	13,105	2,097	1.00	1.00	13,105	2,097	0.233	0.233	183,208	29,316	153,892
Equipment	6,552	2,752	1.00	1.00	6,552	2,752	0.233	0.233	91,597	38,473	53,124
Fans	4,529	1,573	1.00	1.00	4,529	1,573	0.233	0.233	63,315	21,991	41,325
Pumps	2,939	314	1.00	3.75	2,939	84	0.233	0.233	41,087	1,171	39,917
Total	**53,837**	**17,933**	**N/A**	**N/A**	**51,910**	**9,695**	**N/A**	**N/A**	**686,050**	**135,540**	**550,510**

Figure 3.13. Comparison of operational carbon of initial and refined designs

Operational carbon (B6) was derived from the annual energy demand in Figure 2.13, reducing from 53,837 to 17,933 kWh/yr. The primary saving occurs in heating: replacing the gas boiler (COP 0.9) with a heat pump (COP 3.5) cuts emissions from 268,352 to 43,650 kgCO2e. Cooling drops from 38,490 to 940 kgCO2e through shading and shutters, while fabric improvements reduce heating demand from 19,829 to 10,928 kWh/yr.

3.5 Summary and Reflection

This chapter reviewed the initial design using embodied carbon calculations and a whole-life life cycle assessment (LCA). This process led to a final design with a new structure and layout. The initial plan measured 247 tCO2e (403 kgCO2e/m2) and totaled 963 tCO2e over 60 years. The embodied carbon was slightly higher at 53% compared to operational carbon at 47%. The main impacts were from the structure; the composite slab and screed accounted for 31.7% of embodied carbon, aluminium glazing made up 19.3%, and replacement cycles totaled 180,432 kgCO2e. This confirmed that high carbon structural systems and fossil fuel heating were the main weaknesses, not architectural finishes.

The final design made specific structural changes, replacing steel framing and composite slabs with CLT and GGBS concrete. This reduced embodied carbon in major systems by 55-80%. For operations, the heating switched from gas, which had a coefficient of performance (COP) of 0.9, to a heat pump with a COP of 3.5. This change eliminated gas and reduced operational carbon by 80%, lowering it from 686,050 to 135,540 kgCO2e when combined with fabric-first measures. While this reflects a Sefaira scenario consisting of perfect conditions, it indicates a credible maximum for decarbonization potential.

The analysis of embodied carbon and life-cycle assessment were essential for identifying weaknesses and understanding life-cycle impacts. They confirmed that structural materials, operational energy, and replacement cycles are the main contributors, while end-of-life stages make up less than 3%. These tools helped the project implement targeted improvements. The addition of photovoltaics and a stream turbine support achieving net-zero operational carbon and possible grid export.

4. Holistic Technical Assessment

The initial design proposes a dwelling located on a sloped rural UK site intersected by an active stream, which continues through the building as a central biophilic experiential feature. Architecturally, the project is defined by a large, highly glazed entrance volume, a large cantilever and a suspended master bedroom. The concept prioritises openness, visual permeability and integration with the surrounding natural landscape and ecosystem. While spatially ambitious and contextually responsive, the initial design relied on heavy steel and concrete construction, extensive glazing, and fossil-fuel heating, creating tensions between architectural intent and technical performance within the UK's heating dominated climate.

From a constructive perspective, the initial steel and composite slab system imposed high dead loads on the sloped terrain and concentrated load paths at the cantilever and western column, increasing structural intensity and embodied carbon. Additionally, moisture exposure from the stream and green roof introduced durability risks, particularly at ground level.

Sefaira modelling was used for environmental assessments. It showed an energy use intensity of 97 kWh/m2/yr, with the entrance volume as the main thermal weakness. Despite good cross and stack ventilation, large south-facing windows and a 7.4 m high void increased winter heat loss and summer solar gains. In terms of materials, embodied carbon reached 247 tCO2e (403 kgCO2e/m2), with 53% of the total carbon linked to embodied impacts. Major carbon sources included the composite slab, aluminium glazing systems, and replacement cycles. These findings indicated that the initial design created an environmental burden due to its structural and material choices.

The steel and concrete approach improved structural stability and moisture resistance but greatly reduced environmental performance because of high embodied carbon and thermal bridging. Similarly, the large amounts of glazing improved daylight and views with a biophilic intent but significantly raised operational energy needs and lifecycle carbon. This was counterproductive to the biophilic goal. In the UK climate, the balance between structural expression and energy efficiency became evident. The large volumes and exposed glazing hurt winter performance, while lightweight timber systems improved carbon results but made the building more sensitive to moisture issues. The initial design showed good integration with the site and landscape but lacked optimisation among construction, environmental, and material systems.

The final design resolves these issues through precise adjustments rather than conceptual compromises. Steel framing and composite slabs were replaced with prefabricated CLT and glulam. This cut embodied carbon in major systems by up to 80% while decreasing ground loads on the sloped site. GGBS concrete was kept only where structurally required. Fabric-first improvements, reducing glazing, refining airtightness, and adding a semi-enclosed lobby moderated the entrance volume without losing spatial identity. Operational systems were electrified using a heat pump, completely removing gas and cutting operational carbon by about 80% under modeled conditions. On-site photovoltaics and a hydro turbine could make use of the stream's flow to offset leftover demand, creating a path toward net-zero operational carbon.

These changes maintain the biophilic narrative and site integration while uniting structure, materials, and environmental strategy into a low carbon system. As a result, the final design strengthens relationships through a refined structure, passive moderation, electrification, and on-site energy production. It also reduces previous negative impacts, achieving a technically optimised and environmentally improved biophilic architectural outcome.

