The Third Space

EMBODIED ENVIRONMENTAL IMPACT

Contents

This project takes place on the unceded traditional territories of the x�m��k��y��m (Musqueam), S�wx�wú7mesh (Squamish), and s�lilw�ta� (Tsleil-Waututh) Nations.

Embodied Environmental Impact

From its conception Third Quadrant Design (TQD), has been focused on low carbon and regenerative design. For the Third Space Commons project, we took a new approach to low carbon compared to a net-zero Passive House. Given that the project was only granted a 10-year permit, and that British Columbia already has a 97% renewable energy grid, we knew that a zero-carbon building could only be achieved by aiming to keep embodied carbon low instead of prioritizing low operational carbon and counting on carbon offsetting from on-site energy generation over a typical 60-year building life.

Therefore, we implemented several design and collaboration strategies in our process to achieve a low carbon build, which will be described and supported with examples below.

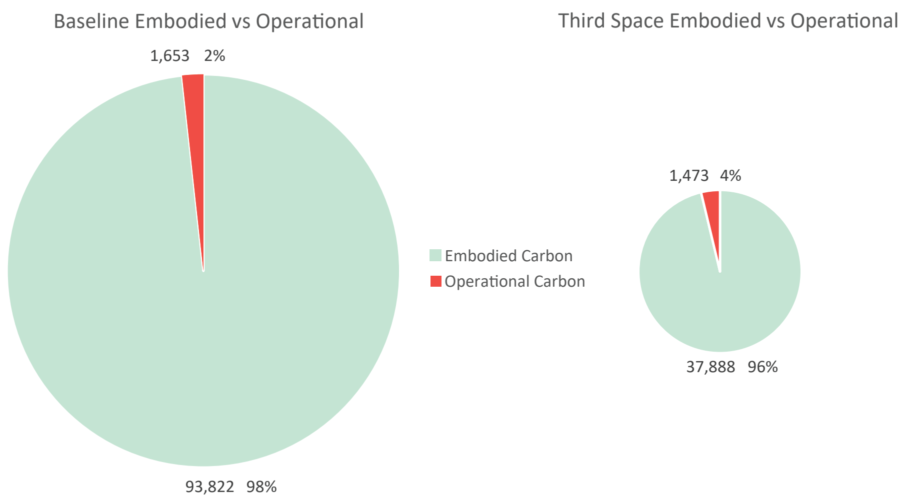

Figure 1- Baseline vs. Third Space

CARBON MINIMIZATION DESIGN STRATEGIES

At project conception, TQD selected four carbon minimization strategies which would influence building system, material, and sourcing decisions. All sub-teams were aware of these strategies, so these were implemented at all levels of the team from the very beginning. See the Innovation section for the quantified impacts of the design strategies.

These are the four strategies, which are expanded in the next two pages:

1. Adaptive reuse
2. Low-carbon alternatives to conventional materials
3. Local Sourcing
4. Carbon Sequestration

Embodied Environmental Impact

Adaptive Reuse

The easiest way to minimize embodied carbon is to design with materials that have no carbon! The team has focused on adaptively reusing materials from buildings slated for demolition on campus, project sites across the lower mainland, and 'faulty' products that would have otherwise been sent to the landfill. This includes reused appliances, triple-paned high-performance windows, single-pane windows, a transformer, and an entire photo-voltaic (PV) system.

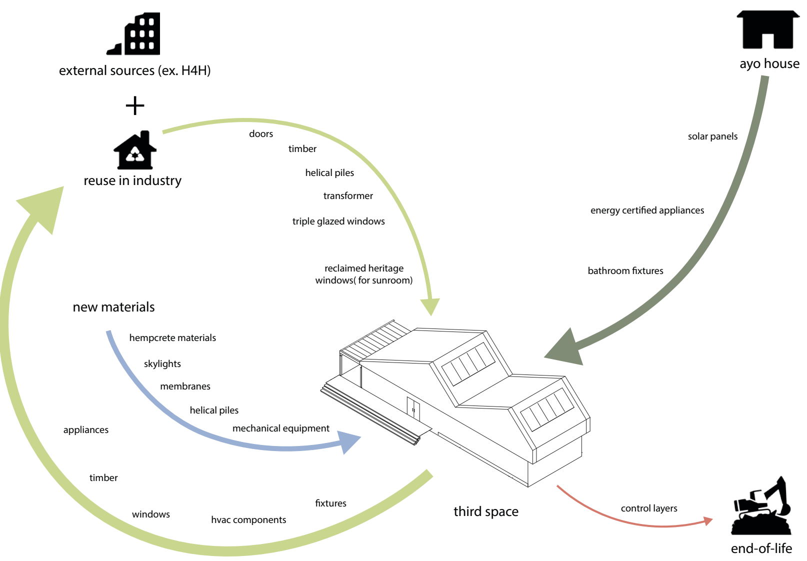

Figure 2- Lifecycle demonstrating adaptive reuse

Low-carbon alternatives to conventional materials

During design ideation, we brainstormed a variety of conventional and innovative materials that could be present in our project, and we began to eliminate and find alternatives to the higher-carbon options, such as concrete, steel, and foam insulations. Once we had generated different design options, we undertook a high-level LCA to be able to roughly compare systems and choose the lowest carbon options. This led to our selection of helical piles over concrete strip footings for the foundation, cellulose over XPS or EPS for the floor and roof, and hempcrete over rockwool for the walls.

Local Sourcing

By collaborating with local retailers and manufacturers, we are promoting low carbon building alternatives in our local construction ecosystem, which is important to enable future projects to have low carbon design options. Local sourcing is also a strategy that enabled our adaptive reuse strategy, since we leveraged our local industry for reuse opportunities.

Given the project's emphasis on reused and reclaimed materials, we have had to clearly define the scope of our LCA and make appropriate omissions and substitutions where necessary. The final LCA will follow a full cradle to grave methodology and include calculations both with and without Module D.

Embodied Environmental Impact

Carbon Sequestration

Hempcrete has been used as insulation in the wall of the Third Space building, and it has been chosen over other insulative materials for its sequestration potential.

Hempcrete is a mixture of hemp hurd, also called shiv, which is the wood core of the hemp plant, and hydrated lime, scientifically called calcium hydroxide. Both composites have carbon dioxide sequestration potential, the first through photosynthesis, and the second through carbonation [1]. See Appendix A for details on how carbon sequestration was calculated for this material. There was also plans to have active sequestration on site from landscaping, but ultimately the landscape design was taken out of the scope for current team and competition, and will be designed at building handover, so it was not included in LCA calculations.

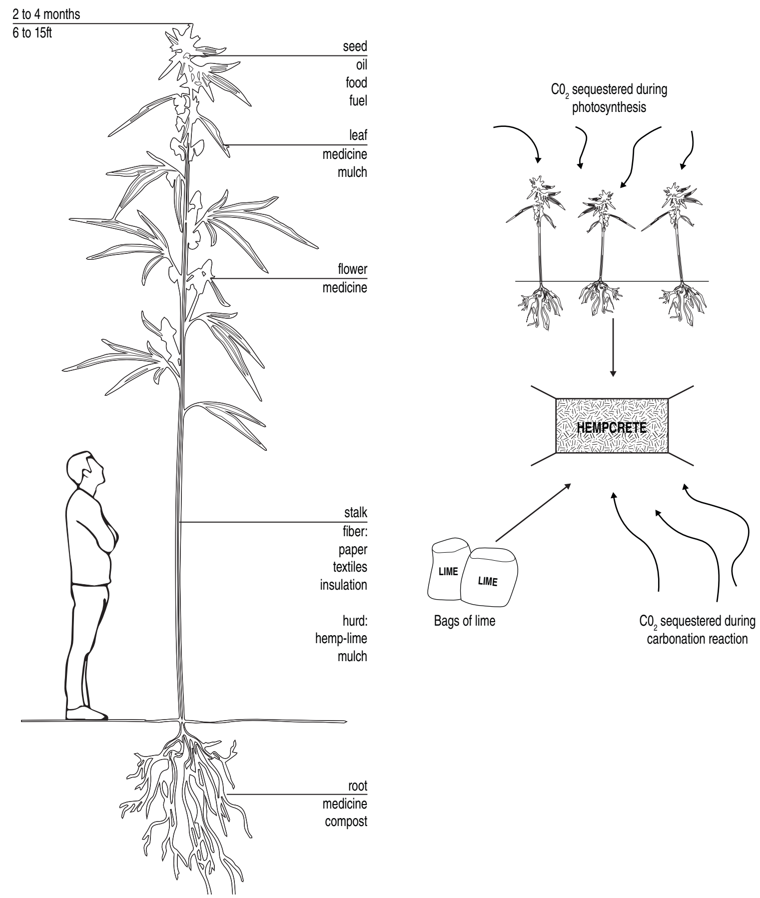

Figure 3- Hemp Carbon Sequestration Process

COLLABORATIVE DESIGN STRATEGIES

An integrated design environment was one of the biggest enablers for this low-carbon design. The complications introduced by the innovative strategies listed above required every member of our team to work together at every step of design and construction to continue to prioritize our low carbon goal.

Iterative Energy and Carbon Modelling

The team implemented an iterative energy and carbon modelling process that was integrated into the weekly design cycle. After design decisions were proposed during the weekly team meeting, the energy modelers and carbon modelers would update their respective models and report back to the team at the following meeting. In this way, the impacts of design decisions were being assessed from both an embodied and operational carbon perspective. This process influences every aspect of the building, including the form, structure, envelope, and mechanical system.

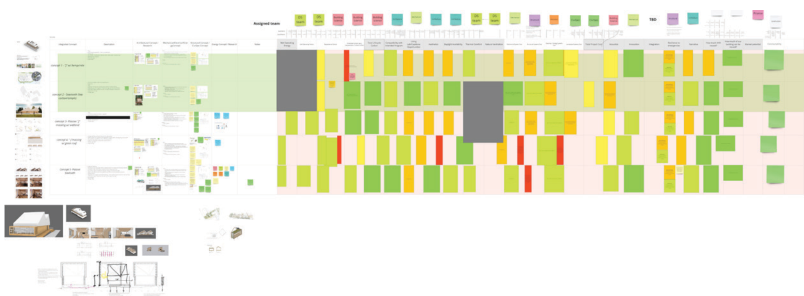

Figure 4- Weighted Decision Matrix for Iterative Design Process

A Unique Mechanical System

A significant outcome of the above iterative design process was the project's unique mechanical system. The team ultimately chose a low-carbon heating system, using direct electric resistance heating mats with very few materials and low CO_2e/kW. Lower total carbon (embodied+operational) relied on a 97% 'renewable' energy grid with low CO_2e/kWh. The team also designed for passive cooling in the summer to remove the need for additional cooling infrastructure, especially targeting the complex and carbon-intensive heat pump solution with highly processed equipment and risk of coolant leakage CO_2e emissions. Also, Third Space Commons' ventilation system has minimal ductwork while maintaining the efficiency (CO_2e/cfm) of a single centralized HRV. The HRV was manufactured locally in Burnaby.

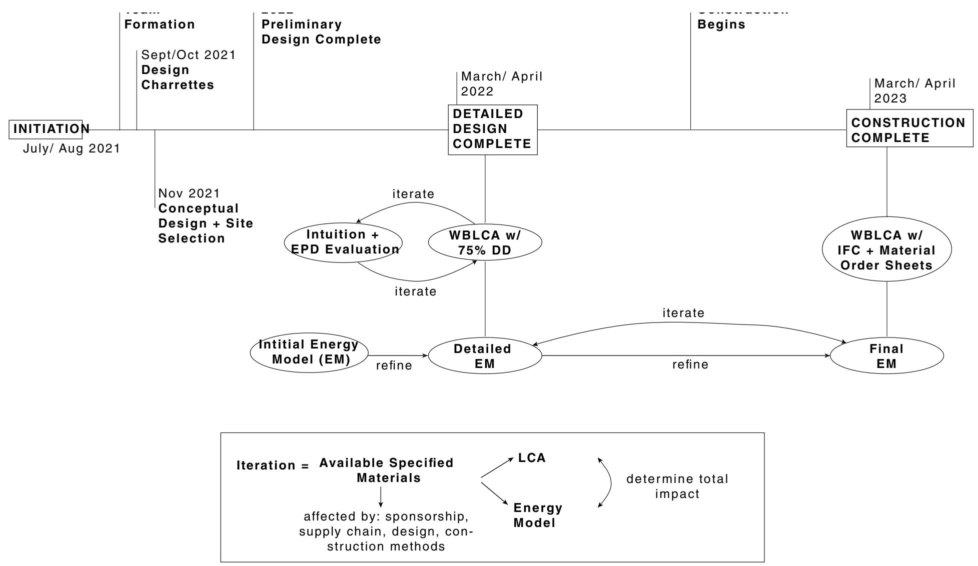

Figure 5- Iterative Design Process and Timeline

Life Cycle Assessment

The current industry standard for conducting an LCA is to include the structure and envelope systems of a building, excluding any external areas or building services. This is currently the material scope required by the City of Vancouver, as seen in their Green Buildings Policy for Rezoning – Process and Requirements document [2].

The table below reports the LCA results of Third Space Commons compared to a baseline developed by our team which is described later in this report. We have reported these numbers because we want our results to be comparable with typical industry benchmarks and with what other competing teams might report. However, the rest of the report will discuss a much more thorough analysis and will report results of a more detailed and complete LCA.

	BASELINE	THIRD SPACE	% REDUCTION
TOTAL CARBON ($kgCO_2eq$)	46,352	11,970	**74%**
TOTAL CARBON INTENSITY ($kgCO_2eq/m2$)	321	83	

Figure 6- Third Space and Baseline Comparison

LCA METHODOLOGY

Our approach to the Lifecycle Assessment (LCA) calculation on this project has been to capture all possible embodied carbon impacts from the project, to support our approach to achieving as low-carbon as possible.

Calculation Tool

We have used the One Click LCA tool to assess the impacts of the Third Space building. This tool was chosen because it is ISO and EN compliant, it has regionally specific data for British Columbia, and it allows the user to make very specific and detailed material and quantity selections. Because we have used some unconventional materials and design approaches, this user-specification was very important for the accuracy of our analysis.
Note that values for the embodied carbon and sequestered carbon of the hempcrete materials were not found in One Click LCA, but were taken from an article on hempcrete published by researchers at CU Boulder (1).

Lifecycle Inventory Analysis

We started by conducting a material inventory using the issued as-built drawings and referring to submittals and site instruction documentation to capture material changes made during construction. This LCA was completed once most of the materials and components had been procured or ordered, so we were able to use the appropriate material inputs in One Click LCA, choosing appropriate equivalents when the exact material used in our building did not have a corresponding EPD in the tool.

For example, One Click LCA does not have an EPD for PSL mass timber, but it does have an EPD for LVL, and since these materials are similar in extraction, manufacturing and sourcing, the LVL documentation was used as an equivalent.

Transportation distances for Phase A4 were calculated using actual distances from manufacturing locations to site when known and were left as the One Click defaults when unknown.
Impacts for phase A5 were assumed to be 10% of impacts from phases A1-A3.

LCA Scope

The building lifespan is assumed to be 10 years, in accordance with the length of the permit granted by UBC. This is a cradle to grave life cycle assessment. Table X shows the phases that have been included in our assessment. Below are several notes to clarify our approach:

- Where reused materials have been used in the design, their impact for phases A1-A3 has been considered as zero.
- Impacts from B1-B4 have been considered as zero, since most materials in the building have a longer lifespan than the building itself and are unlikely to be replaced or repaired.
- There is a renovation planned for the building after the competition is complete, but there are no existing plans or documentation of what this renovation will be, so the impact for phase B5 has been considered as zero.
- Module D has been excluded from the scope in terms of possible future reuse or recycling of materials, since we are unable to guarantee how the building demolition and disposal will go.

The complete material scope of Third Space Commons includes the following building systems:

- Foundation
- Structural
- Envelope
- Windows & doors
- Interior walls
- Exterior structures (deck, stairs, ramp)
- Building Services (including mechanical, civil, and PV systems)

A complete bill of materials is included in Appendix B.

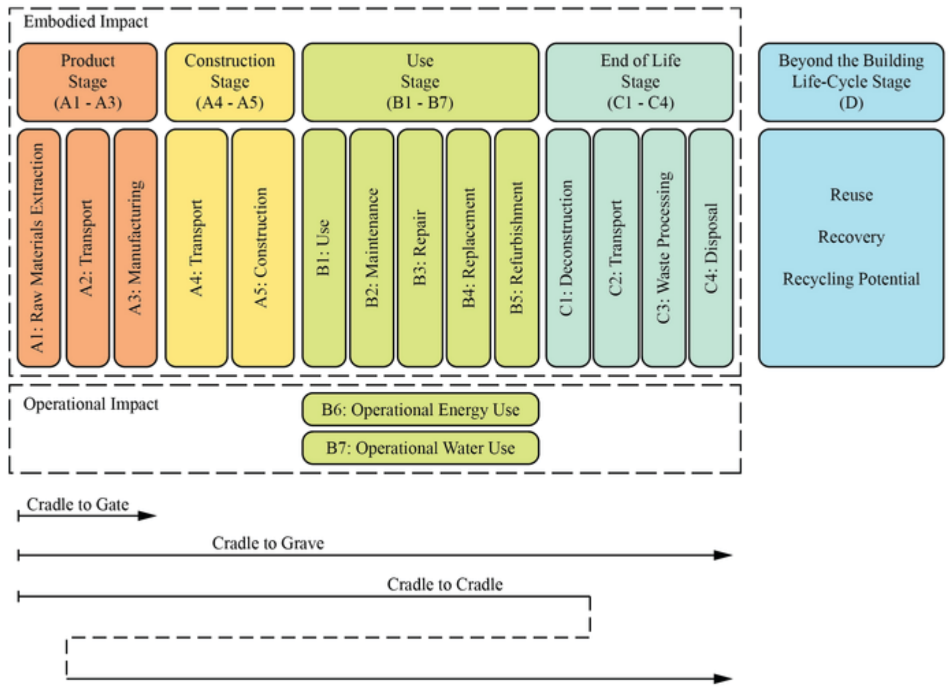

Figure 7- LCA Phases (Source: Universitat der Kunste Berlin)

Exclusions

The electrical system has been excluded from the scope because One Click LCA did not have suitable EPDs in its database to capture most of the electrical equipment. Historically, building services have not been included in typical LCA scopes which explains the lack of data for these materials.

The only calculation framework that we could find to try and capture this information is the CISBE TM65 tool, but we struggled to successfully use it because it requires electrical equipment manufacturers to supply detailed raw material inventories that tend to be proprietary.

Third Quadrant Design would like to see building development policy that requires building services to be included in LCA scopes which would cause this data to be readily available. As seen in our results from the mechanical system alone, building services can have high embodied carbon impacts, especially if the rest of the building systems are relatively low in embodied carbon. They should not be considered as less significant, and they should be targeted by building policy as much as other building systems are.

Operational Carbon Calculation

The embodied carbon from operation energy used was calculated within One Click LCA, with 11025 kWh/year as the input data. This energy use intensity was obtained using an energy model developed in ClimateStudio, a building performance analysis plug-in to Rhinoceros 3D. The model was developed by following City of Vancouver and UBC Energy Modelling Guidelines.
ClimateStudio was also used to determine the power generation from our PV system, and it is expected to generate about 6,000 kWh/yr. We converted this number to an embodied carbon value using One Click LCA.

Baseline Development

The baseline building used for comparison has the same form and interior area, but with conventional materials and no material reuse. The key material substitutions are:

- Concrete strip foundation instead of helical pile foundation
- Mineral wool insulation in walls instead of hempcrete
- Fiber cement siding instead of wood and metal siding
- XPS in roof and floor instead of blown-in cellulose
- Heating from heat pump and hydronic radiant heating instead of electric heating mats

We choose not to use a passive house as our baseline design. We simply calculated the quantities of the conventional insulation materials to achieve equivalent R-values as Third Space Commons.
It is worth noting that a hydronic radiant heating system was included in the baseline over other heat pump heating systems such as air-source systems. This is because the Third Space Commons design has an electric radiant heating system and we wanted to compare radiant heating systems for consistency. Radiant heating systems are very popular because of the occupant experience and comfort they provide, making them a popular design choice. Third Quadrant Design's 2020 and 2021 Solar Decathlon submissions both feature hydronic radiant heating systems. However, hydronic radiant heating systems are much higher in carbon compared to other heating systems because of the concrete and piping that is needed to move the water and conduct the heat.

LCA Results

Whole Life Energy Use

	BASELINE		THIRD SPACE		INCREASE
	kWh	$kgCO_2eq$	kWh	$kgCO_2eq$	
ENERGY USE	55,650	1,653	109,250	3,244	+49%
ENERGY GENERATION	52,850	1,771	52,850	1,771	

Greenhouse Gas Emissions

PHASE	COMPONENT	BASELINE	THIRD SPACE
		($kgCO_2eq$)	($kgCO_2eq$)
A1-A4; C1-C4	Foundation	11762	1323
	Structure	3938	3938
	Envelope	25100	3260
	Windows & Doors	4466	2719
	Interior Partitions & Finishes	1086	730
	Exterior structures	765	765
	Building Services	29760	18275
	PV	10068	0
A5	Constuction	6877	6877
B6	Operational Energy Use	-119	1473
	Total carbon	93703 $kgCO_2eq$	39361 $kgCO_2eq$
	Total intensity	**648 $kgCO_2eq/m2$**	**272 $kgCO_2eq/m2$**

Embodied Environmental Impact

All LCA Impact Parameters

PARAMETER	BASELINE	THIRD SPACE	REDUCTION
Global Warming Potential ($kgCO_2e$)	93,703	39,361	58%
Acidicfication ($kgSO_2e$)	415	289	30%
Eutrophication (kgNE)	362	337	7%
Ozone Depletion (kg CFC11e)	11	11	0%
Formation of Tropospheric Ozone (kg O3e)	5,824	3,921	33%
Fossil Fuel Primary Energy (MJ)	1,465,571	679,254	54%
Total Use of Primary Energy (MJ)	1,802,434	1,334,363	26%

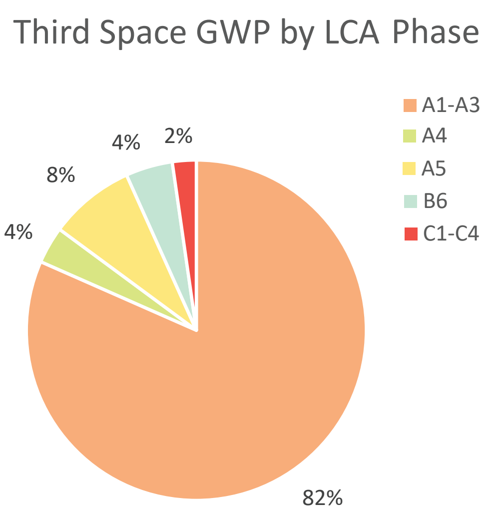

Figure 8- GWP by LCA Phase

PHASE	BASELINE	THIRD SPACE	REDUCTION
A1-A3	68,775	26,936	61%
A4	4,076	1,159	72%
A5	6,877	2,694	61%
B6	-119	1,473	N/A

Innovation

Everything about this project is innovative from an embodied environmental impact perspective. From our four carbon minimization design strategies to our LCA methodology, we have challenged what a conventional zero-carbon building looks like in industry.

The prioritization of **adaptive reuse** had a large impact on design decisions, as our architecture team had to shape the space around existing building components instead of designing with a blank canvas.

The construction team and industry build partners had to adapt to using unusual materials such as hempcrete and find **innovative construction solutions** along the way to keep the build on schedule.

The LCA team has pushed the envelope of what a typical LCA methodology and scope would be in order to create a **more complete and detailed picture** of what the impacts of this building are.

Our ways of thinking and designing for low carbon are asking industry to take a different path to zero carbon and our project shows the steps that can be taken to get there.

The figure below shows the "steps" that TQD has taken to get to low carbon, and the magnitude of of these design decisions allows other designers to make design decisions that will have the biggest impact on lowering their embodied carbon of their future projects.

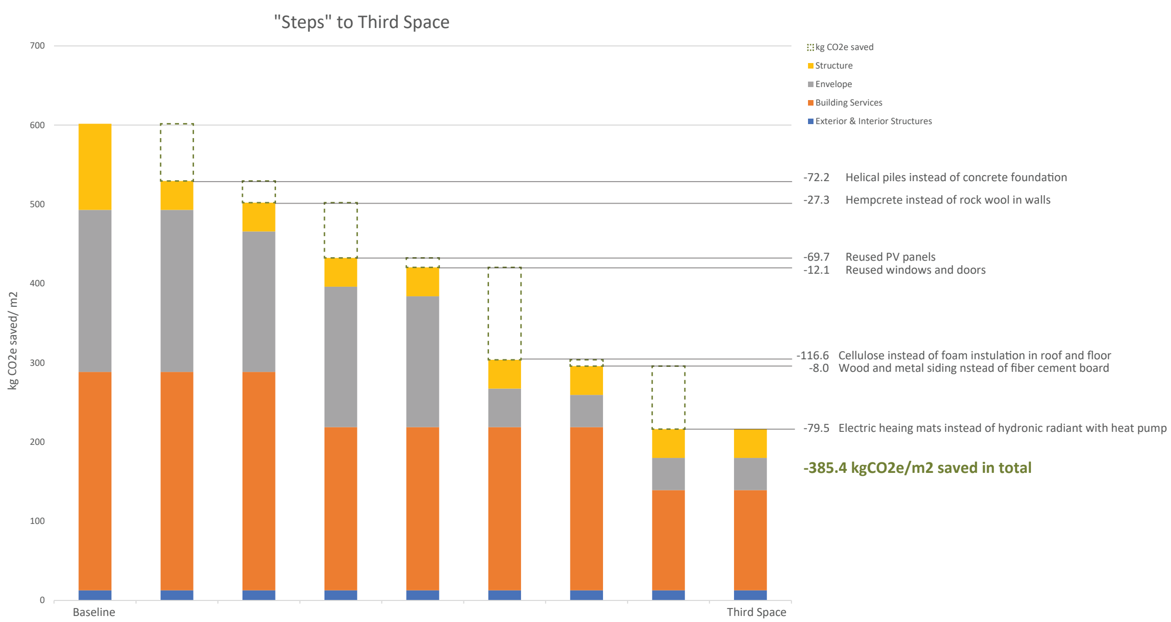

Figure 9- Steps to Net Zero

References

(1) Arehart, J. H., Nelson, W. S., & Srubar, W. V., III. (2020). On the theoretical carbon storage and carbon sequestration potential of hempcrete. In Journal of Cleaner Production (Vol. 266, p. 121846). Elsevier BV. https://doi.org/10.1016/j.jclepro.2020.121846

(2) City of Vancouver, "Green Buildings Policy for Rezonings," May 2022. https://guidelines.vancouver.ca/

APPENDIX A: Sequestration

There are two mechanisms of sequestration considered in this assessment: through photosynthesis (referred to as biogenic carbon) and through carbonation.

The total biogenic carbon from wood products is 32 658 kg from the softwood lumber and 5542 kg from the mass timber including plywood. These numbers have been obtained using the Canadian Wood Council Carbon Calculator tool (1). It is worth noting that the baseline building would also contain this amount of biogenic carbon.

The following calculations will focus on the sequestration potential of the hempcrete walls through the chemical reaction that occurs when the lime binder is mixed with water and hemp hurd. The key part of this reaction is the carbonation reaction where calcium hydroxide consumes atmospheric carbon dioxide and produces calcium carbonate.

The following methodology is based on a 2020 article from the Journal of Cleaner Production. The best approximation for the Third Space hempcrete mix in the article is the "OPC+LOW+M" theoretical mixture design formulation. Model A has been selected due to the lime binder used in Third Space being high calcium hydrated lime with no other additives. These assumptions result in estimating that 14 kg of CO2 is sequestered per functional unit of hempcrete. The functional unit in this case 0.31 m3. (2)

There is a total of 107 m3 of hempcrete in the Third Space building. This results in a total sequestration of 4837 kg of CO2 from the carbonation reaction in the hempcrete.

The biogenic carbon of the hemp hurd is 26 277 kg, also calculated using data from this journal article. In regards to the biogenic sequestration of hemp, hemp hurd can be considered an agricultural by-product since hemp is primarily cultivated for its fiber and seed. It is a fast growing crop with high yields, making it very different from lumber. It is for this reason that we have chosen to include the biogenic carbon of hemp in our global warming potential calculations.

While the mining of the lime does cause carbon release similar to other mined insulations like mineral wool, the sequestration from the hemp more than offsets this, and the sequestration from the carbonation creates a carbon sink. As the mining of lime is electrified, the embodied carbon of the lime will decrease and more carbon savings from this material can be expected.

In total, the materials in Third Space have sequestered 4837 kg of CO2 through carbonation and 64 477 kg of biogenic carbon, though only 26 277 kg of the biogenic carbon have been counted.

(1) Canadian Wood Council Carbon Calculator (https://cwc.ca/en/design-tools/carbon-calculator)

(1) Arehart, J. H., Nelson, W. S., & Srubar, W. V., III. (2020). On the theoretical carbon storage and carbon sequestration potential of hempcrete. In Journal of Cleaner Production (Vol. 266, p. 121846). Elsevier BV. https://doi.org/10.1016/j.jclepro.2020.121846

APPENDIX B: Bill of Materials

Building System	Building Structure	Building Component	Material	Quantity	Unit	Reused
Site Prep	sub-base	Well graded base	recycled concrete gravel	20580.00	kg	
Structural	Foundation	Helical pile 114mm OD x 7.4mm thick	Steel	0.04	m^3	
Structural	Foundation	Helical pile 140mm OD x 9.2mm thick	Steel	0.25	m^3	Yes
Structural	Foundation	Helical piles	Steel	0.29	m^4	
Structural	Floor	F01-FG01, FG04-FG07, FG10, Vertical chords and webs	No 2 SPF, 2 x 4	24.35	m^3	
Structural	Floor	F01-FG01, FG04, FG10 Horizontal chords	2100F 1.8E SPF, 2x4	2.27	m^3	
Structural	Floor	F01-FG07, FG10, Plates	Steel	0.03	m^3	
Structural	Floor	F-G02 and G02, all lumber	No 2 SPF, 2 x 4	3.28	m^3	
Structural	Floor	F-G03, all but bottom chord	No 2 SPF, 2 x 4	1.56	m^3	
Structural	Floor	FG03, bottom chord	2100F 1.8E SPF, 2x4	0.08	m^3	
Structural	Floor	FG05, horizontal chords	2100F 1.8E SPF, 2x6	0.25	m^3	
Structural	Floor	FG06-G07, horizontal chords	No 2 SPF, 2 x 4	0.24	m^3	
Structural	Floor	Floor Trusses	SPF	32.06	m^3	
Structural	Deck	FG08, all lumber	Pressure treated no2 SPF, 2x4	0.75	m^3	
Structural	Deck	FG08, steel plates	Steel	0.00	m^3	
Structural	Deck	FG09, all lumber	Pressure treated no2 SPF, 2x4	0.35	m^3	
Structural	Deck	FG09, steel plates	Steel	0.00	m^3	
Structural	Floor	Girder truss nails	0.122x3" spiral nails	0.00	m^3	
Structural	Deck	Deck truss nails	0.122x3" spiral nails	0.00	m^3	
Structural	Floor	Perimeter beam including decks	PSL	5.05	m3	
Structural	Wall	Wall stud 2x4	Stud wall	76.89	m^2	
Structural	Wall	Shear wall stud 2x4	Stud wall	86.33	m^2	
Structural	Wall	Main level nails in shear walls	64 nails	0.00	m^3	
Structural	Wall	Roof level nails in shear walls		0.00	m^3	
Structural	Wall	Shear clips		0.00	m^3	
Structural	Wall	Screws (top and bottom)		0.00	m^3	
Structural	Wall	Sheathing	15.5mm Doug Fir plywood	86.33	m^2	
Structural	Wall	Hold down, HDU8	Steel	0.01	m^3	
Structural	Wall	Hold down, HDU11	Steel	0.01	m^3	
Structural	Wall	Hold down, HDU14	Steel	0.01	m^3	
Structural	Wall	Built up posts, 2x4 post plies	2x4 stud posts	1.37	m^3	
Structural	Wall	Posts	6x6 posts	0.11	m^3	
Structural	Wall	PSL Posts	PSL column	0.76	m^3	
Structural	Roof	Drop beams, B1DB	2-2x10	0.25	m^3	
Structural	Roof	B3	3.5"x9.5" PSL	0.26	m^3	
Structural	Roof	B8 DB	2-2X10 edge, 2-2x10 flat	0.81	m^3	
Structural	Roof	B9 DB	3-2x10	0.12	m^3	

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Building System	Building Structure	Building Component	Material	Quantity	Unit	Reused
Structural	Roof	B6	7"x19"PSL	3.09	m^3	
Structural	Roof	B5	7"x14"PSL	0.38	m^3	
Structural	Roof	B4- Bulkead	5.25"x19"PSL	1.11	m^3	
Structural	Roof	B3- Bulkhead	3.5"x9.5"PSL	0.10	m^3	
Structural	Roof	J01-3	2X6" SPF	0.21	m^3	
Structural	Roof	T01-2	2X6" SPF	4.25	m^3	
Structural	Roof	T03-5	2X6" SPF	1.13	m^3	
Structural	Roof	T06-7	2X6" SPF	0.13	m^3	
Structural	Roof	T08-T09	2X6" SPF	1.59	m^3	
Structural	Roof	T10-T12	2X6" SPF	1.24	m^3	
Structural	Roof	T13-14	2X4" SPF	0.08	m^3	
Structural	Roof	Plates and connections	Steel connections	0.01	m^3	
Enclosure	Roof	Skylights	Triple paned alumninum frame	7.37	m2	
Enclosure	Roof	standing seam metal roofing		210.00	m2	
Enclosure	Roof	Ventilation mat		210.00	m2	
Enclosure	Roof	Bitumen based SAM		210.00	m2	
Enclosure	Roof	Plywood		3.11	m3	
Enclosure	Roof	2x4 vertical strapping (455mm OC)		420.30	m	
Enclosure	Roof	2x4 horizontal strapping (455mm OC)		424.92	m	
Enclosure	Roof	Cellulose mesh		194.40	m2	
Enclosure	Roof	Dense pack cellulose (3.75 lb/cf)	kg	122.85	m3	
Enclosure	Roof	Air/vapor membrane		194.40	m2	
Enclosure	Roof	gypsum ceiling finish		194.40	m2	
Enclosure	Roof	Insulation fill in girder beam cavities		1.25	m3	
Enclosure	Wall	Lanefab windows	Triple paned wood and alumini	2.77	m2	Yes
Enclosure	Wall	Donated triple paned IGUs		13.36	m2	
Enclosure	Wall	Framing by Innotech		8.80	m2	
Enclosure	Wall	Double exterior door		4.18	m2	Yes
Enclosure	Wall	Single exterior door		2.21	m2	
Enclosure	Wall	Single interior door		8.88	m2	Yes
Enclosure	Wall	Wood siding		141.78	m2	
Enclosure	Wall	standing seam metal siding		152.70	m2	
Enclosure	Wall	1x3 vertical strapping (405mm OC)	SPF	762.14	m	
Enclosure	Wall	1x3 (19mm x 63.5mm) horizontal strapping (406mm OC)	SPF	762.14	m	
Enclosure	Wall	VP water/air SAM	3-ply thermoplastic (2-ply poly	294.48	m2	
Enclosure	Wall	5/8" plywood		4.81	m3	
Enclosure	Wall	Hempcrete		107.11	m3	

APPENDIX B: Bill of Materials

Building System	Building Structure	Building Component	Material	Quantity	Unit	Reused
Enclosure	Wall	lime binder		22849.87	kg	
Enclosure	Wall	hemp hurd		14281.17	kg	
Enclosure	Soffit	VP water/air SAM		17.24	m2	
Enclosure	Soffit	3/4" wood finish		17.24	m2	
Enclosure	Soffit	2x6 framing		116.88	m	
Enclosure	Floor	wood flooring		105.05	m2	
Enclosure	Floor	tile flooring		10.19	m3	Yes
Enclosure	Floor	natural cork mat		105.05		
Enclosure	Floor	3/4" plywood		144.50	m2	
Enclosure	Floor	Cellulose	kg	42.65	m3	
Enclosure	Floor	Marine grade 5/8" plywood	m3	144.50	m2	
Interior	Wall	2x6 studs	m3	55.00	m	
Interior	Wall	2x4 studs	m3	35.70	m	
Interior	Wall	Gypsum wall board		54.73	m2	
Interior	Wall	water resistant gypsum wall board		2.97	m2	
Interior	Wall	1x2 strapping	m3	24.00	m	
Interior	Wall	vertical wood battens	m3	9.81	m2	
Interior	Wall	tiles		2.97	m2	Yes
External feature	Deck	Decking		124.75	m2	
External feature	Deck	2x12 pressure treated joists	m	0.50	m3	
External feature	Deck	2x10 pressure treated joists	m	1.01	m3	
External feature	Deck	2x12 pressure treated stair planks	treated SPF	0.76	m3	
Ramp	Deck	4x12 SPF		0.78	m3	
Ramp	Deck	2x6 SPF @ 460mm O/C				
Ramp	Deck	4x4 SPF		0.17	m3	
Ramp	Deck	2x12 SPF @ 460mm O/C		0.81	m3	
Ramp	Deck	18x18 precast concrete base		0.15	m3	
Ramp	Deck	lockblock	concrete	0.84	m3	
Ramp	Deck	Steel connections		0.05	m3	
Civil	Utility service	150mm storm pipe	PVC	32.11	kg	
Civil	Utility service	50mm water connection pipe (assume 3.0656 kg/m)	Type K copper	21.24	kg	
Civil	Utility service	150mm sanitary pipe	PVC	285.03	kg	
Civil	Utility service	50mm ELEC conduit	?	8.79	m	
Civil	Utility service	50mm TELECOM conduit	?	8.79	m	
Mechanical	Heating	Environ Flex WarmlyYours heating mat		38.15	m2	
Mechanical	Heating	Tempzone WarmlyYours heating mat		1.39	m2	
Energy		aluminium sheet	2mm aluminium sheet	434.94	kg	

APPENDIX B: Bill of Materials

Building System	Building Structure	Building Component	Material	Quantity	Unit	Reused
Mechanical	Drainage	RWT to storm utility pipe 100mm	PVC	29.39	kg	
Mechanical	Drainage	30mm sewer vent pipe	ABS - acrylonitrile butadiene st	4.39	kg	
Mechanical	Drainage	40mm sewer vent pipe	ABS - acrylonitrile butadiene st	8.60	kg	
Mechanical	Drainage	50mm sewer outflow pipe	assuming ABS	5.72	kg	
Mechanical	Drainage	75mm sewer outflow pipe	assuming ABS	26.02	kg	
Mechanical	Drainage	20mm HRV condensate pipe	PEX	0.58	kg	
Mechanical	Hot Water	10L DHW mini-tank (1.5 kW)	use electric boiler in oneclick	0.04	m3	
Mechanical	Ventilation	Heat recovery ventilator	use hrv in oneclick			
Mechanical	Ventilation	250mm ducting	galvanized steel sheet metal (t	21.91	m	
Mechanical	Ventilation	390mmx250mm ducting		4.07	m	
Mechanical	Ventilation	250mmx450mm ducting		2.30	m	
Mechanical	Ventilation	500mmx200mm ducting		3.60	m	
Mechanical	Ventilation	350mmx150mm ducting		2.30	m	
Mechanical		EPS insulation surrounding ducting		0.41	m3	
Mechanical	Ventilation	50L/s exhaust fan	use from oneclick	4.00	kg	
Mechanical	Ventilation	Supply diffuser	Aluminum	1.83	kg	
Mechanical	Ventilation	Return grille	Aluminum	2.56	kg	
Mechanical	Heating	28 L/s 3000W pre-heater	use as fan coil heater from one	23.00	kg	
Mechanical	Plumbing	50mm water supply piping	PEX	21.90	kg	
Mechanical	Plumbing	20mm water supply piping	PEX	2.66	kg	
Mechanical	Plumbing	12mm water supply piping	PEX	0.77	kg	