Building Toward Low Cost and Carbon

Clean construction doesn't have to mean costly construction

April 2025

CLEAN ENERGY CANADA

Acknowledgments

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SFU MORRIS J. WOSK CENTRE FOR DIALOGUE

Executive summary

Canada needs to build. As housing costs are soaring, the country is embarking on a generational housing build-out, with five million more homes and their surrounding infrastructure needed to properly address Canada's housing affordability crisis.[1]

But woven into this very necessary build-out are some sizable but often overlooked climate implications. Specifically, manufacturing the construction materials that make up our buildings—from the concrete foundations to the drywall—creates between 20 to 120 tonnes of emissions per home.[2–4] To put that in context, meeting the previous federal government's housing plan (which would support nearly four million houses by 2030) was expected to generate the equivalent of more than a year's worth of Canada's total emissions by 2030.[5,25] **Thankfully, building cleaner doesn't mean compromising on cost.**

What's more, with the U.S. no longer the reliable partner it once was, Canadian materials producers will be increasingly looking to the domestic market as well as other international partners like the EU for business.

While this may seem tangential to our housing problems, there is a single elegant solution to a multi-layered issue: **clean construction products and practices.**

Designing buildings more efficiently and selecting materials that are made using cleaner processes and power sources can have a significant impact on the emissions embodied in a building or infrastructure project. **Conveniently, as this report explores, many of these products are both cost-competitive and made in Canada—a dual opportunity to cut carbon and boost our homegrown industries.**

Lower-carbon materials are already being produced across the country, from steel produced in electric arc furnaces to concrete mixes that reduce emissions while delivering the same performance, to low-emissions alternatives for drywall and insulation.

But at a time when we need to be building affordable housing, cost is key. **This report looks at the price differential of using cleaner products and finds that lower-carbon equivalents are available in Canada at the same cost or for a negligible cost premium across almost all building materials and case studies explored.** Where small premiums do exist, in most cases they add less than $3,000 for the material budget, which is a rounding error for multi-million dollar construction projects and falls within the price variations that construction projects face every day. **Put simply, cutting carbon won't break the bank.**

In addition, **our analysis found that designing lower-carbon buildings from the start and reducing the amount of material we use can reduce overall costs and compensate for any clean material premiums that do exist.** Specifically, making a few deliberate changes like not overbuilding, or switching to above-ground parking garages, can reduce embodied emissions by as much as 41% while saving hundreds of thousands of dollars in material costs.

Crucially, there are many countries in the world looking to slim down this slice of their emissions pie. By making the products that these jurisdictions want, Canada is moulding itself into a more competitive exporter to jurisdictions with carbon border adjustments like the EU.[6] In a time of trade tensions, investing in Canadian-made clean materials is the right economic move.

But to be successful abroad, Canada should support its market here at home. **"Buy Clean" policies, where governments require that cleaner materials are used in public construction projects, is the first and most important port of call.** In fact, using this approach in public procurement policy could avoid up to 4 million tonnes of emissions by 2030 (the equivalent of 850 thousand cars).[7]

In addition, **governments should reevaluate building codes and design guidelines to remove unnecessary restrictions on lower-carbon designs while focussing on carbon performance over prescriptive requirements.** Finally, they should remove any other barriers to clean construction including support for smaller producers to develop emissions-related data on their products.

One thing is clear: clean construction doesn't have to mean costly construction.

	CONCRETE	STRUCTURAL STEEL	REBAR	DRYWALL	INSULATION
Emissions reduction	3% to 32%	10% to 100%	3% to 53%	4% to 55%	2% to 98%
Cost increase per material unit	**Generally 0%;** Some premiums between 1-16%	**Generally 0%;** Instances of a 5-25% premium	**Variable from 0% to 25%;** one outlier of 80% premium	**Consistently 0%**	**Generally 0%;** Instance of a 30% premium
Cost increase as share of budget	0% to 0.55% of foundations budget; 0% to 0.28% of structure budget	0% to 1.1% of structure budget	0% to 5.7% of structure budget	0% of envelope budget	0% to 0.06% of envelope budget

The emissions embodied in our buildings

With a growing population and housing affordability crisis, Canada is in need of more buildings and infrastructure. At the same time, now more than ever we must support Canadian producers and reduce our emissions. Fortunately, there is a way to reduce the emissions stored in our built environment without increasing costs.

The Canada Mortgage and Housing Corporation has estimated that Canada needs over five million new housing units by 2030 to restore affordability.[1] Building these homes and the infrastructure that supports them could significantly increase greenhouse gas emissions. Currently, the construction of the average Canadian home causes 20 to 120 tonnes of emissions, or even more if surrounding infrastructure is required for a new neighbourhood.[2–4] For the previous federal government's housing plan, this would translate into 729 million tonnes by 2030 (more than a year's worth of Canada's total emissions).[5, 25] But with 78% of Canadians believing housing should be built in a way that minimizes pollution, governments should consider how to achieve both goals at once.[8] Until now, the conversation around building emissions has largely been about the "operational emissions" of these homes and buildings—that is, the carbon pollution that is created by heating and cooling them, keeping the lights on, and running appliances. The emissions caused by actually building these homes and infrastructure, however, have not been fully recognized to date.

Embodied emissions (or "embodied carbon") are the emissions associated with the building's materials (production, transportation, assembly, maintenance, and end-of-life disposal) and construction process.[9] As buildings get more energy efficient and operations (such as heating systems) are electrified, the embodied emissions will make up a relatively larger share of a building's emissions impact. Analysis by the Canada Green Building Council (CAGBC) shows that in cities with low-emissions electricity, the embodied emissions of an efficient electrically heated building can make up as much as 93% of the building's cumulative emissions impact by 2050 (see Figure 1).[10]

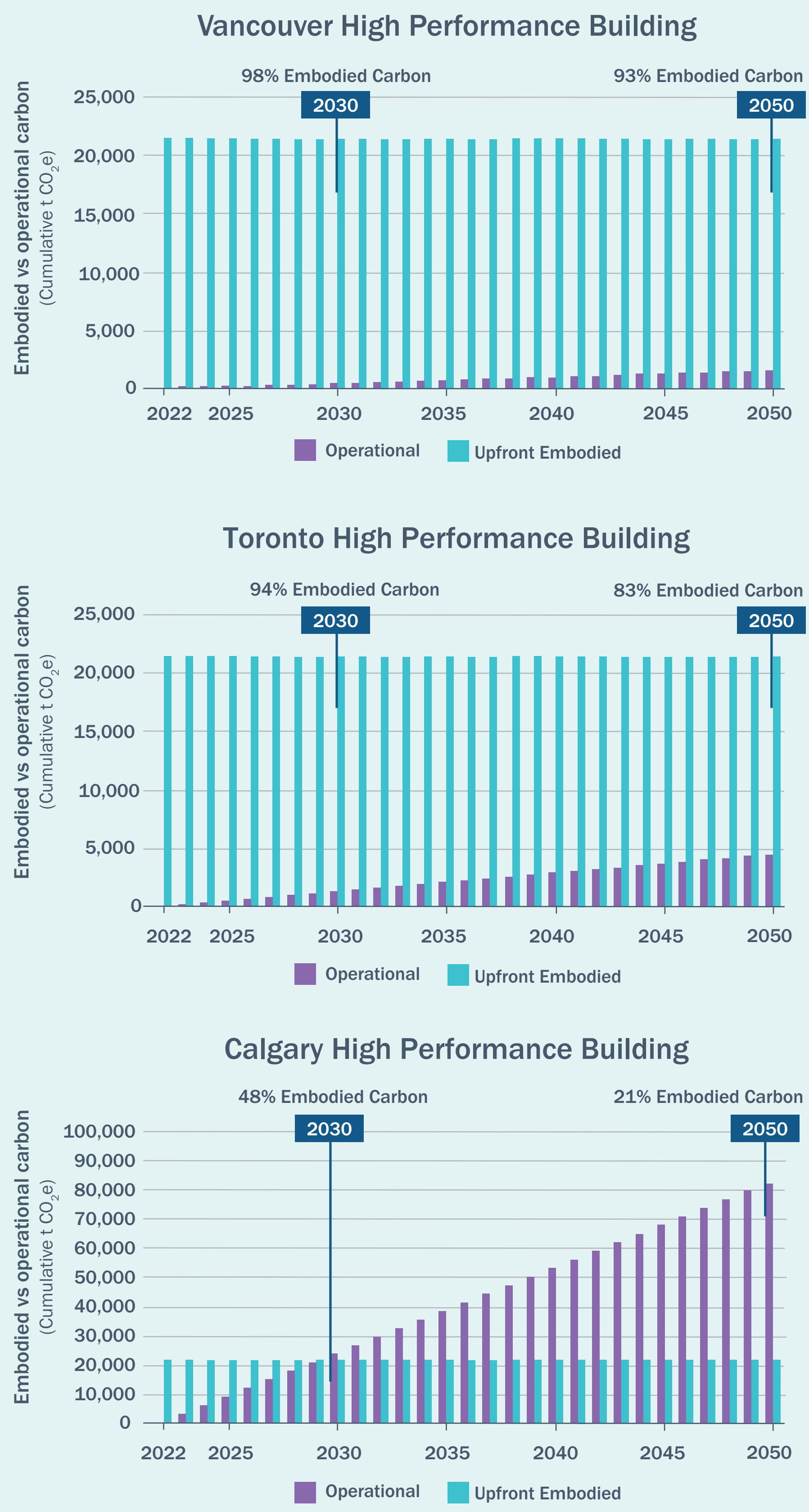
The graphs on the right show the emissions over the lifetime of efficient buildings built in different Canadian cities, and what share is made up by the upfront embodied emissions. The buildings are all heated and cooled with electricity.

The embodied emissions of around 21,500 tonnes of CO_2e are locked in at the beginning of the building's lifetime, while the operational emissions add up over time, with each year of heating, cooling and running appliances.

In Vancouver and Toronto, while the share of operational emissions rises over time, the operations never emit as much as the construction processes did.

This is different for a high-performance building in Calgary, where the electricity supply is less clean and heating needs are higher because of the colder climate, causing emissions from operations to overtake those from construction approximately eight years after the building was built. Still, each of these pictures shows how much of a (highly efficient) building's climate impacts will be determined by its construction.

Figure 1: Share of embodied carbon in the emissions of buildings



Source: CAGBC (2022). Embodied Carbon: A Primer for Buildings in Canada.[10]

The good news is that solutions already exist and are available in Canada. More efficient design and lower-emissions materials can significantly reduce the emissions embodied in our buildings.

In fact, **many Canadian construction material producers already have a built-in advantage** when it comes to producing lower-carbon materials, owing mainly to our relatively clean electricity grid. Steel imported from the U.S., EU, and China is between 16% and 200% more carbon-intensive than steel made in Canada, while aluminum from those countries is between 170% and 535% more carbon intensive than Canadian products.[11,12]

Decreasing emissions without increasing cost

Governments at different levels have already started to unlock opportunities to leverage public dollars to reduce construction emissions while encouraging increased uptake of clean Canadian materials. Canada's public sector makes up about a fifth of all infrastructure spending in the country, and a third of the market for both cement and construction steel.[7] Requiring the materials used in public construction projects to be lower-carbon by taking a Buy Clean approach in public procurement policy could avoid up to 4 million tonnes of emissions by 2030.[7]

The federal government has integrated Buy Clean commitments into its Greening Government Strategy and the Canada Green Building Strategy, requiring a 30% overall reduction in the embodied carbon of federally procured major construction projects starting in 2025 and setting low-carbon requirements for specific materials.[13,14] Leading local governments such as the cities of Vancouver, Toronto, and Hamilton have adopted their own embodied carbon measures, setting reporting and reduction requirements.[15–17]

However, the construction sector is still hesitant about these types of requirements and the widespread adoption of lower-emissions materials. Crucially, there is concern among some industry stakeholders and government decision makers that policies to reduce embodied carbon will result in increases in housing costs, project budgets, or public spending in a time when affordability is top-of-mind. Cost uncertainty was one of the main hurdles identified in an October 2023 workshop hosted by Clean Energy Canada and the Future of Infrastructure Group, as well as during CAGBC's 2024 National Embodied Carbon Summit.[9,18]

While some data exists on the costs of lower-carbon construction, evidence in the Canadian market is limited. In the U.S., the Rocky Mountain Institute completed a 2021 assessment of low- and no-cost options to reduce embodied carbon. They found emissions savings potential of up to 33% per material for no- or low-cost premiums for several different material categories.[19]

In Canada, one study was conducted for the City of Vancouver, finding that embodied carbon reductions could actually come at overall cost savings. For 30-storey, 6-storey, and 3-storey buildings in Vancouver, researchers found construction cost savings of up to 25% for embodied carbon reductions between 10 and 20% compared to a 2018 baseline.[20] Recent case studies published by the Carbon Leadership Forum, British Columbia (CLF BC) also showed embodied carbon reductions were possible through improved design and low-carbon materials without increasing the project budget, and in one case demonstrated a 9% reduction in embodied carbon was achieved at cost savings.[21,22]

In this report, Clean Energy Canada, Chandos Construction, and Ha/f Climate Design aim to expand the knowledge base on the cost implications of reducing embodied carbon in construction, studying the cost of switching to lower-carbon construction materials across Canada, and demonstrating how more efficient design choices can reduce embodied emissions as well as the amount of construction materials needed.

Research approach

This research investigates two of the primary ways to reduce embodied carbon: through using lower-carbon construction materials and through more efficient design choices that minimize material use.

This approach is aligned with policies that require reduced embodied carbon in public buildings (Buy Clean policies). These policies are either applied at a material level, such as the requirement in the federal Standard on Embodied Carbon in Construction to use concrete and structural and reinforcement steel that meets a low-carbon standard, or at a whole-building level, such as the Greening Government Strategy's 30% reduction for major construction projects.[14]

The first part of the research investigates material-specific emissions reductions and their pricing. The aim is to show what cost premium, if any, is charged for sourcing lower-carbon equivalents of key material categories (concrete, structural steel, rebar, drywall, and insulation). Material swaps are like-for-like and do not address the cost implications of switching to a different material category, such as using a timber frame instead of a steel frame. This work was conducted in collaboration with Chandos Construction.

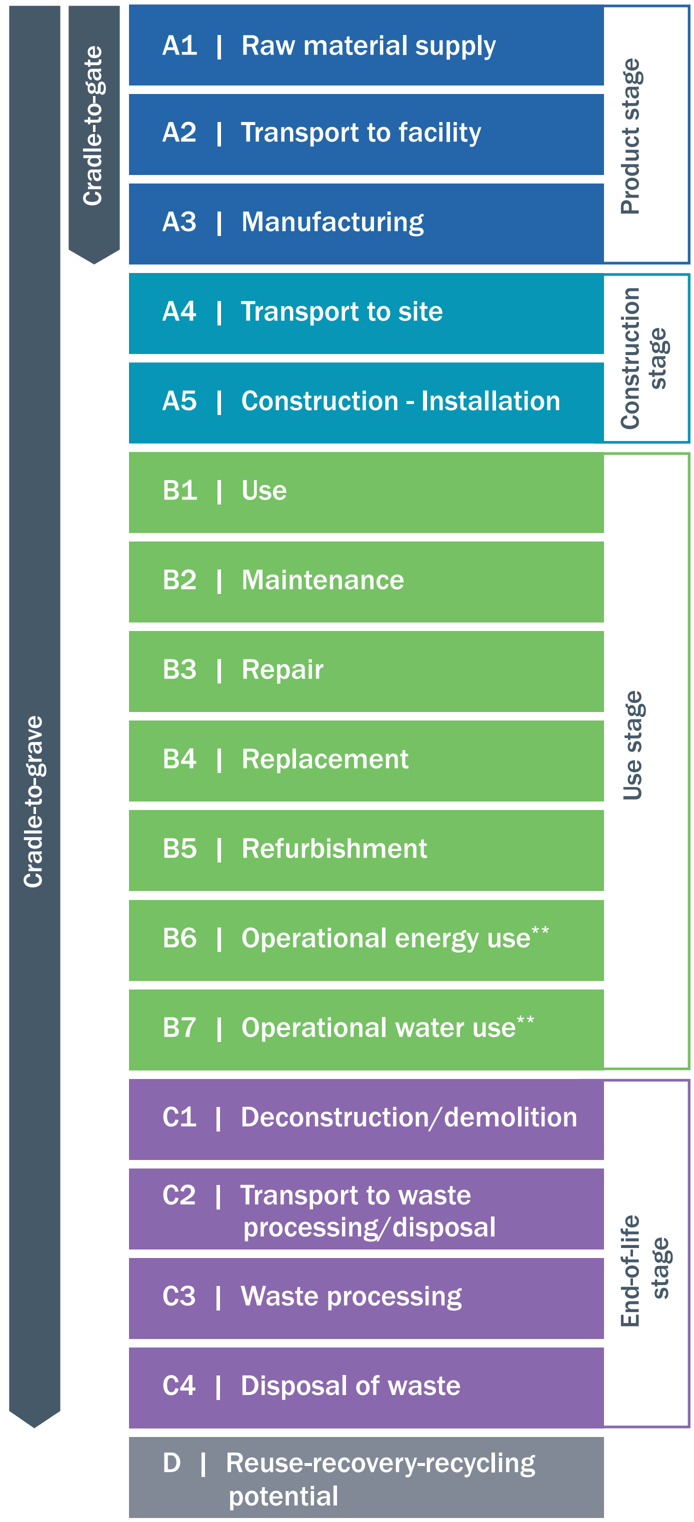
The second part of the research demonstrates the cost-effective embodied carbon reductions that are made possible by design choices. This does not include precise costing estimates for all interventions, but does illustrate the material savings that can reduce overall budget, as well as avoided costs, e.g. from building underground or reducing the need for replacement over a building's lifetime. The development of these case studies was led by Ha/f Climate Design.

The third component of the research is a qualitative assessment of co-benefits and non-material costs that can result from reducing embodied carbon. The research team conducted interviews with experts—including architects, structural and geotechnical engineers, and general contractors—and asked about their experience reducing embodied carbon in projects. These interviews were further supplemented with findings from existing case studies, such as those published by CLF BC and research conducted by the University of Toronto's Centre for the Sustainable Built Environment.[23,24]

The research covers emissions from the production of materials for the material-costing study (stages A1-A3 in the life cycle as shown in Figure 2, which make up the vast majority of product and construction stage emissions[25]). The analysis of the design studies largely focuses on A1-A5 stages, with some notable considerations on maintenance and repair savings. End-of-life emissions and reuse and recovery of materials can also play a role in reducing embodied emissions, however they are not covered here.

As explained in the following section, what we build (or do not build), such as choosing whether new neighbourhoods consist of single-family homes or higher-density, mid-rise buildings, is a crucial factor in embodied carbon, but falls outside of the scope of this research.

Figure 2: Lifecycle stages



** Operational carbon stages that are typically excluded from life cycle assessments focused on embodied carbon.

Changing the way we build

We need to build out Canada's supply of affordable, comfortable, and safe housing units and the infrastructure that underpins our economy. A reduction in embodied emissions can and should be achieved alongside those objectives, rather than act as a barrier that stands in the way.

There are several strategies to reduce embodied carbon that can simultaneously ensure we are building the affordable houses and infrastructure we need. Broadly, these can be summarized into the categories of what we build, how we build it, and the materials we build with.

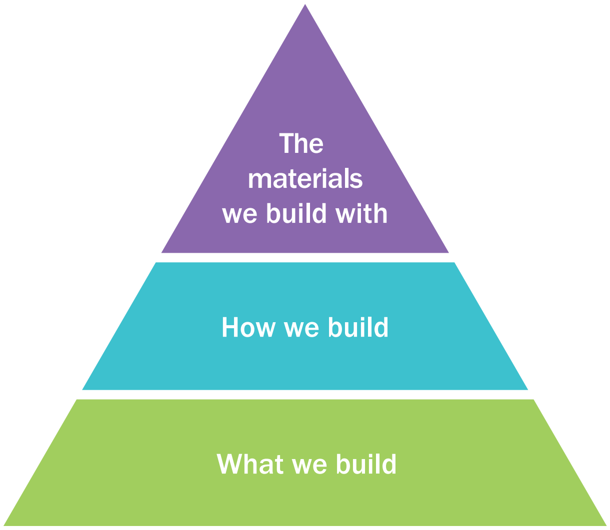


Figure 3: Interventions in embodied emissions

What we build matters

With a need for more and more affordable housing and reliable infrastructure, the question is how to deliver function and comfort with the lowest possible emissions. Before interventions through design or material selection, the type of buildings we build can be determinative.

In a large study of the embodied carbon of neighborhoods across Canada, researchers from the University of Toronto found clear patterns in what urban design choices lead to higher or lower embodied carbon.[4] The neighborhoods with the lowest embodied emissions per resident were very dense, with many low-rise multi-unit buildings such as those typical to urban Montreal. Neighborhoods where fewer than 10% of the buildings were single-family homes were found to have 57% lower emissions than typical single-family neighborhoods. The researchers estimate that shifting construction away from single-family homes to neighborhoods made up of multi-unit buildings (mid-, high-, or low-rise) could reduce the emissions of building all the homes we need by 58%.

Building denser neighborhoods can come with additional benefits such as closer proximity to facilities and community spaces, lower infrastructure and service costs, and transit-oriented and pedestrian-friendly neighborhoods.[26]

The materials we build with

Lower-carbon equivalents in the Canadian market

A large share of the emissions embodied in our buildings is made up by a small number of materials used in the structure and envelope. In this research, we focus on five of the most common construction materials: concrete (precast and ready-mix), rebar, structural steel, drywall, and insulation.

The production of construction materials like steel and concrete is emissions-intensive, requiring high temperatures to initiate chemical processes with significant emissions that are hard to abate. However, Canada is home to a range of companies and products that have made substantial reductions in the emissions of these products in recent years—and with Canada's clean electricity advantage, emissions will be reduced even further in the near future.

For concrete, Canadian producers are already reducing emissions in multiple ways.[27] Most emissions in concrete production come from the clinker used to manufacture cement. Using cleaner fuels in cement kilns and capturing the carbon that is emitted (CCS) in the chemical reaction can significantly reduce these emissions. Producers have also found ways to use less clinker in cement, using other Supplementary Cementitious Materials (SCMs) instead. Portland Limestone Cement, for example, can reduce emissions by 10% compared to traditional Portland cement and is quickly becoming the industry standard.[28] Canadian-grown companies such as Carbon Upcycling also use fly ash, iron and steel slag or clays, and captured CO_2 to produce a low-carbon cement mix, with a pilot facility in Alberta and a larger production facility soon to be launched in Ontario.[29] Similarly, SCMs can also be used during the concrete mixing process, reducing the share of cement in the concrete. Combined with efficient construction practices that prevent overuse and waste, these innovations provide a pathway to net zero for concrete while still delivering the same performance.[27]

Steel produced in Canada is already lower in embodied emissions than imported steel, with steel imported from the U.S., EU, and China between 16% and 200% more carbon-intensive than that made in Canada.[11] Producing steel in an Electric Arc Furnace (EAF) instead of a Blast Furnace, either from recycled scrap metal or eventually from direct reduced iron ore (DRI), significantly reduces emissions. Recycled rebar is already produced in Canadian mills, such as by Gerdau in Whitby, ON, and large Canadian steel mills owned by Algoma and ArcelorMittal are being transitioned to EAF steelmaking (with significant support from federal and provincial governments), and some have plans to shift to a hydrogen-DRI process which would substantially reduce their embodied carbon.[30–32] In addition, Canada is home to a number of iron ore mines that have 'DRI grade' iron that can be used in these next-generation facilities.[33]

Gypsum drywall products can be recycled to reduce waste and emissions. North America's first zero-carbon gypsum wallboard plant is set to begin production in Quebec in 2025, with a product promising up to a 60% reduction in embodied carbon (cradle-to-gate) compared to traditional wallboard.[34] Production of low-carbon gypsum wallboard is also slated to start in Alberta, providing more options in local markets.[35]

Insulation is commonly made of emissions-intensive, fossil fuel-based products. Replacing it with recycled or bio-based content or improving formulas can drastically reduce emissions. The company SOPREMA, for example, which manufacturers insulation in Canada, has created an XPS rigid insulation panel with 98.7% lower emissions than the industry average by replacing the blowing agents that rely on powerful greenhouse gases.[36]

Research approach

While lower-carbon materials with equal performance are available in most Canadian markets, it is somewhat unclear whether they are sold at a different price point. To ascertain whether the use of lower-carbon materials comes at a cost premium, we analyzed eight case studies covering three building types in three regions of Canada. Each of these projects were recently constructed by Chandos Construction without an intention to reduce embodied carbon in the original projects.

For each of the case studies, the project team at Chandos Construction studied recent material cost estimates and compared the cost of low-carbon alternatives to standard market rates for each material.

Buying clean and Canadian in a time of trade tensions

Recent trade tensions with the United States and China have created uncertainty in the construction sector, as well as among material producers and manufacturers. One of the most effective ways to mitigate the impact of tariffs on construction materials is to expand and strengthen domestic supply chains for these essential products and inputs. By increasing domestic production capacity, Canada can reduce reliance on imports, stabilize prices, and enhance long-term economic resilience. Additionally, investing in lower-embodied carbon materials can position Canada as a leader in sustainable construction. Reducing emissions can also boost export opportunities with like-minded trading partners such as the EU, which is imposing a cost on high-carbon products through the new carbon border adjustment mechanism.[6]

Developing new manufacturing facilities and expanding existing ones would create jobs in raw material extraction, processing, manufacturing, and transportation. Already, the manufacturing of construction products like steel, concrete, and glass employs over 250,000 people in Canada.[37] With government support, the green building sector is expected to grow more than threefold by 2030, supporting hundreds of thousands of new jobs and billions of dollars in economic benefits.[38]

Costing estimates were obtained for concrete, structural steel, rebar, drywall, and insulation. Lower-carbon equivalents for each material were selected with careful alignment to performance criteria. To ensure consistency, swaps were made considering total volume as well as equivalent performance, particularly in the case of insulation. Not all material (sub)categories are covered for each case study as they may not have been used in the construction project, or in the case that costing or emissions data was not available to study a low-carbon alternative. Product-specific Environmental Product Declarations (EPDs) for lower-carbon materials were obtained through One Click LCA and were compared to the regional market average emissions of the baseline product to calculate emissions reductions.

The following building types were included (projects have been anonymized to protect market-sensitive data):

- Three mid-rise, multi-unit residential buildings (MURBs) with a steel-reinforced concrete slab and traditional timber framing above grade. These case studies covered affordable housing units, making cost an important consideration. They are located in urban settings in B.C.'s Lower Mainland and southern Alberta, and in rural southern Ontario.
- Three commercial buildings with a steel-reinforced concrete slab, and steel and concrete above grade in urban settings in B.C.'s Lower Mainland, southern Alberta, and southern Ontario.
- Two tilt-up construction warehouses in B.C.'s Lower Mainland and southern Alberta. The B.C. case study is in an urban setting, while the Albertan case study is in a rural area.

Results

Figure 4: Material-specific emissions reductions and cost implications*

	CONCRETE	STRUCTURAL STEEL	REBAR	DRYWALL	INSULATION
Emissions reduction	3% to 32%	10% to 100%	3% to 53%	4% to 55%	2% to 98%
Cost increase per material unit	**Generally 0%;** Some premiums between 1-16%	**Generally 0%;** Instances of a 5-25% premium	**Variable from 0% to 25%;** one outlier of 80% premium	**Consistently 0%**	**Generally 0%;** Instance of a 30% premium
Cost increase as share of budget	0% to 0.55% of foundations budget; 0% to 0.28% of structure budget	0% to 1.1% of structure budget	0% to 5.7% of structure budget	0% of envelope budget	0% to 0.06% of envelope budget

* The last row shows cost increases relative to the relevant budget category to put any "premiums" into perspective. The structure budget, for example, is the cost of materials and labour for constructing the structure, including the wood or steel frame. For the multi-unit residential and commercial buildings, the structure budget was around 5-15% of the total project budget.

Lower-carbon equivalents were available at no or low premiums for almost all material categories in all case studies. The range of emissions reductions and cost increases for each material are summarized in Figure 4 and 5.

Our research found that concrete (precast and ready-mix) could be swapped out for an equivalent with up to 32% lower emissions. **In most cases, the lower-carbon concrete comes at the same price points,** with a few instances of small per-unit cost premiums between 1 to 16%.

Drywall emissions could be reduced by up to 55% without any increase in the price point. Lower-carbon insulation is available at a range of emissions reductions from 2% up to 98%. Almost all of these products (including those with the highest emissions reductions) came at the same market rate without a cost premium. **Structural steel similarly could be sourced with significant emissions reduction at no cost increase.** By sourcing intentionally, some steel products available in the market within standard pricing can even demonstrate almost 100% lower emissions than the market average.

Rebar stands out as having the highest instance of a cost premium in the dataset. One project in British Columbia found that using low-carbon EAF rebar from a local supplier (a potential 46% emissions reduction) would come at almost double the price of using the higher-carbon international supply. However, this instance is not necessarily representative of the entire market. A project of a similar nature in a different province identified a local supplier able to provide rebar with 28% lower emissions at no cost increase.

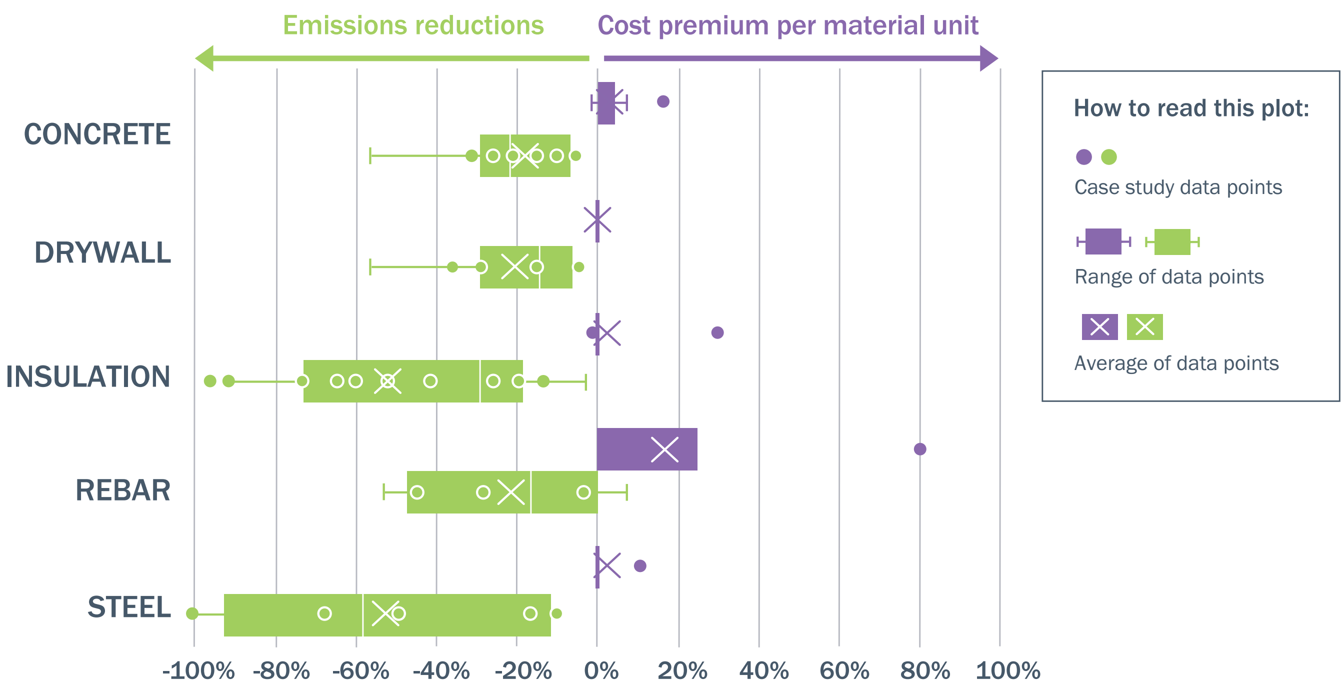
The cost premiums are presented as a percentage increase per material unit. However, any cost increase is usually negligible in comparison to the budget line item. In one case study, for example, lower-carbon concrete foundations came at a 16% price premium (the highest identified premium), but this represented only a 0.55% increase in the foundation budget (or 0.035% of the project's total budget). **Most cost premiums, if any, came to a total of less than $3,000 for the project, which is a rounding error for multi-million dollar construction projects** (case study projects had total budgets between $8 and $48 million).

Cost premiums should also be placed in the context of highly variable markets for construction materials where prices can be dependent on many factors including international supply chains, local availability, and bulk pricing. This research found that the price of baseline (higher-emissions) materials already varied substantially from project to project. The per-unit price of concrete for the foundations in a residential project in one province was already 39% higher than for a commercial project in another province, as one example.*

While we also saw variations in the cost of lower-carbon options, this was not greater than the variability across industry standard options. In another example, high-emissions rebar in one project cost double per kilogram what it cost in another project. These baseline price differences in fact far exceed any premium for low-carbon materials identified in any of the projects. Complex supply chains and variable availability of materials are already common realities in construction. **In short, switching to lower-carbon options may be a new variable for contractors and estimators, but the costs fall well within the variances the industry already deals with on a daily basis.**

Emissions reductions and cost premiums were fairly consistent across provinces, with no notable regional differences. Within material categories, the opportunities for cost-effective emissions reductions do vary. More detailed results for material subcategories (e.g. hot-rolled or cold-rolled structural steel sections) can be found in the appendix.

Figure 5: Ranges of emissions reductions and cost premiums



* Comparing per-m³ prices for poured 25 MPa concrete.

How we build: design interventions for carbon and cost reduction

While lower-carbon construction materials can effectively reduce the embodied carbon in buildings, even bigger gains can be made earlier on in construction projects.

Through optimizing design choices, the same functionality of buildings can be achieved while reducing the material use, and consequently the embodied carbon and cost of projects.[3] The cement and concrete sector's own *Roadmap to Net-zero* acknowledges that we cannot reach net-zero without building more efficiently and reducing waste, modelling that construction efficiencies (design optimization and reducing waste on-site) will make up 14% of the necessary emissions reductions in the sector by 2050.[39]

How buildings are designed has a large impact on how much material is needed. A study of the embodied carbon in single-family dwellings in Toronto found that there was a very wide range in how much material was used to construct each home.[40] It also found that certain elements of the buildings were disproportionate drivers of material use. Concrete basements, for example, made up on average half of the material used by mass.[40] Other key determinants are indoor parking and the thickness of slabs in mid- or high-rise buildings.[3]

Even where premiums on low-carbon materials exist, reducing material waste and optimizing design creates savings that far outweigh any costs.

Modern structures often use more material than is functionally required, such as using thick concrete transfer slabs between layers of a building when using a thinner layer would still meet safety requirements.[41] While lower-carbon versions of materials like concrete, structural steel, and insulation are already available in most Canadian markets at no additional cost, sometimes innovative near-zero-emissions products may come at a slight cost premium, for example cement from the first production sites using CCS or steel from the first plants to use hydrogen-DRI.

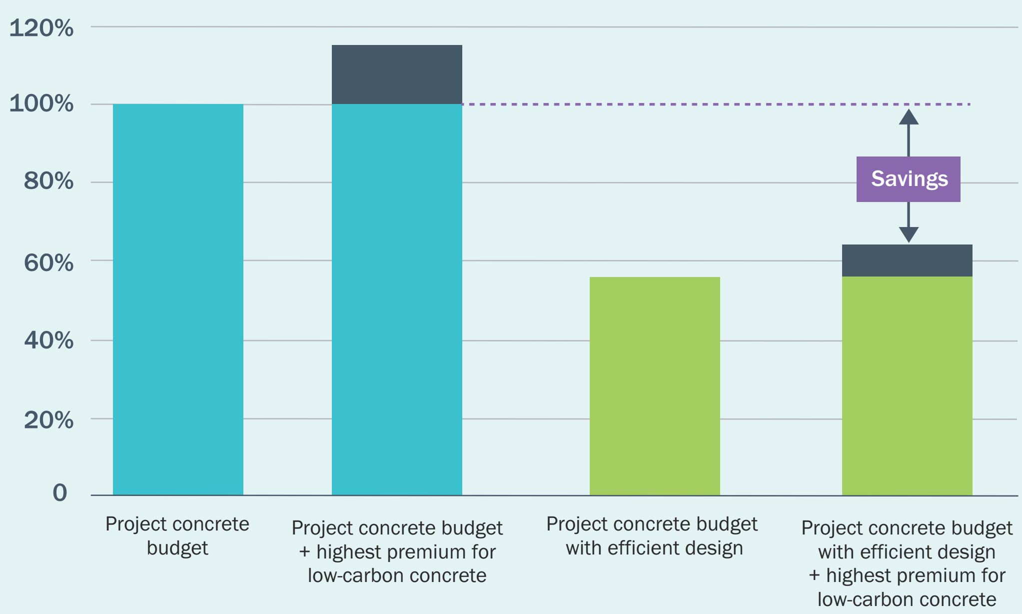
These potential premiums, however, pale in comparison to the cost savings that can be made by using only the material we need. If a project uses significantly fewer kilograms of rebar, it may create room in a budget to pay slightly more per kilogram to use low-emissions recycled rebar while still saving money overall.

One recent Canadian study showed, for example, that high-rise buildings usually use the same reinforcement and concrete design for all stories.[42] However, as stories more toward the top of the building carry less weight, they do not actually need the same level of support. If each storey was designed optimally, a 15-20 floor building could save as much as 45% of the column, beam, and wall concrete. That reduction would free up the budget to use lower-carbon concrete for those structural elements. **Even if a high-rise project paid the highest per-unit premium found in our material-swap study (16%), the overall concrete budget for columns, beams, and walls would still be reduced by 36% by combining low-carbon materials and more efficient design.**

There is a wide range of options to reduce embodied carbon through design changes. Increased efficiency and reduced waste in existing designs can often already yield savings without changing the form or function of the building at all. On the other hand, by thinking about embodied carbon early on in the design process, when a building is conceptualized, projects could provide the same or improved function, while significantly reducing the use of carbon-intensive materials. Resources are available for project teams to identify fitting, low-cost design options to reduce embodied carbon, including a low-carbon design primer developed by Ha/f Climate Design and the Treasury Board Secretariat of Canada[43] and ZGF Architects' technical guide for reducing concrete emissions in construction projects.[44]

In the following section, Ha/f Climate Design explores design interventions that could reduce both cost and carbon. Some of these make more significant changes to urban form and might not be possible on every site, but there are also many smaller changes that can be more easily implemented in existing designs.

Figure 6: interactions between design and material swaps cost effects



Research approach

In cooperation with a consortium of architects, building owners, and structural and geotechnical engineers, Ha/f Climate Design evaluated three existing buildings that were not initially built with an intention to reduce embodied carbon. For each of these buildings, interventions are studied that would have reduced the embodied carbon of these projects, while also reducing the overall cost.

The study questions fall into three broad categories:

- **Urban design,** including the massing of the buildings and how they are placed on the lot;
- **Architecture,** including wall-to-window ratios, facade materials, assembly methods, and simplification of the envelope; and
- **Structural engineering,** including foundation and structural systems, and excavation needs.

The case studies are a low-rise housing unit, a mid-rise, multi-unit residential building, and a high-rise, mixed-use residential and commercial building, all located in the Greater Toronto Area (GTA). As with the material costing study, the case studies were anonymized.

Ha/f Climate Design conducted life cycle assessments (LCAs) for the buildings, analyzing both baseline and low-emissions scenarios (with the baseline LCA for the high-rise completed by BDP Quadrangle). The scope of all LCAs included the structure and envelope, with the mid-rise and high-rise assessments also incorporating shoring (the use of a temporary structure to stabilize the soil during excavation) as a separate figure. The low-rise LCA was further expanded to include interiors and finishes. The assessments primarily covered life cycle stages A1-A5 (product to construction), but in some cases, the scope was expanded to include stages A-C over a 60-year service life. This broader analysis was used to evaluate the impacts of durability and replacement cycles.

More efficient design of a townhouse

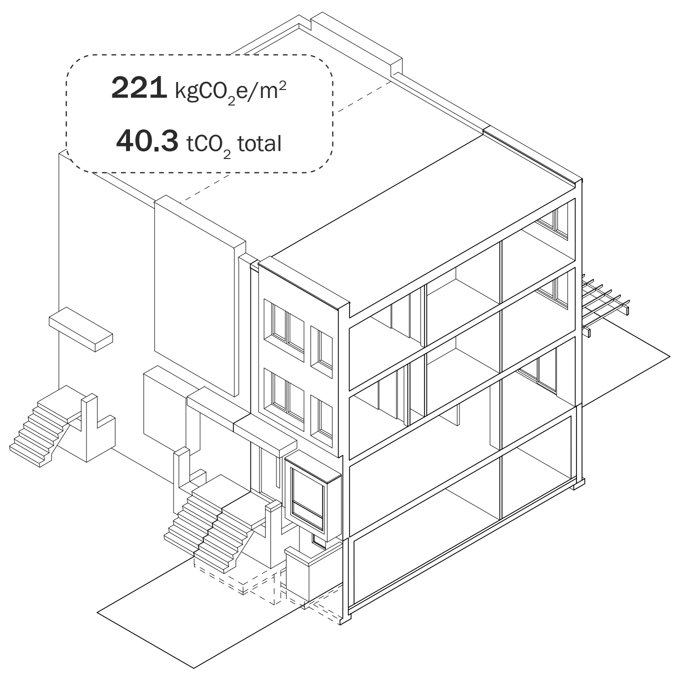
The original townhouse has an embodied carbon level of 221 kgCO_2e/m^2, or 40.3 tonnes CO_2e per townhouse.* That is the equivalent of approximately eleven years of operational emissions for a typical GTA townhouse heated with natural gas.[45]

Interventions

Four interventions were studied for this townhouse:

- **Urban design—a pitched roof made of low-carbon materials instead of a flat roof:** By moving to a pitched metal roof, the house's roofing systems last longer, are higher performing, and are far less likely to have water-related issues in the future, which can reduce emissions over the building's lifetime and enhance climate resilience.
- **Architectural—flattening the facade:** The original design featured 'pop-outs' around windows as a visual effect to distinguish units. Replacing the pop-outs with a contrasting colour of the base brick envelope assembly and using a single-plane of wall assembly simplifies construction, reduces material use, and allows for lower-carbon materials to be more easily employed.
- **Engineering—adjusting the basement structure:** Cast-in-place concrete foundation walls are now most commonly used in Canada, but replacing them with reinforced concrete masonry unit blocks (which used to be the industry standard) and limiting the height of the foundation can provide equal structural performance while significantly reducing the amount of material (and concrete specifically) that is needed.
- **Additional—removing the use of vinyl in windows and floors:** Switching vinyl plank flooring and vinyl window frames for engineered wood flooring and aluminum clad wood window frames can reduce carbon and has significant health benefits.

Figure 7: Baseline LCA results for the low-rise case study



* The total project comprises six townhouse units.

Impacts on carbon and cost

Together, the design interventions could **reduce embodied carbon by 26%**

Figure 8: Emissions savings from design interventions in low-rise case study

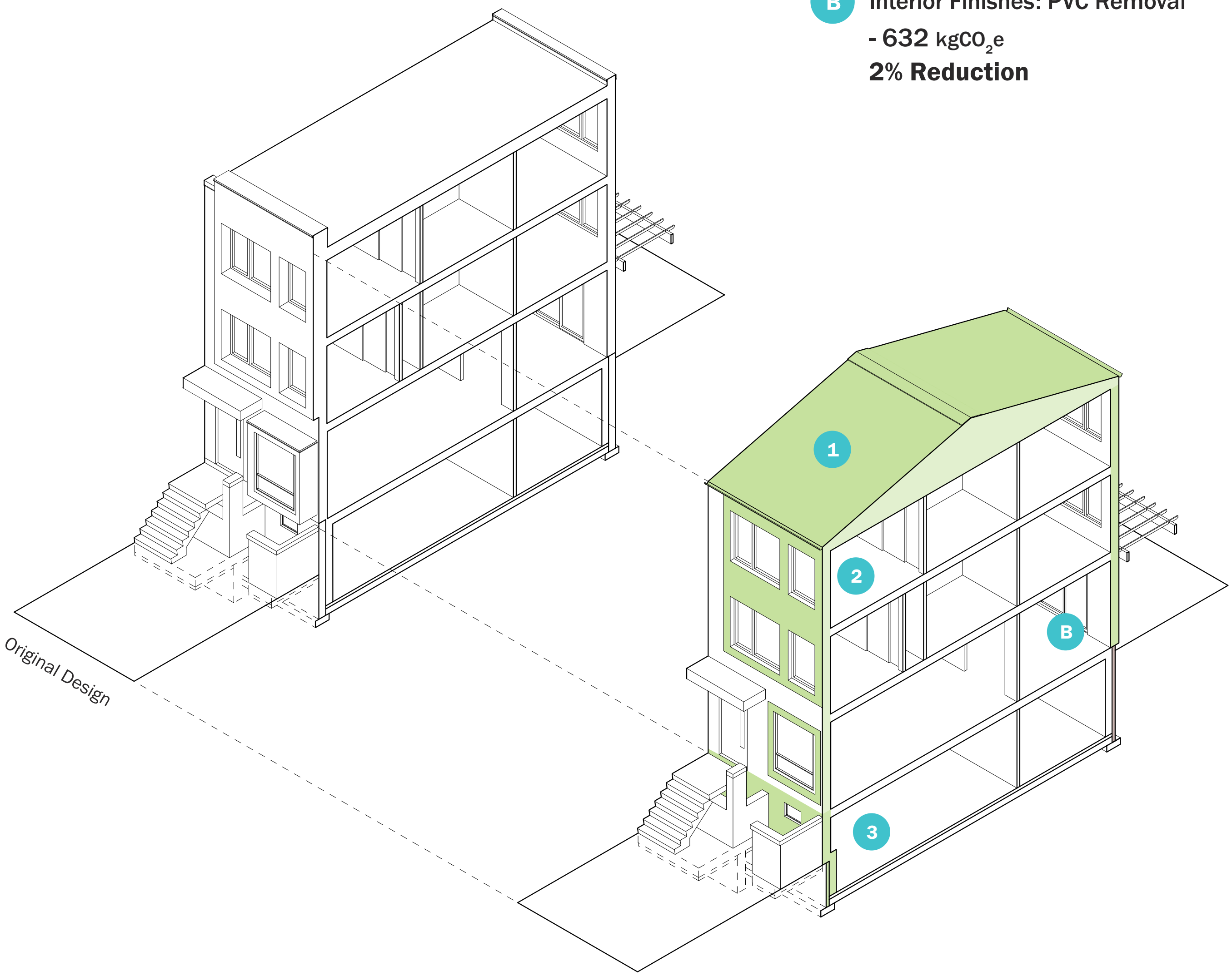
-27%
11 tCO_2e
Whole Building Reduction

1 Urban Design: Roof Form
- 337 $kgCO_2e$
1% Reduction
Over the entire lifespan of the building, this increases to: **- 1,156** $kgCO_2e$

2 Architecture: Envelope Efficiency and Materiality
- 4,694 $kgCO_2e$
9% Reduction

3 Engineering: Basement Structure
- 5,894 $kgCO_2e$
15% Reduction

B Interior Finishes: PVC Removal
- 632 $kgCO_2e$
2% Reduction



1 The pitched roof reduced the project's embodied emissions by 1%. Moving to a sloped roof required some additional materials including cavity insulation and drywall. However, the metal pitched roof will last longer than a flat roof and is more resilient to water issues. This means that there will be lower replacement costs over the lifetime of the building. In terms of emissions, it leads to a **lifetime carbon saving of 1,156 kgCO_2e**, more than triple the upfront emissions savings.

2 Flattening the facade and instead achieving desired visual outcomes through colour differentiation means that the assembly of the facade requires less material. This results in an **embodied carbon reduction of 9% for the project.** At the same time, it eliminates the cost of the material for steel framing (0.03 m^3 per unit) and wood panels (0.1 m^3 per unit). The original pop-outs also relied on carbon-intensive spray-foam and XPS insulation products, which can be avoided through this alternative design.

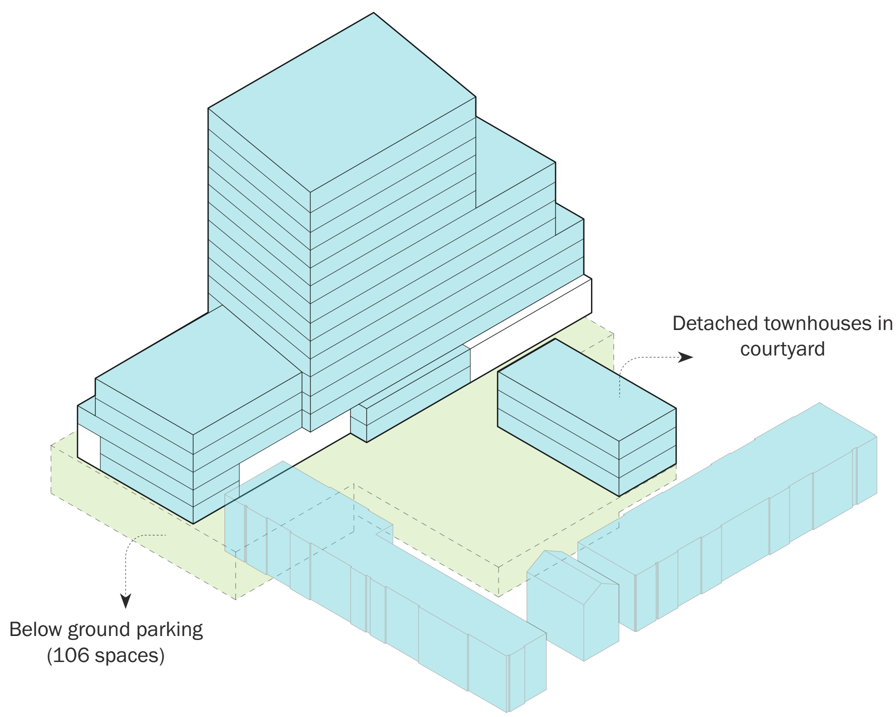
3 Replacing the concrete foundation walls with concrete masonry units saves 5,894 kgCO_2e in embodied carbon, a **15% reduction** for the entire project by starkly reducing the use of one of the most carbon-intensive materials. **The project saves 12.7 m^3 of cast-in-place concrete.** This is replaced by an additional 10.9 m^2 of brick cladding, so cost savings depend on the relative price points of these two materials.

B The project can **save an additional 2% of its embodied emissions** (632 kgCO_2e) by replacing carbon-intensive vinyl materials in the windows and floors with an aluminum-clad wood frame for the windows and engineered wood for the floors. In addition to reducing carbon, eliminating vinyl can have health benefits for the construction crew and occupants, as vinyl flooring contains chemicals that may present health risks during use and at the end-of-life stage.[46]

More efficient design of a mid-rise housing complex

This mid-rise multi-unit residential building has an original embodied carbon intensity of 410 kgCO_2e/m^2, totalling 7,205 tonnes CO_2e for the building (41 tonnes per apartment). That means the embodied emissions of these 174 apartments are equivalent to around 1,800 Canadians driving a gas-powered car for a year.

Figure 9: Baseline LCA for the mid-rise case study



Building

410 kgCO_2e/m^2

7,205 tCO_2 total

Shoring

42 kgCO_2e/m^2

740 tCO_2 total

Interventions

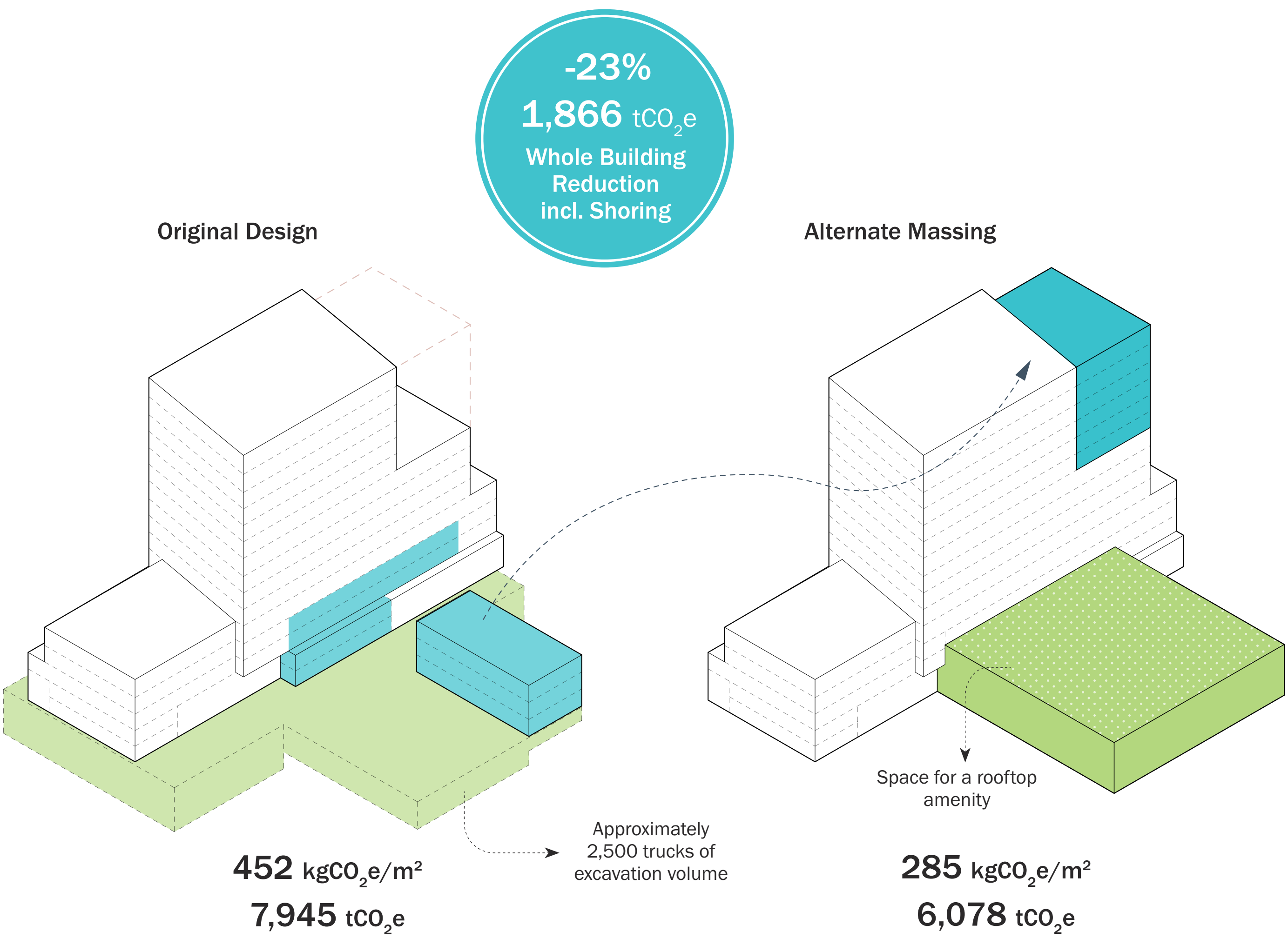
Three interventions were studied for the mid-rise housing complex:

- **Urban design—moving parking above ground:** By placing the parking at ground-level rather than underground, the building can avoid costly below-grade construction and a transfer slab, while maintaining the same number of housing units and parking spots.
- **Architectural—window-wall design:** Changing the material used in the window-wall system used for cladding can significantly reduce carbon without compromising thermal performance, appearance, and constructability.
- **Engineering—eliminating shoring:** By moving the parking garage above-ground, the project additionally eliminates the need for shoring, the material and carbon-intensive process of securing underground construction that is often left out of LCA calculations.

Impacts on carbon and cost

Together, the design interventions could **reduce embodied carbon by 41%**

Figure 10: Emissions savings from design interventions in mid-rise case study



	Original Design	Alternate Massing
Housing Area	1,309 m^2 (Townhouses Removed)	1,371 m^2 (Upper Floor Units Added)
Parking Spaces	116	125
Total Floor Area (incl Parking)	22,869 m^2	22,310 m^2

1 **Urban design—moving parking above-ground:** Moving the parking facilities from below-ground to ground-level **reduces the project's total embodied carbon by 16%** (1,126 tonnes CO_2e). These savings are largely attributed to the removal of a concrete transfer slab which would need to be placed between a below-ground parking garage and the above-ground structure. **Removing the transfer slab reduces the concrete volume of the building by 3% and the rebar weight by 4%. That would translate to savings of approximately $101,500 worth of concrete (not including any impact on labour costs) and $212,000 in rebar supply and install costs.** That would also open up room in the material budget to accommodate any potential premiums paid for lower-carbon concrete or rebar.

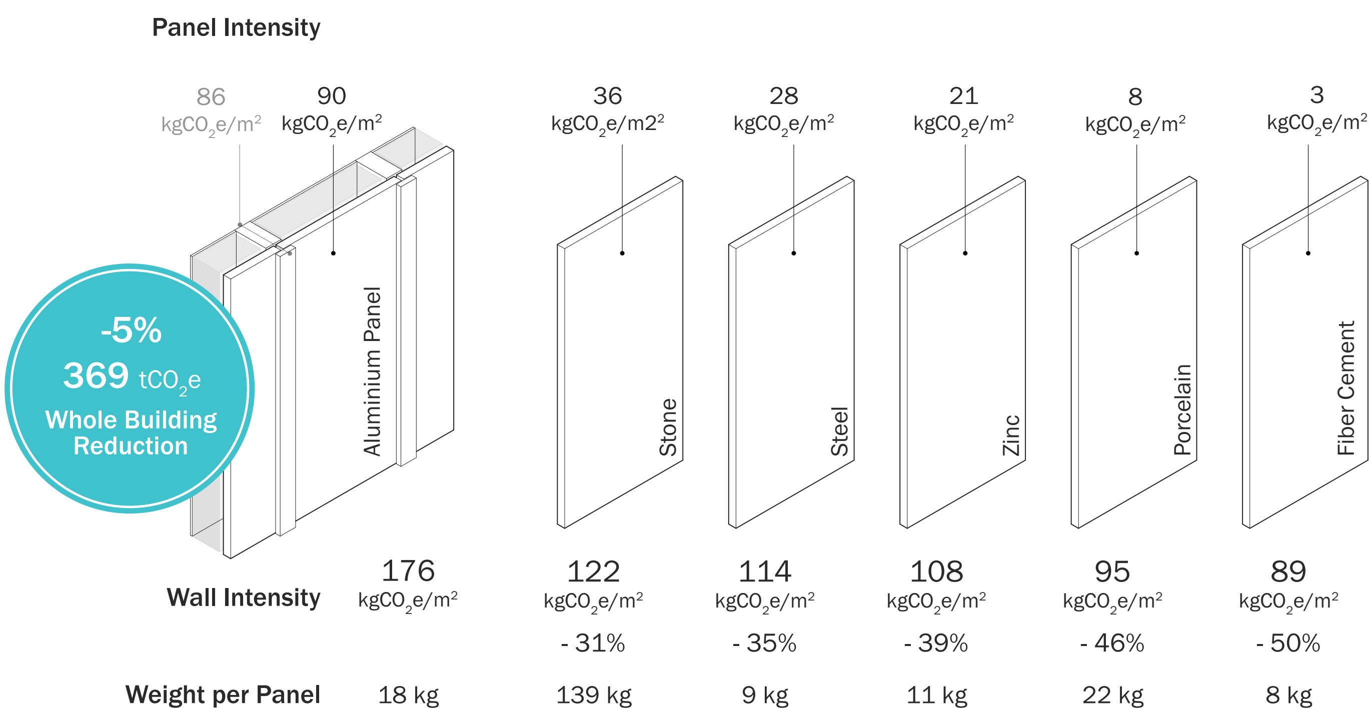
In addition to direct carbon and cost savings, the alternative massing provides a number of co-benefits. Most prominently, basements are at risk for flooding, which is becoming increasingly common with climate change causing rising storm severity. By moving parking above-ground, that risk is eliminated.

The new form increases the square meters of housing area by 5%. To accommodate ground-floor parking, the townhouses in this project are replaced with additional apartment units. While this is a change in use of the building, it may actually make the project more financially viable. The architects on the projects shared that in their experience, townhomes in this market are more difficult to sell pre-construction and are often the last to be sold.

This alternative massing maintains the same number of parking units (in fact adding nine additional spots), while reducing the amount of parking could reduce embodied carbon even further. The rooftop of the parking garage offers an additional opportunity for amenities or neighborhood benefits. The rooftop could be used, for example, for solar energy generation, urban agriculture, a park, or other resident initiatives, and could be designed for disassembly or conversion to future uses.

2 **Architectural—window-wall design:** Cladding, which is typically built using a window-wall system in multi-unit residential buildings in Toronto, can make up between 15-25% of total building embodied carbon.[47] High-carbon metals like aluminum typically make up the majority of opaque window wall systems, but there are many alternative materials available with much lower carbon impacts, including natural stone, steel, zinc, porcelain, and fiber cement. These offer

Figure 11: Embodied emissions of different window-wall systems



30-50% reductions to the whole wall system depending on the material selected. This could translate into a 5% whole-building reduction depending on the proportion of solid panels in the window-wall system.

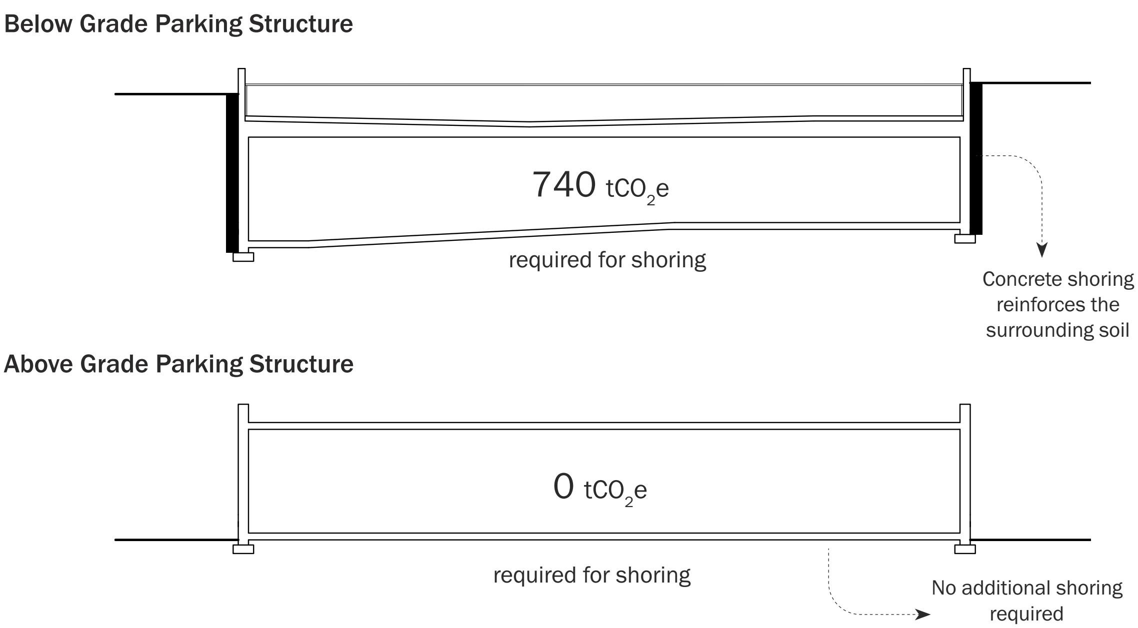
There are several lower-carbon options that a project could opt for, weighing other factors like price and local availability.

3 **Engineering—eliminating shoring:** Shoring is not commonly included in a whole-building life cycle analysis (wbLCA) quantifying the embodied emissions of a project. However, it can have a significant impact. In the original project, the concrete shoring used to reinforce the surrounding soil resulted in an additional 740 tonnes of CO_2e (equivalent to 185 gas cars over a year's time). By moving the parking facilities above-ground and eliminating the need for shoring, these emissions are avoided entirely.

In addition to avoiding emissions, this also means **the project saves the cost of 1,466 m^3 of concrete and 39,985 kg of steel.** In concrete costs alone, that would amount to approximately $365,000, in addition to savings in labour costs. These savings could be put toward any increases in material costs for using lower-carbon materials in the rest of the building.

In fact, the project may save even more on avoiding the cost and schedule implications of excavation. Digging below ground takes time and can provide additional safety risks. Clearing the space for underground parking would require approximately 2,500 trucks of excavation volume alone.

Figure 12: Embodied emissions savings from eliminating shoring



More efficient design of a mixed-use, high-rise tower

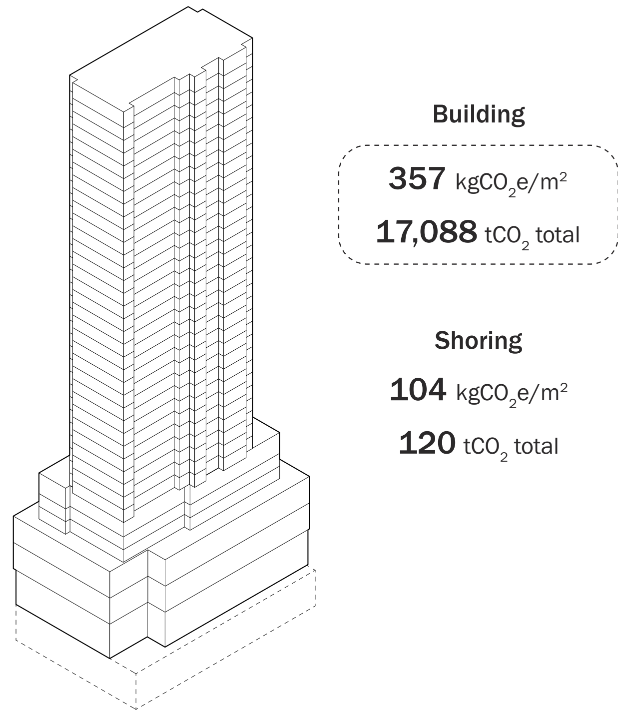
This 48-floor tower has mixed use. The bottom two floors (the podium) accommodate retail units with street access, while the top floors house one- and two-bedroom apartments, as well as some studio apartments (over 600 units in total). There are three levels of underground parking. The embodied emissions of the original building total 13,549 tonnes of CO_2e (22 tonnes per apartment). The total building's emissions are equivalent to 3,400 Canadians driving their gas-powered cars for a year.

Interventions

Three interventions were studied for the high-rise mixed-use tower:

- **Urban design—simplifying and shifting the tower:** Simplifying the structure and shifting the tower from the southwest to the northeast can create more efficient massing, reducing the sizing of transfer structures, and reducing the overall material requirements.
- **Architectural—simplified balconies and facade:** A simplified approach to balconies can lower the amount of wall material needed, lower window-to-wall ratios, and consequently reduce the embodied carbon.
- **Engineering—reusing existing foundation structures:** The site of the project contained an existing underground garage. By securing the old foundation wall, a thinner wall could be used for shoring instead of the typical thicker piled wall, avoiding material use for the excavation support system.

Figure 13: Baseline LCA for the high-rise case study



Impacts on carbon and cost

Together, the design interventions could **reduce embodied carbon by 26%**

1. **Urban design—simplifying the tower:** The different floors with different functions (parking, retail, housing) each have their own structure, but are stacked on top of each other in the tower. They each come with their own requirements and urban design guidelines on setbacks, floor sizes, and ceiling heights, which leads to high complexity. Because each layer has a different grid, the original design required thick concrete transfer slabs between the layers, which have a high level of embodied carbon. Additionally, the stacking of different grid structures makes it more difficult to use lower-carbon structural systems, such as mass timber or steel framing.

In the original project, the tower was placed on the southwest corner of the building in response to current urban design guidelines. This meant the tower was located directly on top of the retail floor area, creating a misalignment of structural grid spacing and requiring significant transfer slabs. By moving the tower to the northeast corner, where the loading areas of the building are, the grid sizes can be more consistent between floors, reducing or eliminating the need for transfers throughout the building.

Simplifying the tower and placing it on the other side of the building can reduce the total embodied emissions by 22%. This alternative design could also seriously **reduce the material budget, cutting the amount of concrete required for the structure by 22% and the amount of rebar by 13%.** It also cuts down on materials required for the envelope, including aluminum (12%), glass (12%), brick (7%), precast concrete (8%), and insulation (9%). **This would mean significant cost savings, including an estimated $1.6 million in concrete costs, $1.6 million for supply and install of rebar, and $260,000 in insulation costs.**

Figure 14: Emissions savings from design interventions in high-rise case study

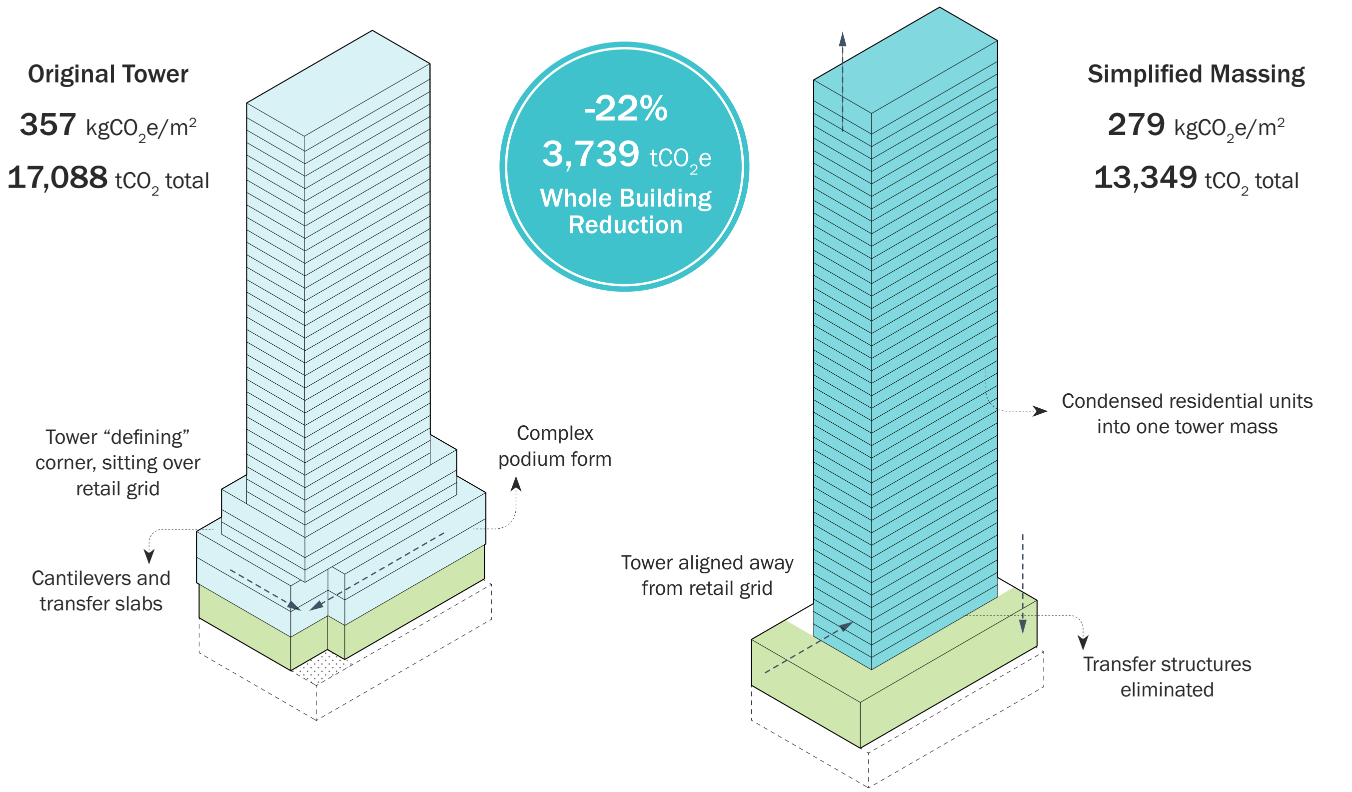
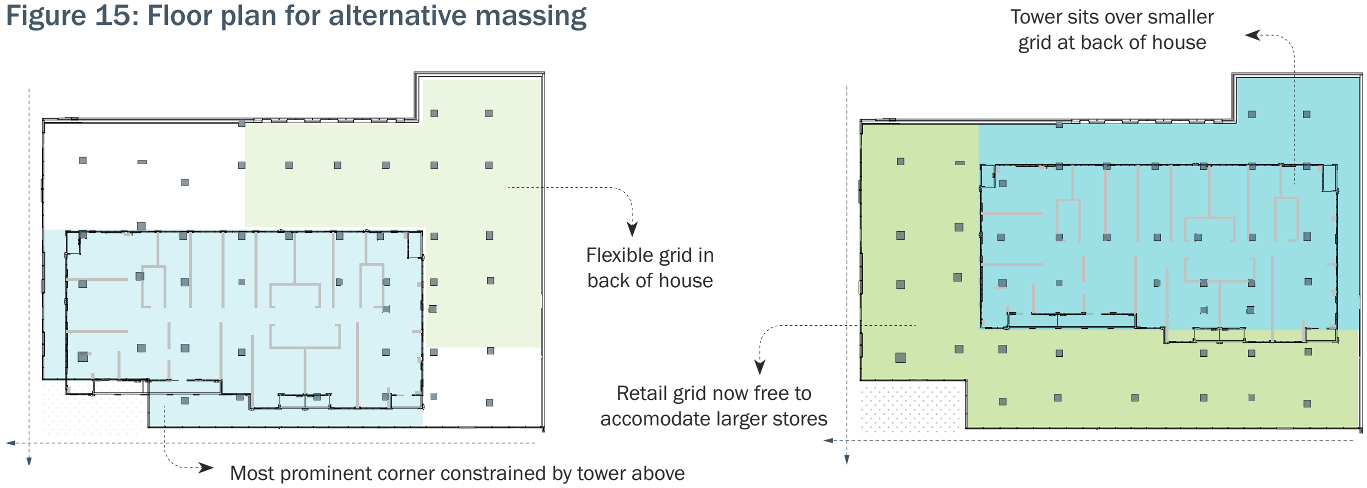


Figure 15: Floor plan for alternative massing

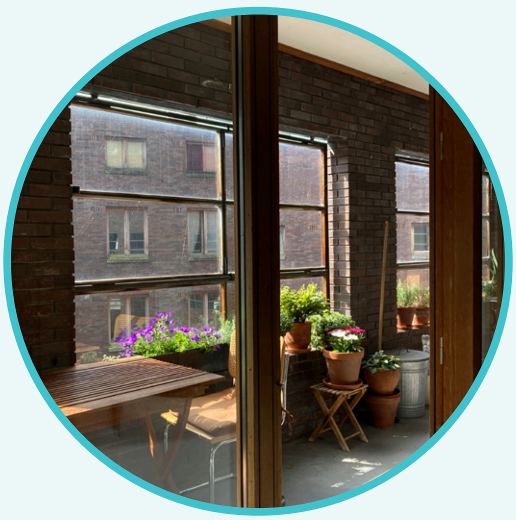


2 **Architectural—simplified balconies and facade:** Balconies are relatively commonplace in high-rise buildings in downtown areas. However, they are often relatively small and wind exposed (especially on higher floors) and not used for a significant part of the year in cold Canadian climates. The alternative design moves the floor area of the balconies into the interior space, creating larger units. This simplifies the outside wall to a flatter surface area. It effectively reduces the amount of envelope area required per unit.

By simplifying the outside of the building and creating larger indoor apartments, the **building could reduce its embodied carbon by 4%.** The simplified design would also save on materials for the envelope, **reducing the required amount of precast concrete panels by an additional 17%, the insulation boards by 16%,** and other materials including glass, brick, copper panels, and aluminum by similar shares.

The clearest co-benefit of this alternative design is that it provides residents with additional square meters of living space. Architects have been rethinking the concept of a balcony and have come up with new ideas for alternative half-open spaces that would require less material, increase

Figure 17: Examples of reimagined balconies



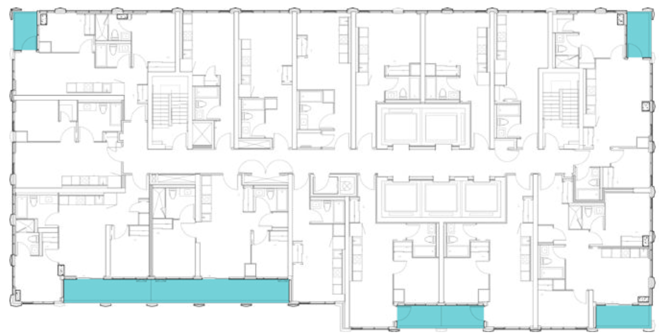
Photos (top to bottom): Quadrangle, Miriam Palmer, Kollhof + Pols

year-round floor space, and still provide the benefits of a balcony, such as room for plants or access to fresh air (see Figure 17).

Balconies can also be a source of heat loss, making the unit less energy efficient and more costly to heat. This alternative design has the added benefit of removing that thermal bridge.

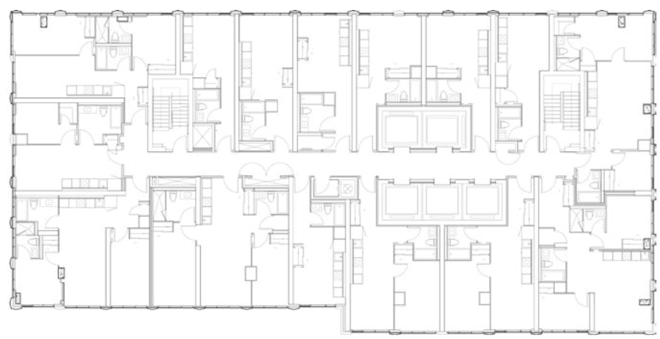
Figure 16: Floor plan for alternative facade design

Original Design



Building Floor Area	47,826 m²	**VFAR*** 61%
Linear Facade per Floor	4,725 m	

Alternate Massing



Building Floor Area	49,671 m²	**VFAR*** 51%
Linear Facade per Floor	4,965 m	

3 **Engineering—reusing the old foundations:** By working with existing underground structures, the multi-level basement could avoid the high cost and carbon that usually comes with building underground. Securing underground construction for a typical project of this kind would have led to approximately 40 times higher emissions from shoring, meaning that this intervention effectively **reduced 98% of embodied emissions from shoring.** It also saved on significant costs for material, with a **58% reduction in the amount of rebar** needed for shoring and a **14% reduction in Portland Cement,** as well as the time and labour cost of constructing entirely new foundations.

The reductions are very specific to this particular project and site, but it is illustrative of the fact that thinking about the site and any existing structures that may be reused can present great opportunities for saving cost and carbon.

* The VFAR is an indicator for how much outside surface area there is relative to floor area

Beyond material cost

In addition to quantitative and case study research outlined above, the research project involved engagement with experts from multiple disciplines, including architects, structural engineers, geotechnical engineers, and general contractors.

The experts agreed that in their experience working on construction projects, a reduction in embodied carbon generally does not come at a cost premium. In fact, lowering embodied carbon could well reduce overall construction costs when design choices are taken into account. However, reducing embodied carbon may still bring about some harder-to-measure costs as well as co-benefits. Some of these are outlined below.

Schedule impacts

A switch to low-carbon materials can require a slight change in schedule, for example if a low-carbon concrete mix has a longer curing time. Conversely, timing can also influence carbon. Scheduling concrete pours in warmer months, for example, can reduce embodied carbon.

Design choices can also positively impact the schedule. By simplifying the design of the tower and facade, the high-rise design case study would have significantly reduced the construction time. In the mid-rise case study, reducing underground construction greatly reduces material use and embodied carbon, and also saves time on excavation and shoring. Overall, experts pointed out that "designs that prioritize simplicity, repeatability, and sufficiency (not building more than what is needed) are inherently faster*" and that time is a big driver of project cost.

The cost of measuring carbon

Embodied carbon is a relatively new metric for construction projects to measure their success against. Quantifying or estimating embodied emissions is a new step in the construction process that requires additional time, reliable data and expertise, and adds a new line in the budget. For material producers, creating EPDs and updating these regularly also presents an additional cost and potential need for more personnel. On the other hand, demonstrated carbon reductions can be a selling point in the short term and in the longer term, as carbon reporting becomes increasingly standardized, time and financial costs are expected to decrease.

> **"Simplification of form and reduction of material is the most effective carbon reduction strategy and has a benefit to cost."**
>
> **Jeff Watson, P.Eng | Jablonsky, Ast and Partners**

* Quote by Juliette Cook | Ha/f Climate Design

“It’s easy for clients to be convinced what they’ve always done is fine, when minor changes that usually go unnoticed can make significant improvements at the same cost.”

Drew Adams, OAA | LGA Architectural Partners

Trade-offs between embodied and operational carbon

In recent years and the development of new building codes, there has been increased attention for energy efficiency and the emissions caused by a building’s operation, which mostly come from heating and cooling. Increasing insulation or using triple-glazed windows can prevent heat seeping out of buildings and thereby reduce the amount of energy needed to heat. However, this also means an increase in the use of carbon-intensive materials. With embodied carbon becoming an increasingly important share of building emissions, a full lifecycle approach to emissions needs to take into account the tradeoffs between operational carbon savings, increased material use, and embodied carbon. A Vancouver housing retrofit described in one of CLF BC’s case studies consciously used double-pane windows instead of triple-pane to save on embodied carbon while still achieving a relatively high level of energy efficiency.[48]

Expertise and project planning

Sometimes using alternative design practices or materials to lower embodied carbon may require additional training or expertise.

When it comes to construction crews on-site, experts said that generally the use of lower-carbon materials or designs is not a problem. A lower-carbon equivalent insulation board is installed the same way and concrete with higher SCMs generally pours similarly to traditional concrete. If low-carbon products are not in the early specifications of the product, however, there may be an issue with risk assumptions, especially where the material poses other considerations, such as thermal performance, fire performance, or warranty.

“A focus on performance-based specifications and requirements gives designers license to harness their expertise while still ensuring structures function as needed.”

Katie Castelo, P.Eng | Isherwood Geostructural Engineers

Careful planning is key, with embodied carbon as a metric of success from the early planning phases through the entire construction process. Case studies have shown that early coordination with all parties including the contractor is important for ensuring timely delivery of a low-carbon building.[49] Involving general contractors early and throughout the project, as well as planning seasonally, can also reduce the on-site fuel emissions from heating or transportation.

The hurdles in urban design guidelines and codes

While technical solutions exist to reduce embodied carbon, experts pointed out that “municipal zoning and urban design requirements can really limit lower-carbon design approaches.”* Sometimes inefficient building forms persist because of prescriptive measures like setbacks, maximum floor plate areas, and geodetic height maximums. In the mid-rise design case study, for example, the size of the upper stories was limited by the City of Toronto’s Tall Building Guidelines, leading to inefficient massing.

Ha/f Climate Design has worked with the City of Toronto on a comprehensive review of the unintended carbon impacts of urban design guidelines. They found a number of guidelines that make buildings more complicated, carbon intensive, and costly.[50]

The interviewed experts suggested a number of specific changes could go a long way. These include increasing maximum floor plate sizes and reducing or eliminating minimum parking requirements and the mandate for underground parking. Overall, experts in the sector recommend that guidelines be reformed to be performance-based rather than prescriptive, so that buildings can be designed efficiently, while meeting required levels of safety, daylight, wind, comfort, etc. Simplicity, consistency, and a focus on practical implication in provincial building codes can also help ease adoption of lower-carbon materials and design practices.

* Quote by Michelle Xuereb, OAA | BDP Quadrangle.

Takeaways for policymakers and project managers

Building out the housing and infrastructure we need while meeting our climate goals is possible, but will require increased attention to embodied carbon. If we do not adopt lower-carbon design practices and materials, building the housing we need could lock in 729 million tonnes of emissions by 2030 (more than a year's worth of Canada's total emissions).[5,25]

We already have the necessary made-in-Canada alternatives to reduce embodied carbon. This research provides clear evidence that **lower-carbon materials are available in markets across Canada at no or negligible cost premiums and large improvements can be made with better designs already within the toolkits of Canadian architects and engineers.**

What's more, **buying clean often means buying Canadian,** presenting an opportunity to support domestic producers in times of trade tensions. Construction materials manufactured in Canada are already lower-emissions than most imported materials and Canadian producers are developing innovative low-carbon solutions that are ready to be implemented in new buildings.

Even where small premiums do exist for lower-carbon materials, these can be compensated by reducing the project's overall material budget with optimized design.

Building more efficiently and reducing waste of high-carbon materials can significantly reduce cost and carbon. Combining considerations of design and material choices and thinking about embodied carbon early on when deciding on the shape of the building can lead to large savings in cost and carbon, as shown in the design case studies outlined in this report. By avoiding underground structures like basements and below-grade parking garages, designing to decrease or eliminate transfer slabs, avoiding shoring, and simplifying facades, the projects achieved overall embodied emissions reductions as high as 41%, while saving hundreds of thousands of dollars in material costs. At the same time, optimized design can make building projects quicker, safer, and higher-performance, and require shorter financing periods.

Recommendations

Policymakers at all levels of government can do their part to support low-cost, low-carbon housing and infrastructure while supporting Canadian suppliers by following these recommendations:

- **Implement Buy Clean policies** that set both material-specific and whole-building requirements for lower embodied carbon in government procurement processes to stimulate the market for made-in-Canada, low-carbon materials and incentivize the sector to design for lower embodied carbon. These policies can be implemented without generally increasing the cost of procured projects, as demonstrated by this research.
- **Ensure Buy Clean requirements are predictable, performance-based, and ramp up over time.** Performance-based requirements should be integrated into project specifications.
- **Build flexibility into material-specific requirements to account for variable markets.** Material-specific requirements could include a provision to exempt a project from requiring lower-carbon material equivalents if they exceed a certain premium (e.g. 2% of the structure budget).
- **Re-evaluate building codes, zoning, and urban design guidelines** to focus on performance rather than prescriptive requirements and remove guidelines that unnecessarily limit the options for lower-carbon design.
- **Provide financial support for the development of EPDs by smaller material producers** so that data does not need to be a barrier for building lower-carbon and complying with Buy Clean requirements.
- **Provide capacity building and clear implementation guidance for practitioners** to support uptake of practices that reduce embodied carbon.

Project managers can reduce embodied carbon without increasing project costs. They should:

- **Take a carbon budgeting approach to projects** by adding emissions as a metric for the project from the start, providing the time and mandate for project partners to think about the most accessible, low-cost solutions to reduce embodied carbon.
- **Engage all project partners early on,** from designers and structural engineers to the general contractor, so that projects can avoid material waste, optimize designs for cost and carbon, and plan for the effective implementation of low-carbon materials. It may also mean allocating more of the budget to improved design in order to save on budget for materials.
- **Encourage creativity in design.** While diverging from common designs may be expected to increase cost and prolong the schedule, it can actually reduce both budget and timelines by cutting unnecessary material use.

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Appendix: detailed material swap costing results

	Commercial				Industrial			MURB				TOTAL
	AB	BC	ON	Average	AB	BC	Average	AB	BC	ON	Average	Average
CONCRETE												
Concrete - precast												
Emissions reductions		3%		3%	5%		5%					**4%**
Cost premium per m³ concrete		0%		0%	0%		0%					**0%**
Cost premium as share of structure budget		0%		0%	0%		0%					**0%**
Concrete foundations												
Emissions reductions	12%	32%	28%	24%		20%	20%	15%			15%	**21%**
Cost premium per m³ concrete	2%	7%	0%	3%		3%	3%	16%			16%	**6%**
Cost premium as share of foundations budget	0%	0%	0%	0%		0.1%	0.1%	0.6%			0.6%	**0.1%**
Concrete slab on grade												
Emissions reductions	7%	27%	28%	21%	26%	10%	18%	32%			32%	**22%**
Cost premium per m³ concrete	0%	1.5%	0%	0.5%	0%	3%	1.5%	7%			7%	**2%**
Cost premium as share of structure budget	0%	0%	0%	0%	0%	0.1%	0.1%	0.1%			0.1%	**0%**
Concrete superstructure (above grade)												
Emissions reductions	8%	28%		18%	5%	20%	13%					**15%**
Cost premium per m³ concrete	0%	1%		-0.5%	0%	3%	1.5%					**0.5%**
Cost premium as share of structure budget	0%	0%		0%	0%	0.3%	0.1%					**0.1%**
Concrete superstructure (below grade)												
Emissions reductions	7%		24%	16%								**16%**
Cost premium per m³ concrete	0%		0%	0%								**0%**
Cost premium as share of structure budget	0%		0%	0%								**0%**
Concrete average emissions reduction	**9%**	**22%**	**27%**	**19%**	**12%**	**17%**	**14%**	**24%**			**24%**	**18%**
Average cost premium per m³ concrete	**0.6%**	**1.8%**	**0%**	**0.9%**	**0%**	**3%**	**1.5%**	**11%**			**11%**	**2.2%**
Concrete average of cost premium as share of budget category	**0%**	**0%**	**0%**	**0%**	**0%**	**0.2%**	**0.1%**	**0.3%**			**0.3%**	**0.1%**
DRYWALL												
Drywall - ceiling tile												
Emissions reductions	27%			27%								**27%**
Cost premium per m² drywall	0%			0%								**0%**
Cost premium as share of envelope budget	0%			0%								**0%**
Drywall - Type C												
Emissions reductions	25%	36%	4%	21%					29%	55%	42%	**30%**
Cost premium per m² drywall	0%	0%	0%	0%					0%	0%	0%	**0%**
Cost premium as share of envelope budget	0%	0%	0%	0%					0%	0%	0%	**0%**

	Commercial				Industrial			MURB				TOTAL
	AB	BC	ON	Average	AB	BC	Average	AB	BC	ON	Average	Average
Drywall - Type X												
Emissions reductions	13%			13%	4%	13%	8%	13%	15%	4%	11%	**10%**
Cost premium per m^2 drywall	0%			0%	0%	0%	0%	0%	0%	0%	0%	**0%**
Cost premium as share of envelope budget	0%			0%	0%	0%	0%	0%	0%	0%	0%	**0%**
Drywall average emissions reduction	**21%**	**36%**	**4%**	**21%**	**4%**	**13%**	**8%**	**13%**	**22%**	**30%**	**23%**	**20%**
Average cost premium per m^2 drywall	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Drywall average of cost premium as share of envelope budget	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
INSULATION												
Insulation - EPS												
Emissions reductions										42%	42%	**42%**
Cost premium per m^3 insulation										0.4%	0.4%	**0.4%**
Cost premium as share of envelope budget										0%	0%	**0%**
Insulation - Fibreglass												
Emissions reductions									51%		51%	**51%**
Cost premium per m^3 insulation									0%		0%	**0%**
Cost premium as share of envelope budget									0%		0%	**0%**
Insulation - Mineral wool												
Emissions reductions						60%	60%	49%	25%	16%	30%	**38%**
Cost premium per m^2 insulation						0%	0%	0%	0%	0%	0%	**0%**
Cost premium as share of envelope budget						0%	0%	0%	0%	0%	0%	**0%**
Insulation - Mineral wool batts												
Emissions reductions			19%	19%								**19%**
Cost premium per m^3 insulation			0%	0%								**0%**
Cost premium as share of envelope budget			0%	0%								**0%**
Insulation - Mineral wool board												
Emissions reductions			64%	64%								**64%**
Cost premium per m^2 insulation			0%	0%								**0%**
Cost premium as share of envelope budget			0%	0%								**0%**
Insulation - Polyisocyanurate board (HFO)												
Emissions reductions		2%		2%	69%	98%	83%					**56%**
Cost premium per m^2 insulation		0%		0%	0%	0%	0%					**0%**
Cost premium as share of envelope budget		0%		0%	0%	0%	0%					**0%**
Insulation - Polyurethane spray												
Emissions reductions		73%		73%								**73%**
Cost premium per m^2 insulation		0%		0%								**0%**
Cost premium as share of envelope budget		0%		0%								**0%**

	Commercial				Industrial			MURB				TOTAL
	AB	BC	ON	Average	AB	BC	Average	AB	BC	ON	Average	Average
Insulation - XPS												
Emissions reductions	14%		96%	55%	91%		91%					**67%**
Cost premium per m^2 insulation	30%		0%	15%	0%		0%					**10%**
Cost premium as share of envelope budget	0.1%		0%	0%	0%		0%					**0%**
Insulation average emissions reduction	**14%**	**38%**	**60%**	**45%**	**80%**	**79%**	**79%**	**49%**	**38%**	**29%**	**37%**	**51%**
Average cost premium per m^2 or m^3 insulation	**30%**	**0%**	**0%**	**5%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0.2%**	**0.1%**	**2%**
Insulation average of cost premium as share of envelope budget	**0.1%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
STEEL												
Structural steel - cold-rolled												
Emissions reductions	100%		100%	100%		48%	48%					**83%**
Cost premium per kg steel	0%		0%	0%		0%	0%					**0%**
Cost premium as share of structure budget	0%		0%	0%		0%	0%					**0%**
Structural steel - hot-rolled												
Emissions reductions	16%	10%	67%	31%		10%	10%	67%			67%	**34%**
Cost premium per kg steel	0%	0%	0%	0%		0%	0%	11%			11%	**2%**
Cost premium as share of structure budget	0%	0%	0%	0%		0%	0%	1%			1%	**0.2%**
Steel average emissions reduction	**58%**	**10%**	**83%**	**59%**		**29%**	**29%**	**67%**			**67%**	**52%**
Average cost premium per kg steel	**0%**	**0%**	**0%**	**0%**		**0%**	**0%**	**11%**			**11%**	**1.4%**
Steel average of cost premium as share of structure budget	**0%**	**0%**	**0%**	**0%**		**0%**	**0%**	**1%**			**1%**	**0.1%**
REBAR												
Rebar - standard												
Emissions reductions	3%		7%	2%	28%	46%	37%	3%	53%		28%	**21%**
Cost premium per kg rebar	0%		0%	0%	0%	80%	40%	0%	23%		11%	**17%**
Cost premium as share of structure budget	0%		0%	0%	0%	6%	3%	0%	0.6%		0.3%	**1%**
Rebar average emissions reduction	**3%**		**7%**	**2%**	**28%**	**46%**	**37%**	**3%**	**53%**		**28%**	**21%**
Average cost premium per kg rebar	**0%**		**0%**	**0%**	**0%**	**80%**	**40%**	**0%**	**23%**		**11%**	**17%**
Rebar average of cost premium as share of structure budget	**0%**		**0%**	**0%**	**0%**	**6%**	**3%**	**0%**	**0.6%**		**0.3%**	**1%**
Total Average emissions reduction	21%	26%	42%	30%	33%	36%	35%	30%	34%	29%	31%	**31%**
Total Average of Cost premium per material unit	2.9%	0.9%	0%	1.4%	0%	10%	6%	6%	5%	0.1%	4%	**3%**
Total Average of Cost premium as share of budget category	0%	0%	0%	0%	0%	0.7%	0.4%	0.3%	0.1%	0%	0.2%	**0.1%**

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