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ORIGINAL ARTICLE

Making embodied carbon mainstream: a framework for cities to leverage waste, equity, and preservation policy to reduce embodied emissions in buildings

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Abstract
With anticipation building around embodied carbon as a "new frontier" of climate policy, it may appear that cities need to develop a whole suite of dedicated institutions and mechanisms to support its implementation. However, to do so risks placing an undue burden on already overstretched local and regional governments. Instead, embodied carbon policy can build on existing priorities that already galvanize resources and attention and have benefited from decades of policy development. Making strong links to a larger urban agenda offers a way to forge buy-in from a wide range of stakeholders. Current visions for embodied carbon policy broadly fall into two categories: (1) material substitution strategies, or technical solutions that incrementally reduce emissions, and (2) demand reduction strategies, more transformative solutions that avoid emissions. Both of these areas have strong ties to existing urban strategies for waste, equity, and preservation. Foundations in waste policy include increasing waste diversion, expanding green demolition, and increasing material efficiencies. Foundations in equity-oriented policy include retrofitting affordable housing, workforce development for deconstruction, and building lower carbon, lower cost housing. Foundations in preservation policy include incentivizing building reuse, supporting the use of low carbon materials for retrofits, and encouraging vertical infill. Amplifying existing policy efforts can bring substantive embodied carbon reductions to the forefront, leapfrogging a long technical start-up phase for implementing stand-alone embodied carbon policy.

Keywords Embodied carbon · Built environment · Mitigation · Urban planning · Climate governance

Introduction

Globally, leading practitioners in the construction sector are well-equipped to reduce greenhouse gas (GHG) emissions from heating and cooling buildings. Of course, this does not always translate into practice, weakening mitigation efforts. At least as importantly, many ambitious efforts to achieve zero emission buildings neglect the underlying emissions from extracting, processing, transporting, and disposing of building materials, typically known as embodied carbon. In conventional classifications of CO_2, buildings comprise a hefty 39% of the global total. And a full 11% of that total is due to embodied carbon from buildings (Architecture 2030 2020; Global Alliance for Buildings and Construction et al. 2018; Pak 2019). If operational emissions continue to decline, embodied carbon will account for an increasing proportion of building emissions. In conventional buildings, embodied carbon accounts for approximately 25% of the impact, but in high efficiency buildings, the share of embodied carbon can be upwards of 50% (Röck et al. 2020). Net zero targets for the building sector have begun to include both operational and embodied emissions on the premise that buildings can only be considered "decarbonized" when embodied carbon is eliminated (Canada Green Building Council 2021).

Infrastructure is another major challenge. As more roads, bridges and wastewater treatment plants are built, concrete consumption rises in tandem. Concrete consumption is expected to increase from 4 billion tonnes per year to 5 billion tonnes per year in the next 30 years (Lehne and Preston 2018). Some analysis suggests that taken together, the embodied carbon of construction materials in buildings and

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infrastructure makes up 23% of global emissions (Global Alliance for Buildings and Construction et al. 2018). As this perspective begins to register within the construction industry, embodied carbon is emerging as an important component of the climate agenda for local and regional governments (Brandmayr et al. 2018; Broekhoff et al. 2019).

In response, leading city networks and green building organizations have been shaping a policy vision. They have laid out a roadmap for built environment stakeholders to meet milestones on the path to net zero carbon by 2050 (Adams et al. 2019) and they have made a financial case for redevelopment and the flexible, adaptable use of buildings, or "buildings as a service"(Arup and Ellen MacArthur Foundation 2020; Urban Land Institute Greenprint 2019). One recent framework assembles specific policy measures for cities, ranging from requiring low carbon products to "redefining the solution." This could mean, for example, maximizing the use of under-utilized spaces in place of new construction (Carbon Neutral Cities Alliance et al. 2020). There is no silver bullet: a wide array of these strategies will need to be used together (Pomponi and Moncaster 2016). Acting alone and in networks, cities may wield influence beyond their borders through their role in shaping demand in global supply chains (Brandmayr et al. 2018).

Before this latest round of policy leadership, urban organizations and researchers had been elevating the profile of consumption-based, or Scope 3, emissions for at least a decade (Chavez and Ramaswami 2011; Ramaswami et al. 2011). Accounting for consumption-based emissions often more than doubles a city's footprint (C40 Cities et al. 2019; Doust et al. 2018). Shifting standard emissions accounting practices may be too onerous at the international level; but for cities, simplified methods of consumption-based accounting can be feasible (Broekhoff et al. 2019) At the local level, this can be a practical lens to inform decision-making and help prioritize climate action.

Current strategies for tackling embodied carbon

Dominant approaches to embodied carbon in the building sector fall under material substitution and demand reduction strategies. In general terms, material substitution strategies reduce embodied emissions through incremental technical solutions that shift business as usual construction toward greener production and consumption. Demand reduction strategies avoid embodied emissions through more transformative solutions such as widespread building and material reuse and shifting land use norms that challenge growth-based economies and high-consumption lifestyles (Fig. 1). Both approaches face social and technical hurdles; however, they are beginning to be integrated into land use plans, zoning, and building codes, laying the groundwork for more transformative change. While some in the building sector place more emphasis on one or the other, many take a holistic approach that considers them as complementary.

Material substitution

Material substitution strategies typically represent an incremental approach that *reduces* embodied carbon. This includes methods such as substituting lower carbon and carbon sequestering materials for conventional construction materials. It can also mean reducing overall material use by modifying the fabrication of individual building components and designing for material efficiency at the whole building scale.

Low carbon materials include lower carbon concrete (Carbon Smart Materials Palette 2021),[1] steel produced in an electric arc furnace, and timber produced from sustainably harvested wood. At times, these materials can become "carbon positive," sequestering more carbon in a material such as timber than was emitted in the extraction and manufacturing process (Churkina et al. 2020). Lower carbon concrete and mass timber are becoming more common in Canada and beyond as municipal and provincial codes now enable them (Bland 2020; Government of B.C. 2022). Synergies may be found in using them together; for example, building with mass timber allows for lighter concrete foundations.

Material efficiencies include avoiding oversizing structural components, using concrete technologies which reduce the use of concrete per unit area,[2] using offcuts, eliminating construction waste, and prefabrication in a controlled factory setting. Reducing materials may conflict with energy efficient construction which requires thicker assemblies; this tradeoff would need to be accounted for in the analysis of operational and embodied carbon for a given project.

Demand reduction

Demand reduction strategies *avoid* embodied carbon by reducing resource extraction and repurposing materials already in circulation. For the built environment, demand

[1] Concrete can be produced with a "supplementary cementitious material" such as fly ash or slag instead of Portland cement, reducing emissions by 20–50% depending on the percentage used in the cement mix.

Lower energy intensity kilns and furnaces powered by renewable energy can also reduce emissions. These strategies are central to Buy Clean policies in the USA.

[2] Biaxial slab systems such as bubble deck require less material by replacing concrete with voids (bbdna.com).

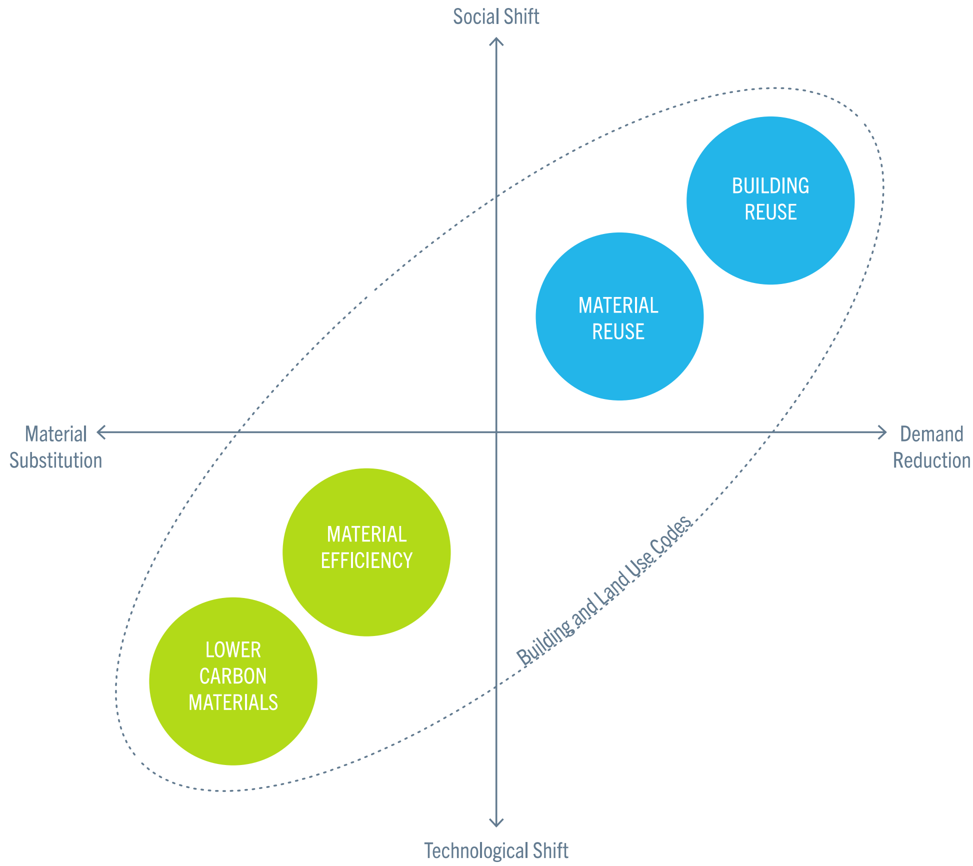

Fig. 1 Embodied carbon strategies range from material substitution to demand reduction. Material substitution strategies tend to involve technological developments that produce incremental emissions reductions. Demand reduction strategies involve more transformative shifts in construction and land use practices

reduction strategies include not only salvaging and reusing building materials, but re-using the core and shell of existing buildings. This type of material reuse, and to some extent building reuse, has recently gained attention as part of the circular economy toolset (Arup and Ellen MacArthur Foundation 2020; Lynch 2022; Sparandara et al. 2019). Achieving a significantly circular economy would entail a massive shift from disposability to durability, largely in high-income countries (Environment and Climate Change Canada 2021). But the feasibility of this also rests on reducing material throughput as the material currently in circulation cannot meet growing demand. In North America, this would require demand reduction through a shift in building and land use norms such as reducing the building area per occupant, prioritizing efficient occupancy of existing buildings, and removing provisions for private transportation. Material substitution presents a significant hurdle to the transition to a net zero built environment, entailing a shift in production, engineering, building codes, and construction practices to mainstream low carbon materials (Dell 2020). But demand reduction will be equally if not more significant. This aspect has so far received insufficient attention within the suite of climate action tools because it would require a greater cultural transformation away from high-consumption lifestyles (Creutzig et al. 2018; Dale et al. 2020; Heikkinen et al. 2019; Wiedmann et al. 2020).

At the building scale, the primary means for achieving demand reduction is reusing the existing building stock through flexible space management, retrofits, and adaptive reuse (Elefante 2012; Frey et al. 2011; Hasik et al. 2019). Salvaging and recycling building materials through deconstruction is another essential component of demand reduction. Much typical waste diversion actually results in downcycling, so serious deconstruction efforts focus on achieving material reuse at the highest level possible (Nunes et al. 2019). Implementing this effectively at scale requires experience and expertise across the value chain in steps from physically reclaiming materials to inspecting and regrading them (Lamb-Yorski 2021). It also requires significant industrial space to warehouse materials and the logistics systems to facilitate their reuse, such as material passports.[3] Material reuse can extend from buildings into infrastructure; for example, salvaged concrete from construction and

[3] Material passports are typically digital documentation of the characteristics of building components that facilitate their recovery and reuse. They are most commonly used in the Netherlands which has a more advanced circular economy sector (metabolic.nl/news/circular-economy-materials-passports/).

demolition waste can be repurposed for road bases and potentially even paved surfaces (Maduabuchukwu Nwakaire et al. 2020).

Codes and standards

All of these approaches can be influenced through procurement, land use policy, zoning and building codes, and waste management plans (Bionova Ltd 2018; Circle Economy 2019; National Zero Waste Council 2019; Zizzo et al. 2017). For example, requests for proposals (RFPs) for public buildings can require low carbon materials, building codes can permit the use of salvaged and regraded material, and zoning can require or incentivize building reuse. Rating systems such as LEED and the Living Building Challenge include credits for low carbon materials, and these can be directly integrated into local policy as requirements. Leading policies in North America provide examples of how to take steps toward requiring deconstruction, waste diversion, low carbon materials, and whole building life cycle assessment. The cities of Portland and Vancouver require deconstruction for older single-family homes. The Buy Clean California Act establishes maximum Global Warming Potential for steel, glass and insulation in public construction (State of California 2017) while Marin County California goes further with a Low-Carbon Concrete Code (County of Marin 2019). These early incremental steps are providing a foundation for wider uptake.

An integrated framework building on urban sustainability policies

In spite of high-level commitments from global players, it is unclear how the vision for embodied carbon policy will translate into practice, especially for organizations and cities that are not already dedicated to climate action. In response, this investigation focused on how, why, and to what effect local and regional governments in British Columbia were implementing embodied carbon policy. However, it became apparent that outside of the City of Vancouver, and perhaps Metro Vancouver, there was very little momentum. For governments and organizations with lower capacity, the prospect of yet another climate agenda item risked shutting down conversations, let alone policy development. Consulting with 31 built environment stakeholders in the public and private sector in Metro Vancouver and the Capital Regional District (the Victoria region), analyzing plans and policies, and reviewing current best practices led to reframing the question: how can local governments pursue reductions in embodied carbon even without dedicated, robust technical infrastructure?

This research revealed opportunities for local governments that do not have in-house GHG accounting specialists and life-cycle analysis capacity. Instead of developing a whole suite of dedicated institutions and mechanisms, local government staff have opportunities to build on existing priorities that already galvanize resources and attention.[4] In particular, waste, equity, and preservation are common local government priorities for which there is also strong evidence of embodied carbon reductions (Bergman et al. 2010; Doran 2021; Frey et al. 2011; Hasik et al. 2019; Nunes et al. 2019; Stephan and Crawford 2016). Building on these foundations to bring embodied carbon from the margins to the mainstream offers multiple benefits.

First, highlighting the co-benefits of common practices and expanding them creates an opportunity to tangibly reduce embodied carbon (Bain et al. 2016; Karlsson et al. 2020). Local governments across the spectrum from high capacity to low capacity cities can accelerate action with this approach. However, for lower capacity cities where there tends to be significantly less climate action, this feasible pathway can be especially impactful (Haupt et al. 2022; Homsy 2018; Shi et al. 2016). Integrating embodied carbon with existing practices builds on evidence for strategies to buttress capacity including building relationships between departments, involving practitioners as local experts, building intermunicipal linkages, engaging with city networks, and relying on proxy data (Alm et al. 2021; Caldwell et al. 2021; Krause and Hawkins 2021; Lesnikowski et al. 2021; Oke et al. 2022). In addition, cities with low growth can reframe what is conventionally seen as a disadvantage as an opportunity to make progress: centering demand reduction, they can focus on requiring and incentivizing upgrades to their existing building stock.

This mainstreaming approach offers benefits for climate leaders as well. Making strong links to a larger urban agenda offers a way to forge buy-in from a wide range of stakeholders and build coalitions with interest groups already taking a stand around waste, equity and preservation to advance climate justice (Klinsky and Mavrogianni 2020; Tozer 2020). Finally, local governments can use this momentum to enhance their role as climate champions, taking responsibility for emissions beyond their own borders (Baker 2018; Solecki et al. 2018).

Waste

Zero waste goals have become a feature of local policy over the last decade (Eco-Cycle Solutions 2016). While this serves environmental objectives, it has more tangible

[4] This strategy was initially outlined in a guide for local and regional governments in North America (Teicher 2021).

urgency because landfills across North America are reaching capacity and will have to either be closed or expanded (Ontario Waste Management Association 2018; Waste Advantage Magazine 2018). Even in a region like Metro Vancouver where construction and demolition waste diversion is high, it still comprises a quarter of the waste going to local landfills (Metro Vancouver 2019). In addition to capacity constraints, landfills present risks of contaminating groundwater, compromising air quality, and degrading habitat. As part of the drive to "zero waste," the circular economy movement proposes that materials already in circulation should be repurposed, largely replacing extraction (National Zero Waste Council 2021). Waste strategies can help reduce embodied emissions in three main ways: material salvage, green demolition, and more efficient construction methods.

Equity

Equity has recently gained new urgency as rising income inequality, xenophobic nationalism, and conspicuous racism galvanize political attention. As housing prices have climbed exponentially in cities across North America, low- and moderate-income residents have been increasingly squeezed out of urban centers (Klachkin et al. 2022; Le et al. 2022). Calls for global climate justice and local environmental justice highlight the connections between multiple forms of discrimination, rising emissions, and vulnerability (Schlosberg and Collins 2014). In the policy world, this has motivated development of various Green New Deals, an increasing focus on housing affordability, and attention to the disparate impacts of energy infrastructure and industrial emissions on marginalized communities (Aronoff et al. 2019; Brinkman and Miller 2021; City of Vancouver 2022). Equity-centered policy can reduce embodied emissions through several strategies including affordable housing retrofits, inclusive workforce development and lower cost, lower carbon residential construction.

Preservation

Heritage preservation has been a persistent interest for cities and neighborhood advocates for decades, if not centuries. Given this long history, the definition of heritage has expanded beyond nineteenth century stone edifices to encompass mid-century modern buildings and beyond (Tyler et al. 2018). Preservation extends beyond heritage conservation to adaptive reuse, renovation, retrofits, and even maintenance. All of these can contribute to a larger vision of sustaining culture and a sense of place through maintaining historic layers in the urban fabric, values which have frequently been integrated into zoning and development plans (Kalman and Letourneau 2020). Preservation strategies can help reduce embodied emissions through building reuse, low carbon retrofits, and vertical infill.

Fig. 2 Embodied carbon policy can build on existing priorities. This approach is rooted in demand reduction (blue bands) and can be enhanced with material substitution strategies (light green band). Building on waste, equity, and preservation policy can make embodied carbon a more mainstream concern

Years of policy development in waste, equity, and preservation can serve as a foundation for embodied carbon policy (Fig. 2). All three of these areas coalesce in an emerging model of growth that veers toward the circular economy, shifting energy and resources to retrofit and reuse. This can contribute to a larger economic transition, supporting lower consumption, and creating demand for additional expertise and labor throughout the building sector.

Strategies in waste, equity, and preservation

Building on waste pathways

Material salvage

Waste regulations are more comprehensive than green demolition bylaws so contractors have found they have a greater impact on waste diversion. However, both approaches could be significantly expanded. Currently, waste is only regulated in limited jurisdictions and for some materials. For example, Metro Vancouver introduced a clean wood ban[5] in 2015. Typically, the success of waste management is measured by the diversion rate rather than the end use of materials; material reuse is not carefully tracked, if at all (National Zero Waste Council 2021). Displacing the use of newly extracted materials with materials already in circulation has been demonstrated to reduce emissions (Nunes et al. 2019), so pursuing that benefit even without strict emissions accounting would represent a substantive action. Simple estimates of emissions reductions are becoming more accessible with online tools available to estimate the avoided emissions of building reuse (*BEAM* Estimator 2023; Caretool.org 2023). In addition, material reuse presents an indicator of climate action that could be simpler to track and measure than emissions accounting because it does not require the same level of technical expertise.

Green demolition

Green demolition regulations that mandate diversion and deconstruction are still relatively rare in North America. Existing deconstruction requirements in Portland, Oregon and Victoria and Vancouver, British Columbia concentrate on older single-family homes, representing a small fraction of demolition waste (City of Victoria 2023; Elliott et al. 2020; Nunes et al. 2019). This is justified by the assumption that older buildings contain the most valuable materials and that processing and storage capacity is insufficient for a greater volume of material (Badelt 2018; Falk 2002). Across BC, houses were often constructed with old growth timber through the 1970s, so there could be great value in reclaiming those materials. Recent lumber supply shortages and price spikes demonstrate that even newer recovered materials could have substantial value (Montgomery 2020). Additional cities are beginning to explore deconstruction, encouraging rather than requiring it. For example, the City of Seattle implemented a pilot deconstruction incentive program in October 2022 which is open to residential, wood-framed buildings (Seattle Public Utilities 2023). Reinforcing this effort, King County developed sample design specifications for construction waste management and building deconstruction (King County 2023). Palo Alto, California, is an outlier in requiring deconstruction of all residential and commercial projects that require a demolition permit (City of Palo Alto 2023).

Material salvage and reuse is acknowledged to emit less than conventional demolition, but further analysis of precise quantities would be necessary to determine results for a specific region (Chase 2010). One study of the relative impact of new lumber for framing and flooring found a greater global warming potential (GWP)[6] of three times and five times on average than reclaimed lumber across various regions (Bergman et al. 2010). If the woody biomass used to fuel kilns for drying the new wood were also taken into account, the GWP would rise to 10 to 16 times more than reclaimed wood. While some argue that burning wood is carbon neutral, that is increasingly disputed as it neglects the long timeframe for forests to adequately reabsorb carbon as well as the need for responsible forest management (Daley 2018; Harvey and Heikkinen 2018; Schlesinger 2018).

As one of the earliest jurisdictions to implement a deconstruction ordinance, the City of Portland has been able to study the results. Analyzing material salvage from 36 houses, they found that deconstruction yielded a net benefit of 7.6 tonnes of CO_2 equivalent per house (Nunes et al. 2019). This benefit is largely a result of avoiding production of new materials and carbon sequestration in wood. At 100 houses a year, they equate this to removing 161 cars from the road.[7] In Portland, the highest salvage rate was most strongly correlated with the level of contractor experience rather than house age or size. That suggests that where green demolition does occur, further training and capacity building are necessary (Badelt 2018; Dalo 2020). Both deconstruction workers and engineers would need to further develop methods and skills for effectively salvaging and reusing materials. A new program in "zero waste buildings" at the British Columbia Institute of Technology provides an example of the type of training that could facilitate this. Deconstruction hubs, or depots for the storage and marketing of reclaimed materials, would also need to scale up, providing adequate space to store, sort, and display the increased volume of materials (Elliott et al. 2020).

While single-family deconstruction could be significantly expanded, other building types represent an opportunity as well. Multifamily, commercial and industrial buildings could be tested with pilot projects to determine the salvage potential for different building types and to inform the reuse market (Sparandara et al. 2019). A recently formed network of building professionals, All for Reuse (All for Reuse 2020), is developing an agenda for the reuse of commercial building materials and could help support this effort. For all building types, developing technical capacity and a sizable market for salvaged material remains challenging (Light House Sustainability Society 2021), though organizations such as the Habitat for Humanity Rebuild Hub serve as nascent examples.

[5] This policy added a surcharge on loads of garbage containing over 10% clean wood, that is solid wood, lumber, and pallets that are unpainted, unstained, free of glue and untreated but which may be pierced with nails or other metal fasteners.

[6] In Bergman study cited, GWP is calculated as carbon dioxide and methane over a 100-year time horizon.

[7] These results do not directly translate to other regions given differences in building materials and recovery rates.

Efficient construction

Best practice for new construction includes waste management, commonly integrated into green rating systems. This tends to focus on minimizing demolition and construction waste, but can also extend to "right-sizing" structural and mechanical systems and prefabrication in a controlled factory environment. Putting material efficiency into practice will likely incur an innovation premium as it initially requires more time in the design and construction phases. For example, building with voided biaxial slabs, or concrete slabs with air bubbles, should theoretically cost less due to the lower volume of concrete, but can still cost more because it is not the industry standard (Gismondi 2018). However, just as in other areas of green building, materially efficient construction provides benefits over the long-run even if it incurs additional upfront costs (Zhang et al. 2018). Until this benefit is factored in, incentives and financing mechanisms could support more efficient building.

Deconstruction in practice: unbuilders

In 2014, the City of Vancouver passed its first Green Demolition Bylaw. Subsequent amendments expanded the requirements to full deconstruction of homes built before 1910 and reuse and recycling of 75% of materials by weight for houses built before 1950 ("Vancouver Green Demolition Bylaw Expanded," 2018). As a Passive House contractor focused on sustainable building in Vancouver, Adam Corneil had become aware of the substantial amounts of old-growth lumber going to the landfill in the process of residential demolition. Given these concerns, and with the Green Demolition Bylaw creating a feasible business model, he founded Unbuilders in 2018. It has since become the dominant deconstruction company in the Lower Mainland of BC (Lam 2022). Since demonstrating the viability of this business, Corneil has also served as a policy entrepreneur in cities across Canada including Calgary, Toronto, and Halifax; he advocates for regulations to prevent construction and demolition waste going to landfill and demolition regulations as the most effective policy levers (Caulfield 2021). Employing a green development lens, the Vancouver Economic Commission now touts deconstruction as a massive untapped business opportunity which not only reduces landfill needs but reduces embodied carbon (Elliott et al. 2020; Vancouver Economic Commission 2021). This case demonstrates how the appropriate regulatory environment can create tangible benefits that are recognizable even without detailed GHG accounting.

Building on equity pathways

Retrofit affordable housing

To reduce direct emissions from heating and cooling, governments, NGOs, and utility programs have directed some retrofit programs to lower income housing to enhance equity (Reames 2016; Tsenkova 2018). Taking embodied carbon into account, retrofitting affordable housing would reduce emissions even more than previously considered. As of 2020, BC Housing is adopting this strategy through the Reframed Lab initiative, (BC Housing 2020) and a Toronto-based organization facilitates the retrofit of mid-century affordable housing towers across Canada (Santopinto and Stewart 2020), an effort that could be scaled up further (discussed below).

Workforce development

Training and capacity building to salvage materials can address equity in addition to waste. Workforce development policy could target both skilled and unskilled labor pools for demolition, material salvage, and processing needs. Researchers and policy-makers project that the deconstruction industry would generate five to eight jobs in place of a single job in machine demolition (Chase 2010; Elliott et al. 2020; Sparandara et al. 2019). This approach could benefit workers dislocated by the transition away from fossil fuels and increasing automation. It also offers an opportunity to build on alliances between environmental and labor organizations which are already developing around "buy clean" policy and the green economy (Blue Green Canada 2021).

Build lower carbon housing

Retrofitting existing housing will not fulfill current housing demand given the absolute lack of supply. As of 2020, the US had a housing supply shortage of 3.8 million units, and this has been exacerbated during the pandemic (Badger and Washington 2022; Khater 2021). Similarly, Canada would require an additional 3.5 million housing units by 2030 in addition to the 2.3 million already projected to be built in order to restore housing affordability (CMHC 2022). For new multi-family housing, one relatively simple, immediate way to reduce embodied carbon is through material substitution such as replacing concrete and steel with wood. In 2009, British Columbia passed the Wood First Act which requires provincially funded projects to use wood as the primary construction material and also revised the building code to permit six-storey wood-frame residential buildings (Frey 2018). Quebec has similarly revised building codes and implemented supportive provincial policy to foster a high-value forestry sector and reduce the carbon footprint of buildings (Government of Quebec 2020). In 2018, the Washington State Building Code Council revised its code to allow mid- and high-rise mass-timber construction up to 18 storeys (Pacheco 2018). In Maine, a Mass Timber Commercialization Center is promoting the industry with the support of a grant from the US Economic Development Administration. A medical school building under construction there is projected to reduce embodied carbon 28% below a baseline building with conventional materials (Shemkus 2022). In 2022, BC launched a Mass Timber Action Plan highlighting the potential for economic development and innovation in addition to replacing concrete and steel for lower carbon construction. As of mid-2022, 307 mass timber buildings ranging from office towers to university residential facilities had been built (Todd 2022). While this is still a small fraction of new building, high-rise mass timber construction supported by pilot projects, government grants, and supportive building codes is resetting the default away from carbon intensive materials. Prioritizing lower carbon materials can provide the additional benefit of reducing toxic emissions from manufacturing which disproportionately impact marginalized communities (Healthy Building Network 2019).

For more transformative change, local land use policy can be a tool to reduce embodied carbon. In multi-family housing development, underground parking requires a major outlay of concrete and can cost upwards of 40,000 USD per space (Doran 2021; Long 2016). Avoiding this expense can be a means to build more affordable housing in urban areas if the cost savings are passed on to residents. In Metro Vancouver, in areas with high transit access, parking is already overbuilt (TransLink and Metro Vancouver 2019). Where underground parking is eliminated, this move would have to be accompanied by robust alternative transportation options. Limiting dwelling unit size can also be an important, and often overlooked, carbon reduction strategy (Stephan and Crawford 2016; Toronto Environmental Alliance 2020). This can often be achieved through densifying the existing building stock and can be built into reporting through measuring emissions per capita rather than per floor area. For new construction, cities may consider regulations for residential construction that include floor area maximums per capita in addition to minimums. Affordable housing agencies already tend to regulate the minimum area of units based on the number of bedrooms; sometimes, maximums are included as well (BC Housing 2019; Oregon Housing and Community Services n.d.). Extending this to market rate units could help to moderate the emissions of high-consumption households (Cohen 2021; Karlen et al. 2022).

Equity in practice: tower renewal partnership

Post-war apartment towers form an essential supply of purpose-built rental stock in cities across Canada, housing over half of Canadian high-rise households. Many of these units serve lower income and marginalized populations, but their livability and affordability are increasingly threatened by rising utility costs and deferred maintenance. The Tower Renewal Partnership, a cross-sectoral collaboration of architecture, research, and social purpose organizations, advocates for renewing these buildings through deep retrofits. The Ontario-based organization analyzes policy options across Canada, engaging with social housing agencies about their retrofit strategies (Santopinto and Stewart 2020).

Putting Tower Renewal into practice, ERA Architects is currently transforming the Ken Soble Tower, a once deteriorating 18-storey multi-residential building from 1967, into a model of renewed social housing. When CityHousing Hamilton was deciding how to address the decline of their oldest high-rise, they determined that a low energy retrofit would be the most cost-effective option (Case Study: Raising the Bar on Community Housing Retrofits n.d.). With the project designed to a Passive House standard, operational GHGs have been modeled to decline by 94%. At the same time, a consultant's back of the envelope calculation showed that if the upgraded building had instead been replaced with a new building, it would take 180 years to offset the additional carbon.

The project was primarily motivated by creating healthy, resilient housing; however, reducing embodied carbon helped make the case. When social housing agencies confront decisions about their aging housing stock, avoiding embodied carbon offers an additional benefit on top of avoiding displacement of vulnerable populations and saving on construction costs through retrofits (Affordability and Resilience: The Challenge of Tower Renewal in Private Rental Apartment Buildings 2020). Spillover benefits also accrue beyond the individual buildings, as projects like this increase demand within a larger retrofit economy.

Building on preservation pathways

Building reuse

Life cycle assessment is more commonly applied to new construction; however, several studies have assessed the impact of retrofitting buildings, generally finding lower environmental impacts (Ghisellini et al. 2018). One study of a whole range of building conversions across the US found that in almost every case,[8] reusing buildings reduced climate impacts compared to energy efficient new construction. Depending on the building type and grid mix, it can

[8] Except warehouse to multifamily residential because of the quantity and type of materials used to improve energy efficiency in this building type.

take from 10 to 80 years for new construction to compensate for climate impacts as compared to an upgraded existing building (Frey et al. 2011; Hasik et al. 2019). These studies bear out the notion that "the greenest building is one that is already built (Elefante 2012)." A study of a new conventional residential development in Finland revealed that over the 50-year time horizon relevant to climate targets, the emissions from a comparable renovation were 35% lower. In light of medium-term climate targets and the carbon spike produced with new construction, this research shows that building new runs counter to climate targets (Säynäjoki et al. 2012). Working from this premise, the Climate Heritage Network collaborated with Architecture 2030, the Carbon Leadership Forum and others to develop a simple, accessible life cycle assessment (LCA) tool that allows municipalities or project teams to make the determination "to build or not to build" for themselves. The tool allows comparisons of the carbon impact of building reuse, green retrofits, and new construction (Caretool.org 2023; Climate Heritage 2020).

Limiting the construction of new floor area is virtually guaranteed to avoid emissions (Ness 2020; Seton et al. 2019), but demand for new space will persist. Therefore, new construction could be leveraged to create a financial reward for building reuse. Incentives for retrofit and reuse could be funded through a tax or fee on embodied carbon for new development. Making reuse financially more attractive than new construction would offer significant leverage to avoid carbon expenditures (Calder 2020). In addition to financing, zoning and development planning can be more actively leveraged to meet the expanded intent of reducing emissions. Zoning bylaws can incentivize the retention and conversion of zero lot line buildings by allowing additional uses or more density than would otherwise be approved in that location. Where development decisions are discretionary, building reuse can be given greater weight than other factors. To achieve substantive reuse rather than simple preservation of historic facades, reuse would need to be defined rigorously to include the structure, envelope, and other reusable components. Where buildings are preserved, full occupancy would deliver the greatest carbon benefit. For public and private building owners, this would depend on a commitment to strategic asset management (Ness 2020).

While preservation offers an opportunity to avoid carbon emissions, historically it has also been considered a problematic tool of NIMBYism (Cheong 2021). In the name of preservation, wealthy communities have condemned efforts to remedy the widespread housing shortage and to build affordable housing (Bertolet 2017; Cortright 2022). In addition, investment in historic districts may cause gentrification and displacement, though the effects are inconclusive due to limited studies (Avrami 2016). In response to the unequal effects of preservation, both real and perceived, equity-centered preservation is beginning to emerge in practice (Cheong 2021; Lephew and Gajewski 2022). Centering equity as part of the preservation agenda can move preservation toward being a more comprehensive vehicle for sustainability.

Low carbon retrofits

In renovations, materials matter. Using carbon-intensive materials can undermine the benefit of retrofitting over building new (Frey et al. 2011; Hu 2020). This highlights a key opportunity for low carbon materials to be used in building retrofits. For example, residential retrofits could incorporate cellulose insulation and commercial retrofits could include lower carbon drywall and flooring. Existing programs that offer incentives and rebates for energy efficiency upgrades could be refined to offer greater incentives for lower carbon materials. Replacing mechanical systems presents an opportunity to mitigate leaks and use newer refrigerants with lower global warming potential (Rodriguez Droguett 2019). For major retrofits, municipalities could adopt existing user-friendly tools and guidelines such as Builders for Climate Action's BEAM carbon estimator tool (*BEAM* Estimator 2023) to nudge developers toward lower carbon material choices.

Vertical infill

Another way to bridge the gap between demand for new space and building reuse is with vertical infill, or building on top of existing buildings. This is already common practice in some cities that are highly built out where real estate is at a premium. Where existing bearing capacity is adequate, this can be an efficient way to add new space. This type of infill helps to avoid the additional embodied carbon associated with new foundations and new infrastructure and can also be constructed with lower carbon materials.

Preservation in practice: the Friedman building renewal

With its stark modernist façade, the Friedman building is a far cry from conventional notions of heritage. Yet, the University of British Columbia administration took the opportunity to retrofit this building for 75% of the cost of a new build, transforming dingy 1961 anatomy labs into a state-of-the-art physiotherapy training facility. In 2006, when the project began, avoiding embodied emissions per se was not one of the project goals, though reducing construction waste was part of the plan for achieving a LEED Gold rating. In a 2010 review of the project, the Vancouver Heritage Foundation posed embodied energy[9] as a factor in considering the energy efficiency of replacing versus rehabilitating existing windows. They also noted that reusing the building resulted in 1.5 million kg of waste diverted from the landfill, and avoided emissions of 822 tonnes of CO_2 (Vancouver Heritage Foundation 2010).

Funding for the project came from the UBC Renew Program, a UBC/provincial/federal partnership which extended the life of twelve buildings by an additional 40 years for just over half the cost of new buildings. The goals of the program were to preserve heritage buildings, address deferred maintenance, reduce environmental impacts, and save money (Poohkay 2016). In retrospect, maintaining the steel and concrete block also represented a significant savings of embodied carbon.

Agenda for research and practice

The integrated embodied carbon strategies discussed here are similar to those recommended elsewhere (Brandmayr et al. 2018; Carbon Neutral Cities Alliance et al. 2020; Doust et al. 2018), but heavily emphasize pathways for lower capacity cities and demand reduction over material substitution. These strategies are ripe for greater uptake by local governments through mechanisms that have been shown to enhance sustainability capacity such as building relationships between departments, involving practitioners as local experts, building intermunicipal linkages, engaging with city networks, and relying on proxy data (Alm et al. 2021; Caldwell et al. 2021; Krause and Hawkins 2021; Lesnikowski et al. 2021; Oke et al. 2022). In some areas, additional research could help cities, especially those with lower capacity, take these strategies further.

Building on waste pathways

Policy and practice recommendations

- Advocate for regional and state authorities to develop sample waste regulations which are ready for local government adoption.
    - Borrow best practices for diverting construction waste from the landfill such as material restrictions and putting a price on waste from jurisdictions that have already implemented these measures.[10]
    - Track and publicize material salvage and reuse.
- Collaborate with local contractors and other construction industry stakeholders to identify and overcome barriers to green demolition and deconstruction requirements.
- Work with local economic development agencies to position deconstruction as a business opportunity.
- Partner with local organizations to facilitate informal and formal material salvage infrastructure and markets.

Research recommendations

- Analyze barriers and enablers for green demolition requirements for commercial construction.
- Develop efficient methods for rating salvaged materials so they can be used to their highest potential, i.e. as structural members rather than finishes.

Building on equity pathways

Policy and practice recommendations

- Partner with affordable housing providers to identify the embodied carbon co-benefits of maintaining existing affordable housing.
    - In local discussions of affordable housing, highlight the embodied carbon co-benefits.
- Work with local economic development agencies on workforce development for deconstruction and material reuse, prioritizing the employment needs of lower-income communities.
    - Work with local institutions of higher education and technical institutes to develop these programs.
- For new housing development, remove requirements for underground parking and reduce overall parking requirements.
- For new residential construction, consider introducing a maximum floor area per capita with a fee for area exceeding that maximum.

Research recommendations

- Analyze the community economic development potential of large-scale salvage and reuse.
- Review, synthesize, and establish equity indicators for emissions per capita to inform embodied carbon reporting.

[9] There is not a one to one correlation between embodied energy and embodied emissions because the energy source dictates the emissions levels, but they represent related concepts.

[10] This has already been done in some jurisdictions in BC including Metro Vancouver and the Capital Regional District.

Building on preservation pathways

Policy and practice recommendations

- Adopt existing tools to compare emissions of new construction and retrofit to inform development approvals.
    a In development decisions, give building retention greater weight based on embodied carbon benefits in addition to other preservation benefits.
- Work with local financial institutions to incentivize retrofits over new construction with favorable lending terms.
- Lead by example with public facilities, maximizing the use of existing facilities, favoring retrofit over new construction in public procurement, and using low carbon materials for retrofits
- Collaborate with green preservation networks to build knowledge and capacity.

Research recommendations

- Perform economic analysis of adaptive reuse and flexible leasing models for the commercial real estate industry to develop business cases for extending the life of existing buildings.
- Develop reference standards for embodied carbon by building type and assembly to inform municipal fee structures.
- Analyze the embodied carbon effects of building electrification policy, for example the impact of refrigerants in heat pumps commonly sourced for fuel switching.

Conclusion

As a new climate policy area, embodied carbon can be daunting to tackle. Building on existing foundations in waste, equity, and preservation will make it more feasible while also delivering co-benefits. Even where precise emissions accounting is impractical, applying an embodied carbon lens can be useful in evaluating order of magnitude trade-offs. Retrofitting high-rise rental buildings can help to preserve affordable housing, enabling adaptive reuse can preserve historical character and expanding material salvage can divert waste from landfills, all while reducing embodied carbon. These methods to bring embodied carbon from the margins to the mainstream are not necessarily simple, but within the current policy landscape they are achievable. They all contribute to maximizing the value of the carbon already sunk into the built environment. And if they are taken to their full potential, they can lay the groundwork for the more transformative change implied in tackling embodied carbon. The building industry will not be decarbonized—nor will cities or countries reach their net-zero targets—unless these underlying emissions are eliminated.

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Declarations

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