Policy Strategies to Support Innovation in New Housing Construction

Kevin Lockhart, Brendan Haley

Efficiency Canada

Carleton University

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University 1125 Colonel By Drive
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About the authors

Kevin Lockhart is the City of Toronto's Program Manager of Public Energy Initiatives for Existing Buildings. Previously, he acted as Efficiency Canada's Director of Buildings Policy. He holds an MPP in sustainable energy policy and a BA in political science from Carleton University. He also completed and instructed in the Advanced Housing: Construction Carpentry program at Algonquin College. Kevin has contributed several publications to the sector, including Strengthening Canada's Building Code Process to Achieve Net Zero Emissions and Codes4Climate, Canada's first online resource connecting building codes as a tool for climate action.

Brendan Haley is Senior Director of Policy Strategy at Efficiency Canada and adjunct research professor at Carleton University's School of Public Policy and Administration. He has a background in promoting innovative energy efficiency policy solutions, including advocacy for the creation of Canada's first energy efficiency utility (Efficiency Nova Scotia) while at the Ecology Action Centre, founding an energy poverty advocacy organization (Affordable Energy Coalition), leading the writing of Efficiency Canada's Retrofit Mission report which proposes an innovation-oriented approach to building retrofits, authoring academic publications on topics such as moving utility demand side management towards a low-carbon transition governance paradigm. He completed a

Public Policy PhD at Carleton University relating systems of innovation and Canadian political economy approaches to Canada's low-carbon transition, a Bachelor of Science in Economics from Dalhousie University, a Master of Environmental Studies (ecological economics) from York University, and was awarded the prestigious Banting Postdoctoral Fellowship in 2016-2018.

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About Efficiency Canada

Efficiency Canada is the national voice for an energy-efficient economy. Our mission is to create a sustainable environment and better life for all Canadians by making our country a global leader in energy efficiency policy, technology, and jobs. Efficiency Canada is housed at Carleton University's Sustainable Energy Research Centre, which is located on the traditional unceded territories of the Algonquin nation.

Summary

A new paradigm of housing construction is needed to deliver the housing necessary to address Canada's housing crisis. To address affordability concerns, Canada must build 3.5 million more new homes by 2030 than would otherwise be built, assuming current trends. Yet, the current new housing construction sector faces several headwinds, including labour force constraints, rising costs and long lead times in production, low productivity and low investment in new technologies. Innovation in construction practices is needed to overcome these challenges.

At the same time, we cannot afford to miss the opportunity to build new housing that is energy efficient and minimizes environmental impact. Even if we manage to scale up new housing construction to resolve the present affordability crisis, using today's building standards will lock in 12.9 megatonnes of greenhouse gas emissions each year those buildings are in operation.[1] Given the long lifetime of a typical new house, missing this one-time opportunity will make Canada's national emission reduction targets even more challenging to meet.

Innovation studies have demonstrated that technological change is systems change, requiring new assemblages of multiple technologies, problem sets, institutions and actors. Like other technological systems, new housing construction has evolved around and optimized to solve a particular issue. Consequently, new practices, problems, and policies can be challenged to break through and revolutionize the system's operation. A new residential housing construction paradigm is needed to realize the industry's potential to build sufficient housing and the opportunity to build it in a way that realizes energy efficiency and environmental goals.

Four sets of technologies are particularly promising for increasing the potential of housing construction and realizing the opportunity to build efficiently with minimal impact. These include increased use of pre-manufactured building components, built off-site and transported to new developments, increased use of biogenic materials, like

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[1] Lockhart and Simon, "Building for Tomorrow".

mass timber, which can reduce embodied carbon in mid-size buildings, adopting and utilizing a range of new digital technologies to model buildings, streamline approval processes, address complex work site issues and finally, exploring new avenues for delivering thermal energy and electrification, such as district heating and cooling.

A single innovation alone will not be enough to scale up new housing construction and orient it toward Canada's climate goals–a coordinated, multi-pronged policy approach is needed. While the aforementioned technologies are not necessarily 'new,' they have not been adopted in such a way as to significantly change how new housing is constructed. To realize the full potential of such technologies and processes, a comprehensive, supportive policy regime must be built around them to "bring it all together" provide certainty to the industry, coordinate investment and market development, and set goals for energy efficiency and environmental impact.

Standardization: A national standardized design catalogue is an opportunity to create a policy "push" to encourage the development of new combinations of technologies, policies, and business models. This would define a new problem set for the construction of a technological system and lead to substantial incremental learning, improvement, and refinement.

Codes and standards: Few instruments in the federal government's current climate toolbox can be as effective in transforming the market and accelerating innovation for net-zero energy or net-zero emissions buildings as building codes. Modernizing building codes for innovation could include developing specific code requirements to enable prefabrication or modular builds, mass timber, or to allow for single egress for multi-family buildings.

Retrofit opportunity: Innovation in new construction can help to alleviate similar challenges in the retrofit industry by freeing up labour for inherently more complicated renovation work or by developing practices in the use of digital tools that are transferable to this sector. Taking a "mission-oriented" approach to the retrofit challenge is necessary, including implementing building performance standards to guide the work toward desired policy outcomes.

All levels of government in Canada have tools at their disposal to help create and nurture innovation in new housing construction in the pursuit of policy goals. The federal government can play a role in setting standards of excellence, supporting research and development, providing clarity and guidance through codes and standards, creating frameworks to ensure needed data is available, and embedding a principle of circularity in policy and programs. Local governments have a role to play in acting as "solution providers" by de-risking early-stage solutions or creating markets through procurement processes and guiding new housing construction toward more transit-oriented communities.

Résumé

Un nouveau paradigme pour la construction est requis afin d'offrir le nombre de logements nécessaires pour faire face à la crise du logement au Canada. Afin de répondre aux préoccupations liées à l'abordabilité, le Canada doit construire, d'ici à 2030, 3,5 millions de nouvelles maisons de plus qu'il ne le ferait autrement, compte tenu des tendances actuelles. Pourtant, à l'heure actuelle, le secteur de la construction de logements neufs fait face à plusieurs obstacles, notamment les contraintes liées à la main-d'œuvre, la hausse des coûts et les longs délais de production, la faible productivité et le faible investissement dans les nouvelles technologies. Les pratiques de construction ont besoin d'innovation pour surmonter ces défis.

Par ailleurs, nous ne pouvons pas nous permettre de rater l'occasion de construire de nouveaux logements éconergétiques qui réduisent au minimum les incidences sur l'environnement. Même si nous parvenons à intensifier la construction de nouveaux logements pour résoudre la crise actuelle de l'abordabilité, l'application des normes de construction actuelles mobilisera 12,9 mégatonnes d'émissions de gaz à effet de serre chaque année, là où ces bâtiments seront en exploitation. Compte tenu de la longue durée de vie d'une nouvelle maison typique, le fait de manquer cette occasion unique rendra encore plus difficile l'atteinte des objectifs nationaux de réduction des émissions du Canada.

Des études sur l'innovation ont démontré que le changement technologique va de pair avec un changement de système, ce qui nécessite de nouveaux assemblages de technologies multiples, d'ensembles de problèmes, d'institutions et d'intervenants. À l'instar d'autres systèmes technologiques, la construction de nouveaux logements a évolué et a été optimisée pour résoudre un problème particulier. Par conséquent, de nouvelles pratiques, de nouveaux problèmes et de nouvelles politiques peuvent être mis à contribution pour percer et révolutionner le fonctionnement du système. Un nouveau paradigme de construction résidentielle est nécessaire afin de permettre à l'industrie de construire un nombre suffisant de logements tout en atteignant les objectifs en lien avec l'efficacité énergétique et l'environnement.

Quatre ensembles de technologies sont particulièrement prometteurs pour accroître le potentiel de la construction de logements et saisir l'occasion de construire efficacement, avec une incidence minimale. Il est notamment question d'une utilisation accrue d'éléments de construction préfabriqués, construits hors chantier et transportés vers de nouveaux lotissements; d'une utilisation accrue de matériaux biogènes, comme le bois massif, qui peuvent réduire le carbone incorporé dans les bâtiments de moyenne; l'adoption et l'utilisation de diverses nouvelles technologies numériques pour modéliser les bâtiments, simplifier les processus d'approbation et remédier à des problèmes complexes sur les chantiers; et, enfin, de l'étude de nouvelles possibilités de production d'énergie thermique et d'électrification, comme le chauffage et la climatisation à distance.

Une seule innovation ne suffira pas à intensifier la construction de logements neufs et à l'orienter vers les objectifs climatiques du Canada; une approche stratégique coordonnée et à volets multiples est nécessaire. Bien que les technologies susmentionnées ne soient pas nécessairement « nouvelles », elles n'ont pas été adoptées de façon à modifier considérablement la façon dont les nouveaux logements sont construits. Pour réaliser le plein potentiel de ces technologies et de ces processus, il convient d'élaborer un régime de politiques global à leur appui afin de « rassembler tous les éléments », et d'apporter des certitudes à l'industrie, de coordonner l'investissement et le développement des marchés, et de définir des objectifs en matière d'efficacité énergétique et d'incidence sur l'environnement.

Normalisation: L'adoption d'un catalogue de conception normalisée à l'échelle nationale est une occasion de mettre en place un « effort » politique visant à encourager l'établissement de nouvelles combinaisons de technologies, de politiques et de modèles de fonctionnement. Cela donnerait lieu à un nouvel ensemble de problèmes pour la construction d'un système technologique, et mènerait à l'apprentissage incrémental, à l'amélioration et aux perfectionnements.

Codes et normes: Peu d'instruments dans la boîte à outils du climat actuelle du gouvernement fédéral peuvent être aussi efficaces pour transformer le marché et accélérer l'innovation pour les bâtiments à consommation énergétique nette zéro ou à émissions nettes zéro que les codes du bâtiment. La modernisation des codes du bâtiment à des fins d'innovation pourrait passer par la mise au point d'exigences précises de codes pour permettre la préfabrication ou la construction modulaire, l'usage de bois massif ou les sorties uniques pour les bâtiments multifamiliaux.

Possibilités offertes à l'industrie de la rénovation: L'innovation dans les nouvelles constructions peut aider à atténuer des défis semblables dans l'industrie de la rénovation en libérant de la main-d'œuvre pour des travaux de rénovation intrinsèquement plus complexes, ou en élaborant des pratiques d'utilisation d'outils numériques qui sont transférables à ce secteur. Il est nécessaire d'adopter une approche « axée sur la mission » pour relever le défi de la rénovation, y compris la mise en œuvre de normes de rendement des bâtiments pour orienter le travail vers les résultats stratégiques souhaités.

Tous les ordres de gouvernement au Canada ont des outils à leur disposition pour favoriser l'innovation dans la construction de logements neufs en vue d'atteindre des objectifs stratégiques. Le gouvernement fédéral peut jouer un rôle pour définir des normes d'excellence, soutenir la recherche et le développement, apporter de la clarté et des orientations au moyen de codes et de normes, créer des cadres pour assurer la disponibilité des données nécessaires et l'intégration d'un principe de circularité dans les politiques et les programmes. Les administrations locales, en particulier, ont un rôle à jouer en tant que « fournisseurs de solutions » en réduisant les risques à un stade précoce ou en créant des marchés au moyen de processus d'approvisionnement et en orientant la construction de nouveaux logements vers des collectivités plus axées sur les transports en commun.

Introduction

An oft-quoted figure from a Canada Mortgage and Housing Corporation (CMHC) study suggests that Canada needs to build 5.8 million housing units to restore affordability by the end of 2030.[2] Based on current trends, that's 3.5 million more units than expected to be built. It will be extremely difficult (if not impossible) to achieve this through business-as-usual construction practices and attempting to do so will close a unique window of opportunity to make each new home affordable, energy-efficient, and climate-friendly.

Today's construction industry is diffuse, relatively low-tech and labour-intensive, and characterized by low productivity. Inflationary pressures, tightening financial conditions, and a shortage of skilled labour in the construction industry have throttled production and escalated construction costs, exacerbating affordability concerns. Furthermore, suppose new construction is built to today's minimum standards. In that case, each new home will become a long-lived source of greenhouse gas (GHG) emissions while failing to protect occupants from extreme heat, forest fire smoke and other severe weather events associated with climate change. Less-efficient buildings are also less affordable in operation and without costly and unnecessary retrofits, leaving owners and occupants vulnerable to rising energy and maintenance costs over the life of those buildings.

The unprecedented need for new housing and innovative approaches to building it is an opportunity for improving energy efficiency and carbon reduction we can't afford to miss. However, new construction processes and technologies will not meet climate related building performance goals without embedding these objectives in new

[2] Canadian Housing and Mortgage Corporation, Canada's housing supply shortages: Estimating what is needed to solve Canada's housing affordability crisis by 2030. June 2022.

construction production and policy systems. To foster a new construction paradigm embedded with high environmental and energy efficiency performance, there must be clear and specific standards for energy-efficient and low-carbon building construction and operations. These goals must be the primary component of any policy framework intended to result in faster, affordable, and green construction.

The residential construction process can be streamlined by driving innovation in new materials and industrialized building processes and creating a policy environment that encourages these innovations. This would improve the overall cost and efficiency of producing new housing units and reduce greenhouse gas emissions from building operations and building materials.

This paper explores how technological innovation and industrialization in the construction sector could alleviate these challenges and support the rapid delivery of affordable and climate-neutral housing units. These opportunities can be realized by combining innovative approaches to residential construction, such as the greater use of prefabrication of building components, assemblies and modules, advanced wood construction, low-carbon energy systems, and digital technologies with a policy system designed to reinforce and support their adoption. For each group of technologies, we also explore how they can help address energy efficiency and environmental impacts of new housing construction and how policy can help catalyze change.

We conclude by noting the importance of connecting policy with technological innovation to "bring it all together," particularly regarding standardization, building codes and standards, and the retrofit sector. The report highlights policy recommendations for the federal, provincial, and local governments that could help create the conditions for meaningful and lasting change in new housing construction.

The need for innovation

As noted above, Canada faces a momentous challenge of building 5.8 million housing units by 2030 - 3.5 million (~1.7 times) more units than what can be expected, based on current trends if we wish to restore housing affordability.[3] This challenge is magnified by several headwinds in the residential construction sector which contribute to lower productivity, increasing construction lead times, and hindering affordability - headwinds such as increased borrowing costs, challenges in acquiring land or building materials, and labour shortages.[4]

The construction of new housing accounts for a significant share of Canada's national economy. With over 260,000 new housing units started each year, the new home construction industry provides approximately 560,000 on- and off-site jobs, pays out $39.7 billion in wages, and contributes over $84 billion to Canada's gross domestic product.[5] Labour capacity has been identified as one of the critical challenges facing the industry, particularly given estimates that 20 per cent of the aging workforce is set to retire over the next decade.[6]

This exit of employees and challenges related to attracting new workers to residential construction will hamper the industry's capacity to deliver affordable, climate-neutral buildings at scale. One solution is to rely more on off-site construction, which may reduce the labour intensity of new construction. The figure below demonstrates the growing gap between forecasted construction requirements and a dwindling labour force for the province of British Columbia. Offsite construction is one way to help reduce workforce requirements and construction costs.

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[3] Canada Mortgage and Housing Corporation (CMHC), "Canada's Housing Supply Shortage"; Canada Mortgage and Housing Corporation (CMHC), "Housing Supply Report: Canadian Metropolitan Areas."

[4] Canada Mortgage and Housing Corporation (CMHC), "Canada's Housing Supply Shortage."

[5] Lee, "Economic Impacts of the Residential Construction Industry: 2022 Factsheets."

[6] Ferreira, Scollan, and Strickland, "Short-Term Contractions May Ease Some Labour Market Challenges, but Canada's Construction Industry Is Poised for Further Growth through 2032."

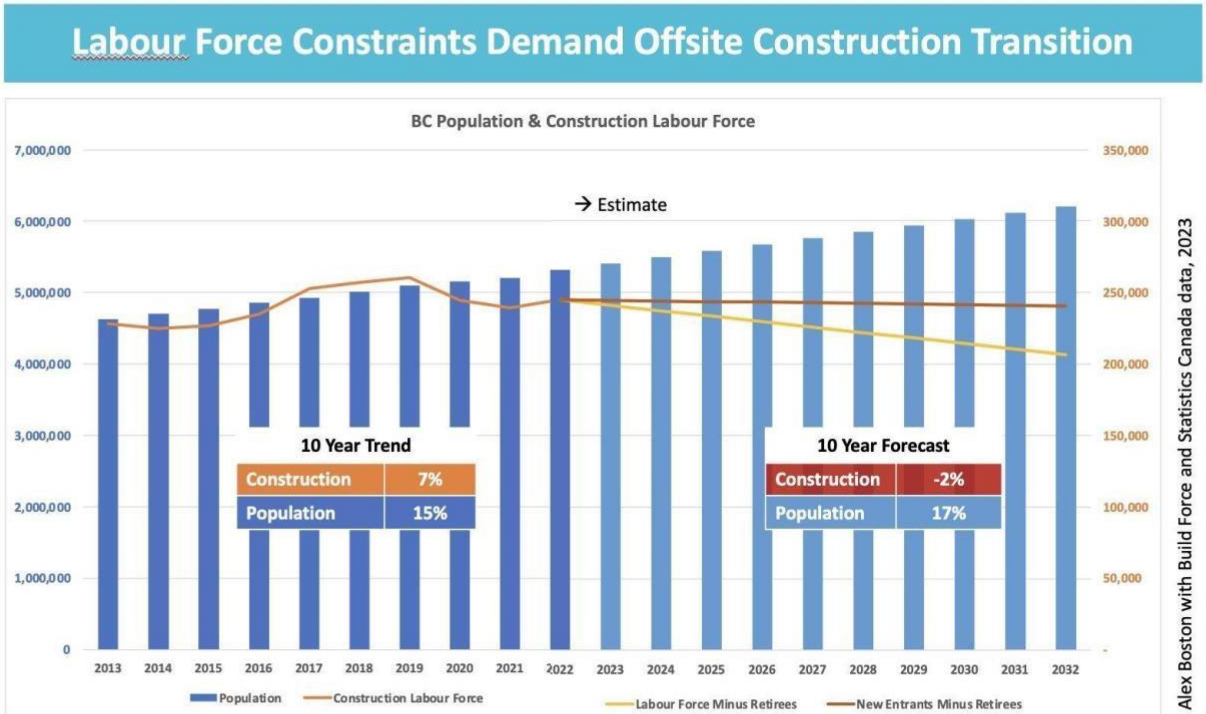

Figure 1. Labour force constraints demand offsite construction transition.[7]

Headwinds facing residential new construction

- Labour woes are expected to continue as the labour shortage grows to over 60,000 workers by 2032.[8]
- Labour productivity in Canada's construction industry has remained stagnant for years and experienced a negative growth rate of -1.2 per cent during the first quarter of 2023.[9]
- Record population growth primarily driven by immigration. Canada's annual population growth rate at 2.7 per cent, the highest since the post-World War II baby boom.[10]

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[7] Alex Boston [@AlexBostopolis], "BC Builds Can Be Coupled with a Strategy to Build a Pipeline for Offsite Construction Projects to Solve the TOP Constraint: Labour Force. Offsite Construction Can Reduce Workforce Requirements 50%, Schedules 30% & Cost 20%. Without Offsite, Our Crisis Will Worsen."

[8] Ferreira, Scollan, and Strickland, "Short-Term Contractions May Ease Some Labour Market Challenges, but Canada's Construction Industry Is Poised for Further Growth through 2032."

[9] Statistics Canada, "Labour Productivity, Hourly Compensation and Unit Labour Cost, First Quarter

[10] Statistics Canada, "Canada's Population Reaches 40 million."

- An additional 3.5 million homes, the Canadian Mortgage and Housing Corporation estimates are needed by 2030 to meet rising demand.[11]
- Post-pandemic challenges have slowed investment in residential building construction to the lowest levels since June 2020, particularly in the new multifamily segment.[12]
- Construction costs have risen 51 per cent since the first quarter of 2020, driven mainly by cost increases for key building materials like concrete and structural steel, which have risen by 55 per cent and 53 per cent in the same time frame.[13]
- The construction sector still needs to make the advances in productivity achieved in other sectors through streamlining, manufacturing, and adoption of new technologies. It continues to rely on traditional materials, processes, and practices. Though the federal government has recently invested in advancing innovative residential construction technologies[14] the uptake of new housing technology can take 10 to 25 years to achieve full market penetration.

Thus, there is an urgent need to facilitate greater industrialization and innovation in new housing construction to overcome labour shortages and declining productivity and meet our ambitious housing requirements. At the same time, there is a concerted national effort to increase the energy and emissions performance and the resilience of newly constructed residential buildings. Even if we manage to scale up new housing construction to resolve the present affordability crisis, using today's building standards will lock in 12.9 megatonnes of greenhouse gas emissions each year those buildings are in operation.[15] Given the long lifetime of a typical new house, missing this one-time opportunity will make hitting Canada's national emission reduction targets even more difficult.

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[11] Canada Mortgage and Housing Corporation (CMHC), "Estimating How Much Housing We'll Need by 2030 | CMHC."

[12] Canada Mortgage and Housing Corporation (CMHC), Housing Market Outlook, Canadian Metropolitan Areas 2024 | CMHC.

[13] Statistics Canada, "Building Construction Price Indexes, by Type of Building and Division."

[14] Office of the Prime Minister of Canada, "Changing How We Build Homes in Canada."

[15] Lockhart and Simon, "Build It Right the First Time."

The challenge is thus two-fold: scaling up the capacity of the new residential construction industry to substantially increase productivity and ensuring that we take advantage of the opportunity to ensure these houses are highly energy efficient, low emissions, and resilient to the impacts of climate change.

Barriers and opportunities for innovation

Achieving both objectives will require innovation in new construction building practices and technologies. Yet, the barriers to fostering an innovation ecosystem in the construction industry must be acknowledged and understood. First and foremost is the cyclical nature of new construction. The ebb and flow of new construction activity, rising and falling with economic fortunes, combined with the lack of a long-term framework to engage in research and development, limits the capacity of the buildings sector to invest in new ways in which to deliver better, more efficient, more durable and, most importantly, affordable housing, at scale.

Compounding cyclical forces is the highly diffuse and segmented nature of residential construction, in which regional actors dominate local markets, which are segmented by price, market conditions, and buyer preferences. This sector fragmentation limits breakthrough technologies from reaching key markets and achieving the necessary scale to reach market penetration. Late adopters of innovative technologies and practices are often reasonably concerned with potential financial and market risks that may impact their reputation or present significant risks to their existing business lines or bottom lines. This leaves a small cohort of the construction industry to pursue innovation, typically in pursuit of competitive advantages in the market. This segment does not have a consistent source for new information; instead, it learns about innovations through existing sales channels, trade shows, vendors and subcontractors, and technology transfer programs often found within academia.

As noted above, the major problem facing the construction industry is lagging productivity, fed in part by low levels of digitization, skilled-labour shortages and an overall lack of education and awareness of available new technologies, low levels of automation, risk aversion, and behavioural and structural factors favouring entrenched interests and a continuation of the status quo.[16] If policymakers and the industry can't fix this problem, attempting to scale up, housing will result in higher construction costs, poor building performance for owners and occupants, more risk of cost overruns and project delays, as well as reinforcing the boom-bust pattern that keeps workers away from careers in the trades.

The term innovation applies to various processes and technologies, such as new management practices and procedures to encourage energy-efficient residential housing, streamlining building activities, or specific smart home technologies or materials. It thus involves all actors within the sector–builders, building owners, financial institutions, and government agencies. Doing this right means realizing the potential of the industry to build and capturing the opportunity to do so in a way that maximizes social and environmental benefits.

Adopting new processes and technologies can help lower energy and lifecycle costs for building owners and occupants, enhance building durability, provide greater resilience in extreme weather events, and reduce operational and upfront emissions. Additional benefits include reduced resource consumption and construction waste and opportunities for enhanced circularity of materials. In the section below, "Unlocking affordable, climate-neutral housing," we review several process and technological innovations and outline how they could help reduce environmental impact and benefit climate change mitigation efforts more broadly.

Yet, research suggests that industry innovation, on its own, will not rise to the challenge of addressing productivity, affordability, and social and environmental impacts. Policy needs to provide clear direction and shape innovation systems to better ensure the potential of innovative construction practices to improve energy efficiency and environmental outcomes. This means more than just adopting new technologies: a new residential housing construction paradigm is needed to realize both the potential to

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[16] See Barbosa et al., "Reinventing Construction through a Productivity Revolution"; Tomkiewicz, "Barriers to Implementation of Sustainable Construction Practices in the Homebuilding Industry."

build more and the opportunity to embed energy efficiency and environmental performance in new residential construction practices.

A new residential construction paradigm

Innovation in housing construction can enhance productivity and lead to higher energy efficiency and environmental performance, yet this potential will only be realized with clear direction and shaping through policy. Fostering innovation in construction will require breaking the status quo, optimizing the current system around a narrow set of technological practices and objectives, and investing in labour-saving and productivity improving practices.

It can be helpful to think of the state of practice within the construction industry (or any industry) as a system built around specific technologies, thus constituting a "technological paradigm." Emerging technologies may, at the outset, be capable of addressing a range of problems, though systems built around them tend to narrow in focus around particular "normal" conditions over time. As a consequence, such systems come to exclude alternative problem definitions; engineers, specialists and organizations operating within them become "blind with respect to other technological possibilities."[17]

This system 'focusing' may increase performance and productivity but can also lead to rigidity and inflexibility, even in the face of widely recognized problems (like environmental degradation). As Dosi states, "unsolved technological difficulties do not automatically imply a change to another path."[18] Such systems are akin to a funnel, starting with multiple technological possibilities linked to different problems that could be solved, gradually narrowing to become more focused and powerful in advancing the particular technologies and problem definitions selected.

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[17] Dosi, "Technological Paradigms and Technological Trajectories," 153.
[18] Dosi, 156.

A second insight is that performance within a system is often the result of multiple technologies working in combination rather than a single technology alone. While the early performance of a single technology system may be lackluster, it can become transformative when combined with other technologies within a cluster, moving the system toward a new state. For example, the diffusion of electric light in the early 20th century succeeded not because of the invention of the light bulb but more so Thomas Edison and George Westinghouse's vision for an entire system, encompassing power stations, transmission, customer metering, and so on.[19] A contemporary example is the takeover of many conventional industries (book retailing, automotive manufacturing, agriculture and defense) by software.[20]

Breaking the "lock-in" effect of technological paradigms, in part through marrying diffuse and separate technologies in new and innovative practices, is a key element in a sustainability transition.[21] Yet, transitions are built upon and occur through more than just technological development, diffusion and adoption - they also require supportive social systems (i.e., policy and regulations, institutions, beliefs and values) to protect, nurture and bring together emergent, novel practices into "configurations that work."[22]

These concepts of technological combinations relate to construction, which does not involve one technology but rather multiple technologies, skills, and practices, creating the potential for numerous combinations or systems of production. What mix of technologies are ultimately used, in what order, and for which purpose will play a vital role in determining whether we can meet productivity and environmental performance goals.

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19 Rosenberg, *Inside the Black Box*.

20 Andreessen, "Why Software Is Eating the World."

21 Unruh, "Understanding Carbon Lock-In"; Kemp, "Technology and the Transition to Environmental Sustainability."

22 Rip and Kemp, "Technological Change."

Academic literature on innovation and sustainability transitions offers three lessons for how we can think about the potential of innovation in the construction industry to improve both productivity and energy efficiency:

1. **No single technology is sufficient** to improve technology or environmental impact. The opportunity for higher performance exists, but it is up to policy and industry actors to prioritize and exploit this opportunity.
2. **This opportunity is likely to be time-bound.** Creating a new construction paradigm opens a window of opportunity to embed high environmental and energy efficiency performance. However, this window might close quickly and exclude the necessary goals and complementary innovations if they are not present at the outset.
3. **Goals matter.** Builders, manufacturers, architects, and policymakers need to establish a collective understanding, or a "new common sense," on how to do things.[23] This can help "guide the search" towards productivity and energy efficiency performance enhancements.[24] Thus, policy has a clear role in establishing an end goal to direct market transformation and regulatory system adaptations to co-evolve and complement new technological systems.

In the following section, we review a series of innovative technological and process options for new residential housing construction, identify how they can help mitigate energy use and environmental impact, and how policy can help to catalyze their adoption. In the final section, we will "bring it all together" to show how multiple technologies can be combined with supportive policy regimes to establish a new construction paradigm for residential housing.

[23] Perez, "Technological Revolutions and Techno-Economic Paradigms."
[24] Grubler et al., "Policies for the Energy Technology Innovation System (ETIS)," 1689.

Unlocking affordable, climate-neutral construction

The goal of a new residential construction paradigm is to scale the construction of low carbon, affordable residential buildings.[25] Faster, replicable, affordable, and desirable solutions that also derisk innovative approaches are needed to overcome barriers and obstacles to the uptake of high-performance, low-carbon building construction practices and solutions.[26]

Below, we highlight several enabling innovations in the design, materials, production, and installation of construction materials and assemblies. When appropriately combined, these innovations can spur further innovation and support achieving multiple policy goals.

Sub-assembly manufacturing

First popularized in North America at the turn of the century with the advent of residential build kits, such as the Sears Craftsmen homes,[27] sub-assembly or off-site manufacturing has long been an alternative approach to on-site construction. Off-site manufacturing holds vast potential to build more quickly safely, and avoid interruptions due to weather, material damages, or staffing challenges.

Under the umbrella of 'prefabrication,' there are distinct variations in approaches. The term prefabricated refers to panelized systems, prefab pods or other units or systems constructed off-site and delivered for assembly.[28] Prefabricated solutions, in which building components, assemblies, modules, or complete packages, are available for both single-family residential or multi-family buildings and are ideally suited for the replicable nature of these building types, as well as institutional buildings (see Table

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[25] Berg et al., "The 2020 State Energy Efficiency Scorecard."

[26] Goldstein, Turnbull, and Higgins, "A National Retrofit Challenge to Meet the Paris Goal of 1.5 Degrees."

[27] Jackson, "Assembly Required: A Brief History of 20th-Century Kit House Designs."

[28] BC Housing, Manufactured Housing Association of BC, and Real Estate Institute of BC, "Modular and Prefabricated Housing: Literature Scan of Ideas, Innovations, and Considerations to Improve Affordability, Efficiency, and Quality."

1).[29] These are constructed in a factory and then transported to the construction, offering faster completion time and delivering factory-implemented quality assurance.

Type of prefabrication	Description	Use cases
Sub-assembly manufacturing	Two-dimensional panelized solutions can be offered in both new and retrofit solutions. Panels are prefabricated custom solutions that can be simple wall assemblies, such as Structural Insulated Panels (SIPS) or precast concrete panels or may contain the necessary conduits for services such as heating, ventilation, and air conditioning (HVAC). In both scenarios, the construction process is similar to conventional stick frame construction.	It is common in new types of construction, particularly wall and floor assemblies, and in deep retrofit applications.
Modules	A module or unit, such as a complete bathroom, kitchen, or mechanical room, can be manufactured in a factory and shipped to a site. These modules can be integrated into an existing project or assembled/stacked as low-rise or multi-storey buildings or as a mid- or high-rise superstructure.	Common in the construction of multi-unit buildings, such as low rise apartments, and in retrofit scenarios in which additions can be added seamlessly and can help reduce resources used in the construction process.

[29] Ferdous et al., "New Advancements, Challenges and Opportunities of Multi-Storey Modular Buildings-A State-of-the-Art Review."

Volumetric	Six-sided (four walls, floor, ceiling) enclosed spaces are manufactured in a module. Units can comprise an apartment, room, or other unit shipped to a site and assembled into a larger building, including tall buildings.	Commonly used in rapid housing initiatives, such as Toronto's Modular Housing Initiative, which combines individual modules/units built off-site in a factory and transported to the site for assembly as multi-unit buildings.

Table 1. Variations of pre-manufactured building components and assemblies.

Much like their conventional on-site (e.g. stick-built) counterparts, offsite construction solutions use common materials such as steel, concrete, wood, and glass. Also referred to as modern methods of construction (MMC), off-site solutions use prefabricated components to increase productivity and shorten construction schedules. Off-site solutions also bring opportunities to optimize energy and emissions performance, capture structural efficiencies, reduce waste, and minimize risk associated with onsite activities, including disruptions in the local community.

Bringing the residential construction process within the factory environment also reduces potential delays due to poor weather and centralizes material storage, limiting losses to weather or theft. A factory setting can also address the shortage of skilled tradespeople by moving more construction into a factory environment protected from the elements. It can extend the careers of those already in the sector and attract new participants by offering a stable, safe work environment protected from the elements. Robotics may also support this transition in forms ranging from exoskeletons that assist workers in moving heavy components to autonomous robotics capable of executing repetitive or potentially dangerous tasks.

Speed of construction is one of the primary benefits of prefabrication. Up to 80 per cent of modular construction can take place in an off-site and controlled environment, meaning up to 50 per cent faster construction completion than conventional on-site alternatives.[30] Modular construction moves away from the sequential nature of onsite construction by embracing repeatable designs and bringing together prefabricated building systems (e.g., building envelopes, lighting and power, HVAC) within a factory environment. Not only can this mean an end to challenges related to coordination, project delays, labour disruption, supply chain problems, inflation shocks and material waste, but it can also enable concurrent assembly of different units, resulting in a building process that is much faster than conventional approaches.[31]

Energy and environmental impacts

While this approach holds potential cost savings, derived from a shorter project schedule and reduced work in weather-exposed conditions, additional energy and environmental benefits result from the increased vertical integration of the construction process.[32] For example, using Building Information Modeling (BIM) technology (described in more detail below), the design parameters of the building can be more quickly inputted and aligned with relevant building codes and standards, including energy efficiency standards. This can lead to improved building code compliance and facilitate alignment with higher standards (e.g., the Passive House Standard), thereby reducing the operational energy and emissions of the building.

Pre-manufactured or modular construction is also ideally suited to optimizing building design (simple building forms) and materials (fewer materials needed for less complex design). Optimizing design and materials can reduce operational and embodied carbon in new buildings. Prefabricated components, or units intended to be cost-effective, are

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[30] Bertram et al., "Modular Construction: From Projects to Products."

[31] Dragicevic and Riaz, "Seizing the Modular Construction Opportunity."

[32] BC Housing, Manufactured Housing Association of BC, and Real Estate Institute of BC, "Modular and Prefabricated Housing: Literature Scan of Ideas, Innovations, and Considerations to Improve Affordability, Efficiency, and Quality."

also inherently simpler and use fewer materials. This leads to fewer articulations in the building form (leading to less energy loss) and inherent benefits in embodied energy. Prefabricated components, particularly volumetric units, can also leverage airtightness testing both in-factory and on-site once assembled to measure quality control.

How policy can catalyze change

Several policies and programs are in place to support the greater use of prefabricated components, assemblies, panels, and volumetric units in new residential construction (see Table 2). While these policies can potentially reduce the burden of building code compliance on builders, municipal staff, and building officials, existing regulatory systems have not been adapted to foster the uptake of prefabrication at scale. Instead, a regulatory system that pulls the construction sector towards the widespread adoption of prefabrication, particularly one that mandates higher energy and emissions performance, is needed.

Much like other construction materials, manufacturers require certification of their prefabricated components and products with the Canadian Construction Materials Centre (CCMC), which assesses a product's compliance with Canadian building, energy and safety codes.[33] This process could encourage a broader uptake of prefabrication if oriented toward a thorough yet affordable and timely process for certification for innovative products. By streamlining the approval of assemblies and components and coordinating with authorities having jurisdiction (AHJs) to ensure information about how innovative products are used in the field–and how they meet compliance requirements–this process could help save time and money.

For prefabricated solutions in general, challenges are typically related to the National Model Codes (and, once adopted, provincial codes) and a lack of clear requirements and/or the application of standard CSA-A277–the industry procedure for certifying prefabricated assemblies and components. The CSA-A277 standard is currently only

[33] National Research Council Canada, "Canadian Construction Materials Centre."

referenced in the National Building Code's notes. It is not a mandatory requirement and may be interpreted by AHJs with a great degree of latitude. Moving this standard to a mandatory requirement will alleviate the AHJs of a compliance burden by clarifying that certified products or assemblies meet building code requirements and that previously certified components do not require re-inspection onsite, thereby avoiding the use of 'alternative solutions' to include these components.[34] This step will remove a layer of complexity and time in the use of prefabricated components, and bolster the advantages of prefabrication in faster project approvals and delivery schedules.[35]

Jurisdiction	Program/policy	Description
Federal	Rapid Housing Initiative[36] (RHI)	Intended to create 3,000 new permanent, affordable housing units in part using modular construction, showing the recognition of the potential for factory-built solutions.
Federal	Housing Supply Challenge	$300 million fund to support innovation in the construction sector by improving productivity by adopting new designs, digital tools, and modular and prefabricated construction techniques. Adopting new and innovative ways to build high-quality housing and boosting Canada's housing supply at an unprecedented rate.
Federal	Housing Accelerator Fund	$4 billion investment to remove barriers to building more homes more quickly. Aimed at creating 100,000 affordable homes, including student housing, homes near public transit, and more rental units.
Federal	Affordable Housing Innovation Fund	$759 million to support new, innovative financing models and unique designs to make housing more accessible and

[34] Alternative solutions allow for flexibility in building construction. They are considered a locally acceptable solution to an existing prescriptive or performance code requirement and are a site specific design solution negotiated between the regulator(s) and the designer(s). Alternative solutions must demonstrate that the proposed approach provides an equal or better level of performance to the prescribed provisions in the Building Code.

[35] Haylestrom and Koe, "Exploring the Existing Regulatory Framework for Modular Construction in Canada."

[36] Canada Mortgage and Housing Corporation (CMHC), "Rapid Housing Initiative."

		lower the costs and risks associated with affordable housing projects.
British Columbia	BC Rapid Response to Homelessness program	The Province committed $291 million over two years to build 2,000 modular supportive housing units for people who are homeless or at risk of homelessness.
New Brunswick	NB Housing Strategy: Housing for All	New Brunswick Housing Corporation (NBHC) will raise public awareness of the benefits of a modular approach, encourage municipalities to amend their existing by-laws and zoning to better facilitate modular construction and create a pipeline of government-led modular projects.
Municipal (Toronto)	Modular Housing Initiative[37]	The City has committed to creating 1,000 new modular homes in Toronto by 2030. With 261 units completed, the Initiative encourages innovation in small-scale infill housing for vulnerable populations.
Canadian Standards Association	CSA-A277, CSA-Z250, CSA Z240 MH, CSA Z240.10.1	These standards provide guidance for the certification of prefabricated buildings, modules, and panels, the delivery of volumetric buildings, compliance for manufactured homes, and site preparation, foundation, and building installation.

Table 2. Select policies and programs to support prefabrication in new residential construction.

Biogenic materials, mass timber, and wood structures

Several Canadian municipalities–particularly in British Columbia, Ontario, and Quebec–have made significant advances in biogenic materials and wood construction. With similar fire and seismic performance to concrete and steel, wood-based products are increasingly considered an alternative to structural, load-bearing components, particularly in multi-unit residential buildings.

[37] City of Toronto, "Modular Housing Initiative."

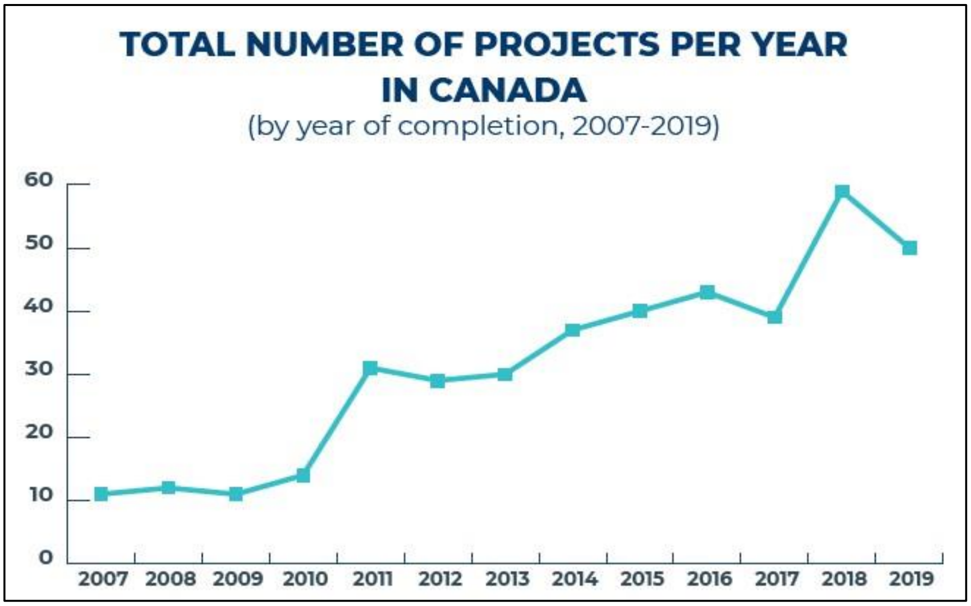

Figure 2. Number of construction projects (>300m2) with structural use of mass timber products.[38]

Biogenic materials, or materials made from biomass (straw, hemp, wood, bamboo, cork, wool, etc.), are increasingly considered an alternative to conventional resource-intensive materials. This is partly because these materials inherently sequester carbon by removing CO^2 from the atmosphere during photosynthesis and storing it within the building material, where it is preserved for the life of the building component. These materials then act as a carbon sink, resulting in significant reductions in embodied carbon.[39] Some biogenic materials–such as straw, cork, hemp, and bamboo–can also be classified as rapidly renewable. Using these materials in off-site construction offers additional opportunities to reduce embodied emissions through design optimization. Wood and mass timber products are wood-based building materials manufactured in factories. Common forms of mass timber include:[40]

- Glue-laminated timber (glulam) consists of smaller board pieces pressed together in a parallel direction and connected with glue.

[38] Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood Program, "The State of Mass Timber in Canada 2021."
[39] Kriegh, Magwood, and Srubar, "Carbon-Storing Materials: Summary Report."

[40] "Wood Products."

- Cross-laminated timber (CLT). While glulam is made up of smaller board pieces pressed together in a parallel direction, CLT is pressed together in a perpendicular pattern.
- Laminated veneer lumber (LVL). Similar to glulam, LVL is a dried and graded wood veneer coated with a waterproof phenol-formaldehyde resin adhesive that serves as a structural member.

Structural composite lumber products are made up of strands, veneers, or wood flakes from smaller trees and bonded with specific adhesives. They include laminated strand lumber, laminated veneer lumber, and parallel strand lumber. Respectively, these products are commonly used as structural members such as beams and studs, columns and beams, and decking or wall panels.[41]

In conventional construction, construction material is often delivered to the building site en masse, cut to size, and assembled. Mass timber components are made in-factory (similar to prefabrication) to exact specifications, complete with door and window openings in place, and ready for the addition of mechanical, electrical and plumbing infrastructure. They are then delivered to the site ready to assemble, making this approach ideal for the complexities of urban development.

Mass timber can be leveraged through the design and fabrication process with Building Information Modeling (BIM), computer numeric control (CNC) and Virtual Design and Construction (VDC)[42] modeling to deliver a range of efficient structural solutions. These tools support a design-led construction process that relies heavily on digital tools to optimize material use, the construction process, and the sequencing and delivery of materials and their installation, leading to better outcomes in terms of project customization, speed of construction, cost efficiencies, energy use, and safety. This enables increasingly taller mass timber buildings with innovative designs that are

[41] Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood Program, "The State of Mass Timber in Canada 2021."
[42] Jones, "What Is Virtual Design and Construction?"

designed and assembled more quickly, using fewer resources, and delivered in a cost competitive manner.[43]

In sum, the benefits of mass timber for buildings include:

- Faster construction due to scheduling and logistical advantages ranging from reduced transportation, fewer labour resources, and reduced waste. Less heavy equipment is needed, resulting in greater site safety.
- With up to 75 per cent fewer trades needed on-site to construct mass timber structures, labour constraints are resolved and costs associated with labour requirements are reduced, and worker safety is increased.[44]
- 80 to 90 per cent of construction material deliveries can be eliminated because mass timber, unlike conventional construction materials (concrete and steel), can be delivered and stored until needed on a construction site.
- As a result of fewer material deliveries required, vehicle activity associated with deliveries can be reduced which has benefits in terms of energy used to construct the buildings, as well as easing site traffic to create safer working conditions.[45]

[43] See, for example, naturally:wood, "Brock Commons Tallwood House."
[44] Think Wood, "Projects That Pencil Out."
[45] Truong-Regan, "Timber Rising."

Jurisdiction	Program/policy	Description
Federal / provincial	National Building Code	After extensive research, the 2015 *National Building Code of Canada* (NBC) allowed wood frame construction of up to six stories. British Columbia, Quebec, Ontario, Alberta, and Nova Scotia all subsequently adopted these regulations in their provincial building codes.
Federal	Green Construction through Wood (GCWood)	As of March 2023, the program has funded four tall wood building projects, ten low-rise non-residential building projects, and two timber bridge projects. These projects have helped de-risk wood construction and support the greater adoption and commercialization of wood-based products in tall and low-rise wood buildings.
Federal	Tall Wood Building Demonstration Initiative	Starting in 2013, this program supports research and development of new materials and commercial-scale demonstration projects.
British Columbia	Mass Timber Action Plan	In collaboration with forest product manufacturers, developers and constructors, the program aims to develop mass timber as an economic sector, maximize its benefits for people, and support a sustainable, low-carbon future.
Ontario	Mass Timber Program	This program, primarily focused on supporting research and partnerships via the Mass Timber Institute of Ontario, has also funded four mass timber building projects across the province.
Toronto	Integrating a Climate Action Approach to City Real Estate Decisions - Mass Timber Pilot Program	Explores using mass timber construction (such as cross-laminated timber (CLT) or glue-laminated timber structural materials to reduce carbon emissions in delivering affordable and market housing. Toronto's Regional Conservation Authority's headquarters provide a strong example of mass timber and wood construction.

Table 3. Mass timber programs and policies in Canada.

Energy and environmental impacts

In terms of reduced energy and emissions, the benefits of wood and timber construction primarily lay in the reduced embodied carbon, both in the material itself and the differing construction process. In addition to storing carbon, wood products are associated with low levels of carbon emissions during manufacturing, thus reducing the overall carbon footprint of a building's construction.[46] Mass timber as a substitute or complement to concrete and steel holds the potential to cut embodied emissions in buildings by as much as 25 per cent, which could lead to sector emissions reductions of nearly 10 per cent by 2030.[47] Wood and mass timber products also weigh significantly less than their steel and concrete counterparts, meaning structural efficiencies within the building design can be found, resulting in a streamlined design requiring less carbon-intensive structural materials. Circular approaches lower the lifecycle impact of those materials by acting as 'material banks' to be re-used or re-purposed for future uses.[48]

Despite these advantages, there is a need to further explore the optimal heights of tall buildings, including those constructed with mass timber. While there has been strong momentum in building taller structures, early evidence suggests that as the height of the building increases, operational and embodied emissions may increase disproportionally.[49] In essence, when compared to taller buildings, even those constructed with wood/timber, shorter, boxier buildings can often have lower upfront and operating emissions.[50]

How policy can catalyze change

Since 2007, over 750 mass timber projects have been completed or are under construction in Canada.[51] This includes British Columbia, which requires all provincial

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46 Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood Program, "The State of Mass Timber in Canada 2021."
47 Truong-Regan, "Timber Rising."
48 Lockhart, "What Municipalities Need to Know about Canada's Net-Zero Emissions Building Codes."
49 Pomponi et al., "Decoupling Density from Tallness in Analysing the Life Cycle Greenhouse Gas Emissions of Cities."
50 Alter, "How Tall Should a Building Be."
51 Truong-Regan, "Timber Rising."

buildings to be mass timber.[52] The Ontario Building Code allows encapsulated mass timber construction buildings up to 12 storeys and plans to amend the province's building code to permit encapsulated mass timber construction up to 18 storeys. In the US, several building code changes are taking place that will expand the potential for taller wood buildings, including the adoption of the 2021 International Building Code, which allows for mass timber structures up to 18 stories (twenty-eight states, either as a whole or for certain jurisdictions, have adopted the 2021 IBC as of September 2023).[53]

To reach mainstream status, innovations like mass timber construction require consistent demand, which is unlikely to build organically if the supply of materials, products, and processes is not accessible or consistently available. This interplay is illustrated clearly by the 2015 changes to Canada's building codes, which allowed for 6storey mass timber construction. After implementing this change, mass timber construction grew by over 40 per cent each year. This shows that requirements allowing for 12-storey or higher mass timber construction in Canada's model codes are needed to encourage taller mass timber projects, the widespread use of prefabrication and offsite construction, and digital tools.[54]

Digital technologies

A range of digital tools, sensors and smart technologies, and robotics have significant potential to de-risk complex construction projects by enhancing information access and communication between different project partners, vendors, builders, and owners. In doing so, a number of efficiencies can be gained that reduce costs by improving the accuracy of estimates and avoiding or limiting changes to the construction plans or specifications that arise due to incomplete information or missed areas of oversight. Compared to conventional paper-based processes, digital technologies can be used to

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52 Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood Program, "The State of Mass Timber in Canada 2021"; Young, "How Can Construction Innovations Make Housing More Affordable?"

53 Natural Resources Canada, Canadian Forest Service, and Green Construction through Wood Program, "The State of Mass Timber in Canada 2021."

54 Mantle Developments, "Mass Timber Market in Canada and Beyond."

test changes in the design or construction process, such as the type of materials used, without impacting the project's schedule, labour needs, equipment, and costs, and avoid delays associated with capturing these changes and assessing their impact.

Moreover, these technologies can help alleviate labour constraints by optimizing the human resources involved in construction activities. They can also help attract a new generation of workers motivated by environmental sustainability and interested in using digital technologies.

Building Information Modelling (BIM)

BIM is an intelligent 3D model-based process that gives architecture, engineering, and construction professionals the insight and tools needed to more efficiently plan, design, construct, and manage buildings and infrastructure.[55] It leverages a shared data environment to provide a collaborative means by which project proponents can share project information, including drawings and schedules. BIM is highly visual, meaning that project teams can test different design scenarios, construction techniques, and materials and identify project pinch points in a low-cost way that doesn't impact construction timelines or budgets.

BIM offers a range of benefits, including reduced construction costs and time efficiencies, fewer design clashes and costly reworking on site, greater accuracy in design and build, and fewer defects in new housing units. Material use can be optimized, and efficiency conservation measures can be tested. Next-generation BIM is capable of capturing project costs, schedules, and details related to geometry, specifications, aesthetics, thermal, and acoustic properties.[56] Electronic permitting via a BIM-based framework is also an enticing integration for the development community and municipalities interested in speeding the approval process.

Digital procurement platforms

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[55] Agarwal, Chandrasekaran, and Sridhar, "Imagining Construction's Digital Future."
[56] Agarwal, Chandrasekaran, and Sridhar, "Imagining Construction's Digital Future."

Beyond BIM, there is a range of digital tools that can help cut construction costs, as well as upfront emissions associated with the construction process, by maximizing locally sourced materials and materials that have low lifecycle emissions. These tools can provide real-time data, transparency, and increased efficiency in material sourcing, as well as reduce material wastage, improve safety, and maximize energy efficiency. For example, smart contracts can be leveraged to select locally made materials and products accompanied by robust Environmental Product Declarations. Such contracts can further limit costs by reducing potential areas of fraud and by reducing risks associated with scheduling project sequencing. Planning supply chains in response to demand promotes better access to sustainability enhancing materials and services, with faster and more cost-effective delivery.

Stage of construction	Use case
Design	Can help visualize drawings and deliver multiple design iterations. Project materials can be easily updated, annotated, and granted signed approval. Integrated Project Delivery (IPD), a collaborative design approach, can benefit significantly from digital tools that facilitate new approaches to contract structures that encourage innovation through risk sharing.
Scheduling	Project tasks and accountability can be assigned, prioritized and tracked throughout the construction process. Project stakeholders can be seamlessly notified of changes to the construction schedule.
Materials	Materials can be sourced within construction management tools based on performance, availability, lifecycle emissions, and their potential to be deconstructed and repurposed. On-site materials can be identified, tracked and located to better avoid losses due to theft, waste, weather and other events.

Workforce	Human resources can be tracked in real-time to better adjust to changing site conditions or project task delivery. Labour can also be monitored to ensure site safety and productivity.
Quality control	A range of tools can be used to monitor progress, capture real-time images of completed work, and assess the quality of that work.
Contract management	Project management or BIM tools can be used to identify responsibilities and tasks, record communications, and ensure contract compliance.
Document management	To better manage document flow and distribution, digital solutions offer new ways for stakeholders to review, edit, and record outcomes across multiple projects and organizations.

Table 4. Use cases for digital technologies (adapted from Agarwal et a., 2016).

Robotics

While still a nascent technology, robot-assisted technologies are making inroads in areas such as 3D printing, bricklaying, or other relatively simple tasks. Robotics, either wholly automated or those that can provide mechanical assistance, can help alleviate labour concerns in new home construction through increased productivity and execution of tasks that can lead to accelerated construction schedules. Some studies suggest that the use of robotics on site could cut construction costs by 20 per cent.[57]

Additional benefits can be captured as well, including improvements to worksite safety or remote technology that enables more tasks to be automated or conducted virtually.[59] Alongside fully automated processes, robotics offer a means to support longer and healthier careers for those working on-site. Robotic arms and manipulators, typically in the form of exoskeletons, can help mitigate the anticipated wave of construction sector retirements by making it easier for workers to move materials and perform challenging

[57] AsterFab, “Robotics in the Construction Industry.”
[59] AsterFab.

tasks like overhead work without the risk of injury or work more safely. In addition to fewer labour requirements on-site, improved worker safety and longevity can also help direct skilled labour to more complex retrofit activity, filling a much-needed gap in the retrofit market.

Building on the use of BIM, there is potential to automate specific tasks through robotics, such as the Semi-Automated Mason (SAM), which can lay large volumes of bricks accurately and with enhanced speed or monitor progress in projects. This includes the use of autonomous drones and rovers that leverage BIM models to inspect the quality of work completed and note progress.[58]

Artificial Intelligence

Artificial Intelligence (AI) sprang to the fore in recent years, most often as a means to create content such as reports or emails, or to summarize text. While the technology used in this way can help construction firms, particularly smaller, more resource-constrained firms, it can also save time carrying out repetitive and mundane tasks. AI builds upon the mature ecosystem for proptech (property technology) and is now used in various innovative ways.

These include:

- Creating early concept development or generative design.
- Sorting material data to decrease the embodied carbon footprint of new construction projects.
- Conducting or verifying energy modelling or specific calculations.
- Optimizing pricing and scheduling for construction projects.
- Integration with construction robots, enabling them to make autonomous decisions, optimize routes, and improve operational efficiency.

[58] Jones, "Robots Are Coming to the Construction Site."

- Drones equipped with AI are increasingly used for site surveys, monitoring, and data collection, contributing to more informed decision-making in construction projects.

Sensors and smart technologies

Sensors can conduct various tasks, from alerting construction site managers to water pipe leaks and material damage to making job sites safer by using sensors embedded in safety vests and other clothing that can assess operating conditions in real time. Each of these can increase costs and insurance premiums. Sensors typically contain microprocessors connected to a central data repository and can be used to automatically monitor and control specific conditions on the worksite.

Smart sensors can help cut construction costs by enabling better coordination, scheduling, and tracking of materials and equipment to be easily accessible and used efficiently, reducing project delays and associated cost overruns.[59] Several technologies can also contribute to accelerating site preparation and minimizing disruptive on-site activities. From high-definition photography 3-D laser scanning, and geographic information systems, these site tools can be combined with drone and unmanned aerial-vehicle (UAV) technology to quickly assess and record site conditions. In addition to uncovering potential issues that will delay construction, high-definition images of site-specific conditions and measurements can be integrated with project-planning tools like BIM to rapidly accelerate the design process.[60]

Energy and environmental impacts

BIM and other digital tools help ensure that material use can be optimized and efficiency conservation measures can be tested. BIM and digital procurement platforms serve supply chain actors and those involved in the construction process by creating end-to-end transparency across the supply chain. They can help builders and designers

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[59] Chui, Collins, and Patel, “The Internet of Things: Catching up to an Accelerating Opportunity.”
[60] Agarwal, Chandrasekaran, and Sridhar, “Imagining Construction’s Digital Future.”

verify a product or materials sustainability claims and contribute to the tracking and tracing of materials. Supply chain actors can also leverage the data collected to better forecast product demand, thereby limiting resource waste and ensuring broader access to sustainable materials and products.

Resource optimization extends to the greater use of robotic technologies on-site as well. Robotics can also optimize material use and reduce material waste, resulting in a construction process that consumes fewer resources and lowers the lifecycle emissions of the project.

After construction, sensor technologies optimize energy systems based on factors such as weather and the number of people in the building, providing information on how to improve future designs. For example, CO^2 sensors can be employed to track variable occupancy schedules to scale back building ventilation systems when the building is unoccupied, thereby eliminating 'building idling' and associated GHG emissions.[61]

How policy can catalyze change in these technologies:

While BIM was first introduced in the early 2000s, uptake has been relatively slow. This is due, in part, to the considerable investment of time and resources to learn how to use it, as well as the lack of skilled practitioners within the residential construction sector.[62] The lack of market penetration is most acute within smaller projects and smaller builders representing a significant component of Canada's residential sector, either because it isn't relevant, investment costs, lack of support for non-standard designs, lack of interoperability or ability to pass BIM data over to the building owner on completion, and a lack of industry support for residential products.[63]

Despite its many advantages, Canada remains the only G7 country without a national mandate to require the use of BIM, for example, in government construction projects, to

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[61] andyro, "TEDI and Ventilation, the Tail That Wags the Dog."

[62] Poirier, "ISO 19650 - A Gateway to Standardized Digital Practices to Design, Deliver and Maintain Canada's Built Environment."

[63] Cao et al., "The Benefits of and Barriers to BIM Adoption in Canada."

establish standards and guidelines for the deployment of BIM, to ensure robust information exchange capability requirements, and rely on open standards for data and information exchanges.[64] Instead, its uptake has been dependent on proponents within the sector.[65]

Concerning digital tools, more generally, it is critical that a new construction paradigm also works to 'push' innovative technologies to the fore. This speaks to the role of federal R&D funding programs.[66] They can be critically important in helping entrepreneurs and innovators finance and test their ideas while developing more sustainable business models and markets for their products. A mission-oriented policy is needed to avoid potential boom-bust cycles destabilizing the broader market and thereby stifling innovation over the long term.

Such an approach would stimulate innovation by harnessing resources, coordinating stakeholders, and encouraging collaboration between governments, aiming to introduce productivity-enhancing and net-zero emission construction practices in Canada. The current Construction Sector Digitalization and Productivity Challenge program at the National Research Council could be a starting point for a mission-oriented approach to construction innovation policy alongside initiatives like the local energy efficiency partnerships program. Comprehensive studies and educational materials on how whole building energy-efficient design reduces costs, as well as incentives for integrated design principles, can further alleviate concerns related to costs and feasibility.

Alternative sources of thermal energy and electrification

Heating and hot water systems account for over 80 per cent of all residential energy use.[67] Installing conventional fossil fuel heating systems requires a number of different trades on-site, thereby impacting project sequencing and scheduling, increasing on-site

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64 Froese et al., "Proceedings of ICSC'15."

65 Shahi and Lyall, "BIM Can Transform the Canadian Construction and Design Industry."

66 National Research Council Canada, "Construction Sector Digitalization and Productivity Challenge Program."

67 Canada, "Energy Efficiency Trends in Canada 1990 to 2013."

traffic, and increasing the risk of diminished building performance in terms of energy consumption if installation requirements are not strictly adhered to.

Heat pumps

Cleaner heating options, particularly at least 100 per cent efficient systems, such as heat pumps that use electricity highly efficiently to heat and cool buildings while replacing fossil fuels, are increasingly available on the Canadian market. Industrializing the construction process could expand the heat pump supply chain, reducing equipment and installation costs, while their high efficiencies create long-term operational cost savings.

Installed heat pumps could be future-proofed, particularly with installing ductwork and other infrastructure that can accommodate higher capacity (or variable flow) heat pumps, as heating and cooling loads change as the climate warms. Pairing ductless heat pumps with industrialized buildings could also reduce the complexity, and therefore the cost, of the design. Heat pumps could also benefit significantly from standardized designs that specify the correct size and configuration for the heat pump in specific building designs and the particular climate where the housing unit is located.

As an alternative, the following thermal energy sources deliver heating and cooling generated at a central plant to the building, thereby eliminating much of the burden for these systems from the construction process. As a result, the building can be constructed faster and more affordably and reach higher levels of energy and emissions performance.

Heat recovery

With projects underway in Vancouver, Toronto, and Halifax, sewage waste heat recovery is increasingly an option–particularly in dense urban environments–for capturing and distributing waste resources to be used as low-carbon energy for heating and hot water.[68] Leveraging the thermal energy of sewage resources, waste is diverted,

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[68] Lorinc, "Tapping Sewage for Clean Energy Is the Ultimate Circular-Economy Play."

concentrated, and used to replace fuels such as natural gas. This approach is best used in large buildings, such as institutional buildings. Within a closed loop, sewage is run through the heat exchanger and then back into the sewer. It can be used to capture heat or remove heat from the building and be reinjected into the existing sewer main.

One of the first examples of this approach occurred in Vancouver's False Creek Neighborhood as the Neighborhood Energy Utility (NEU). It supplies low-carbon energy for heating and hot water to 6.4 million square feet of mixed-use buildings and aims to deliver 70 per cent of its energy from renewable sources. A significant portion of the NEU's renewable energy supply comes from sewage heat recovery, where the latent heat from sewage is captured using a heat pump process at the False Creek Energy Centre.[69] Similar efforts are also underway in Toronto, where a sewage waste heat recovery system is being constructed to capture the heat from sewage for use in Toronto's Western Hospital.[70]

District Energy

District energy systems leverage centralized heating or cooling resources produced offsite alongside a network of distribution pipes to act as a thermal grid serving multiple types of buildings. District energy systems can help building owners and communities, improve energy efficiency, enhance reliability, cut costs, and reduce greenhouse gas emissions. District energy networks can use different fuel sources, ranging from conventional fuels to sewage heat recovery systems, cold water from freshwater sources, or deep boreholes that capture latent heat within the ground.[71]

Each of these technologies can help reduce the emissions generated from heating and hot water systems and cooling in new construction. They can also increase the leasable square footage of newly constructed buildings by forgoing the need for large mechanical rooms and space allocated to utilities, including rooftop or penthouse

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[69] City of Vancouver, "False Creek Neighbourhood Energy Utility (NEU)."
[70] Lorinc, "Tapping Sewage for Clean Energy Is the Ultimate Circular-Economy Play."
[71] Sustainable buildings and communities group, "Integrated Energy Solutions for Communities."

mechanical systems that require additional structural consideration. Not only can this space be converted to more housing units or common spaces for amenities, but developers can also reduce capital costs associated with those mechanical systems by forgoing large mechanical systems. Further cost efficiencies can be captured through district energy as these systems can be fuel-flexible, enable fuel switching at scale, and centralize emissions controls in a way that individual heating systems cannot.[72]

Building electrification

Building electrification shifts heating/cooling loads and appliances such as stoves to electricity rather than fossil fuels. Within this shift, energy efficiency remains a core aspect. A well-insulated building envelope and equipment and appliances that use less energy reduce the thermal and electrical energy demands of the building and enable a low-carbon heating option, a heat pump or connection to a low-carbon district energy system, for example, to meet all or the vast majority of the heating load.

Within the construction process, electrification can serve to control capital expenditures and speed the construction process (resulting in further savings), mainly because fewer trades are required on-site, fewer pieces of gas infrastructure, including supply lines, a gas regulator, gas metering and venting equipment required for building operations, and fewer penetrations required in the building envelope that erode the airtightness of the buildings envelope. As a result, an electrified residential housing unit can be delivered cost-competitively, more quickly, and have improved operational efficiency compared to a conventional counterpart.[73]

Building on electrification, energy-efficient buildings are also ideal candidates for driving energy and cost savings system-wide by helping utilities manage peak demand loads and mitigate constraints related to integrating more electrified buildings and vehicles. Energy efficient buildings can leverage smart technologies, energy storage, and

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[72] QUEST Canada, “District Energy 101.”

[73] Billimoria et al., “The Economics of Electrifying Buildings”; Denniston et al., “Cost Study of the Building Decarbonization Code: An Analysis of the Incremental First Year Cost and Life Cycle Cost of Two Common Building Types”; Forestry Innovation Investment and bty, “Construction Cost Analysis of HighPerformance Multi-Unit Residential Buildings in British Columbia.”

distributed energy technologies to deliver demand flexibility while opening new opportunities to optimize energy costs and services both within the building and across the entire electricity system.[74]

Grid-integrated or grid-interactive buildings complement the intermittent nature of variable renewable energy, energy storage systems, and the increasing deployment of distributed energy resources.

Energy and environmental impacts

Thermal energy networks can complement the electrification of residential heating, as each connection to the network lessens the potential burden to the electricity system, particularly peak loads related to heating or cooling, and helps to avoid the need to add additional and costly generation capacity. Similarly to the technologies outlined above, the innovation aspect of thermal energy networks, as outlined in this section, is how they can be combined in new ways that enhance the energy performance, affordability, and speed of new construction to enable many options for heating and cooling newly constructed buildings.

Highly efficient buildings, paired with smart building technology and renewable or clean energy sources, enable greater flexibility as buildings actively generate, consume, store, and buy and sell electricity back to the grid.[75] Combined, these technologies facilitate the management of peak loads and enable the shifting, shaving, or avoidance of a building's peak power demands, as well as the time it spends at that demand level. This means a utility in a relatively clean grid system will not need to rely on emissions intensive fossil fuel plants to accommodate peak demands, thereby reducing emissions associated with electricity generation.[76]

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[74] Office of Energy Efficiency & Renewable Energy, "Grid-Interactive Efficient Buildings: Technical Report Series."

[75] International Energy Agency, *Efficient Grid-Interactive Buildings*.

[76] Reducing operational emissions via electrification depends on a jurisdiction's electricity fuel mix. Although some provinces have the advantage of an inherently low-emission grid via hydropower or

These digital tools that manage individual distributed resources can also be aggregated so that buildings can become grid resources or virtual power plants. In this scenario, grid-interactive buildings act as aggregated resources to monitor electricity generation and oversee generation, consumption, and storage physically located across different sites. This further helps building owners and occupants save on energy costs, access new revenue streams, and benefit from reduced operational emissions, as demand response programs optimize electricity cost savings peak and off-peak electricity consumption.[77]

How policy can catalyze change in these technologies

Alternative thermal energy sources typically require high capital inputs and high degrees of collaboration between different levels of government and the private sector. Policies and programs to support early initiatives, particularly those that require high levels of financing for untested projects, are critically important in helping entrepreneurs and innovators develop more sustainable business models and markets for their products.

As with other innovations discussed above, these solutions also need to weather potential boom-bust cycles destabilizing the broader market and have the effect of stifling innovation over the long term. Policy for building electrification must, therefore, consider the more comprehensive collections and combinations of multiple social and technological elements. For building electrification, this includes both building level technologies, social and economic barriers to electrification, the broader grid at scale, and the individual technologies, organizations, regulatory systems, and best practices coming together as a complete system.

These technological systems are undoubtedly complex. Nonetheless, their success can be realized in a mission-oriented approach that coordinates federal/provincial/ municipal actors and initiatives. For example, a coordinated effort to map potential

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nuclear energy resources, other provinces might place immediate focus on building envelope improvements and more limited electrification in preparation for a cleaner grid in the future.

[77] Carmichael et al., "The Value of Grid-Interactive Buildings to Building Owners."

thermal energy sources and nodes or connections across different levels of government and the private sector can help build the necessary demand for low-carbon heating and cooling systems, positioning those systems for long-term success.

Bringing it all together

The technologies listed above are familiar in and of themselves. However, integrating these approaches into the construction of new housing units in a holistic way, rather than a piecemeal approach, presents opportunities to reimagine the construction process as an industrialized effort that results in faster, greener, and more cost-effective construction. This is particularly true in dense, urban or infill construction settings.

Digital tools	• Accelerated site preparation, design, and completion • Early identification of supply chain challenges/opportunities • Tighter control over the scope of work • Potential for faster permitting and site approvals
BIM	• Standardized designs and components, iterative design process for lower operational energy use and emissions, lifecycle analysis of materials, building materials optimized for lowest embodied carbon and circularity
Pre-manufacture	• Optimized material selection for embodied carbon, waste considerations, durability, low-carbon • Compliance with building code and local requirements • Opportunities to meet advanced voluntary certifications • Higher levels of airtightness and other quality assurance metrics. • Reduced labour burden due to indoor manufacturing environment and increased automation • Reduced time to completion
Site delivery	• Less invasive for the community, reduced lane closures, and site traffic

	• Safer environment for labour resources • Fewer deliveries mean fewer emissions associated with material transportation.
Building completion	• Quicker turnaround of construction, financial, and other construction documents • Handoff of BIM digital twin to building operator to better facilitate optimal energy and carbon emissions efficiency operations.
Disassembly	• Material data can be tracked, and building interventions can be recorded with digital passports or logbooks.

Table 5. Bringing it all together.

Building more residential housing units in urban areas with ready access to services and amenities increases density and offers those who live in these areas enhanced options for active transportation and transit.[78] Increased density also makes it possible to aggregate demand for alternative thermal energy sources, making it possible to heat and cool with energy-efficient district energy systems or recovered waste heat systems.

Yet, building in high-density environments can present challenges not found in greenfield development: assessing the capacity and condition of existing infrastructure, complex construction sites with limited space, restrictive regulations governing construction activities, and community concerns about noise and dust.[79] This is where a modular construction approach, combined with many of the technologies above, has a chance to shine.

For example, robotics or drones equipped with light-detection-and-ranging (lidar) technology can quickly provide high-definition images of survey areas, accurately measuring and assessing site conditions and uploading data automatically to BIM. BIM can then be used to develop site-specific designs that adhere to all municipal standards and relevant building codes.[80] After design iterations have been considered, BIM

[78] Urban Land Institute Toronto, "Getting to Transit-Oriented Communities: Experiences in Canada."
[79] Federal of Canadian Municipalities, "Backgrounder: New Research—Canada's Housing Challenge Is Also an Infrastructure Challenge - Cloned."
[80] Agarwal, Chandrasekaran, and Sridhar, "Imagining Construction's Digital Future."

software can be used to submit those designs via e-permitting to the municipality, and once approved, uploaded to the prefabrication vendor. With off-site construction of modular units and site work being conducted simultaneously, the length of the construction process can be significantly reduced. The resulting high-performance structures would also produce less waste, an important consideration given the impact of the embodied carbon in construction materials.

This approach positions municipalities as catalysts in developing a market for rapid, high efficiency and affordable new housing units. In this scenario, there is more scope for municipalities to act as active participants in the process, helping to develop local markets for high-efficiency and affordable housing units and to act as project aggregators to better leverage and coordinate investment in capacity across the public and private sectors. In other words, innovation in construction practices and the governance of new construction can be mutually reinforcing. A streamlined permitting process with coordination across municipal departments would also help to set clear and specific rules and requirements, enabling modular component vendors to tailor their manufacturing and delivery process to local needs, thus working together to speed construction time.

New approaches in the construction process also offer opportunities to design buildings with simpler shapes, which can have a reinforcing effect on density, energy efficiency, and environmental impact.[81] Simpler building shapes are easier to make energy-efficient, less prone to defects, and thus reduce energy and materials costs. Lower-impact building designs could also drive more opportunities for electrified midrise construction, reducing or eliminating natural gas distribution service costs.[82] Such mid-rise buildings can be built with less-costly and lower-carbon wood instead of concrete or steel, further bolstering the benefits of increased urban density.

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[81] See, for example, HCMA Architecture + Design, Integral Group, and Focal Engineering, "BC Energy Step Code – Design Guide."

[82] To realize these opportunities regulatory changes are required. A number of Canadian jurisdictions, including Ontario, have existing building code requirements for residential buildings with 6 or more storeys to install back-up/emergency generators, which are typically natural gas-fired.

A role for standardization

In recent years, there has been increasing recognition of the role that standardization can play in scaling up the construction of residential buildings quickly, affordably, and in a climate-friendly way. Standardization–or the development of a national catalogue of pre-approved designs, such as those recently proposed by the federal government–is intended to support the speedy development of higher-density construction and encourage different forms of housing construction, such as mass timber, modular, and prefabricated homes.[83]

Standardized designs provide guidelines and templates for a limited set of specific housing types, which, combined with provincially standardized zoning regulations, can be made available "open source" and reduce requirements for additional design review. Widespread use of standardized designs can more easily facilitate and increase demand for energy-efficient and low embodied carbon building components and assemblies (e.g., high-performance windows, clean heating and cooling technologies) paired and appropriately sized for the design plan.

A national standardized design catalogue is thus an opportunity to create a policy "push" to encourage new combinations of technologies, policy, and business models to be developed, defining a new problem set for the construction of a technological system and leading to substantial incremental learning, improvement, and refinement. The federal government could reinforce this process by providing access to public land and real estate holdings for the development of off-market housing.[84] If such a move was coupled with requirements for meeting the highest levels of energy and emissions performance and aligned with efforts to support standardization, this would help create a condition of predictability necessary to mobilize investment in component manufacturing plant expansion.

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[83] Infrastructure Canada, "Federal Government Lays the Foundation to Change How Canada Builds Homes." A critical barrier to overcome will be the flexibility of standardized design to accommodate local seismic and climatic considerations, which often dictate local construction practices and AHJ approvals.
[84] This idea has already been floated by the Minister. See Younglai and Anderssen, "Federal Land Could Be Used for Housing to Bring down Costs, Minister Sean Fraser Says."

Building codes and standards as an accelerator

It bears repeating: to reach the full potential of innovative technologies and standardization, the broader policy system must remove barriers to the development of affordable, climate-neutral projects and catalyze various technologies by helping to pull them into the market. Clear and specific standards for energy-efficient and low-carbon building construction and operations are critical policy elements in this system.

The cost of new construction is impacted by design choices, the level of supply chain and project coordination, and the mix of people, technologies, and practices available. Building codes, particularly tiered codes, are one of the most effective policy instruments for providing a long-term focal point for the sector and avoiding cyclical ebbs and flows. Tiered codes establish an end-state–in effect, a market pull–around which builders, manufacturers and suppliers can orient their activities. A clear pathway to higher efficiency levels can foster confidence in the market and offer regulatory certainty and an anchor to develop a long-term strategy. They also deliver direction and focus to better help the workforce (carpenters, energy advisors, architects, and more) invest in themselves to build the knowledge and skills that pay off in the form of good local jobs. Tiered codes also make aligning incentives with municipal, provincial, territorial, and federal climate commitments easier for utilities and other program providers.

Few instruments in the federal government's current climate toolbox can be as effective in transforming the market and accelerating innovation for net-zero energy or net-zero emissions buildings as building codes.[85] Yet, while tiered codes were introduced Canada-wide in 2022 and have been adopted by most provinces as of May 2024,[86] there is more that can be done to realize their potential.

To date, building codes have been best suited to the oversight of conventional construction techniques and will need to be modernized to facilitate the industrialization

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[85] Lockhart, "What Municipalities Need to Know about Canada's Net-Zero Emissions Building Codes."
[86] Canada, "Provincial and Territorial Tiered Energy Code Adoption Landscape."

of the construction sector and to help manufacturers deliver more cost-effective products to the market faster.[87] This could include developing specific code requirements to enable modular builds, mass timber, or to allow for single egress for multi-family buildings up to 16 storeys. Existing building code requirements require two means of egress (a “double-loaded corridor” building would have apartments on both sides of the corridor) for any multi-unit residential building of more than two storeys. Allowing for single-egress rules for buildings up to 16 storeys would allow for more units per building, thereby enhancing affordability while also expanding opportunities for ‘missing middle’ housing forms and low-rise multi-unit housing.[88]

Other policies to support the long-term certainty necessary for large-scale investments in technology, processes, and people could include the introduction of a Prefabrication and Modular Code as a Part of NBC and NECB, similar to Part 13 Alterations to Existing Buildings, or a Section under the NBC, like Section 9.36 Energy Efficiency which applies to residential buildings (Group C) less than or equal to $600m^2$ and buildings of certain occupancies. Building codes could strengthen references to standards like the CSAA277 to further streamline the approvals process and adapt it to the unique nature of prefabrication’s factory setting.

More efficient design and production processes based on repeatability and scale can reduce the inspection burden on-site to assembly verification only, freeing building code compliance resources for higher uses while also enhancing valuable energy efficiency measures like airtightness testing.[89] For example, in the U.S., the Housing and Urban Development (HUD) code is available to states to allow third-party certification of prefabricated components in the factory rather than the field, saving resources devoted to compliance. More importantly, the HUD code has delivered the certainty needed to advance industrialization, including support for technology, design, and financing for prefabrication and modular construction.

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[87] Richter, Moffatt, and Brooks, “A Multi-Sector Approach to Ending Canada’s Rental Housing Crisis.”
[88] Speckert, “Urban Progress - The Curse of the Double Egress.”
[89] Bertram et al., “Modular Construction: From Projects to Products”; Richter, Moffatt, and Brooks, “A Multi-Sector Approach to Ending Canada’s Rental Housing Crisis.”

Innovation benefits retrofits as well

Many of the technologies and innovations presented in this report have been discussed in the context of newly constructed residential buildings. With 75 per cent of the anticipated building stock in 2030 already built, however, energy use and emission performance in existing buildings is a critically important challenge to meeting net-zero goals.[90]

Retrofit activity in Canada's existing 14.5 million residential buildings already comprises $127 billion of economic activity and over 950,00 jobs.[91] While this level of activity will need to grow rapidly in coming years, the existing building retrofit industry faces many of the same challenges as new construction: affordability, speed and performance of retrofits, rapid increases in real estate prices, low market inventory, etc.

Innovation in new construction can help to alleviate these same challenges in the retrofit industry. For example, the available skilled labour pool dedicated to retrofits must increase to meaningfully improve existing building energy efficiency performance. Industrialization of new construction could allow for workforce resources to be reallocated toward inherently more complex renovation work. At the same time, many of the tools outlined above–particularly digital tools, modular units serving as additions, and digital twins–can also cut time spent on retrofit project design and the time needed to carry out such projects.

Digital tools can be used to introduce the Integrated Design Process (IDP) collaborative approach to find efficiencies across the retrofit process, such as cloud-based platforms that evaluate individual project needs and help decision-makers identify optimal energy retrofitting strategies. Digital twins provide options for iterative designs and help alleviate potential issues in construction assemblies or sequencing.[92] Digital sensors

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[90] Schulte, "Better Buildings for a Low-Carbon Future / Deborah Schulte, Chair."

[91] Lee, "Economic Impacts of the Residential Construction Industry: 2022 Factsheets."

[92] See, for example, this EU project: European Commission, "New Integrated Methodology and Tools for Retrofit Design towards a next Generation of ENergy Efficient and Sustainable Buildings and Districts." [96] Carbonari et al., *Building Logbook State of Play*.

can be deployed to monitor the buildings before and after retrofit activities take place to monitor and assess the viability of specific interventions. Digital logbooks serve to increase transparency and access to relevant building data for property owners, investors, financial institutions, and government. Retrofit activities may span decades, and a digital logbook can store a long-term building retrofit roadmap, information on past interventions, or information related to building materials or performance. This approach has been successful in Europe, as Digital Building Logbooks (DBLs) underpin efforts to decarbonize the existing building stock.[96]

Adapting the Energiesprong model to the Canadian market would lead to less disruptive retrofits across a range of housing models.[93] Further cost savings can be realized by aggregating demand for prefabricated walls, roofs and units that can come complete with solar panels, ventilation, heat pumps and other technical systems. Dedicated projects in this area, such as the Prefabricated Exterior Energy Retrofit (PEER) program, are advancing prefabricated solutions and supporting industry in providing dedicated service offerings for exterior deep energy retrofits.[94]

Codes and standards can play an essential role in retrofits by setting long-term performance targets for the existing buildings stock around which the sector can plan for the future. Building performance standards, like the Energy Performance of Buildings Directive (EPBD) in the European Union, have proven to be a vital tool in providing a stable investment framework. The EPBD mandates the development of “Long-Term Renovation Strategies,” providing a roadmap for energy-efficient renovations over extended periods; establishes minimum energy performance standards (MEPS) for new constructions and major renovations, ensuring a consistent benchmark for energy efficiency; and promotes Nearly Zero-Energy Buildings, encouraging investments in renewable energy sources and on-site energy generation.[95] By offering precise requirements and targets, the EPBD fosters investor confidence and stability in the

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[93] For more information, see Global Energiesprong Alliance, “Energiesprong.”

[94] Natural Resources Canada, “PEER – Prefabricated Exterior Energy Retrofit.”

[95] European Commission, “Long-Term Renovation Strategies”; European Commission, “Nearly-Zero Energy and Zero-Emission Buildings.”

sector. These measures facilitate long-term commitments to sustainable building practices, contributing to the reduction of GHG emissions and the advancement of a low-carbon built environment in the EU.

With several Canadian jurisdictions poised to implement building performance standards for existing buildings, there is a significant opportunity to deliver much needed certainty to the retrofit market.[96] Bolstered by certainty, there is an opportunity to foster innovative retrofit solutions that encourage scaling of the market and deploy zero-carbon retrofit solutions at an unprecedented scale, speed, and level of performance.[97]

Policies to support innovation

Attempting to build more housing units each year with the same practices, processes, and systems will squander the opportunity to build a generation of affordable, high-performance homes quickly and at the scale outlined in this report. Responding to this opportunity will require policy to drive cost-effective manufacturing approaches oriented towards constructing homes that are comfortable, efficient, and cost-effective.

This means we need to bake in a system of residential housing construction with low carbon products and materials today. And, importantly, consider the deconstruction and recovery of those resources tomorrow. The innovations discussed in this report, prefabrication, biogenic and timber products, and digital tools, are ideally suited for a structural shift towards modular components and assemblies that can be tracked and monitored throughout their initial useful life and readily prepared for disassembly practices at the end of its life to retain the value of materials.

Many of the technologies and standards needed to enhance the speed, energy, carbon, performance and cost effectiveness of new residential construction already exist—it's

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[96] Efficiency Canada, "Advancing Mandatory Building Performance Standards in Canada: A Call for Federal Leadership."
[97] Haley and Torrie, "Canada's Climate Retrofit Mission: Why the Climate Emergency Demands an Innovation-Oriented Policy for Building Retrofits."

more a matter of finding ways to share and minimize risk amongst stakeholders. This can take many forms, including the development and testing of innovations by trade associations, research and government partners, or other mechanisms. By embracing a culture of innovation, the buildings sector can facilitate an increasingly industrialized approach to residential construction and, as a result, ensure it is prepared to rapidly deliver climate-neutral housing.[98]

This speaks to a role for government at all levels to define areas they value most and to develop an innovation ecosystem that encourages the adoption of housing technologies such as prefabrication, mass timber in multi-residential housing, and digital technologies. Together, these innovative approaches can drive greater uptake of durable housing construction with disaster-proof resilient materials and strategies for reducing operational and embodied carbon emissions in housing.

Recommendations for the federal government

Set a standard of excellence:

In late 2023, the White House announced the development of a standard for a Zero Emissions Building (ZEB) to create consistency in the private sector marketplace for measuring progress toward zero emissions. It is expected to require buildings to be energy efficient, produce no on-site emissions and use 100 per cent renewable energy.[99]

It is critically important for Canada's transformation to a net zero economy to define a national net zero standard for energy and emissions. While the 2023 Green Buildings Strategy discussion paper highlights the need for new buildings to achieve the highest levels of energy, carbon performance, and climate resiliency, the recently released Strategy did not adequately clarify the implications.[100] On energy, a standard of excellence requires clarity on the performance that can be expected of the highest tiers

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98 Boland et al., "Overcoming Barriers to Innovation in the Home Building Industry."

99 Office of Energy Efficiency & Renewable Energy, "National Definition for a Zero Emissions Building."

100 Natural Resources Canada, "The Canada Green Buildings Strategy."; Government of Canada, Government of Canada, "The Canada Green Buildings Strategy: Transforming Canada's buildings sector for a net-zero and resilient future."

of the national model codes. On emissions, the government must work to incorporate a definition of net zero within the national model codes.

Setting such standards will add clarity to the market and is an opportunity to galvanize the domestic market for energy-efficient, low-carbon, and disaster-proof resilient materials; develop strategies for reducing carbon emissions in housing; support advancements in mass timber and steel construction; and further explorations in expanding options in offsite construction.

Develop a robust building technology agenda and research program:

Federal R&D funding can be critically important in helping entrepreneurs and innovators finance and test their ideas while developing more sustainable business models and markets for their products. To avoid destabilizing boom-bust cycles, a mission-oriented policy to introduce productivity-enhancing and net-zero emission construction practices in Canada is recommended. A mission-oriented policy can build on the Construction

Sector Digitalization and Productivity Challenge program at the National Research Council, as well as adoption-oriented initiatives like the local energy efficiency partnerships program. Comprehensive studies and educational materials on how whole building energy-efficient design reduces costs, as well as incentives for integrated design principles, can further alleviate concerns related to costs and feasibility.

Ensure Canada's proposed design templates deliver green, resilient, and affordable residential housing that can be built fast

A range of pre-approved design templates for the most needed building types, such as multi-residential, should be designed to be ready as off-the-shelf patterns but also guide the industry as a starting point for further refinement. To facilitate the highest levels of building performance and climate resilience, design templates should include different building systems, including wall, mechanical, and ventilation. This approach will de-risk construction projects, reduce completion times, and build a market for offsite modules, components, and assemblies.

Ensure building codes and standards are designed to support and encourage innovation

Many of the innovations discussed require nurturing to better transition from niche to mainstream. To reach mainstream status, these innovations require consistent demand. However, this demand is unlikely to build organically if the supply of materials, products, and processes is not accessible or consistently available. This chicken and egg problem highlights a role for the building code, as it can act as a stable endpoint that provides an additional impetus to adopt innovative tools, processes, and approaches that improve energy and climate performance while improving construction productivity.

This interplay is illustrated clearly by the 2015 changes to Canada's building codes, which allowed for 6-storey mass timber construction. Since this change, this practice has grown over 40 per cent annually each year since. Efforts such as requirements that will enable 12-storey mass timber construction in Canada's 2020 model codes are needed to encourage taller mass timber projects, the widespread use of prefabrication and offsite construction, and digital tools. There is also a strong need to align code compliance activities with different jurisdictions involved in the construction process.

A federal government agenda to change how we build should support tiered code adoption to add much-needed certainty to building sector investments, foster collaboration and research, coordinate supply chain developments, and support career development. The federal government can do this through continued funding of the Codes Acceleration Fund to support provincial, municipal and third-party code adoption and compliance activities. It can also require buildings constructed with federal funding to meet the top tiers of energy and emissions performance in building codes, and for provinces and territories using the Housing Infrastructure Fund to adopt higher tiers of the 2020 and forthcoming 2025 building codes.

Support industry in the transition to housing industrialization

Building on the recommendations of the 2023 National Housing Accord, the federal government should develop a robust innovation strategy for housing that extends to procurement policy and establishing innovation centres for housing construction.[101]

Acting as leaders through procurement and by supporting emergent building information exchanges such as those in Vancouver, Toronto, Calgary, Edmonton, and Halifax, all levels of government can bolster the industry's capacity to promote innovations, particularly among builders, developers, large-scale owners, subcontractors, manufacturers, and other suppliers. As the primary decision-makers in adopting innovative measures, it is critical that they are aware and comfortable with implementing an innovation.

Senior government can also support the industrialization of residential construction by leveraging incentives, programs, and partnerships with private investors to increase the pool of available financing in social housing, purpose-built rentals, co-op housing, and other forms of off-market housing. Taking advantage of governments' "patient" capital, long-term investments can help industry weather cyclical economic conditions, and ensure a consistent supply of new housing while fostering innovative approaches.

Apply a "mission-oriented" policy framework to the building retrofit challenge

In tandem with the industrialization of new residential construction, develop a mission oriented strategy that "combines many buildings into large-scale retrofit projects, coordinates the supply chain, uses mass-produced and standardized wall assemblies and mechanical pods, and provides long-term financing and performance guarantees for building owners."[102]

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[101] Richter, Moffatt, and Brooks, "A Multi-Sector Approach to Ending Canada's Rental Housing Crisis."
[102] Haley and Torrie, "Canada's Climate Retrofit Mission: Why the Climate Emergency Demands an Innovation-Oriented Policy for Building Retrofits."

Ensure housing data is robust and accessible:

As highlighted in the Green Buildings Strategy: What We Heard document, private investors need centralized, accurate, and accessible climate and energy use data to support decision-making and enable more investments.[103] Federal and provincial governments play a critical role in providing better market data for all stakeholders that helps identify appropriate land uses, residential housing gaps and potential opportunities, appropriate market actors and vendors, and navigate complex energy and emissions performance requirements.

Aside from reversing changes to CMHC housing start data collection, immediate areas that could be leveraged to increase access to housing data is to build on the Local Energy Efficiency Partnership (LEEP) program.[104] This program aims to help builders reduce time and risk identifying, exploring, and adopting innovations related to new residential construction.

As the Task Force for Housing and Climate highlights, there is also an opportunity to increase coordination and evidence-based decision-making by enhancing data collection. The Task Force recommends developing consistent definitions of terms such as "affordability" and "affordable housing," as well as innovative measures such as BIM interactive zoning bylaws.[105]

Lower the impact of construction by applying circularity

Building materials account for an increasing amount of materials in our waste stream.[106] Without intervention, attempting to construct an unprecedented number of new housing units via conventional processes will exacerbate this issue. A circularity centered policy framework can help to address concerns around the quality and consistency of both

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[103] Natural Resources Canada, "Toward a Canada Green Buildings Strategy: What We Heard from the Public and Buildings Sector Stakeholders."

[104] Natural Resources Canada, "LEEP Technology Guides and Tools."

[105] Task Force for Housing & Climate, "Housing and Climate."

[106] Environment and Climate Change Canada, "National Waste Characterization Report: The Composition of Canadian Residual Municipal Solid Waste."

new and recovered materials and ensure consistent supply and costs.[107] This can help open new economic opportunities by extending the life and value of materials and resources.

Such a policy framework includes roles for:

- Senior levels of government to bolster education and awareness, particularly for industry and regulators, and to develop and support pilot projects that demonstrate how to implement circularity strategies into new construction, and support market uses for different materials by establishing requirements for Extended Producer Liability.[108]
- Lower levels of government can further the market for cyclical materials through secondary content requirements, beginning with their own provincial or municipal procurement requirements. Based on market maturity and the perspectives of non-governmental actors, these requirements have the potential to be added to municipal green development standards or stand as individual by-laws.
- Third-party organizations such as the Canadian Standards Association can contribute to developing standards that define key terms and activities, methodologies for lifecycle analysis, assessing the useful life of new buildings, and the accounting of embodied carbon.

There is also a role for building codes to play in the circular economy. For example, introducing requirements for building passports or logbooks to track designs, significant interventions, and materials for eventual deconstruction and recovery; or through technical requirements that use a design for disassembly and adaptability approach to plan for eventual interventions, maintenance, and end of life.[109]

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[107] CSA Group, “Z782-06 - Guideline for Design and Disassembly and Adaptability in Buildings.”
[108] Lopoukhine, “Developing a Circular Building Materials System and Fostering Innovation from Construction, Demolition and Renovation (CRD) Waste.”
[109] Shorthouse, “Circular Economy & the Built Environment Sector in Canada.”

Recommendations for provincial and local governments

Leverage the procurement process to support innovation in housing

Zero energy and emissions performance standards can be baked into procurement processes to ensure these standards are an uncompromised component of all new municipally owned/developed residential construction projects.

Municipalities can play a leading role in developing new residential housing by using a design-build approach. This will help de-risk projects, particularly those at the forefront of innovation, and maximize the value of municipal resources, ranging from land holdings to technical expertise.

Municipalities can further compress upfront timelines and accelerate the construction process by leveraging tools and digital tech to design multiple iterations of newly designed builds that fit a specific site. This approach can be aided by using pre-vetted vendor rosters that meet the municipality's environmental and affordability goals and timelines.

To go a step further, municipalities can aggregate projects by identifying multiple projects to be undertaken in a given period to justify capital investments and ensure a stable pipeline of projects and demand for innovative technologies, products or materials. The certainty provided by a stable pipeline of projects spanning decades is critical to offset the capital costs needed to initiate thermal energy projects or investments in prefabrication or modular factories.

This approach may require greater collaboration within different departments to clarify and streamline the permitting process. The traditional siloed approach to municipal projects must be avoided to be more responsive and provide greater accountability for project delivery.

Municipalities need to act as a solutions provider

Municipalities–as either the project proponent, aggregator, or facilitator–are well positioned to create solutions for the market that will further enable green, affordable, faster construction. This is particularly the case for promising technologies such as waste heat or deep borehole district energy projects, in which the municipalities can take the role of an energy solutions developer, thereby absorbing the risk entailed in large projects. After construction, the municipality can offload operations to a third party with a specific interest in long-term investments.

Seek opportunities to densify by integrating housing and transportation infrastructure

Higher-density, mixed-use development connected to local transportation hubs can be mid-rise, zero-carbon, prefabricated buildings constructed of light wood frames, mass timber, and other low-embodied carbon materials.[110] This includes integrating affordable housing, retail, daycares, market housing, or commercial offices with transportation infrastructure planning.

Municipalities can help establish and support industry in meeting this demand by contracting with existing and new prefabrication construction companies. Due to transportation constraints, offsite construction is a regional activity. Governments can support offsite construction by contracting with regional vendors to construct nonmarket rental homes, encouraging further investments in offsite processes that spill over into the private sector. Local governments can also further aggregate demand and remove friction in the design/build process by collaborating with the private sector to standardize designs and a seamless permitting process. Sharing lessons learned, case studies, and best practices can amplify these projects' impact by demonstrating that their cost-effective, rapid outcomes are achievable for other entities, such as social housing providers.

[110] Urban Land Institute Toronto, “Getting to Transit-Oriented Communities: Experiences in Canada.”

Conclusion

If Canada wants to meet its housing goals it needs to build both fast and at higher energy and emissions performance levels. These dual goals are only at odds within the existing construction paradigm. Innovation can unlock the capacity to do both.

To change this paradigm, we need to provide certainty on what the construction sector of the future will look like and push markets to recognize the value of construction techniques like sub-assembly manufacturing, biogenic materials, digital technologies, and thermal and electrified energy that have the potential to both increase productivity and environmental performance. High-performance, net-zero-aligned, building standards can accelerate the transition to this better construction paradigm by providing a clear endpoint that increases the value proposition of promising construction technologies.

Policymakers at all levels of government need to establish a clear pathway towards better construction techniques by demanding high performance. They then need to adapt local and national rules to remove barriers to new construction techniques and take advantage of the opportunity to embed high energy and environmental performance into a more productive construction technology system.

Building fast, productive, energy-efficient and low-carbon are complementary objectives, not trade-offs, if policymakers establish the proper rules and missions.

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