Strategic roadmap: research and development of additive construction in Canada

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NRC·CNRC CONSTRUCTION

Strategic Roadmap

Research and Development of Additive Construction in Canada

Non-sensitive

April 20th, 2026

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Canada

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Executive Summary

Additive Construction (AC), commonly referred to as 3D Construction Printing (3DCP), is a transformative technology poised to revolutionize the Canadian construction industry. By building structures layer by layer using digital fabrication techniques, AC offers potential advantages in cost, speed, sustainability, and design flexibility. This roadmap, developed through a multi-stakeholder initiative led by the National Research Council (NRC), outlines the current state, challenges, and strategic direction for AC in Canada.

The Promise of Additive Construction

AC is a disruptive innovation that challenges traditional construction methods, which have dominated Canadian residential construction for centuries. The technology potentially enables:

- **Reduced construction time and cost** through automation, precision and lower manual labour.
- **Enhanced design freedom**, allowing for organic and non-linear architectural forms.
- **Minimized material waste**, especially in formwork.
- **Improved environmental performance**, with potential for carbon-negative materials and better insulation.
- **Increased labour pool** to supplement trades availability
- **Greater safety and resilience**, reducing on-site hazards and enabling climate-adaptive structures.

Currently, AC is in a hybrid phase, combining printed components with conventional building techniques. The long-term vision is fully printed homes and infrastructure, tailored to Canada's diverse climate and housing needs.

Initiative Overview

Globally, AC is expanding rapidly. North America has seen a 311% market growth since 2023, driven by housing demand and climate pressures. Canada's AC sector is in its early stages, with limited adoption due to regulatory uncertainty, high upfront costs, and a lack of skilled professionals. Only a few companies are actively printing, and most materials are not optimized for Canada's cold climate. Despite these challenges, AC presents a compelling solution to the country's housing crisis, labor shortages, and environmental goals.

Canada contributes approximately 15% of North America's AC activity, with growing interest driven by sustainability and affordability imperatives. However, broader adoption requires overcoming technical, regulatory, and social barriers.

In 2021, NRC began assessing AC's readiness and barriers. By 2024, this evolved into a national initiative under the NRC's *Platform to Decarbonize the Construction Sector at Scale*. The roadmap, aiming to position Canada as a global leader in sustainable, innovative construction, was informed by:

- Stakeholder engagement with over 180 participants from industry, academia, and government,
- Scoping studies on AC's potential in northern climates and its productivity and emissions impacts,
- Surveys and workshops, and
- Global benchmarking, drawing insights from international leaders like Dubai and Saudi Arabia.

Key Challenges and Strategic Responses

1. Materials

- **Challenge:** Lack of printable materials validated to Canadian climate and building codes.
- **Opportunities:** Develop geopolymers, bio-based alternatives, and low-carbon mixes; standardize testing; create open-source databases for mix designs.

2. Construction Digitalization

- **Challenge:** Fragmented digital infrastructure and lack of interoperability.
- **Opportunities:** Integrate AI, BIM, IoT, and digital twins; standardize data formats; build comprehensive platforms for end-to-end digital workflows.

3. Resilience & Durability

- **Challenge:** Limited data on long-term performance in extreme conditions.
- **Opportunities:** Conduct fire, freeze-thaw, and seismic testing; improve ductility and reinforcement; monitor buildings for climate resilience.

4. Standards

- **Challenge:** Absence of AC-specific standards, codes and inspection protocols.
- **Opportunities:** Adapt international standards (e.g., ISO/ASTM 52939, ICC AC509); develop Canadian guidelines; train inspectors and regulators.

5. Social Factors

- **Challenge:** Workforce gaps, unclear public perception, and limited socio-economic data.
- **Opportunities:** Partner with academia for training; conduct cost-benefit analyses; promote AC through model projects and public outreach.

Recommendations and Next Steps

Additive Construction offers a transformative opportunity for Canada to address its housing, environmental, and labor challenges. By investing in research, standards, and collaboration, Canada can lead the global shift toward sustainable, digital construction. The roadmap proposes the following to accelerate AC adoption and digitalization in construction:

1. **Establishing a Construction Digitalization Center of Excellence or Consortium** to unify stakeholders and drive innovation.
2. **Creating a comprehensive framework** that includes technical and non-technical domains such as workforce development and safety.
3. **Developing project-centric strategies** that address real-world challenges rather than promoting technology for its own sake.
4. **Launching financial support platforms** to subsidize R&D and pilot projects.
5. **Building a "single source of truth" platform** (e.g., data trusts) for data sharing and collaboration.
6. **Promoting multilateral collaboration** with international partners to harmonize standards and best practices.
7. **Instituting a collaborative permitting ecosystem** to streamline regulatory approvals.
8. **Engaging public and private sectors** to support SMEs and scale up AC initiatives.
9. **Leveraging lessons from other industries,** such as manufacturing and agriculture, to inform construction innovation.

Introduction

What is Additive Construction?

3D Printing, a disruptive and digital construction technology, which can potentially cause a paradigm shift in construction.

Additive Construction (AC), also known as 3D Construction Printing (3DCP), represents a significant advancement in construction technology, with the potential to change the industry by increasing efficiency, reducing waste, and enhancing design flexibility.

The term Additive Construction was coined to describe technologies that build large-scale structures layer by layer.[1]

Applications of AC cover all construction sectors and expand to large-scale real estate projects, elements of buildings, entire structures, civil infrastructure, and disaster relief. AC also encompasses relevant areas of architecture, engineering, robotics, as well as project and facility management.

Many consider AC as relating only to the walls of houses 3D printed from cement-based materials. However, the field of AC is much broader. It extends beyond concrete and involves other materials such as polymers, metals, geopolymers, and more.

3DPC is becoming a promising alternative to the traditional construction techniques due to various benefits such as:

- **Reduction in construction cost and time:** Compared to conventional construction techniques, it is possible to print buildings faster and at a lower cost, which would result in a significant increase in productivity.
- **Design flexibility and improved accuracy due to its highly digital nature:** The technology is completely digital, and the entire process, from design to printing, can be automated and controlled by computer programs and algorithms.

[1] The term was defined and adopted by the ISO/ASTM JG80 committee during the development ISO/ASTM 52939 - Additive manufacturing for construction — Qualification principles — Structural and infrastructure elements.

- **Reduction of waste in materials, especially in formwork:** By extruding material only where needed, AC drastically reduces waste—especially in formwork—making it a more resource-efficient approach.
- **Potentials for building resilient structures:** 3D printed houses can be designed to be resilient and adapted to the changing climate and other environmental conditions.
- **Environmentally friendly**: The current and future materials for AC can potentially: lower greenhouse gas emissions (e.g., through carbon-negative or recycled materials), and improve energy efficiency and insulation, reducing heating and cooling demands.
- **Labour benefits:** AC reduces the need for heavy manual labour, creating safer and more technical roles that can attract a broader workforce. This shift may bring more women and non-traditional workers into construction while expanding opportunities for training and upskilling.
- **Flexible**: If printed in modular pieces, a printed structure can fit the changing family needs throughout the years.

A Disruptive Technology

Currently the 3D printed houses are in the "hybrid stage": 3D printed components are matched with traditional house building technologies.

A technological innovation that fundamentally reshapes the way industries operate is known as a disruptive technology. In Canada, the way houses are built has not changed much over the last few centuries, and wood-frame construction has been the predominant method for building homes. 3D printing construction has recently emerged as a disruptive and innovative technology in the construction industry. By enabling the reimagining of both design and manufacturing processes, AC paves the way for a complete reinvention of traditional construction methods.

Once AC reaches full technological maturity, it has the potential to seamlessly integrate the strengths of both conceptual and traditional construction methods—while introducing groundbreaking capabilities previously unimaginable. This innovation could revolutionize the construction industry, enabling mass customization at minimal additional cost, accelerating time-to-market, reducing construction expenses, and offering unprecedented design freedom and functional integration.

The way we construct homes is poised for a significant transformation with the advent of technologies such as AC and a growing commitment to environmental sustainability. Figure 1 illustrates this conceptual evolution. At present, 3D-printed homes are in a "hybrid phase", where components such as walls and foundations are produced using 3D printing. At the same time, traditional methods are still used for horizontal flat elements such as floors and roofs. Looking ahead, the goal is to achieve fully 3D-printed homes, where every structural component—including the floor and roof—is fabricated using this innovative technology.

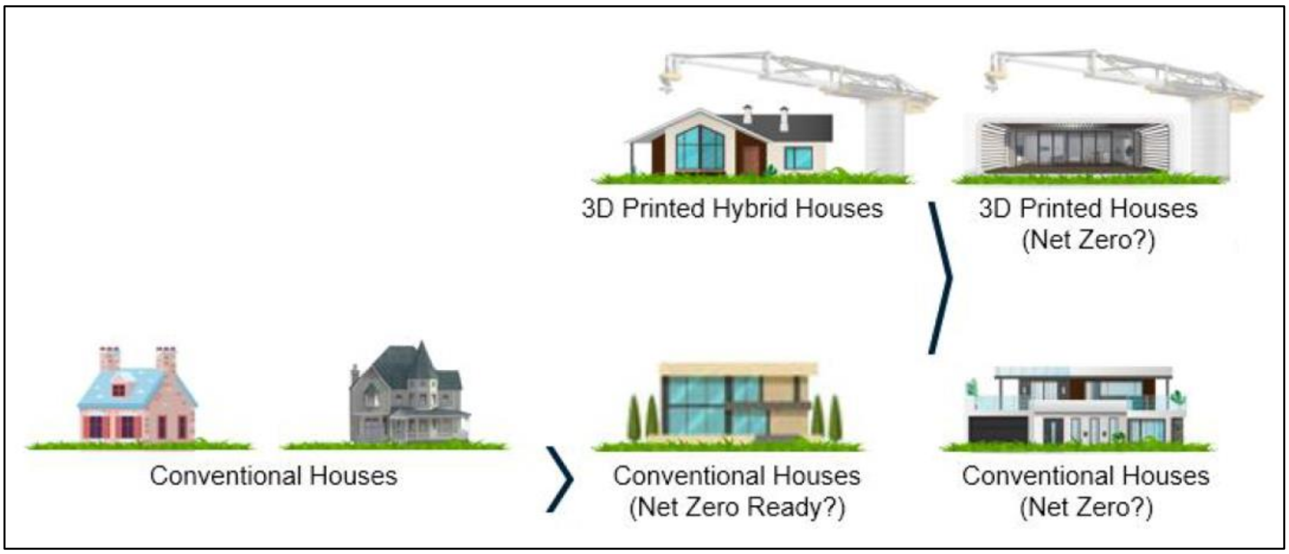

Figure 1. The paradigm shift and future of housing.

Potential Paradigm Shift

3D printing **improves safety, enhances quality**, and **unlocks new design possibilities** beyond traditional construction limits.

The ongoing paradigm shift in construction will also have a profound impact on the workforce. By limiting human exposure to hazardous conditions, 3D printing significantly improves on-site safety. It also decouples construction activities from traditional time constraints, enabling improved occupational health and safety standards. Moreover, the precision and consistency offered by automated production—through high geometric accuracy and uniform material quality—will elevate the overall quality of construction outcomes.

The paradigm shift initiated by AC extends far beyond construction methods—it is poised to transform architectural design itself. Traditional wood-frame construction has long favored rectangular and square floor plans, largely because these shapes are simpler, faster, and more cost-effective to build with conventional materials such as stone, concrete, brick, or wood.with However, with AC, these geometric constraints begin to dissolve. The technology enables greater design freedom, allowing for more organic, curved, or unconventional forms that were previously impractical or prohibitively expensive to realize.

Vision and Objectives

Purpose of the Initiative

NRC launched an initiative to accelerate 3D-printed construction in Canada by engaging stakeholders, identifying barriers, and creating a roadmap to drive sustainable, scalable building solutions.

In 2021, the National Research Council (NRC) began evaluating the readiness level of AC in Canada, focusing on barriers, economics, productivity gains, and environmental impact using data from the Canadian industry. In May 2024, these efforts were intensified under the Platform to Decarbonize the Construction Sector at Scale, establishing an internal advisory committee to connect with Canadian stakeholders, identify existing barriers, and assess private-sector interest.

Our Vision:

To bring together stakeholders to identify the challenges of Additive Construction and develop a research and innovation roadmap, which will guide the advancement of sustainable building technologies in Canada, fostering collaboration and practical solutions for the industry's future.

This initiative was designed to tackle some of the most pressing challenges facing Canada's construction industry today. The sector is under immense pressure to improve productivity, reduce carbon emissions, and respond to the dual crises of housing affordability and labor shortages. Traditional construction methods often struggle to meet these demands, leading to inefficiencies, material waste, and environmental impacts.

By increasing the adoption of AC projects, this initiative seeks to transform how buildings and infrastructure are designed and delivered. AC offers a powerful solution to reduce construction waste, enhance sustainable building practices, and accelerate project timelines.

Beyond efficiency and sustainability, AC could also unlock new opportunities for customization and architectural creativity, enabling creative designs. This flexibility may be particularly valuable in addressing the housing crisis, as it allows for rapid production of affordable, high-quality homes tailored to diverse community needs.

The initiative also explored other key application areas, including large-scale infrastructure projects, where 3D printing can deliver durable, resilient structures with reduced reliance on scarce labor resources. By embracing this technology, Canada can build a more innovative, resilient, and competitive construction industry, positioning itself as a global leader in advanced building solutions.

Lastly, this initiative was aimed at better understanding the needs and challenges involved to support broader adoption and long-term impact of 3D printing, so that Canada can advance the development of scalable and cost-effective 3D printing technologies. This included reducing implementation risks, facilitating smoother adoption across the industry, and expanding outreach to a wider range of builders and construction professionals. These efforts will be essential to ensure that the benefits of Additive Construction can be realized at scale across diverse projects and communities.

Initiative Overview

The initiative engaged nearly 180 stakeholders through surveys, workshops, and studies to identify barriers and opportunities for additive construction in Canada.

These efforts culminated in a strategic roadmap to accelerate technology adoption and position Canada as a leader in sustainable, innovative building solutions.

The initiative followed a structured, multi-step process designed to build a strong foundation for advancing Additive Construction in Canada (Figure 2).

→	→	→	→	→	✔
Stakeholder Identification	**Scoping Studies**	**Online Survey**	**Online Workshops**	**In-person Workshop**	**Strategic Roadmap Development**

Figure 2. The structure: multi-step process followed by the initiative.

It began with identifying nearly 180 key Canadian stakeholders, leveraging NRC resources, including Intelligence & Analytics (NRC I&A), the Industrial Research Assistance Program (NRC IRAP), Business Development teams, and the Construction Decarbonization Platform leads. This broad engagement ensured representation from industry, academia, and government.

Next, two **in-depth scoping studies** were conducted to establish a knowledge base:

- *3D Printed Construction: A Review of Literature and its Potential Use in the North* (NRC Internal Report No. A1-019954-01, June 23, 2022).
- *3D Printed Construction: Analysis of Productivity, GHG Emission, Challenges and Research Gaps* (NRC Internal Report No. A1-023512.1, March 31, 2024).

To capture real-world perspectives, an **online stakeholder survey** gathered insights on barriers and pain points. These findings informed two **virtual workshops** held on October 30 and November 4, 2024, organized by NRC's Construction Research Centre. Discussions focused on advancements and challenges in AC, including material performance, technology integration, and the durability of printed structures under extreme environmental conditions. The workshops aimed to validate key challenges, foster networking, and gauge interest in collaborative next steps.

Building on this momentum, an **in-person workshop** took place in Toronto on January 29, 2025, co-hosted by NRC and the Standards Council of Canada (SCC). This event convened 65 participants—representing industry (30%), academia (40%), and government (30%)—including major organizations such as CSA Group and the Cement Association of Canada. Nearly all significant players in Canada's AC ecosystem were present. The workshop provided a platform to share current efforts, best practices, and strategic directions, while emphasizing collaboration to avoid fragmented progress. Discussions centered on innovation to meet Canada's housing needs and the importance of unified action.

What you are reading right now it the product of all the comments, suggestions and needs told to us by the stakeholders. This **Strategic Roadmap for Research and Development of Additive Construction in Canada** serves as a guide to accelerate technology maturation, identify pathways for market adoption, and position Canada as a leader in this emerging field.

Global Market Overview

North America is now the second most active region in additive construction, with **rapid growth** since 2020; Europe leads globally, and Canada represents about 15% of the North American segment.

The market includes over 600 stakeholders, dominated by technology/service providers (54%) and cement-based materials (78%), **reflecting strong demand for scalable, cost-effective solutions.**

Since 2020, particularly amid the COVID-19 pandemic, rising housing demand, and the implications of climate change, North America has become the second most active region in AC.

It should be noted however, that a major catalyst for AC adoption initially emanated from the Arabian Gulf around 2016 through such initiatives as Dubai's 3D Printing Strategy, Saudi Arabia's Vision 2030, and projects such as NEOM. Such initiatives have triggered innovative and increasing sustainable requirements imposed on the architecture, engineering and construction sector.

The demand for AC has given rise to a sharp increase in the number of market players. As of October 2025, 609 stakeholders were identified as currently active in AC (Figure 3).

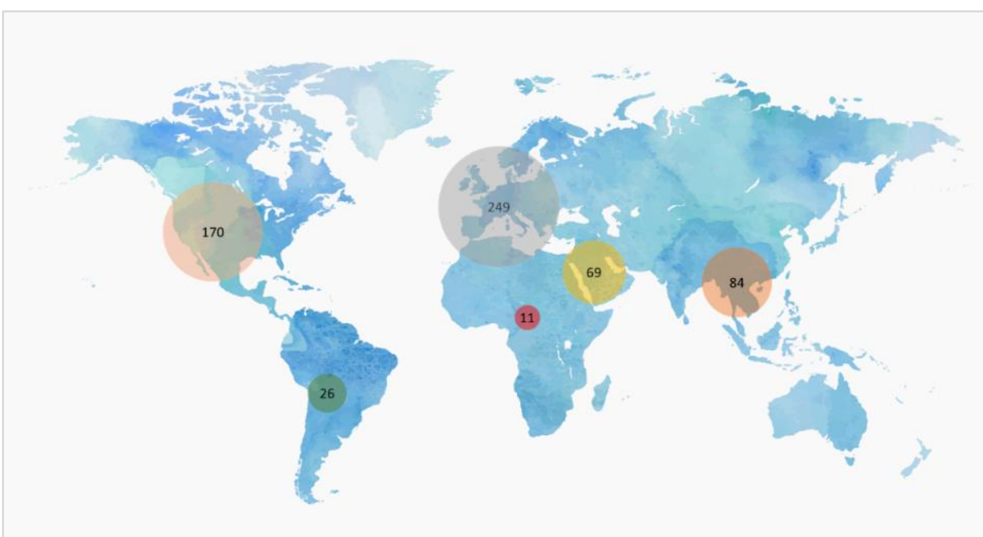

Figure 3 - Global landscape of AC Stakeholders.

Table 1 describes the categorization used in AC market represented data.

Table 1. Additive Construction Stakeholders.

Category	Description
Technology Provider	Entity that develops and sells AC solutions (gantry, robotic arm, … etc.).
Service Provider	Entity providing AC as a service using their own or acquired AC solutions.
Material Supplier	Entity supplying material to the AC sector (technology providers, service providers, research institutions, etc.).
Developer	General contractor acquiring the services of a technology provider / service provider or has invested directly into an AC solution and established in-house AC operations.
Architectural / engineering	Entity having direct involvement in an AC project providing architectural / engineering support.
Academic institution	Entity undertaking R&D efforts or providing support to AC projects, technology / service providers, and material suppliers.

Compared to 2023, 2024 has seen an increased market ratio of 311% in North America, 165% in Europe, and 300% in Asia/Pacific. So far globally, 2025 has seen a change ratio of 73% compared to 2024.

Worth noting, from the beginning of 2025 through October, the sector grew by 111 new entrants in the AC segment, resulting in a 59% change ratio in Europe, 108% in North America, and 58% in the Middle East compared to 2024 (Figure 4).

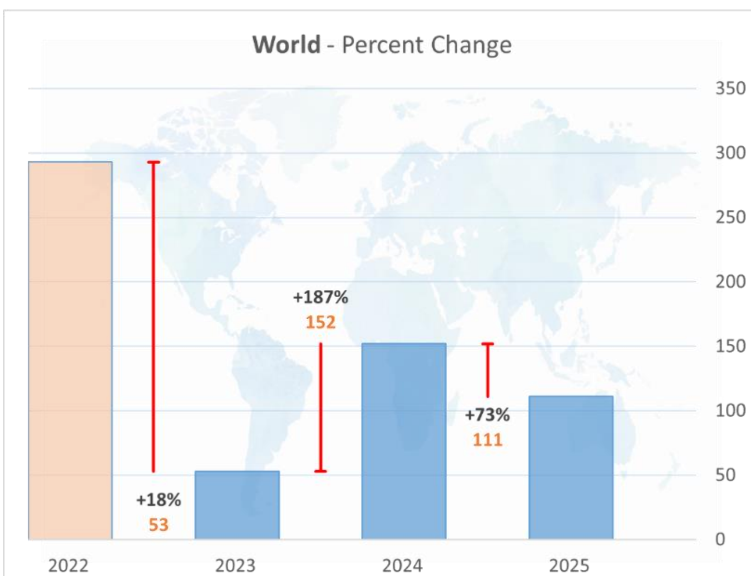

Figure 4 - AC Market year over year.

Technology and service providers account for approximately 54% of the Additive Construction market, underscoring their dominant role in driving innovation and operational support (Figure 5).

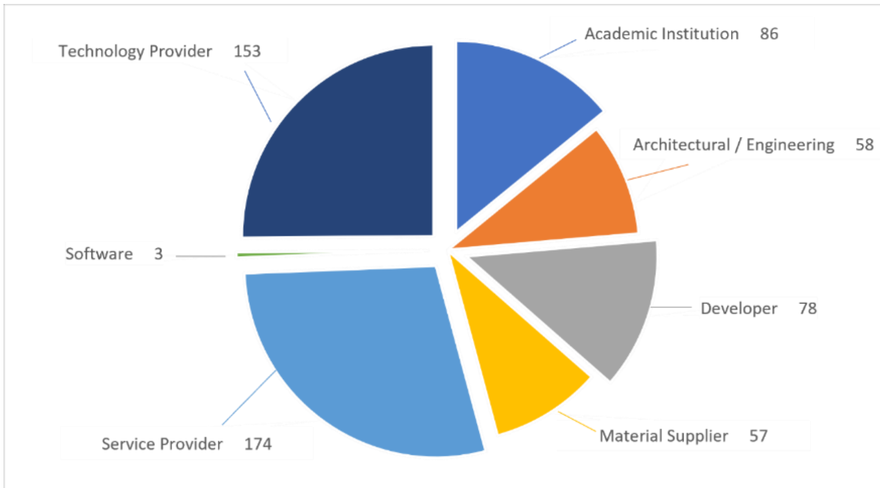

Figure 5 - AC Stakeholders by Category (data from 2024).

Meanwhile, cement-based materials are the leading category in market applications, accounting for nearly 78% of usage. This strong preference for cement-based solutions reflects their widespread availability, cost-effectiveness, and compatibility with existing construction practices, making them the material of choice for most additive construction projects worldwide (Figure 6).

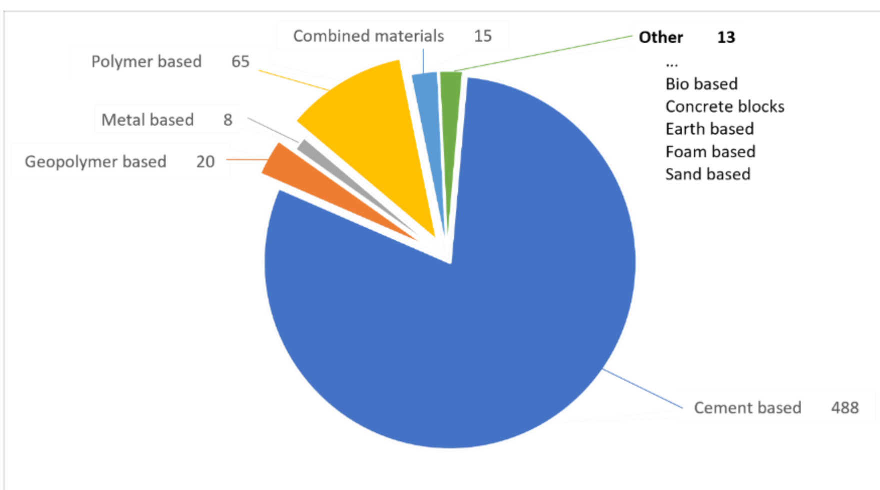

Figure 6 - AC Material Breakdown (data from 2024).

Comprising about 41% of the entire AC segment, Europe, for the past 10 years, has led in AC innovation and adoption with infrastructure and residential projects. Since 2020, North America has grown rapidly to become the second-most active region, accounting for 23% of the AC sector.

As of October 2025, North America has already surpassed 2024 stakeholder numbers. Canada accounts for about 15% of the North American market, while the United States leads at about 83%.

Additive Construction in Canada

Additive Construction in Canada is in its early stages, with few active companies and growing interest driven by sustainability and efficiency goals.

Adoption is limited by regulatory gaps, high costs, lack of skilled workforce, and climate-suitable materials, but offers opportunities for faster, safer, and more sustainable housing and infrastructure.

In Canada, Additive Construction remains in the innovation stage, with only a few pioneering companies actively exploring its potential, while the US and the Middle East are further along the additive construction adoption curve and benefiting from faster, more efficient builds. (Figure 7). The AC technology has demonstrated clear advantages, such as reduced material waste, faster build times, and improved worker safety, however, it remains a novel and emerging approach within the broader Canadian construction industry.

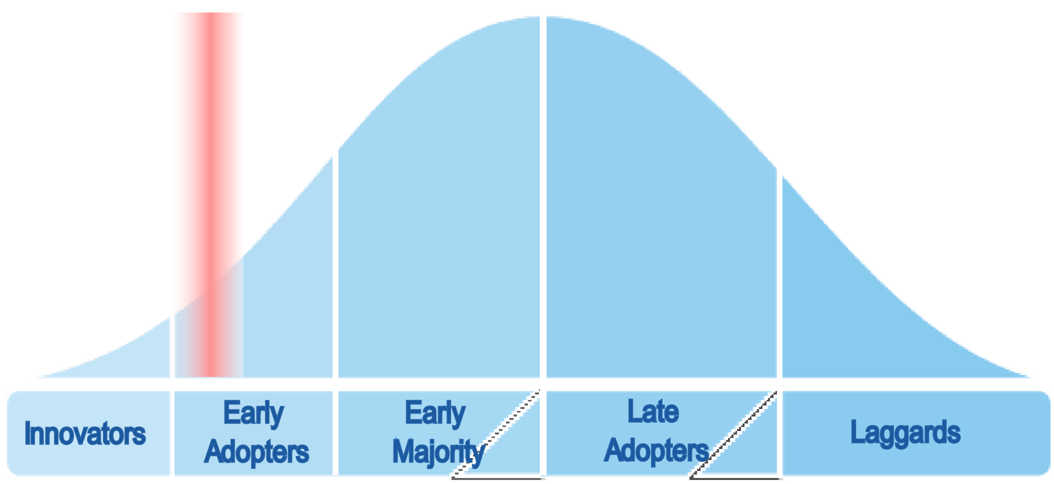

Figure 7. The current status of AC in Canada (red line), plotted on the Technology Adoption Curve.

As interest in sustainable and efficient building methods grows, Additive Construction is gaining traction as a promising solution for the future of Canadian housing.

Despite building momentum and traction, adoption remains limited due to regulatory uncertainty, high upfront investment costs, limited availability of skilled professionals, and the lack of acceptable solutions within building codes for 3D-printed structures. However, the opportunities are equally compelling: 3D printing offers the potential for faster construction, reduced material waste, improved worker safety, and greater design flexibility. It also opens the door to affordable housing solutions in remote or underserved communities.

A major hurdle for 3D printing in Canadian construction is the lack of printable materials engineered to suit the country's harsh climate. Most existing mixes are designed for milder conditions and struggle with Canada's extreme cold, freeze-thaw cycles, and humidity. Without materials tailored for durability and reliable curing in these environments, year-round construction and structural performance remain limited.

For the Additive Construction industry to succeed, a solid foundation is needed to sustain and enable growth, be inclusive, addressing all aspects of the industry (technical and non-technical), and be relevant to global market requirements.

Over the past 10 years, several initiatives have been established to support the Additive Construction industry and address construction sector challenges. The initiatives center around digitalization and Construction 5.0[2] principles of technology integration, human-robot collaboration, sustainability, safety/regulatory compliance, and resilient structures.

[2] Facilitating Construction 5.0 for smart, sustainable and resilient buildings: opportunities and challenges for implementation - Ibrahim Yitmen et. al. – April 2024

Challenges in Canada

Additive Construction is emerging in Canada but faces significant barriers, including lack of standards, suitable materials, digital infrastructure, skilled workforce, and investment.

As in many parts of the world, 3D printing technology is steadily gaining momentum in Canada, driven by its potential to transform traditional construction practices through automation, efficiency, and design flexibility. However, despite this growing interest, the technology remains in its early stages of adoption and faces a range of challenges. Some of these challenges—such as material performance, equipment reliability, and workforce training—are common across global markets. Others, however, are uniquely shaped by Canada's specific conditions, including regional variations within building codes, extreme climate variations, and a relatively conservative construction industry. Understanding this dual context is essential for identifying both the opportunities and barriers that will influence the successful integration of additive construction in Canada.

The following sections provide a detailed examination of these challenges, offering insights into both their underlying causes and potential implications for the adoption of additive construction.

Printing Materials	**Lack of compliant materials:** The few commercially available 3D printable construction materials are expensive and the National Model Codes do not contain acceptable solutions within Division B that permit their use. Material performance in additive construction also varies with printing methods and environmental conditions, adding uncertainty. **No cold-climate solutions:** There are currently no printable materials specifically engineered to perform reliably in Canada's cold climate conditions.
Construction Digitalization	**Digital dependency challenge:** While AC offers high precision and reduced waste through digital control, it also relies heavily on advanced digital tools, software, and skilled operators. This creates a barrier in regions or companies lacking the necessary digital infrastructure, training, or integration with Building Information Modeling (BIM) systems, potentially slowing adoption and limiting its benefits.

	Need for digital infrastructure: Current analog construction practices are incompatible with 3D printing; a robust digital infrastructure is essential for successful implementation.
Resilience & Durability	**Climate resilience demand:** Rising risks from climate change, wildfires, and degrading permafrost underscore the need for alternatives to traditional wood-frame construction. **Need for innovation in housing:** More research is required to develop resilient and durable housing solutions—3D printing presents a promising pathway to meet these evolving demands.
Codes and Standards	**Lack of a regulatory framework:** Canada currently has no building codes or standards specifically tailored to 3D-printed construction. **Limited industry activity:** Only a few companies are actively printing in Canada, and they often face delays and increased costs due to the absence of clear regulatory guidance.
Social Factors	**Workforce readiness gap:** There is a lack of specialized workforce across all levels—from education and training to practical application—affecting both designers and construction workers. **Uncertain user acceptance:** Consumer perception of 3D-printed housing remains largely unknown, with no scientific studies on post-occupancy evaluations of existing printed structures.

Further to the above, but not addressed in this report, there are a few key challenges impacting Additive Construction. For instance, now, developers and general contractors make up only 13% of stakeholders, while technology and service providers dominate the space. This imbalance hinders the development of practical AC solutions tailored to real-world construction needs, including residential, commercial, and infrastructure projects. Without deeper engagement from traditional construction players, the industry risks creating innovations that lack relevance or scalability.

Financial support structures also pose a challenge. The AC sector is largely sustained by startups, material suppliers, and academic institutions, with much of the work being voluntary and exploratory. This limits the pace and scale of progress, especially in establishing industry standards and best practices. Without robust public and private investment, the sector may struggle to transition from experimental to mainstream, leaving its potential to address construction inefficiencies unrealized.

Challenge: Printing Materials

Develop sustainable materials like geopolymers and bio-based alternatives using local, low-carbon resources.

Ensure performance through standardized testing and real-time mix adjustments for durability and adaptability.

Support adoption by integrating materials into codes, sharing data openly, and designing for recyclability and carbon capture.

The advancement of Additive Construction faces several critical challenges. Traditional construction materials and methods are not inherently optimized for additive manufacturing, limiting their effectiveness in 3D printing applications. In Canada, the absence of standardized procedures and the lack of integration of 3D-printable materials into building codes further complicate adoption. Additionally, concerns around the environmental impact and sustainability of currently used materials underscore the need for innovative, eco-conscious solutions.

Most Additive Construction initiatives currently focus on cementitious materials because they are the lowest common denominator across the construction industry.

However, with increasing international environmental awareness and local initiatives such as Canada's "*2030 Emissions Reduction Plan: Clean Air, Strong Economy*"[3] equal and parallel attention needs to be allocated to address eco-friendly and sustainable materials that could replace cement. These materials could provide low-carbon alternatives to clinker, sourced from either construction/industry waste, or comprise of locally sourced adobe, geopolymer, polymer, or metal-based materials.

Advancing 3D printing in construction requires innovation in materials, optimized mix designs, and sustainable practices. The following key areas outline strategies to improve performance, standardization, and environmental impact.

[3] Government of Canada - 2030 Emissions Reduction Plan: Clean Air, Strong Economy.

Proposed solutions	Opportunities to explore
Advance Material Innovation in Additive Construction	• Develop alternative materials such as binders, geopolymers, recycled, bio-based materials, and materials with low CO_2 footprints and recyclability at end-of-life. • Incorporate carbon capture and storage techniques to reduce emissions from Additive Construction materials. • Improve productivity by integrating precast techniques where suitable. • Explore the recyclability of 3D printed structures to support circular economy practices.
Understand and Improve Material Properties and Performance	• Establish procedures to assess the properties of cementitious-based mixtures. • Ensure materials meet performance criteria: flowability, buildability, shrinkage control, setting time, thixotropy, adhesion, bonding, weather resilience, durability, extrudability, and layer stability. • Address alkali-silica reaction and water demand in mix designs.
Optimize Mix Design for Better Results	• Enable real-time mix adjustments (e.g., water content, superplasticizers) based on environmental conditions. • Develop performance-based standards for local material testing and adaptation. • Create an open-source database to share mix designs and performance data between academia and industry.
Standardize Testing to Ensure Quality	• Define standard test methods for live and post-print evaluations, such as squeeze test, shrinkage, temperature, layer adhesion, compression, shear stress and others. • Ensure appropriate gradation of components and water demand. • Assess alkali-silica reaction potential and other durability factors. • Consider aggregate size in relation to mixing, pumping, nozzle design, and print head performance to avoid honeycombing and poor finishes

Challenge: Construction Digitalization

Integrate AI, 3D printing, and traditional methods to boost efficiency, reduce material use, and respect local practices.

Enhance digital infrastructure by standardizing data formats and integrating BIM, IoT, and digital twins for real-time control and system precision.

Tackle data and security challenges through open-source sharing, climate-specific datasets, and encryption for digital workflows.

Construction digitization - the use of digital technologies to improve how construction projects are designed, managed, and built – is helping make processes more efficient, accurate, and connected. While progress is being made, there are immediate challenges that hinder their effectiveness. Industry stakeholders rarely share data due to the lack of standardized formats and open-source platforms. Hardware and software systems often don't communicate well, and without real-time control, construction processes lose precision and efficiency.

A recurring talking point within the construction sector is "Silos", be it in collaboration and/or data sharing. This "Silo effect" has unfortunately metastasized into the exploration and adoption of innovative approaches to address construction sector pain points.

Efforts and platforms exist to explore individual solutions such as Artificial Intelligence, Construction Tech, Property Tech, Robotics, Cloud Computing, Internet of Things, etc., but no podium integrates a holistic digitalization approach.

A viable construction digitalization roadmap is only viable if a comprehensive platform exists that addresses not only the technical solutions but also the non-technical areas, such as workforce development, training, and regulatory compliance.

The following key areas outline strategies to improve construction approaches, leverage AI and digital tools, and build robust digital infrastructure.

Proposed solutions	Opportunities to explore
Integrate Hybrid Construction Approaches for Flexibility and Cultural Relevance	• Combine traditional methods with new technologies to create adaptive, culturally respectful building systems. • Use topology optimization to reduce concrete use in hybrid prefabricated 3D printed structures.
Leverage AI and Digital Tools to Enhance Precision and Efficiency	• Use AI for data reading, validation, and formulation; enhancing Building Information Modeling (BIM) accuracy and digital twin integration; real-time geometry monitoring and material efficiency; and optimizing material selection and process outcomes. • Apply Internet of Things (IoT) for real-time adjustments during printing.
Build Robust Data and Digital Infrastructure to Support Innovation	• Address the lack of experimental data for large-scale and climate-specific projects. • Develop standardized data formats (e.g., ISO 19650, buildingSMART Data Dictionary). • Create open-source databases to facilitate collaboration and innovation. • Normalize data communication protocols and schemas to enable seamless information sharing and real-time analytics across platforms, stakeholders, and projects • Ensure interoperability of digital tools and technologies—including Big Data, IoT, Cloud Computing, and Additive Construction—by adopting common protocols, structures, and frameworks
Improve System Communication and Compatibility for Seamless Operations	• Improve integration between software and hardware systems. • Develop standards for real-time quality control and feedback loops during printing. • Enhance hardware precision to match software capabilities.

Strengthen Data Security to Protect Digital Construction Workflows	• Implement robust data encryption models to protect digital workflows in additive construction

Challenge: Resilience & Durability

Test materials, propose compliant assemblies, develop fire testing methods.

Monitor durability, design for climate, improve ductility with reinforcement.

Develop cost-effective tests for extreme conditions.

Study effects on bonds and joints; define freezing behavior and material needs.

Researchers and builders face challenges in advancing Additive Construction due to limited field data on structural integrity, thermal performance, moisture resistance, fire safety, and energy efficiency. High costs and the complexity of full-scale testing slow down progress. The industry also lacks sufficient data tailored to Canadian climate conditions and long-term durability, making it difficult to assess the viability of these structures locally.

Proposed solutions	Opportunities to explore
Strengthen Fire Resistance in 3D-Printed Structures	• Test materials for combustibility using existing standards; explore alternatives to costly large-scale tests. • Propose compliant wall assemblies and benchmark against prefabricated concrete. • Develop standard geometries, connection testing, and checklists for compliant wall/column/beam assemblies. • Consider fire testing for sub-units, including honeycomb shapes and fillers.
Enhance Long-Term Performance for	• Conduct long-term monitoring of buildings to assess durability under regional climate stressors (e.g., floods, temperature swings). • Design for year-round indoor comfort and resilience.

Climate Resilience	• Improve ductility and integrate reinforcement—potentially automated—for better structural longevity.
Develop Cost-Effective Testing Protocols and Address Knowledge Gaps	• Develop cost-effective methods for testing extreme conditions: wind-driven rain, freeze-thaw, fire, and seismic loads. • Address the lack of data on variable selection and climate-specific impacts.
Improve Freeze-Thaw Resistance for Cold Climate Durability	• Study freeze-thaw effects on interlayer bonds, joints, and walls. • Define freezing behavior in materials, layers, and mixtures, including air entrainment and dosing. • Consider element thickness and reinforcement in freeze-prone regions

Challenge: AC-Specific Codes and Standards

Develop AC-specific codes, standards, test methods, and performance criteria.

Create fire testing frameworks and benchmark with prefab concrete.

Standardize inspections and train inspectors.

Adapt international standards and use existing data to accelerate progress

Additive Construction faces several regulatory and technical challenges that hinder its broader adoption and integration into mainstream construction practices. The current National Model Codes do not contain acceptable solutions that permit the use of AC, nor does it provide guidance for methods that may be used to evaluate performance since these products behave differently compared to conventional construction materials. There is limited data available on critical performance factors such as fire resistance, material variability, and long-term durability, which complicates risk assessment and quality assurance. Additionally, inspection protocols and digital tools have not yet evolved to meet the specific needs of AC processes. Canada's diverse climate and regional conditions further underscore the need for localized testing and adaptation to ensure reliability across different environments.

While international standards provide a starting point, significant gaps remain that must be addressed to enable consistent, scalable implementation.

For true adoption of innovative approaches in construction, a review/update of existing standards and regulatory requirements is needed. Based on vetted scientific and actionable data, a framework is required within permitting and approval agencies to allow for and facilitate the adoption of construction digitalization solutions.

Proposed solutions	Opportunities to explore
Advance Building Codes, Guidelines, and Standards for Additive Construction	• Adapt existing building codes and develop new standards tailored to the unique properties of AC. • Create standardized test methods to evaluate material performance, long-term durability, and fire resistance. • Establish baseline performance criteria for 3D-printed structures to ensure safety and reliability.
Strengthen Fire Performance Evaluation for AC Materials	• Assess the combustibility of AC materials using current fire safety standards. • Develop a comprehensive testing framework for fire resistance in wall assemblies and structural sub-units. • Use prefabricated concrete as a benchmark to compare and validate AC fire performance.
Address Material Variability Across Projects	• Analyze how project-specific variables impact the performance of printed elements. • Collect and synthesize data from multiple AC projects to inform robust quality control guidelines. • Develop targeted test methods for freeze-thaw cycles, chloride diffusion, and fire resistance.
Modernize Inspection Practices for Additive Construction	• Update inspection protocols to reflect the unique features and processes of AC. • Train inspectors in AC technologies and integrate drone-based remote inspection capabilities.
Enhance Collaboration and Climate	• Build interdisciplinary frameworks to connect research institutions with industry stakeholders. • Utilize existing Canadian and international field data to accelerate AC development.

Adaptation Strategies	• Conduct supplemental testing to ensure AC materials and methods are adapted to Canada's diverse climate conditions.
Align Canadian Practices with International Standards	• Review and adapt relevant international standards (e.g., ICC AC509, ISO/ASTM 52939, RILEM 303-PFC) to guide Canadian AC practices. • Identify gaps in global standards and align Canadian approaches with international benchmarks to support harmonization and scalability.

Challenge: Social Factors

AC adoption is hindered by limited workforce readiness, unclear economic and regulatory pathways, and low public and industry acceptance.

Education, clear standards, and outreach are essential to build confidence and enable implementation.

All stakeholders must be involved to ensure a holistic perspective and benefits across the construction process.

Opportunities for real-world testing and access to projects are critical to address onsite integration and operational challenges.

AC adoption is hindered by limited workforce readiness and training, unclear economic and regulatory pathways, and low public and industry acceptance.

Addressing these gaps through education, clear standards, and outreach is essential to building confidence and enabling implementation. At minimum, all stakeholders need to be involved in the initiatives to provide a holistic perspective and ensure the benefits are realized throughout the construction process from design to handover.

Beyond education, opportunities to test and realize innovative approaches to construction operations are needed. Access to actual projects and use cases are critical to address onsite integration, environmental conditions, and operations.

Proposed solutions	Opportunities to explore
Strengthen Education and Workforce Development for AC	• Partner with academic institutions to integrate AC into curricula and upskill the construction workforce. • Deliver hands-on training in robotics, materials science, BIM, and design for manufacturing. • Promote diversity in skilled trades through inclusive education and targeted outreach. • Organize conferences, workshops, and internships to inspire and engage future professionals.
Conduct Comprehensive Cost-Benefit Analyses to Support AC Adoption	• Perform life cycle and cost-benefit comparisons between AC and traditional construction methods. • Quantify savings in labor, time, and materials to demonstrate economic advantages. • Analyze various building scales and designs to streamline regulatory approvals. • Highlight the environmental and resiliency benefits of 3D-printed structures to build stakeholder confidence.
Address Cost and Regulatory Barriers to Enable Market Entry	• Evaluate full construction and post-construction costs, including HVAC and lifecycle impacts. • Compare the cost per square foot of 3D-printed versus conventional structures. • Leverage existing data to inform regulatory discussions and close knowledge gaps.
Build Public Engagement and Industry Confidence in AC	• Promote AC through model projects and public demonstrations to showcase feasibility. • Encourage local material sourcing to support economic development and sustainability. • Support the development of user-friendly, human-centric design software to broaden accessibility.

Conclusion

Construction is an end-to-end process requiring integration across all phases, standards, and stakeholders for efficiency and sustainability.

Current digitalization efforts are siloed; cohesive strategies are needed to integrate AI, robotics, and cross-disciplinary collaboration.

The roadmap sets short-term goals (pilots, partnerships), medium-term goals (scaling, R&D, workforce training), and long-term goals (market adoption, updated codes, and innovation-driven growth).

Construction is a comprehensive, end-to-end process that integrates multiple stakeholders, disciplines, and operational phases. It spans the entire project lifecycle—from initial contract negotiations and architectural, design, and engineering development, through procurement and resource mobilization, to project management and controls. It further encompasses on-site construction activities, commissioning, and eventual decommissioning, followed by handover and post-completion obligations, including maintenance and warranty services. Each stage is interconnected, requiring seamless coordination to ensure quality, safety, cost efficiency, and timely delivery. Auxiliary domains are critical enablers within the construction ecosystem, providing the foundational support needed for successful project delivery. These domains encompass a wide range of functions, including the development and enforcement of standards, adherence to regulatory compliance, and rigorous safety protocols. They also address workforce development and training to ensure skilled labor availability, manage environmental impact to promote sustainability, and maintain political and economic predictability to reduce risk and foster long-term stability. Collectively, these elements create the conditions under which core construction activities can operate efficiently, safely, and responsibly.

A comprehensive strategy is required to address the full cycle of operations end-to-end, not just particular fragmented segments. This will enable us to fully understand the true results of construction digitalization. A simple example is addressing supply chain optimization using digitalization, but not following through with optimizing the construction process for the results to translate to the final product. Addressing the challenges identified in this report will help advance AC in Canada.

When looking at the Construction Digitalization initiative landscape, efforts remain “silo-ed” in their scope, therefore falling short of addressing integration into a cohesive and successful operational end-to-end process that enables the entire construction eco-system.

When exploring AI, Robotics, and other digital technologies, integration into an existing and evolving construction ecosystem is equally important. Integration includes addressing cross-disciplinary and departmental communication, standards to enable the new solution, training requirements, safety and security prerequisites, just to name a few.

The strategic roadmap for advancing Additive Construction begins with short-term objectives focused on proving viability and building foundational partnerships. This includes conducting pilot projects to showcase feasibility and benefits, collaborating with technology providers and construction firms, and initiating standardization efforts for materials and processes. Medium-term goals aim to scale operations and strengthen capabilities by expanding the scope of 3D-printed projects, increasing investment in research and development to enhance printer technology and material performance, and establishing comprehensive workforce training programs. In the long term, the vision is to achieve widespread market penetration and cost competitiveness, influence regulatory bodies to adapt building codes and standards, and foster a robust, innovation-driven ecosystem that supports continuous improvement and sustainable growth (Figure 8).

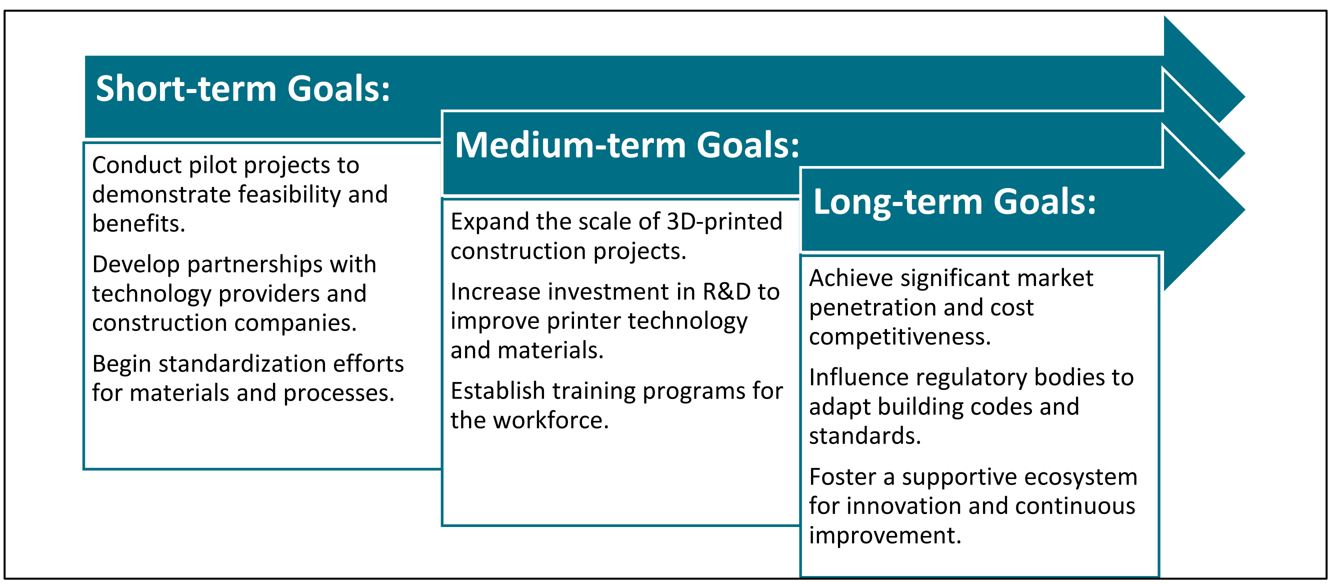

Figure 8. The Short, Medium, and Long-Term Goals Driving Adoption and Innovation of AC in Canada.

Below are key recommendations to advance construction digitalization, positioning Canada as an international collaborative partner and leading platform for innovation resurgence, development, and evolution.

Launch a Construction Digitalization Center of Excellence or Consortium

The establishment of a Construction Digitalization Center of Excellence or Consortium that will, at minimum, include local and international stakeholders from the construction sector, industry, regulatory bodies, standard development organizations, health and safety organizations, universities, research, and testing organizations, and labor and trade unions

Create a Comprehensive Construction Digitalization framework

Institute a comprehensive construction digitalization framework that is not only inclusive of technical but also non-technical domains. These areas could comprise, but are not limited to, workforce development/training, safety, security, and knowledge management, especially in creating a renewed purpose for the retiring construction workforce by capturing and sharing their decades' worth of invaluable tacit knowledge.

Form Project and Challenge Centric Strategies

Establish strategies that are project or construction industry challenge-centric and not technology or construction approach-specific. Construction digitalization is meant as a ***tool*** to address sector challenges and not to be force fit as an all-encompassing solution for every problem.

Maintain a Clear Distinction between Process Evolution and Process Innovation

Distinguish between process evolution and process innovation focusing on construction digitalization solutions that deliver innovative and efficient comprehensive operations, not just being apparatus specific (*process evolution*) or repeating the same talking points and repackaging existing approaches in different narratives.

Develop Supportive Financial Platforms

Create financial platforms to support initiative execution and subsidize the time, materials, and operations required to achieve construction digitalization objectives.

Establish a Single Source of Truth Platform

Attune to national and international construction demand, requirements, and challenges (*including disaster response from environmental and political incidents*) by providing a single globally accessible *source of truth platform* where construction digitalization can be explored to address challenges and exemplify Canada as a leader in innovation realization and adoption.

Lead and Promote Multilateralism Collaboration

Collaborate with Canadian and international governments in establishing directives to encourage and incentivize construction digitalization adoption through multilateral collaboration.

Institute a Collaborative Permitting Eco-System

Consolidate international efforts by providing a regulatory and permitting eco-system that defines a unified strategy for the digitization of the building permit process based on vetted data that enables construction digitalization and aids in mitigating risk allocation.

Build Public and Private Support

Most construction digitalization efforts are led by Technology and Service Providers who are, for the most part, Small and Medium-sized Enterprises (SMEs). Although extensive collaboration between the SMEs and Academic and Research Institutions exists in realizing digitalization solutions, further cooperation and participation are required from the construction and government sectors, specifically by providing a supportive financial framework.

In Canada, and specifically within the Additive Construction industry, Canadian expertise is leading international efforts in research, testing, material development, milestone projects, and standard development at a global scale through ISO, ASTM, and in collaboration with other organizations such as ACI, ICC, and NIST. These efforts are primarily led by SMEs with little financial support from the construction and/or public sectors.

Harness other Industry Experiences

Leverage other industry experiences and lessons learned, such as those from Manufacturing and Agriculture, to support construction digitalization initiatives and ensure robust solution integration and operations.

Appendix: Standard Development and Regulatory Initiatives

What follows is an overview of efforts to advance AC through standards development and regulatory initiatives.

ISO/ASTM

Officially established in March 2021, *ASTM F42.07.07 – Construction* and *ISO - TC 261/JG 80 - Additive Construction* committees set out to develop a standard to bridge the gap between Traditional and Additive Construction – how to use existing standards to certify/qualify 3D printed elements. This initial effort led to the publication of ISO/ASTM 52939:2023 - *Additive manufacturing for construction — Qualification principles — Structural and infrastructure elements*.

Based on feedback from the construction and AC industries, ISO/ASTM efforts have since expanded. The following initiatives were established to address the critical gaps in standards and regulatory compliance that are required to enable Additive Construction and foster the industry's foundation. The development of these standards is enabled by close collaboration with stakeholders across the private and public sectors.

- *WK81114 - New Practice for Additive Manufacturing -- General Principles -- Design Process of Additively Manufactured Building Elements. This work item is a joint effort under ISO/ASTM 52962.*
- *WK84415 - New Practice for - Additive Construction – General Principles – Standard Practice for the Evaluation of Structural Printed Elements. This work item is a joint effort under ISO/ASTM 52963.*
- *WK89299 - (Specification) Additive Manufacturing for construction – Qualification principles – Structural and infrastructure elements. This is a revision of ISO/ASTM 52939 published in December 2023 to include latest industry updates.*
- *WK89706 - Standard Practice for Additive Manufacturing -- Fresh and Very Early Age properties of concretes used for Additively Constructed Concrete by Means of Extrusion*
- *WK89707 - Standard Practice for Additive Manufacturing -- Construction and Documentation of Additively Constructed Concrete and Mortar Components*
- *WK90347 - Standard Practice Additive Manufacturing -- Curing and Extraction of Sample from Additively Constructed Concrete and Mortar Components*
- *WK90348 - Standard Test Method Additive Manufacturing -- Determination of Hardened Mechanical Properties of Additively Constructed Concrete and Mortar*

- *WK95215 - New Standard Additive Manufacturing - Determination of Flexural Strength of Additively Constructed Concrete and Mortar*
- *WK95216 - New Standard Additive Manufacturing - Determination of interlayer Bond Strength of Additively Constructed Concrete and Mortar by Splitting Tensile Method*
- *WK94968 - New Test Method for Defining the Printability Zone of Manually Fed Extrusion Printers*

American Concrete Institute (ACI) – Committee 564 - 3-D Printing with Cementitious Materials

Established in 2018, an important goal of ACI 564 is collaborating with technical organizations outside of ACI to facilitate collaboration in addressing challenges preventing AC from wide adoption in the concrete construction community[4].

Below are associated subcommittees:

- *564-0A Emerging Technology Report*
- *564-0B Structural Design and Testing*
- *564-0C Material Testing and Formulation*
- *564-0D Modeling and Performance Prediction*
- *564-0E Codes and Standard Review*

In February 2024, ACI formed Innovation Task Group 93-12 ITG-12 (ITG-12) "*to develop code requirements, design, and prescriptive provisions for additively constructed above-grade concrete walls for residential structures for incorporation into ACI 332 and the International Residential Code (IRC).*[5]"

International Code Council (ICC) 1150 - Certification of 3D Automated Construction Technology for 3D Concrete Walls

With an initial call for the establishment of a committee in January 2023 to solicit members, the ICC Board of Directors finalized appointments in July 2023. As of October 2025, the first edition of ICC 1150 is still under development and adhering to the Code Council's ANSI Accredited Consensus Procedures.

[4] The ACI Foundation's Request for Proposal on Behalf of ACI's Innovation Task Group 93-12
[5] ICC - 3D Automated Construction Technology for 3D Concrete Walls Consensus Committee (IS-3DACT)

The Code Council is developing this new standard to provide structural criteria applicable to additive construction technologies with specific use of concrete materials to construct interior and exterior walls, with or without structural steel reinforcing, used as bearing walls, non-load bearing walls and shear walls, in one-story or multi-story structures[6].

Slated for publication by the end of 2025, ICC 1150 will also be included in the next revision of the International Building Code (IBC) in January 2027.

RILEM – Technical Committee (TC) 304-ADC: Assessment of Additively Manufactured Concrete and Structures

The committee kicked off its efforts in 2021 with the objective of exploring and developing;

- *A scientific base for predicting and testing properties of hardening and hardened concrete printing,*
- *Using the tested properties for purposes of structural design, and*
- *Exploring reinforcement integration strategies to enhance the bond quality between the concrete and the element as well as corrosion mitigation.*

RILEM TC 304-ADC efforts are in close collaboration with Additive Construction standard development initiatives led by ACI, ISO, ASTM, and NIST just to name a few[7].

Construction Digitalization Roadmap and the ACE Consortium

A yearlong effort kicked off in September 2022 by ASTM to develop a Construction Digitalization Roadmap. The initiative was funded through a financial assistance award from the U.S. Department of Commerce, National Institute of Standards and Technology (NIST).

Published in September, 2023[8] the roadmap[9] identified existing gaps, challenges, and proposed recommendations for the digitalization of the construction industry. NIST in collaboration with the U.S. Army Engineer Research and Development Center (ERDC) established the Additive Construction by Extrusion (ACE) consortium in September 2023[10] as a direct result of the roadmap's proposed recommendations.

[6] RILEM - 304-ADC: Assessment of Additively Manufactured Concrete Materials and Structures
[7] ASTM International Unveils Roadmap on Advanced Technologies for Digitalization of the Construction Industry
[8] ASTM - Advanced Technologies for Digitalization of Construction Industry Roadmap
[9] US Federal Register - Additive Construction by Extrusion (ACE) Consortium
[10] NIST Additive Construction by Extrusion (ACE) Consortium

With the objective of addressing gaps in current standards related to materials, methods, structural performance, and engineering design the ACE consortium established specific task groups that focus on education, sustainability, bonding, infrastructure, durability, testing procedures, and rheology. The consortium is also in the process of creating a secure and collaborative platform to capture and share research analytics from industry stakeholders[11].

UAE Decree No. 24, Dubai as the Regional and International Hub in 3D Printing Technologies

Dubai's 2021 decree was issued to regulate the use of 3D printing technology in Dubai's construction sector[12]. The Dubai Municipality is playing a crucial role in overseeing and implementing 3D printing technology in construction through the following efforts:

- *Developing and publishing laws and technical standards for 3D printing.*
- *Providing specialist training for engineers in 3D printing.*
- *Reviewing designs and issuing permits for 3D printing projects.*
- *Monitoring project implementation to ensure compliance with standards and safety.*
- *Certifying plants producing 3D printing concrete mixtures.*

The municipality further issued a 3D Printing Guide – Design and Construction Guidelines for 3D Concrete Printing – in June 2024[13].

[11] Dubai Decree No. (24) of 2021 Regulating the Use of Three-dimensional Printing in Construction Works in the Emirate of Dubai.
[12] 15. Dubai Municipality – 3DCP Guideline – Guideline for 3D Concrete Printing in Design & Construction – 1st Edition – June 2024.
[13] Live Science - This House Was 3D Printed in Less Than 24 Hours.