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CANADIAN CONSTRUCTION AUTOMATION AND ROBOTICS ROADMAP



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I. Executive summary

Productivity in Canada's construction industry must be improved sustainably to address urgent threats to our well being. Automation and robotics play a key role in construction productivity gains. Prioritizing resource allocation requires a construction automation and robotics R&D roadmap that focuses on higher technology readiness levels. Just as the threat is urgent, the solutions must be addressed urgently. Such a roadmap requires:

- An overall framework for how key Canadian stakeholders may participate in a technology pipeline that creates construction productivity gains through application of automation and robotics
- Identification of key knowledge and implementation gaps from the perspective of the construction industry
- Identification of historic impediments to implementation of automation and robotics in construction
- Suggestions for means by which such impediments can be overcome
- Recommendations for implementation of a construction automation and robotics R&D program that will expedite deployment of solutions at scale

To support development of a construction automation and robotics R&D roadmap for Canada, the University of Waterloo was contracted to conduct workshops and interviews with a diverse range of key stakeholders and then produce a report. The first workshop, conducted entirely in-person, included a broad group of primarily industry participants (27 of the 45 external attendees) for a strategic-level discussion and better understanding of the current automation and robotics landscape in Canada and Globally.

The second workshop focused on a review by a select group of participants, again primarily industry, of a draft framework and roadmap.

A final recommended framework and roadmap are presented in this report, as well as the detailed background research and findings that underlay the recommendations. Three R&D thrusts are recommended:

- Technology demonstration projects should be delivered by joint industry, NRC and academic teams. They must report on the technical success and business readiness of the demonstrated solutions using standard and comparable performance metrics. They must also recommend a strategy and means to overcome impediments encountered. This thrust could be delivered within a Collaborative Research Testbed (CRT) framework, directed by industry, NRC, and academic experts. Such a CRT may enforce standard and comparable performance metrics by which productivity improvement progress can be measured.
- Research infrastructure support projects should be continuously funded. They may also include ongoing NRC initiatives that address the benchmarking and metrics needs for measuring progress and success, including lessons learned from demonstration projects, and overarching challenges like cyber security.
- A consortium should be formed to support actions towards deployment on a scale that may include workshops, competitions, venture capital raises, and tech transfer seminars.

II. Glossary

AI: Artificial Intelligence

BIM: Building Information Modeling

CAE: Canadian Academy of Engineering

CII: Construction Industry Institute

CMHC: Canada Mortgage and Housing Corporation

CP: Challenge Program

CSA: Canadian Standards Association

CSDP: Construction Sector Digitalization and Productivity Challenge Program

DARPA: Defense Advanced Research Projects Agency

DOE: Department of Energy

DT: Digital Twin

FHWA: Federal Highway Administration

GDP: Gross Domestic Product

GHG: Greenhouse Gas

IP: Intellectual Property

IRAP: Industrial Research Assistance Program

KPI: Key Performance Indicator

MARR: Minimum Attractive Rate of Return

R&D: Research and Development

ROI: Return on Investment

TFP: Total Factor Productivity

TRL: Technology Readiness Level

1. Introduction

As part of the NRC Platform to support the 'Decarbonization of the Construction Sector at Scale', the Construction Sector Digitalization and Productivity (CSDP) Challenge Program (CP) seeks to lower construction time and cost, while improving sector innovation potential and productivity, in order to increase the pace at which low-carbon solutions can be deployed in new and retrofit construction projects. Within this program, construction automation and robotics is envisioned to be a key driver of the successes of this platform regarding improving productivity at scale for the Canadian construction sector.

To better understand the automation and robotics gaps and challenges in the industry and to identify potential collaboration opportunities for the overall platform, NRC needed more detailed information on the current challenges and gaps on high TRL automation and robotics technologies in the construction sector. This would help spur impactful projects for the entire NRC Platform and provide a roadmap for the industry on areas that do not necessarily fit within the NRC Platform and CSDP Program scope. Thus, the objective for the study that is reported here was, "To better understand key R&D gaps on high Technical Readiness Level (TRL) technologies in construction automation and robotics for accelerated adoption by the Canadian industry, this project aims to produce a concrete Construction Automation and Robotics R&D Roadmap which will help inform future R&D activities required to increase adoption of such technologies by the sector at scale while informing R&D collaborative project ideas for the NRC Platform."

In terms of scope, it was intended that the roadmap would include:

- An overall framework for how automation and robotics achieves the objectives stated above through application of human-robotic systems, AI, mixed reality tools, exoskeletons, factory automation for prefabrication, 3D printing at scale, BIM, IT integration, digitalization, digital twins, and other emerging technologies that improve processes, add value, and make work easier.
- Identification of key knowledge and implementation gaps from the perspective of the construction industry.
- Identification of historic impediments to implementation of automation and robotics in construction.
- Suggestions of means by which NRC, other government agencies, trade associations, and owners can support adoption of automation and robotics including for example: policy implementation, financial incentives, collaborative projects, benchmarking and metrics for program impact assessment, and knowledge sharing.
- Prioritization of construction automation and robotics R&D gaps by impact and need for industry in terms of enhancing productivity.

The methodology by which this was achieved in the space of about six months included three main activities:

- Industry Workshops – Two workshops were conducted for this project.

The first, on 19-20 November 2024, included a broad group of primarily industry participants (27 of the 45 attendees) for a strategic-level discussion and better understanding of current automation and robotics landscape in Canada and Globally. The second workshop, on 13 February 2025, focused on review by a select group of participants (approximately one dozen) of specific topics and high TRL technologies, a draft framework, and a draft roadmap.

- Interviews – Preceding and follow-up interviews with workshop participants as well as individuals and organizations who were unable to attend the workshops were conducted throughout the project to seek their input and feedback.
- Consolidate data, draft and publish R&D Roadmap - Information collected was consolidated to clearly identify key gaps and challenges in the construction industry in terms of automation and robotics adoption. The R&D Roadmap was developed using the consolidated data while prioritizing needs by strategic thrusts and milestones.

The report that follows first delves deeper into the background of productivity in construction, the roles automation and robotics play in productivity gains, the known impediments to widespread adoption of automation and robotics in construction, and the landscape for construction automation and robotics R&D and commercialization in Canada. The report describes the conduct and outcomes of workshops I and II. It presents a suggested framework and roadmap for construction automation and robotics R&D in Canada.

- It ends with a summary and suggests next steps. Figure 1 presents a visual summary of the thematic mappings generated during the workshop.

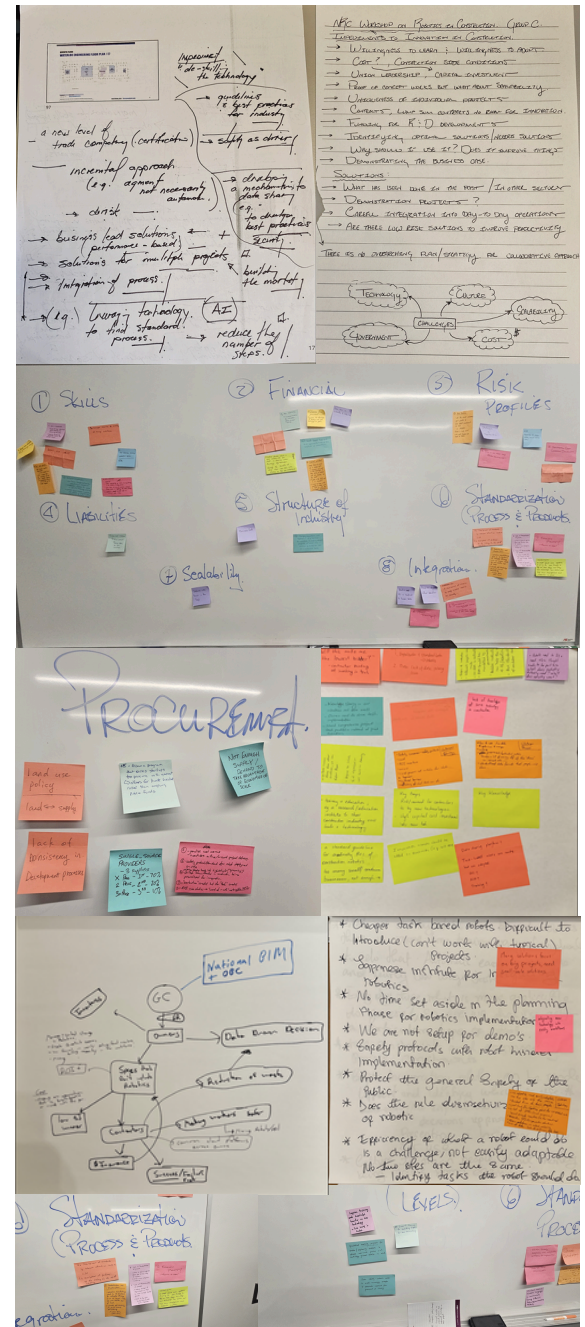


Figure 1 – Consolidated Visual Summary of Key Discussion Themes and Workshop Notes from the NRC Construction Automation Workshop

2. Background and Literature review

In the broadest sense, the goal of the Construction Sector Digitalization and Productivity (CSDP) Challenge Program (CP) is to contribute to low-carbon solutions that would enable Canada to efficiently and rapidly provide critical infrastructure, such as sufficient housing or energy independence. Housing shortages are particularly urgent. Root causes of housing shortages in Canada, for which commensurate solutions must be provided, are complex, interdependent and difficult to prioritize (Figure 1). For example, Canada has less land zoned for housing per capita than most western countries (Wright, 2024). Interest rates remain significantly higher than the previous ten years; every percent increase results in several hundred to a thousand dollars more per monthly payment for the typical Canadian mortgage, disincentivizing demand for new homes.

Permitting regimes in parts of Canada can also result in substantial financing costs and project delays, including: (a) reported requirements of up to 100 permits and reports for housing to be built, (b) reported durations of almost two years before home construction begins – as much as ten years for a mine or pipeline (Bray, 2024; Wright, 2024; and Loffreda, 2024). Unemployment is low, yet a doubling of the rate of housing construction would require a 50% addition to the supply of construction labour, because residential construction comprises about 50% of the construction labour force (and, since construction is about 7.5% of Canada's GDP, and is labour intensive, it would require finding 3-4% more Canadian workers; this would be unprecedented), so industry capacity is limited (Statistics Canada 2025).

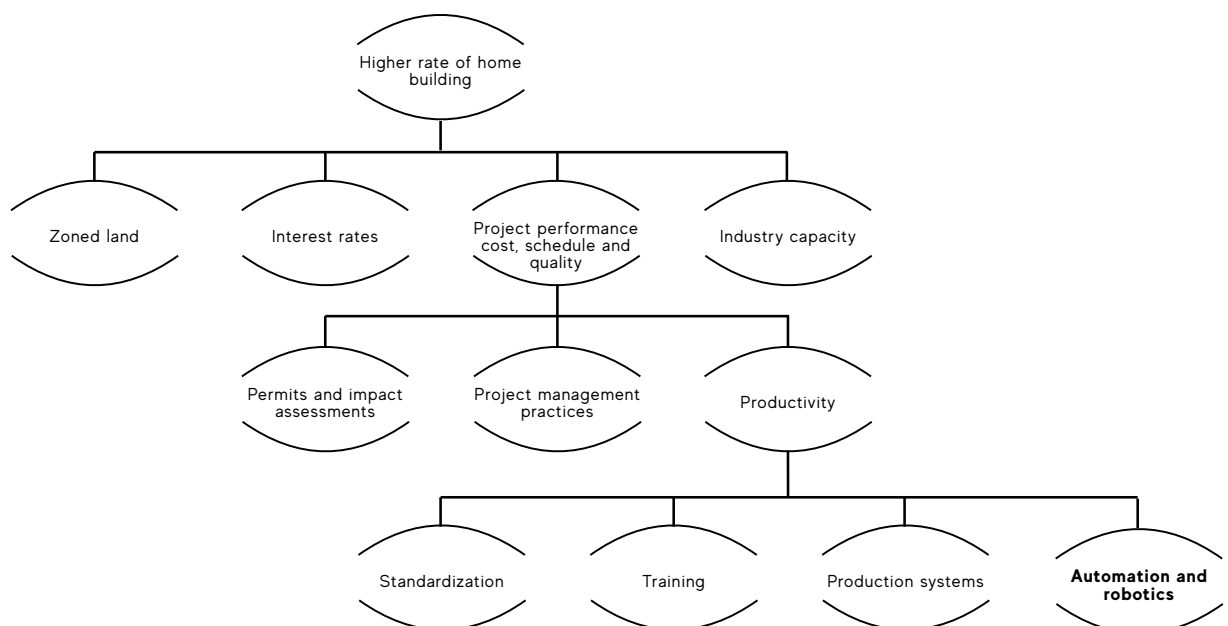


Figure 2 – Root causes of housing shortages in Canada

Project performance can be improved by reducing and expediting permits and impact assessments (Altus, 2022), by improving implementation of project management practices (Caldas et al., 2015; Nasir et al., 2012, 2014, 2016; Shan et al., 2011), and by improving productivity. Construction productivity can be improved with standardization, new materials, production systems (Eastman & Sacks, 2008), and the combination of automation and robotics (including AI). Automation and robotics in construction is a key solution category addressing productivity improvement, and it is the focus of the remainder of this report.

In national conversations, productivity problems are frequently cited. Unfortunately, productivity in construction can mean many things, which can be confusing. This chapter briefly reviews the challenge of productivity measurement in construction so that subsequent conversations around construction productivity improvement will be guided by precise and accurate use of language.

Well reported problems in construction productivity over time, including its widely regarded stagnation are addressed. Ways productivity can be improved and the role that improved construction productivity plays in addressing the housing shortage in Canada are briefly summarized. Then, the ways that categories of construction automation and robotics solutions contribute to productivity gains is explored. Finally, known impediments to adoption at scale of automation and robotics in construction are identified.

2.1 Productivity measurements and challenges in construction



Photo by Nathan Water

Construction performance metrics and their definitions include:

- Direct work rate – typically refers to the proportion of time that workers spend on productive, value-adding activities directly related to the construction project. A synonym is "tool time". Non-direct work includes time spent on preparation, acquiring tools and equipment, material handling, waiting, travel, and personal needs. Direct work rate can be improved through "activity analysis". Its relationship to labour or total-factor productivity is controversial.

- Labour productivity – (labour hrs)/(output unit) – most construction industry practitioners implicitly mean "labour productivity", when they use the term "productivity". It is the rate used to estimate and control projects. It can also be used to compare performance of relatively alike projects, and to relate that performance statistically with management practices or technologies that were implemented to improve performance.
- Productivity factor – (actual cost per unit/estimated cost per unit) – on large projects this is tracked and used to identify performance that is not meeting expectations, so that interventions can be applied in a timely manner. It is also used in project close-out reports.
- Project performance – is typically defined in terms of the dimensions of cost, schedule, quality, predictability, safety, and business success.
- Total factor productivity – (labour\$ + materials\$ + equipment\$)/(output unit\$) is an economic measure of the efficiency of a business or industry sector. It may be the truest measure of competitiveness of a company or country.
- Circularity and sustainability – are terms that relate to the social, economic and environmental performance of a project or industry sector over a long time-horizon.
 - Embodied and operating energy (or carbon or GHG emissions)
 - Aiming to keep products, components, and materials at their highest utility and value at all times
- Industrial capacity utilization rate – is the ratio of an industry's actual output to its estimated potential output.

This is a KPI (key performance indicator), because nonworking capital is an opportunity cost. This may be the most appropriate measure for the capital effectiveness of the off-site fabrication sector of construction. According to Statistics Canada, the Canadian construction industry's capacity utilization rate declined to 82.7% in the fourth quarter of 2023 from 86.2% in the fourth quarter of 2022. For 2024, according to Statistics Canada (2025), "Capacity utilization in the construction sector rose 1.0 percentage point to 84.0% in the fourth quarter. This is the second straight quarterly increase after a series of nine consecutive declines. It coincided with increased activity in residential and non-residential building construction."

- Heavy construction equipment utilization rates – for individual pieces of construction equipment, such as cranes, excavators and dozers, common KPI's are related to industrial capacity utilization rates, and they include: utilization rate, operating hours, equipment productivity, fuel usage, idle time, unplanned downtime, and location tracking. All of these, except location tracking are KPIs that can be applied to equipment in an off-site construction facility. For example, with poor equipment spread and flow balancing (mitigated through "lean" manufacturing techniques), idle time for equipment and labour can be excessive and is wasteful. Ultimately, all these measures need to be rolled-up into some sort of aggregate measure such as cost-per-meter-squared, which is a form of TFP (total factor productivity).

Applications of performance metrics depends on time scale (or frame) of the problems being addressed. A brief summary of their relationships, ordered commensurately, is conceptually illustrated in Figure 3. It is commonly argued in the literature that construction labour and total factor productivity have remained stagnant or have declined over the last several decades, in contrast with positive developments in select activity areas such as earth moving (Goolsbee and Syverson 2023; Marple 2024; Mischke et al. 2024).

Figure 4 illustrates how earth moving productivity experienced two positive step changes historically. Both could be interpreted as having some relationship with automation and robotics. Yet, according to (Goolsbee and Syverson 2023), total factor productivity has been lagging in construction behind all other industries since the 1960s as illustrated in Figure 5, despite capital investments tracking those in other sectors (Figure 6).

It is possible Construction productivity truly is flat or declining, assuming the Construction Price Index is the correct deflator (Figure 7). However, if we are not measuring value or quality (such as longer useful life) of output properly, and if we used the GDP Price Index as a deflator, construction productivity may be improving more like the overall economy. Evidence does in fact exist that homes built today last longer than those built decades ago (Aktas and Bilec 2012) and that they require far less energy and cost to operate (Unit 2009). Regardless, the impediments to overall construction sector performance persist (Figure 1). Those impediments need to be addressed, and productivity needs to be improved substantially for Canada to solve its housing shortage and to compete more effectively globally.

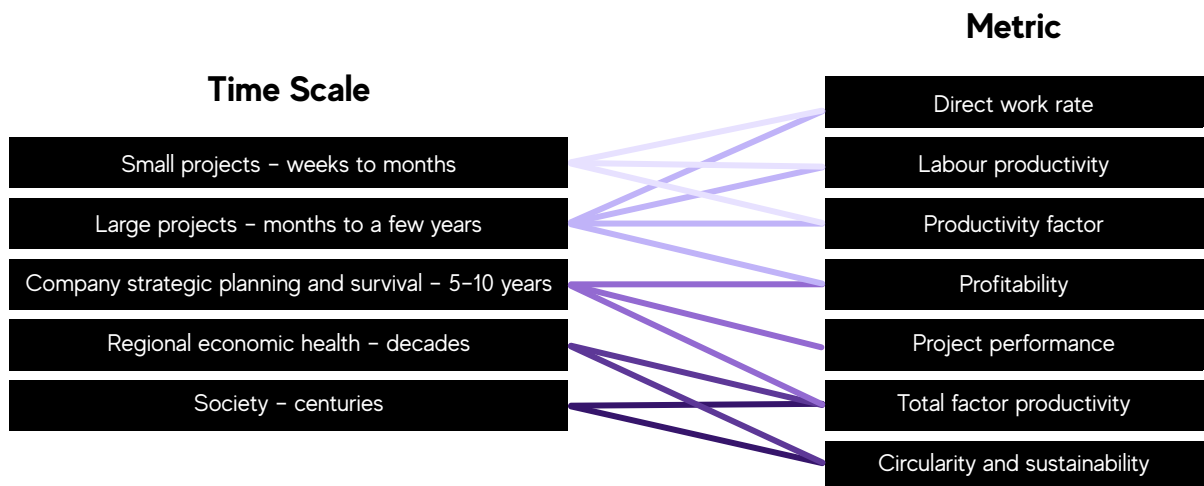


Figure 3 – Construction metrics and their time scales

HYDRAULIC POWER (1950S)

400% improved productivity



- Substitute hydraulic actuation for cable actuation
- More power for the dollar
- More machine hours for the dollar

AUTOMATION & ROBOTICS (2000S)

50% improved productivity



- Reduces rework (moving the same dirt around many times)
- Eliminates steps (laying out grade stakes)
- Faster and more coordinated control than humans

Figure 4 – Earth moving productivity improvement step changes

In summary, observations on the state of construction productivity and performance in North America and especially Canada, include:

- Prices are up
- Quality is up (useful life, energy efficiency)
- Project durations are being extended due to permitting requirements (Altus 2022)

- Projects still exceed budget and schedule
- Industry volume and skilled labour shortages are highly cyclical
- Technology is making a positive difference over time
- Construction productivity is improving in many ways, but there are good arguments that it is stagnating overall

While we know that technology is making a positive difference over time, there are not many studies that quantify and compare the impact on productivity of different construction technologies.

In a widely cited pair of articles Goodrum & Haas, (2002, 2004) showed that productivity was changing for many activities due to advances in power, mobility and control for different types of tools and equipment. In another highly cited article, Grau et al., (2009) studied the impact of materials tracking technologies on productivity on a power plant construction project. Also Zhai et al., (2009) studied over 500 projects through the Construction Industry Institute's Benchmarking and Metrics Database to estimate the relationship between automation and integration of construction information systems and labor productivity in four areas of construction: concrete, structural steel, electrical, and piping.

Those projects that had high levels of information technology automation and integration experienced productivity performance 30-45% better than those projects that had low levels of information technology automation and integration. However, as we all know, correlation is not proof of cause and effect.

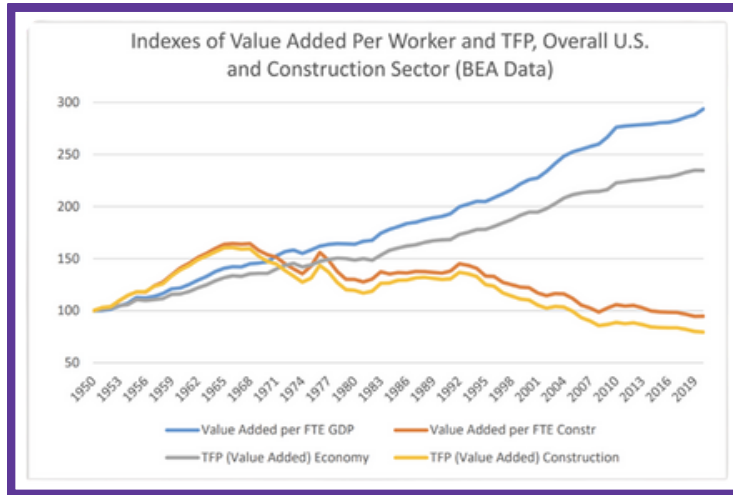


Figure 5 – Total factor productivity in construction vs the economy as a whole (Goolsbee and Syverson 2023)

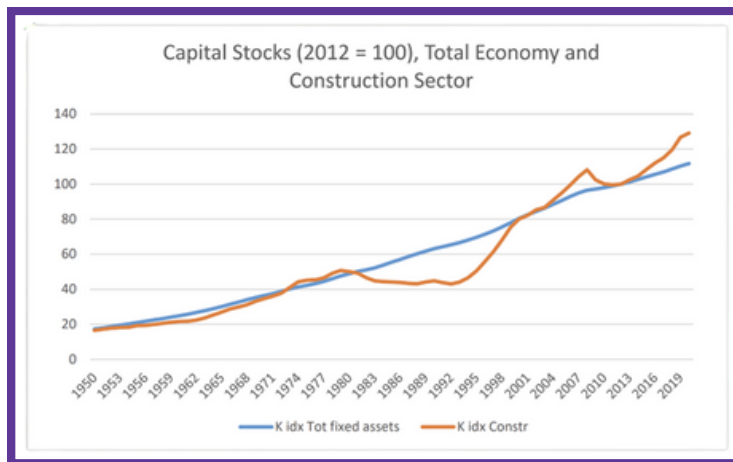


Figure 6 – Capital stocks (Goolsbee and Syverson 2023)

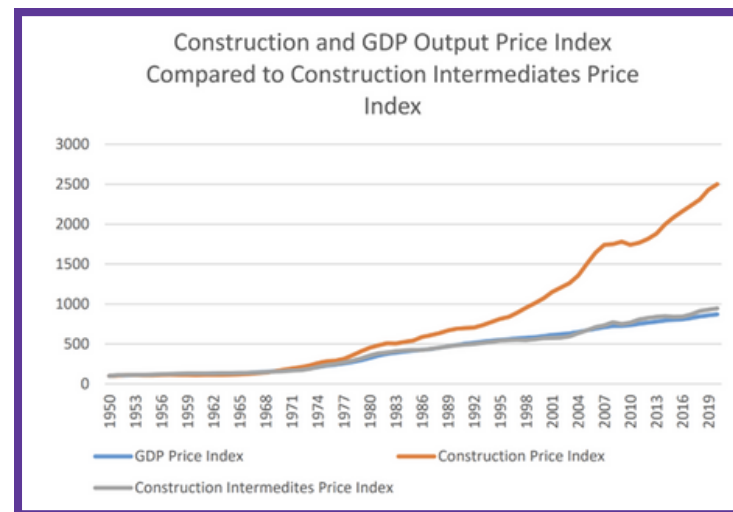


Figure 7 – Price indices (Goolsbee and Syverson 2023)

There now exist a wide range of commercial variations on this class of technologies offered by heavy construction equipment manufacturers such as Caterpillar, Komatsu and others (Komatsu, 2025). Their systems include dozers, graders, excavators and related equipment. Typically, these types of automated earth moving solutions require a 3D cut-and-fill model to work from, robotic control of the actuators (typically hydraulic cylinders) on the equipment, and GPS receivers on control points of the equipment for global 3D coordinates updating. Robotic control of the actuators requires sets of inverse kinematics solutions from the desired end effector (blade) pose to the equipment joint space to the actuators' space. Varying levels of autonomy exist from automated blade angle control to assist mostly manual operation to completely autonomous operation.

For example, heavy off-road autonomous haul vehicles have been in use in open pit mine sites for over two decades. This technology succeeded because: (1) it reduced the need for surveying support (Figure 8 – simplify and eliminate steps), (2) it resulted in a decrease in the number of passes (Figure 8 – eliminate rework), (3) it resulted in an increase in operational efficiency (Figure 8 – amplify human and cognitive abilities), (4) it typically made the operator's job (such as grader blade control) easier, and (5) it reduced waste in fuel (Figure 8 – reduce waste). It did the work faster, with fewer man-hours, and with less total cost. Early in its introduction, one impediment that automated earth moving encountered was the difficulty of transferring 3D cut-and-fill design models into the machines' control systems (an IT data exchange standards issue). This was eventually largely overcome.

Success was achieved for automated earth moving by avoiding impediments such as: (1) needing to be approved by a standards committee, (2) disrupting project processes or workflows (because large earthmoving jobs can be conducted in relative isolation from the rest of the project), (3) safety challenges such as road-worthiness, and fragmentation of the industry (most heavy construction companies rent their equipment from companies such as United Rentals, (2025), so financing and purchase price compared to the alternatives is not an issue). There are limitations of course to the impact of this technology, since: (1) small and medium sized jobs may not have 3D cut-and-fill designs, (2) it does not yet manage buried hazards well, and (3) setup of relative locating systems may be required in some cases.

2.2 Automation and robotics impact on construction productivity

Technology is hard to define. In construction, its main categories might include vertically integrated production systems, off-site production equipment and factories, new materials, information technology, automation and robotics. Automation and robotics in construction may be classified in many ways (Gharbia et al. 2020). For the purposes of this report, Figure 8 summarizes the categories addressed in this project.

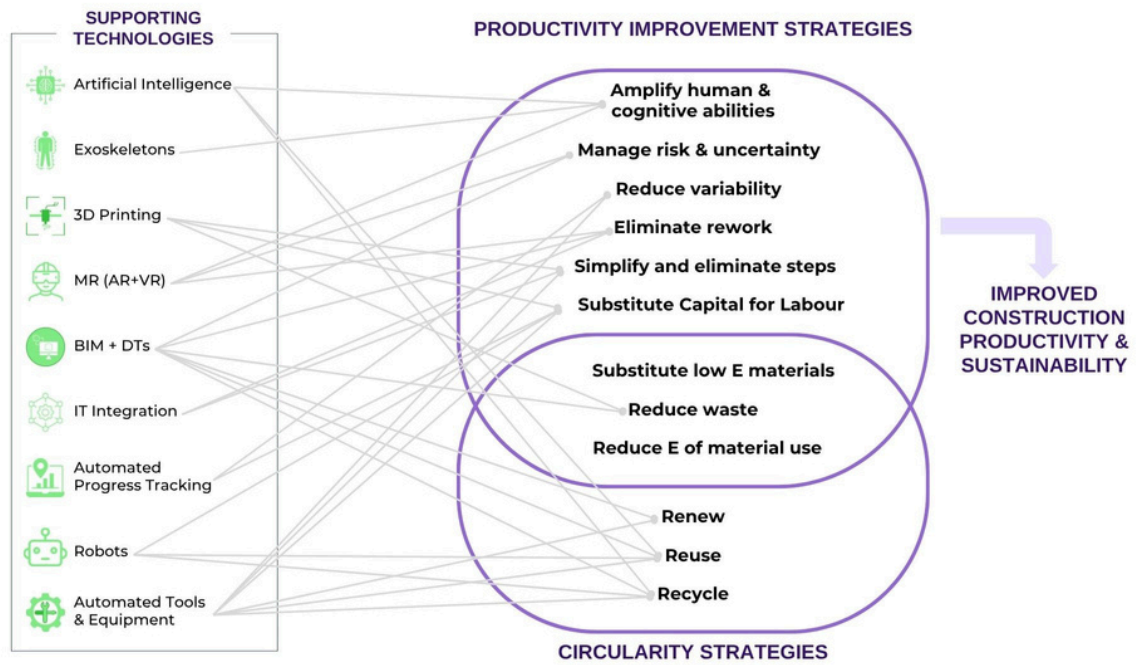


Figure 8 – Automation and robotics impact on productivity and sustainability

Figure 8 illustrates the mechanisms by which each category may improve construction productivity. Understanding these relationships is critical to any meaningful progress. It also illustrates the interdependency and synergy of productivity improvement and circularity strategies. Some examples of the successful integration of automation and robotics in construction follow. Most of them require background infrastructure including BIM and IT integration. **Earth moving automation** (Figure 4) was used earlier in this report as an example of a successful construction automation and robotics technology. It is also one of the best documented improvements, based on an excellent paper by (Jonasson et al., 2002). From their abstract:

"This paper presents an initial step in seeking to understand just how the adoption of advanced machine guidance technology, especially global positioning systems, leads to improvements in performance by the earthwork contractor."

Two grading scenarios and one dozing scenario are examined based upon site observations and interviews with field personnel. Analysis demonstrated that productivity and unit cost improvements result from a reduction in surveying support, grade checking, an increase in operational efficiency, and a decrease in the number of passes. These results are in agreement with published results of benefits of 3D guidance over 2D guidance."

In the 1980's and 1990's, a few of the largest Japanese construction companies (Obayashi, Kajima, Taisei etc.) attempted to leverage Japan's robotics successes at the time to develop **automated building construction systems**. These systems had some common elements. They were focused on high-rise commercial buildings construction. They were comprised of an enclosed, weather controlled self-elevating assembly system that rose above the building as floors were added. It required a highly controlled supply chain with just-in-time and sequentially ordered delivery of specific fabricated steel sections.

Each company developed its own bespoke integrated and automated information technology systems for control of the project. Many buildings were erected with these systems. To justify the investment in the technology development, and the structural and erection control systems for each project, a substantial substitution of capital for labour was required.

Anecdotally, the results did not achieve the expected degree of substitution, and the systems mostly failed to replace conventional approaches commercially. The reaction in the industry was such that little robotics research was conducted in those companies for many years afterward. A later example is Miyakawa et al., (2000) "Application of Automated Building Construction System for High-Rise Office Building.". Illustrations of this system are shown in Figure 9 and are copied from the paper.

Articles can still be accessed on these systems in the [IAARC open access website](#) for over four decades of ISARC proceedings. A very early example is in the 1991 Proceedings of the 8th ISARC, from Stuttgart, Germany, "Research and Development of Totally Mechanized Construction System for High-Rise Buildings," (Sakamoto & Kumano, 1991).

Katerra is an interesting example of a combined approach to automation, robotics and production systems in construction. To dissect why the AEC startup failed, this report uses Microsoft Copilot to generate responses to a set of predefined questions aimed at identifying challenges faced by Katerra which aimed to revolutionize the construction industry through integrated use of advanced technologies.

The AI-generated responses are presented in Table 1. Industry articles on Katerra's collapse have also been published (Rawlinson 2021). A Youtube video by Belinda Carr called "[The Rise and Fall of Katerra | WeWork 2.0](#)" has its own take.

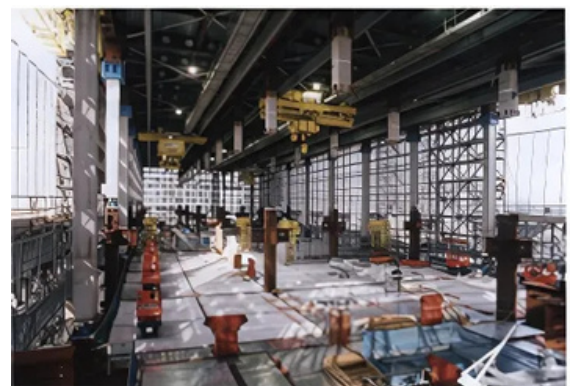
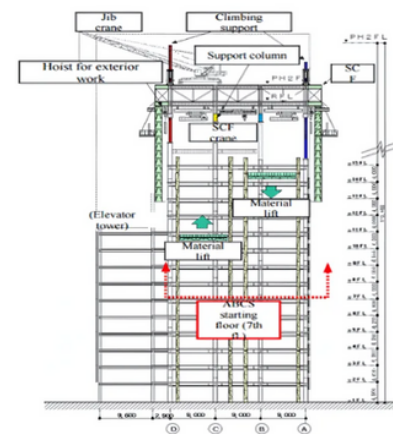


Figure 9: Illustrations from Miyakawa et al., (2000)

Table 1 – MS Copilot queries and responses on the construction industry startup, Katerra.

Query	Response
Query on April 16, 2025: "Please summarize Katerra's business model" (In the opinion of the lead author of this report, the response from CoPilot is reasonably accurate).	Katerra aimed to revolutionize the construction industry by integrating technology, design, manufacturing, and construction into a single streamlined process. Here are the key aspects of their business model: • Supply Chain Integration: Katerra managed the entire supply chain, eliminating middlemen by shipping directly from factories • Modular Design and Prefabrication: They focused on modular design and prefabrication to make building projects faster and more cost-effective • End-to-End Services: Katerra provided comprehensive services, from design to construction, aiming to reduce project timelines and costs • Tech-Driven Approach: They leveraged technology to digitize and "productize" construction, making it more efficient • Despite their ambitious goals, Katerra faced significant challenges and ultimately filed for bankruptcy in 2021. Their approach, however, has influenced ongoing efforts to innovate in the construction industry.
Query on April 16, 2025: "Why did Katerra fail?" (In the experience and opinion of the lead author of this report, the response may be treated as plausible. Deeper analysis and more evidence would be required to make more reliable observations).	Katerra's failure can be attributed to several key factors: • Lack of Focus: Katerra tried to tackle too many aspects of the construction industry simultaneously, which led to a lack of clear direction • Management Issues: The company experienced frequent changes in leadership, which disrupted its strategic consistency • Financial Mismanagement: Despite raising significant funds, including a major investment from SoftBank, Katerra struggled with financial stability and profitability • Operational Challenges: Factory closures and delays in project deliveries undermined their operational efficiency • Market Resistance: Convincing developers and contractors to adopt their innovative methods proved difficult • Pandemic Impact: The COVID-19 pandemic exacerbated existing issues, leading to increased costs and further delays. These combined factors led to Katerra filing for bankruptcy in June 2021.

Robotic crack sealing has a long history in the automation and robotics in construction domain. Pavement crack sealing is a dangerous and repetitive job. From 1988 to 1990, the lead author of this report participated in a project to automate pavement crack sealing that resulted in the demonstration of a functional prototype in 1990, as illustrated in Figure 10 (Haas et al., 1991; Haas & Hendrickson, 1990). Digital images (2D) were fused with laser scans of the surface profile (2.5D) taken with an X-Y manipulator developed to support the laser scanner and the blowing and sealing end-effectors.

Data fusion and image analysis algorithms were developed to identify and map the crack networks in the field of view (which was equivalent to the manipulator's work envelope). Optimal path plans were developed from the crack networks, and the cracks were then blown and filled. The whole system was intended to be autonomous. Much was learned from this laboratory-based demonstration. Subsequent prototypes were developed by a team led by the lead author of this report at the University of Texas at Austin.

In a project funded by the FHWA, TxDOT, and Crafcro Inc., the final prototype, illustrated in Figure 11, was demonstrated on highways in ten states. The crack network was manually indicated on a touch sensitive monitor showing the scene of the road surface under the robotic frame. The robot was then controlled autonomously, and cracks were filled with a specified sealant at a specified temperature. This system could replace a crew of several workers with one operator, and it could work twice as fast as the manual system and crew, thus labour productivity, total-factor productivity, and schedule duration (thereby reducing road user delay costs as well) were all improved by at least 100%. The payback period would have been much less than one year. This system failed to be adopted commercially for several reasons.

One manufacturer controlled 70% of the equipment market in North America for crack sealing. This disruptive technology would reduce the market size over time and not necessarily improve profits. The manufacturer may not have been interested in disrupting itself with this technology. No other vendor had the distribution, sales and support network to compete. The size of the market was only in the tens of millions of dollars per year, or less. None of the equipment was off-the-shelf; it was mostly custom fabricated. The touch sensitive monitor cost \$7000 in 1999 dollars (\$15-20K in today's dollars), and an equivalent screen would cost a few hundred dollars today. Controllers, robotic equipment, computer vision software, and more, is all off-the-shelf and drag-and-drop today. Computing power is many orders of magnitude cheaper today.

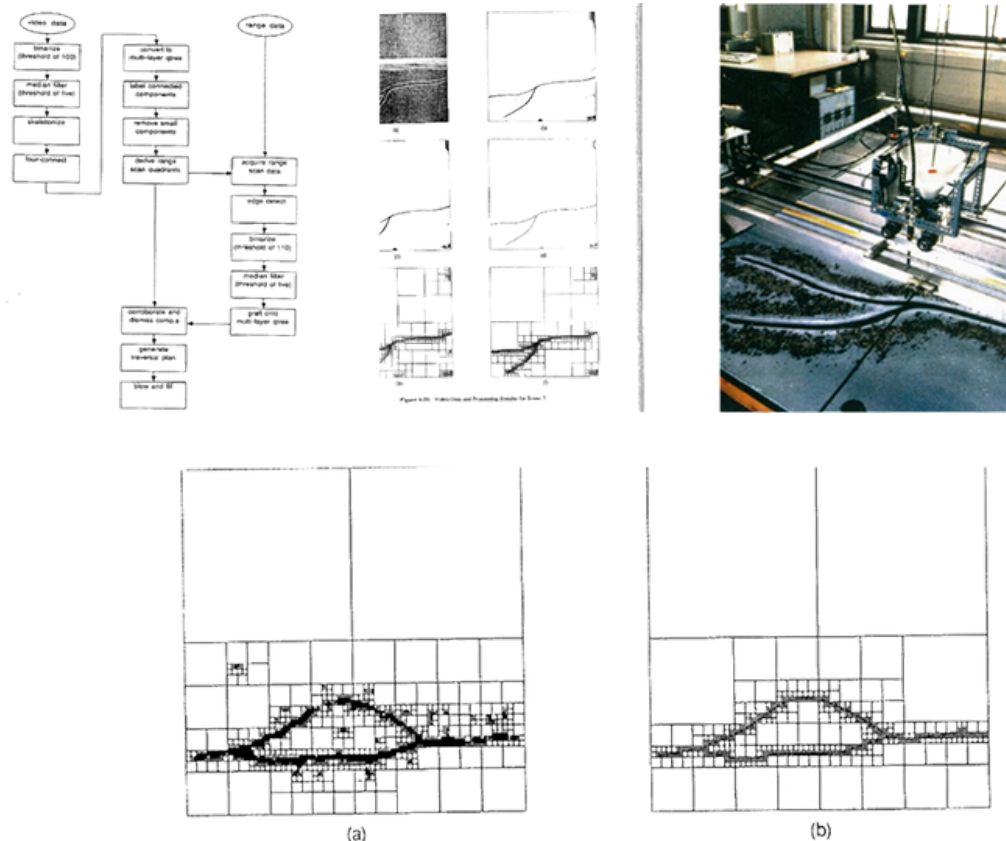


Figure 10 - Elements of an autonomous pavement crack sealing systems demonstrated in 1990 at Carnegie Mellon University

Notwithstanding the relatively small market size, the potentially massive rate of return on investment may have persuaded the maker of the robotic system that is available today (Figure 12) to introduce a newer and better version of this technology. We do not have information on the profitability of this business, although from the website it appears to be viable. The robotic maintenance systems are sold on the basis of: improved safety, reduced labour requirements, materials savings, reduced equipment needs, sealing performance data saved, and operate day and night. This could be translated to the following elements in Figure 8: amplify human and cognitive abilities, substitute capital for labour, and reduce materials use. What can be learned from this example is that timing, business acumen and marketing also play a key role in the success and impact of automation and robotics solutions in construction.

Robotic masonry (Figure 13) is an ongoing quest for dozens of groups globally. Masonry endures in our built environment. Masonry systems possess patina and texture, and they evoke feelings of warmth, solidity, and the hearth. It is part of their charm and why architects love them. Brick laying robots were conceived as early as 1985 and mentioned as an obvious application in several papers. A search of the IAARC archive of ISARC proceedings indicates that at least 29 brick and masonry robotics focused papers were published between 1990 and 2025. A Google Scholar search on the key words “robot mason brick block” yielded over 100 publications within the last five years.

Despite the research allure of robotic masonry solutions, field deployment and successful commercialization has been an elusive goal.

Masonry design and construction has existed for millennia, and nothing could seem more basic in construction, or simpler, until one tries masonry. The masonry units (bricks, concrete, ceramic, stone, etc.) are dimensionally variable in sometimes unpredictable ways. This creates interesting challenges for machine vision and pose estimation, and it creates tolerance stacking issues. It makes them difficult to grasp and manipulate. Unless they are dry stacked, they also require mortar to join them. Mortar is extremely difficult for a robot to apply and work with effectively. For example, despite the investment in 3D printing, the challenges of viscosity, curing rate and slump control, of priming and then cleaning mortar pumps, and of surface texture and form control are immense.

Mobility of masonry robots is challenging due to their necessary mass and volume and the fact that much masonry work is performed at heights on scaffolding or in relatively confined space and on uneven terrain. Mobilization, deployment and demobilization of automated masonry systems will probably continue to make most sense for large uninterrupted walls on site. Off-site systems for prefabricated wall sections may make some sense. In reference to Figure 8, the main function that a masonry robotic system serves in improving construction productivity is substitution of capital for labour. (3D printing has the additional potential of eliminating steps).



Figure 11 - Final version in the series of the CMU-UT automated crack sealing systems, demonstrated in ten states in 1999



Figure 12 - The Sealmaster™ system by RMV. Used with permission. (SealMaster, 2023)



Figure 13– Automated and Robotic Masonry Systems (top – Construction-Robotics' Mule™ system; bottom left – Construction-Robotics' SAM™ system; bottom middle – an early UAV experiment in masonry from ETHZ. Used with permission.

Potential for automation and robotics in masonry in the next 5-10 years may also exist in the deployment of humanoid robots as masons' helpers for retrieving and stacking bricks, mixing mortar, and clearing debris. This would substitute capital for labour and amplify human abilities, while mitigating the deployment and mobility challenges of other automated masonry systems. Potential may also exist in the deployment of passive and active exoskeletons that effectively amplify the mason's physical capacity and ability.

Other robotic systems: There are several robotic systems currently in active use within the construction industry, each designed to support different project types and tasks. For example, many robotic layout systems exist. These are typically mobile rovers equipped with mounted cameras and environmental sensors, enabling them to map and mark construction sites efficiently before project initiation. They automate the layout process by identifying reference points and boundaries directly on the ground, improving accuracy, and reducing manual effort (Figure 14). Then, there is the autonomous rebar-tying robots. These robots automate the tedious task of tying rebar before concrete casting. Designed to operate across large surface areas, they enhance the speed and consistency of rebar installation, particularly on large-scale construction sites

There are large-scale robotic solutions for rebar tying, and other tools that have been developed to make the process easier and more efficient. Smaller handheld devices, for instance, allow users to rotate and secure ties with minimal assistance. There are also midsize robotic systems capable of automatically tying rebar within seconds. Once positioned, the machine performs the task instantly, allowing workers to move quickly to the next section, accelerating the rebar tying process. Within this space, automation exists at different project scales, all contributing to efficiency on site. Similar advancements are apparent in other construction activities such as tiling, painting, and more.

Finally, 3D concrete printing robots exist for both on-site and off-site printing methods. On-site systems are more complex and require higher deployment costs but allow for continuous, large-scale construction. Off-site methods typically involve the prefabrication of modules that are later assembled on-site. The scalability of 3D printing systems varies, depending on the type of infrastructure being built and the intended design flexibility (Figure 15).



Figure 14 - Robotic layout. Used with permission. (Trimble's ProjectSight, 2015)



Figure 15 - 3D concrete printing. Used with permission. (Horizon Legacy. 2025).

While this section has broadly discussed robots that directly impact material usage, equipment, and labour, it is important to note that other areas, such as construction management and process automation, may also be impactful. However, management-related automation has been less emphasized, because:

- Management is about 10% of the cost of a construction project
- Materials, equipment and labour are 90% of the cost

To make significant productivity gains, we have to change the way we do the work, or change the work that we do, so that materials, and labour are reduced, or equipment becomes cheaper or unnecessary or more effective. While there is tremendous evidence that best practices in management (and craft training) can improve project performance, they can only improve performance within a fixed range, because they do not fundamentally change the way that the product is delivered. Only new materials, new production systems, automation and robotics have that potential.

Estimating the impact of the automation and robotics technologies identified above requires at least three levels or types of analysis. These analysis methods are complementary, and they should all be conducted. The first two, engineering economics analysis and business plan development, are very well known and there are many sources of reliable information on how to conduct them. The third one, an impact matrix, is proposed by the authors of this report based on experience, and it is oriented toward the types of prioritization decisions that a government agency may need to make when funding a research program or that a venture capitalist may need to make when considering investment opportunities.

Classical engineering economics analysis (a core course in almost all engineering undergraduate curriculums) is useful for estimating impact of an investment in a new technology.

It requires purchase, start-up, operating and salvage cost data. In construction, there is usually a learning curve, and that must be considered. There should be benefits in terms of reduced labour, material and equipment costs for an amount of work that can be compared with the current approach. A planning horizon or investment period must be chosen, as well as a MARR (minimum attractive rate of return) before and after taxes. For example, an after-tax MARR of 15% is typical for the private sector, and after-tax analysis is important because of depreciation for equipment costs. When all this information is acquired, a cash flow can be estimated for the period up to the planning horizon, and then ROR, NPW, B/C ratio or some other acceptable method of analysis can be applied. To acquire this information, experience-based estimates can be made, or data can be collected from on-site experiments.

A business plan should be developed. (Working with the Velocity incubator in Kitchener, the Creative Destruction Lab at the Rotman School of Management at the University of Toronto, and various start-ups directly, the lead author has observed some basic common elements.) Ways to develop a business plan are typically taught in MBA programs, start-up incubators, and venture capital offices. Market size, accessible market, potential customers, prospects, and actual sales (if any) are used to define a sales funnel. This helps to develop a cash flow projection. Subsequent and continuous cash flow analysis tracks start-up metrics like "burn rate", "cash runway", and "annual recurring revenue".

Basic questions are asked, such as:

- Whose problem is being solved?
- What is the pain point being addressed?
- Who has purchasing power and why would they be motivated to purchase?
- Does this tool make the work easier for its user?
- Who is threatened by this technology, and how can they resist its adoption?
- Is there a skills gap that makes the new technology too great a learning leap?
- Does the new technology have to be approved by a standards body to be used in practice?
- Does the new technology disrupt existing project processes?
- Is the new technology tied to a technology ecosystem controlled by one vendor?
- Does the new technology present data transfer barriers?

There are many more of these types of questions that need to be answered. People other than the developers and their family members should be asked the questions. Startup capital financing is required and typically progresses through several stages: pre-seed, seed, Series A, Series B, and Series C, with the possibility of an IPO as the final exit stage. Each stage represents a different level of company maturity and investor risk tolerance. Making sales and acquiring capital are typically far harder than developing the technology. Some technologies will make sense from an engineering economics perspective and yet fail from a business start-up perspective. Typical reasons are insufficient sales growth, running out of runway, reluctance to pivot as required, and poor user experience design. There are many other ways to fail as well.

An impact matrix should be developed to compare alternatives. An approach is suggested that considers intensity and breadth of potential impact. Intensity of potential impact is defined as the percent productivity improvement expected from application of the technology to its breadth of potential impact. Breadth of potential impact is defined as the product of the percent of project scope of work to which the technology can be applied, and the percent of the construction industry sector that is comprised by that type of project. For example, robotic orbital welders can be used to improve piping productivity. Their overall impact on all types of piping work might be a 5% or 10% productivity improvement. Piping is typically 50% of the cost of an industrial project such as a refinery. Industrial projects comprise about 10% of the construction industry. The impact of orbital welding is plotted on Figure 16 (re. big blue “piping” dot in the bottom left quadrant), which includes additional examples. Placement of technologies on this chart is based on estimates by the authors. For sounder investment and resource allocation decisions, more thorough analysis should be conducted.

Productivity Improvement (Y-axis)

Reflects the intensity of potential impact, defined as the expected percentage improvement in construction productivity (e.g., time, cost, labor efficiency) when the technology is applied within its relevant domain. This follows traditional productivity analysis rooted in labor, material, and equipment optimization.

Breadth of Impact (x-axis)

Represents the reach of the technology across construction activities. This is calculated as:

$\text{Breadth} = (\% \text{ of project scope affected}) \times (\% \text{ of total industry represented by those project types})$.

Maturity (Bubble Size)

The relative size of each bubble reflects current adoption levels. A larger bubble suggests a more mature and widely deployed technology, while smaller bubbles indicate emerging or experimental tools not yet in wide-spread use. By combining these three dimensions, the chart functions as a visual impact matrix, supporting strategic decisions by identifying technologies that offer the greatest immediate value, as well as which innovations to watch for future adoption.

- Technologies positioned higher and further to the right (e.g., Earthmoving, BIM) have both a wide impact and significant productivity benefits.
- Smaller bubbles indicate technologies that are still emerging or in limited use (low maturity), even if they have potential for broader impact in the future.
- Technologies closer to the origin (bottom-left) are more niche or have yet to demonstrate substantial field-level productivity improvements.

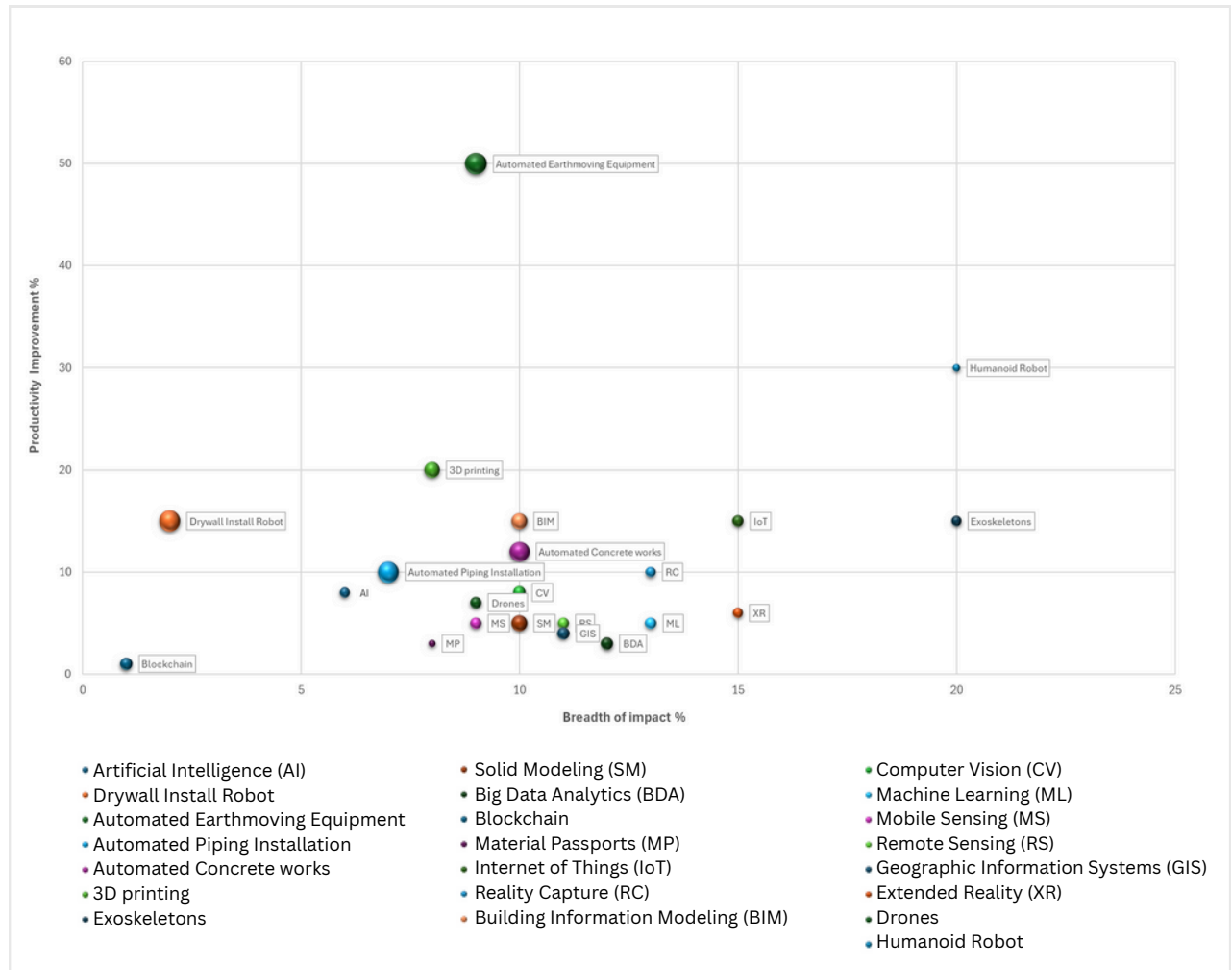


Figure 16 – Impact-mapped construction technologies by productivity improvement, breadth of impact and maturity within the industry.

2.3 How Innovation is managed in Construction Compared to Other Industries

To enhance the assessment of how the construction sector manages innovation in relation to other industries, an AI-assisted methodology was employed. Microsoft Copilot was used to generate responses to a set of predefined questions aimed at identifying similarities, differences, and innovation gaps between the construction industry and sectors such as shipbuilding.

This approach provided an opportunity to supplement the findings of the NRC roadmap workshop by incorporating additional insights into areas where domain-specific expertise may have been limited. The AI-generated responses are presented in Table 2.

Table 2 – MS Copilot query and response on construction innovation compared to other industries.

Query	Response
Query on April 1, 2025, "What are the similarities and differences in how the ship building and construction industries manage innovation?" (In the opinion of the lead author of this report, the response from CoPilot was found to be reasonably, but not uniformly, accurate and useful). This question was asked, because it has been asked many times over the years, especially in the CII community.	Both the shipbuilding and construction industries are embracing innovation to stay competitive and meet evolving demands. However, they do so in ways that reflect their unique challenges and opportunities. Here are some key similarities and differences: Similarities • Digital Transformation: Both industries are leveraging digital technologies like AI, IoT, and digital twins to enhance efficiency and reduce errors. For example, shipyards are adopting smart shipyard technologies, while construction sites are using construction management software (Ellis, 2024; Prasser, 2025) • Sustainability: There is a strong focus on sustainability in both sectors. Shipbuilders are exploring alternative fuels and energy-efficient designs, while the construction industry is incorporating green building practices and sustainable materials (Barnes, 2023; ShipUniverse, 2025) • Automation and Robotics: Automation is transforming both industries. Shipbuilding uses robotic welders and automated assembly lines, while construction is seeing increased use of drones, 3D printing, and robotic construction equipment (Barnes, 2023; ShipUniverse, 2025). Differences • Regulatory Environment: The shipbuilding industry is heavily influenced by international maritime regulations and environmental standards, which drive innovation in areas like emission control and alternative fuels (Barnes, 2023). In contrast, construction innovation is often driven by local building codes and regulations, which can vary significantly by region (ShipUniverse, 2025). • Project Scale and Complexity: Shipbuilding projects are typically larger in scale and complexity, involving intricate designs and long build times. This necessitates advanced project management and design optimization tools (Barnes, 2023). Construction projects, while also complex, often deal with a wider variety of project types and scales, from residential buildings to large infrastructure projects (Prasser, 2025). • Lifecycle Management: Shipbuilding places a strong emphasis on the entire lifecycle of the vessel, including maintenance, retrofitting, and end-of-life recycling (Barnes, 2023). The construction industry also considers lifecycle management, but the focus is more on the initial build and operational efficiency (ShipUniverse, 2025). • Both industries are navigating their unique paths to innovation, but the overarching goal remains the same: to build smarter, more sustainable, and more efficient structures.

Continued.

Query	Response
Query on April 1, 2025, "What other industries has construction been compared with in terms of innovation?" (In the opinion of the lead author of this report, the response from CoPilot was a list, which was less useful yet interesting).	1. Automotive Industry: The automotive industry is known for its high investment in research and development (R&D), with around 3.5% of revenue going towards innovation (Stein, 2018). This sector has been a leader in adopting automation, robotics, and advanced manufacturing techniques, which the construction industry is increasingly looking to emulate. 2. Aerospace Industry: Aerospace companies invest even more heavily in innovation, with about 4.5% of their revenue dedicated to R&D. The construction industry draws parallels with aerospace in terms of precision engineering, use of advanced materials, and the integration of complex systems. 3. Manufacturing Industry: Manufacturing has long been a benchmark for construction, particularly in the adoption of lean manufacturing principles, automation, and the use of digital twins. The construction industry is increasingly adopting these practices to improve efficiency and reduce waste (Blanco et al., 2018). 4. Technology Sector: The tech industry is a major driver of innovation, particularly in digital transformation. Construction is adopting technologies like Building Information Modeling (BIM), AI, and IoT from the tech sector to enhance project management, design, and operational efficiency. 5. Healthcare Industry: The healthcare sector's focus on precision, safety, and regulatory compliance offers valuable lessons for construction. Innovations in healthcare, such as modular construction for hospitals and the use of AI for predictive maintenance, are being adapted for use in construction projects (Sreenivasan, 2025). These comparisons highlight the construction industry's efforts to learn from and integrate innovations from other sectors to address its unique challenges and improve overall productivity and sustainability.

Continued.

Query	Response
Query on April 1, 2025, “What are the similarities and differences in how the manufacturing and construction industries manage innovation?” (In the opinion of the lead author of this report, the response from CoPilot was found to be accurate and useful).	Both the manufacturing and construction industries are actively managing innovation to enhance efficiency, sustainability, and competitiveness. However, they approach innovation in ways that reflect their distinct operational environments and challenges. Here are some key similarities and differences: Similarities • Adoption of Advanced Technologies: Both industries are integrating advanced technologies such as AI, IoT, and robotics to streamline operations. Manufacturing is leveraging smart factories and automation, while construction is adopting Building Information Modeling (BIM) and robotic construction equipment (Anikethsol, 2024; Rao & Malhotra, 2025). • Focus on Sustainability: Sustainability is a priority for both sectors. Manufacturing is exploring energy-efficient processes and sustainable materials, while construction is incorporating green building practices and eco-friendly materials. • Lean Management Principles: Lean management principles are being applied in both industries to reduce waste and improve efficiency. Manufacturing uses lean manufacturing techniques, while construction is adopting lean construction practices. Differences • Regulatory Environment: The manufacturing industry often deals with stringent international standards and regulations, particularly in sectors like automotive and aerospace. Construction innovation is driven by local building codes and regulations, which can vary significantly by region. • Project Scale and Complexity: Manufacturing projects typically involve high-volume production with a focus on precision and repeatability. Construction projects vary widely in scale and complexity, from residential buildings to large infrastructure projects, requiring diverse management approaches. • Supply Chain Management: Manufacturing relies heavily on global supply chains and just-in-time inventory systems. Construction supply chains are more localized, with a focus on timely delivery of materials to specific sites. • Lifecycle Management: Manufacturing emphasizes the entire product lifecycle, including maintenance and end-of-life recycling. Construction focuses more on the initial build and operational efficiency, though lifecycle considerations are becoming increasingly important. • Both industries are leveraging innovation to address their unique challenges and improve overall productivity and sustainability.

2.4 Impediments to adoption at scale of automation and robotics

There are many known and well-documented impediments to adoption at scale of automation and robotics in construction. Two well-regarded summaries include (Bademosi and Issa Raja 2021; Goodrum et al. 2011). Most of these impediments can be reformulated as risks. For example, resistance to change is one of the biggest risks threatening the potential of a new automation and robotics solution. Site conditions are another key risk.

Many automation and robotics solutions have failed to be easy to deploy on-site; robust enough to deal with dirt, impacts, and extreme weather; or simple enough to operate so as not to be excessively disruptive to normal workflows. A synthesis based on the literature, the comments of the workshop participants and interviewees, and the Principal Investigator's experience are presented in Figure 17. Workshop participants highlighted a few strategies to address these impediments to adoption at scale of automation and robotics in construction, including:

- focus on incremental changes that limit risk and disruption
- form incubators, consortiums, centers of excellence, and/or associations to share risk and knowledge, and to support entrepreneurship and innovation in construction, and
- increase government support and subsidies.

These strategies also serve to mitigate innovation investment risk. A more detailed discussion of the workshops follows in the next chapter.



Photo by Adama Olumo

IMPEDIMENTS TO ADOPTION AT SCALE OF AUTOMATION AND ROBOTICS IN CONSTRUCTION

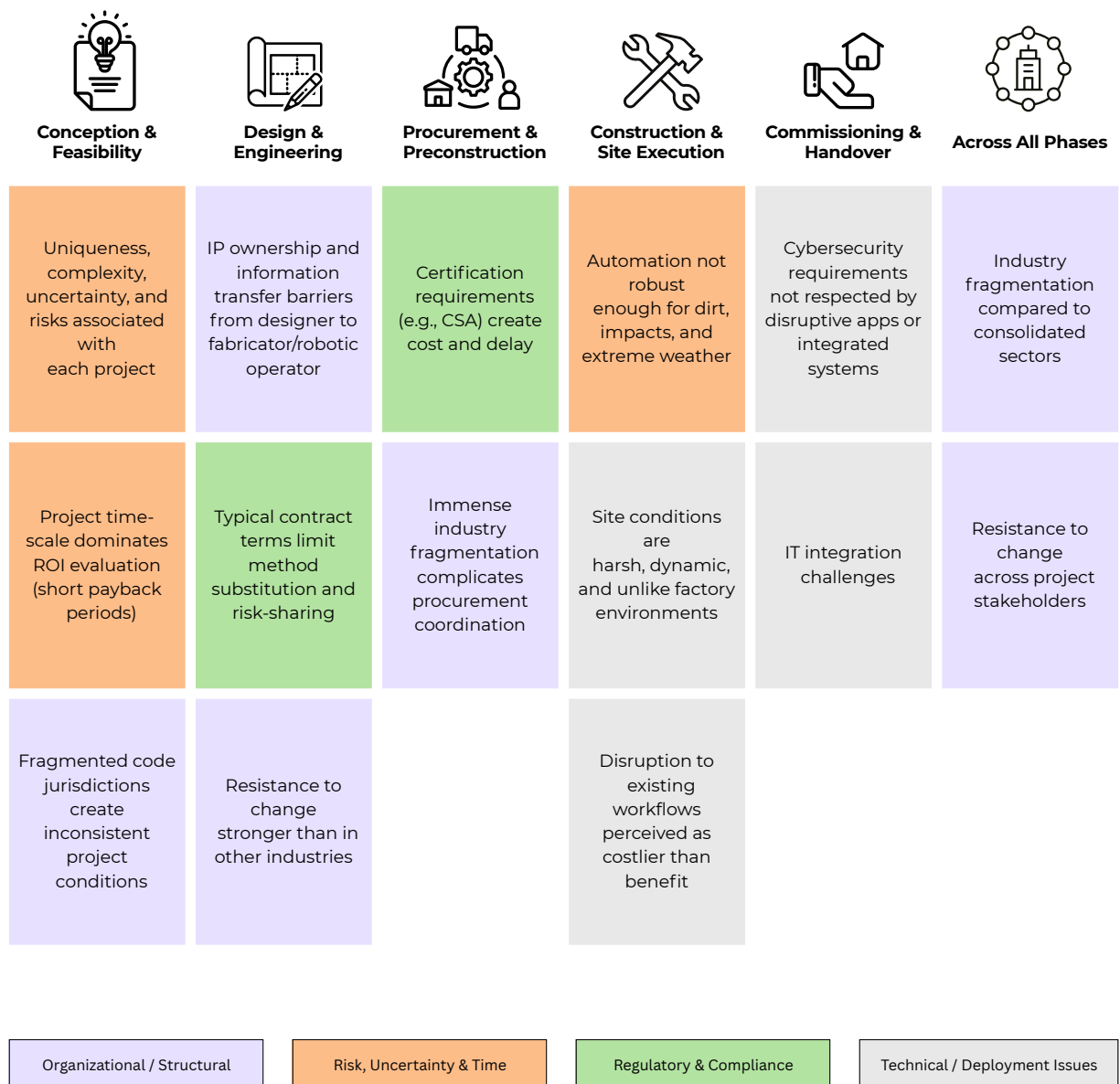


Figure 17 – Impediments to Automation Across Construction Phases (Color-Coded by Theme)

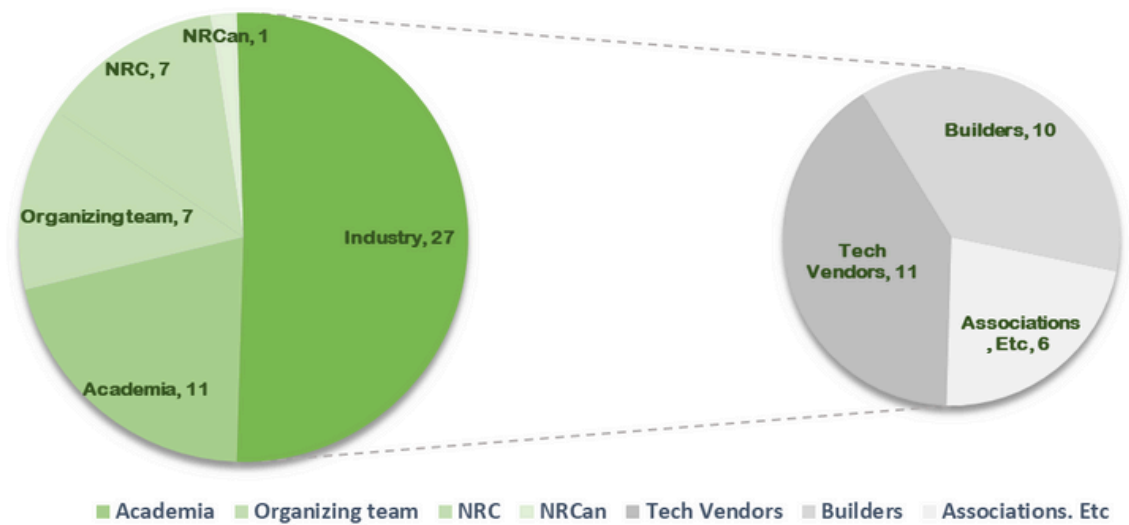


Figure 18 – Participants distribution for the first workshop

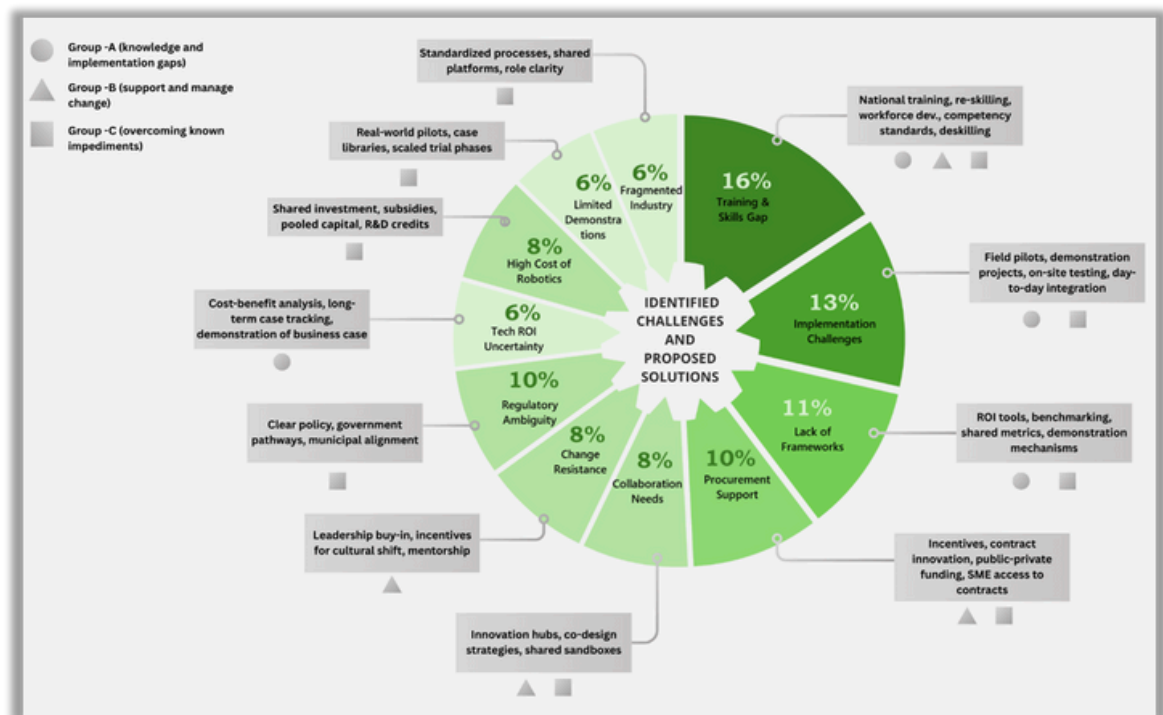


Figure 19 – Themes from the first workshop

3. Workshops

Two workshops were conducted as part of this study to facilitate discussions on future R&D activities required to increase the adoption of construction automation and robotics at scale in Canada. The first workshop brought together a diverse group of participants, primarily from industry (Figure 18), to engage in a broad discussion on the current automation and robotics landscape in Canada and globally. Participants were organized into mixed groups of about 20, comprising industry, academia, and government representatives. Before the breakout sessions, they were provided with an overview of the problem and its scope (Appendix D).

Each breakout session group had a designated facilitator and a scribe. Facilitators were provided with a structured discussion guide and a set of expected questions to ensure productive dialogue. They encouraged participants to engage actively by posing questions, while scribes documented key comments, important insights, and all relevant data from the discussions.



Photo by Kvalifik

The breakout sessions were designed to facilitate quick thinking and dynamic engagement, with participants rotating through two 50-minute sessions, followed by a one-hour report-out session.

The breakout sessions addressed three main areas:

- Identify key knowledge and implementation gaps from the perspective of the construction industry.
- Identify means to support and manage change.
- Identify means to overcome known impediments.

Each breakout session offered valuable insights and constructive feedback. They are consolidated in Figure 19. The insights and feedback from Session A, which focused on identifying knowledge and implementation gaps, are summarized as follows:

- A key takeaway was prioritizing robotic implementation in high-risk sectors, like nuclear decommissioning projects, where safety concerns are paramount.
- Discussions highlighted real-world examples where fully autonomous robotic implementations have struggled. Instead, a task-based, incremental approach was suggested, focusing on specialized robots for tasks like painting, tiling, and other specific functions that can work in collaboration with human workers to minimize failure risks.
- Time constraints and engineering process limitations were noted as challenges. Participants emphasized the importance of incorporating robotics into project planning from the outset, ensuring that the decision to use a robot is made early and supported by a clear business case. Since return on investment (ROI) is a major factor, this approach would provide justification for robotic adoption in specific projects.

- Another critical discussion point was the predictability of project environments. Many projects operate on thin profit margins, making it difficult to take risks on new technologies. To address this, there was a strong push to support small and mid-sized businesses through tax credits, helping them adopt innovative solutions.
- When discussing AI adoption in construction, a major gap identified was the lack of reliable data sharing. Participants also raised concerns about AI hallucinations, as current AI models are not yet mature enough for trusted assessments and condition evaluations.
- Computer vision technologies were also debated, particularly regarding privacy.
- Despite these challenges, some positive aspects of AI and software tools were acknowledged. AI can enhance upstream design activities, enabling generative design processes that compare multiple models and assess alternative options at the early stages.
- The main takeaways from the session revolved around cost-effectiveness, workforce training challenges, robotic advancements, and the financial trade-offs of integrating robotics.

The collective notes and outcomes from Session B, which focused on means to support and manage change, are summarized as follows:

- The discussions highlighted key policies needed to support a national BIM mandate.
- There was a strong recommendation for an intermediary entity to bridge the gap between government, owners, and clients, ensuring smoother implementation and coordination.
- A critical point raised was establishing clear success metrics, particularly determining whether waste reduction serves as a meaningful indicator of effectiveness.
- The sessions also emphasized the importance of incentives to drive the adoption of emerging tools, like financial incentives to de-risk experimental processes and credit mechanisms for integrating robotics.
- Additionally, the need for quality assurance in robotics was identified, particularly as a resource for improving on-site worker safety.

The key insights from Session C, which focused on overcoming known impediments in the construction industry, are summarized as follows:

- One of the main challenges identified was the hesitancy within the construction industry to adopt new technologies, largely due to cultural resistance and fragmentation within the sector.
- The lack of standardization across different municipalities and inconsistencies in permit approval processes are significant barriers. This includes difficulties in navigating interprovincial permit regulations.
- Some of the proposals to address impediments include:
 - Upskilling and reskilling workers to ensure they are equipped to use emerging technologies.
 - Understanding financial implications, including the true cost of implementing new tools and the risk profiles associated with adoption.
 - Developing standardized approaches to streamline processes across jurisdictions.

- Low-cost solutions that minimize entry barriers.
- Incentives for workforce training and funding for continuing education to support skill development.
- Tax credits for small businesses, making it easier for them to integrate new technologies.
- Establishing baseline competency standards for skilled personnel.
- Increased compensation for participation in training programs to encourage engagement.

At the end of the second day, all participants reconvened as breakout session coordinators presented their findings, sparking a broader discussion (Figure 20). While concrete conclusions were limited, the workshop contributed to the foundation for automation and robotics R&D in Canada by providing key insights to consider and established a strong expert network. Additionally, there was strong support for forming an organization, such as an Industry Advisory Board or consortium, to serve as an intermediary between industry and government, facilitating ethical knowledge sharing and funding.

The second workshop focused on review by a select participants group participating online.

During the second workshop, discussions centered on the decision to establish either an Industry Advisory Board, a consortium, or both. Participants explored key questions regarding the hypothetical consortium's scope and its specific role in supporting industry and academia. A major point of emphasis was the need for a solution-based approach tailored to the Canadian environment. Unlike purely advisory groups, such as the Canadian Robotics Society, this initiative should prioritize the implementation of actionable solutions. Rather than merely providing guidance, the advisory board or consortium should act as a facilitator, fostering collaboration among stakeholders in industry, government, and academia to drive meaningful progress. More specifically, the core responsibilities of the organization should include:

- **Facilitating Collaboration & Connectivity:** Serve as a bridge between industry, academia, and government by connecting stakeholders to relevant resources, tools, and potential partners while tracking technological advancements for industry adoption.
- **Action-Oriented & Solution-Driven:** Move beyond advisory roles by investing in scalable solutions and actively addressing gaps in industry-university collaboration



Figure 20 – Image from the first workshop for the development of a Canadian construction automation and robotics R&D roadmap

- **Defining Mission & Focus Areas:** Establish a clear purpose, participant structure, and vision for success. Identify key industry challenges, launch pilot projects, and engage construction firms—particularly project owners and developers—to address adoption barriers.
- **Risk Assessment & Market Fit:** Determine where new technologies will have the greatest impact, focusing on infrastructure and heavy construction while ensuring alignment with industry needs.
- **Ensuring Inclusivity & Market Understanding:** Collect and analyze industry data, safeguard shared knowledge, and prevent dominance by major players, prioritizing support for smaller companies and startups. Implement a tracking system to enhance industry insights.
- **Technology Adoption & IP Considerations:** Identify technologies at various stages of adoption, act as intermediaries for industry and investors, and develop strategies to mitigate IP conflicts and data-sharing concerns through a balanced "give-to-get" model. Establish a shared resource pool while protecting proprietary data.



Photo by Construction Robotics. (2024)

4. Construction automation and robotics R&D program roadmap

Construction automation and robotics knowledge gaps, technology categories, impediments to deployment at scale, and priorities for allocation of R&D resources have been identified in the preceding chapters. They were distilled from the results from the workshops, literature reviews, and interviews with key industry players who could not attend the workshops.

Synthesizing these contributions into an overall Construction Automation and Robotics R&D Framework was another objective of this project and report. As a reminder, the objective is to support Increased Adoption of Automation and Robotics in Construction at Scale to Enhance Construction Productivity (new and retrofit). Such a framework is suggested for Canada, within which one or more NRC research programs could be situated (Figure 21).

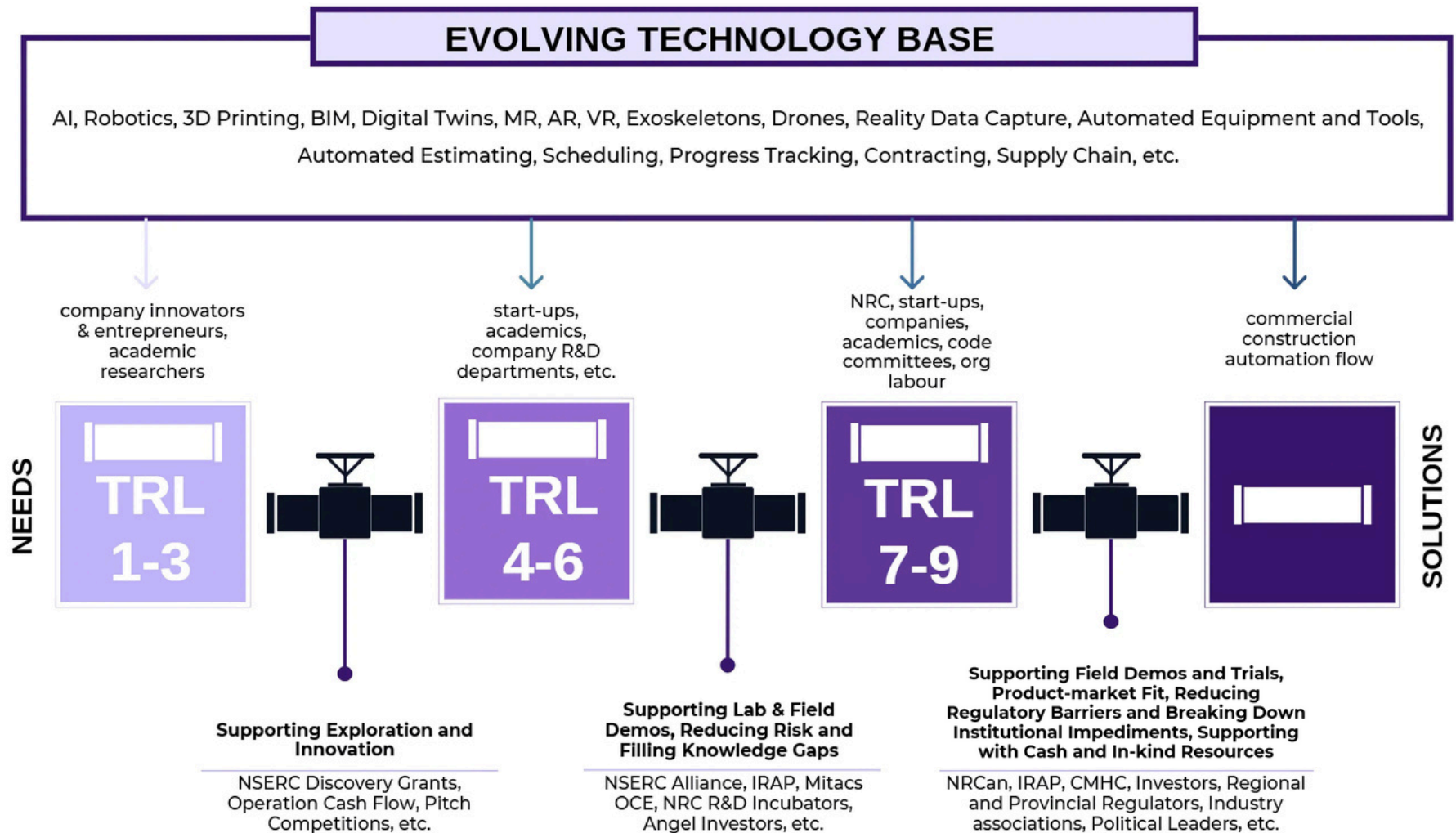


Figure 21 – Construction Automation and Robotics R&D Framework: a solutions pipeline

Table 3 – Key participants, as well as their roles and responsibilities

Stakeholder	Research expertise	Knowledge transfer	Funding support	Training and education	Tech prototyping and risk management	Policy/regulation codes	Industry mobilization and standards
NRC	X	X	X				X
NRCan, CMHC, etc.			X				
IRAP, Mitacs, etc.			X		X		
NSERC alliance	X		X				
Universities	X	X		X			
Community colleges				X			
Construction companies					X		X

Continued.

Stakeholder	Research expertise	Knowledge transfer	Funding support	Training and education	Tech prototyping and risk management	Policy/regulation codes	Industry mobilization and standards
Industry associations		X					X
Organized labour				X	X		
CSA / standards associations						X	X
Structural and building code committees						X	
Local and provincial government			X			X	

Key participants of the framework and their potential roles and responsibilities are identified in Table 3. Suggestions for an expanded set of roles and responsibilities for key participants follows:

- NRC:
 - Collaborate with and contribute funding and internal resources to joint industry, academic and NRC R&D initiatives
 - Archive lessons learned through peer reviewed publications and report with public documents
 - Maintain and manage automation and robotics testbed(s)
- Industry partners:
 - Collaborate with and contribute funding and internal resources to joint industry, academic and NRC R&D initiatives
 - Commercialize construction automation and robotics solutions
- Academia:
 - Contribute internal resources to joint industry, academic and NRC R&D initiatives
 - Archive lessons learned through peer reviewed publications and report with public documents
 - Transfer lessons learned and knowledge discovered to teaching
- NRC and other federal and provincial agencies:
 - Fund and support demonstration projects
 - Clarify regulatory barriers
 - Support tech incubators
- Labour and construction industry associations:
 - Advise and participate in joint industry, academic and NRC R&D initiatives
 - Lead training, tech transfer and implementation actions

A suggestion for a core construction automation and robotics research program follows as well. It would include R&D program mechanisms, such as:

- Industry advisory board &/or Consortium
- Collaborative demonstration projects (launching and reporting out semi-annually)
 - Industry/NRC/academic teams
 - Short duration (2 years or less)
 - Must explain mechanisms of anticipated productivity improvement and estimated project-and-sector percent impact
 - Must identify anticipated roadblocks/bottlenecks/impediments and planned strategies to overcome them in the demonstration project
 - Standardized reporting on observed project performance and productivity metrics
 - Report on impediments encountered, strategies to overcome them, broader lessons learned, and best practices
- Research infrastructure support projects
 - Benchmarking and metrics for program impact assessment and industry improvement, based on a standard set of cost codes and key performance indicators
 - Study of lessons learned from successful and failed construction automation and robotics startups
 - Study to reconsider how TFP (Total Factor Productivity) in construction is defined
- Technology transfer workshops
- Competitions (i.e., masonry or drywall construction, 3D printing of standard module)

Prioritizing the opportunities for automation and robotics in construction may be done on the basis of the three dimensions identified in Figure 16, and on the driver of skilled trades shortages (Tables 4&5 and Figure 22):

- Potential productivity improvement % over the potential breadth of impact
- Potential breadth of impact % over the construction industry
- Maturity within the industry (or TRL)
- Ability to address skilled labour (capacity) shortages

When these factors are taken into account, the following high priority opportunities come into focus for a Canadian Automation and Robotics R&D program:

- **Exoskeletons** (active and passive)
- **Humanoid robots** acting as skilled trades helpers
- **3D printing** (component, assembly and building scales)
- **Automation and robotics in prefabrication, panelization, and modularization facilities**

- **Tolerance control** methods integrating BIM, 3D scanning, and termination/control/tie-in points
- **AI, MR, DT, BIM, materials tracking, etc. for automation and robotics solutions that support site productivity improvements for broad impact and high labour content activities such as painting, placing (concrete, tiles, dry-wall, etc.), and welding**

Again, reducing dollars per unit output (improving TFP) is the goal. Automating design, permitting, approvals, engineering, risk management, schedule and cost management, and related functions is only of interest, if a clear argument can be made that total factor productivity (TFP) will be improved for construction of a capital facility.

A suggested program timeline (Figure 23) for NRC's participation in the Construction Automation and Robotics R&D framework (Figure 21) as well as the framework itself comprise the core of the roadmap recommended here.



Photo by Jeriden Villegas

Table 4 – Occupations showing moderate or strong signs of shortage conditions

Occupations showing moderate or strong signs of shortage conditions	
Trades, transport and equipment operators and related occupations	72100 Machinists and machining and tooling inspectors; 72102 Sheet metal workers; 72104 Structural metal and platework fabricators and fitters; 72106 Welders and related machine operators; 72200 Electricians (except industrial and power system); 72201 Industrial electricians; 72300 Plumbers; 72302 Gas fitters; 72310 Carpenters; 72311 Cabinetmakers; 72320 Bricklayers; 72400 Construction millwrights and industrial mechanics; 72401 Heavy-duty equipment mechanics; 72402 Heating, refrigeration and air conditioning mechanics; 72404 Aircraft mechanics and aircraft inspectors; 72410 Automotive service technicians, truck and bus mechanics and mechanical repairers; 72411 Auto body collision, refinishing and glass technicians and damage repair estimators; 72422 Electrical mechanics; 72600 Air pilots, flight engineers and flying instructors; 72999 Other technical trades and related occupations; 73100 Concrete finishers; 73110 Roofers and shinglers; 73112 Painters and decorators (except interior decorators); 73113 Floor covering installers; 73300 Transport truck drivers; 73301 Bus drivers, subway operators and other transit operators; 75110 Construction trades helpers and labourers

Table 5 – Detailed list of occupations expected to face risks of shortage conditions (2024-2033)

Detailed list of occupations expected to face risks of shortage conditions (2024–2033)	
Trades, transport and equipment operators and related occupations	70010 Construction managers; 70011 Home building and renovation managers; 72100 Machinists and machining and tooling inspectors; 72102 Sheet metal workers; 72106 Welders and related machine operators; 72200 Electricians (except industrial and power system); 72201 Industrial electricians; 72300 Plumbers; 72302 Gas fitters; 72310 Carpenters; 72311 Cabinetmakers; 72320 Bricklayers; 72400 Construction millwrights and industrial mechanics; 72401 Heavy-duty equipment mechanics; 72402 Heating, refrigeration and air conditioning mechanics; 72404 Aircraft mechanics and aircraft inspectors; 72410 Automotive service technicians, truck and bus mechanics and mechanical repairers; 72422 Electrical mechanics; 72501 Water well drillers; 72600 Air pilots, flight engineers and flying instructors; 72999 Other technical trades and related occupations; 73100 Concrete finishers; 73110 Roofers and shinglers; 73112 Painters and decorators (except interior decorators); 73113 Floor covering installers; 73300 Transport truck drivers; 74201 Water transport deck and engine room crew; 75110 Construction trades helpers and labourers

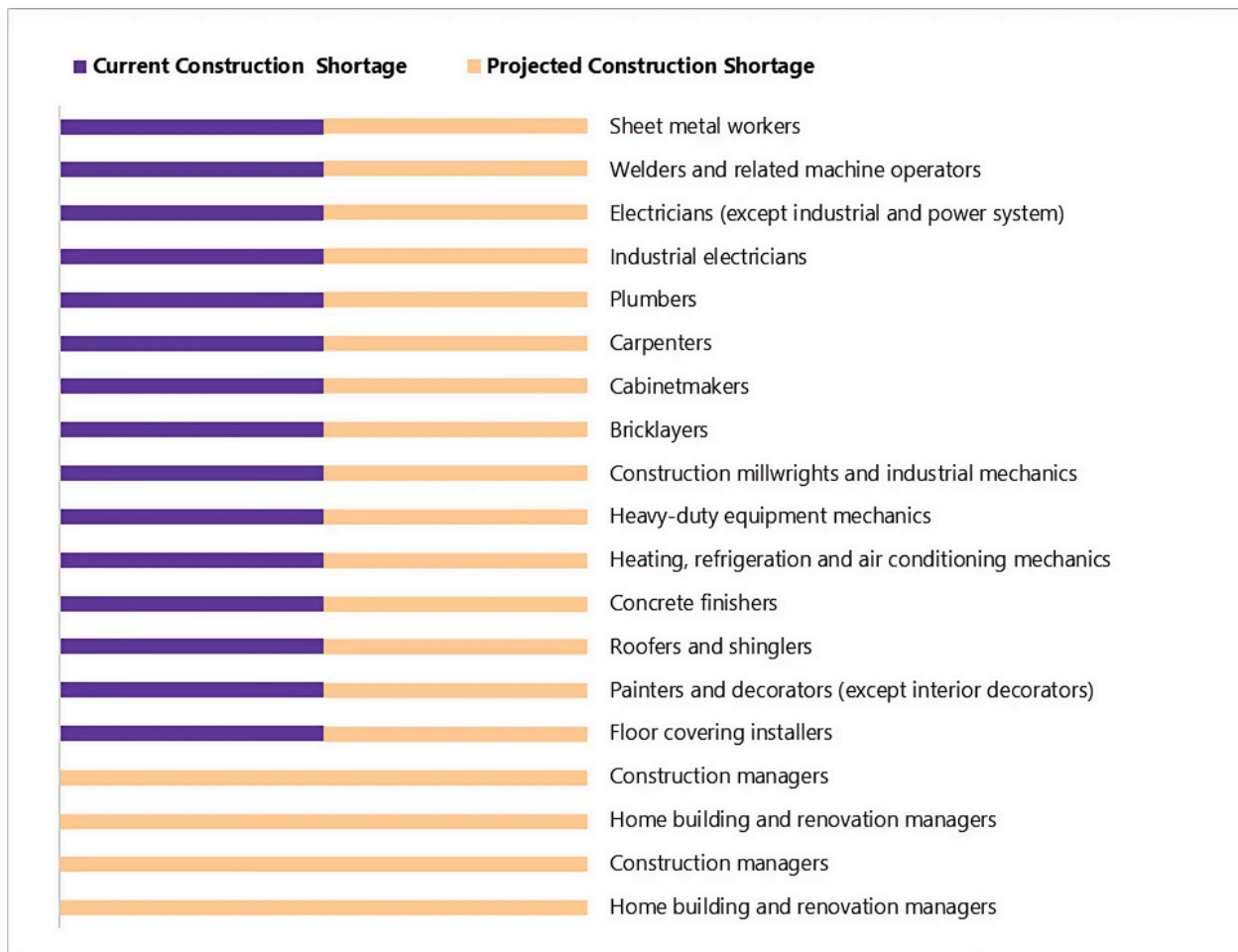


Figure 22 – Canadian Occupational Projection System (COPS) - Summary of results (2024-2033)

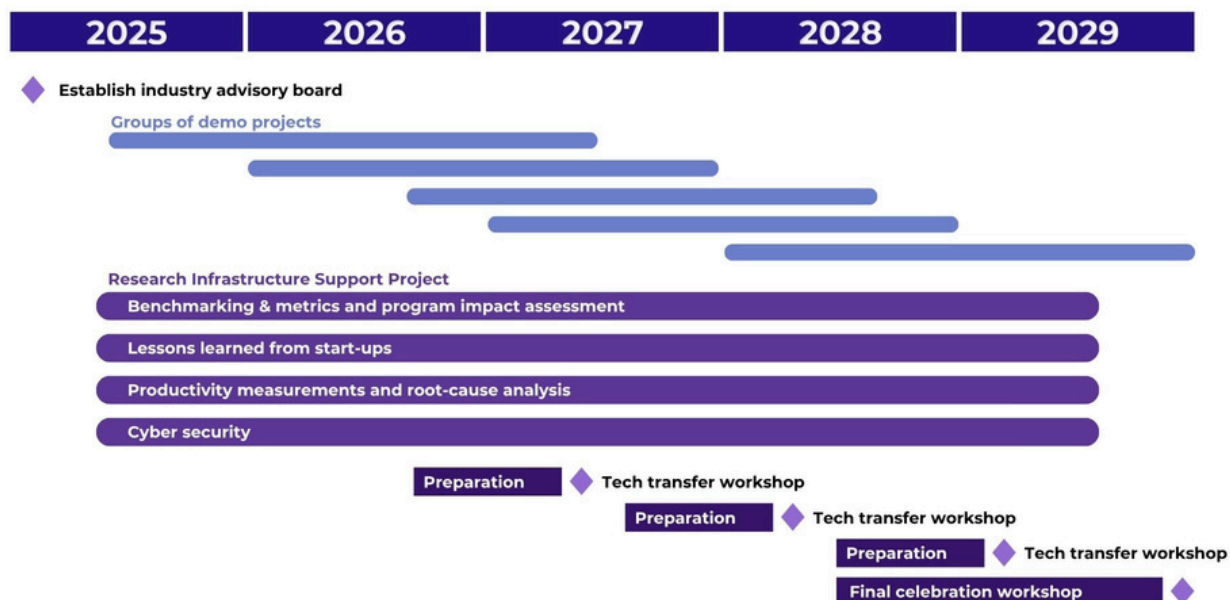


Figure 23 – Suggested Core R&D Program Schedule

5. Related initiatives to support a construction automation and robotics R&D program

Table 6 – Various workshops and events to draw inspirations from to adapt for use by the NRC. These are events that could be supported or sponsored by the NRC.

Initiative	Description	Challenges and opportunities
IAARC Webinar (UBC)	A regularly hosted online webinar by the International Association for Automation and Robotics in Construction, delivered through UBC.	- Provides valuable insights but lacks hands-on experience. - An in-person version may offer more impact but is more expensive and harder to organize due to Canada's low population density. - Difficult to replicate the scale of large U.S. events without incurring significant travel costs.
CII Technology Workshop	Long-running workshop by the Construction Industry Institute, used to share insights on emerging construction technologies.	- Could serve as inspiration for NRC-supported workshops or events. - Offers a strong platform for technology-focused discussions in construction automation.
University Exhibitions (Waterloo & Others)	Smaller-scale exhibitions featuring construction robotics and automation research, often hosted by institutions such as the University of Waterloo.	- Demonstrates emerging construction technologies in academic settings. - Limited industry presence compared to large-scale international showcases.
ISARC (International Symposium on Automation and Robotics in Construction) - ISARC 2025 organized by Concordia in Montreal	A global conference that has run for over 40 years, originally geared toward startups but now largely academic.	- Originally focused on startups, but lacked an ecosystem to support them, leading to an academic orientation. - Represents a strong model to adapt for Canada with growing interest from academic, industry, and government partners.

Continued.

Initiative	Description	Challenges and opportunities
Industry-Sponsored Competitions	Proposed competitions between academic institutions supported by industry, focusing on innovative homebuilding automation.	• Offers the opportunity to engage students in cutting-edge design challenges. • Scoring could include total estimated cost, labor productivity, scheduling efficiency, startup pitch, and sustainability metrics. • Can include two streams: (1) masonry + precast + 3D printing and (2) stud-to-structure wall and roof systems, all benchmarked against a common BIM model.
DOE Green Building Challenge Model	Long-standing competition run by the U.S. Department of Energy, which attracted North American teams and could inspire a Canadian version (BuildingsNEXT, 2023).	• Potential gap if the U.S. discontinues this model, opening the door for Canada to lead. • Universities such as Waterloo and CMU have historically done well in robotics-based competitions like the DARPA Challenge.

The data hub or research data management function is increasingly critical in today's world as well. Most journal publishers have addressed the issue by supporting open access publication of datasets. There are many other online hubs. For example, the web site "[Browse the State-of-the-Art in Machine Learning | Papers With Code](#)" provides access to thousands of datasets used to train and compare performance of new AI's. On May 2, 2025, access to 3170 image data sets, 3043 text datasets, 131 point-cloud datasets, and more was available on the site.

Hosting construction or built environment specific research datasets on Canadian servers may be worthwhile from a strategic perspective. However, it will take sustained funding and commitment, or the effort will be wasted. Archiving of reports, papers and articles will likely continue to be best managed by publishers and mediated by public (e.g. university) libraries. Federally funded research in Canada must be published in open access formats. The [proceedings](#) of the annual International Symposium on Automation and Robotics in Construction (ISARC) have been published in an open access format for over four decades.

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7. APPENDICES

7.1 Appendix A

Briefing Document for Workshop to Develop a Canadian Construction Automation and Robotics R&D Roadmap – sent to participants before the workshop

November 6, 2024

This project aims to produce a roadmap to guide future R&D activities required to increase adoption of construction automation and robotics at scale in Canada. The roadmap will focus on gaps to accelerate adoption primarily in the TRL 7 to 9 range.

Broader needs driving the roadmap include Canada's:

- Housing shortages
- Construction labour shortages
- Lagging construction productivity and capacity
- Desire to decarbonize construction at scale

Recommended reading to prepare for the workshop follows:

- From Bad to Worse: Canada's Productivity Slowdown is Everyone's Problem This article singles out the construction industry in Canada as having the worst productivity performance in the last four years and last forty years.
- The Strange and Awful Path of Productivity in the U.S. Construction Sector This is a recent analysis of construction productivity in the US, and it poses some interesting questions
- Delivering on construction productivity is no longer optional This is a McKinsey report that projects demand globally and identifies productivity as a barrier to meeting demand, unless something is done; they have some suggestions. While some of their terms, sources of data, and system boundaries for analysis are fuzzy, they present an interesting perspective in Exhibit 6.
- Donald Wright: Urban densification is not going to solve our housing crisis - The Hub For a contrarian perspective on the housing crisis in Canada, this article can be read.
- "Robotic technologies for on-site building construction: A systematic review", <https://doi.org/10.1016/j.jobbe.2020.101584> 2020. This is an overview of the technologies being used and the common applications being addressed. (Full access may be restricted.)
- IAARC – the International Association for Automation and Robotics in Construction – over four decades of conference proceedings are freely available at [IAARC](#)
- Factors Influencing Adoption and Integration of Construction Robotics and Automation Technology in the US [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0002103](https://doi.org/10.1061/(ASCE)CO.1943-7862.0002103) 2021. Alternative systems of classification of technologies and impediments are used in this article, which may spur thought. (Full access may be restricted.)
- Model to Predict the Impact of a Technology on Construction Productivity [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0000328](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000328) 2010 (Full access may be restricted.)
- Brick & Mortar Ventures portfolio of companies in construction automation and robotics

7.2 Appendix B

Workshop I information package

DEVELOPMENT OF A CANADIAN CONSTRUCTION AUTOMATION AND ROBOTICS R&D MAP

Location: University of Waterloo

Date: November 19-20

Facilitator: Dr. Arash Shahi - AECO

The information package has been structured into the subsequent sections:

Workshop Agenda	2
Accommodations around Waterloo	4
Parking on University Campus	5
Waterloo Map (link)	6
Attendees	7
Organizing team	8
Guest Access to Wi-Fi	8
Getting around Waterloo	9

Workshop I information package

November 19 th		
6:00 - 9:30PM	Networking reception and dinner	Westmount Golf and Country Club, 50 Inverness Dr, Kitchener, ON N2M 4Z9
November 20 th		
7:45 - 8:30 AM	Breakfast and registration	7 th floor, E7 University of Waterloo
8:30 - 9:00 AM	Welcoming remarks • Background and need. • Purpose of the NRC roadmap • Workshop objectives • Organization and procedure for the workshop	
9:00 - 9:30 AM	Quick review of what is known: • Definitions of productivity, environmental impact and industrial capacity • Construction automation and robotics technology categories • Historic impediments and sources of support for adoption	
9:30 - 9:45 AM	Coffee break	
9:45 - 11:00 AM	First round of breakout session • Identification of knowledge and capability gaps • Means to support and manage change • Means to overcome known impediments	E7-Room 1 E7-Room 2 E7-Room 3

Workshop I information package

11:00 - 11:10 AM	Short break and rotate	
11:10 AM - 12:00 PM	Second round of breakout session • Identification of knowledge and capability gaps • Means to support and manage change • Means to overcome known impediments	E7-Room 1 E7-Room 2 E7-Room 3
12:00 - 1:00 PM	Lunch	
1:00 - 2:00 PM	Report from breakouts	
2:00 - 2:15 PM	Coffee break	
2:15 - 3:15 PM	Identify: • Main strategic transformations required to achieve the vision to "increase adoption of such technologies by the sector at scale" that may be achieved via R&D program thrusts • Milestones and metrics of success	
3:15 - 3:45 PM	Concluding final remarks, follow-up commitments, and date of next workshop	
End of workshop		

Workshop I information package - accommodations around Waterloo

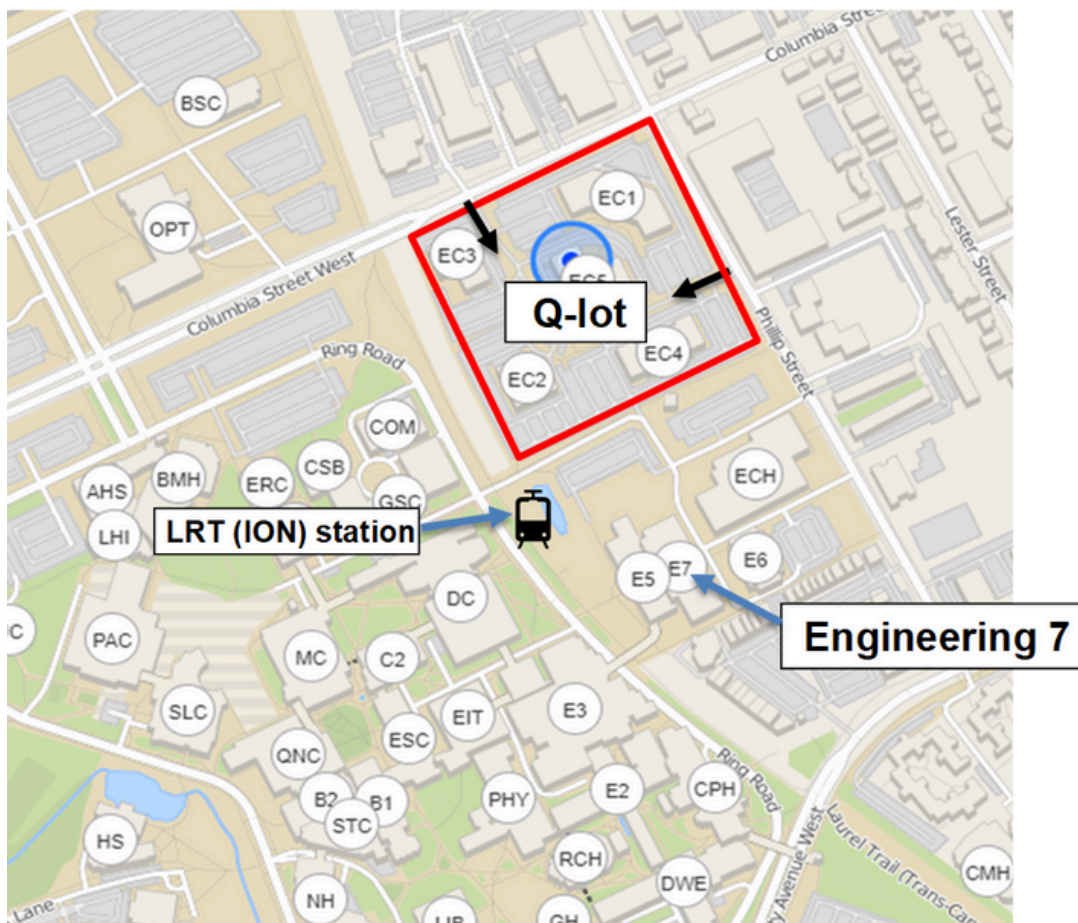
Hotel name	Link	Address	Phone number
Delta Hotels by Marriott Waterloo	https://www.marriott.com/en-us/hotels/ykfdw-delta-hotels-waterloo	110 Erb St W, Waterloo	(519) 514-0404
Courtyard by Marriott Waterloo St. Jacobs	https://www.marriott.com/en-us/hotels/ykfcy-courtyard-waterloo-st-jacobs	50 Benjamin Road E, Waterloo	(519) 884-9295
Hampton Inn & Suites by Hilton Waterloo St. Jacobs	https://www.hilton.com/en/hotels/wlobrh-x-hampton-suites-waterloo-st-jacobs	55 Benjamin Rd, Waterloo	(519) 514-0090
Homewood Suites by Hilton Waterloo/St. Jacobs, Ontario, Canada	https://www.hilton.com/en/hotels/yhmsjhw-homewood-suites-waterloo-st-jacobs-ontario-canada/	45 Benjamin Rd, Waterloo	(519) 514-0088
Holiday Inn Express & Suites Waterloo - St. Jacobs Area, an IHG Hotel	https://www.ihg.com/holidayinnexpress/hotels/us/en/waterloo/ykwws/hoteldetail	14 Benjamin Rd, Waterloo	(519) 772-9800
Staybridge Suites Waterloo - St. Jacobs Area, an IHG Hotel	https://www.ihg.com/staybridge/hotels/us/en/waterloo/ykfw/hoteldetail	10 Benjamin Rd, Waterloo	(519) 514-5500
Crowne Plaza Kitchener-Waterloo, an IHG Hotel	https://www.ihg.com/crowneplaza/hotels/us/en/kitchener/ykfc/hoteldetail	105 King St E, Kitchener	(519) 744-4141
Quality Inn	https://www.choicehotels.com/ontario/kitchener/quality-inn-hotels	2899 King St E, Kitchener	(519) 894-3500
Courtyard Kitchener	https://www.marriott.com/en-us/hotels/ykfcy-courtyard-kitchener	2960 King St E, Kitchener	(226) 336-8059
DoubleTree by Hilton Kitchener	https://www.hilton.com/en/hotels/yhmcm-dt-doubletree-kitchener/	30 Fairway Rd S, Kitchener	(519) 893-1211
Walper Hotel	https://www.hyatt.com/en-US/hotel/canada/the-walper-hotel	20 Queen St S, Kitchener	(519) 745-4321

Workshop I information package - parking on campus

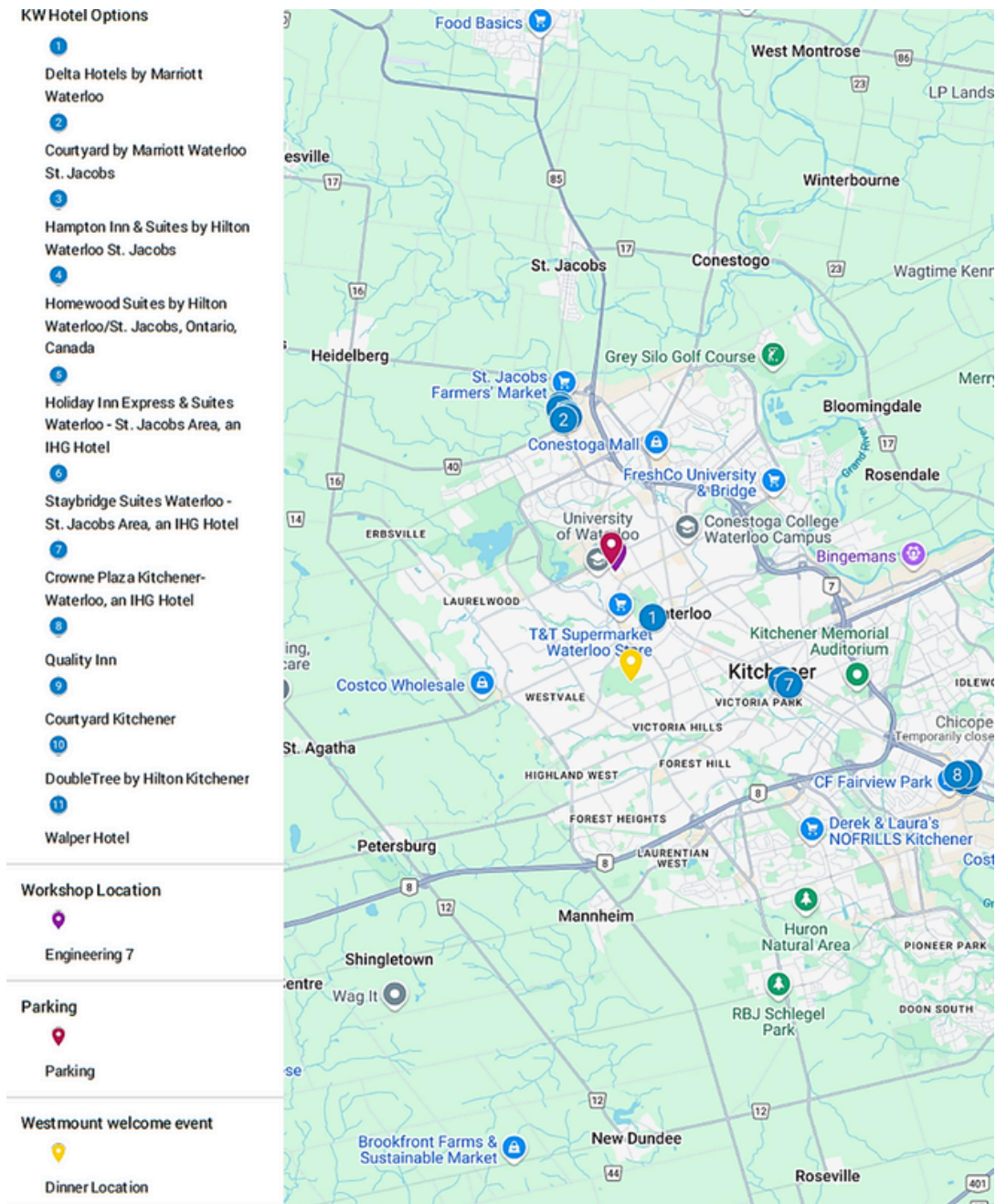
Q-lot is outlined by the red square on the map below (you can set your directions for 295 Phillip Street Waterloo or use this [Google maps link](#)). Access to the parking lot is marked with black arrows on the picture (enter from either Columbia St. or Phillip St.). Note that you cannot access this parking lot by car from the University Ring Road around the main campus.

Park in any unmarked spot in the area. You will be provided with a hang tag (single day parking permit to display on your rearview mirror) at the networking dinner the evening prior to the workshop – ensure that this hang tag is clearly displayed. If you do not attend the dinner, please contact us on arrival and you will be provided with a hang tag permit. It is a short walk to the workshop venue in Engineering 7 (as shown on the map), but the walk will be outdoors.

A more detailed map of campus is available at <https://uwaterloo.ca/map/>



Workshop I information package - Waterloo map



Workshop I information package - organizing team

- Arash Shahi
- Hwang, Joon Ha
- Joyce Kim
- Dave Dietz
- Michele Van Dyke
- Adama Olumo
- Muhammad Bilal
- Manolis Katsimpalis
- Nicole Schmidt
- Carl Haas

Workshop I information package - guest details

Guest Access to Wi-Fi

- Go to Wi-Fi settings and click on UniversityOfWaterloo
- If you're connecting for the first time, a pop-up certificate will appear. Click on "Continue"
- Click on "Or register for guest access"
- Enter your first name, last name, and email address into each respective field then click "Register"
- A confirmation code will be sent via email. Enter the confirmation code into the pop-up window within 10 minutes to connect to the Wi-Fi. If the confirmation code is not entered within 10 minutes the process will time out and need to be restarted.

Getting Around Waterloo

- Bus
- Grand River Transit (GRT): Is the public transit operator for the Region of Waterloo, Ontario, Canada. It operates daily bus services in the region, primarily in the cities of Cambridge, Kitchener, and Waterloo. GRT operates five iXpress routes that provide frequent, limited-stop express service along major corridors in Cambridge, Kitchener and Waterloo. It also operates Route 302 which runs between Fairway Station in Kitchener and Ainslie Street Terminal in Cambridge connecting riders to Route 301 ION light rail service. Route 302 offers express service similar to iXpress, but also features more comfortable high-back seats, free Wi-Fi and USB chargers.
 - Cash fare: \$3.75
 - Single ticket/transfer (from the fare vending machine): \$3.75
- ION Light Rail Transit: Is Waterloo Region's light rail transit (LRT) system. It runs between Kitchener's Fairview Park Mall and Waterloo's Conestoga Mall, with plans for an expansion into Cambridge in the future. ION trains connect passengers to the existing bus system (Grand River Transit), making it easy to travel across the region. Use their trip planner for information about routes and schedules.
 - Cash fare: \$3.75
 - Single ticket/transfer (from the fare vending machine): \$3.75
- Cycling: You can ride your bike anywhere in Waterloo Region. In the cities, bike trips of less than five kilometres often take no more time than driving. You can even use Bus 'n' Bike to combine cycling and Grand River Transit rack-equipped vehicles to make longer rides easier.
- Ride Share: Uber or Lyft
- Taxi: The following are licensed taxi-cabs companies by the Region of Waterloo:
 - Golden Triangle Inc: 519.621.5650
 - Kitchener City Cabs: 519.742.4404
 - United Taxi: 519.888.9999
 - Waterloo Taxi: 519.886.1200
 - A-1 Waterloo Taxi (Elmira): 519.886.1200
 - New Hamburg Taxi: 519.662.3240