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Advancing Technology Adoption in Northern Construction: Overcoming Challenges for Sustainable Growth

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ABSTRACT: The contemporary construction project delivery in Northern Canada (NC) experiences unique challenges due to geographic location, extreme weather, and logistical challenges. Despite being a potential solution, a clear knowledge gap exists on the increase in the uptake of state-of-the-art technology for construction project delivery in NC. This paper explored the current status and barriers to using state-of-the-art technologies in construction project deliver by using expert interviews as the research method. A comprehensive literature review was carried out to design the semi-structured interview script. The questions explore the status, barriers, and potential solutions for adopting state-of-the-art technology. University of Windsor Research Ethics Board approval was obtained for this research. Interview respondents include experienced project and construction management personnel working in NC. Steps were implemented to ensure the validity and reliability of this semi-structured interview process. Thematic Analysis was used to analyze interview responses to evaluate gaps and barriers in technology use and potential solutions. Findings revealed that a strong reliance on traditional practices in managing infrastructure projects in NC, with challenges such as high costs, skilled labor shortages, and poor communication hindering progress. Addressing these issues, the study suggests that implementing critical success factors like leadership support, training, and improved supply chain management can drive technology adoption. The findings from semi-structured interviews and published literature were used to synthesize a framework for implementing state-of-the-art technology solutions. The study is expected to assist digital transformation in the NC`s construction industry.

Keywords: Technology adaptation, Project and construction management, Semi-structured interviews, Northern Canada, Thematic analysis

1. INTRODUCTION

Advancing construction and project management technologies in remote regions like Northern Canada (NC), particularly in the territories of Nunavut, Yukon, and the Northwest Territories, presents a unique set of challenges (Louie et al. 2016; Publisher1953 2013; Quinn 2023). These regions, characterized by their sparse population, extreme weather conditions, and geographical isolation, require innovative solutions to enhance the efficiency, quality, and sustainability of construction projects (Anderson and Poppel 2002; Kozin, Skotarenko, and Plotnikov 2020; Quillerou et al. 2020). Technologies such as Building Information Modeling (BIM), Lean Construction, and other advanced project management tools hold the potential to address these challenges and bring significant improvements to the construction sector in these northern territories. However, the implementation of such technologies is often hindered by the region's unique conditions, which include unpredictable weather, lack of infrastructure, and logistical hurdles.

NC is known for its rugged and unforgiving environment. The geographical isolation of many communities with limited access to southern Canada because of lack of all-weather roads, combined with the harsh subarctic and Arctic climates with temperatures normally range from 15°C to 25°C during summer and plummeting to as low as -30°C to -60°C during winter, creates difficulties in transporting materials, equipment, and personnel. These challenges are compounded by the lack of all-season roads between communities and nearest sea or river docks, the high cost of living and operating in the region, and difficulties in maintaining construction projects year-round due to limited daylight during winter, ranging from just 1 to 5 hours (Anderson and Poppel 2002; Gritsenko and Efimova 2020; Kozin et al. 2020; Majumdar 2021; Quillerou et al. 2020). Moreover, construction projects in NC are complicated by challenges due to the lack of skilled labor. Skilled tradespeople and project managers are often hard to recruit, given the

region's remote location and limited access to housing, schools, healthcare, and other amenities. Local labor markets are small, and the reliance on imported workers from the southern parts of Canada or abroad further complicates the process of building a robust construction workforce. This, in turn, adds to the costs of projects and leads to delays or suboptimal execution (Louie et al. 2016; Publisher1953 2013; Quinn 2023).

Digital technologies such as BIM have emerged as powerful tools to enhance project delivery in these challenging conditions. Digital technologies can play a pivotal role in NC by allowing for better planning, simulation, and collaboration in construction projects. It offers the ability to address the constraints posed by limited access to resources, weather, and terrain. Similarly, project management practices such as lean construction practices can optimize construction processes by reducing waste, improving coordination, and streamlining workflows, which is especially valuable in a region with limited resources and a small labor pool (Aziz and Hafez 2013; Hwang, Zhao, and Yang 2019; Parsamehr et al. 2023; Sacks et al. 2018; Turner et al. 2021).

This paper aims to explore current status of technology adaptation in construction project delivery in NC, specifically in Nunavut and the Northwest Territories. Through a comprehensive review of the existing literature, semi-structured interview scripts were designed to collect insights from experienced project and construction management professionals in NC to understand current state, challenges, and key success factors that could drive adoption of advanced technology in the region's construction industry. Informed by the above implementation framework was proposed for digital transformation of the construction sector.

2. LITERATURE REVIEW

The current construction challenges in NC necessitate the use of innovative technologies that can significantly enhance efficiency, longevity, and cost-effectiveness of construction endeavours (Bryde, Broquetas, and Volm 2013; Damanpour 2018; Sacks et al. 2018). Such technologies encompass the latest equipment, tools, systems, and any combination of these resources, applied throughout the entire project lifecycle - from planning and design phase, construction and commissioning phase, operation and maintenance phase to its demolition phase - in infrastructure projects and construction management (Bryde et al. 2013; Sacks et al. 2018; Sepasgozar and Davis 2018).

The following technologies have garnered significant attention in recent literature: lean construction tools and techniques, building information modeling (BIM), common data environments (CDE), pre-construction data collection via drones and unmanned aerial vehicles (UAVs), 3D scanning, virtual reality (VR), augmented reality (AR), 3D construction printing, artificial intelligence (AI), generative design, modular and offsite construction, smart and resilient construction methods, quality management systems (such as 5S, Total Quality Management (TQM), robotics for construction automation, and automated progress monitoring using robots, drones, UAVs, and 3D scanning. The effective use of these technologies helps reduce construction process inefficiencies and material waste, enhancing productivity, safety, quality, and collaboration among stakeholders, while also preventing time and cost overruns (Ahmed and Sobuz 2020; Pereira and Romero 2017; Sarhan et al. 2018; Sepasgozar and Davis 2018).

Various studies have assessed adoption of technology in construction sectors across different countries. In Bangladesh, for example, Rahman et al. (2023) noted that while the construction sector uses modern technologies, it has not fully leveraged their potential. Despite a national strategy aimed at technological adoption for overall growth, the construction sector remains largely reliant on traditional practices. Key challenges include industry fragmentation, limited awareness of technology's benefits, insufficient resources and skilled labor, and inadequate policy and infrastructure support. In Malaysia, Ibrahim et al. (2021) found that the adoption of technology in the construction sector has been progressing but at a slower pace compared to other Asian countries like South Korea, Japan, and Singapore. The study highlighted that technology is being used for project management, fleet management, site monitoring, and construction safety, but the main obstacles to adoption include resistance to change within organizations, lack of skilled labor, additional costs and time associated with adoption, and unreliable internet infrastructure at construction sites. In the United Kingdom (UK), the construction sector's productivity has remained largely stagnant since 1994, due in part to slow adoption of innovative technology (Noruwa et al. (2022). However, large AEC (Architecture, Engineering, and Construction) companies view technology as a key tool for efficient construction management, rather than a source of cost overruns. The benefits of technology adoption, including the simplification of BIM implementation (which has been mandated in the UK since 2016), are driving the adoption of innovative technologies among companies that have yet to implement them (Noruwa et al. 2022).

Technological adoption in construction has been slower in many countries, but it has gained momentum, with varying degrees of implementation across countries like Denmark, Finland, Norway, the USA, the UK Singapore, France, Italy, Germany, China, and South Korea, in both public and private sector projects (Ahmed and Sobuz 2020; Cao et al. 2019; Noruwa et al. 2022; Rahman et al. 2023). Common barriers to technology adoption include a bias toward traditional construction practices, lack of government policies and incentives, insufficient awareness of the benefits of technology, shortage of skilled labor, inadequate training, contractual and legal challenges, software/hardware issues, and lack of support from top management. In Canada, technology adoption in the AEC industry has been slow and is largely unknown, trailing the global trend (Cao et al. 2019). Canada lacks a BIM mandate and does not have a well-defined national plan for implementing the latest technologies in construction management (Cao et al. 2019). Surveys conducted by the Building Innovation Research Centre at the University of Toronto in 2018, 2019, and 2020 assessed BIM adoption across various provinces (Ontario, Nova Scotia, Quebec, Manitoba, Saskatchewan, Alberta, and British Columbia) (McCabe et al. 2021), but similar data for NC's construction management technology adoption is unavailable. However, Governments of Alberta and Quebec have already begun the processes for advancing the use of BIM for the procurement of infrastructure projects (Zeiss 2018). Table 1 summarizes the findings of previous research on this domain.

Table 1: Synopsis of the published literature

Reference	Country	Remarks
Ahmed and Sobuz 2020	Bangladesh	Studied the challenges for implementing lean construction in Bangladesh
Rahman et al. 2023	Bangladesh	Studied the use of AI for Architecture in Bangladesh
Aziz and Zainon 2023	Malaysia	Studied the driving factors for Lean-BIM implementation in Malaysian construction sector
Ibrahim et al. 2021	Malaysia	Identified methods for the use of IoT towards construction 4.0
Noruwa et al. 2022	UK	Studied the impact of emerging technologies in construction projects
Ojo and Pye 2020	UK	Analyzed BIM implementation practices of construction organizations
Berlak et al. 2021	Germany	Analyzed the impacts of digitalization on the productivity of the Germany's construction sector
Cao et al. 2019 ; McCabe et al. 2021; Tahrani et al. 2015	Canada	Surveyed the use of BIM in the Canadian construction industry. No specific focus on NC

3. METHODOLOGY

This study adopts an exploratory approach, as outlined in (Swedberg 2020), and employs a qualitative research design, primarily using semi-structured interviews. The choice of this research method was influenced by two key factors: (1) lack of existing literature on the use of latest technology in NC, which made hypothesis formulation and validation unfeasible, leading the study to focus on exploration rather than confirmation of ideas, and (2) unavailability of a database of project and construction technology experts or projects in NC, which restricted participant recruitment for surveys, thereby impacting sample size and statistical precision. As a result, semi-structured interviews were chosen, offering both researchers and participants the opportunity to engage in detailed discussions and explore the topic's key aspects.

A literature review was performed to collect and analyze relevant data related to this research. It included articles published in English from a range of databases such as Google Scholar, Science Direct, Emerald, conference proceedings, government websites from Provincial and Territorial authorities, university publications, dissertations, and resources from the Leddy Library at the University of Windsor. The review covered articles published between 1990 and 2024, using keywords like "lean construction," "BIM," "lean-BIM," "digital technology use in construction," "innovative technology use in cold regions for construction," and "infrastructure construction in cold regions." The insights derived from literature review contributed to the development of interview scripts for semi-structured interviews. The study's findings aim to expand knowledge on the current state, barriers, and critical success factors for advancing technology adoption in

construction management in NC. The study was conducted in four distinct phases: Phase 1: Questionnaire development; Phase 2: Semi-structured interviews; Phase 3: Thematic analysis; and Phase 4: Interpretation

3.1   Phase 1: Questionnaire development

The questionnaire was developed using insights from the literature review to ensure the validity of the semi-structured interview scripts. Five questions were selected following consultations with five experts in project and construction management in NC. The feedback from these experts was used to calculate Lawshe's Content Validity Ratio (CVR) for each question (Lawshe 1975). An individual was considered an expert if they had relevant knowledge and 10 to 15 years of experience in the field (Aung et al. 2023; Dodanwala and Santoso 2024). Questions with a CVR value of 0.99 or higher were considered valid (Lawshe 1975) and included in the final set of five questions. As a result, all following five questions were validated for use in this study:

Q1: What are the state-of-the-art technical and managerial solutions that are used in the planning and design phase of infrastructure projects in NC?

Q2: What are the state-of-the-art technical and managerial solutions that are used in the construction and commissioning phase of infrastructure projects in NC?

Q3: What are the state-of-the-art technical and managerial solutions that are used in the operation and maintenance phase of infrastructure projects in NC?

Q4: What are the challenges to implementing state-of-the-art technical and managerial solutions in the delivery of infrastructure projects in NC?

Q5: What are the critical success factors for implementing state-of-the-art technical and managerial solutions in construction projects delivered in NC?

3.2   Phase 2: Semi-structured interviews

The University of Windsor Research Ethics Board (REB) granted approval for the semi-structured interviews to be conducted for this study on November 23, 2023. Semi-structured interviews offer an opportunity to explore a topic in depth from multiple perspectives (Swedberg 2020; Trochim and Donnelly 2008). In qualitative research, when core principles are followed, the sample size generally follows the concept of saturation, where additional data no longer provides new insights (Mason 2010; Ruparathna and Hewage 2015). A list of 20 active and potential research participants for the semi-structured interviews was compiled using the websites of project and construction management-related public and private sector organizations in NC. A formal introductory email was sent to all participants, which included a letter of invitation outlining the purpose of the research and requesting their participation in the semi-structured interviews. Participants were assured of confidentiality regarding their identities.

Out of the 20 potential participants, 17 agreed to participate. Additionally, two participants, motivated by the research, contacted seven more individuals, expanding the pool of participants through snowball sampling. This approach was useful due to the challenge of finding participants in NC (Naderifar et al. 2017). Once responses were received, further details about the interview session—including the interview script, consent form, and interview logistics (date, time, and duration)—were provided and discussed with 16 participants. Semi-structured interviews were conducted between June and September 2024, and final transcriptions with signed consent forms were received from 11 participants. Four participants chose not to sign the consent form, and one participant reported technical difficulties in signing it. The average duration of each semi-structured interview was approximately 60 minutes.

3.3   Phase 3: Thematic analysis to understand the current status of technology use

Thematic analysis was utilized to identify, outline, and evaluate patterns or themes within the study's collected data. To ensure consistent interpretation, the final transcribed data were coded into potential themes through an annotation process conducted by two researchers. The following six steps were carried out as recommended in Barun and Clarke (2006):

1. Familiarization with the data: The data were read and re-read to identify key patterns, ideas, and significant features. This immersion process helped develop a deep understanding of the material.
2. Generation of initial categories: Significant segments of the data relevant to the research questions were identified and marked with short phrases or words (initial categories) that captured the essence of these segments.

3. Searching for sub-themes (codes): The initial categories were grouped into potential sub-themes (codes), identifying patterns and connections between them that reflected overarching concepts within the data.
4. Reviewing the themes: The potential themes were reviewed and refined for coherence and accuracy, ensuring they faithfully represented the data. Some themes were split, others combined, and some discarded to maintain focus and clarity in the analysis.
5. Defining and naming the themes: Each theme was clearly defined, ensuring it captured the key findings. A concise label was assigned to each theme to reflect its essence.
6. Writing the report: The findings were presented with detailed descriptions and examples illustrating each theme, accompanied by interpretations that addressed the research questions.

3.4 Phase 4: Interpretation

The thematic analysis explored the status of advanced technology use in managing construction projects in NC. Key success factors necessary to implement state-of-the-art technology in NC construction sector were separately evaluated from participant's responses. Drawing on these findings, recommendations for incorporating innovative technological and managerial solutions into construction projects were offered as a methodological framework.

4. RESULTS AND DISCUSSION

The semi-structured interview participants represent a diverse group with varied educational and professional backgrounds in the construction and project management fields. Their qualifications include bachelor's and master's degrees in engineering, professional certifications such as PMP and Project Management Certificates, and affiliations with Professional Engineers. They bring 5 to over 30 years of industry experience, with 60% having more than a decade of involvement, specifically in NC. Their work spans both the public and private sectors, with many currently employed in public organizations. This diversity enhances the depth and breadth of expertise reflected in the study findings. The results from interviews of 11 participants highlight the key theme across all three phases – planning and design, construction and commissioning, and operation and maintenance – is the consistent dominance of traditional practices in NC. In traditional project management, the process commences with the Design and Planning Phase, where project managers collaborate with architects, engineers, and stakeholders to develop designs, schedules, and cost estimates, typically without the use of advanced technology. This phase also involves conducting risk assessments, ensuring regulatory compliance, obtaining necessary permits, and finalizing contracts. During the Construction and Commissioning Phase, project managers coordinate with architects, engineers, and construction teams to ensure the project meets design specifications, quality standards, and timelines while managing suppliers, subcontractors, and safety protocols. The commissioning phase ensures the system's functionality is fully validated. In the final Operation and Maintenance Phase, project managers focus on ensuring operational efficiency, developing maintenance schedules, and addressing issues through routine inspections and updates. This process relies on traditional project management techniques and manual oversight to maintain control and ensure project success. Initial Categories Based on Participant Responses (Table 2) highlight how participants primarily rely on traditional methods across three key phases of construction projects: Planning and Design, Construction and Commissioning, and Operation and Maintenance. In the Planning and Design Phase, most participants use conventional approaches such as manual drafting and standard documentation techniques, with only limited mentions of drones or digital documentation. Similarly, in the Construction and Commissioning Phase, traditional methods dominate, with only a few instances of modular construction being adopted for smaller projects. During the Operation and Maintenance Phase, participants predominantly report reliance on traditional practices such as reactive maintenance, with only occasional references to digital tools like drones or digital documentation for inspections and monitoring. The analysis of Sub-Themes (Codes) and Themes (Table 3) refines these insights into three primary themes: 1) Dependence on Conventional Practices, where participants rely heavily on traditional construction methods; 2) Unawareness of state-of-the-art technologies, highlighting the absence of innovations like BIM, Lean, Digital Twins, and construction digitalization; and 3) Infrequent/under-usage of technology, with occasional references to drones or LiDAR applications.

Despite some use of advanced tools like drones and digital documentation, the integration of cutting-edge technologies such as BIM, Lean principles, modular construction, and digital twins is limited. Participants largely rely on local expertise and government guidelines tied to traditional methods, with minimal adoption of modern technical and managerial solutions.

Table 2: Thematic analysis of 11 participants' responses for generation of Initial Categories

Participant Code	Planning and Design Phase	Construction and Commissioning Phase	Operation and Maintenance Phase
P01	No use of advanced technology, use of drone and digital documentation	Use of drone and digital documentation only, no advanced technology use	Use of drone and digital documentation only, no advanced technology use
P02	Traditional practice, use of local expertise	Traditional practice	Traditional practice
P03	Traditional practice, no use of advanced technology, rare use of drone and modular construction	Traditional practice, lack of awareness of advanced technology	Traditional practice
P04	No use of BIM, Lean and Digital Twins, unaware of use of advanced technical and managerial solutions	Lack of awareness of advanced technology	Traditional practice, lack of awareness of advanced technology
P05	Traditional practice	Traditional practice	Traditional practice
P06	Traditional practice	Traditional practice	Traditional practice
P07	Traditional practice, no use of advanced technology, no use of drone and modular construction	Traditional practice, unaware of use of advanced technical and managerial solutions	Traditional practice, lack of knowledge on use of advanced technical and managerial solutions
P08	Traditional practice, no use of advanced technology, rare use of drone only	Traditional practice, no advanced technology use	Traditional practice, no advanced technology use
P09	Traditional practice	Traditional practice, no advanced technology use, use of modular construction for only small projects	Traditional practice, lack of awareness of advanced technology
P10	Traditional practice, use of LiDAR & Topo survey only	Traditional practice, no use of BIM, lean, construction digitalization, generative design, etc.	Traditional practice, no use of BIM, lean, construction digitalization, generative design, etc.
P11	Traditional practice	Traditional practice, unaware of use of advanced technical and managerial solutions	Traditional practice, lack of knowledge on use of advanced technical and managerial solutions

Table 3: Thematic analysis for generating sub-themes (codes) and themes from initial categories

Initial Category	Code	Theme
Traditional practice in planning and design	Traditional methods and techniques	Traditional practice
Traditional practice in construction and commissioning		
Traditional practice in operation and maintenance		
Use of local expertise	Traditional knowledge/craftsmanship	
Lack of advanced technology adoption/modular construction		Unawareness of state-of-the-art technologies
Absence of use of BIM, Lean and Digital Twins	Lack of knowledge of advanced design and data collection methods	
Unaware of use of advanced technical and managerial solutions		
Absence of use of drones		
Lack of awareness of advanced technology		
Absence of use of BIM, Lean, construction digitalization, generative design, etc.	Absence of knowledge on advanced managerial solutions	
Lack of knowledge on use of advanced technical and managerial solutions		
Use of LiDAR and Topo survey only	Limited technology use	Infrequent/under usage of technology
Occasional use of drone only	Infrequent technology use	
Use of drone and digital documentation		
Infrequent use of modular construction		
Use of modular construction for only small projects	Under usage of technology	
Use of drone and digital documentation only		

Despite some use of advanced tools like drones and digital documentation, the integration of cutting-edge technologies such as BIM, Lean principles, modular construction, and digital twins is limited. Participants largely rely on local expertise and government guidelines tied to traditional methods, with minimal adoption of modern technical and managerial solutions. While some expressed plans to adopt more innovative technologies in the future, traditional approaches continue to prevail in all phases of the projects.

The findings identified several challenges in the project and construction management of infrastructure projects in NC, including high costs, a shortage of skilled labor, harsh environmental conditions, lack of leadership support, limited infrastructure and technology, difficulties in supply-chain management, and inadequate quality assurance processes.

The participants suggested the following CSFs for implementing advanced technical and managerial solutions in NC's construction projects: (1) establishing a clear, adaptable strategy and effective risk management practices to achieve project goals and improve performance based on past experiences (Strategic Planning and Risk Management), (2) integrating modern construction techniques, technologies, and traditional knowledge to enhance efficiency, adaptability, and project outcomes, particularly in NC's challenging conditions (Innovation and Technological Advancement), (3) fostering strategic recruitment, continuous training, and capacity-building programs to adopt new technologies and reduce dependency on external labor (Skilled Workforce and Training), (4) ensuring early and continuous involvement of stakeholders, including local communities and government bodies, to support the adoption of new technologies and meet project expectations (Stakeholder Engagement and Collaboration), (5) providing strong leadership and commitment to drive technology adoption and collaboration, ensuring effective allocation of resources (Leadership and Management), (6) adhering to relevant regulations and quality standards to deliver high-quality, compliant projects, especially in the challenging environment of NC (Regulations, Standards, and Compliance), (7) implementing sustainable, resilient construction practices that design infrastructure to withstand harsh conditions and minimize ecological impact (Sustainability and Resilience), (8) managing the supply chain and logistics efficiently to minimize disruptions, ensure timely material delivery, and keep projects on schedule (Supply Chain and Logistics), and (9) effectively managing change and overcoming resistance to new technologies, ensuring successful project implementation, particularly in resource-constrained environments (Change Management and Technology Adoption).

The CSFs outlined will directly address the current status of technology adoption in NC's construction industry, as they tackle key challenges in the three identified themes: (1) Traditional Practice: By integrating modern construction techniques with traditional knowledge (Innovation and Technological Advancement), CSFs bridge the gap between conventional methods and state-of-the-art solutions, enhancing project outcomes while respecting established practices. (2) Unawareness of State-of-the-Art Technologies: Clear, adaptable strategies and continuous training (Strategic Planning and Risk Management, Skilled Workforce and Training) will raise awareness and equip the workforce with the skills needed to adopt new technologies. Moreover, involving stakeholders early (Stakeholder Engagement) ensures that project teams understand technological innovations and their benefits. (3) Infrequent/Under Usage of Technology: Strong leadership, change management, and capacity-building initiatives (Leadership and Management, Change Management) will foster a culture of innovation, ensuring that technology is not only introduced but effectively integrated into routine practices for improved efficiency and performance.
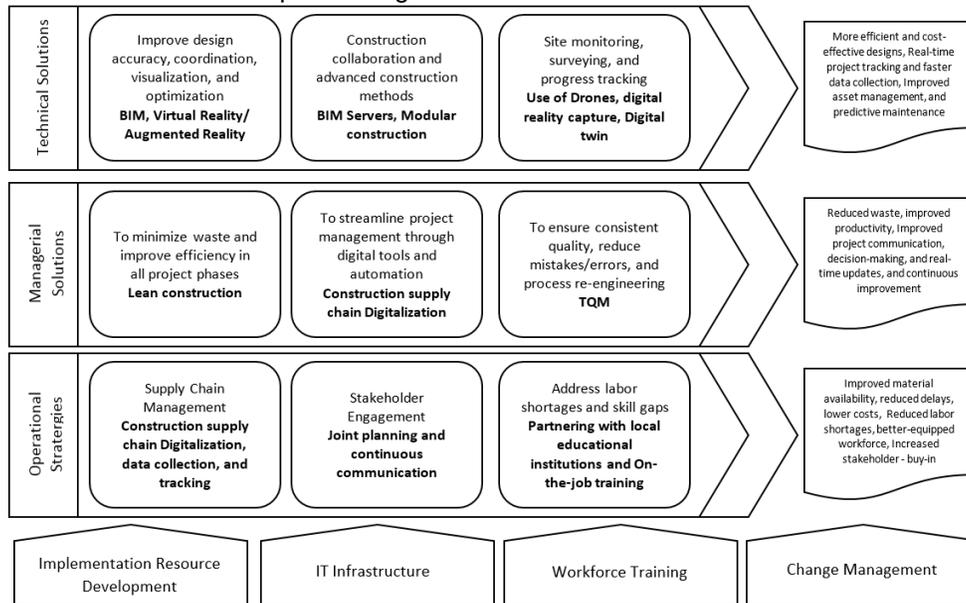
The challenges in advancing technology adaptation in NC can be mitigated by the CSFs suggested by the participants, which align with findings from previous studies on the implementation of advanced project and construction management technologies in construction projects across Asia, the Middle East, Africa, and Europe. Some of the most common CSFs include top management's initiative and support, standardization or consistent guidelines, recruitment and retention of skilled staff, ongoing and relevant training for staff, financial backing, effective communication and collaboration among key stakeholders, managing change and overcoming resistance, and efficient supply chain management (Ahmed and Sobuz 2020; Borrmann et al. 2018; Evans and Farrell 2021; Ibrahim et al. 2021; Majumdar et al. 2024; Sepasgozar et al. 2021; Tahrani et al. 2015; Zhan et al. 2022).

5. FRAMEWORK FOR TECHNOLOGY INTEGRATION

Figure 1 outlines how state-of-the-art solutions can be implemented in NC's construction industry, addressing both existing challenges and creating pathways to overcome them effectively. To implement a state-of-the-art framework in NC's construction sector, a combination of technical, managerial, and operational strategies, along with resource development, is essential. Technical solutions include

integrating BIM and VR/AR for enhanced design accuracy and visualization, modular construction for faster and more efficient assembly, and leveraging drones, digital reality capture, and digital twins for site monitoring and asset management. Managerial solutions focus on Lean Construction to minimize waste, construction supply chain digitalization to optimize logistics and reduce costs, and Total Quality Management (TQM) to enhance project efficiency and decision-making. Operational strategies emphasize digitalized supply chain management, improved stakeholder engagement and communication, and labor and skill development through partnerships with educational institutions. Lastly, resource development requires investments in IT infrastructure, workforce training, and change management to facilitate the adoption of new technologies. By integrating these elements, NC's construction sector can improve efficiency, reduce costs, and enhance sustainability in future projects.

Figure 1: Framework for implementing state-of-the-art solutions in NC's construction sector

Technical Solutions

- Improve design accuracy, coordination, visualization, and optimization — **BIM, Virtual Reality/ Augmented Reality**
- Construction collaboration and advanced construction methods — **BIM Servers, Modular construction**
- Site monitoring, surveying, and progress tracking — **Use of Drones, digital reality capture, Digital twin**
- → More efficient and cost-effective designs, Real-time project tracking and faster data collection, Improved asset management, and predictive maintenance

Managerial Solutions

- To minimize waste and improve efficiency in all project phases — **Lean construction**
- To streamline project management through digital tools and automation — **Construction supply chain Digitalization**
- To ensure consistent quality, reduce mistakes/errors, and process re-engineering — **TQM**
- → Reduced waste, improved productivity, Improved project communication, decision-making, and real-time updates, and continuous improvement

Operational Strategies

- Supply Chain Management — **Construction supply chain Digitalization, data collection, and tracking**
- Stakeholder Engagement — **Joint planning and continuous communication**
- Address labor shortages and skill gaps — **Partnering with local educational institutions and On-the-job training**
- → Improved material availability, reduced delays, lower costs, Reduced labor shortages, better-equipped workforce, Increased stakeholder - buy-in

Implementation Resource Development | IT Infrastructure | Workforce Training | Change Management

6. CONCLUSIONS

The findings of this research demonstrated a consistent dependence on traditional practices in the management of infrastructure projects in NC and identified several challenges in the project and construction management of infrastructure projects in NC, including high costs, a shortage of skilled labor, harsh environmental conditions, lack of leadership support, limited infrastructure and technology, difficulties in supply-chain management, and inadequate quality assurance processes. The challenges and concerns expressed by the participants in their responses are consistent with previous studies conducted by various authors in circumpolar countries or cold regions. These factors collectively hinder the technology adoption in NC.

This research primarily based on semi-structured interviews with construction industry professionals working in NC. The limitations of an interview-based survey include potential bias due to participants' subjective responses, which may not fully represent broader industry trends. Limited sample size can also affect the generalizability of findings, especially if the participants are not diverse or representative of the target population. Additionally, response accuracy may be influenced by recall bias, where participants may not accurately remember or disclose information. Interviewer's influence can also affect responses, as participants may provide answers, they believe are socially desirable rather than their true opinions. Lastly, time and resource constraints may limit the number of interviews conducted, potentially leading to gaps in data coverage.

Future research should focus on gathering regional and context-specific data to refine the framework for different geographic and environmental conditions in NC. Additionally, incorporating socio-economic and policy considerations, such as government regulations and community involvement, will provide a more holistic understanding of barriers to technology adoption. Research should also explore practical implementation challenges, including budget constraints and logistical issues, to develop actionable strategies. Further studies on technology and infrastructure development—such as improving internet

connectivity and local technical capacity—are crucial for effective digital adoption. Investigating stakeholder engagement and readiness will help assess cultural barriers, training needs, and attitudes toward new technologies. Lastly, examining the scalability and adaptability of solutions across different project sizes and resource levels will ensure the framework remains effective in various scenarios. Addressing these will enhance the framework's applicability, supporting the advancement of construction practices in NC.

7. REFERENCES

Ahmed, S., and M. H. R. Sobuz. 2020. "Challenges of Implementing Lean Construction in the Construction Industry in Bangladesh." *Smart and Sustainable Built Environment,* 9(2):174–207.

Anderson, T., and B. Poppel. 2002. "LivingConditionsin Arctic." *Social Indicators Research,* 58(1):191–216.

Aung, Z.M., Santoso, D.S., and Dodanwala, T. 2023. "Effects of Demotivational Managerial Practices on Job Satisfaction and Job Performance: Empirical Evidence from Myanmar's Construction Industry." *Journal of Engineering and Technology Management,* 67:101730.

Aziz, N. M., and Zainon, N. 2023. "Driving Factors for Lean-BIM Implementation in Malaysia's Construction Industry: Interview-Based Study." *Smart and Sustainable Built Environment,* 12(4):872–91.

Aziz, R. F., and Sherif, M.H. 2013. "Applying Lean Thinking in Construction and Performance Improvement." *Alexandria Engineering Journal,* 52(4):679–95. doi: 10.1016/j.aej.2013.04.008.

Barun, V., and Clarke, V. 2006. "Using Thematic Analysis in Psychology." *Qualitative Research in Psychology,* 3(2):77–101.

Bayhan et al. 2023. "A Lean Construction and BIM Interaction Model for the Construction Industry." *Production Planning & Control,* 34(15):1447–74.

Berlak, J., Hafner, S. and Kuppelwieser, V. 2021. "Digitalization's Impacts on Productivity: A Model-Based Approach and Evaluation in Germany's Building Construction Industry." *Production Planning & Control,* 32(4):335–45.

Borrmann et al. 2018. "Building Information Modeling: Why? What? How?" In *Building Information Modeling - Technology Foundations and Industry Practice*, edited by Andre Borrmann, K. Markus, Christian Koch, and Jakob Beetz. Cham: Springer, Switzerland.

Bryde, D., Broquetas, M. and Volm, J.M. 2013. "The Project Benefits of Building Information Modelling (BIM)." *International Journal of Project Management,* 31(7):971–80.

Cao et al. 2019. "The Benefits of and Barriers to BIM Adoption in Canada." *36th International Symposium on Automation and Robotics in Construction*. IAARC: Canada

Damanpour, F. 2018. *Organizational Innovation: A Meta-Analysis of Effects of Determinants and Moderators.* Routledge, New York, USA.

Dodanwala, T., and Santoso, D. S. 2024. "Critical Factors Influencing the Bid/No-Bid Decisions of Small and Medium-Sized Contractors in Sri Lanka." *International Journal of Construction Education and Research,* 1-26.

Evans, M., and Farrell, P. 2021. "Barriers to Integrating Building Information Modeling (BIM) and Lean Construction Practices on Construction Mega-Projects: A Delphi Study." *Benchmarking: An International Journal,* 28(2):652–69.

Gritsenko, D., and Efimova, E. 2020. "Is There Arctic Resource Curse? Evidence from the Russian Arctic Regions." *Resource Policy,* 65:1–10. doi: 10.1016/j.resourpol.2019.101547.

Hwang, B. G., Zhao, X. and Yang, K.W. 2019. "Effect of BIM on Rework in Construction Projects in Singapore: Status Quo, Magnitude, Impact, and Strategies." *Journal of Construction Engineering and Management,* 145(2):1–16.

Ibrahim, F. S., Esa, M. and Rahman, R.A. 2021. "The Adoption of IOT in the Malaysian Construction Industry: Towards Construction 4.0." *International Journal of Sustainable Construction Engineering and Technology,* 12(1):56–67.

Kozin, M., Skotarenko, O. and Plotnikov, O. 2020. "Assessment of Challenges, Threats, and Prospects in Development of Cities and Towns in the Arctic Zone." *In IOP Conference Series: Earth and Environmental Science,* 434(1):1–9.

Lawshe, C. H. 1975. "A Quantitative Approach to Content Validity." *Personnel Psychology,* 28(4):563–75.

Louie, et al. 2016. *Recommendations on Northern Infrastructure to Support Economic Development.*

Majumdar, S. B. 2021. "Effectiveness of Lean Construction Strategy in Management of Public Infrastructure Projects in Arctic Region of Canada." Project and Construction Management: The University of Liverpool, Liverpool, UK.

Majumdar, S., Pulindu, R. and Ruparathna, R. 2024. "Technology Use in Construction Management: An Industry Survey for Northern Canada." *CSCE Annual Conference, Niagara Falls, Ontario*. CSCE: Canada.

Mason, M. 2010. "Sample Size and Saturation in PhD Studies Using Qualitative Interviews." *In Forum Qualitative Sozialforschung: Qualitative Social Research,* 11(3):1–19.

McCabe, B. Y., Shahi, A. and Nasrazadani, H. 2021. *3rd BIM Report 2020 A Benchmark of BIM Use in Canada*. Toronto, Canada.

Naderifar, M., Goli, H. and Ghaljaie, F. 2017. "Snowball Sampling: A Purposeful Method of Sampling in Qualitative Research." *Strides in Development of Medical Education,* 14(3):1–6.

Noruwa, B, I., Arewa, A.O. and Merschbrock, C. "Effects of Emerging Technologies in Minimising Variations in Construction Projects in the UK." *International Journal of Construction Management,* 22(11):2199–2206.

Ojo, A., and Pye, C. 2020. "BIM Implementation Practices of Construction Organisations in the UK AEC Industry." *Project Management Journal,* 9(10):1–9.

Parsamehr et al. 2023. "A Review of Construction Management Challenges and BIM-Based Solutions: Perspectives from the Schedule, Cost, Quality, and Safety Management." *Asian Journal of Civil Engineering,* 24(1):353–89.

Pereira, A. C., and Romero, F. 2017. "A Review of the Meanings and the Implications of the Industry 4.0 Concept." *Procedia Manufacturing,* 13:1206–14.

Publisher1953. 2013. "Northern Construction Economy Thriving despite Logistical Challenges and High Costs." *Canadian Design and Construction Report*, August 24.

Quillerou et al. 2020. "The Arctic: Opportunities, Concerns and Challenges." *Scientific Fact Sheets of the Ocean & Climate Platform,* 73–87.

Quinn, E. 2023. "The Challenges of Construction in the North: Spotlight on Nunavik." *Eye On the Arctic: Radio-Canada.* Retrieved December 30, 2024 (https://ici.radio-canada.ca/rci/en/news/2003918/construction-nunavik-salluit-housing).

Rahman, A.A., Shahul, A.A., and Tasnim, R. 2023. "Architecture and Artificial Intelligence: A Study from the Perspective of a Developing Country like Bangladesh." *Proceedings of International Conference on Planning, Architecture and Civil Engineering*, Rajshahi, Bangladesh: ICPACE: Rajshahi.

Ruparathna, R., and Hewage, K. 2015. "Sustainable Procurement in the Canadian Construction Industry: Current Practices, Drivers and Opportunities." *Journal of Cleaner Production,* 109:305–14.

Sacks et al. 2018. *BIM Handbook: A Guide to Building Information Modeling for Owner, Managers, Designers, Engineers, and Contractors*. 3rd ed., Wiley Publishing, Hoboken, N.J.

Sarhan et al. 2018. "Barriers to Implementing Lean Construction Practices in the Kingdom of Saudi Arabia (KSA) Construction Industry." *Construction Innovation,* 18(2):246-72. doi: 10.1108/CI-04-2017-0033.

Sepasgozar, S. M., and Davis, S. 2018. "Construction Technology Adoption Cube: An Investigation on Process, Factors, Barriers, Drivers and Decision Makers Using NVivo and AHP Analysis." *Buildings,* 8(6):1–31.

Sepasgozar et al. 2021. "Lean Practices Using Building Information Modeling (BIM) and Digital Twinning for Sustainable Construction." *Sustainability,* 13(1):1–22.

Swedberg, R. 2020. "Exploratory Research." In *The Production of Knowledge: Enhancing Progress in Social Science*, edited by C. Elman, J. Gerring, and J. Mahoney. Cambridge University Press, Cambridge.

Tahrani et al. 2015. "Structuring the Adoption and Implementation of BIM and Integrated Approaches to Project Delivery across the Canadian AECO Industry: Key Drivers from Abroad." *5th International/11th Construction Specialty Conference,* Vancouver, CSCE: BC.

Trochim, W. M. K., and Donnelly, J.P. 2008. *The Research Methods Knowledge Base*. 3rd ed. Atomic Dog/Cengage Learning, Mason, Ohio.

Turner et al. 2021. "Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities." *IEEE Transactions on Industrial Informatics,* 17(2):746–56.

Zeiss, G. 2018. "Accelerating the Rate of BIM Adoption in Canada." *Between the Poles: All about Infrastructure*. Retrieved January 4, 2025 (https://geospatial.blogs.com/geospatial/2018/02/progress-on-bim-adoption-in-canada.html).

Zhan et al. 2022. "System Dynamics Outlook on BIM and LEAN Interaction in Construction Quantity Surveying." *Iranian Journal of Science and Technology, Transactions of Civil Engineering,* 46(5):3947–62.