Defining KPIs to assess the impact of innovation in construction: Insights from Public Project Owners

by

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transcripts into English. ChatGPT was occasionally used to enhance the clarity and readability of interview transcripts translated into English. The use of AI tools was limited to the activities outlined above, and I made every effort to ensure accuracy, proper citation, and adherence to academic integrity guidelines.

Montreal, October 20, 2025
Ehsan

Définir des indicateurs de performance clés (KPI) pour évaluer l'impact de l'innovation dans la construction: Perspectives des donneurs d'ouvrage publics

Seyed Mohammad Ehsan TABATABAEE

RÉSUMÉ

Cette thèse vise à définir des indicateurs clés de performance (KPI) pour évaluer l'impact des innovations dans l'industrie AECO. Les concepts de base — innovation, mesure de la performance et évaluation des impacts — ont d'abord été clarifiés afin d'établir un vocabulaire commun et un socle analytique. Sur cette base, une enquête de pratiques a été menée avec des donneurs d'ouvrage publics (DOP) au Québec pour comprendre ce qui est mesuré, comment cela est fait et à quelles fins.

Une approche de 'recherche par la conception' (en anglais - Design Science Research (DSR)) a été mobilisée. Premièrement, une revue de la littérature a recensé 42 KPI répartis en neuf catégories: Coût, Délai, Productivité, Qualité, Sécurité, Portée (modifications/ réclamations/ RFI), Risque, Durabilité et Innovation. Deuxièmement, des entretiens semi-directifs avec cinq DOP québécois ont documenté les pratiques actuelles en matière de KPI, les flux de données et les difficultés rencontrées. Troisièmement, des ateliers de priorisation avec les mêmes quatre DOP, rejoints par un DOP additionnel, ont positionné les 42 KPI sur une matrice utilité–mesurabilité. Enfin, un questionnaire de validation post-atelier (sept réponses provenant de six DOP) a confirmé les priorités d'implantation.

Les résultats mettent en évidence un noyau serré dans les tableaux de bord — coûts et délais — ainsi que des frictions d'implantation : problèmes de qualité des données, systèmes fragmentés et facteurs culturels influençant l'adoption. Parallèlement, les DOP manifestent une volonté claire de dépasser le « triangle de fer » vers la maîtrise de la portée, la gestion des risques, la productivité, la qualité et les résultats pour les parties prenantes, la sécurité, la durabilité et l'innovation. Les apports des ateliers ont été classés en combinant les scores moyens d'utilité et de facilité de mesure avec des pondérations d'accord fondées sur l'intervalle interquartile (IQR). L'utilité a été privilégiée (80 %), tandis que la facilité de mesure a contribué à hauteur de 20 % afin de refléter la faisabilité sans pour autant dominer le processus de hiérarchisation. Cette procédure a produit une liste courte de 17 KPI, validée par les DOP, qui équilibre valeur décisionnelle, consensus et praticité.

L'ensemble priorisé comprend : la prévisibilité des coûts (conception/réalisation), le coût unitaire, la prévisibilité des délais (conception/réalisation), le délai (temps) par unité, la productivité de la main-d'œuvre (en $/unité), la satisfaction des parties prenantes, les accidents avec perte de temps, les ordres de changement (coût) – initiés par le client, les ordres de changement (coût) – initiés par l'entrepreneur, le nombre d'ordres de changement – initiés par le client, le nombre d'ordres de changement – initiés par l'entrepreneur, les demandes d'information (RFI), la génération de déchets, l'empreinte carbone, la consommation d'énergie, l'étendue des risques (score d'exposition) et le coût de mitigation des risques. Ensemble, ces indicateurs couvrent les besoins essentiels de gestion et contrôle, tout en ouvrant la voie à des décisions éclairées par la durabilité et le risque, à mesure que les chaînes de données se renforcent.

La contribution principale de cette maîtrise consiste en : un jeu de KPI validés par les DOP (neuf catégories) et une procédure de priorisation reproductible intégrant valeur, consensus et mesurabilité. Concrètement, les DOP peuvent lancer le suivi avec cette liste, puis adopter progressivement des indicateurs de durabilité et d'innovation à mesure que la gouvernance des données progresse. Les limites incluent un petit échantillon basé au Québec et un aperçu transversal des pratiques actuelles des donneurs d'ouvrage publics. À l'venir, la recherche peut être continuée par des projets pilotes intégrant les KPI, le renforcement de la gouvernance et les études longitudinales reliant les indicateurs de phase aux résultats post-livraison. Ces résultats permettent désormais d'évaluer l'innovation au-delà du duo coût-délai et des effets immédiats, en intégrant des retombées à plus long terme.

Mots-clés: innovation en construction, mesure de la performance, évaluation des impacts, indicateurs clés de performance, AECO

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ABSTRACT

This thesis aims to define key performance indicators (KPIs) for evaluating the impact of innovations in the AECO industry. The work began by clarifying core concepts - innovation, performance measurement, and impact assessment - to build a shared vocabulary and an analytical baseline. With these foundations, an investigation of current practice was carried out with public project owners (PPOs) in Québec to understand what is measured, how it is measured, and why.

A Design Science Research (DSR) approach was used. First, a literature review assembled 42 KPIs grouped into nine categories: Cost, Time, Productivity, Quality, Safety, Scope (changes/claims/RFIs), Risk, Sustainability, and Innovation. Second, semi-structured interviews with five Québec PPOs documented current KPI practice, data workflows, and difficulties. Third, prioritization workshops with the same four PPOs plus one additional owner positioned the 42 KPIs on a usefulness–measurability matrix. Finally, a post-workshop validation questionnaire (seven responses from six PPOs) confirmed priorities for implementation.

Findings show a narrow core in current dashboards - cost and time - together with implementation barriers: data-quality issues, fragmented systems, and cultural factors affecting adoption. At the same time, owners expressed a clear interest in moving beyond the “iron triangle” toward scope discipline, risk management, productivity, quality and stakeholder outcomes, safety, sustainability, and innovation. Workshop inputs were ordered by combining the average scores for usefulness and ease of measurement with agreement weights based on the interquartile range (IQR). Usefulness was emphasized (80%), while ease of measurement contributed (20%) to reflect feasibility without letting it dominate. This procedure produced an owner-endorsed shortlist of 17 KPIs that balances decision value, consensus, and practicality.

The prioritized set comprises the following metrics: cost predictability (design/construction); cost per unit; time predictability (design/construction); time per unit; labor productivity expressed as dollars per unit; stakeholder satisfaction; lost-time incidents; change order (cost) – client-initiated; change order (cost) – contractor-initiated; number of change orders – client-initiated; number of change orders – contractor-initiated; requests for information (RFI); waste generation; carbon footprint; energy consumption; scope of risks (risk-exposure score); and cost of risk mitigation. Together, these cover the main control needs of public owners while opening space for sustainability and risk-informed decisions as data pipelines mature.

The main contribution is an owner-validated KPI set spanning nine categories and a replicable prioritization procedure that integrates perceived value, stakeholder agreement, and measurability. Practically, owners can begin routine reporting with the validated shortlist, while planning staged adoption of sustainability and future innovation-specific indicators as data governance improves. Limitations include a small, Québec-based sample and a cross-sectional snapshot of the current practices of public project owners. Future work will pilot the prioritized KPIs on live projects, strengthen data governance and integration, and run longitudinal studies linking project-phase indicators to post-handover outcomes, enabling a more complete evaluation of innovation impacts across the asset life cycle. With these results, the impact of innovation can be identified across a wider set of dimensions than time and cost, and assessed beyond immediate outputs to include longer-term outcomes.

Keywords: construction innovation, performance measurement, impact assessment, key performance indicators, AECO

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LIST OF ABREVIATIONS AND ACRONYMS

AECO	Architecture, Engineering, Construction, and Operations
BI	Business Intelligence
BIM	Building Information Modelling
CPI	Cost Performance Index
DOP	Donneurs d’Ouvrage Publics
DSR	Design Science Research
EU	European Union
EVM	Earned Value Management
GHG	Greenhouse Gases
HLM	Habitation à Loyer Modique
IQR	The Interquartile Range
KPI	Key Performance Indicator
MS	Microsoft
OECD	Organization for Economic Co-operation and Development
PPOs	Public Project Owners
PMI	Project Management Institute
RFI	Requests for Information
ROI	Return On Investment
SLR	Systematic Literature Review
SPI	Schedule Performance Index
TBL	Triple Bottom Line

INTRODUCTION

The construction industry has long been recognized as a major economic driver and a vital contributor to global development (Giang & Sui Pheng, 2011). Yet, despite its importance, the sector has historically been anchored in traditional processes and is often slow to adopt to new methods or technologies (Chowdhury, Adafin, & Wilkinson, 2019). Over the years, scholars and practitioners have repeatedly drawn attention to persistent performance challenges and low productivity gains in construction. In an increasingly competitive and fast-paced environment, marked by continuous economic growth and shifting client expectations, construction companies face mounting pressures to monitor, measure, and enhance project outcomes (Habibi, Kermanshachi, & Rouhanizadeh, 2019). At the same time, public project owners, who are responsible for ensuring that public investments generate tangible value, face similar challenges. They are increasingly expected to demonstrate accountability, transparency, and the effective use of resources, not only by meeting cost and schedule objectives but also by showing how their projects foster innovation, sustainability, and long-term societal benefits.

One of the most prevalent strategies for gauging success in construction projects is performance measurement, a structured approach that allows key stakeholders to track progress and pinpoint opportunities for improvement (Ali, Al-Sulaihi, & Al-Gahtani, 2013). In particular, Key Performance Indicators (KPIs) serve as essential indicators by which organizations assess various project parameters - such as cost, schedule, safety, and quality - to evaluate efficiency and effectiveness (Cox, Issa, & Ahrens, 2003). KPIs provide the quantitative basis for assessing performance and help practitioners align short-term project goals with overarching strategic objectives. By comparing actual performance to estimated targets, managers can proactively intervene to optimize resources, reduce costs, mitigate risks, and ultimately deliver more successful project outcomes.

However, as the construction industry moves into an era characterized by rapid technological advancements and evolving stakeholder expectations, there is growing recognition that merely tracking short-term or conventional KPIs may be insufficient. An equally pressing need exists to evaluate the impact of innovation within this sector (Delarue, C. & Poirier, É., 2021). Broadly, innovation entails introducing novel ideas, products, or methods that fundamentally alter existing workflows or business models (Carpenter, 1943 ; Schumpeter, 1934). Innovation in construction might involve the adoption of digital tools such as Building Information Modelling (BIM), the use of advanced materials, or the reconfiguration of supply chains to improve efficiency, sustainability, and cost savings. Despite its undeniable importance, the construction industry has been slower than other sectors to embrace disruptive changes and new ways of working (Blayse & Manley, 2004).

Challenges to innovation in the construction industry often arise from deeply entrenched practices, fragmented project delivery structures, and conservative organizational cultures. Moreover, the impact of innovation can be difficult to quantify because it often transcends simple measures like on-time delivery and budget performance, extending instead into broader domains of organizational growth, sustainability, and social well-being. Importantly, in Québec, innovation in the public sector is guided by the provincial digital transformation agenda, most notably the Feuille de route – BIM Québec (BIM Roadmap). This collective initiative aims to coordinate and harmonize the adoption of BIM across public organizations. As such, in the context of this thesis, innovation refers primarily to BIM as both a technical innovation (digital tools and processes) and a process innovation (collaboration methods, data exchange, and integrated workflows).

Because Public Project Owners (PPOs) are collectively expected to implement BIM according to the same roadmap, their ability to measure its impact in a consistent manner is crucial. A common measurement system is therefore not only desirable but necessary to ensure alignment across public agencies and to enable Québec to evaluate the large-scale effects of this shared innovation initiative.

Although various KPIs are already used to assess project performance, the main gap lies in their practical implementation and their limited capacity to reflect the transformative impacts of innovation. Therefore, there is a need for refined and applicable KPIs that not only measure short-term results but also enable public owners to track, implement, and evaluate innovation outcomes over time. In particular, an industry-wide, aligned KPI system would allow PPOs to demonstrate how BIM contributes to improved project performance, organizational capabilities, and long-term value, as expected within the BIM Roadmap.

Given these considerations, the central objective of this research is to define KPIs that specifically evaluate the impact of innovations in the construction industry, with a particular emphasis on PPOs. While numerous studies have investigated project performance using traditional metrics such as cost, time, and quality, the literature reveals a lack of frameworks that enable public owners to both measure and effectively implement KPIs that capture the broader and long-term impacts of innovation. To address this gap, this thesis reviews existing literature and applies a mixed approach, including semi-structured interviews and a validation questionnaire designed to prioritize and confirm relevant KPIs. Ultimately, the aim is to develop a rigorous yet practical, industry-endorsed KPI scorecard - rooted in real-world practice and aligned with public sector needs - that integrates innovation-driven indicators with conventional performance measures for a more comprehensive and forward-looking evaluation framework.

0.1 Problem statement and research questions

Measuring the impact of innovation in the construction industry remains a significant challenge. Although stakeholders generally track short-term results, such as cost and schedule, these conventional performance metrics often fail to capture long-term or indirect effects, including improvements in sustainability, organizational learning, or societal well-being (Kucukvar & Tatari, 2013; Wu, Yang, Frangopol, & Jin, 2021). This gap is especially problematic in an industry that has been historically conservative and slow to adopt change; without a reliable way to evaluate the broader benefits of innovation, decision-makers lack a strong evidence base for implementing new ideas, processes, or technologies.

Despite increasing calls for standardized, impact-oriented KPIs (Alvarez & Jordan, 2024 ; Arshi, Rao, Viswanath, & Begum, 2021 ; Nappi & Kelly, 2022), the key challenge in the construction sector is not the absence of indicators but their effective implementation. PPOs and many organizations struggle to operationalize existing KPIs within their management systems, facing obstacles such as fragmented data environments, inconsistent measurement practices, and limited integration between innovation outcomes and performance monitoring frameworks. Addressing these challenges is essential to enable KPIs to function not merely as reporting tools, but as decision-making instruments that support the systematic evaluation of innovation impacts over both short-term outputs and long-term sustainability gains.

In Québec, public project owners aim to deploy BIM and other digital transformation initiatives on a large scale across public infrastructure projects. However, the absence of robust mechanisms to measure the impact and performance of these innovation efforts remains a major obstacle to their implementation and long-term sustainability. Transformation initiatives are often undertaken with an assumed expectation of improvement, yet limited empirical evidence exists to validate their actual outcomes. This lack of measurable proof constrains decision-makers' confidence and hinders continuous improvement. PPOs also face significant operational barriers: data-quality issues resulting from manual entry, fragmented information systems with limited interoperability, and insufficient integration for effective data collection and analysis (Tabatabaee, Guimarães, Iordanova, & Poirier, in press). Furthermore, regulatory and privacy constraints, coupled with the inherent complexity of interpreting data within unique, project-specific contexts, make it particularly difficult for PPOs to assess the real impact of their innovation initiatives.

In the context of Québec's BIM Roadmap, PPOs are mandated not only to adopt BIM but also to demonstrate its measurable benefits. This creates a direct need for consistent indicators that can distinguish between project impact (performance outcomes tied to the specific project) and innovation impact (changes resulting from adopting BIM). Clarifying this distinction is essential because an innovation may improve processes even when project-level KPIs do not immediately reflect it.

Given this context, the central question guiding this research is:

How can PPOs measure the impact of their innovation initiatives?

To address this overarching query, the study pursues three core objectives:

First, this research clarifies key concepts - performance, impact, and innovation - to establish a shared conceptual framework for the discussion. Differentiating these terms is essential for identifying precisely what is being measured.

Second, the study examines how project success is traditionally assessed by PPOs, focusing on how existing performance metrics (cost, schedule, and quality) frequently fail to capture broader or long-term outcomes. This exploration highlights the gap between conventional measures of success and the need for more expansive, innovation-oriented KPIs.

Third, based on the clarified concepts and identified measurement gaps, the research aims to develop a validated set of KPIs that capture both short-term project performance and the extended, often intangible impacts of innovation. By incorporating these more holistic indicators, practitioners could gain a clearer understanding of how innovative processes and technologies contribute to long-term value across the project life cycle.

By tackling these objectives, this thesis aims to provide a comprehensive understanding of how innovation is defined, measured, and ultimately valued from the perspective of PPOs of Québec, thereby equipping practitioners and researchers with a more robust owner-driven KPI set for strategic decision-making.

0.2 Scope and significance

This thesis focuses on construction projects commissioned by large project owners in Québec, Canada, with a primary focus on public agencies, because their reporting requirements often cascade through the entire supply chain. Insights gleaned from these owners are nevertheless expected to benefit private developers and major contractors whose governance structures impose similar accountability demands.

Field data are collected mainly during the construction phase, yet the proposed KPI set is deliberately life-cycle oriented. While short-term project metrics (cost and schedule) remain essential, the KPI set is designed to be populated later, during operation, maintenance, and even end-of-life, so that practitioners can trace short-term and long-term effects of any innovative intervention. These effects might relate to resource efficiency, safety culture, user satisfaction, organizational learning, or other priorities identified by participating owners.

This alignment is particularly important because the BIM Roadmap aims to standardize practices across public agencies. A shared KPI set would provide PPOs with a common ground for evaluating BIM's contribution, enabling benchmarking and supporting future phases of the Roadmap.

The study is significant in three ways. Practically, it delivers a consolidated list of existing KPIs, augmented by indicators that project owners themselves say they still need. Coupled with the life-cycle structure, this list will let practitioners monitor an innovation's contribution not only at project handover but also in the years that follow - thereby supporting evidence-based decisions about scaling, replication, or corrective action. Crucially, the validated shortlist is designed to feed government benchmarking initiatives in Québec, providing a compact set of measures that can be reported consistently and used to generate rapid feedback on the performance of innovation programs and their return on investment (ROI).

Strategically, a shared KPI language enables benchmarking across projects and organizations, reducing the fragmentation that currently hampers learning and continuous improvement. By mapping indicators to different points in the asset life cycle, the KPI set shows owners how to link day-to-day site data with mid-range organizational targets and longer-range societal goals, without locking them into a single thematic lens.

Academically, the work closes a documented gap between traditional project-performance research (focused on immediate outputs) and innovation studies (concerned with broader change but often lacking concrete metrics). It offers a replicable methodology for synthesizing owner needs, literature findings, and field data into a single, coherent measurement system, laying the groundwork for future validation studies or cross-jurisdictional comparisons, and benchmarking frameworks.

By equipping Architecture, Engineering, Construction, and Operations (AECO) industry stakeholders, especially Québec PPOs, with a life-cycle, impact-oriented KPI set, the thesis ultimately aims to make it easier to see where, when, and how innovation delivers value - whether that value emerges in design phase, next month on-site, three years into operations, or a decade later when the asset is upgraded or retired. In practice, this provides the measurement backbone for Québec's long-term benchmarking, enabling faster feedback loops and a clearer view of innovation ROI across the public portfolio.

0.3 Thesis structure

Some of the content presented in this thesis is derived from two conference papers authored during the course of this research. At the time of thesis submission, the first conference paper was published. The second paper has been accepted, presented, and is pending publication in the conference proceedings.

- Conference Paper 1: *Assessing the Impact of Innovation in Construction: A Literature Review*, presented at the Annual Conference of the Canadian Society for Civil

Engineering (CSCE) in Niagara Falls, ON, on June 6, 2024, at the Sheraton Fallsview Hotel (Tabatabaee, Iordanova, & Poirier, 2025).

- Conference Paper 2: *Developing KPIs and Measurement Processes to Assess the Impact of Innovation in the Construction Industry: Current Practices and Challenges*, presented at the Joint CSCE Construction Specialty and CRS Conference 2025 in Montreal, QC, on July 31, 2025, at Concordia University (Tabatabaee et al., in press).

These articles are included in full as Appendix V and Appendix VI, respectively. Selected sections of the Introduction, Literature Review, and Findings chapters incorporate content from these papers. Where applicable, the reused material is properly cited and clearly identified to maintain transparency and avoid self-plagiarism.

This thesis is organized into five chapters:

Chapter 1 – Literature review: The opening chapter establishes the conceptual foundations for the study. It clarifies and defines the differences between performance, impact, and innovation in the AECO context, surveys the state of KPI practice in construction, and reviews existing frameworks that attempt to measure innovation outcomes. The chapter ends by synthesizing the key knowledge gaps that motivate the research.

Chapter 2 – Research methodology: The second chapter presents the Design Science Research (DSR) methodology adopted in this study to address the complex challenge of measuring innovation impacts in public construction projects. DSR methodology provides a structured, iterative framework that supports both the development and validation of practical, solution-oriented artifacts. In this case, a set of innovation-focused KPIs.

Chapter 3 – Results: KPI identification, measurement strategies, and prioritization: This chapter presents the core empirical results of the study. It integrates insights from interviews, workshops, and the post-workshop validation questionnaire into a coherent analysis of how Québec's PPOs define, measure, and prioritize performance indicators.

The first section outlines the participant and project profiles before describing the current KPI landscape—what is being measured, how it is being measured, and why these metrics are used. Eight thematic categories, aligned with the interview framework (see Appendix III), structure this part of the analysis. These themes capture both current practices and emerging measurement plans, highlighting existing data processes, tools, and organizational challenges.

The second section consolidates the findings from the prioritization workshops and the follow-up validation questionnaire. It introduces the portfolio of 42 candidate KPIs grouped into nine dimensions - Cost, Time, Productivity, Quality, Safety, Scope, Innovation, Sustainability, and Risk - and explains the process by which these metrics were assessed for usefulness and ease of measurement. Results from these exercises yielded a validated shortlist of 17 priority KPIs. This final set reflects indicators that are both decision-useful and feasible to implement within current public-sector data systems, providing a foundation for future benchmarking initiatives and impact evaluation of innovation across public projects.

Chapter 4 – Discussions: This chapter interpreted the study's empirical findings and presented the final validated set of 17 KPIs for assessing innovation in Québec's public construction projects. The discussion showed how these indicators move beyond traditional measures of cost and time to include essential dimensions such as risk exposure, sustainability performance, and scope management. It emphasized that Québec's public project owners prioritize indicators that are both meaningful and feasible to implement, signaling a pragmatic shift toward measurable innovation. This research contributes both conceptually and methodologically: conceptually by framing innovation as an integrated performance dimension within public governance, and methodologically by introducing a consensus-weighted model that aligns stakeholder priorities with data collection capacities. Together, these contributions establish a coherent and adaptable framework that links innovation management to tangible project outcomes and provides a foundation for benchmarking and continuous improvement in public construction performance.

Chapter 5 – Conclusions: This chapter synthesizes the findings in relation to the research questions and discusses practical implications for Québec public project owners. It recaps the steps undertaken in the thesis and proposes a practical, owner-driven approach to KPI selection and prioritization (an approach grounded in the expertise of participating specialists and tailored to the Québec context). The proposed method is designed to capture a broader set of innovation dimensions and to reflect the true value of innovation more accurately. The chapter concludes with a clear statement of the study's limitations and a concise roadmap for future research and implementation.

This progression - from a rigorous review of existing knowledge, through methodical data collection and analysis, to the formulation and discussion of a practical framework - ensures a clear narrative that links theoretical gaps to empirical evidence and, ultimately, to actionable guidance for industry stakeholders.

CHAPTER 1

LITERATURE REVIEW

Part of the content of this section is reproduced from and was previously described in the following articles: "*Assessing the Impact of Innovation in Construction: A Literature Review*", presented at the Annual Conference of the Canadian Society for Civil Engineering (CSCE) in Niagara Falls, ON, Canada, 2024 (Tabatabaee et al., 2025); "*Developing KPIs and Measurement Processes to Assess the Impact of Innovation in the Construction Industry: Current Practices and Challenges*", presented at the Joint CSCE Construction Specialty and CRS Conference 2025 in Montreal, QC, on July 31, 2025, at Concordia University (Tabatabaee et al., in press).

1.1 Innovation definition

The concept of innovation has received diverse interpretations in the literature (Blayse & Manley, 2004) and remains somewhat ambiguous (M. Noktehdan, Shahbazpour, & Wilkinson, 2015). Schumpeter (1934), for example, characterized innovation as the introduction of novel products or methods, discovering smarter production approaches, exploring new markets and supply chains, and developing innovative organizational methods. Carpenter (1943) viewed innovation as bringing novel ideas that significantly alter existing practices and drive industrial advancement. Brown (1994) broadly defined innovation as improving or altering products, processes, or procedures to achieve enhanced value or performance, while West and Altink (1996) presented a more detailed perspective, describing innovation as "intentional introduction and application within a role, group, or organization of ideas, processes, products, or procedures, new to the relevant unit of adoption, designed to significantly benefit the individual, the group, the organization, or the wider society."

Slaughter (1998), whose definition is frequently cited, defined innovation specifically as the practical implementation of substantial changes and improvements in products, processes, or systems that are novel to the organization introducing them. Historically, innovation discussions predominantly occurred within manufacturing and service industries rather than construction (L. Koskela & Vrijhoef, 2001). Pries and Dorée (2005), analyzing publications spanning 55 years in prominent Dutch professional journals, concluded that most construction innovations originate within supplying industries. Thus, a comprehensive definition explicitly addressing innovation within construction contexts is essential.

The OECD (2010) defines innovation as the creation of novel products, services, or business processes that generate wealth or social benefits, differing significantly from traditional innovation frameworks typically employed by researchers, policymakers, and analysts (Loosemore, 2015 ; OECD, 2010). Furthermore, the Oslo Manual (2018) specifies innovation as:

> "An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and has been made available to potential users or brought into use by the unit."

The definition from OECD & Eurostat (2018) involves three primary components: firstly, it explicitly incorporates new or enhanced "products" and "processes"; secondly, it highlights the element of significant differentiation; and finally, it emphasizes the introduction or adoption of these innovations within the market or by the organization itself.

According to OECD & Eurostat (2018), innovation should distinctly differ from existing organizational products or processes. Given the subjective nature of measuring innovation's novelty, additional contextual information regarding economic impact and significance could enhance innovation analysis and comparison (OECD & Eurostat, 2018).

This broader definition from OECD & Eurostat (2018) is supplemented by more focused definitions to streamline data collection across diverse firms and industries:

Product innovation:

> "A new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market."

Business process innovation:

> "A new or improved business process for one or more business functions that differs significantly from the firm's previous business processes and that has been brought into use in the firm."

This research recognizes the OECD & Eurostat (2018) definition as particularly suitable due to its comprehensive integration of key dimensions highlighted throughout the relevant literature.

1.2 Innovation classification

Categorizing innovation within construction is beneficial for stakeholders to facilitate informed decisions and actions (Delarue, Poirier, & Forgues, 2021). Tatum (1988) specifically noted that a well-structured classification system aids stakeholders in effectively comprehending innovations and their associated impacts. Given the inherent complexity of construction—characterized by diverse stakeholders, varied projects, and complex processes—numerous perspectives naturally emerge regarding innovation classification.

Indeed, no universal or singularly optimal classification system exists for construction innovations. Instead, the most suitable approach depends heavily on the specific goals and requirements of individuals or organizations attempting to comprehend or implement construction innovations. However, regardless of classification specifics, categorization fundamentally provides a structured basis for impact assessment.

Table 1.1 synthesizes multiple innovation dimensions, primarily adapted from Delarue et al. (2021) alongside contributions from other researchers, presenting a comprehensive view of innovation aspects within construction:

Table 1.1 Construction innovation aspects

#	Short term	Description	References *
1	Benefit, Impact, Zone of Influence, Output	The different effects of innovations include both tangible aspects (such as time and cost) and intangible aspects (such as competitive advantage).	[1], [2], [3], [4], [5], [6], [7], [8], [9]
2	Discipline, Construction category	Discipline pertains to the diverse branches of stakeholders engaged in the project.	[10], [11], [15]
3	Project phase, Asset life cycle	The project phase or asset lifecycle encompasses the various stages of the construction industry.	[2], [12], [13]
4	Degree of disruption and novelty	The extent of disruption caused by innovation.	[2], [8], [14], [15]
5	Type of innovation	"A **product** can be a good, a service, or a combination of both. "**Business processes** encompass all core activities undertaken by the firm to produce products, as well as any ancillary or supporting activities" (OECD & Eurostat, 2018).	[2], [3], [8], [10], [11], [12], [13], [15], [16], [17], [18], [19], [20], [21]
6	Location	The location of innovation may be physical or symbolic.	[10]
7	Source of Fund	How innovation expenditure is funded.	[1], [15]

* References mentioned in the table: [1] (J. N. Lim & Ofori, 2007), [2] (M. Noktehdan et al., 2015), [3] (B. Ozorhon, Oral, & Demirkesen, 2016), [4] (Froese & Rankin, 2009), [5] (Davidson, 2013), [6] (B. Ozorhon & Oral, 2017), [7] (Fang, Rasiah, & Klobas, 2016), [8] (OECD & Eurostat, 2018), [9] (Beliz Ozorhon, Abbott, & Aouad, 2014), [10] (Delarue et al., 2021), [11] (Tatum, 1988), [12] (Jung & Gibson, 1999), [13] (Froese & Rankin, 2009), [14] (Slaughter, 1998), [15] (OECD, 2005), [16] (Suliman, Rankin, & Caskey, 2023), [17] (Pries & Dorée, 2005), [18] (Reichstein, Salter, & Gann, 2005), [19] (Singh, 2014), [20] (Lopez & Yepes, 2020), [21] (Kuklina, Rogov, Erdinieva, & Urazov, 2021)

Slaughter's (1998) notable innovation categorization includes incremental (minor changes), radical (substantial changes), modular (changes within discrete components), architectural (changes involving component interactions), and system innovations (integrated changes). However, construction innovation predominantly tends toward incremental adjustments rather than radical transformations (Loosemore, 2015; Pries & Dorée, 2005).

Further dimensions addressing tangible aspects (e.g., cost, time) and intangible aspects (e.g., competitive advantage), alongside innovation types (product and process), have been proposed by Noktehdan et al. (2015). OECD & Eurostat (2018) further classifies innovations according to their objects, novelty, and impacts. As outlined in Table 1.2, innovations are primarily divided into product innovations (affecting organizational offerings) and business process innovations (affecting operational methods).

Table 1.2 Major types of innovation by object
Adapted from OECD & Eurostat (2018)

Short term	**Details and subcategories**
Product	**Goods**: tangible objects, knowledge-based products with transferable ownership via markets **Services**: intangible activities altering user conditions produced and consumed simultaneously.
Process	"Production of goods or services, Distribution and logistics, Marketing and sales, Information and communication systems, Administration and management, Product and business process development"

Delarue et al. (2021) introduced additional perspectives on innovation classification, such as construction discipline and innovation location. Similarly, Lim and Ofori (2007) and OECD (2005) examined the significance of funding sources for innovation, recognizing it as vital for policy evaluation. OECD (2005) specifically categorizes innovation funding into six distinct types: "1. Own funds, 2. Funds from related companies (subsidiary or associated companies), 3. Funds from other (non-financial) enterprises, 4. Funds from financial companies (bank loans, venture capital, etc.), 5. Funds from government (loans, grants, etc.), 6. Funds from supranational and international organizations (EU, etc.), and other sources."

Ultimately, the selection of an appropriate innovation classification depends on its intended analytical or practical use, often requiring integration of multiple categories to effectively achieve desired insights.

1.3 Innovation in the construction industry

The construction industry significantly influences global economic growth, reflecting societal progress and technological advancements across diverse fields (AlJaber, Martinez-Vazquez, & Baniotopoulos, 2024 ; Barata & Fontainha, 2017 ; OECD & Eurostat, 2018). Despite its vital economic role, the industry has continually grappled with performance issues that have persisted since the 20th century (Lauri Koskela, 2000). These persistent challenges highlight the industry's critical need to strategically integrate innovation into its practices (Loosemore & Richard, 2015 ; N. Wang, Xu, & Liu, 2023).

Innovation is broadly recognized as essential to productivity improvements across various sectors (OECD & Eurostat, 2018). Its significance is particularly emphasized by economists and industry leaders for enhancing efficiency, productivity, and safety, specifically within construction (Klosova & Kozlovská, 2020 ; N. Wang et al., 2023). Nevertheless, the construction industry exhibits considerable resistance to innovation compared to other sectors, primarily due to its entrenched reliance on traditional methodologies and a generally conservative culture resistant to change (Blayse & Manley, 2004 ; Chowdhury et al., 2019).

In response to economic growth, intensified market competition, and rapid industry evolution, construction firms are increasingly compelled to enhance efficiency and productivity to meet escalating client expectations (Habibi et al., 2019 ; Lechhab, Iordanova, & Forgues, 2021). To effectively address these pressures, the industry should strategically adopt innovative practices, overcoming significant barriers such as industry fragmentation and deeply entrenched conventional methods (Annunen & Haapasalo, 2023 ; Guimarães, 2024).

Ensuring long-term organizational stability also heavily depends on successful innovation implementation (Al-Hakim & Jin, 2010). In construction specifically, effective innovation management necessitates a comprehensive understanding of innovation processes, the development of robust innovation capabilities, and precise measurement of innovation outcomes (Gambatese & Hallowell, 2011). In this context, Quebec's public project owners, actively participating in a collective digital transformation initiative, provide an ideal setting for exploring emerging performance metrics and assessing innovation impacts in construction.

1.4 The role of public project owners in driving innovation

Public project owners play a crucial role in shaping the direction of innovation within the construction industry (Gambatese & Hallowell, 2011). Clients, especially public project owners, are consistently identified as primary demand-side drivers of innovation (Bossink, 2004). Systematic reviews show that when owners specify new performance requirements, adjust procurement models, or mandate process/technology changes, they trigger innovation throughout supply chains. Public owners are particularly influential because they commission large, repeat projects and can diffuse practices through frameworks and standards (Bossink, 2004). This demand-side leverage, coupled with policy mandates, explains why client requirements frequently appear among the strongest predictors of innovation adoption in the sector.

Digital transformation makes the owner’s role even more central. Empirical studies on BIM adoption emphasize that client requirements and governance are decisive: when owners require models for coordination, handover, or asset management, suppliers invest in digital capabilities and data quality (Gambatese & Hallowell, 2011 ; Kivits & Furneaux, 2013). Public owners also shape what gets measured, for example, by asking for predictable cost/time, robust change control, and data suitable for whole-life asset decisions.

In essence, while PPOs recognize the importance of innovation, their capacity to measure and operationalize its impact remains limited. The key issue is not the absence of KPIs but the lack of coherent systems for applying and interpreting them consistently across projects. Addressing this implementation gap requires an owner-driven framework that integrates performance measurement with the realities of data governance, organizational culture, and project delivery. By situating PPOs at the core of KPI identification and validation, this research contributes to developing actionable indicators that enable public owners to implement innovation measurement effectively.

1.5 Performance measurement

Key performance indicators (KPIs) have long been acknowledged as essential tools for ensuring successful construction outcomes. Bassioni et al. (2004) emphasize that systematic and consistent performance measurement has become increasingly important, driven by the construction industry's continuous improvement efforts. Within a competitive, globalized market context, KPIs provide structured methods for benchmarking progress, identifying underperformance areas, and facilitating strategic decision-making (Sibiya, Aigbavboa, & Thwala, 2015). Beyond merely tracking schedules and budgets, KPIs support the alignment of project goals and resource coordination among diverse stakeholders (Habibi et al., 2019). Through objective performance assessment, KPIs enable early identification of potential issues, facilitating prompt remedial actions to enhance the overall project success likelihood.

Historically, project success was narrowly confined to the "iron triangle" parameters of cost, time, and quality (Hussain, Hasmori, Balasbaneh, Khan, & Sohu, 2025). However, the contemporary view of project success encompasses broader dimensions such as safety, scope management, innovation, and sustainability, underscoring construction's complex nature (Chan & Chan, 2004 ; Cox et al., 2003 ; Rankin, Fayek, Meade, Haas, & Manseau, 2008).

Building on foundational research by Poirier et al. (2015) and Zhang et al. (2022), we have compiled and expanded a comprehensive set of KPIs, systematically grouped into nine categories as illustrated in Table 1.3: Cost, Time, Productivity, Quality, Safety, Scope, Innovation, Sustainability, and Risk. This structured categorization captures both traditional indicators, such as cost and time predictability, and progressive metrics like energy consumption and carbon footprint, addressing the immediate and long-term impacts of construction activities, outputs, and outcomes.

Table 1.3 List of metrics and KPIs

#	Metric	Unit	Reference*
1	***Cost***		
1.1	Cost predictability (Design/Construction)	%	[1], [2], [3], [4], [5], [6], [7], [8]
1.2	Cost per unit (estimated & actual)	$/unit	[2], [9]
1.3	Cost in use (operating and maintenance)	%	[2], [10]
	Time		
2.1	Time predictability (Design/Construction)	%	[1], [2], [3], [5], [6], [7], [8]
2.2	Time per unit	hr/unit	[2], [6]
3	***Productivity***		
3.1	Labor productivity	$/unit	[2], [3], [4], [6], [12], [13], [14], [15], [16],
3.2	Labor productivity	unit/hour	
3.3	Decision-making Latency	Days	[17]
4	***Quality***		
4.1	Stakeholder satisfaction	Questionnaire with Likert scale	[1], [2], [4], [7], [8], [18], [15], [19]
4.2	Quality issues (punch-list)	# (items)	[2], [4], [15], [19], [20], [21], [6], [7]
4.3	Cost for defects-warranty	%	[1], [4], [17], [20], [21], [22]
4.4	Time for defects-warranty	%	[2], [20], [21], [22]
4.5	Rework Rate	%	[7], [8], [19], [14], [20], [21], [22]
5	***Safety***		
5.1	Reportable incidents	qty/100 000hr	[1], [2], [4], [6], [15]
5.2	Lost Time	qty/100 000hr	[1], [2], [4], [6], [14]
6	***Scope***		
6.1	Change order (Cost) - client initiated	%	[2], [4], [18]
6.2	Change order (Cost) - contractor initiated	%	
6.3	Change order (Time) - client initiated	%	
6.4	Change order (Time) - contractor initiated	%	
6.5	Change orders - client-initiated	# (Count)	
6.6	Change orders - contractor-initiated	# (Count)	
6.7	Claim numbers	# (Count)	[23]
6.8	Claim amount	$	[23]
6.9	Requests for information (RFI)	count/month or count/$M	[4], [19]
7	***Innovation***		
7.1	Procurement type	Questionnaire with Likert scale	[2], [15]
7.2	Management innovation	Questionnaire with Likert scale	[1], [2], [15]
7.3	Lean Implementation Index	Score or index	[13], [4], [16]

Table 1.3 List of metrics and KPIs (continued)

#	Metric	Unit	Reference*
7.4	BIM Adoption Level	Score or BIM Level	[3], [24], [25], [26], [27]
7.5	Technological innovation	%	[3], [15], [28]
8	***Sustainability***		
8.1	Certification	(checklist or rating)	[2], [15]
8.2	Material Consumption	(ratio of actual/planned)	[5], [29], [30]
8.3	Waste generation	(tons or % vs. target)	[29], [30], [31]
8.4	Carbon Footprint	Tons	[30], [32], [33]
8.5	Waste Recycling Rate	%	[30], [34], [35]
8.6	Energy Consumption	kWh	[29], [30], [31], [36]
8.7	Air Pollution	mg/m^3 or $\mu g/m^3$ (concentration)	[29], [31]
8.8	Community effect	Questionnaire with Likert scale	[31]
8.9	Water Pollution	mg/L or kg of pollutant	[5], [29], [31]
9	***Risk***		
9.1	Number of risks quantified	# (Count)	[37], [38], [39], [40]
9.2	Scope of risks (Risk-exposure score)	Severity × Probability (e.g., $ or index)	
9.3	Cost of risk mitigation	$	
9.4	Risk materialization	$	

*References mentioned in the table: [1] (John Egan, 1998), [2] (Rankin et al., 2008), [3] (Coates et al., 2010), [4] (Cox et al., 2003), [5] (Kamali, Hewage, & Milani, 2018) , [6] (Hwang, Fang Tan, & Sathish, 2013), [7] (Yeung, Chan, & Chan, 2008), [8] (Radujković, Vukomanović, & Dunović, 2010), [9] (Hwang et al., 2013), [10] (Gluch & Baumann, 2004), [12] (Khanzode, Fischer, & Reed, 2008), [13] (Forbes & Ahmed, 2010), [14] (Suermann & Issa, 2009), [15] (Azhar, 2011), [16] (Mossman, 2009), [17] (Kunz & Fischer, 2012), [18] (Barlish & Sullivan, 2012), [19] (Kuprenas & Mock, 2012), [20] (Palaneeswaran, Ramanathan, & Tam, 2007), [21] (Love, 2002), [22] (Love, Edwards, & Smith, 2005), [23] (El Asmar, Hanna, & Loh, 2013), [24] (Haryanti, Rakhmawati, & Subriadi, 2023), [25] (Gu & London, 2010), [26] (Kamari, Makowski, & Kirkegaard, 2019), [27] (Z. Wang & Ma, 2021), [28] (Hosseini, Chileshe, Zuo, & Baroudi, 2015), [29] (Pan, Linner, Pan, Cheng, & Bock, 2018), [30] (Zhong & Wu, 2015), [31] (Shen, Wu, & Zhang, 2011), [32] (X. Zhang &

Wang, 2015), [33] (Peng, 2016), [34] (Lu, Chen, Ho, & Wang, 2016), [35] (Esa, Halog, & Rigamonti, 2017), [36] (Zabalza Bribián, Valero Capilla, & Aranda Usón, 2011), [37] (Hussain et al., 2025), [38] (Akintoye & MacLeod, 1997), [39] (Jaymin-Sanchaniya, Thomson, Kundzina, & Geipele, 2024), [40] (Nagarajan & Ganapathi, 2023)

Table-A I-1 and Table-A I-2 (see Appendix I) provide additional details for each KPI, including their type, calculation formulas (where applicable), and illustrative examples. In these complementary tables, KPIs are classified into two primary types, as depicted in Figure 1.1; quantitative and qualitative (Abdirad, 2017 ; Barlish & Sullivan, 2012 ; Cox et al., 2003 ; Lechhab et al., 2021).

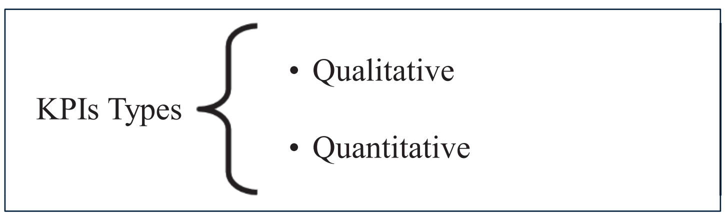

Figure 1.1 KPI types: quantitative and qualitative

A thorough examination of recent industry trends indicates a notable shift within the construction sector from predominantly focusing on short-term performance metrics such as immediate cost management toward a broader, more comprehensive approach targeting long-term objectives (Habibi et al., 2019 ; Tabatabaee et al., in press). Liu et al. (Liu, Chan, Chan, Darko, & Oppong, 2024), for example, recently identified five critical KPIs for construction, highlighting factors such as safety, technological advancement, and effective communication. These indicators represent a significant departure from traditional performance measurements, which have historically focused on cost control. This transition emphasizes the growing relevance of broader dimensions, including stakeholder collaboration, innovative practices, and the integration of new technologies, as key determinants of contemporary project success.

Furthermore, as the industry increasingly adopts a forward-looking perspective, it becomes clear that assessing project performance exclusively through short-term indicators is insufficient. There is rising recognition of the necessity to consider long-term effects, notably encompassing environmental sustainability, social accountability, and sustained operational effectiveness. In response to these evolving demands, our expanded KPI framework now incorporates diverse, long-term-oriented metrics such as carbon footprint and community impact. These indicators enable a deeper and more meaningful evaluation of project outcomes, extending beyond immediate results to capture the broader and enduring influences of construction activities.

1.6 Impact assessment

Impact assessment plays a pivotal role in evaluation research by clearly highlighting areas of success and pinpointing opportunities for improvement (O'Flynn, 2010 ; Rossi, Lipsey, & Freeman, 2004 ; Sivesind, Simsa, Rauscher, Schober, & Moder, 2014). Measuring innovation in the construction sector, however, poses considerable challenges due to the inherent complexity associated with its project-oriented nature and extensive stakeholder interactions (Abbott, Ozorhon, Aouad, & Powell, 2010 ; Nesta, 2006). Despite these challenges, innovation significantly enhances living standards and generates wide-ranging effects at multiple societal and economic levels (OECD & Eurostat, 2018). Consequently, measuring innovation assists decision-makers in comprehending socio-economic changes, evaluating innovation's contribution to societal goals, and assessing policy effectiveness (OECD & Eurostat, 2018).

Specific features unique to the construction industry, including site-specific operations and temporary supply chain structures, further complicate the perception and measurement of innovation (N. Wang et al., 2023). Nonetheless, the Oslo Manual emphasizes the necessity of measuring innovation comprehensively, addressing various analytical scales from individual products to national impacts (OECD & Eurostat, 2018). Although innovation measurement typically focuses on construction firms, innovation manifests throughout the lifecycle of construction activities, encompassing design, construction, and ongoing maintenance phases (Abbott et al., 2010). Furthermore, much innovation occurs at the project level, often remaining

hidden from conventional measures, indicating that existing methodologies fail to fully capture innovation's true scope (Abbott et al., 2010 ; Nesta, 2006).
A review of existing literature indicates recognition of the importance of measuring innovation within construction; however, inconsistencies persist regarding the terminologies employed, leading to varied interpretations (Tabatabaee et al., in press). Some articles describe this process as the evaluation or analysis of innovation outcomes, while others utilize terms like measurement, assessment, or impact evaluation interchangeably, despite subtle distinctions among them. Such inconsistencies highlight the necessity for deeper investigation into their specific meanings and contexts, demanding precise definitions and careful examination of their usage. (Tabatabaee et al., in press)

Clarifying these terms is fundamental to understanding impact measurement. Thus, this thesis refers primarily to the "Glossary of Key Terms in Evaluation and Results-Based Management for Sustainable Development," an authoritative source published by the OECD (2023). Where necessary, additional terms not defined in this glossary were supplemented with definitions from complementary academic sources.

Within the literature, definitions of "impact" vary. For example, Abbott et al. (2010) regard outcomes as including outputs, and impacts as encompassing broader benefits. In contrast, Ozorhon (2009) describes impacts as subsequent occurrences following outputs. Additionally, Clark et al. (Clark, Rosenzweig, Long, & Olsen, 2004) introduce the concept of deadweight, defining impact specifically as " the portion of the total outcome that occurred as a result of the activity of the venture, above and beyond what would have happened anyway". This perspective acknowledges direct project outcomes and explicitly differentiates them from outcomes that would naturally emerge without the intervention (Sivesind et al., 2014). The OECD (2023) definition aligns closely with this nuanced perspective, emphasizing all effects, positive or negative, intended or unintended, that result or are expected to result from activities, explicitly noting their potential for enduring consequences (Stern, 2015).

To effectively measure innovation impacts within projects, organizations, or industry sectors, the impact value chain model developed by Schober and Rauscher (Schober & Rauscher, 2014 ; Simsa, Rauscher, Schober, & Moder, 2014) is particularly suitable. Originally created for contexts outside construction, this approach, illustrated clearly in Figure 1.2, focuses explicitly on differentiating between the assessment of activities and the outcomes derived from these activities (Schober & Rauscher, 2014 ; Simsa et al., 2014 ; O'Flynn, 2010). Within impact measurement, it is essential not only to identify and quantify outcomes but also to attribute value to these outcomes by incorporating the concept of deadweight (Schober & Rauscher, 2014 ; Simsa et al., 2014). Ozorhon (2009) and Abbott et al. (2010) also integrate deadweight adjustments into outcome assessment, enhancing the clarity and accuracy of impact measurement.

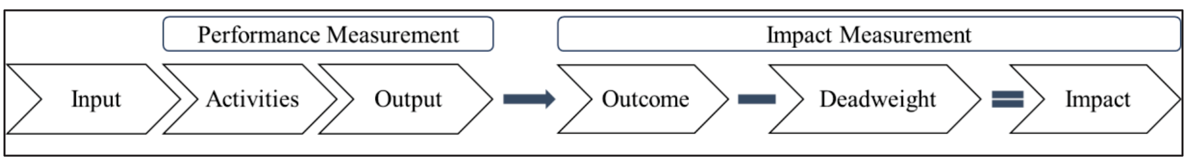

Figure 1.2 Impact value chain

Adapted from Schober & Rauscher (2014) and Simsa et al. (2014)

Over recent decades, the construction industry has increasingly integrated sustainable construction practices, systematically addressing economic, environmental, and social considerations (Kamali & Hewage, 2015). Recognizing that traditional performance metrics alone may inadequately reflect broader impacts, researchers emphasize incorporating additional dimensions, such as cultural and psychological impacts (Simsa et al., 2014 ; Stern, 2015). By evaluating impacts across short-, medium-, and long-term horizons, as well as at different scales - micro-level (individual projects), meso-level (organizational), and macro-level (societal) - impact assessment offers a more comprehensive view of how construction activities influence immediate stakeholders and wider societal and environmental contexts.

One influential approach reflecting this broader conceptualization is the Triple Bottom Line (TBL), which prompts organizations to assess performance across economic, social, and environmental domains (M. Lim, 2014). Often succinctly described as "people, planet, and profits," TBL extends beyond conventional financial measures to embrace broader organizational responsibilities (Slaper, Hall, & others, 2011). Initially popularized by Elkington and Rowlands (1999), TBL has become a prominent framework guiding sustainable development initiatives (Said & Berger, 2014). Despite widespread adoption in various sectors, the construction industry has shown limited integration of TBL principles (Goh, Chong, Jack, & Mohd Faris, 2020 ; Zainul Abidin, 2009), partly due to the absence of standardized methodologies for comprehensively assessing social, environmental, and economic factors (Slaper et al., 2011).

Nevertheless, construction remains fundamentally critical to the global economy, society, and environment (Agenda, 2016). Economically, the industry generates nearly $10 trillion annually, constituting approximately 6% of global GDP, and employs more than 100 million individuals worldwide (Agenda, 2016). Environmentally, it significantly influences global resource consumption, accounting for half of worldwide steel use and nearly 40% of the solid waste generated in the United States, thus substantially contributing to carbon emissions (Agenda, 2016 ; Illankoon, Tam, & Le, 2017 ; Khoshnava, Rostami, Valipour, Ismail, & Rahmat, 2018). Scholars have categorized TBL dimensions explicitly into economic indicators (such as cost-effectiveness and economic viability), environmental measures (pollution control, resource efficiency), and social criteria (equity, stakeholder welfare) (Dobrovolskienė & Tamošiūnienė, 2016 ; Zainul Abidin, 2009). Despite TBL's strengths, Pawłowski (2008) identifies additional considerations - moral, legal, and technical, that TBL alone may not adequately encompass (Illankoon, Tam, & Le, 2017).

Ultimately, viewing construction activities through the lens of comprehensive impact assessment, grounded in TBL principles, enables stakeholders to transcend short-term performance assessments, systematically addressing broader, lasting consequences associated with built environments (Habibi et al., 2019). This expanded approach emphasizes the critical importance of evaluating outcomes across economic, social, environmental, moral, legal, and technical dimensions throughout all phases of a construction project's lifecycle. Hence, this research proposes a holistic framework that incorporates these various impact dimensions, providing a structured path for practitioners and academics to align innovative construction practices with multi-dimensional sustainability objectives (Tabatabaee et al., in press).

1.7 Research gap

The literature reviewed thus far underscores the construction industry's significant economic role, yet it also highlights persistent challenges that have hindered the sector's performance and limited its capacity to effectively integrate innovation (Lauri Koskela, 2000 ; Loosemore & Richard, 2015 ; N. Wang et al., 2023). While innovation is widely recognized as critical for improving productivity, efficiency, and long-term sustainability in construction (Klosova & Kozlovská, 2020 ; OECD & Eurostat, 2018), the sector remains notably conservative and slow to adopt new methodologies due to entrenched traditional practices and fragmented industry structures (Blayse & Manley, 2004 ; Chowdhury et al., 2019 ; Guimarães, 2024).

The existing body of research reveals a predominant reliance on conventional KPIs, primarily oriented around immediate project outcomes such as cost control, scheduling, and quality measures (Bassioni et al., 2004 ; Cox et al., 2003 ; Hussain et al., 2025). However, as current trends indicate, the narrow focus on these short-term performance metrics inadequately captures the broader, transformative impacts brought about by innovations, particularly those affecting sustainability, stakeholder coordination, technological advancement, and social value creation (Habibi et al., 2019 ; Liu et al., 2024 ; Tabatabaee et al., in press, 2025)

Moreover, the review emphasizes that existing frameworks for impact assessment, such as those grounded in the TBL, while insightful, have not been systematically integrated within the construction context due to their complexity and lack of standardization (Goh et al., 2020 ; Slaper et al., 2011). There remains a considerable gap between theoretical recognition of innovation's importance and the availability of practical, measurable indicators capable of capturing both immediate outputs and long-term socio-economic and environmental impacts (Abbott et al., 2010 ; Beliz Ozorhon, 2009 ; Schober & Rauscher, 2014 ; Simsa et al., 2014).

Despite increasing calls for standardized, impact-oriented KPIs (Alvarez & Jordan, 2024 ; Arshi et al., 2021; Nappi & Kelly, 2022), there is still no widely accepted, comprehensive framework tailored specifically to the unique needs of the construction industry. Existing measures often fail to differentiate clearly between short-term performance outcomes and long-term impacts, such as environmental stewardship, community acceptance, organizational learning, and strategic innovation capabilities, thus leaving significant blind spots in performance assessment and strategic decision-making(Kucukvar & Tatari, 2013 ; Wu et al., 2021).

This research gap becomes particularly evident in Québec's construction sector, where public project owners, despite participating in digital transformation initiatives, lack a coherent and robust KPI framework capable of aligning short-term project-level metrics with long-term strategic and societal outcomes. Consequently, there is a pressing need to develop and validate a life-cycle-oriented KPI framework that systematically integrates traditional performance indicators with broader, innovation-specific metrics. Such a framework would not only provide consistent terminology and measurement standards but would also enable more comprehensive evaluation and evidence-based decision-making regarding innovation investments across construction projects.

In response to this identified gap, the current research aims to clearly define and operationalize key concepts of innovation impact assessment within construction projects. Specifically, it seeks to develop an integrated KPI framework capable of capturing immediate outcomes alongside extended impacts, thus offering a holistic assessment tool that supports both short-term project efficiency and long-term strategic objectives for PPOs.

CHAPTER 2

RESEARCH METHODOLOGY

2.1 Design science research methodology

This research employs the Design Science Research (DSR) methodology, recognized for systematically addressing complex real-world problems through the development and evaluation of innovative artifacts (Hevner, March, Park, & Ram, 2004 ; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Given its dual emphasis on theoretical foundation and practical applicability, DSR is particularly appropriate for construction management research, where solutions must be both academically rigorous and relevant to practitioners.

The primary artifact developed in this study is a prioritized and validated list of KPIs for assessing the impacts of innovation in construction projects commissioned by public project owners in Québec. This research follows the six-stage DSR process outlined by Peffers et al. (2007, p.11), illustrated in Figure 2.1:

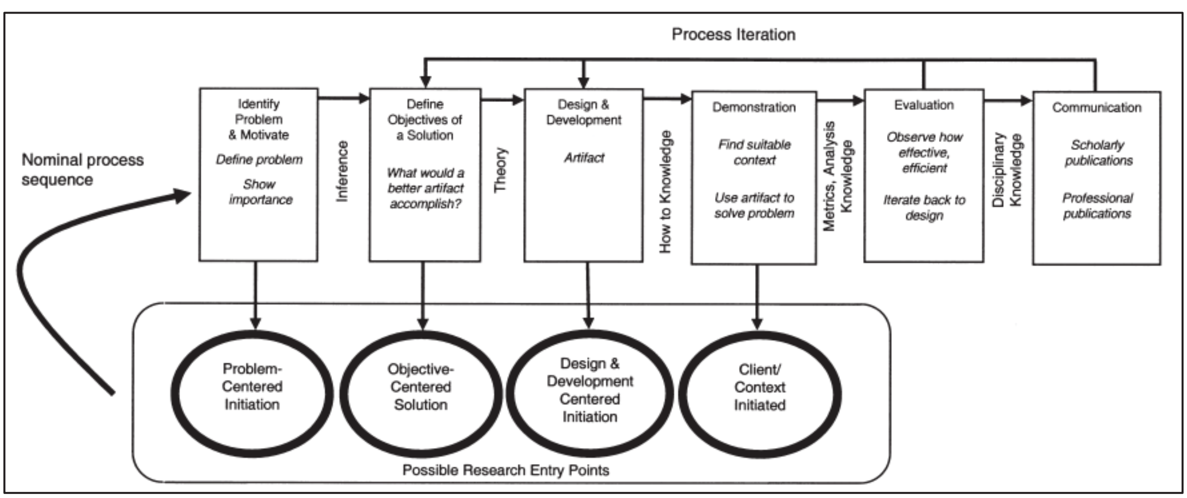

Figure 2.1 Design Science Research (DSR) methodology process
Taken from Peffers et al. (2007, p.11)

The specific phases carried out are as follows:

2.1.1 Phase 1: problem identification and motivation

The initial phase involved clearly identifying practical and academic gaps regarding performance measurement, specifically the limited capability of existing KPIs to capture long-term impacts of innovation beyond traditional short-term outcomes, as detailed in Chapter 1.

2.1.2 Phase 2: defining objectives for the solution

Guided by the identified research gaps, three explicit research objectives were formulated:

1. Clarify essential concepts: performance, impact, and innovation.
2. Critically analyze existing performance measurement approaches in construction.
3. Identify, prioritize, and validate KPIs that effectively link short-term project outcomes with broader, long-term innovation impacts.

2.1.3 Phase 3: design and development (artifact creation)

The design and development of the KPI artifact encompassed two primary research activities:

2.1.3.1 Systematic Literature Review (SLR)

A rigorous systematic literature review (SLR) was conducted following the established guidelines outlined by Kitchenham and Charters (2007). To fulfill the first objective of the study, clarifying key concepts, an SLR was conducted. The SLR serves as a rigorous and transparent approach for synthesizing prior research, enabling the identification of gaps and informing the development of a conceptual framework for innovation performance measurement in construction.

Following the PRISMA 2020 guidelines (Page et al., 2021), the review focused on peer-reviewed literature published in English between 2003 and 2023. The Scopus database was used for its comprehensive coverage of engineering and social science publications. The search query executed was as follows:

TITLE-ABS-KEY ((impact* OR measur* OR assess* OR evaluat* OR analys*) AND ("construction innovation*" OR "innovation in construction*")) AND PUBYEAR > 1800 AND PUBYEAR < 2024 AND PUBYEAR > 2002 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE , "English"))

This search yielded an initial set of 414 records. After excluding 33 records published before 2003 and 18 non-English articles, 363 records proceeded to the screening phase. A detailed review of titles and abstracts, guided by inclusion criteria focused on definitions, classification, and impact measurement of construction innovation, led to the exclusion of 267 records. As a result, 96 articles were selected for full-text review and detailed analysis. A PRISMA 2020 flow diagram summarizing the review process is presented in Figure 2.2.

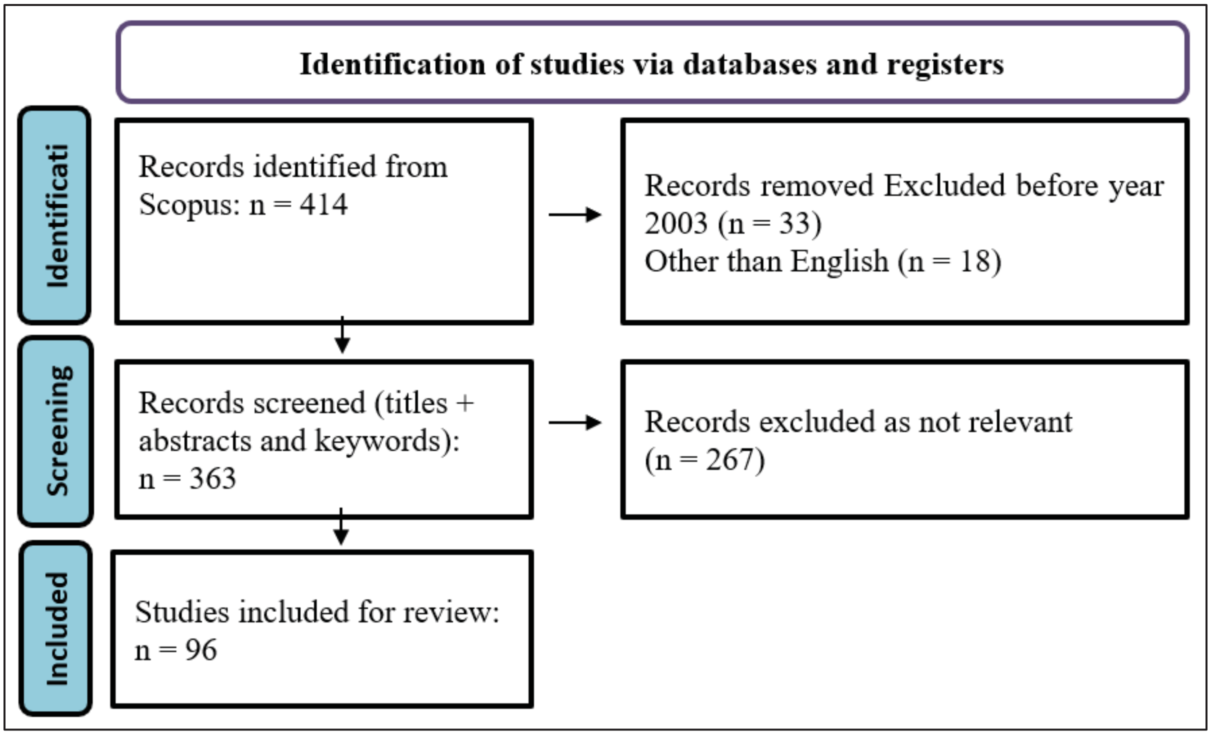

Figure 2.2 PRISMA 2020 flow diagram template for systematic reviews
Adapted from Page et al. (2021)

To further enrich the dataset and capture influential but possibly uncited works, the snowballing technique (Wohlin, 2014) was applied to the references of the selected articles. This dual approach ensured both breadth and depth, providing a robust foundation for the conceptual model and preliminary KPI list proposed in this thesis.

The findings of the systematic review were presented and published as a conference article: "Assessing the Impact of Innovation in Construction: A Literature Review" (Tabatabaee et al., 2025)

2.1.3.2 Qualitative empirical research (semi-structured interviews)

Following the SLR, qualitative data were gathered through semi-structured interviews with five major public project owners in Québec, selected purposively for their active roles in regional infrastructure and digital transformation initiatives. To facilitate informed and productive discussions, interviewees were provided with a questionnaire detailing all interview questions (see Appendix II) prior to their interviews.

Each interview, approximately 60 minutes in duration, involved senior project managers and technical experts with direct influence over KPI selection and innovation management. Across the participating organizations, the number and profile of interviewees varied according to the internal structure of each PPO: PPO1 contributed two participants (one from higher management and one technical expert); PPO2 contributed three participants, all from management; PPO3 contributed one management-level participant; PPO4 contributed one senior manager; and PPO5 contributed one senior manager. Topics covered included:

- KPIs in use and how they are applied
- Underlying rationale for KPI selection
- Approaches to data collection and analysis
- Identification of particularly critical KPIs
- Interest in additional or missing metrics
- Barriers or difficulties in collecting and interpreting KPI data
- The influence of KPI findings on decision-making
- Emerging methods for measuring initiative impacts beyond immediate outputs

All interviews were recorded, transcribed, and analyzed using an iterative thematic coding approach following Miles and Huberman’s (Miles, Huberman, & Saldana, 2013) qualitative data analysis methodology. The analysis began with initial analytical categories, including KPI usage, challenges, and measurement practices. These preliminary categories were systematically reviewed and refined through continuous comparison as new insights emerged from the data. During each iteration, themes were clarified, expanded, or merged, allowing a deeper understanding of interview content, enhancing analytic rigor, and ensuring that emergent patterns genuinely reflected participant perspectives and organizational practices.

In alignment with Miles and Huberman's principles, data reduction and data display techniques were applied, where key excerpts and themes were visually organized into matrices and summary tables, enabling clearer identification of relationships and distinctions among themes. This structured yet flexible approach provided robust insight into the varying levels of maturity, implementation challenges, and effectiveness of KPIs across different organizational contexts. It also ensured validity and reliability through rigorous cross-validation of codes, regular peer debriefing, and careful documentation of analytic decisions.

The comprehensive and systematic findings derived from this thematic analysis process were then synthesized and documented (Appendix III). These were subsequently presented and validated through dissemination in a second presented conference paper, “Developing KPIs and measurement processes to assess the impact of innovation in the construction industry: current practices and challenges” (Tabatabaee et al., in press), further enriching the credibility and transferability of the study’s conclusions by facilitating scholarly dialogue and peer review.

2.1.4 Phase 4: demonstration and evaluation

Building on interview findings, the next crucial step, exclusive to this thesis by now, was conducting stakeholder-driven workshops with the previously interviewed public project owners to prioritize and validate the KPIs identified through the literature and interviews.

Participants from 5 PPOs engaged in interactive exercises using a 2D Usefulness-Measurability Matrix, Figure 2.3 is an example to map each KPI from Table 1.3, based on two key dimensions:

- Horizontal Axis: Usefulness ("Highly Useless" to "Highly Useful")
- Vertical Axis: Measurability ("Extremely Hard" to "Extremely Easy")

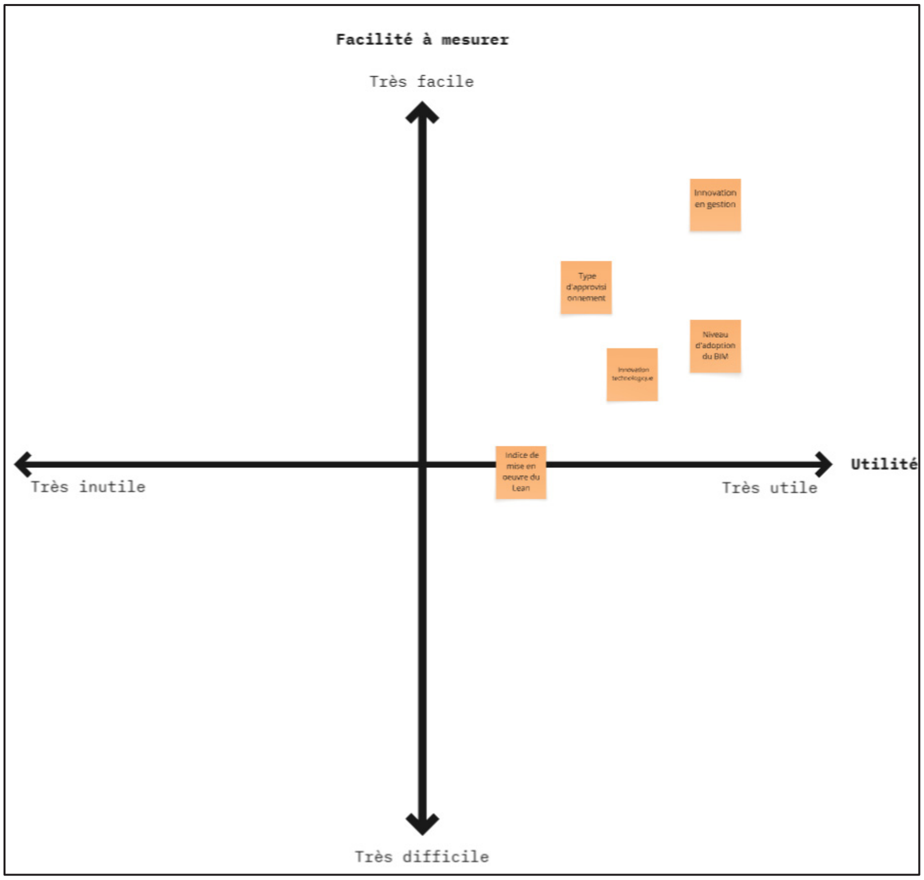

Figure 2.3 KPI Usefulness-Measurability matrix example

The participants positioned KPIs on the Usefulness–Measurability matrix, facilitating transparent discussion about the trade-offs between practical feasibility and strategic importance. Once the visual placements were agreed upon during the workshop, each KPI's position was translated into numerical values to enable systematic comparison and prioritization. The two axes of the matrix were discretized into a scale ranging from −10 to +10, where the magnitude represented the KPI's distance from the nearest axis, and the sign indicated direction (positive to the right or above each axis, negative to the left or below). This transformation ensured that the qualitative deliberations of participants could be converted into consistent, analyzable scores for each KPI.

These workshops were conducted individually with each public project owner to respect organizational context and ensure that discussions reflected each entity's internal priorities and constraints. In nearly all cases, PPOs requested additional time following the workshop to consult their internal teams before finalizing their positions on the matrix. As a result, the outputs were not concluded during the workshop itself; instead, participants revisited the matrix internally, obtained feedback and consensus from their broader team, and returned refined or confirmed results to us, typically within one week to one month. This multi-stage validation process strengthened the reliability of the prioritization by ensuring that KPI scoring represented not only the views of the workshop participants but also the collective professional judgement within each organization.

Following the workshops, a post-workshop validation questionnaire (Appendix IV) was distributed to the same group of six Québec PPOs to further confirm the priorities identified during the sessions. The 17 shortlisted KPIs from the workshops were rated on a 1–5 scale (1 = low priority; 5 = top priority) according to their relevance for performance monitoring and innovation impact assessment. The questionnaire also included an open-ended question inviting participants to suggest additional indicators or contextual factors not captured in the list. Seven responses were collected in total from all 6 PPOs, providing both numerical validation and qualitative feedback.

This extended validation phase directly addresses the third research objective: to prioritize and validate KPIs that bridge short-term project outcomes and broader innovation impacts, ensuring that the final KPI framework is practically applicable, stakeholder-aligned, and endorsed by Québec's public project owners.

2.1.5 Phase 5: communication of results

Research findings were communicated academically through two peer-reviewed conference papers:

- “Assessing the Impact of Innovation in Construction: A Literature Review” (Tabatabaee et al., 2025)
- “Developing KPIs and Measurement Processes to Assess the Impact of Innovation in the Construction Industry: Current Practices and Challenges” (Tabatabaee et al., in press)

The full, detailed validation workshops and the final prioritized KPI set are first presented and extensively documented within this thesis.

2.1.6 Methodological limitations and summary

Several limitations should be noted:

- The small number of interviewees (five organizations) potentially limits generalizability.
- Findings specifically reflect the public-sector context in Québec, possibly constraining broader applicability.
- Workshops relied on subjective perceptions and consensus-building, introducing potential interpretative biases.
- Practical, longitudinal validation of prioritized KPIs in ongoing projects remains necessary for further reliability.

By employing DSR methodology, incorporating a rigorous literature review, in-depth stakeholder interviews, and structured workshops, this thesis systematically addresses the critical research gap concerning the measurement and prioritization of innovation impact KPIs in construction projects. The final artifact, a prioritized and validated KPI framework, integrates theoretical insights and empirical validation, providing construction practitioners and researchers with a robust, practical tool for strategic decision-making.

CHAPTER 3

RESULTS: KPI IDENTIFICATION, MEASUREMENT STRATEGIES, AND PRIORITIZATION

This chapter presents the empirical findings derived from the qualitative research conducted with PPOs in Québec. It consolidates results from the semi-structured interviews, prioritization workshops, and the post-workshop validation questionnaire, offering a comprehensive picture of how innovation performance is currently understood, measured, and prioritized in public construction projects. The interview results presented here have been previously analyzed and presented in an academic conference paper titled “Developing KPIs and Measurement Processes to Assess the Impact of Innovation in the Construction Industry: Current Practices and Challenges.” (Tabatabaee et al., in press). These findings reflect public project owners' practices, perceptions, and experiences in KPI selection, measurement, and utilization in Québec. The questionnaire and interview protocols used for data collection were reviewed and approved by the Research Ethics Committee of École de technologie supérieure (ÉTS).

The results are organized around two major analytical dimensions:

1) KPI Identification and Measurement Strategies (What, How, and Why) – presenting how public project owners currently define, collect, and interpret performance indicators across various project stages. This section synthesizes the key themes derived from the coded interview data, including existing measurement frameworks, reporting processes, and persistent data management and organizational challenges.

2) KPI Prioritization and Validation – presenting the prioritization results from stakeholder-driven workshops and the follow-up validation questionnaire. These results highlight how PPOs evaluated the usefulness and measurability of 42 candidate KPIs grouped into nine dimensions: Cost, Time, Productivity, Quality, Safety, Scope, Innovation, Sustainability, and Risk. Using the two-axis Usefulness–Measurability matrix and the interquartile-range weighting method, a ranked and validated list of 17 priority KPIs was produced.

3.1 KPI identification and measurement strategies (What, How, and Why)

Following transcription, interview responses were systematically coded into eight thematic categories derived directly from the semi-structured interview questionnaire (Appendix II). These categories were developed to specifically address three core research questions: (1) *What is being measured?*, (2) *How is it being measured?*, and (3) *Why is it being measured?* The analysis covered both current practices and future measurement plans. Table 3.1 summarizes these thematic categories.

Table 3.1 Eight key theme categories

No.	Thematic category	Respond to the question	Timeframe
1	KPIs in use and how they are applied	**What** is being measured?	Current practice
2	Why each KPI is chosen.	**How** is it being measured?	Current practice
3	Data collection and analysis methods.		Current practice
4	KPIs seen as most critical.		Current practice
5	Challenges in gathering or interpreting KPI data.		Current practice
6	How KPI results influence decisions.	**Why** is it being measured?	Current practice
7	Wanted or missing metrics.	**What** is being measured?	Future plan
8	Measurement of initiative impacts	**Why** is it being measured?	Future plan

Table-A III- 1 through Table-A III- 8, Appendix III, present the initial, interview-by-interview outputs of our thematic coding process. They trace how individual responses were mapped to the eight analytic themes introduced above. The consolidated tables that follow integrate these codes across all PPOs and serve as the basis for the result explanations in the subsequent sections. After coding each interview individually, all entries were merged into consolidated tables to enable clearer, cross-owner comparisons. During this step, semantically equivalent terms used by different organizations were grouped under a single heading, eliminating redundancy and highlighting true variations. For instance, one owner referred to "Cost KPI" while another spoke of "Financial Metrics"; because both address cost management, they are combined in the consolidated table under "Cost / Financial." The same harmonization was applied to other domains. In the pages that follow, each consolidated table, Table 3.2 to Table 3.8, is presented, accompanied by a brief narrative highlighting the most significant patterns and explaining how these findings inform the broader analysis in this chapter. Throughout these tables, a checkmark indicates that a PPO monitors or applies the corresponding KPI theme, while a dash (–) denotes that the KPI was not explicitly referenced.

3.1.1 Key performance indicators used

Table 3.2 provides a consolidated overview of the main KPIs used by PPOs categories identified in the qualitative analysis.

Table 3.2 Consolidated KPIs used by PPOs

KPI / Theme	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Cost / Financial	✓	✓	✓	✓	✓	Includes budget gaps, cost compliance, earned value (CPI/SPI), and disbursement tracking. All PPOs emphasize cost.
Schedule / Time	✓	✓	✓	✓	✓	All PPOs tracked (often with colour-coded “time control,” schedule gap/ compliance).
Scope	✓	✓	✓	–	–	Focused on planned vs. actual scope (e.g., “scope gap,” change notices). Not explicitly mentioned by PPO 4 or 5.
Risk Management	✓	✓	✓	–	–	Colour-coded risk levels or risk tracking logs. Potential shift toward more proactive risk approaches.
Resource / Productivity	✓	✓	–	–	✓	Workforce capacity, labor attendance, or “workload” metrics. PPO 5 correlates on-site hours with planned tasks.
Supplier / Stakeholder	✓	✓	–	–	–	Supplier evaluation, social acceptability, or client feedback appear in PPO 1–2. Others rarely mention these.
Project Condition / Health	–	✓	–	✓	–	PPO 2 uses a “health index”; PPO 4 focuses on building condition (A–E rating) or HLM renovation progress.
Sustainability	–	✓	✓	–	–	PPOs 2 & 3 monitor environmental impact, energy performance, or compliance. Indications of growing interest.
Safety	–	✓	–	–	–	PPO 2 explicitly identifies safety metrics (health & safety). Others did not detail formal safety indicators.
Innovation	–	✓	–	–	–	PPO 2 explicitly labels “innovation initiatives.” One PPO references advanced “tactical/strategic” approaches but not as “innovation.”

As shown in Table 3.2, Cost/Financial and Schedule/Time metrics are the most commonly monitored, with all PPOs referencing some form of budget or timeline control. Scope and Risk indicators appear in three out of five PPOs, typically linked to gap analyses, change notices, or risk registers documenting potential overruns. Resource/Productivity metrics vary more widely, but at least two PPOs closely monitor workforce capacity or labor attendance.

Notably, Safety is underrepresented, only one PPO explicitly references it, suggesting that formal safety KPIs may be embedded within broader reporting systems or considered standard practice and thus not separately highlighted.

Sustainability metrics, including environmental impact and energy targets, are emphasized by two PPOs, indicating a modest yet potentially growing focus. Innovation appears explicitly as a standalone KPI in only one case, though related practices are discussed under different terminology by others.

Overall, the range of KPIs, from foundational cost and schedule metrics to emerging categories like innovation and sustainability, suggests a gradual evolution in the sector's performance focus.

3.1.2 KPI determination and criticality

PPOs in Quebec reported diverse strategies for selecting KPIs, often grounded in core project management principles such as cost, time, and scope, as well as strategic alignment with organizational goals (PPOs 1, 2, 3, and 5). As summarized in Table 3.3, some PPOs incorporated formal input from external bodies, such as ministerial directives or auditor requirements (PPOs 4 and 5), while others used internal methods like portfolio-level evaluations or gap analyses to refine and evolve their KPI frameworks.

Despite these variations, interviews consistently confirmed that cost and schedule are regarded as "primary KPIs" across all organizations. Notably, some PPOs (e.g., PPO 2) elevate safety and environmental performance to an equal level of importance. Beyond these core metrics, several PPOs expressed an ambition to broaden their frameworks to include indicators related to quality, earned value, resource utilization, productivity, and environmental impacts, signaling a shift toward more comprehensive and integrated project performance assessments.

Table 3.3 KPI determination and criticality

KPI Focus	Selection	Criticality	Key Observations
Cost	PMI standards, board confirmations, annual planning	All PPOs	Cost remains universal. Some owners want more precise cost-tracking (CPI/SPI).
Schedule	Strategic alignment, official input, portfolio approach	All PPOs	Time synergy with cost. Some adopt milestone-based or "delivery speed" measures.
Scope	Gap/process improvement in some PPOs	Sometimes	Not universal, but certain owners see scope compliance or change notices as vital.
Safety/ Environment	Ministerial demand (PPO 2), occasional board endorsement	only PPO 2	One PPO elevates it to main priority, others approach environmental efforts incrementally.
Quality	Gap analysis, stakeholder input	Sometimes	Remains an optional add-on for deeper oversight, especially rework or on-site issues.
Resource/ Productivity	Evolving approach, not always formal	Rarely top-tier	Some owners see workforce capacity as important but have minimal formal tracking.
Innovation	Portfolio expansions or official impetus (BIM)	Rarely top-tier	Mandates, pilot programs, or advanced indicators suggest slow integration beyond the cost/time core.

All five public project owners identify cost and schedule as indispensable KPIs, often anchored in PMI standards or broader strategic planning frameworks. While safety and environmental performance are elevated to top-tier status only by PPO 2, other owners acknowledge these dimensions more modestly or anticipate expanding their focus, particularly through emerging metrics such as greenhouse gas (GHG) emissions.

Scope and quality indicators appear inconsistently, yet growing attention to rework rates, non-conformities, and scope compliance suggests a trend toward more detailed project oversight.

Resource and productivity metrics also draw attention, although formalized tracking systems remain in the early stages of development. Innovation, including BIM and other advanced tools, is increasingly acknowledged, though rarely prioritized as a core KPI, indicating a gradual broadening of performance frameworks as such practices gain maturity.

Collectively, these findings reflect how each PPO's KPI strategy is shaped by organizational mandates, ministerial directives, and portfolio-specific complexities. Despite differing emphasis, most KPI sets converge around core dimensions of cost and schedule, with a growing orientation toward impact-focused and forward-looking performance measures.

3.1.3 Data collection frequency, methods, and tools

Based on the interviews, it is noticed that the ways PPOs collect and report KPI data can be grouped into just a few main patterns. These patterns involve how the data is entered, which digital tools are used, and how often the information is updated. Table 3.4 gives an overview of these patterns and shows which PPO follows each one.

Table 3.4 Consolidated data collection frequency, methods, and tools

Method / Tools	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Manual Data Entry	✓	✓	✓	✓	✓	Commonly done or partially in Excel or in-house sheets. Causes potential data delays and manual errors.
Multiple Systems	–	✓	–	✓	✓	Integrated PM tools plus manual tables. System integration issues hamper real-time analysis.
Data Type: Mix (Actual & Self-Reported)	✓	✓	✓	–	–	Three PPOs rely on a mix data type. Encourages data validation but slows updates. Two others are self-reported data.
Data Frequency: Monthly	✓	✓	✓	–	✓	Many projects updated monthly. Some PPOs do weekly/daily (PPO 2) or bi-monthly (PPO 5). PPO 4 follows a no-strict interval, updating as projects move stages.
Excel-Based Dashboards	✓	✓	✓	✓	✓	All PPOs used for entry and visualization; forms the baseline for advanced tools.
Visualization	–	✓	✓	✓	✓	Four PPOs moving from Excel to power BI platforms for real-time or public transparency dashboards.
Software	–	✓	–	–	✓	PPO 2 and PPO 5 adopt specialized scheduling/cost control software. Facilitates advanced metrics (e.g., earned value) but integration remains a challenge.

All five PPOs rely, at least in part, on manual data entry, most commonly through Excel spreadsheets, which can delay updates and introduce the risk of human error. Three PPOs supplement these inputs with actual measurements (e.g., data from contractors) alongside self-reported figures, offering greater validation but resulting in longer processing times. The remaining two PPOs rely primarily on self-reported data. While monthly reporting remains the norm, some variability exists: PPO 2 occasionally conducts weekly or daily check-ins, PPO 5 holds bi-monthly workshops to finalize KPI reporting, and PPO 4 updates data "on demand," typically aligned with project milestones or program phases.

Excel-based dashboards continue to serve as the foundational reporting tool across organizations. However, four PPOs are in the process of transitioning to business intelligence

(BI) platforms, most notably Power BI, to enable more dynamic analysis and, in some cases, support public-facing dashboards. PPOs 2 and 5 have also integrated specialized software (e.g., scheduling and cost-control tools) to track advanced metrics such as earned value, though integration across systems remains a challenge. Collectively, these practices suggest a gradual evolution from manual, Excel-centric processes toward more automated and interconnected data environments, with each PPO progressing at a different pace.

3.1.4 Challenges in data collection and analysis

The interviews revealed a range of challenges related to the collection, interpretation, and reporting of KPI data. Table 3.5 synthesizes these issues into five primary categories and identifies which PPOs reported each one. Further contextual insights and implications are discussed in the concluding observations.

Table 3.5 Consolidated challenges in data collection and analysis

Challenge Theme	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
System Integration	✓	✓	–	✓	✓	Reliance on Excel or lack of advanced tools, multiple disjointed systems, no single source of data, limited interoperability.
Data Quality	✓	✓	✓	✓	✓	Potential errors from manual entry, variable data formats, or “garbage in, garbage out.” Discrepancies between different sources.
Human Factors	✓	–	✓	–	✓	High staff turnover, limited data-monitoring resources, varied reporting quality, cultural resistance to KPI scrutiny.
Data Analysis / Reporting	✓	–	✓	–	–	No baseline capability, delayed updates due to invoicing/payment, inconsistent methods across project managers.
Resource Constraints	–	–	–	✓	–	Inspector shortages (PPO 4) and similar limitations cause long delays (e.g., a five-year horizon for full building stock assessments).

All five PPOs report concerns related to data quality, most commonly stemming from manual data entry or the use of multiple, uncoordinated systems. System integration emerges as a prominent issue for four PPOs, often linked to continued reliance on Excel, fragmented tool adoption, or the absence of a centralized data repository. Human factors further complicate KPI implementation: several organizations cite challenges such as staff turnover, skill gaps, or hesitancy among project managers to disclose performance data.

In addition to these structural and personnel issues, delays in reporting and the lack of advanced data analysis capabilities affect at least two PPOs. Notably, PPO 4 highlights a distinct constraint, limited resources for conducting large-scale inspections, representing a strategic limitation beyond routine data management.

Taken together, these challenges illustrate the inherent complexity of achieving consistent, real-time KPI reporting in public construction projects. Despite a shared commitment to more transparent and data-driven decision-making, practical barriers persist at multiple levels.

3.1.5 Utilization of KPI data for decision-making

Participants described how KPI results are translated into concrete decision-making processes, ranging from real-time interventions and escalation procedures to more proactive, portfolio-level strategies. Table 3.6 consolidates these practices into core categories, while the paragraphs below the following table highlight the distinctive approaches employed by each PPO.

Table 3.6 Consolidated approaches to KPI-based decision-making

Decision-Making Approach	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Immediate Action	✓	✓	✓	–	✓	When KPI signals (e.g., red/yellow) appear, teams intervene quickly to prevent larger overruns or schedule slips.
Corrective Steps (Action Plans / Realigning)	✓	✓	–	–	✓	PPOs 1, 2, and 5 implement formal action plans (e.g., "Realigning Projects," "Action-Oriented Reports") to address cost/time anomalies.
Escalation Process (Committees / Raising Flags)	✓	–	✓	–	✓	Certain issues—budget crises, critical delays—are escalated to higher-level boards or committees for prioritization, rebalancing, or strategic decisions.
Proactive / Performance Support	–	✓	–	✓	–	PPO 2 uses "Proactive Support" in reviews; PPO 4 uses "Proactive Measures" to accelerate delivery. Both stress anticipating problems before they grow.
Ministerial / Organizational Targets	–	–	–	✓	–	PPO 4 cites "Delivery Accountability" (minister monitors KPI data for timely housing). May link to broader political/board-level directives.
Portfolio / Renovation Prioritization	✓	–	–	✓	–	PPO 1 "rebalances" entire portfolios; PPO 4 channels resources based on building condition data.
Cultural / Behavioral Change	–	✓	–	–	–	PPO 2 notes that transparency from KPI dashboards fosters "positive impact," leading to better team behaviors and more accountability.

For Immediate Action, four owners (PPO1, PPO2, PPO3, PPO5) react quickly when a KPI turns yellow or red, usually from traffic-light dashboards or milestone checks. Typical responses are short coordination meetings, resequencing near-term tasks, shifting crews, or asking for contractor recovery plans.

Corrective Steps, formal action plans or "realigning" programmes, appear in PPO1, PPO2, and PPO5 when deviations persist or cross thresholds. These plans assign owners and deadlines and may include rebasing or resequencing subcontract packages.

The Escalation Process moves issues to steering committees or boards when impacts are material and cannot be solved at the project level. PPO1, PPO3, and PPO5 escalate budget crises, float erosion, or major risks for decisions on re-prioritization, funding, or scope trade-offs. This works best when KPIs are standardized across projects so committee members can compare like with like.

Proactive or Performance Support is stressed by PPO2 and PPO4. Instead of waiting for lagging indicators, they act on early signals such as procurement lead times, supply-chain risks, or early risk-register trends. Typical actions include clearing approvals earlier or preparing contingency packages.

Ministerial or organizational targets drive KPI use directly in PPO4, where delivery commitments (for example, housing) are monitored by the minister's office. This "delivery accountability" speeds decisions and resource allocation, but it can bias attention toward schedule unless governance also protects quality, safety, and long-term value.

Portfolio or Renovation Prioritization shows how PPO1 and PPO4 use KPIs above the single-project level to triage and sequence work. PPO1 rebalances the portfolio when indicators deteriorate; PPO4 channels resources using building-condition indices within the HLM programme. This requires comparable KPIs and stable definitions across projects to avoid subjective choices.

Cultural or Behavioural Change is reported by PPO2: transparent dashboards create positive pressure, leading teams to prepare better, escalate earlier, and follow through. Openness improves practice even with basic tools.

In summary, most actions begin with cost and schedule signals: fast operational fixes, formal corrective plans, and, when needed, escalation to committees. Two owners emphasize prevention through leading indicators; one aligns strongly with ministerial targets; two operate clearly at portfolio scale; and one highlights culture as a performance lever. For our framework, this implies clear thresholds for rapid detection, simple documentation for corrective plans, escalation-ready views, a few leading indicators for proactive work, portfolio-level aggregation, and a transparent, non-punitive use culture, all supported by more timely and integrated data.

3.1.6 Desired additional KPIs and metrics

Interviewees were asked which additional KPIs they would like to see implemented, reflecting either identified gaps or future performance aspirations. Table 3.7 highlights a few common themes or categories mentioned by PPOs.

Table 3.7 Desired additional KPIs and metrics

Initiative / Future Plan	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Earned Value (CPI/SPI)	✓	–	–	–	✓	PPOs 1 & 5 want more precise performance tracking (cost/schedule).
Quality / Non-Conformities	✓	✓	–	–	–	PPOs 1 & 2 hope to track changes, addenda, or complaints for deeper quality metrics.
Proactive / Predictive	–	✓	–	–	–	PPO 2 wants to identify major milestones, supply chain issues in advance.
Resource / Productivity	✓	–	–	–	✓	PPOs 1 & 5 mention resource utilization or standardized productivity rates (labor attendance, consistent tracking).
Environmental / Sustainability	–	–	–	✓	✓	PPO 4 & 5 aim to measure carbon footprint, GHG reductions, or community impacts more systematically.
Portfolio-Level Monitoring	–	–	✓	–	–	PPO 3 seeks centralized tools, potential to add more KPIs as the portfolio approach evolves.

Cost and schedule accuracy remain areas that multiple PPOs wish to refine via tools like Earned Value Management (EVM). Quality metrics that capture non-conformities or complaints are also of interest, especially for PPOs 1 and 2, pointing to a desire for more granular oversight. In addition, productivity and resource measures (PPOs 1, 5) underscore the trend toward a more nuanced view of workforce capacity and performance.

Meanwhile, environmental and sustainability concerns show up in at least two PPOs, who propose GHG or carbon footprint indicators. PPO 3 envisions expanded portfolio-level monitoring, whereas PPO 4 wants to ensure cost stability in public renovation programs. Overall, these emerging or additional KPIs reflect a shift beyond the standard iron triangle, incorporating quality, sustainability, and innovation in pursuit of more holistic and impact-oriented project assessment.

For Earned Value (CPI/SPI), PPO1 and PPO5 want more precise, integrated control of cost and schedule. In practice, this means tracking planned value, earned value, and actual cost to calculate CPI/SPI and act earlier when variance appears.

For Quality / Non-Conformities, PPO1 and PPO2 want deeper quality oversight by counting and classifying issues such as changes, addenda, defects, or complaints.

For Proactive / Predictive indicators, PPO2 wants to anticipate trouble before it becomes visible in lagging KPIs. This includes tracking early signals like supply-chain risks, long-lead procurement, or milestone exposure. The idea is to plan mitigation earlier.

For Resource / Productivity, PPO1 and PPO5 point to resource use and standardized productivity rates (for example, labour attendance matched to planned tasks). The goal is to detect under- or over-resourcing and to compare crews or packages more fairly.

For Environmental / Sustainability, PPO4 and PPO5 want to measure items such as carbon footprint, GHG reductions, or broader community effects in a more systematic way.

For Portfolio-Level Monitoring, PPO3 seeks centralized tools that aggregate KPIs across projects. This allows managers to prioritize and rebalance work at the programme level (not just project by project) and to add new KPIs as the portfolio approach matures.

Overall, these requested KPIs show a shift from only cost–time control to a more rounded view of performance: quality depth, predictive risk management, workforce efficiency, sustainability outcomes, and portfolio oversight. This direction supports more informed decisions in both the short term and the long term.

3.1.7 Measurement of initiative impacts and future plans

The interviews highlighted how each public project owner is extending their focus beyond immediate performance metrics, exploring emerging initiatives, such as BIM, and pursuing longer-term sustainability objectives. Table 3.8 summarizes these recurring themes and forward-looking strategies.

Table 3.8 Key initiative impacts and future plans

Initiative / Future Plan	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
BIM Implementation	✓	✓	✓	✓	✓	All PPOs express interest in BIM, though at varied maturity levels. Some compare BIM vs. non-BIM KPIs or look to reduce change orders.
Collaboration Index / Partnerships	✓	–	✓	–	–	PPOs 1 & 3 mention “collaboration” metrics or open analysis. Relates to measuring synergy among teams and external stakeholders.
Energy / Environmental Expansion	✓	–	–	✓	✓	PPOs 1, 4, and 5 highlight future goals such as carbon footprint, energy commissioning, or climate resilience.

Table 3.8 Key initiative impacts and future plans (continued)

Initiative / Future Plan	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Standardization / Trends	–	✓	–	–	–	PPO 2 aims to unify measurement processes across projects, working toward consistent performance trends.
Portfolio Management Approach	–	–	✓	–	–	PPO 3 plans a broader portfolio strategy, hoping to add additional KPIs and centralized monitoring.
Future Data Collaboration	–	–	✓	–	✓	PPO 3 and 5 want to collaborate on data collection or compare “traditional” vs. “BIM” projects more systematically.

For BIM Implementation, all five owners show interest, but their maturity is not the same. Some are in pilot mode; others already try to compare BIM vs. non-BIM projects using existing KPIs (for example, fewer change orders or fewer site directives). The shared intention is to use BIM to reduce errors, improve coordination, and make performance more predictable.

For Collaboration Index / Partnerships, PPO1 and PPO3 mention indicators that try to capture how well teams and external stakeholders work together. In practice, this could include structured feedback, joint planning discipline, or the stability of information flows. The goal is to make “collaboration” visible.

For Energy / Environmental Expansion, PPO1, PPO4, and PPO5 plan to track items such as carbon footprint, energy commissioning outcomes, or climate resilience. These bring long-term environmental performance into regular reporting.

For Standardization / Trends, PPO2 focuses on unifying measurement processes across projects. This means clearer definitions, common data structures, and repeated indicators over time so that trends become visible.

For the Portfolio Management Approach, PPO3 wants to move from single project tracking to a portfolio view with centralized monitoring and the possibility to add more KPIs later. This helps leaders prioritize, rebalance, or phase projects based on comparable signals, not only on local intuition.

For Future Data Collaboration, PPO3 and PPO5 are open to collaborating on shared datasets or structured comparisons (for example, "traditional" vs. BIM projects). This points to benchmarking and learning across organizations.

In summary, these plans show a common direction: owners want to strengthen digital practices (BIM), make teamwork measurable (collaboration indices), expand environmental tracking, stabilize methods through standardization, lift the analysis to portfolio level, and cooperate on data. Together, these steps aim to build a more complete view of performance that includes both short-term delivery and longer-term impacts.

3.1.8 Summary of interview findings

The interviews conducted with public project owners in Quebec clearly indicate an evolving landscape in the use of KPIs within the public construction sector. While traditional metrics such as cost and schedule remain foundational due to their critical role in budget adherence and timely project delivery, there is an emerging trend towards the inclusion of broader, impact-oriented indicators. These evolving KPIs encompass areas like sustainability, quality, risk management, productivity, and notably, innovation. Although currently used to varying degrees, these broader indicators reflect a growing recognition among PPOs that construction projects should not be assessed solely on immediate outcomes but also on their enduring social, environmental, and economic impacts.

Nonetheless, several consistent challenges were highlighted through the interviews. PPOs frequently identified data quality concerns, primarily attributed to manual data entry and lack of automated integration among different systems. This manual approach is further compounded by issues of system interoperability, creating barriers to real-time and accurate reporting. Moreover, organizational culture and resource constraints were reported as significant obstacles, affecting both the willingness and capacity of personnel to engage fully with comprehensive KPI tracking and analysis.

Despite these challenges, KPI data are actively leveraged to inform various decision-making processes, ranging from immediate corrective actions to higher-level strategic interventions, such as escalation to management committees, portfolio rebalancing, and proactive project management approaches. The use of visual dashboards and emerging integration of advanced software tools like Power BI illustrate ongoing efforts to improve real-time data analysis and transparency.

Overall, the interviews suggest that public project owners work with a limited set of KPIs, and even with this small set, they face considerable difficulties in use and follow-up. The clearest gap is that, under the current arrangements, the measurement of innovation impact is very constrained, mostly confined to the construction phase and largely reduced to its effects on time and cost. In other words, the present system makes it unlikely to capture broader or longer-term consequences of innovation beyond schedule and budget during delivery.

3.2 KPI prioritization and validation

Following the empirical insights from the semi-structured interviews, a two-stage validation was conducted to evaluate and refine the KPI set derived from the literature and practice. First, prioritization workshops were held to position 42 KPIs (nine categories) on a usefulness–measurability matrix and to generate a shared priority view among Québec public project owners. Second, a post-workshop validation questionnaire was administered to confirm and stress-test the workshop priorities and to document any adjustments before finalizing the list.

The prioritization workshops involved five PPOs: four previously interviewed organizations and one new participant. The follow-up validation questionnaire yielded seven responses representing six PPOs (one organization submitted two responses). This mixed validation approach broadened representation and strengthened the robustness and practical applicability of the results within the Québec public construction context.

3.2.1 Objectives of the prioritization and validation

The workshops were designed with three main objectives:

First, validation of practical relevance and applicability: The proposed KPIs were examined with stakeholders directly involved in Québec's public construction projects to ensure that they are meaningful for decision-making and feasible within existing reporting practices.

Second, prioritization on two dimensions: The KPIs were prioritized according to perceived usefulness for managerial decisions and ease of measurability given current data, tools, and processes, thereby supporting practical adoption.

Third: refinement and finalization of the KPI set: Targeted feedback was gathered with the aim of producing a clearer and more implementable KPI list for subsequent application.

3.2.2 Workshop methodology and activities

Each workshop was conducted separately with every public project owner. Participants received the full list of 42 KPIs organized into nine categories, together with short definitions, exactly as introduced in the previous chapters. The goal was to ensure a common understanding of the indicators before prioritization.

3.2.2.1 Workshop structure and procedure

Workshops were conducted separately with each PPO. At the beginning, the purpose of the activity was explained, and the procedure was explained with a worked example. Participants were then introduced to the KPI Usefulness–Measurability matrix (described in the

Methodology chapter). We reviewed the two axes: (i) usefulness on the horizontal axis and (ii) ease of measurement on the vertical axis. After this brief calibration, participants were asked to place each KPI on the matrix.

In some cases, many of the KPIs were placed during the session. However, some participants requested additional time to consult internally or reflect on certain indicators. These participants finalized the exercise after the workshop and submitted their completed matrices within a couple of days. All placements were collected in the same format and prepared for analysis in the subsequent sections.

3.2.2.2 KPI Usefulness-Measurability matrix

To systematically capture participants' evaluations, a two-dimensional matrix was employed, defined as follows:

Horizontal Axis: Ranging from "Highly Useless" (left) to "Highly Useful" (right), reflecting the perceived strategic value and relevance of each KPI to organizational objectives.

Vertical Axis: Ranging from "Extremely Hard to Measure" (bottom) to "Extremely Easy to Measure" (top), reflecting the perceived feasibility and practicality of data collection for each KPI.

Participants placed each KPI onto this matrix through collaborative discussion, achieving consensus or majority agreement for each placement. To see the example, please see Figure 2.3 in the Methodology chapter.

3.2.2.3 Data collection and analysis method

For the prioritization exercise, the two axes of the Usefulness–Measurability matrix were divided into numeric intervals from −10 to +10. A value of 0 was assigned to placements on an axis, and 10 to placements farthest from that axis. Thus, the magnitude reflects distance from the nearest axis.

Each KPI received two signed scores according to its agreed position on the matrix:

1) A Usefulness score (horizontal axis) in the range −10 to +10: values to the right of the vertical axis were recorded as positive, and values to the left as negative.

2) A Measurability score (vertical axis) in the range −10 to +10: values above the horizontal axis were recorded as positive, and values below as negative.

The value of each score corresponds to the discrete distance (−10 to +10) from the relevant axis. An illustration of the scoring grid is provided in Figure 3.1. For example, a KPI in green placed near the upper-right boundary would receive approximately (+9, +10), while a KPI in blue slightly left of the vertical axis and below the horizontal axis could receive around (−1, −3).

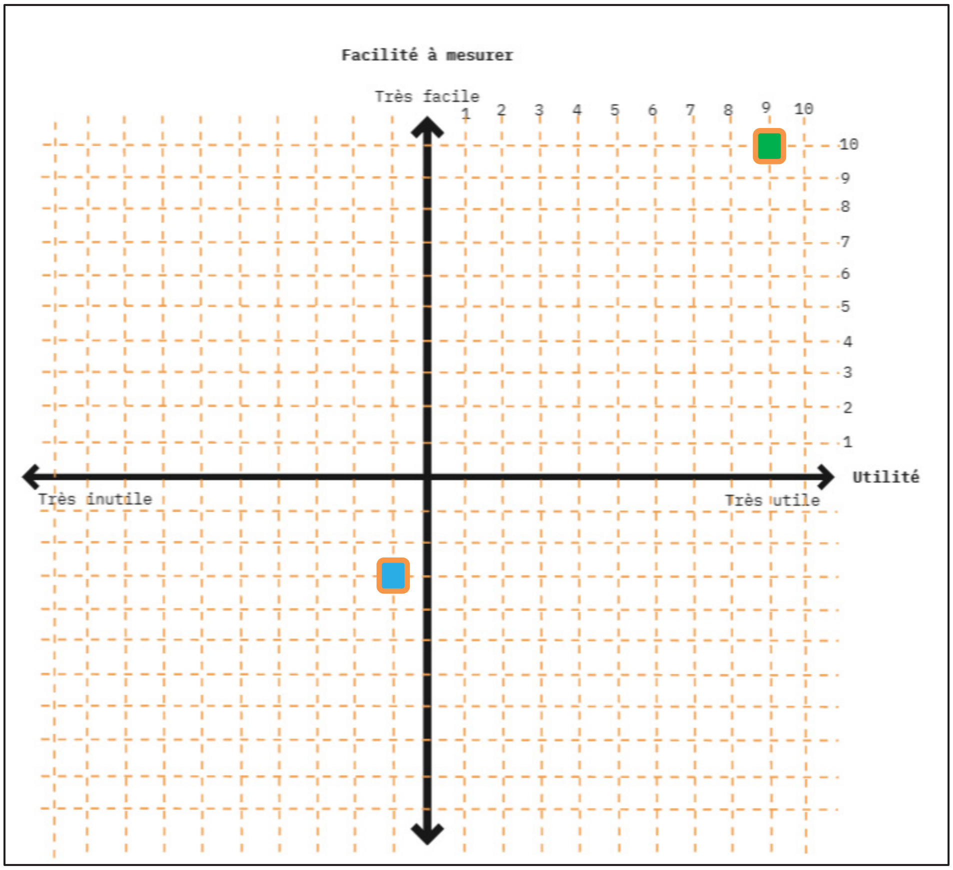

Figure 3.1 Usefulness–Measurability matrix scoring grid example

All KPI placements were converted to these numeric scores using the same rules. The resulting values were then aggregated in Table 3.9 and Table 3.10, supporting a clear prioritization of KPIs by usefulness and measurability across participating organizations. The averages represent the central tendency of PPO judgments and allow comparison of perceived importance across metrics. Although averages provide an intuitive, interpretable summary, they are used here primarily for descriptive, not statistical, inference. The following results in Table 3.9, therefore, summarize how valuable each KPI is considered in practice, followed by an interpretation across families of indicators:

Table 3.9 Aggregated KPI usefulness scores by PPOs

KPI	**Metric**	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 5**	**PPO 6**	**AVG.**
Cost	Cost predictability (Design/Construction)	10	9		10	8	**9.25**
Cost	Cost per unit (estimated & actual)	9	10	8	5	6.5	**7.70**
Cost	Cost in use	8.5	9		10	8	**8.88**
Time	Time predictability (Design/Construction)	10	10		10	7	**9.25**
Time	Time per unit	0	10	5.5	10	4	**5.90**
Productivity	Labor productivity - $/unit	7	10	4	10		**7.75**
Productivity	Labor productivity - unit/hour	7	10	2	5	6	**6.00**
Productivity	Decision-making Latency	4	4	4	5	6	**4.60**
Quality	Stakeholder satisfaction	8	4.5	6.5	10	6.5	**7.10**
Quality	Quality issues (punch-list)	5.5	8	8.5	10	1.5	**6.70**
Quality	Cost for defects-warranty		6.5	6.5	-5	6	**3.50**
Quality	Time for defects-warranty		7	0	10	5.5	**5.63**
Quality	Rework Rate	1	-3	5		4.5	**1.88**
Safety	Reportable incidents	10	10		5	3	**7.00**
Safety	Lost Time	10	10		10	5	**8.75**
Scope	Change order (Cost) - client-initiated	8.5	10	5	10	9.5	**8.60**
Scope	Change order (Cost) - contractor-initiated	6.5	10	7	10	9.5	**8.60**
Scope	Change order (Time) - client-initiated	7.5	10	2	10	8.5	**7.60**
Scope	Change order (Time) - contractor-initiated	5.5	10		10	8.5	**8.50**
Scope	Change orders - client-initiated	9	1.5		10	9	**7.38**
Scope	Change orders - contractor-initiated	8	6.5		10	10	**8.63**
Scope	Claim numbers	4.5	10	0	10	2.5	**5.40**
Scope	Claim amount	4.5	10	0	10	3	**5.50**
Scope	Requests for information (RFI)	3	8.5	-2	10	4.5	**4.80**
Innovation	Procurement type	3	4.5	1.5	10	8.5	**5.50**
Innovation	Management innovation	10	8	1.5	-5	8.5	**4.60**
Innovation	Lean Implementation Index	1.5	2.5	1.5	5	9	**3.90**
Innovation	BIM Adoption Level	10	7.5	5	0	9	**6.30**
Innovation	Technological innovation		5.5	5	10	4.5	**6.25**
Sustainability	Certification	10	-4	-3	5	1	**1.80**
Sustainability	Material Consumption	-7	3	2.5	0	7	**1.10**

Table 3.9 Aggregated KPI usefulness scores by PPOs (continued)

KPI	Metric	PPO 1	PPO 2	PPO 3	PPO 5	PPO 6	AVG.
Sustainability	Waste generation	1.5	3	3.5	5	7	**4.00**
Sustainability	Carbon Footprint	8	3	10	5	8.5	**6.90**
Sustainability	Waste Recycling Rate	5.5	3		5	6	**4.88**
Sustainability	Energy Consumption	10	3	10	10	7.5	**8.10**
Sustainability	Air Pollution	8.5	3	6.5	10	-1.5	**5.30**
Sustainability	Community effect	10	3	3	7.5	8	**6.30**
Sustainability	Water Pollution	3	3	8.5	0	5.5	**4.00**
Risk	Number of risks quantified	9	-1.5	6	-5	6	**2.90**
Risk	Scope of risks (Risk-exposure score)	9	10		10	9	**9.50**
Risk	Cost of risk mitigation	9	10		10	9	**9.50**
Risk	Risk materialization	10	10	4.5	10	4.5	**7.80**

Cost: Within the Cost family, Cost predictability (Design/Construction) is the clear leader (average = 9.25). It shows strong consensus and sits among the highest-scoring metrics overall. Cost in use follows closely (8.88), signalling interest in life-cycle operating implications, not only initial budgets. Cost per unit (estimated & actual) is moderately high (7.70), but variation across PPOs is greater than for the two leaders.

Time: Time predictability (Design/Construction) ranks very high (9.25), with solid agreement. Time per unit is notably lower (5.90), suggesting it is less universally useful across owners.

Productivity: Usefulness concentrates on Labor productivity – \$/unit (7.75) and, to a lesser extent, Labor productivity – unit/hour (6.00). Decision-making latency scores lower (4.60), which implies that, while relevant, it is not yet considered a frontline, decision-driving metric by most owners.

Quality: The most valued quality metric is Stakeholder satisfaction (7.10), followed by Quality issues (punch-list) (6.70). Warranty-related indicators are mixed: Time for defects-warranty (5.63) is mid-range, whereas Cost for defects-warranty is low (3.50) due to clear disagreement (one PPO rated it negatively). Rework rate is the least useful in this family (1.88).

Safety: Safety remains important. Lost time achieves a very high average (8.75) and Reportable incidents are also strong (7.00). These two metrics form the core of owners' safety monitoring.

Scope (Change Management): Scope-related indicators are consistently useful. The top positions are Change orders – contractor-initiated (8.63) and both Change order (Cost) – client-initiated and Change order (Cost) – contractor-initiated (each 8.60). Change order (Time) – contractor-initiated is also high (8.50). Claims (Claim numbers 5.40; Claim amount 5.50) and RFI (4.80) sit clearly below the change-order measures, indicating owners see change management itself as more decision-oriented than downstream requests.

Innovation: Usefulness concentrates on mainstream adoption signals. BIM adoption level (6.30) and Technological innovation (6.25) lead the group. Procurement type is mid-range (5.50). Management innovation shows notable disagreement and a lower average (4.60), and the Lean implementation index is the least useful here (3.90). Overall, innovation metrics are viewed as moderately useful, with more divergence across PPOs than in cost/time/risk.

Sustainability: Usefulness is uneven in this family. The stand-out metric is Energy consumption (8.10), which sits in the high-priority band. Carbon footprint (6.90) and Community effect (6.30) are mid-range and trending upward. Others are mixed to low, e.g., Waste generation (4.00), Water pollution (4.00), Air pollution (5.30). Certification (1.80) and Material consumption (1.10) are clearly low due to disagreement and perceived limited decision value.

Risk: Risk metrics are among the strongest overall and show the highest agreement. Risk exposure score (scope of risks) and Cost of risk mitigation share the top average (each 9.50) with very tight dispersion, indicating robust consensus on their usefulness. Risk materialization also ranks high (7.80), whereas the Number of risks quantified is low (2.90), suggesting owners prefer risk quality (exposure and mitigation) over simple counts.

The results in Table 3.10 emphasizing which metrics are easiest or hardest to measure within each KPI category:

Table 3.10 Aggregated KPI ease of measurement scores by PPOs

KPI	Metric	PPO 1	PPO 2	PPO 3	PPO 5	PPO 6	AVG.
Cost	Cost predictability (Design/Construction)	-2.5	10		-5	3.5	**1.50**
Cost	Cost per unit (estimated & actual)	-10	9	8.5	-5	5.5	**1.60**
Cost	Cost in use	-2.5	9		5	5	**4.13**
Time	Time predictability (Design/Construction)	3.5	10		-2.5	7	**4.50**
Time	Time per unit	-1.5	8.5	8.5	-10	9	**2.90**
Productivity	Labor productivity - $/unit	3.5	10	-3	-2.5		**2.00**
Productivity	Labor productivity - unit/hour	3.5	10	-3	-10	5.5	**1.20**
Productivity	Decision-making Latency	-9	3	2.5	5	3.5	**1.00**
Quality	Stakeholder satisfaction	10	8	7	10	-1	**6.80**
Quality	Quality issues (punch-list)	-8	9	7	10	1.5	**3.90**
Quality	Cost for defects-warranty		6.5	3	-7.5	8.5	**2.63**
Quality	Time for defects-warranty		6	-1	6	6.5	**4.38**
Quality	Rework Rate	-9	-3	3		8.5	**-0.13**
Safety	Reportable incidents	-8.5	10		10	5	**4.13**
Safety	Lost Time	-7	10		10	-7	**1.50**
Scope	Change order (Cost) - client-initiated	-2.5	10	10	10	5.5	**6.60**
Scope	Change order (Cost) - contractor-initiated	-4	10	10	10	1.5	**5.50**
Scope	Change order (Time) - client-initiated	-2.5	10	10	-10	1.5	**1.80**
Scope	Change order (Time) - contractor-initiated	-4	10		-10	5.5	**0.38**
Scope	Change orders - client-initiated	3.5	8.5		10	2.5	**6.13**
Scope	Change orders - contractor-initiated	1.5	8.5		10	5.5	**6.38**
Scope	Claim numbers	8	10	6.5	10	8	**8.50**
Scope	Claim amount	6.5	10	4.5	10	1.5	**6.50**
Scope	Requests for information (RFI)	3.5	-2	5	10	1.5	**3.60**

Table 3.10 Aggregated KPI ease of measurement scores by PPOs (continued)

KPI	**Metric**	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 5**	**PPO 6**	**AVG.**
Innovation	Procurement type	-9.5	5	10	10	10	**5.10**
Innovation	Management innovation	-10	8	7	7.5	1	**2.70**
Innovation	Lean Implementation Index	1	0	4.5	-5	-5.5	**-1.00**
Innovation	BIM Adoption Level	-6	3.5	10	-5	-7.5	**-1.00**
Innovation	Technological innovation		2.5	7	-5	1	**1.38**
Sustainability	Certification	8	5.5	10	4	6.5	**6.80**
Sustainability	Material Consumption	-9	-6	0	-7.5	6.5	**-3.20**
Sustainability	Waste generation	2.5	-6	0	2	8	**1.30**
Sustainability	Carbon Footprint	-6.5	-6	-2	-5	-3.5	**-4.60**
Sustainability	Waste Recycling Rate	-9	-6		-10	1.5	**-5.88**
Sustainability	Energy Consumption	10	-6	5	-5	-1.5	**0.50**
Sustainability	Air Pollution	8.5	-6	7.5	-5	-1.5	**0.70**
Sustainability	Community effect	-10	-6	-10	-5	1	**-6.00**
Sustainability	Water Pollution	-10	-6	7.5	-5	9	**-0.90**
Risk	Number of risks quantified	5	10	7	10	1	**6.60**
Risk	Scope of risks (Risk-exposure score)	7	10		10	9	**9.00**
Risk	Cost of risk mitigation	-10	10		0	2.5	**0.63**
Risk	Risk materialization	-10	10	5	10	1	**3.20**

Cost: Measurement feasibility is mixed. Cost in use (average = 4.13) and Cost predictability (1.50) sit in the low–moderate band. Cost per unit (1.60) shows strong disagreement (ranges from -10 to +9), suggesting different costing methods and data availability across owners.

Time: Time predictability is moderately measurable (4.50), likely due to established scheduling baselines. Time per unit (2.90) is less consistent; one owner's -10 indicates difficulty tracing this metric.

Productivity: Productivity remains hard to operationalize. Labor productivity ($/unit) (2.00) and unit/hour (1.20) sit near the floor, and decision-making latency (1.00) is similarly weak.

Quality: Quality presents a split picture. Stakeholder satisfaction (6.80) is among the easier items to measure. Quality issues (punch-list) is moderate (3.90). Time for defects-warranty (4.38) is measurable for some, whereas Cost for defects-warranty (2.63) suffers from incomplete capture (one negative outlier).

Safety: Reportable incidents (4.13) sit mid-range; Lost time (1.50) shows wide variation, which may imply differences in how lost-time definitions and reporting systems are applied.

Scope (Change Management): Claim numbers (8.50) and Claim amounts (6.50) are straightforward extracts from formal logs. Change orders, client-initiated (6.13) and contractor-initiated (6.38) are also relatively easy, as are Change order (Cost) for both client and contractor (6.60 and 5.50). Change order (Time) shows more dispersion (1.80 and 0.38), and RFI is moderate (3.60).

Innovation: Innovation measures are generally hard to measure consistently. Procurement type (5.10) is the only item clearly above mid-range, as it is categorical and documented. Management innovation (2.70) is modest, while both the Lean implementation index and BIM adoption level average -1.00. Technological innovation (1.38) remains difficult to quantify beyond qualitative descriptions.

Sustainability: Strong divergence is evident. Certification (6.80) is among the easier items because it relies on structured checklists. By contrast, Carbon footprint (-4.60), Waste recycling rate (-5.88), Community effect (-6.00), and Water pollution (-0.90) are hard to measure. Energy consumption (0.50) and Air pollution (0.70) cluster near neutral. Waste generation (1.30) and Material consumption (-3.20).

Risk: Risk exposure score (9.00) is among the highest averages in the whole table. The Number of risks quantified (6.60) is also easy. Risk materialization (3.20) is moderate, while the Cost of risk mitigation (0.63) is harder to measure.

3.2.3 Ranking and weighting

This section explains how the final priority order in Table 3.11 was produced from the workshop scores. The procedure keeps the original average scores on the two axes (Usefulness and Ease of measurement), but explicitly incorporates stakeholder agreement, measured by the interquartile range (IQR) as a weight. In short, metrics with high averages and strong agreement are rewarded; metrics with disagreement are down-weighted. Usefulness remains the primary driver, and measurability is included with a lighter weight to reflect feasibility.

While averages offer a straightforward way to summarize participants' evaluations, they present significant limitations when used as the sole decision criterion. A simple mean value cannot reveal the level of consensus or disagreement behind it. For example, if one project owner rates a KPI as extremely important (10) while another rates it as irrelevant (0), the resulting average (5) would misleadingly suggest that the indicator has moderate importance. In reality, such dispersion indicates that the metric is highly divisive and may not be suitable for standardized benchmarking. Moreover, with a small expert group, such as the five to six public project owners participating in this study, each individual's rating carries more weight, amplifying the effect of disagreement on the final prioritization. Therefore, a more nuanced approach was required to distinguish between shared priorities and isolated preferences.

To address this limitation, the analysis integrates a measure of stakeholder agreement using the interquartile range (IQR). The IQR captures the spread of the middle 50% of responses, providing a robust and interpretable measure of dispersion that is less affected by outliers. By normalizing IQR values and transforming them into weights, the approach gives greater influence to metrics that not only have high average scores but also strong agreement among participants. Conversely, indicators with wide variability in ratings are penalized proportionally. This method ensures that the final ranking reflects collective judgment rather than numerical coincidence. The use of IQR weighting therefore enhances the credibility, transparency, and reproducibility of the prioritization process, ensuring that selected KPIs represent both the importance and the consensus of Québec's public project owners.

To operationalize this approach, the next step was to calculate the agreement weights derived from the IQR for each KPI on both axes, Usefulness and Ease of Measurement. This translation of qualitative consensus into quantitative weights allowed a transparent integration of expert agreement directly into the prioritization algorithm. The resulting weighted scores retain the intuitive interpretability of averages while correcting for disagreement, thus producing a ranking that reflects both the perceived value and the collective confidence of the participating public project owners. The following subsections detail the computation procedure and the weighting formulas used in the analysis.

3.2.3.1 Agreement weights derived from IQR

For each KPI and for each axis (Usefulness(U), Measurement(M)), stakeholder agreement was summarized by the interquartile range:

- Q1 (first quartile) is the value below which 25% of the PPO scores fall (the "lower hinge").
- Q3 (third quartile) is the value below which 75% of the PPO scores fall (the "upper hinge").
- IQR = Q3 – Q1 measures the spread of the middle 50% of opinions.
- A smaller IQR indicates higher agreement among PPOs.

To transform IQR into a 0–1 weight that rewards agreement, a min–max normalization was applied within each axis:

$$\text{Weight}(U, M) = 1 - \frac{IQR - \min(IQR)}{\max(IQR) - \min(IQR)} \tag{4.1}$$

- The KPI with the smallest IQR on an axis receive a weight near 1 (highest agreement).
- The KPI with the largest IQR receive a weight near 0 (lowest agreement).

This normalization was performed separately for Usefulness and for ease of Measurement.

3.2.3.2 Agreement-weighted axis scores

Next, the agreement weight was applied to the corresponding average on each axis:

$$Usefulness\ weighted\ score = MeanUsefulness \times WeightUsefulness \quad (4.2)$$

$$Measurement\ weighted\ score = MeanMeasurement\ \times WeightMeasurement \quad (4.3)$$

These adjusted scores keep the original [-10, +10] directionality but reduce the influence of metrics where owner views were dispersed (high IQR).

3.2.3.3 Composite prioritization score and sorting

Finally, a single composite score was computed to balance decision value and feasibility, with Usefulness emphasized:

$$Priority\ weighted\ score = 0.80 \times\ Usefulness\ weighted\ score + 0.20\ \times\ Measurement\ weighted\ score \quad (4.4)$$

- The 80%-20% split reflects the workshop's aim: prioritize decision-useful KPIs (including consensus) while still rewarding feasibility.
- KPIs were then sorted by priority weighted score (ascending) to produce the final order in Table 3.11.

Table 3.11 Metric sorted by weighted rank score

Measure	Usefulness					Ease of measurement					Priority weighted score
	Mean	IQR	Weight	Weighted Score	Rank	Mean	IQR	Weight	Weighted Score	Rank	
Scope of risks (Risk-exposure score)	9.5	1.0	0.9	8.4	2	9.0	1.0	1.0	8.9	1	**1.8**
Time predictability (Design/Construction)	9.3	0.8	0.9	8.5	1	0.8	6.9	0.6	0.4	23	**5.4**
Change order (Cost) - client-initiated	8.5	2.0	0.7	6.1	7	7.0	5.0	0.7	4.9	5	**6.6**
Energy consumption	8.0	0.8	0.9	7.4	5	3.9	10.0	0.3	1.4	16	**7.2**
Cost in use	8.9	1.5	0.8	7.1	6	4.1	7.5	0.5	2.2	13	**7.4**
Cost of risk mitigation	9.5	1.0	0.9	8.4	3	-0.1	10.0	0.3	0.0	32	**8.8**
Cost predictability (Design/Construction)	9.3	1.3	0.8	7.8	4	-0.4	11.4	0.3	-0.1	34	**10.0**
Labor productivity - $/unit	7.8	2.8	0.6	4.7	11	1.9	5.3	0.7	1.3	17	**12.2**
Lost time	9.0	2.5	0.6	5.8	8	1.5	14.9	0.0	0.0	30	**12.4**
Change orders - contractor-initiated	8.7	3.5	0.5	4.2	16	6.4	3.1	0.8	5.4	3	**13.4**
Air pollution	5.5	1.5	0.8	4.4	14	3.5	0.9	1.0	3.5	11	**13.4**
Stakeholder satisfaction	6.8	2.5	0.6	4.4	15	4.4	2.0	0.9	4.0	8	**13.6**
Change order (Time) - contractor initiated	8.0	2.0	0.7	5.8	9	-0.9	13.1	0.1	-0.1	35	**14.2**
Technological innovation	6.0	1.8	0.8	4.6	13	1.0	5.0	0.7	0.7	20	**14.4**
BIM adoption level	7.8	2.3	0.7	5.3	10	-1.6	11.0	0.3	-0.4	37	**15.4**
Cost per unit (estimated & actual)	7.7	2.8	0.6	4.6	12	-0.3	13.1	0.1	0.0	31	**15.8**
Change order (Cost) - contractor initiated	8.5	3.5	0.5	4.1	17	3.7	11.4	0.3	0.9	18	**17.2**
Decision-making Latency	4.6	1.0	0.9	4.0	18	0.8	1.0	1.0	0.8	19	**18.2**
Number of risks quantified	3.8	2.0	0.7	2.7	22	6.6	5.0	0.7	4.7	6	**18.8**
Time for defects-warranty	5.6	3.5	0.5	2.7	23	3.9	1.9	0.9	3.6	9	**20.2**
Claim numbers	5.2	3.8	0.4	2.3	26	8.5	2.0	0.9	7.8	2	**21.2**
Procurement type	5.5	2.6	0.6	3.4	20	3.3	14.0	0.1	0.2	28	**21.6**
Waste generation	4.1	2.0	0.7	3.0	21	0.5	4.0	0.8	0.4	26	**22.0**
Carbon footprint	7.1	3.0	0.6	4.0	19	-4.3	3.0	0.8	-3.6	42	**23.6**
Cost for defects-warranty	2.6	0.3	1.0	2.6	25	0.8	2.6	0.9	0.7	21	**24.2**
Labor productivity - unit/hour	6.0	3.8	0.4	2.6	24	-0.9	6.3	0.6	-0.5	38	**26.8**
Lean implementation index	3.8	2.8	0.6	2.3	27	-0.8	9.1	0.4	-0.3	36	**28.8**
Water pollution	4.2	3.3	0.5	2.2	29	-0.8	13.1	0.1	-0.1	33	**29.8**
Risk materialization	7.1	5.3	0.2	1.4	34	3.4	8.0	0.5	1.7	15	**30.2**
Change order (Time) - client-initiated	7.2	5.0	0.2	1.7	31	0.2	11.4	0.3	0.1	29	**30.6**
Community effect	7.1	4.5	0.3	2.3	28	-4.8	7.5	0.5	-2.5	41	**30.6**
Time per unit	6.4	5.0	0.2	1.5	33	1.0	8.6	0.4	0.4	22	**30.8**
Claim amount	5.1	5.5	0.2	0.8	37	6.5	5.0	0.7	4.6	7	**31.0**
Rework rate	2.9	2.8	0.6	1.7	32	0.8	11.0	0.3	0.2	27	**31.0**
Requests for information (RFI)	4.6	5.0	0.2	1.1	36	3.3	1.5	1.0	3.1	12	**31.2**
Waste recycling rate	5.0	4.0	0.4	2.0	30	-4.9	10.0	0.3	-1.7	40	**32.0**
Reportable incidents	7.0	5.5	0.2	1.1	35	2.3	12.5	0.2	0.4	25	**33.0**

Table 3.11 Metric sorted by weighted rank score (continued)

Measure	Usefulness					Ease of measurement					Priority weighted score
	Mean	IQR	Weight	Weighted Score	Rank	Mean	IQR	Weight	Weighted Score	Rank	
Quality issues (punch-list)	6.2	6.0	0.1	0.5	38	3.9	7.5	0.5	2.1	14	**33.2**
Certification	0.8	6.3	0.0	0.0	42	7.0	4.6	0.7	5.1	4	**34.4**
Change orders - client-initiated	7.4	6.5	0.0	0.1	41	5.1	5.0	0.7	3.6	10	**34.8**
Management innovation	5.2	6.0	0.1	0.4	39	0.7	7.0	0.6	0.4	24	**36.0**
Material consumption	1.4	6.0	0.1	0.1	40	-2.5	6.8	0.6	-1.4	39	**39.8**

Based on the workshop placements and the weighted-priority analysis, a shortlist of 17 KPIs (highlighted in Table 3.11) was selected for a follow-up validation questionnaire. This shortlist balances three considerations: (1) decision usefulness with owner consensus (high mean usefulness with low dispersion), (2) measurability in current systems (reasonable average on the measurement axis and workable data sources), and (3) coverage of owners' needs across core control areas (cost, time, scope, risk, safety, productivity, quality) and selected forward-looking dimensions (sustainability). Concretely, items such as Cost/Time predictability, Change orders (client/contractor initiated), Risk exposure score, Cost of risk mitigation, and Lost time were retained because they ranked high and showed relatively strong agreement; they are also already visible in most reporting cycles. Stakeholder satisfaction remains to capture the user/quality dimension. Requests for Information (RFI) and labor productivity ($/unit) were kept as operational signals of coordination and efficiency. Finally, three sustainability metrics: Energy consumption, Carbon footprint, and Waste generation, were included to reflect owners' declared intent to move beyond the iron triangle, even if current measurement practices are heterogeneous; validating these items now helps prepare a realistic adoption path.

At the same time, some innovation-labelled items (e.g., BIM adoption level, management/technological innovation) were not taken into the 17-item questionnaire. This decision follows the workshops: owners valued the innovation conceptually, but definitions and data pipelines are still inconsistent, which produced wider dispersion in placement. These items are therefore earmarked for subsequent pilots once measurement conventions are agreed.

3.2.4 Post-workshop validation questionnaire results

A post-workshop validation questionnaire (Appendix V) was used to confirm the priority KPIs emerging from the workshop results. The 17 shortlisted metrics were rated by six Québec public project owners (seven responses received in total – PPO 5 submitted two responses) on a 1–5 scale (1 = low priority; 5 = top priority). The following Table 3.12 reports the per-owner scores and the average for each metric. Numbers for PPO 5 are an average of two responses.

Table 3.12 Post-workshop validation questionnaire result

Metrics	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	PPO 6	Average
Cost predictability (Design/Construction)	5	5	5	5	5.0	5	5.0
Time predictability (Design/Construction)	5	5	4	5	5.0	5	4.8
Cost per unit	4	5	5	5	3.5	4	4.5
Stakeholder satisfaction	5	4	4	3	3.5	5	3.9
Change order (Cost) - contractor initiated	5	4	5	2	4.0	4	4.0
Change orders - contractor-initiated	5	4	5	2	4.0	4	4.0
Scope of risks (Risk-exposure score)	5	5	3	1	3.5	5	3.5
Time per unit	2	5	4	4	3.0	4	3.6
Lost Time	5	4	4	1	4.0	4	3.6

Table 3.12 Post-workshop validation questionnaire result (continued)

Metrics	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	PPO 6	Average
Change order (Cost) - client-initiated	5	4	5	2	3.0	3	3.8
Labor productivity - $/unit	4	5	3	2	3.5	4	3.5
Carbon Footprint	5	3	4	3	2.5	4	3.5
Cost of risk mitigation	5	5	3	1	3.5	4	3.5
Change orders - client-initiated	5	4	5	2	3.0	2	3.8
Energy Consumption	5	3	4	2	3.0	4	3.4
Requests for information (RFI)	3	4	4	1	4.0	4	3.2
Waste generation	3	3	3	2	2.5	4	2.7

Results show a strong confirmation of the workshop ranking. Cost predictability (design/construction) and Time predictability (design/construction) sit at the top with averages of 5.0 and 4.8, respectively. Both items also exhibit high agreement across respondents: cost predictability is uniformly scored 5 by all owners; time predictability is scored 5 by five owners and 4 by one. This indicates shared reliance on these indicators for routine control and escalation.

Alongside the two leaders, several items cluster in the 4.0–4.5 range: Cost per unit (4.4), Stakeholder satisfaction (4.1), Change orders (No.) - contractor-initiated (4.0) and Change orders (cost) - contractor-initiated (4.0). All other priorities are between 3.0 and 4.0, but Waste generation was the least important with a score of 2.9.

Open-ended suggestions were recorded. The final question invited additional priorities. Responses converged on four themes:

1. **Design quality**: a proposed KPI capturing change orders due to design errors/omissions (e.g., unmodeled slopes, constructability oversights). This extends "change orders" with an explicit attribution to design stage quality.
2. **Progress/Earned Value:** requests to include CPI/SPI-type indicators for a sharper cost–time view.
3. **Strategic and compliance alignment:** tracking mission alignment, scope/quality attainment, and compliance with environmental, heritage, archaeological, and health and safety requirements.
4. **Stakeholder and community:** interest in community impact and an all-stakeholder collaboration index.

This chapter combined workshop prioritization with a questionnaire validation, producing an owner-endorsed shortlist and clear signals on where measurement can expand as data pipelines improve. The next chapter discusses the implications of these results, presents conclusions, and outlines future work, including plans for pilot testing of the prioritized KPIs.

CHAPTER 4

DISCUSSIONS

This thesis set out to assist Québec public project owners in measuring the impact of innovation with indicators that are both decision-useful and feasible to collect. While project success in construction has historically been framed by the "iron triangle" of cost, time, and quality (Atkinson, 1999 ; Chan & Chan, 2004), recent research argues for broader performance dimensions, including risk, stakeholder value, sustainability, and innovation (OECD & Eurostat, 2018 ; Oesterreich & Teuteberg, 2016 ; Toor & Ogunlana, 2010). By building on this expanded performance logic, the present research clarifies how innovation-related performance can be measured within the operational realities of Québec's public construction governance. The empirical findings confirm this overall trajectory yet refine it for the provincial context by showing where public owners are ready to act now, where consensus is still forming, and how measurement can be made operational within existing data capacities.

Interviews and workshops reaffirmed that PPOs continue to rely on a narrow operational core, chiefly cost and time predictability—findings consistent with prior international studies (Bassioni, Price, & Hassan, 2005 ; Tabatabaee et al., in press). However, three key departures from existing literature emerged, demonstrating a distinctive orientation of Québec's public project owners toward risk, sustainability, and scope management as foundations for innovation performance.

First, rather than emphasizing simple tallies (e.g., number of risks), owners ranked the Scope of risks (risk-exposure score) and the Cost of risk mitigation among the most useful KPIs. This shifts attention from frequency to exposure reduction and mitigation effectiveness, aligning with a value-oriented view of risk management largely underdeveloped in earlier KPI frameworks. In several systematic reviews of construction performance indicators, risk metrics were either peripheral or represented only by basic counts without assessing mitigation effectiveness or exposure (Barlish & Sullivan, 2012 ; Bassioni et al., 2005 ; Coates et al., 2010 ; Cox et al., 2003 ; John Egan, 1998 ; Rankin et al., 2008 ; Y. Zhang, Pan, Pan, & Wu, 2025 ; Z. Zhang et al., 2022 ; Zou, Zhang, & Wang, 2007). By contrast, Québec's PPOs placed risk-related indicators among their top priorities, signalling a clear recognition that managing uncertainty and resilience is intrinsic to public value creation. This result extends previous work (Aven, 2016) by showing how risk quality has become a central pillar of innovation evaluation, representing a shift from reactive control to proactive governance. It also highlights that in a public-sector context, where accountability and transparency are paramount, risk exposure and mitigation costs provide tangible evidence of innovation's effectiveness in reducing vulnerability.

Second, PPOs demonstrated a preference for concrete and measurable sustainability indicators—specifically Energy consumption, Carbon footprint, and Waste generation—rather than high-level certifications or broad "community effect" measures. This pragmatic orientation contrasts with previous sustainability frameworks (Illankoon et al., 2017 ; Z. Zhang et al., 2022) that propose comprehensive multidimensional indicator sets but often fail to account for the data and governance constraints typical of public agencies. The focus on operational sustainability illustrates a gradual, data-driven evolution: PPOs aim to measure what can be implemented now, while building capacity to expand toward higher-order social and ecological outcomes over time. This incremental logic mirrors findings by Oesterreich and Teuteberg (2016), who observed that digital maturity and sustainability readiness evolve hand-in-hand; performance systems must therefore begin with tangible metrics that can later scale into integrated environmental accounting frameworks.

A third notable finding concerns the prominence of scope-management indicators. Nearly one-third of the validated shortlist, five of the 17 KPIs, fall under the scope category, including Change orders (cost and number, client- and contractor-initiated) and Requests for Information (RFI). While scope-related metrics appear in earlier frameworks (Galjanić, Marović, & Hanak, 2023 ; Mohammadali Noktehdan, Shahbazpour, & Wilkinson, 2015 ; Z. Zhang et al., 2022), their elevated importance here reveals how Québec's PPOs interpret innovation not merely as technological advancement but as an organizational transformation in coordination, documentation, and decision-making processes. Accordingly, scope-related KPIs serve as proxies for innovation maturity, capturing how effectively new digital and procedural tools are embedded into governance practice. The frequency and nature of change orders or RFIs thus become leading indicators of collaboration quality and knowledge integration within project delivery.

Beyond these findings, the study also highlights varying levels of innovation readiness and persistent implementation challenges. Although BIM adoption or “technological innovation” is prominent in the literature (Volk, Stengel, & Schultmann, 2014), PPOs questioned their immediate feasibility and comparability, emphasizing that reliable definitions, standardized data, and governance frameworks are prerequisites for systematic measurement. This insight aligns with findings by Heaton, Parlikad, and Owens (2019), who stressed that digital transformation performance in infrastructure organizations cannot be meaningfully assessed until data maturity and inter-organizational interoperability are in place. Consequently, this thesis advances the field by distinguishing between what is conceptually valuable and what is operationally achievable in the current public governance context.

A notable finding of this study is that no societal KPIs were retained, despite their prominence in international public-sector performance frameworks (OECD, 2009 ; OECD & Eurostat, 2018). This outcome illustrates a recurring tension between the theoretical relevance of broad societal outcomes and the practical feasibility of measuring them within the current Québec public-project environment. Societal impacts require long-term, cross-project, and often qualitative evidence, none of which are currently standardized or systematically tracked across PPOs. The absence of such indicators should therefore not be interpreted as a lack of importance, but rather as a reflection of institutional and data-system constraints that limit what can be meaningfully monitored at present.

This finding aligns with a broader methodological insight that emerged from the prioritization exercise: while measurability was treated as a central criterion, many of the assigned scores reflected participants’ perceptions of measurability rather than the objective measurability of the KPIs. Several indicators rated as “difficult to measure” are, in fact, routinely quantified in large public projects elsewhere. Quality non-conformities are systematically documented, claim amounts are formally recorded, and safety and communication metrics have been collected for decades. The gap, therefore, is not one of inherent technical difficulty but one of organizational awareness, accessibility, and routine use of data.

This misalignment between perceived and actual measurability highlights deeper organizational realities. Data that exist in principle may be difficult for PPO teams to access due to siloed information systems, fragmented responsibilities, or weak coordination between operational and strategic functions. Indicators associated with higher administrative overhead may be judged burdensome even when the underlying data are already captured elsewhere. For sensitive metrics, such as claims or disputes, concerns about confidentiality may shape PPOs’ judgments about practicality more strongly than the true ease of measurement. As a result, measurability scores often reflect organizational readiness and comfort, rather than technical feasibility. This dynamic helps explain both the exclusion of societal KPIs and the undervaluation of several well-established performance indicators, underscoring the need for more integrated data governance and clearer internal visibility of existing information systems.

These insights call for a more critical interpretation of the prioritization results. A KPI deprioritized due to “low measurability” may still represent a highly valuable innovation indicator once structural or procedural barriers are addressed. Therefore, the findings should not be read as a definitive assessment of what is or is not measurable in Québec’s public sector, but rather as a snapshot of current practices, perceptions, and institutional constraints. A more robust approach in future work could involve challenging PPO assessments using objective audits of existing data streams, demonstrating where data already exist, and highlighting how certain indicators could be operationalized with minimal additional effort. Such a comparative exercise would not only refine the prioritization outcomes but also support capacity-building across PPOs by revealing untapped data sources and reinforcing a culture of evidence-based performance monitoring.

Another consideration is the potential influence of deadweight, defined as the portion of observed outcomes that would have occurred independently of the innovation initiative. At this stage, accurately quantifying deadweight is not feasible, largely because public organizations lack the baseline data, counterfactual comparisons, and longitudinal tracking required for such calculations. Nevertheless, recognizing the existence of deadweight remains essential. Even if it cannot be measured directly within the current research scope, the study has sought to incorporate the concept conceptually by acknowledging that not all performance improvements can be fully attributed to innovation interventions. Some changes may stem from ongoing organizational maturation, standardization of practices, or broader sectoral trends. Anticipating deadweight in this way ensures that future applications of the KPI framework, and future calculations of innovation ROI, are interpreted with appropriate caution. Moving forward, research should incorporate project-level comparative assessments or counterfactual analyses to distinguish genuine innovation impacts from natural project evolution. Integrating deadweight at the conceptual stage strengthens the methodological rigor of the framework and prevents overstating the contribution of innovation.

A central conceptual challenge emerging from this study is distinguishing project impact from innovation impact. Project impact reflects the performance outcomes directly tied to the characteristics of a specific project—its budget, scope, complexity, design maturity, or contractor performance. Innovation impact, by contrast, refers to the incremental value generated by new processes, tools, or technologies, such as BIM-enabled coordination, enhanced risk visibility, or digital communication workflows. In practice, these two layers of performance are intertwined, making clean separation difficult. This study addresses the issue by emphasizing KPIs that reveal process improvements rather than final project outcomes alone. Indicators such as RFIs, change orders, risk exposure, or mitigation cost reflect how coordination, documentation, and decision-making evolve under innovation, regardless of the project's baseline complexity. By prioritizing KPIs that capture underlying processes, the framework provides a clearer distinction between outputs of project execution and outputs attributable to innovation adoption. This conceptual decoupling does not fully eliminate overlap but offers a practical approach for PPOs to isolate the contribution of innovation to performance improvement.

The usefulness of the KPI framework lies in its ability to translate the abstract notion of "innovation impact" into measurable, comparable, and operational indicators aligned with Québec public-sector constraints. In the absence of standardized KPIs, PPOs have difficulty demonstrating value to internal decision-makers, justifying investments in digital transformation, or benchmarking performance across agencies. The validated set of 17 KPIs offers an actionable starting point that can be progressively implemented without requiring new IT infrastructure or advanced data maturity. For instance, risk exposure scoring, change-order patterns, and RFI volume are already tracked—though inconsistently—across several agencies. Aligning these into a common structure provides an immediate instantiation of the framework. Recommendations include: (1) adopting the 17 KPIs as a baseline set for all major public projects, (2) mapping each KPI to the project life cycle to determine the appropriate moment of measurement, (3) establishing data-governance protocols to support comparability, and (4) gradually expanding toward innovation-specific indicators once organizations achieve greater digital readiness. These steps allow PPOs to build toward long-term benchmarking while collecting meaningful evidence in the short term.

The slow progress in establishing innovation-related KPIs reflects deeper structural and institutional challenges rather than lack of interest. Several PPOs emphasized that innovation measurement requires data maturity, governance standards, interoperable systems, and cultural readiness, all of which take years to develop. Prior to the BIM Roadmap, agencies were operating with disparate project-management tools, inconsistent definitions of performance, and varying levels of digital readiness. Without shared terminology or comparable data structures, KPI implementation would have produced unreliable and non-actionable outputs. Additionally, innovation in the public sector is subject to stringent accountability, risk aversion, and procurement regulations, which slow down experimentation and limit the ability to introduce new metrics without formal validation. The time invested in this research reflects the need for consensus-building across organizations, ensuring that the selected KPIs are not only theoretically sound but also feasible within current reporting capabilities. Thus, implementation did not occur earlier because the organizational, technological, and cultural foundations required for meaningful measurement were not yet in place.

Finally, the methodological contribution of this research lies in its ability to balance coverage and feasibility. The consensus-weighted prioritization model introduced here adjusts the average usefulness and measurability of each KPI by stakeholder agreement. This approach rewards metrics that are not only highly valued but also consistently supported across participants, producing a balanced prioritization where usefulness carries 80% of the total weight and measurability 20%. This ensures that indicators are both decision-relevant and feasible to collect within existing systems.

Such weighting provides a transparent, replicable mechanism for identifying “owner-ready” indicators, those that combine practical significance with strong consensus, and establishes a framework that other jurisdictions can adopt to institutionalize innovation measurement in their own contexts.

While the initial list comprised 42 KPIs across nine performance dimensions, a smaller subset of 17 indicators was retained for operationalization. This reduction was guided by practical feasibility and representativeness rather than by ranking alone. Implementing a large number of indicators simultaneously would be unrealistic given current data-system maturity and reporting capacity. The selected 17 KPIs therefore, represent an optimized balance between comprehensiveness and manageability: broad enough to capture key facets of project performance yet compact enough to be actionable within current governance structures.

Importantly, these 17 KPIs were not simply the top-ranked items by score. Post-workshop validation and expert review confirmed that each included metric satisfied two essential conditions: (1) strong consensus among PPOs on both usefulness and measurability, and (2) adequate coverage across all performance categories (except innovation). At this stage, the absence of a dedicated innovation metric reflects the limited data maturity and inconsistent measurement practices across public organizations. However, as digital infrastructures evolve and data governance frameworks mature, the Innovation category can be expanded. This progressive approach ensures that the KPI system remains both practical today and scalable for the future, allowing the framework to grow with technological readiness.

Moderately ranked indicators, such as Waste generation and Carbon footprint, were intentionally retained to ensure environmental representation, while overrepresented categories, such as cost and time, were limited to maintain balance. The resulting set is thus context-appropriate, implementable, and capable of capturing innovation's multifaceted impacts. The final shortlist demonstrates balanced coverage shown in the following Table 4.1:

Table 4.1 Final 17 KPIs and coverage

Category	**Metrics**
Cost	Cost predictability (Design/Construction) Cost per unit
Time	Time predictability (Design/Construction) Time per unit
Productivity	Labor productivity - $/unit
Quality	Stakeholder satisfaction
Safety	Lost Time
Scope	Change order (Cost) - client-initiated Change order (Cost) - contractor initiated Change orders - client-initiated Change orders - contractor-initiated Requests for information (RFI)
Sustainability	Carbon Footprint Energy Consumption Waste generation
Risk	Scope of risks (Risk-exposure score) Cost of risk mitigation

In practical terms, these 17 KPIs establish a robust, evidence-based foundation for Québec's emerging benchmarking initiatives, enabling PPOs to track innovation performance systematically, refine data collection processes, and progressively connect project-phase indicators to post-handover and life-cycle outcomes. Over time, as the system matures, this KPI framework will enable a more comprehensive evaluation of the true return on innovation (ROI) across Québec's public infrastructure portfolio.

CONCLUSIONS

This research set out to address a central question: **How can Québec PPOs measure the impact of their innovation initiatives?** To answer this, the study pursued three specific objectives:

1) To clarify essential concepts, performance, impact, and innovation;
2) To critically analyze existing performance measurement approaches in the construction industry; and
3) To identify, prioritize, and validate a set of KPIs that link short-term project outcomes with broader, long-term innovation impacts.

This first objective was achieved through a systematic literature review (Appendix V), which synthesized definitions and frameworks from both construction and broader innovation-evaluation research. The review clarified the conceptual boundaries between performance measurement (concerned with activities and outputs) and impact assessment (concerned with long-term outcomes and value creation), adapting established definitions from the Oslo Manual and related impact-measurement literature.

Through this conceptual clarification, the study demonstrated that innovation in construction should not be treated solely as a technological change, but rather as a process of organizational, social, and environmental transformation that influences performance across multiple levels, from project delivery to public value creation. This conceptual groundwork directly informed the design of later research phases by ensuring that the KPIs selected were aligned not only with operational performance but also with innovation's extended impacts.

The second objective was achieved through both the literature synthesis and semi-structured interviews with Québec PPOs. The analysis confirmed that existing performance measurement systems in the construction sector remain dominated by conventional "iron triangle" indicators, cost, time, and quality, while broader dimensions such as risk, sustainability, and innovation are inconsistently measured or poorly integrated.

However, this study went beyond critique: it empirically mapped how PPOs currently measure performance, identifying gaps between conceptual frameworks and real-world practice. The interviews and subsequent workshops revealed that challenges are not due to a lack of indicators but rather stem from implementation barriers, fragmented data systems, inconsistent analytics, and limited integration between innovation efforts and monitoring frameworks.

By combining insights from the literature and field data, this phase positioned the study within the global discourse on digital transformation and innovation measurement, demonstrating that the Québec context mirrors international challenges but also shows readiness for incremental progress through structured, owner-driven KPI frameworks.

The third and primary objective was realized through an iterative process involving workshops and a post-workshop validation questionnaire. Building on the initial list of 42 KPIs identified in the literature and refined through interviews, participants collaboratively assessed each metric's usefulness and measurability using a two-dimensional matrix.

A novel methodological contribution of this thesis is the consensus-weighted prioritization model, which integrates stakeholder agreement (measured by interquartile range) with the average usefulness and measurability scores. This weighting method, emphasizing usefulness (80%) over measurability (20%), ensured that the final KPI shortlist reflects both strategic relevance and practical feasibility.

The outcome was a validated shortlist of 17 KPIs covering eight performance dimensions: Cost, Time, Productivity, Quality, Safety, Scope, Sustainability, and Risk. This shortlist balances traditional project controls with forward-looking indicators that capture the wider dimensions of innovation. In doing so, the research delivers a well-developed, evidence-based measurement framework that PPOs can apply in both routine reporting and long-term benchmarking.

Through this structured and multi-phase approach, the thesis provides an answer to the guiding research question. Québec's public project owners can measure the impact of innovation by adopting a tiered, consensus-driven KPI framework that integrates traditional performance metrics with emerging sustainability and risk-based indicators. The framework emphasizes what can be reliably measured today while remaining scalable as digital infrastructures mature.

This practical approach enables PPOs to transition from static, short-term reporting to dynamic, impact-oriented monitoring, bridging the gap between innovation implementation and measurable outcomes. The process itself, based on stakeholder engagement, validation, and iterative refinement, serves as a transferable model for other jurisdictions seeking to operationalize innovation measurement within public-sector governance.

Limitations and Future Work

The main limitation of this study lies in its regional scope, and small sample size. The research was conducted exclusively within the Québec public sector and involved a limited number of public project owners. While this focus allowed for in-depth engagement and contextual precision, it also constrains the generalizability of the findings to other jurisdictions or governance structures. Broader validation across additional Canadian provinces or international public agencies would be necessary to test the transferability of the proposed KPI framework.

A second limitation concerns that by interviewing selected individuals rather than entire teams, there is a risk that knowledge gaps affect prioritization, as participants may not have full visibility over all organizational processes. Mitigation strategies included diverse representation across management and technical roles, iterative workshops, and post-workshop questionnaires. Broader organizational participation would enhance robustness in future studies.

A third limitation concerns the absence of field application. While the study developed, validated, and prioritized KPIs through participatory workshops and a post-workshop questionnaire, it did not extend to pilot implementation on active projects. This omission was intentional, as the field application was not defined among the objectives of this master's thesis, and the research was conducted within a limited timeframe under individual academic constraints. The principal goal was to establish and validate a conceptual and methodological foundation for innovation measurement, an essential preliminary step before real-world implementation. Consequently, field validation is proposed as a subsequent phase of research.

Another limitation of this study is that the analysis did not consider the appropriate timing for measuring each KPI within the project lifecycle or at the organizational level. While the study identified and prioritized KPIs based on usefulness and measurability, it did not specify at what stage, initiation, planning, execution, close-out, or post-project, each indicator becomes meaningful or actionable. This temporal dimension is essential, as certain KPIs are only valid when measured at specific milestones, whereas others require continuous monitoring. The absence of this consideration limits the practical guidance for implementation, and future work should develop a timeline or deployment framework indicating when each KPI should be assessed to maximize accuracy and relevance.

Future work should also focus on operational pilots to test the proposed KPIs under real project conditions, document data collection challenges, and refine thresholds, weighting, and reporting protocols where applicable. Over time, as digital infrastructures and interoperability improve, additional innovation-oriented indicators can be incorporated to capture innovation's full impact across the asset life cycle.

Finally, comparative studies involving private-sector owners or inter-provincial benchmarking initiatives would strengthen external validity and allow the measurement of innovation return on investment across different organizational and regional contexts.

APPENDIX I

DETAILED METRIC DESCRIPTIONS, FORMULAS, AND ILLUSTRATIVE EXAMPLES - CHAPTER 1

Table-A I- 1 Descriptions of metrics - Table 1.3 reference

#	Metric	Description
1	***Cost***	
1.1	Cost predictability (Design/Construction)	The difference between the actual design/construction cost at the start of procurement and the estimated design/construction cost at the investment commitment stage, expressed as a percentage of the actual design/construction cost at the start of procurement.
1.2	Cost per unit (estimated & actual)	The average cost of the product at the tender stage (e.g., dollars per kilometer of pipe, dollars per square meter of floor space).
1.3	Cost in use (operating and maintenance)	The annual operating and maintenance cost after the "available for use" stage expressed as a percentage of the actual design and construction cost at the "available for use" stage.
	Time	
2.1	Time predictability (Design/Construction)	The difference between the actual design/construction time at the start of procurement and the estimated design/construction time at the investment commitment stage, expressed as a percentage of the actual design/construction time at the start of procurement.
2.2	Time per unit	The average time for the product at the tender stage (e.g., months per kilometer of pipe, months per square meter of floor space).
3	***Productivity***	
3.1	Labor productivity	Productivity measured as dollars per unit performed or units per hour.
3.2	Labor productivity	Productivity measured as units per hour.
3.3	Decision-making Latency	The average duration from the moment a decision is initiated (e.g., a formal decision request) to when the decision is formally made. Reflects how quickly the project team resolves decisions.
4	***Quality***	
4.1	Stakeholder satisfaction	The level of stakeholder satisfaction with the final product after all defects have been resolved.
4.2	Quality issues (punch-list)	The total count of punch-list items (non-conformances) identified at a given point (e.g., handover), indicating how many issues were found.
4.3	Cost for defects-warranty	The contractor's cost to rectify all defects during the maintenance period, between the "available for use" stage and the end of the contractually agreed defect rectification period, expressed as a percentage of the actual construction cost at the agreed defect rectification period.
4.4	Time for defects-warranty	The time taken by the contractor to rectify all defects during the maintenance period, between the "available for use" stage and the end of the contractually agreed defect rectification period, expressed in weeks.
4.5	Rework Rate	The proportion of project work (cost of rework amount in $) had to be redone or corrected after initial completion.

Table-A I- 1 Descriptions of metrics - Table 1.3 reference (continued)

#	Metric	Description
5	***Safety***	
5.1	Reportable incidents	The number of reported incidents measured against the hours worked during construction, expressed as incidents per 100,000 hours worked.
5.2	Lost Time	The amount of lost time due to incidents measured against the hours worked during construction, expressed as lost time per 100,000 hours worked.
6	***Scope***	
6.1	Change order (Cost) - client initiated	The change, attributable to client-approved change orders originating from the client or client representative, between the actual construction cost at the "available for use" stage and the estimated construction cost at the "commit to construct" stage, expressed as a percentage of the estimated construction cost at the "commit to construct" stage. This is measured by the approved cost of changes originating from the client or designer from the "commit to construct" stage to the "available for use" stage.
6.2	Change order (Cost) - contractor initiated	The change, attributable to client-approved change orders originating from the contractor, between the actual construction cost at the "available for use" stage and the estimated construction cost at the "commit to construct" stage, expressed as a percentage of the estimated construction cost at the "commit to construct" stage. This is measured by the approved cost of changes originating from the contractor from the "commit to construct" stage to the "available for use" stage.
6.3	Change order (Time) - client initiated	The change, attributable to client-approved change orders originating from the client or client representative, between the actual construction time at the "available for use" stage and the estimated construction time at the "commit to construct" stage, expressed as a percentage of the estimated construction time at the "commit to construct" stage. This is measured by the approved time for changes originating from the client or designer from the "commit to construct" stage to the "available for use" stage.
6.4	Change order (Time) - contractor initiated	The change, attributable to client-approved change orders originating from the contractor, between the actual construction time at the "available for use" stage and the estimated construction time at the "commit to construct" stage, expressed as a percentage of the estimated construction time at the "commit to construct" stage. This is measured by the approved time for changes originating from the contractor from the "commit to construct" stage to the "available for use" stage.
6.5	Change orders - client-initiated	The total number of client-initiated change orders
6.6	Change orders - contractor-initiated	The total number of contractor-initiated change orders
6.7	Claim numbers	Total number of claims submitted/logged.
6.8	Claim amount	The ratio of the total cost of claims awarded in the claimant's favor.
6.9	Requests for information (RFI)	The number of formal requests for information (RFIs) issued by contractors, consultants, or clients, typically measured per month or per million dollars of project value, indicating the clarity and completeness of design documents.
7	***Innovation***	
7.1	Procurement type	A measure of non-standard procurement practices compared against a checklist of standard practices from the "commit to invest" stage to the "commit to construct" stage (e.g., Did you use a procurement practice that was new to your organization?).

Table-A I- 1 Descriptions of metrics - Table 1.3 reference (continued)

#	Metric	Description
7.2	Management innovation	A measure of non-standard measurement practices compared against a checklist of standard practices from the "commit to invest" stage to the "available for use" stage (e.g., Did you use a management practice that was new to your organization?).
7.3	Lean Implementation Index	A measure of the adoption of lean principles (such as waste reduction, continuous improvement, and improved flow) within the project, assessed by the number of lean practices implemented and their effectiveness.
7.4	BIM Adoption Level	The degree to which Building Information Modeling (BIM) is integrated throughout the project lifecycle, typically measured against a recognized BIM maturity scale or the number of disciplines fully using BIM.
7.5	Technological innovation	The extent of new or advanced technologies deployed in the project's processes, measured by the proportion of tasks using these technologies or by comparing actual implementation against standard technology-adoption benchmarks.
8	***Sustainability***	
8.1	Certification	A measure of the improved level of sustainability in design and construction, assessed against a checklist of standard practices (e.g., measured against LEED Canada-NC Version 1.0 for buildings) from the "begin detailed design/commit to construct" stage to the "begin procurement/available for use" stage.
8.2	Material Consumption	The total amount of materials used in the project, measured against design estimates or industry benchmarks, expressed as the ratio of actual material usage to planned usage.
8.3	Waste generation	The volume of waste (construction or demolition) generated or minimized, measured by comparing total waste sent to landfill with project- or industry-specific targets.
8.4	Carbon Footprint	The total greenhouse gas emissions (in CO_2-equivalent) associated with the project's activities, from material production to construction and operation, measured over the project's lifecycle or a defined phase.
8.5	Waste Recycling Rate	The proportion of project waste that is recycled or repurposed, expressed as a percentage of the total waste generated during construction and demolition.
8.6	Energy Consumption	The amount of energy used throughout the project's construction and operation phases, measured in kilowatt-hours (kWh) or joules, and compared to baseline estimates or industry benchmarks.
8.7	Air Pollution	The level of atmospheric pollutants (e.g., particulates, NO_x, SO_x) emitted by the project, measured against local air quality regulations or relevant industry standards.
8.8	Community effect	The project's social and environmental impacts on surrounding communities, assessed by feedback from local residents, number of complaints logged, and any mitigation measures taken.
8.9	Water Pollution	The extent to which construction or operational activities introduce contaminants into water bodies, measured by pollutant concentrations or total discharge volume relative to regulatory limits.
9	***Risk***	
9.1	Number of risks quantified	The total number of risks identified on a project.
9.2	Scope of risks (Risk-exposure score)	The development of the project's risk profile, characterized as the total amount of risks identified on the project and their score as evaluated through their severity and probability.
9.3	Cost of risk mitigation	The total cost of risk mitigation is budgeted on a project.
9.4	Risk materialization	The total cost of the risks that have materialized on a project.

Table-A I- 2 Metric formulas and illustrative examples - Table 1.3 reference

#	Metric	Type	Formula	Example
1	***Cost***			
1.1	Cost predictability (Design/Construction)	Quantitative	((actual cost of design/construction – estimated cost of design/construction)/estimated cost of design/construction) x 100	If the estimated cost was $4M and the actual cost $5M, then vs. estimate = 25%.
1.2	Cost per unit (estimated & actual)	Quantitative	(tendered/actual cost)/(capacity measurement)	f $2,000,000 is spent to build 10,000 sq. m, then cost per unit =$200/m2
1.3	Cost in use	Quantitative	(annual operating cost arranged over years)/(final cost for construction & design) x 100	If annual O&M = $100k and the final cost = $2M, the ratio is 5%.
	Time			
2.1	Time predictability (Design/Construction)	Quantitative	(actual design/construction time – estimate design/construction time)/(actual design/construction time) x 100	If the actual time is 10 months and the estimate is 9 months, 10%
2.2	Time per unit	Quantitative	(contract time for construction)/ (capacity measurement)	If the contract time is 12 months for 4 km of pipeline, then 3 months/km.
3	***Productivity***			
3.1	Labor productivity	Quantitative	(Total $ value of work) / (Units produced)	If $12,000 of work for 120 units ⇒ $100/unit.
3.2	Labor productivity	Quantitative	(Units produced) / (Hours worked)	If 120 units are produced in 40 hours ⇒ 3 units/hr
3.3	Decision-making Latency	Quantitative	Average Decision Time = ∑ (Decision Made Date −Decision Start Date) / (Total Number of Decisions)	If 5 decisions took a total of 30 days from request to final decision, average latency = 6 days.
4	***Quality***			
4.1	Stakeholder satisfaction	Qualitative	Rating of performance from 1 to 7 with 1 being Extremely Dissatisfied and 7 being Extremely Satisfied	If 10 stakeholders rate it a total of 50 (on a 1–7 scale), average = 5.0 => "Satisfied."
4.2	Quality issues (punch-list)	Quantitative	- Punch-List Items = total number of items identified.	If 12 items are identified at handover ⇒ 12 punch-list issues.
4.3	Cost for defects-warranty	Quantitative	(construction cost of rectifying all defects)/(final cost for construction) x 100	If the final construction cost is $1M and defect rectification is $50k, then 5%
4.4	Time for defects-warranty	Quantitative	(time taken to rectify all defects/actual construction time) x 100	If it took 4 weeks to fix defects and the total construction time was 20 weeks, 20%
4.5	Rework Rate	Quantitative	(rework cost) / (total project amount) x 100	If $50 k rework on a $2 M project ⇒ 2.5 %.
5	***Safety***			
5.1	Reportable incidents	Quantitative	(number of reported incidents)/ (100 000 h worked)	If 2 incidents occur in 200,000 hr => 2 / (200,000) × (100,000)= 1 incident per 100k hr.
5.2	Lost Time	Quantitative	(amount of lost time to incidents)/ (100 000 h worked)	If 160 hr lost in 400,000 hr => (160) / (400,000) × 100,000 = 40 lost hr per 100k hr worked.

Table-A I- 2 Metric formulas and illustrative examples - Table 1.3 reference (continued)

#	Metric	Type	Formula	Example
6	***Scope***			
6.1	Change order (Cost) - client initiated	Quantitative	(approved cost for change originating from client)/(total project cost) x 100	If $200k in client-driven changes / $10M total cost = 2%
6.2	Change order (Cost) - contractor initiated	Quantitative	(approved cost for change originating from contractor)/(total project cost) x 100	If $300k in contractor-driven changes / $12M total cost = 2.5%.
6.3	Change order (Time) - client initiated	Quantitative	(approved time for change originating from client)/(total project time) x 100	If 3 weeks added to a 60-week schedule= 5%
6.4	Change order (Time) - contractor initiated	Quantitative	(approved time for change originating from contractor)/(total project time) x 100	If 2 weeks added to a 40-week schedule= 5%
6.5	Change orders - client-initiated	Quantitative	Number of change orders initiated by the client	If the number of change orders is 3, the KPI = 3.
6.6	Change orders - contractor-initiated	Quantitative	Number of change orders initiated by the contractor	If the number of change orders is 3, the KPI = 3.
6.7	Claim numbers	Quantitative	Number of Claims = ∑(All formal claims submitted)	If 3 formal claims have been lodged, the KPI = 3.
6.8	Claim amount	Quantitative	Total cost of claims awarded in claimant's favor	$200k is awarded to the claimant.
6.9	Requests for information (RFI)	Quantitative	(Total RFIs) / (total project time) or (Total RFIs) / (total project cost)	If total number of RFIs is 100: KPI = 100 / 10 = 10/Months or KPI = 100 / 25$M = 4/M$
7	***Innovation***			
7.1	Procurement type	Qualitative	No strict formula — typically an average Likert rating or count of new practices.	If the team rates their procurement innovation as 4.2 out of 5 => "High innovation."
7.2	Management innovation	Qualitative	No strict formula — typically an average Likert rating or count of new management methods.	If participants rate 4.5 out of 5 on 'new management practices' => "High management innovation."
7.3	Lean Implementation Index	Quantitative	Often calculated as Score = ∑ (Lean practices adopted ×Effectiveness weighting).	If 5 of 7 recommended lean tools are used effectively, LII might be 5 × 0.8 = 4.0 out of a possible 7.
7.4	BIM Adoption Level	Quantitative	Could be "BIM Level" (e.g., Level 2 or Level 3) or a numeric score summing adoption across disciplines.	If the project meets all Level 2 criteria => "BIM Level 2 Achieved.".
7.5	Technological innovation	Quantitative	(Tasks using new tech) / (Total tasks) ×100%	If 20 of 100 tasks used new technology => 20%.

Table-A I- 2 Metric formulas and illustrative examples - Table 1.3 reference (continued)

#	Metric		Type	Formula
8	***Sustainability***			
8.1	Certification	Qualitative	No strict formula. Often a score or certification level (e.g., LEED Silver).	If 75% of sustainability checklist items are met => "High sustainability compliance."
8.2	Material Consumption	Quantitative	(Actual material used) / (Planned material usage) ×100%	If actual steel usage is 900 t vs. 1000 t planned => 90%.
8.3	Waste generation		(Waste generated) / (Waste target) ×100% or simple "Total tons of waste sent to landfill."	If 50 t of waste is generated vs. a target of 80 t => 62.5% of the target.
8.4	Carbon Footprint	Quantitative	∑(Emission sources in CO_2e)	If raw materials + on-site operations total 5000 t CO_2e => project carbon footprint = 5000 t CO_2e.
8.5	Waste Recycling Rate	Quantitative	(Recycled or repurposed waste) / (Total waste) ×100%	If 80 t out of 100 t of waste is recycled => 80%.
8.6	Energy Consumption	Quantitative	Total Energy used= ∑(Energy usage over project phases)	If the project used 2,000,000 kWh in construction => compare to typical or planned usage.
8.7	Air Pollution	Quantitative	(Total pollutant mass) / (Volume of air) (or measure average concentration in mg/m³)	If average $PM_{2.5}$ is 50 µg/m³ vs. a 60 µg/m³ limit => within limit.
8.8	Community effect	Qualitative	Typically an average Likert rating or "# of complaints" vs. resolution.	If the average community satisfaction rating is 4.5/5 => "High acceptance."
8.9	Water Pollution	Quantitative	(Total pollutant mass) / (Discharge volume) or direct comparison to a limit (e.g., mg/L)	If effluent is 20 mg/L of pollutant vs. 25 mg/L limit => within limit.
9	Risk			
9.1	Number of risks quantified	Quantitative	∑(Risks identified)	If 5 risks were identified, so it is 5.
9.2	Scope of risks (Risk-exposure score)	Quantitative	Risk Exposure= Σ(Probability × Impact)	Risk A: 40 % × \$250 k = \$100 k; Risk B: 20 % × \$500 k = \$100 k ⇒ Total exposure = \$200 k.
9.3	Cost of risk mitigation	Quantitative	∑(Mitigation Budget for each risk)	Training = \$45 k, Backup generator = \$25 k, Insurance premium = \$10 k ⇒ KPI = \$80 k.
9.4	Risk materialization	Quantitative	∑(Actual cost impact of each risk that occurred)	Design error = \$120 k + Weather delay = \$40 k ⇒ KPI = \$160 k.

APPENDIX II

SEMI-STRUCTURED INTERVIEW QUESTIONNAIRE – CHAPTER 3

Identifier les indicateurs clés de performance (KPI) et les métriques pour le suivi et l'évaluation de la performance
Entretien semi-structuré
2024-10-21

Introduction

Ce document présente un ensemble de questions destinées à guider les entretiens avec les Donneurs d'ordres publics (DOP) Québécois sur la question du suivi et la mesure du progrès et du succès des projets. Le but de ce questionnaire est de comprendre les mécanismes que les DOP utilisent pour évaluer la performance de leurs projets. Cette étude fait partie de la première phase d'un projet de recherche visant à comprendre et documenter l'impact de la mise en œuvre d'innovations en matière de réalisation de projet, notamment la modélisation des données des infrastructures (BIM), sur la performance des projets publics dans le cadre de la Feuille de route gouvernementale pour le BIM. En recueillant des informations sur les pratiques actuelles, cette recherche vise à contribuer à une meilleure compréhension de la mesure de la performance dans la gestion des projets de construction.

Cette étude s'inscrit également dans le cadre d'une thèse de maîtrise et vise à fournir des recommandations pratiques pour la sélection et l'utilisation des indicateurs clés de performance (KPI) dans les projets de construction. Les résultats seront basés sur les expériences et pratiques des professionnels du secteur, garantissant ainsi l'applicabilité de la recherche aux scénarios réels.

Participation

Vous êtes invité(e) à participer à cette étude de recherche. Après avoir examiné ce document et accepté de participer, vous participerez à un entretien basé sur dix questions (+6 questions courtes pour la description de la personne interrogée) sur la mesure de la performance des projets. Il est estimé que l'entretien prendra entre 45 et 60 minutes. La participation est entièrement volontaire, vous pouvez donc vous retirer à tout moment. Si vous souhaitez interrompre l'entretien, vous pouvez en informer l'intervieweur et arrêter de répondre aux questions sans fournir de raisons.

Confidentialité

Les données recueillies dans le cadre de ce projet resteront confidentielles, conformément à la loi. Le chercheur principal à l'École de Technologie Supérieure conservera ces données pendant cinq ans. Leur seule utilisation sera de faire progresser les connaissances dans ce domaine. Elles pourront être publiées dans des rapports de thèse ou des articles, faire l'objet de discussions scientifiques ou être utilisées pour l'enseignement. Dans aucun de ces cas, il ne sera possible de vous identifier.

Votre participation est inestimable pour le succès de cette recherche et vos connaissances contribueront à façonner les recommandations pratiques.

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Bloc 1: Description de la personne interrogée

Table-A II- 1 Metric formulas and illustrative examples

1	Organisation :		
2	Département:		
3	Domaine principal de votre entreprise : **(choix multiple disponible)**		
3.1	☐	Résidentiel	Maisons unifamiliales, maisons multifamiliales, immeubles à appartements, etc.
3.2	☐	Industriel	Usines, entrepôts, usines de fabrication, centrales électriques, etc.
3.3	☐	Infrastructures	Routes, ponts, autoroutes, aéroports, tunnels, etc.)
3.4	☐	Institutionnel	Écoles, hôpitaux, bâtiments gouvernementaux, etc.
3.5	☐	Autres:	
4	Rôle/fonction actuelle dans l'entreprise :		
4.1	☐	Exécutif/Direction	PDG, COO, Président, Vice-Président, Directeur Général, Directeur.
4.2	☐	Gestion	Chef de Projet, Directeur des Opérations, Chef de Chantier, Chef d'Équipe, Directeur de Département.
4.3	☐	Ingénierie/Technique	Ingénieur (Civil, Structure, Mécanique, Électrique, etc.), Estimateur, Planificateur, Coordinateur de Bureau, Ingénieur de Chantier, Architecte, Géomètre, Superviseur de Chantier, Ingénieur de Terrain.
4.4	☐	Autres:	
5	Nom complet:		
6	E-mail:		

Bloc 2 : Identifier les indicateurs clés de performance (KPI) et les métriques pour le suivi et l'évaluation de la performance

1.1. Quels indicateurs clés de performance (KPI) utilisez-vous pour suivre les progrès et le succès de votre projet?

1.2. Comment avez-vous déterminé ces KPI et quels facteurs ont influencé votre sélection?

1.3. Quels types de données collectez-vous pour ces KPI? Sont-elles basées sur des mesures réelles, des données autodéclarées (enquêtes), ou un mélange des deux? Veuillez expliquer.

1.4. Y a-t-il des KPI spécifiques que vous considérez comme plus critiques que d'autres? Si oui, pourquoi?

1.5. Y a-t-il des KPI que vous croyez manquer ou que vous aimeriez ajouter? Si oui, quels sont-ils et pourquoi pensez-vous qu'ils sont importants?

1.6. À quelle fréquence collectez-vous des données pour soutenir vos KPI, et quels outils ou méthodes utilisez-vous pour les mesurer? Veuillez préciser les logiciels ou outils utilisés.

1.7. Comment analysez-vous les données des KPI? Comment présentez-vous les données des KPI? Pouvez-vous décrire le processus et les outils ou rapports que vous utilisez?

1.8. Rencontrez-vous des défis ou des limitations dans la collecte ou l'analyse des données des KPI? Comment gérez-vous ces défis?

1.9. Comment utilisez-vous les données des KPI pour prendre des décisions concernant les ajustements ou corrections de projet? Pouvez-vous donner un exemple?

1.10. Mesurez-vous l'impact d'une initiative au sein de vos projets? Pouvez-vous donner un exemple de la manière dont vous avez mesuré l'impact d'une initiative?

APPENDIX III

INTERVIEW THEMATIC ANALYSIS TABLES – CHAPTER 3

Table-A III.1 Key performance indicators used

Interview No.	**Theme**	**Code**	**Description**
Interview 1	Cost Management	Cost Gaps	Comparing initial and revised budgets
Interview 1	Cost Management	Disbursement Forecast Gaps	Monitoring financial disbursements over a 10-year plan
Interview 1	Schedule Management	Schedule Gap	Monitoring project timelines against initial plans
Interview 1	Scope Management	Scope Gap	Assessing differences between planned and actual project scope
Interview 1	Risk Management	Risk Levels	Evaluating risks using a color-coded system
Interview 1	Supplier Performance	Supplier Evaluation	Assessing the efficiency and performance of suppliers
Interview 1	Customer Satisfaction	Client Feedback	Measuring client satisfaction levels
Interview 1	Resource Management	Workload	Tracking workforce performance and capacity
Interview 2	Cost Management	Cost Control	Monitoring project costs and budget adherence
Interview 2	Schedule Management	Time Control	Monitoring project timelines and schedule adherence
Interview 2	Scope Management	Scope Control	Monitoring and controlling project scope
Interview 2	Environmental Management	Environmental Indicators	Monitoring environmental impact and compliance
Interview 2	Safety Management	Health and Safety	Tracking safety performance on construction projects
Interview 2	Resource Management	Workforce Monitoring	Tracking workforce performance and capacity
Interview 2	Innovation	Innovation Initiatives	Monitoring innovation within projects
Interview 2	Supplier Performance	Supplier Evaluation	Assessing the efficiency and performance of suppliers

Table-A III.1 Key performance indicators used (continued)

Interview No.	Theme	Code	Description
Interview 2	Social Management	Social Acceptability	Assessment of the social acceptability of the projects
Interview 2	Project Health Management	Health Index	Overall Project Health Index
Interview 3	Cost Management	Disbursement Tracking	Monitoring project disbursements compared to planned disbursements
Interview 3	Schedule Management	Schedule Tracking	Monitoring project timelines using color-coded indicators
Interview 3	Scope Management	Change Notice Tracking	Tracking directives and change notices, categorizing them
Interview 3	Risk Management	Risk Tracking	Monitoring and reporting risks for some projects
Interview 3	Sustainable Development	Energy Performance Targets	Targeting to exceed energy codes by a certain percentage
Interview 4	Schedule Management	Project Stages	Following projects in development, production, or operation (housing units)
Interview 4	Schedule Management	Delivery of Housing Units	Tracking delivery times and compliance with program-defined deadlines for housing projects
Interview 4	Building Condition	Condition Index	Using condition index (A to E) to monitor state of buildings and impact of renovations on reducing dilapidation
Interview 4	HLM Renovation	Building Health	Tracking HLM renovation projects to see improvement in overall building condition
Interview 4	Cost Management	Cost monitoring	Cost of production
Interview 5	Tactical Indicators	Three-Layer Indicators	Portfolio evolution and risk management
Interview 5	Cost Management	Cost Compliance	Comparing authorized budget vs. final cost
Interview 5	Schedule Management	Schedule Compliance	Checking schedule vs. planned duration
Interview 5	Cost Management	Earned Value (CPI, SPI)	Using earned value analyses for each subcontract or specialized work package
Interview 5	Productivity Rates	Labor Attendance	Correlating on-site labor hours with planned tasks to identify performance issues

Table-A III.2 Determination and selection of KPIs

Interview No.	Theme	Code	Description
Interview 1	PMI Standards	Golden Triangle	Based on cost, budget, and schedule for project balance
Interview 1	Strategic Planning	Annual Planning	Setting objectives through annual, program, and portfolio planning
Interview 1	Efficiency Through Gap Analysis	Identification of Gaps	Using KPIs to identify gaps and adjust
Interview 2	PM Principles	Project Management Triangle	Based on cost, time, and scope for project balance
Interview 2	Strategic Alignment	Priority Areas	Cost, time, health, safety, and environment are top priorities
Interview 2	Evolving Indicators	Indicator Evolution	Indicators evolve based on current issues and feedback
Interview 2	Stakeholder Collaboration	Collaboration with Teams	Working with project teams to develop indicators
Interview 3	Stakeholder Expectations	Elected Officials' Questions	Indicators based on questions from elected officials and general management
Interview 3	Portfolio Management	Project Portfolio Approach	Implementing a more mature project portfolio management approach
Interview 3	Strategic Alignment	Link to Strategic Planning	Aligning indicators with strategic planning of the department
Interview 3	Process Improvement	Additional Indicators	Opportunity to add more KPIs through the portfolio approach
Interview 4	Ministerial Request	Transparency	KPIs chosen based on minister’s desire for transparency and demonstration of project progress
Interview 4	Government Dashboards	Public Bar Chart	Standard approach to show data publicly, influenced by Health/Education dashboards
Interview 4	Program-Specific KPIs	PRHLM Program	Need for building condition, renovation impact, compliance with program standards
Interview 5	Portfolio Expansion	Rapid Growth of Projects	Need for uniform performance approach due to a surge in government investments in major projects
Interview 5	Auditor General	Accountability Requirements	Mandate to introduce objective cost/schedule indicators and consistent data integrity
Interview 5	Strategic Plans	Targets for Cost & Time	Authorized budget vs. final cost and schedule param tied to organizational plan
Interview 5	Executive & Ministerial	Ministerial Priorities	Indicators responding to high-level demands for transparent, timely project performance data

Table-A III- 3 Data collection frequency, methods, and tools

Interview No.	Theme	Code	Description
Interview 1	Data Entry Methods	Manual Data Entry	Using Excel-based tools with manual data entry
Interview 1	Tools Used	MIGP	Integrated Project Management Methodology for data centralization
Interview 1	Data Challenges	Data Delays	Delays hinder real-time analysis
Interview 1	Data Measurement	Mix	Actual and self-reported data
Interview 1	Data Frequency	Monthly Data Collection	Data is collected and extracted every month
Interview 1	Tools Used	Excel	Primary tool for data entry and analysis
Interview 1	Tools Used	Clicsense	Used for accessing financial data
Interview 1	Visualization Tools	Dashboards and Indicators	Using Excel to create dashboards
Interview 1	Data Analysis	Forecast Trend Curves	Visual representations of projections
Interview 1	Data Consolidation	Global Dashboard	Provides an overall picture of the portfolio
Interview 2	Data Entry Methods	Multiple Systems	Data collected from various systems
Interview 2	Tools Used	Cost Management System	Using Planisware for project cost management
Interview 2	Tools Used	Schedule Management Systems	Using MS project and Primavera for schedule management
Interview 2	Tools Used	Cognos and Power BI	Using Cognos and Power BI for data extraction and reporting
Interview 2	Tools Used	Excel	Using Excel to create dashboards
Interview 2	Tools Used	Power BI	Using Power BI to create dashboards
Interview 2	Data Challenges	System Integration Issues	Challenges due to multiple systems and lack of full integration
Interview 2	Data Measurement	Mix	Actual and self-reported data
Interview 2	Data Challenges	Data Delays	Delays hinder real-time analysis
Interview 2	Data Frequency	Monthly Measures	Performance measured monthly, with some weekly/daily follow-ups
Interview 2	Data Challenges	Data Refresh Cycles	Data availability depends on system updates and cycles

Table-A III- 3 Data collection frequency, methods, and tools (continued)

Interview No.	Theme	Code	Description
Interview 2	Tools Used	Daily Management Systems	Using daily systems for health, safety, and environment
Interview 2	Visualization Tools	Dashboards	Using Excel and transitioning to Power BI for data visualization
Interview 2	Data Presentation	Uniform Presentation	All indicators presented in the same standardized format
Interview 2	Data Presentation	Multi-Level Dashboards	Same view presented at different organizational levels
Interview 3	Data Entry Methods	Manual Data Entry	Project managers manually input data into systems
Interview 3	Tools Used	SharePoint and Excel	Using SharePoint lists and Excel for data collection and dashboards
Interview 3	Change Notice Tracking	Change Notice System	Organized process for collecting change notices
Interview 3	Schedule Data	Reliance on Contractors	Using contractor's schedule to assess progress
Interview 3	Data Challenges	Lack of Integration	Difficulty linking project management and financial systems
Interview 3	Data Measurement	Self-reported data	Entered manually by the project managers
Interview 3	Data Challenges	Data Delays	Delays hinder real-time analysis
Interview 3	Data Frequency	Monthly Updates	Financial and schedule data updated monthly
Interview 3	Sustainable Development	Milestone-Based Updates	Energy calculations updated at specific project milestones
Interview 3	Visualization Tools	Excel and Power BI	Using Excel for dashboards; plans to transition to Power BI
Interview 3	Tools Used	Excel	Using Excel to create dashboards
Interview 3	Tools Used	Power BI	Using Power BI to create dashboards
Interview 3	Data Presentation	Standardized Tools	Project managers use the same templates and tools
Interview 3	Data Challenges	Variation in Reporting	Variation in how project managers report and assess project health
Interview 4	Tools Used	Excel	Using Excel to create dashboards
Interview 4	Tools Used	Power BI	Using Power BI to create dashboards
Interview 4	Data Entry Methods	Multiple Systems	Some data in internal systems and some from manual tables or project manager updates

Table-A III- 3 Data collection frequency, methods, and tools (continued)

Interview No.	Theme	Code	Description
Interview 4	Data Frequency	No strict single interval	Some data updated as projects move stages, no strict single interval, depends on program/initiative
Interview 4	Visualization Tools	Dashboards	Power BI used to display data, ensure public transparency, also fosters data culture
Interview 4	Tools Used	BSI Tool	Using building condition index for HLM, data fed into Power BI for dashboards
Interview 4	Data Presentation	Ministerial Transparency	Presenting data publicly in user-friendly dashboards for accountability
Interview 4	Data Entry Methods	Manual Data Entry	Project managers manually input data into systems
Interview 4	Data Challenges	Data Delays	Delays hinder real-time analysis
Interview 5	Tools Used	SA (In-House System)	Stores financial/contract data, feeding strategic & tactical indicators, with partial integration
Interview 5	Tools Used	Excel	Project control officers use Excel for operational-level CPI/SPI
Interview 5	Tools Used	Power BI	Data is visualized via Power BI
Interview 5	Visualization Tools	Power BI	Project control officers compile data in Excel, transform into dashboards or bar charts in Power BI for multi-level reviews
Interview 5	Schedule Software	MS Project, Primavera	Projects use scheduling tools; data is cross-checked by project control officers for monthly or quarterly updates
Interview 5	Labor Attendance Data	Security Punch System	Collecting real-time site attendance from contractors to measure actual workforce productivity
Interview 5	Data Validation	Quality Audits	Auditing projects at least once a year to ensure data reliability before final KPI reporting
Interview 5	Data Frequency	Quarterly Updates	Collecting official data on Mar 31, Jun 30, Sep 30, Dec 31 for government budget cycles
Interview 5	Data Frequency	Monthly Service Notes	Many projects get monthly or bi-monthly KPI updates with service notes or operational reports
Interview 5	Data Frequency	Bi-Monthly Workshops	Project managers and project control officers align on data collection, then finalize results in a second session
Interview 5	Data Frequency	Operational Real-Time	For large in-play projects, PCO can access site attendance in near real-time for performance checks
Interview 5	Data Entry Methods	Multiple Systems	Data collected from various systems
Interview 5	Strategic/Tactical	Summary Progress Reports	Quarterly or four times a year, data is audited and presented to executives, aligning with budget cycles
Interview 5	Service Notes	Monthly/Quarterly Issue Notes	Delivering in-depth cost, schedule, risk evaluations to directors and VPs

Table-A III- 3 Data collection frequency, methods, and tools (continued)

Interview No.	Theme	Code	Description
Interview 5	Operational Reports	PCO Detailed Analysis	CPI, SPI, labor productivity, critical path reviews in a 10-20 page format
Interview 5	Security & Access	Common Repository	Project files stored in a secure central space with role-based access
Interview 5	Data Entry Methods	Manual Data Entry	Project managers manually input data into systems

Table-A III- 4 Critical KPIs

Interview No.	Theme	Code	Description
Interview 1	Primary KPIs	Costs and Budget	Indicates potential overruns; crucial due to tight budgets
Interview 1	Portfolio Impact	Impact on Portfolio	Slippages affect overall portfolio of 450 projects
Interview 1	Proactive Management	Early Intervention	Enables early detection and intervention
Interview 2	Primary KPIs	Costs and Deadlines	Cost and time are critical KPIs due to their impact
Interview 2	Safety and Environment	Health, Safety, Environment	High priority areas monitored closely
Interview 2	Organizational Priority	Board Confirmation	Top KPIs confirmed by Board of Directors
Interview 3	Primary KPIs	Cost and Schedule	Cost and time are the primary focus due to stakeholder interest
Interview 3	Simplicity Preference	Limit on Number of KPIs	Managers prefer not to have too many KPIs or cumbersome methodologies
Interview 3	Emerging KPIs	Under Development	Additional KPIs may emerge from the portfolio management approach
Interview 4	Delivery Focus	Housing Delivery Speed	Crucial KPI ensuring projects don't remain too long in development, meeting ministerial commitments
Interview 4	Building Health	Reducing Dilapidation	Improving building condition index for social housing as a top strategic goal
Interview 5	Primary KPIs	Cost & Schedule Focus	Monitoring compliance with authorized budget and planned duration
Interview 5	Enterprise Risk	Thresholds and Tolerance	Managing corporate risk by linking cost/schedule deviations to corrective measures if passing certain bounds
Interview 5	Primary KPIs	Scope Compliance	Ensuring final project meets surface area/functional requirements authorized by the government

Table-A III- 5 Desired additional KPIs and metrics

Interview No.	Theme	Code	Description
Interview 1	Earned Value Management	CPI, SPI, TCPI, CV	Metrics for accurate performance assessment
Interview 1	Human Capacity Metrics	Resource Utilization	Tracking hours spent per phase
Interview 1	Project Complexity	Complexity Statistics	Measuring complexity levels
Interview 1	Quality Metrics	Number of Change Orders	Evaluating on-site changes
Interview 1	Quality Metrics	Number of Addenda	Tracking issued addenda for professional performance
Interview 1	Depth of Analysis	Deeper Insights	Need for more in-depth analysis
Interview 2	Proactive Indicators	Proactive Measurement	Need for more predictive and proactive indicators
Interview 2	Milestone Analysis	Major Milestones	Analyzing major milestones for better forecasting
Interview 2	Supply Chain Visibility	Supply Issues	Lack of visibility on supply chain impacting projects
Interview 2	Quality Metrics	Non-conformities and complaints	Interest in indicators like non-conformities and complaints
Interview 2	Standardization	Project Categories	Implementing project categories to adapt monitoring
Interview 3	Portfolio Visibility	Centralized Monitoring	Desire to implement more centralized project monitoring tools
Interview 3	Energy Performance	Post-Construction Validation	Interest in validating energy targets after construction
Interview 3	Process Improvement	Additional Indicators	Opportunity to add more KPIs through the portfolio approach
Interview 4	Environmental/ Social	Impact Indicators	Opportunity to measure carbon footprint, sustainability metrics, or community impact
Interview 4	Cost Metrics	Additional Indicators	Monitoring whether costs remain within the initial amount, especially for HLM renovation
Interview 5	Sustainability Goals	GHG Reductions	Interest in carbon footprint or climate risk indicators aligned with strategic plan
Interview 5	Social Acceptability	Stakeholder/Community Impact	Monitoring social acceptance for large projects

Table-A III- 5 Desired additional KPIs and metrics (continued)

Interview No.	Theme	Code	Description
Interview 5	BIM & Collaboration	BIM-Specific Indicators	Planning to measure changes, errors, or site directives correlated with BIM usage
Interview 5	Productivity Standard	Standardizing Productivity	Hoping to expand consistent tracking of labor attendance and performance across more projects

Table-A III- 6 Challenges in data collection and analysis

Interview No.	Theme	Code	Description
Interview 1	System Integration/Limitations	Inadequate Systems	Reliance on Excel; lack of advanced tools
Interview 1	Data Analysis	No Baseline Capability	Unable to perform multi-baseline analyses
Interview 1	Data Quality	Variability in Data Entry	Inconsistencies in data entry and interpretation
Interview 1	Human Factors	Human Resources	High staff turnover affects data quality
Interview 1	Human Factors	Project Manager Expertise	Varying levels of knowledge among project managers
Interview 2	System Integration/Limitations	Multiple Systems	Challenges due to many systems not fully integrated
Interview 2	Data Quality	Data Discrepancies	Potential discrepancies between systems
Interview 2	Standard System	System Interoperability	Lack of seamless data flow between systems
Interview 2	Standard System	Need for Uniform Tools	Working towards standardizing tools and systems by 2025
Interview 3	Human Factors	Lack of Dedicated Resources	Lack of resources for data collection and monitoring
Interview 3	Data Quality	Manual Data Entry Issues	Potential for errors due to manual data entry by project managers
Interview 3	Data Lag	Delayed Data Updates	Time lag in data due to invoicing and payment processes
Interview 3	Human Factors	Variability in Reporting	Variation in how project managers report and assess project health

Table-A III- 6 Challenges in data collection and analysis (continued)

Interview No.	Theme	Code	Description
Interview 4	Data Quality	Manual Data Entry Issues	Much data from project managers in tables, no centralized system for new initiatives
Interview 4	System Integration/Limitations	No Single Source	Integrating data from different sources is difficult, requiring careful validation
Interview 4	Limited Resources	Inspector Constraints	Five-year horizon to assess entire HLM building stock
Interview 5	Data Quality	Garbage In, Garbage Out	Projects occasionally feed incorrect data, so auditing is crucial
Interview 5	Cultural Resistance	Performance Anxiety	Some project managers resist close KPI scrutiny, requiring a shift to collaborative mindset
Interview 5	Standard System	Multiple Tools & Systems	Système d'Analyse for financial data, Excel/Power BI for operational details, requiring careful alignment
Interview 5	Human Factors	Varied Reporting Quality	Project control officers must ensure clarity in KPI reports; not all produce similarly actionable or concise outputs

Table-A III- 7 Utilization of KPI data for decision-making

Interview No.	Theme	Code	Description
Interview 1	Immediate Action	Team Leader Intervention	Intervening when indicators slip to yellow or red
Interview 1	Corrective Actions	Realigning Projects	Working with project managers to rectify situations
Interview 1	Escalation Process	Prioritization Committee	Issues brought to higher-level management
Interview 1	Portfolio Management	Rebalancing Portfolio	Adjusting planning based on KPI data
Interview 2	Immediate Action	Flagging Issues	Using data to detect anomalies and investigate further
Interview 2	Corrective Actions	Action Plans	Implementing action plans to address issues
Interview 2	Performance Reviews	Proactive Support	Supporting teams to improve performance based on data
Interview 2	Cultural Change	Positive Impact	Transparency leading to positive changes in behavior
Interview 3	Escalation Process	Raising Flags	Using red indicators to signal critical issues needing management attention

Table-A III- 7 Utilization of KPI data for decision-making (continued)

Interview No.	Theme	Code	Description
Interview 3	Management Intervention	Critical Situations	Management decisions required for significant cost overruns or delays
Interview 3	Immediate Action	Managing Within Team	Preference to manage issues internally before escalating
Interview 4	Accelerating Delivery	Proactive Measures	SHQ aims to be more proactive, pushing projects forward to meet deadlines
Interview 4	Ministerial Targets	Delivery Accountability	Minister monitors and uses KPI data to ensure housing is delivered within the promised timeframe
Interview 4	Focus on HLM Stock	Renovation Prioritization	Data on building condition guides where resources are allocated first
Interview 5	Escalation Process	Steering Committees	Project data used in monthly/quarterly committees, culminating in high-level decisions or ministerial guidance
Interview 5	Corrective Actions	Action-Oriented Reports	Monthly or quarterly notes lead to quick interventions for cost or schedule adjustments
Interview 5	Real Example	Delay Reduction	Project 16 months behind was cut to 8 months behind by targeting specific bottlenecks identified by KPIs
Interview 5	Immediate Action	Continuous Monitoring	Ongoing KPI reviews allow timely correction of budget or schedule slippages

Table-A III- 8 Measurement of initiative impacts and future plans

Interview No.	Theme	Code	Description
Interview 1	BIM Implementation	Early Stages	BIM is still being structured internally
Interview 1	Pilot Projects	Upcoming Pilots	Starting in January with more structured frameworks
Interview 1	Using Current KPIs	Comparing BIM Projects	Using existing KPIs to compare BIM and non-BIM projects
Interview 1	Collaboration Index	Implementing PCI Projects	Aiming to implement Project Collaboration Index
Interview 1	Energy Considerations	Future Energy Projects	Increasing requirements in commissioning
Interview 2	Initiative Management	Project Performance Strategy	Team dedicated to managing and measuring initiatives
Interview 2	Benefits Calculation	Calculating Benefits	Calculating benefits and ensuring implementation

Table-A III- 8 Measurement of initiative impacts and future plans (continued)

Interview No.	Theme	Code	Description
Interview 2	BIM Implementation	BIM as an Initiative	BIM is part of the improvement initiatives being tracked
Interview 2	Challenges in Measurement	Isolating Variables	Difficulty in isolating the impact of specific initiatives
Interview 2	Future Goals	Standardization and Trends	Working towards standardization and observing performance trends
Interview 3	BIM Implementation	Lack of Systematic Measurement	No systematic approach to measuring BIM impact yet
Interview 3	Observations on BIM	Reduced Site Directives	Noted that BIM projects may have fewer change notices
Interview 3	Interest in Collaboration	Open to Analysis	Interest in collaborating to analyze BIM projects and measure impact
Interview 3	Future Initiatives	Portfolio Management	Implementing a project portfolio management approach
Interview 3	BIM Measurement Plans	Interest in Data Collection	Open to collaborating on data collection and analysis
Interview 4	BIM Measurement Plans	BIM as an Initiative	The SHQ offers more subsidies if developers adopt BIM, hoping to track real-time data on projects
Interview 4	New Initiatives	HLM Renovation Program	Measuring improvement in building condition (A to E rating) to reduce dilapidation
Interview 4	Future Initiatives	Environmental Measures	Potential for tracking carbon footprint or sustainability in future versions of SHQ dashboards
Interview 5	Future Initiatives	Carbon & Climate Measures	Long-term plan to measure carbon footprint, building resilience, but not fully integrated in main KPI set
Interview 5	BIM Measurement Plans	Pilot Data Analysis	Currently limited data linking BIM usage to fewer errors or time savings; more robust sampling needed
Interview 5	Interest in Collaboration	Change Order Database	Hope to segment changes by cause to compare 'traditional' vs. 'BIM' projects for improved correlation

APPENDIX IV

POST-WORKSHOP VALIDATION QUESTIONNAIRE – CHAPTER 3

Validation des indicateurs de performance

Dans le cadre du projet de mesure de la performance, une série d'ateliers a été organisée avec les DOPs participants afin d'identifier et de prioriser les indicateurs de performance des projets d'infrastructures publiques. Pour valider les résultats issus de ces ateliers, veuillez s.v.p. compléter le sondage suivant. Celui-ci a pour but de confirmer les mesures prioritaires

établies dans le cadre du projet, ainsi que de comprendre la disponibilité des sources de données pour opérationnaliser les mesures prioritaires.

* Obrigatória

- Identification de la personne répondante

1. Quelle est le nom de votre organisation ? *

◆ Validation des indicateurs

2. Êtes-vous en accord que les mesures suivantes devrait être prioritaires? *

Table-A IV- 1 Les mesures

Les mesures	**1 - Total désaccord**	**2**	**3 - Indifférent**	**4**	**5 - Fortement en accord**
Prévisibilité des coûts (conception/construction)	☐	☐	☐	☐	☐
Coût par unité	☐	☐	☐	☐	☐
Prévisibilité de la durée (conception/construction)	☐	☐	☐	☐	☐
Temps par unité	☐	☐	☐	☐	☐
Satisfaction des parties prenantes	☐	☐	☐	☐	☐
Production de déchets	☐	☐	☐	☐	☐
Empreinte carbone	☐	☐	☐	☐	☐
Consommation d'énergie	☐	☐	☐	☐	☐
Ordre de changement (coût) – initié par le client	☐	☐	☐	☐	☐
Ordre dechangement (coût) – initié par le entrepreneur	☐	☐	☐	☐	☐
Ordre de changement - client	☐	☐	☐	☐	☐
Ordre de changement - entrepreneur	☐	☐	☐	☐	☐

Table-A IV- 1 Les mesures (continued)

Les mesures	**1 - Total désaccord**	**2**	**3 - Indifférent**	**4**	**5 - Fortement en accord**
Demande d'information (QRT)	☐	☐	☐	☐	☐
Productivité du travail - $/unité	☐	☐	☐	☐	☐
Portée des risques	☐	☐	☐	☐	☐
Coût de l'atténuation des risques	☐	☐	☐	☐	☐
Incidents temps perdu	☐	☐	☐	☐	☐

3. Y a-t-il des mesures de performance qui ne figurent pas dans la liste ci-dessus, mais que votre organisation considère comme prioritaires pour le suivi de la performance des projets ? Si oui, lesquels ?

APPENDIX V

ASSESSING THE IMPACT OF INNOVATION IN CONSTRUCTION: A LITERATURE REVIEW – CHAPTER 1

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Abstract

The construction industry encounters significant challenges in embracing innovation, primarily due to underfunding, existing barriers like the fragmented nature of the construction industry, unwillingness to change, and a lack of long-term perspective. Recognizing the essential role of innovation as a catalyst for progress, it is crucial to introduce novel ideas that challenge the status quo and drive industrial development forward. While there have been extensive discussions and advancements in implementing innovative practices within the construction industry, accurately determining the true impact of these innovations remains a complex task. This paper, through a comprehensive literature review, identifies various definitions and classifications of innovation within the construction industry and explores the concept of impact. The findings indicate that understanding innovation, along with its classification and impact assessment, is context-dependent, reflecting the multifaceted nature of the construction industry. Moreover, it is observed that most existing practices and frameworks, although adapted from other contexts, are not adequately tailored to meet the specific needs of the construction industry.

Keywords: Innovation, Innovation classification, Impact Assessment, Construction Industry.

A V.1 Introduction

The construction industry significantly contributes to the global economic landscape (Barata & Fontainha, 2017) and faces persistent performance challenges that have been discussed since the 20th century, remaining equally relevant today (Lauri Koskela, 2000). Despite its pivotal role, the construction sector often appears to lag behind other industries in terms of innovation, encountering significant barriers in adopting innovative practices from different fields (N. Wang, Gong, Xu, Liu, & Han, 2021 ; N. Wang et al., 2023).

Innovation is crucial for enhancing the productivity of the industries (OECD & Eurostat, 2018). The importance of innovation in driving performance improvements in the global construction industry is widely recognized by economists and business leaders, sparking a growing interest in fostering innovation within this sector (Loosemore & Richard, 2015 ; N. Wang et al., 2023) However, the construction industry struggles to adopt innovation due to its reliance on traditional methods and resistance to change (Chowdhury et al., 2019). Economic growth, intense competition, and fast-paced changes in the construction industry, companies must constantly enhance their efficiency and productivity to meet the rising expectations of their customers (Habibi et al., 2019), (Lechhab et al., 2021). This underlines the need for the industry to overcome its challenges through innovation, requiring a strategic shift towards embracing new practices.
The question arises: how can we accurately measure the impact of innovation in the construction industry?

Addressing this question could provide stakeholders in the construction industry with a comprehensive understanding of innovation and introduce effective methods for measuring it. This knowledge would significantly enhance their decision-making processes regarding the implementation of innovation.

This research has the objective to find the various definitions of innovation within the construction industry and the related classifications. Furthermore, the innovation's impact assessment will be explored.

A V.2 Research Methodology

To achieve the research objectives, the paper initiated with a Systematic Literature Review (SLR), marking it as a thorough method for a detailed exploration of scientific publications within our research area. The review exploited the Scopus database to sift through article titles, abstracts, and keywords, limiting the search to English-language publications from the past two decades, beginning in 2003. The search query executed was as follows:
TITLE-ABS-KEY ((impact* OR measur* OR assess* OR evaluat* OR analys*) AND ("construction innovation*" OR "innovation in construction*")) AND PUBYEAR > 1800 AND PUBYEAR < 2024 AND PUBYEAR > 2002 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE , "English"))
A total of 414 records were initially identified. From these, 33 were excluded due to their publication date being before 2003, and 18 were excluded for not being in English, resulting in 363 records progressing to the screening phase. After the primary screening—focused on titles and abstracts relevant to the research interests in definitions of innovation, its classification within the construction industry, and impact assessment concepts—267 records were further excluded. Consequently, 96 articles remained for comprehensive analysis.

Subsequently, the research broadened its viewpoint on the concept by integrating the snowballing technique with the SLR among the selected articles after the comprehensive analysis. This dual approach ensures that our methodology is not only inclusive but also solidly based, allowing us to bring to light new insights and thereby affirming our selection of the SLR as both appropriate and meticulously designed.

A V.3 Innovation in the construction industry

A V.3.1 Innovation definition

The concept of innovation has been interpreted in many ways(Blayse & Manley, 2004) and is somewhat ambiguous(M. Noktehdan et al., 2015). Various definitions of innovation have been defined in the literature. For instance, Schumpeter (Schumpeter, 1934) defined innovation as “new products or methods, find smarter ways to make things, explore new markets and supply chains, and even create new ways of organizing our work”. Carpenter (Carpenter, 1943) defined innovation as “bringing fresh ideas that shake things up and drive industrial progress”. Brown (Brown, 1994) defined it as “doing things differently or better across products, processes or procedures for added value and/or performance” and West and Altink (West & Altink, 1996) defined innovation with more details which is: “intentional introduction and application within a role, group or organization of ideas, processes, products or procedures, new to the relevant unit of adoption, designed to significantly benefit the individual, the group, the organization or the wider society”. Over time, many definitions of innovation have emerged and terms like product, process, and procedure being common across many of them. Consequently, the definition of innovation provided by Slaughter (Slaughter, 1998) which encompasses most of these aspects is frequently referred in the literature: “Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change”.

It seems in the literature that the concept of innovation has received more attention in the manufacturing and service industry rather than in the construction industry (L. Koskela & Vrijhoef, 2001). Pries & Dorée (Pries & Dorée, 2005) also focused on the primary types and sources of innovation within the construction industry, conducting an analysis of 55 years of publications in two prominent Dutch professional journals. Their findings indicate that two-thirds of innovations originate from supplying industries. Some existing definitions of innovation may include terms that pertain to innovations in other industries rather than construction. Hence, adopting a comprehensive definition that explicitly encompasses innovation within the construction industry would be more appropriate.

According to the Organization for Economic Cooperation and Development (OECD) (OECD, 2010), “innovation is the creation of new products, services, or business processes that create wealth or social welfare”. This explanation is valuable because it diverges from traditional innovation frameworks typically used by researchers, governments, and analysts to assess organizational innovation (Loosemore, 2015 ; OECD, 2010). In the latest edition, the 4th edition of, Oslo Manual 2018, the general definition of an innovation outlined as follows:

“An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)”(OECD & Eurostat, 2018).

“A business innovation is a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm”.

The definition provided by OECD & Eurostat (OECD & Eurostat, 2018) comprises three main components. Initially, it addresses new or improved “product” and “process”- the term “improved” has been incorporated alongside “new” in this definition. Subsequently, it pertains to something “significantly different”, followed by considerations of changes made to “products” or “processes” introduced to the market or adopted by the firm.

Within the frameworks of the OECD & Eurostat (OECD & Eurostat, 2018), an innovation must be notably distinct from the firm's existing products or business processes. Given that the degree of difference is subjective and dependent on the firm's situation and capabilities, the analysis and comparison of innovation data could be enhanced by additional information on the significance of the innovations, considering their novelty or economic impact (OECD & Eurostat, 2018). This approach leads to the following definitions:

This definition was further developed by OECD & Eurostat (OECD & Eurostat, 2018), for example a narrower definition of the business innovation to facilitate data collection on innovation and related activities for any scale of firms with a single-product firms to multinational firms in different industries and countries:

"A product innovation is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market."

"A business process innovation is a new or improved business process for one or more business functions that differs significantly from the firm's previous business processes and that has been brought into use in the firm."

This research finds the definition introduced by OECD & Eurostat (OECD & Eurostat, 2018) to be more applicable because it incorporates key areas that have emerged in the literature.

A V.3.2 Innovation classification

According to Delarue et al. (2021), classifying innovation in construction aids stakeholders in decision-making and action. As emphasized by Tatum (Tatum, 1988), a successful classification effort enables industry stakeholders to better understand innovations and identify their scope of impact. The complexity inherent in construction arises from its multifaceted nature, involving numerous stakeholders, diverse projects, and intricate processes. Given this complexity, it is reasonable to anticipate the emergence of diverse perspectives on innovation classification within the construction industry literature. Moreover, the classification of innovation could provide a framework for analyzing their impact.

The complexity inherent in construction arises from its multifaceted nature, involving numerous stakeholders, diverse projects, and intricate processes. Given this complexity, it's natural to expect different viewpoints on how to classify innovations in construction literature. Indeed, there isn't a one-size-fits-all "best" classification system when it comes to construction innovations. The most efficient method depends on the particular needs and objectives of the individual or organization aiming to comprehend and apply construction innovations.

However, it's crucial to recognize that categorizing innovations serves to provide a structured framework for evaluating their impact. However, the important point is categorizing innovations can offer a structured way to assess their impact.

Therefore, Table 1 compiles various aspects and dimensions of innovation in construction. This table primarily derives from the literature review conducted by Delarue et al. (2021), but it also integrates new facets from other researchers. The objective behind compiling and refining this table is to provide a comprehensive overview of the diverse facets of innovation within the construction industry.

Table A V.1 Construction innovation aspects

#	Short term	Description	References *
1	Benefit, Impact, Zone of Influence, Output	The different effects of innovations include both tangible aspects (such as time and cost) and intangible aspects (such as competitive advantage).	[1], [2], [3], [4], [5], [6], [7], [8], [9]
2	Discipline, Construction category	Discipline pertains to the diverse branches of stakeholders engaged in the project.	[10], [11], [15]
3	Project phase, Asset life cycle	The project phase or asset lifecycle encompasses the various stages of the construction industry.	[2], [12], [13]
4	Degree of disruption and novelty	The extent of disruption caused by innovation.	[2], [8], [14], [15]
5	Type of innovation	"A **product** can be a good, a service, or a combination of both. "**Business processes** encompass all core activities undertaken by the firm to produce products, as well as any ancillary or supporting activities" (OECD & Eurostat, 2018).	[2], [3], [8], [10], [11], [12], [13], [15], [16], [17], [18], [19], [20], [21]
6	Location	The location of innovation may be physical or symbolic.	[10]
7	Source of Fund	How innovation expenditure is funded.	[1], [15]

* References mentioned in the table: [1] (J. N. Lim & Ofori, 2007), [2] (M. Noktehdan et al., 2015), [3] (B. Ozorhon et al., 2016), [4] (Froese & Rankin, 2009), [5] (Davidson, 2013), [6] (B. Ozorhon & Oral, 2017), [7] (Fang et al., 2016), [8] (OECD & Eurostat, 2018), [9] (Beliz Ozorhon et al., 2014), [10] (Delarue et al., 2021), [11] (Tatum, 1988), [12] (Jung & Gibson,

1999), [13] (Froese & Rankin, 2009), [14] (Slaughter, 1998), [15] (OECD, 2005), [16] (Suliman et al., 2023), [17] (Pries & Dorée, 2005), [18] (Reichstein et al., 2005), [19] (Singh, 2014), [20] (Lopez & Yepes, 2020), [21] (Kuklina et al., 2021)

Table 1, highlights the benefit or impact of innovation, along with the type of innovation, that emerges as the most widely classified type in construction. Notably, Slaughter (Slaughter, 1998) offers a comprehensive classification for innovation, categorizing it based on the degree of disruption and novelty. This classification includes “incremental” (small changes), “radical” (significant changes), “modular” (changes within components), “architectural” (changes in links between components), and “system” (integrated innovations). However, it's observed that innovation in the construction industry predominantly leans towards incremental changes (Loosemore, 2015 ; Pries & Dorée, 2005).

Additional dimensions of innovation benefit, encompassing both tangible aspects (such as time and cost) and intangible aspects (such as competitive advantage), and type (Product and process) have been proposed to enrich the innovation classification in the construction industry by Noktehdan et al. (M. Noktehdan et al., 2015). Additionally, four types of innovations are distinguished: “product innovations, process innovations, marketing innovations, and organizational innovations” (OECD, 2005 ; OECD & Eurostat, 2018). However, OECD & Eurostat (OECD & Eurostat, 2018) categorized innovation by object or novelty and impact. As shown in Table 2, there are primarily two categories of innovation based on their object: product innovations, which alter the firm's products, and business process innovations, which modify the firm’s operations. Product innovations are further classified into goods and services, whereas business process innovations encompass six types. A single innovation can be the result of blending various types of innovations in products and business processes.

Table A V.2 Major types of innovation by object
adapted from OECD & Eurostat (OECD & Eurostat, 2018)

Short term	Details and subcategories
Product	**Goods**: tangible objects, knowledge-c products with transferable ownership via markets **Services**: intangible activities altering user conditions produced and consumed simultaneously.
Process	"Production of goods or services, Distribution and logistics, Marketing and sales, Information and communication systems, Administration and management, Product and business process development"

There are some other aspects of innovation reflected in the table. Delarue et al. (2021) introduced the concept of construction discipline (Tatum, 1988) and the location of innovations as other facets of innovation classification. Lim & Ofori (J. N. Lim & Ofori, 2007),, along with OECD (OECD, 2005), also delve into the aspect of how innovation is financed as another aspect of innovation classification.

Lim & Ofori (J. N. Lim & Ofori, 2007), along with OECD (OECD, 2005), explore how innovation is financed, which is a crucial aspect of innovation classification. Despite its importance, this classification receives less attention in literature. For instance, understanding how innovation expenditure is financed is essential for evaluating the role of public policy in the innovation process OECD (OECD, 2005).

OECD (OECD, 2005) provides a classification by source of funds, including: "1. Own funds, 2. Funds from related companies (subsidiary or associated companies), 3. Funds from other (non-financial) enterprises, 4. Funds from financial companies (bank loans, venture capital, etc.), 5. Funds from government (loans, grants, etc.), 6. Funds from supranational and international organizations (EU, etc.), and other sources."

Various researchers' classifications are compiled in Table 1. While the terms used by the authors may differ, they correspond to similar dimensions. In conclusion, the most suitable classification of innovation depends on its intended purpose and may incorporate a combination of categories to effectively classify items based on their purpose.

A V.4 Innovation's Impact Assessment

Impact measurement is crucial in evaluation research, as it helps demonstrate success and identify areas for improvement [45], [47]. The inherent complexities of the construction industry, such as its project-specific nature and the diverse stakeholder landscape, make measuring its innovation challenging. (Abbott et al., 2010 ; Nesta, 2006). Nonetheless, innovation drives improvements in living standards and impacts various levels of society and the economy (OECD & Eurostat, 2018). Consequently, measuring innovation assists decision-makers in comprehending socio-economic changes, evaluating innovation's contribution to societal goals, and assessing policy effectiveness (OECD & Eurostat, 2018). The construction industry's unique attributes, such as site-based operations and temporary supply chains, make innovation harder to perceive and measure (N. Wang et al., 2023). However, the Oslo Manual stresses the importance of measuring innovation, with emphasis on levels of analysis ranging from the product to the national level (OECD & Eurostat, 2018). Despite most attention being directed at the construction firm level, innovation occurs across various stages of the lifecycle, including design, construction, and maintenance (Abbott et al., 2010). Much of the innovation in construction happens at the project level and often remains concealed, suggesting that traditional measures fail to capture its true extent(Abbott et al., 2010 ; Nesta, 2006).

It appears that the literature has addressed the topic and necessity of measuring innovation in the construction industry. However, there seems to be a lack of consistency in the terminology used across various articles, leading to differing interpretations. For instance, while some articles discuss the analysis or outcome of innovation, others employ terms such as measurement, evaluation, or impact assessment. At times, these terms are used interchangeably, despite their nuanced differences. Consequently, a more thorough investigation into the definitions and appropriate usage of these terms is warranted. Hence, it becomes necessary to delve deeply into their meanings and examine the extent of their applications.

To establish the definitions of impact, it is necessary to first clarify the definitions and terms in this field. Therefore, this article references one of the specialized and globally recognized sources, the "Glossary of Key Terms in Evaluation and Results-Based Management for Sustainable Development" published by the OECD (OECD, 2023). However, to ensure comprehensiveness, terms not included in this glossary were supplemented with definitions from other sources in examining the meanings.

The definitions of impact exhibit some differences across the literature. For instance, Abbott et al. (Abbott et al., 2010) consider outputs as outcomes and outcomes include both benefits and impact. Ozorhon (Beliz Ozorhon, 2009) regards impact as whatever occurs after outputs. However, it appears important to also consider the concept of deadweight, as defined by Clark et al. (Clark et al., 2004). They describe the impact as "the portion of the total outcome that occurred as a result of the activity of the venture, above and beyond what would have happened anyway." This suggests a nuanced understanding that not only acknowledges the direct outcomes of a venture's activities but also distinguishes these outcomes from what would have transpired regardless of the venture's efforts (Sivesind et al., 2014). The definition given by the OECD (OECD, 2023) takes these considerations into account. It emphasizes the importance of any effect, whether intended or unintended, positive or negative, that is produced or anticipated to be produced, including those with long-term impacts (Stern, 2015).

To measure the impact of innovation on a project, an organization, or a sector, this article finds the impact value chain approach developed by Schober and Rauscher (Schober & Rauscher, 2014 ; Simsa et al., 2014) appropriate for the construction industry innovation assessment. This approach, although originally applied in contexts other than construction, is illustrated in .
Performance measurement typically focuses on assessing either the activities or their outcomes(Schober & Rauscher, 2014 ; Simsa et al., 2014 ; O’Flynn, 2010). However, within the realm of impact measurement, it is essential to identify, measure, and possibly assign value

to the outcomes, while also taking into account the concept of deadweight(Schober & Rauscher, 2014 ; Simsa et al., 2014). The concept of deadweight, which is derived from this framework and was integrated into the model by Ozorhon (Beliz Ozorhon, 2009) and Abbott et al. (Abbott et al., 2010), is employed to adjust the outcomes, providing a clearer understanding of the impact.

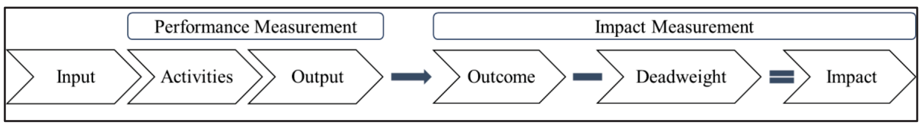

Figure A V.1 Impact value chain adapted from Schober and Rauscher (Schober & Rauscher, 2014 ; Simsa et al., 2014)

A V.5 Discussion

The impact assessment examines a broad spectrum of dimensions—economic, social, political, ecological, cultural, and physical and psychological impacts—across short-, medium-, and long-term time frames and at the micro (individual), meso (organizational or group), and macro (societal) structural levels.(Simsa et al., 2014), (Stern, 2015).

Developing appropriate measures for construction innovation is complicated by its diversity and the absence of a uniform method for innovation (Abbott et al., 2010). Oslo Manual 2018 (OECD & Eurostat, 2018) explains strategies for measuring innovation. An effective measurement strategy must navigate choices between focusing on the innovation itself (object approach) or the entities driving it (subject approach), and balance qualitative with quantitative data collection, sources, and collection responsibilities. Strategies evolve with user needs and data types, benefiting from integrating multiple approaches to enhance data utility through linkage and analysis. While object-based approaches offer detailed insights into specific innovations but risk-biased samples, subject-based approaches provide comprehensive data on organizational innovation activities, allowing for industry or region-specific analyses. Combining these approaches, especially in surveys, enriches innovation measurement, adapting to both broad organizational practices and specific innovation details.

Considering the extensive range of impact dimensions alone, the process is immensely complex and multifaceted. Additionally, addressing the complexities of innovation within the construction industry, particularly in terms of measurement, presents numerous challenges. This complexity is further amplified by the diversity of innovation and the absence of a standardized measurement approach, necessitating a nuanced understanding and innovative strategies to effectively capture and analyze the multifarious aspects of innovation and its impacts.

A V.6 Conclusion

This paper explores Innovation in the construction industry, which is pivotal for the sector's advancement, necessitating a shift towards novel methodologies for enhanced efficiency. Through examining various innovation definitions, classifications and impact assessment concepts, this research realizes the lack of appropriate methods to identify and measure the impact of innovation in construction.

In this article, we explored the concept of innovation within the construction industry, examining its various definitions and existing classifications from multiple perspectives. Additionally, we delved into the notion of impact, drawing upon and adapting concepts from sources outside the construction industry due to the quality of available resources. This comprehensive approach allowed us to gain a deeper understanding of innovation's multifaceted nature and its potential impacts on the construction industry, highlighting the need for a broader and more inclusive perspective in assessing and implementing innovative practices. Our findings emphasize the need for industry-specific, adaptable frameworks to nurture an innovative culture within construction, promoting operational and strategic reevaluations for integrating innovative practices. Therefore, future work will focus on developing a framework to facilitate measuring the impact of innovation in the construction industry, which considers the multifaceted nature of both construction innovation and its impacts. The main limitation of this research stems from the initial scope of the literature review, which was restricted by publication year and keywords.

The Bibliography section is presented at the very end of the thesis.

APPENDIX VI

DEVELOPING KPIS AND MEASUREMENT PROCESSES TO ASSESS THE IMPACT OF INNOVATION IN THE CONSTRUCTION INDUSTRY: CURRENT PRACTICES AND CHALLENGES – CHAPTERS 1 and 3

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ABSTRACT

The construction industry's role as a key economic driver underscores the need for robust mechanisms to measure and manage innovation. While conventional metrics often emphasize cost, schedule, and immediate outputs, emerging trends highlight broader, long-term impacts—particularly those related to sustainability, social well-being, and organizational growth. This study examines current practices and challenges in performance measurement among five major public project owners in Quebec, selected due to their involvement in a digital transformation roadmap, drawing on semi-structured interviews with senior managers and technical teams. Our findings reveal a strong reliance on traditional Key Performance Indicators (KPIs), such as cost and schedule, complemented in some cases by environmental, safety, or innovation-oriented indicators. However, limited standardization, disparate data-collection methods, and fragmented systems impede consistent, real-time reporting. Moreover, long-term outcomes and intangible benefits frequently remain under-assessed, reflecting a gap between immediate project control and strategic, impact-focused goals.

Despite these challenges, a gradual shift is evident: several public owners express intentions to adopt more holistic KPI sets that address sustainability, resource productivity, and innovation. Efforts to streamline data gathering—through integrated software platforms and

stakeholder collaboration—indicate a growing recognition of the need for accurate, forward-looking measurements. By pinpointing the limitations and emerging directions in current practices, this research contributes new insights into how performance management can evolve to capture both immediate project results and broader societal impacts in the construction industry.

A VI.1 Introduction

The construction industry is widely recognized as a cornerstone of economic development, reflecting societal progress and technological advancements across multiple domains, playing a crucial role in fostering economic growth, and significantly contributing to the global economic landscape(AlJaber et al., 2024 ; Barata & Fontainha, 2017 ; OECD & Eurostat, 2018). However, fragmented structures (Annunen & Haapasalo, 2023 ; Guimarães, 2024), a conservative culture, and reliance on traditional processes often hinder the adoption of innovative practices (Blayse & Manley, 2004).

Innovation is crucial to ensuring the long-term stability of organizations (Al-Hakim & Jin, 2010). In addition, a large number of studies in the construction sector emphasize that new technologies have a positive effect on overall productivity, efficiency, and safety (Klosova & Kozlovská, 2020). Effectively managing and advancing innovation requires a comprehensive understanding of the innovation process, the enhancement of innovation capabilities, and the measurement of innovation outcomes (Gambatese & Hallowell, 2011). Quebec’s public owners were chosen specifically for their involvement in a shared digital transformation roadmap, making them an ideal context for examining evolving performance metrics.

Impact and performance measurements are critical frameworks for capturing both the tangible and intangible benefits of innovation (OECD & Eurostat, 2018). Performance measurement often focuses on evaluating either the activities themselves or their immediate outputs (Schober & Rauscher, 2014 ; Simsa et al., 2014 ; O’Flynn, 2010). In contrast, impact measurement involves assessing the long-term, significant effects—whether positive or negative, intended or unintended. In this context, it becomes crucial to identify, measure, and, where possible, assign value to these outcomes (OECD & Eurostat, 2018).

Additionally, the concept of deadweight (Schober & Rauscher, 2014 ; Simsa et al., 2014) highlights the extent to which the outcomes would have happened anyway. This concept can be employed to adjust the measured outcomes, offering a more accurate picture of an initiative's net impact. These approaches collectively underscore the need for rigorous metrics and frameworks to reliably gauge innovation's contributions and guide better decision-making in the construction sector.

A VI.1.1 Problem Statement

The construction industry's emphasis on immediate economic gains often results in the neglect of long-term and indirect benefits. Conventional performance metrics, which prioritize operational aspects such as cost, schedule, and quality, typically emphasize the immediate outputs of innovative interventions. Consequently, these metrics frequently overlook long-term effects - such as sustainability improvements viewed through the Triple Bottom Line (TBL) perspective, encompassing social, economic, and environmental impacts (Kucukvar & Tatari, 2013 ; Wu et al., 2021). This gap can lead to incomplete decision-making, ultimately affecting stakeholders and limiting broader industry progress.

Moreover, it seems there is no single set of widely accepted performance indicators for evaluating the impact of new and innovative initiatives, and there is a recognized need for developing standardized indicators that can be applied across different innovation systems to facilitate better performance measurement and comparison (Alvarez & Jordan, 2024 ; Arshi et al., 2021 ; Nappi & Kelly, 2022). This standardization would help create a common language and framework for evaluating innovation initiatives, specifically in the construction industry, which is known as an industry lagging in the adoption of innovation.

A VI.2 Background

A VI.2.1 Performance Measurement

KPIs have long been recognized as pivotal to ensuring successful outcomes in construction projects. As Bassioni et al. (2004) note, the need for consistent performance measurement has grown with the construction industry's push for continuous improvement. In an increasingly competitive and globalized market, KPIs offer a systematic way to benchmark progress, highlight areas of underperformance, and support strategic decision-making (Sibiya et al., 2015). Beyond simply tracking whether a project is on time and on budget, KPIs help practitioners align objectives and coordinate resources across multiple stakeholders (Habibi et al., 2019). By objectively gauging how well a project meets defined metrics, KPIs enable project managers and clients to identify gaps early, implement remedial measures, and, ultimately, enhance the probability of meeting or surpassing targets.

Historically, the success of a construction project was often measured using a narrow "iron triangle" framework—focusing primarily on cost, time, and quality (Hussain et al., 2025). Over time, however, the concept of project success has expanded considerably. Early discussions (Chan & Chan, 2004 ; Cox et al., 2003) recognized that factors such as safety and scope changes also influence final outcomes, while Rankin et al. (2008) highlighted innovation and sustainability as essential dimensions of performance. Consequently, the body of literature now presents a broad set of KPIs spanning eight core categories: Cost, Time, Productivity, Quality, Safety, Scope, Innovation, and Sustainability (Poirier, 2015 ; Z. Zhang et al., 2022). This extended range of metrics addresses both the traditional project-control indicators (e.g., cost/time predictability) and progressive measures (e.g., energy consumption and carbon footprint) with implications for long-term impacts on the environment, society, and overall operational efficiency.

A closer look at these emerging trends confirms that the construction industry is shifting from short-term project performance—such as immediate cost control—to long-term, holistic considerations (Habibi et al., 2019). For example, a recent study by Liu et al. (Liu et al., 2024) identified five central KPIs for construction, emphasizing safety, technological advancement, and communication—indicators that notably diverge from the traditionally dominant focus on cost. This shift underscores how broader concerns, including stakeholder coordination, have risen to prominence in defining project success. Moreover, as the industry adopts a more future-oriented outlook, simply gauging short-term performance appears insufficient. Instead, long-term impact—encompassing aspects such as environmental stewardship, social well-being, and sustained operational efficiency—has become increasingly relevant. Consequently, an expanded KPI set not only addresses diverse and long-term metrics but also paves the way for more comprehensive impact measurement, moving beyond immediate project outputs toward far-reaching, enduring outcomes.

A VI.2.2 Impact Assessment

During the past few decades, the construction industry has been exposed to "sustainable construction" processes, addressing the environmental, economic, and social dimensions of (Kamali & Hewage, 2015). Building on the acknowledgment that performance metrics alone may be insufficient, it is essential to recognize broader impact dimensions, including cultural and psychological (Simsa et al., 2014 ; Stern, 2015). By encompassing short-, medium-, and long-term horizons at micro (project), meso (organizational), and macro (societal) levels, impact assessment provides a holistic view of how construction activities and outcomes affect not only immediate stakeholders but also the larger community and environment.

One prominent approach reflecting this expanded scope is the TBL, which encourages organizations to measure their economic, social, and environmental dimensions (M. Lim, 2014). Often summarized as "people, planet, and profits," TBL goes beyond traditional financial metrics to account for broader responsibilities (Slaper et al., 2011). First popularized by John Elkington (Elkington & Rowlands, 1999), TBL has gained considerable traction as a framework for sustainable development (Said & Berger, 2014). Over the past few decades, the construction industry has been particularly exposed to sustainable construction processes that address TBL concerns throughout the entire life cycle of a building (Kamali & Hewage, 2015).

Despite its popularity in many sectors, however, TBL adoption in construction remains limited (Goh et al., 2020 ; Zainul Abidin, 2009), partly due to the lack of a standardized method for measuring social, environmental, and economic dimensions comprehensively (Slaper et al., 2011).

Nonetheless, the construction industry is undeniably critical to society, the economy, and the environment (Agenda, 2016). Economically, it generates nearly $10 trillion in annual revenues—about 6% of global GDP—employing over 100 million people worldwide (Agenda, 2016). Environmentally, it accounts for significant resource use, including half of global steel consumption and nearly 40% of solid waste in the United States—making it a major contributor to carbon emissions (Agenda, 2016 ; Illankoon et al., 2017 ; Khoshnava, Rostami, Valipour, Ismail, & Rahmat, 2018). In response, various scholars have categorized the TBL dimensions in depth: economic indicators (cost, viability), environmental metrics (pollution, resource efficiency), and social measures (equity, stakeholder well-being) (Dobrovolskienė & Tamošiūnienė, 2016 ; Zainul Abidin, 2009). Although TBL is powerful, Pawłowski (2008) highlights moral, legal, and technical considerations as well (Illankoon et al., 2017), suggesting TBL alone may not capture the full complexity of responsible development.

Overall, by reframing construction through impact assessment rooted in TBL, stakeholders can move beyond short-term measures to address the long-term consequences of built environments (Habibi et al., 2019). This broader perspective underscores the need to evaluate economic, social, and environmental outcomes—along with moral, legal, or technical factors—across the entire life cycle of a construction project. In this research, we propose a framework that integrates these varied dimensions, offering a roadmap for practitioners and researchers who seek to align innovative construction practices with sustainable, multi-level project goals.

A VI.3 Methodology

This study began with a targeted literature review on construction project performance measurement, focusing on widely used KPIs and existing frameworks. Insights from academic journals and industry reports guided the development of a semi-structured interview guide, aimed at understanding how KPIs are currently selected, tracked, and utilized by public project owners in Quebec.

To capture real-world practices, five major public project owners in Quebec were selected through purposive sampling, as they are active participants in a regional digital transformation roadmap. Collectively, these organizations oversee projects in residential, industrial, infrastructure, and institutional sectors. Each interview featured a senior manager—often joined by a technical or engineering team member—reflecting roles that directly influence KPI choice and monitoring. The semi-structured interviews, each approximately 60 minutes in length, covered questions on KPI usage, selection criteria, data collection methods, perceived challenges, and strategies for measuring project impact. All sessions were recorded, transcribed, and analyzed via iterative thematic coding, using an initial set of analytical categories (e.g., KPI usage and data collection) and refining them as new themes emerged.

A VI.4 Findings

Following transcription, interview responses were coded based on core analytical angles derived from the interview questions. These angles encompassed (1) the KPIs in use and how they are applied, (2) the underlying rationale for KPI selection, (3) approaches to data collection and analysis, (4) identification of particularly critical KPIs, (5) interest in additional or missing metrics, (6) barriers or difficulties in collecting and interpreting KPI data, (7) the influence of KPI findings on decision-making, and (8) emerging methods for measuring initiative impacts beyond immediate outputs. These thematic categories ultimately shaped the structure of the findings by illuminating how public project owners perceive, select, and leverage various construction KPIs.

A VI.4.1 Key Performance Indicators (KPIs) used

Although each organization used slightly different terminology, Table 1 presents a unified view of the main KPI categories identified. Checkmarks indicate that a Public Project Owner (PPO) monitors or applies that KPI theme; a dash (–) signifies the KPI was not explicitly mentioned.

Table A VI.1 Consolidated KPIs used by PPOs

KPI / Theme	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	Key Observations
Cost / Financial	✓	✓	✓	✓	✓	Includes budget gaps, cost compliance, earned value (CPI/SPI), and disbursement tracking. All PPOs emphasize cost.
Schedule / Time	✓	✓	✓	✓	✓	All PPOs tracked (often with colour-coded “time control,” schedule gap/ compliance).
Visual Indicators	✓	–	✓	✓	✓	Red/yellow/green dashboards are common. Four PPOs employ color-coded signals to convey overall project status quickly.
Scope	✓	✓	✓	–	–	Focused on planned vs. actual scope (e.g., “scope gap,” change notices). Not explicitly mentioned by PPO 4 or 5.
Risk Management	✓	✓	✓	–	–	Colour-coded risk levels or risk tracking logs. Potential shift toward more proactive risk approaches.
Resource / Productivity	✓	✓	–	–	✓	Workforce capacity, labor attendance, or “workload” metrics. PPO 5 correlates on-site hours with planned tasks.
Supplier / Stakeholder	✓	✓	–	–	–	Supplier evaluation, social acceptability, or client feedback appear in PPO 1–2. Others rarely mention these.
Project Condition / Health	–	✓	–	✓	–	PPO 2 uses a “health index”; PPO 4 focuses on building condition (A–E rating) or HLM renovation progress.
Sustainability	–	✓	✓	–	–	PPOs 2 & 3 monitor environmental impact, energy performance, or compliance. Indications of growing interest.
Safety	–	✓	–	–	–	PPO 2 explicitly identifies safety metrics (health & safety). Others did not detail formal safety indicators.
Innovation	–	✓	–	–	–	PPO 2 explicitly labels “innovation initiatives.” One PPO references advanced “tactical/strategic” approaches but not as “innovation.”

As shown, Cost/Financial and Schedule/Time metrics dominate, with every PPO referencing some form of budget or timeline management. Scope and Risk appear in three of the five PPOs, often tied to "gap" analyses or logs indicating change notices or potential overruns. Resource/Productivity indicators vary, but at least two PPOs track workforce capacity or labor attendance in detail. Meanwhile, Safety is surprisingly under-represented (only one PPO references it explicitly), suggesting that formal safety KPIs may be embedded elsewhere or assumed.

Sustainability (environmental impacts, energy targets) is highlighted by two PPOs, reflecting a modest yet potentially growing priority. Only one PPO explicitly frames Innovation as a standalone KPI category, though other organizations mention advanced practices under different labels. Lastly, Visual Indicators (traffic-light colour-coding) feature prominently in four PPOs, showing a clear preference for quick, at-a-glance project health assessments.

This broad spectrum of KPIs—from cost and schedule fundamentals to more progressive metrics like energy performance —suggests a shift in the construction sector's emphasis. Beyond immediate project outputs, public project owners are gradually exploring long-term or impact-focused measures, including innovation and environmental stewardship, albeit at varying degrees of adoption.

A VI.4.2 Determination, Critical Indicators, and Additional Metrics

Public project owners in Quebec reported varied strategies for selecting KPIs, commonly referencing project management fundamentals (e.g., cost–time–scope) and strategic alignment (PPOs 1, 2, 3, and 5). As shown in Table 2, some introduced official input from ministerial or auditor demands (PPOs 4 and 5), while others relied on portfolio approaches or gap analysis to refine or evolve their metrics. Nonetheless, interviews consistently revealed that cost and schedule remain "primary KPIs" across the board, though certain owners (e.g., PPO 2) elevate safety/environment to the same priority level. Beyond these staples, many PPOs aspire to expand into quality, earned value, resource/productivity, or environmental measures, illustrating a shift toward more holistic project assessment.

Table A VI.2 KPI determination and criticality

KPI Focus	Selection	Criticality	Key Observations
Cost	PMI standards, board confirmations, annual planning	All PPOs	Cost remains universal. Some owners want more precise cost-tracking (CPI/SPI).
Schedule	Strategic alignment, official input, portfolio approach	All PPOs	Time synergy with cost. Some adopt milestone-based or "delivery speed" measures.
Scope	Gap/process improvement in some PPOs	Sometimes	Not universal, but certain owners see scope compliance or change notices as vital.
Safety/ Environment	Ministerial demand (PPO 2), occasional board endorsement	only PPO 2	One PPO elevates it to main priority, others approach environmental efforts incrementally.
Quality	Gap analysis, stakeholder input	Sometimes	Remains an optional add-on for deeper oversight, especially rework or on-site issues.
Resource/ Productivity	Evolving approach, not always formal	Rarely top-tier	Some owners see workforce capacity as important but have minimal formal tracking.
Innovation	Portfolio expansions or official impetus (BIM)	Rarely top-tier	Mandates, pilot programs, or advanced indicators suggest slow integration beyond the cost/time core.

All five public project owners cite cost and schedule as indispensable KPIs—often validated through PMI standards or strategic planning. While safety/environment is uniquely top-tier at PPO 2, other owners incorporate it more modestly or plan future expansions (e.g., GHG metrics). Scope and quality appear variably, yet interest in rework rates, non-conformities, or thorough scope compliance signals a desire for more granular oversight. Resource/productivity indicators also draw attention, though formalized approaches are still emerging. Lastly, innovation (BIM or advanced tools) is recognized but seldom top-tier, indicating a gradual broadening of KPI scope as new initiatives mature. Taken together, these findings reflect each owner's organizational mandates, ministerial priorities, and portfolio complexities, all contributing to distinct but overlapping KPI sets—most of which revolve around cost, schedule, and a growing set of impact-focused measures.

A VI.4.3 Data collection frequency, methods, and tools

Although each organization used its own terminology and combined various platforms, the interview data can be distilled into a few overarching categories of data entry methods, tools, and reporting cycles. Table 3 presents these broad approaches and indicates which PPOs adopt them.

Table A VI.3 Consolidated data collection frequency, methods, and tools

Method / Tools	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	Key Observations
Manual Data Entry	✓	✓	✓	✓	✓	Commonly done or partially in Excel or in-house sheets. Causes potential data delays and manual errors.
Multiple Systems	–	✓	–	✓	✓	Integrated PM tools plus manual tables. System integration issues hamper real-time analysis.
Data Type: Mix (Actual & Self-Reported)	✓	✓	✓	–	–	Three PPOs rely on a mix data type. Encourages data validation but slows updates. Two others are self-reported data.
Data Frequency: Monthly	✓	✓	✓	–	✓	Many projects updated monthly. Some PPOs do weekly/daily (PPO 2) or bi-monthly (PPO 5). PPO 4 follows a no-strict interval, updating as projects move stages.
Excel-Based Dashboards	✓	✓	✓	✓	✓	All PPOs used for entry and visualization; forms the baseline for advanced tools.
Visualization	–	✓	✓	✓	✓	Four PPOs moving from Excel to power BI platforms for real-time or public transparency dashboards.
Software	–	✓	–	–	✓	PPO 2 and PPO 5 adopt specialized scheduling/cost control software. Facilitates advanced metrics (e.g., earned value) but integration remains a challenge.

All five PPOs rely at least partially on manual data entry, often through Excel sheets, which can slow updates and introduce potential errors. Three PPOs combine actual measurements (e.g., from contractors) with self-reported figures, leading to more thorough validation but longer processing times, while two others mention primarily self-reported data. Although monthly updates remain prevalent, PPO 2 occasionally uses weekly or daily check-ins, and

PPO 5 conducts bi-monthly workshops to finalize KPI reporting; in contrast, PPO 4 updates data "on demand," linked to project milestones or program phases.

Excel-based dashboards dominate the landscape as a baseline, yet four PPOs are transitioning toward BI platforms—particularly Power BI—for improved real-time analysis or public-facing dashboards. PPO 2 and PPO 5 incorporate specialized software (e.g., scheduling/cost control tools) to track advanced metrics such as earned value, although system integration challenges persist. Collectively, these methods signal a gradual shift from purely manual, Excel-driven processes to more dynamic, fully integrated data environments, albeit at different stages of adoption among the five PPOs.

A VI.4.4 Challenges in Data Collection and Analysis

Interviews revealed a variety of obstacles when collecting, interpreting, and reporting KPI data. Table 4 condenses these issues into five main categories, indicating which Public Project Owner (PPO) reported each challenge. Additional context appears in the concluding observations.

Table A VI.4 Consolidated challenges in data collection and analysis

Challenge Theme	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	Key Observations
System Integration	✓	✓	–	✓	✓	Reliance on Excel or lack of advanced tools, multiple disjointed systems, no single source of data, limited interoperability.
Data Quality	✓	✓	✓	✓	✓	Potential errors from manual entry, variable data formats, or "garbage in, garbage out." Discrepancies between different sources.
Human Factors	✓	–	✓	–	✓	High staff turnover, limited data-monitoring resources, varied reporting quality, cultural resistance to KPI scrutiny.
Data Analysis / Reporting	✓	–	✓	–	–	No baseline capability, delayed updates due to invoicing/payment, inconsistent methods across project managers.
Resource Constraints	–	–	–	✓	–	Inspector shortages (PPO 4) and similar limitations cause long delays

All five PPOs report data quality concerns, most often tied to manual entry or multiple, unaligned systems. System integration stands out in four PPOs, citing Excel dependence, partial tool adoption, or no single data repository. Human factors also complicate KPI usage: some organizations face staff turnover, skill gaps, or reluctance among project managers to expose performance data. While delays and lack of advanced analysis affect at least two PPOs, PPO 4 deals specifically with limited resources for large-scale inspections, reflecting a strategic challenge beyond routine data tasks. Collectively, these challenges underscore the complexity of achieving consistent, real-time KPI reporting in public construction projects—despite a shared ambition for more transparent, data-driven decision-making.

A VI.4.5 Utilization of KPI data for decision-making

Participants described how they translate KPI results into concrete decisions, ranging from immediate interventions and escalation processes to more proactive or portfolio-level maneuvers. Table 5 consolidates these practices into core approaches, while the short paragraph below elaborates on distinctive methods at each PPO.

Table A VI.5 Consolidated approaches to KPI-based decision-making

Decision-Making Approach	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Immediate Action	✓	✓	✓	–	✓	When KPI signals (e.g., red/yellow) appear, teams intervene quickly to prevent larger overruns or schedule slips.
Corrective Steps (Action Plans / Realigning)	✓	✓	–	–	✓	PPOs 1, 2, and 5 implement formal action plans (e.g., “Realigning Projects,” “Action-Oriented Reports”) to address cost/time anomalies.
Escalation Process (Committees / Raising Flags)	✓	–	✓	–	✓	Certain issues—budget crises, critical delays—are escalated to higher-level boards or committees for prioritization, rebalancing, or strategic decisions.
Proactive / Performance Support	–	✓	–	✓	–	PPO 2 uses “Proactive Support” in reviews; PPO 4 uses “Proactive Measures” to accelerate delivery. Both stress anticipating problems before they grow.

Table A VI.5 Consolidated approaches to KPI-based decision-making (continued)

Decision-Making Approach	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	Key Observations
Ministerial / Organizational Targets	–	–	–	✓	–	PPO 4 cites “Delivery Accountability” (minister monitors KPI data for timely housing). May link to broader political/board-level directives.
Portfolio / Renovation Prioritization	✓	–	–	✓	–	PPO 1 “rebalances” entire portfolios; PPO 4 channels resources based on building condition data.
Cultural / Behavioral Change	–	✓	–	–	–	PPO 2 notes that transparency from KPI dashboards fosters “positive impact,” leading to better team behaviors and more accountability.

Overall, cost and schedule deviations typically trigger immediate or corrective measures, sometimes escalating to higher management. A few owners go further, employing proactive or portfolio-level strategies to prompt issues. Even more specialized processes—like PPO 4’s ministerial accountability or PPO 5’s systematic “continuous monitoring”—underscore the variety of ways in which public project owners turn KPI data into actionable decisions, whether through swift interventions or broader cultural changes.

A VI.4.6 Desired additional KPIs and metrics

Interviewees were asked which additional KPIs they would like to see implemented, reflecting either identified gaps or future performance aspirations. Table 6 highlights a few common themes or categories mentioned by at least two PPOs.

Table A VI.6 Desired additional KPIs and metrics

Initiative / Future Plan	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	Key Observations
Earned Value (CPI/SPI)	✓	–	–	–	✓	PPOs 1 & 5 want more precise performance tracking (cost/schedule).
Quality / Non-Conformities	✓	✓	–	–	–	PPOs 1 & 2 hope to track changes, addenda, or complaints for deeper quality metrics.

Table A VI.6 Desired additional KPIs and metrics (continued)

Initiative / Future Plan	**PPO 1**	**PPO 2**	**PPO 3**	**PPO 4**	**PPO 5**	**Key Observations**
Proactive / Predictive	–	✓	–	–	–	PPO 2 wants to identify major milestones, supply chain issues in advance.
Resource / Productivity	✓	–	–	–	✓	PPOs 1 & 5 mention resource utilization or standardized productivity rates (labor attendance, consistent tracking).
Environmental / Sustainability	–	–	–	✓	✓	PPO 4 & 5 aim to measure carbon footprint, GHG reductions, or community impacts more systematically.
Portfolio-Level Monitoring	–	–	✓	–	–	PPO 3 seeks centralized tools, potential to add more KPIs as the portfolio approach evolves.

Cost and schedule accuracy remain areas that multiple PPOs wish to refine via tools like Earned Value Management (EVM). Quality metrics that capture non-conformities or complaints are also of interest, especially for PPOs 1 and 2, pointing to a desire for more granular oversight. In addition, productivity and resource measures (PPOs 1, 5) underscore the trend toward a more nuanced view of workforce capacity and performance.

Meanwhile, environmental and sustainability concerns show up in at least two PPOs, who propose GHG or carbon footprint indicators. PPO 3 envisions expanded portfolio-level monitoring, whereas PPO 4 wants to ensure cost stability in public renovation programs. Overall, these emerging or additional KPIs reflect a shift beyond the standard iron triangle, incorporating quality, sustainability, and innovation in pursuit of more holistic and impact-oriented project assessment.

A VI.4.7 Measurement of Initiative Impacts and Future Plans

The interviews revealed how each public project owner looks beyond immediate performance, exploring new initiatives (e.g., BIM) or longer-term sustainability goals. Table 7 consolidates these recurring ideas.

Table A VI.6 Key initiative impacts and future plans

Initiative / Future Plan	PPO 1	PPO 2	PPO 3	PPO 4	PPO 5	Key Observations
BIM Implementation	✓	✓	✓	✓	✓	All PPOs express interest in BIM, though at varied maturity levels. Some compare BIM vs. non-BIM KPIs or look to reduce change orders.
Collaboration Index / Partnerships	✓	–	✓	–	–	PPOs 1 & 3 mention "collaboration" metrics or open analysis. Relates to measuring synergy among teams and external stakeholders.
Energy / Environmental Expansion	✓	–	–	✓	✓	PPOs 1, 4, and 5 highlight future goals such as carbon footprint, energy commissioning, or climate resilience.
Standardization / Trends	–	✓	–	–	–	PPO 2 aims to unify measurement processes across projects, working toward consistent performance trends.
Portfolio Management Approach	–	–	✓	–	–	PPO 3 plans a broader portfolio strategy, hoping to add additional KPIs and centralized monitoring.
Future Data Collaboration	–	–	✓	–	✓	PPO 3 and 5 want to collaborate on data collection or compare "traditional" vs. "BIM" projects more systematically.

All five PPOs reference BIM in some capacity, some adopting pilot phases, others analyzing BIM vs. non-BIM performance data or seeking to reduce errors and site directives. At least three PPOs are broadening their environmental focus, addressing carbon footprint or energy commissioning. Collaboration metrics (PPOs 1, 3) indicate a push toward capturing synergy benefits, while PPO 2 pursues a more standardized approach to long-term measurement. Finally, PPO 3 and PPO 5 mention of "future data collaboration" underscores a general trend toward collective or benchmarking efforts, especially for advanced initiatives like BIM.

A VI.5 CONCLUSION

This paper underscores the evolution of KPIs within Quebec's public construction sector, highlighting the continued dominance of cost and schedule metrics alongside an emerging interest in sustainability, safety, and innovation. Despite their significance in project oversight, traditional KPIs alone do not sufficiently account for the long-term societal, environmental, and economic outcomes of construction projects. The interviews confirm that many public project owners seek more integrated systems and standardized frameworks to address these broader dimensions. They also reveal persistent challenges related to data quality, system interoperability, and organizational culture, which constrain the effective use of performance data in decision-making.

Future research may focus on developing a comprehensive framework that captures both immediate and longer-term impacts of innovative initiatives in the construction industry. Such a framework would encompass commonly recognized KPIs—such as cost—while also incorporating sustainability, social well-being, and strategic innovation measures, linked to life cycle considerations and multi-level impact assessments. By integrating short-term performance tracking with long-range impact monitoring, the construction sector can better align project execution with economic, environmental, and social objectives, ultimately facilitating more responsible and future-oriented development. This study has certain limitations, including the relatively small number of interviewees, which may affect the generalizability of the findings.

The Bibliography section is presented at the very end of the thesis.

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