# Data-driven Construction Management
## A trilogy, Part I:
## "Digital infrastructure as an agreement of intrinsic value within large-scale projects in the United States of America."[1]

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## Abstract

In 2021, Dr. Timea Nochta presented: "Urban Governance and Digital Technologies – Evolution or Revolution?" She stated: "Technology providers offer 'revolutionary' solutions that promise to fundamentally transform urban planning and development, infrastructure management and services, as well as life and experience in city [2]." This prompts us to consider: *What would be the strategies to integrate these technologies into markets that already perceive their results as 'adequate,' without imposing their adoption?*

Current strategies serve as a starting point for addressing the inherent intricacy of the digital transformation ecosystem. In this context, the coexistence of established operational practices and emerging digital capabilities introduces organizational complexity, especially when trying to alter established work habits and methodologies. Additionally, ongoing projects are growing in scale and require information management that is more: advanced, transparent, digitalized, sophisticated, and auditable. Furthermore, the limited availability of specialized professionals, both those who are trained and those still in training—to operate and manage these technologies, increases the complexity of the environment and poses a considerable challenge.

In 2025, Hayden Jr., W. (2025), in his article "Human Systems Engineering™ - A Trilogy, Part III: Managing Projects Successfully in a World of Uncertainty," published in PM World Journal, Vol. XIV, Issue IX, September [3], states: "*A bad system will beat a good person every time.*" This innovative concept introduces the methodology of "Systems Thinking" emphasizing the understanding that projects operate as systems, where people, processes, technology, and leadership interact harmoniously to achieve successful outcomes.


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[2] Urban Governance and Digital Technologies – Evolution or revolution? – Dr Timea Nochta
[3] Hayden, Jr., W (2025). Human Systems Engineering™ - A Trilogy, Part III: Managing Projects Successfully in a World of Uncertainty, featured paper, PM World Journal, Vol. XIV, Issue IX, September.

Technological Innovation + Systems Thinking → Data-Driven Infrastructure Management

***Keywords:*** *Data, Systems Thinking, Technology, Innovation, Management, Governance*

## 1.0 Introduction

### 1.1. Data: The New Oil in Various Industrial Markets

Industries in general do not have a data problem. They have a data fragmentation problem. In 2019, my professional experience in industrial settings involved working with single and double-layer laminates made from materials such as CPP and PEBD for food packaging in Santiago, Chile. This role marked a shift from my previous work in the construction sector. I had foundational skills in data analysis and Power BI, along with familiarity with Tableau and Qlik Sense. Because the company had lost its quality certification, we implemented key performance indicators (KPIs) to support the annual recertification process and restore the certification. The procedure resembled earlier ones, requiring daily extraction of databases from platforms connected to machines used for laminating, cutting, and other processes.

At that time, I noticed that industrial environments needed to incorporate digital transformation and control tools to make strategic decisions. We can say: Technology was being implemented but not integrated. Digital solutions were beginning to replace pen and paper, responding to efficiency demands, but they lacked a *robust methodological framework for transforming data into operational intelligence.* Likewise, I observed that the construction industry faces similar challenges in adopting new technologies, especially in traditional sectors, due to a shortage of staff, resources, professional biases, or limited openness to change. The challenge is not the availability of technology. It is the inability to orchestrate it. Rather than making it easier, technological integration often becomes a socio-professional challenge. Technologies such as AR[4], VR[5], MR[6], XR[7], Lidar[8], IoT sensors[9], and drones have become increasingly accessible and useful; today, it is common to manage information on digital platforms within the sector. However, the biggest challenge remains managing change effectively. Understanding the true value of generated data is essential for driving organizational digital transformation, as it delivers immediate benefits that far outweigh the required adaptation efforts.

[4] Augmented Reality
[5] Virtual Reality
[6] Mixed Reality
[7] Extended Reality
[8] Light Detection and Ranging
[9] Internet of Things

## 2. The Digital Transformation of Construction Project Management.

The technical references previously mentioned, along with experience gained across different sectors, have helped identify two important approaches to analysis. Both focus on examining the systems that make up today's digital business environment. First, there is a process of renewal, modernization, and structural development of established and emerging technologies. Second, there is a generational resistance rooted in traditional production models within various companies, especially when integrating new technologies is perceived as disruptive.

### 2.1. Methodological Approach to Data in Construction

Undoubtedly, there are technological ecosystems that support both processes and methodologies dedicated to information management and the vast flow of data generated in large companies and construction firms. While some aspects related to the management of certain assets have been resolved, the challenge remains in leveraging data to build meaningful narratives and give them operational purpose within organizations. Some of the main methodologies include:

- **DataOps [10]:** the modern equivalent of DevOps, focuses on creating automated data pipelines and dashboards, and is utilized by companies such as Amazon, Netflix, and Uber.
- **CRISP-DM [11]:** a classic methodology for data science and information analysis, widely used in predictive analytics and data research through to the development of a final product (Dashboard, App, Agents, Platform, Software, etc.).
- **DAMA-DMBOK [12]:** an institutional standard for data governance, defining disciplines and roles in data management, like a specific ISO standard.
- **DATA MESH [13]:** a standard used as an organizational architecture for data in large-scale data ecosystems.
- **ISO 19650 [14]:** a standard for information management in BIM projects using databases and digital assets.

[10] What is DataOps? | DataKitchen
[11] What is CRISP DM? - Data Science PM
[12] The Global Data Management Community, DAMA-DMBOK® 3.0 , Body of Knowledge | Data Management Body of Knowledge
[13] Data Mesh Architecture
[14] ISO 19650-1:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles

- **Digital Twin Framework [15]:** a methodology (ISO 23247) used for data capture and asset operation (BIM, IoT, integration, predictive analytics, operation, maintenance, real-time simulation, and optimization), applied by large-scale companies.
- **Data-Centric BIM [16]:** where BIM acts as a master node within a data ecosystem that integrates all areas, from cost planning, sensors, production, and dashboards, all converging into a master data platform.

In general, day-to-day operations are multifunctional, organic, and grow rapidly based on experience, requiring quick problem-solving that does not exclusively depend on these technological ecosystems. Many are pre-designed and often need to be redefined to make agile technical decisions.

Despite the increase in available digital tools, the construction sector still lacks a *structured methodological framework* that enables the transformation of project data into actionable **operational analytics intelligence**. This may be because, traditionally, the construction industry has focused on optimizing or addressing processes in isolation and in silos.

Based on existing research on BIM-enabled project delivery (Eastman et al., 2018) and data governance frameworks (DAMA-DMBOK), this paper proposes an **Operational Data Intelligence Framework for Construction (ODIFC),** as it allows us to systematize these elements as a hallmark in the digital transformation of construction and the level of collaborative, functional, and operational participation of the various stakeholders involved.

## 2. Data-Driven Construction Management.

To understand this section, it is necessary to highlight the following: *"The construction industry has historically lagged behind other sectors in productivity growth and digital adoption, making the integration of data-driven approaches a strategic opportunity to improve project performance" (McKinsey Global Institute, 2017).*

The concept of digitalization has experienced delays in its implementation over the past decade, especially when compared to industrial sectors that have already comprehensively adopted advanced technologies and innovation policies.

[15] ISO 23247-1:2021 - Automation systems and integration — Digital twin framework for manufacturing — Part 1: Overview and general principles
[16] Powering a Data-Driven Future with BIM & Digital Twins

## 2.1. Operational Data Intelligence Framework for Construction (ODIFC)

An adaptable and easy-to-implement conceptual model for any company begins with a thorough understanding of the environment's workings and the objectives to be achieved. Sometimes, it is mistakenly thought that the process starts with the creation or use of original files; however, this approach is incorrect. While all ideas and initial concepts about the desired product can influence the process, the **first essential step** is to *analyze how the different layers of data are integrated*. For this reason, Eastman (2018) notes: "*As digital technologies continue to transform the architecture, engineering, and construction (AEC) sector, Building Information Modeling (BIM) has emerged as a central platform for integrating project data across disciplines and phases of the lifecycle*."

It is crucial to consider ethical and legal aspects, such as information standards, ETL[17] Processes, quality rules, permissions, roles, pipelines, data warehouses, automation, and responsibilities regarding information governance and management. Afterwards, the layer of visual analytics and intelligence, together with the use of tools and 3D models, codes, applications, GIS [18], SQL databases [19], UI/UX developments [20], and various software, makes it possible to transform information into useful and practical results. Finally, the decision-making layer encompasses analysis, planning, risk management, optimization, and strategies, where logical thinking emerges as the *conclusion of the analytical process.*

## *2.2.* Operational Data Intelligence Framework for Construction (ODIFC) Layers

| |
|---|
| Preconceptualization –> Data Sources → Data Integration →Data Governance →Analytics & Intelligence →Operational |

Figure 1. ODIFC Framework Structure.
Source: Own elaboration.

Based on this analysis, the ODIFC is structured into six sequential layers

### 1. Pre-conceptualization Layer

This layer marks the starting point, where the objectives of the data system, the operational problems to be solved, and the strategic questions guiding the analysis and information integration are identified.

[17] Extraction, Transformation, Load
[18] Geographic Information System
[19] Structured Query Language
[20] UI (User Interface) and UX (User Experience)

### 2. Data Sources Layer

This layer brings together all information sources generated throughout the project life cycle, such as BIM models, scheduling systems, cost control platforms, field reports, IoT sensors, spreadsheets, departmental databases, and other corporate systems; these sources form the foundation of the data ecosystem.

Choosing the right platforms and technologies is crucial, as many digital solutions do not place data at the center and operate in closed environments where data is not structured or easily exportable. Therefore, digital tools should be evaluated for their ability to generate structured, accessible, and interoperable data, as well as the presence of APIs, data models, export functions, and external compatibility, all of which are essential requirements for the scalability of the data ecosystem.

### 3. Data Integration Layer

The integration layer is responsible for consolidating information from multiple heterogeneous systems. This phase involves data cleaning, normalization, and transformation processes, enabling the establishment of logical relationships between different sources of information originally created for independent operational purposes.

### 4. Data Governance Layer

Data governance defines the rules, standards, and responsibilities necessary to ensure information quality, traceability, and security. This layer includes aspects such as information standards, permission management, version control, organizational roles, and regulatory compliance, allowing the data system to operate reliably within the organization.

### 5. Analytics and Business Intelligence Layer

In this layer, structured data is transformed into analytical knowledge using visualization tools, analytical models, applications, GIS platforms, query languages, and other digital technologies. The goal is to generate indicators, patterns, and analyses that help understand project behavior from an operational perspective.

### 6. Operational Layer

This layer represents the practical use of the intelligence generated by the data system. Here, analytical results are integrated into decision-making processes related to planning, risk management, cost control, progress tracking, and resource optimization within the project.

## 2.2. Professional Profiles for Operational Data Intelligence Framework for Construction (ODIFC)

Participation in the framework is not limited to certain individuals. However, it is crucial to recognize the value and benefits that the inclusion of the following specialties would bring, especially when considering the growth and strength of each team. Resource allocation will be determined by the advantages and expected workload, with department, project, and company levels playing a fundamental role—not only in the quantity, but also in the quality of the resources involved.

- **A: Construction Manager specialized in Digital Transformation**

This profile is essential for verifying whether the proposed solutions for the road and bridge construction sector work in practice. It enables evaluation of whether the suggested framework solves real project issues and whether the integration of operational data is feasible in empirical, fast-paced construction environments. The individual must possess sufficient technical, operational, organizational, and digital expertise to address large-scale challenges.

- **B: Digital Transformation and Innovation Engineer in A/E/C**

A professional knowledgeable about technological changes in Architecture, Engineering, and Construction (A/E/C), capable of implementing digital ecosystems in construction companies and managing the transition from paper to innovative solutions.

- **C: Data Architect / Information Governance Specialist**

A technical expert responsible for validating the design and implementation of large-scale data ecosystems, building data pipelines, and automating dashboards. This role ensures technical rigor across all layers of the model (sources, integration, storage, governance, analytics) and supports the methodological approach of "data as the new oil."

- **D: Expert in "Systems Thinking" and Organizational Development**

Responsible for implementing technological changes in traditional sectors, coordinating and documenting multidisciplinary teams, and facilitating cross-departmental integration with appropriate documentation. Additionally, this role values strong arguments about the interaction between people, processes, technology, and leadership to achieve success, as well as the feasibility of overcoming generational resistance.

Summary of the ideal composition: A panel of three- or four-members combining expertise in heavy construction, data architecture, and digital transformation strategy within organizational contexts.

### 2.3. Operational Data Intelligence Framework for Construction (ODIFC) Uses Cases

A relevant case in daily operations, where multiple generations and stakeholders converge, is exemplified by installing photogrammetric cameras on machinery to conduct 4D scans that record the amount of excavated material (Data Sources Layer). This information is then compared with the project's BIM model. The data flow begins at the camera (Computer Vision) on the data source layer; afterward, the data undergoes a quality validation process based on production, considering the BIM Model's metadata (data governance layer).

Next, the information flows through data pipelines to be stored in an information database, ultimately feeding a predictive dashboard with alerts regarding earthmoving activities (Analytics and Intelligence Layer). This example demonstrates how the various layers of the framework can be effectively integrated, enabling all involved stakeholders to properly manage the information plan.

With this proposal, we demonstrated that: *"Data-driven decision-making has increasingly become a competitive advantage for organizations capable of transforming large volumes of operational data into actionable information"* (Davenport & Harris, 2017).

## 3. Digital Infrastructure as an Intrinsic Value Agreement in Large-Scale Projects in the United States

In this context, the fundamental value of digital infrastructure goes beyond mere technology or isolated innovative initiatives. It lies in the consolidation of organizational agreements geared toward international projects and multisector investments. Digitalization becomes strategically relevant by enabling efficient integration of ideas within operational data environments, where multiple sources of information—varying in format, scale, and size—converge. This capability is essential for meeting the standards required by major projects in the United States.

Moreover, the cultural transformation and the way this resource is valued and incorporated are crucial for the international market. They drive significant investments, strengthen trust and security in commercial strategies, and underscore the need for comprehensive technical leadership that supports these initiatives—not only from a pragmatic perspective, but also with a global understanding necessary to ensure the proper functioning of the methodological framework.

Maturity in data analytics enables the prevention of specific cost overruns by avoiding rework through early alerts and improving the accuracy of quantity take-offs.

Managing information silos[11] [21] should always consider data sensitivity. In situations where communication is limited for justified reasons, it is advisable to implement APIs or common, secure environments that allow efficient and protected access to and sharing of information.

## 4. Betting on Digital Project Management Environments as the Structural Backbone for Multinational Companies Specializing in Road and Bridge Construction Worldwide

In this context, the integration of digital tools should not become a "white elephant"—in other words, an expensive resource that is underutilized—but must be established as a structured and integrated technical process. This is where numerous teams collaborate across departments to develop operational intelligence systems within organizations. For this reason, multinational construction companies are committed to fostering healthy professional competition through new initiatives, reinforcing safety, transforming work environments, and equipping staff from different departments with the digital skills required for their respective fields. Undoubtedly, this is a positive development for all professionals advancing in this area. While in the past large projects were completed without these tools, the advance of the digital revolution is inevitable and, over time, will become deeply embedded in our workflows.

For large-scale infrastructure projects, the challenge of digital transformation goes far beyond simply adopting new technologies. Construction projects involve the simultaneous participation of multiple organizations, disciplines, stakeholders, and information systems, all generating data from different operational perspectives. Designers, contractors, subcontractors, suppliers, and public agencies each produce their own information using various platforms, often resulting in fragmented data ecosystems and information silos that are difficult to connect.

The real challenge is constantly evolving and is not just about digitizing existing processes, but about establishing digital environments capable of integrating these diverse information flows into coherent project management systems that provide security and efficiency. Without this structured integration, decision-making remains reliant on manual reports, isolated spreadsheets, and informal information flows, which limits the analytical potential of the data generated throughout the project lifecycle for end users.

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[21] What Are Data Silos? | IBM

For this reason, the development of digital project management environments is becoming a strategic necessity for multinational companies dedicated to infrastructure construction. These environments connect different information sources, enable data traceability, and build operational intelligence systems that facilitate planning, cost control, risk management, and decision-making in projects with high technical and financial complexity. Ultimately, this generates a *positive ROI*, even if that return is not immediately measurable.

## 5. Conclusions

The analysis carried out throughout this article suggests that digital transformation in the construction sector does not depend solely on the adoption of technological tools, but rather on the organizational capacity to structure and properly manage project information flows. Although, in recent decades, well-established methodologies have been developed in areas such as planning and cost management, and a participative culture has emerged, with active initiatives around data modelling and project management, there is still no widely accepted methodological framework that holistically articulates the data lifecycle in infrastructure projects.

In this context, ODIFC is introduced so that digital environments for project data and management control begin to consolidate, organize, and position themselves as the structural backbone that enables the integration of multiple information sources. This makes it possible to transform operational data into analytical knowledge and support more agile and better-informed decision-making processes within organizations managing large-scale projects.

In response to the initial question—what strategies could be adopted to incorporate these technologies in international industrial markets where performance is already considered "satisfactory", and the adoption of such technology is not necessarily required?—we agree that the value of digital transformation lies less in the technological progress achieved and more in the practical solutions it offers.

For instance, this can be demonstrated by creating digital infrastructures in which the technology team is responsible for entering data—thus avoiding placing additional pressure on field operatives—by designing tools that diversify data collection, or by implementing extremely simple user interfaces (UI/UX) that mimic physical forms and enhance operational efficiency, enabling geospatial visualization and the achievement of objectives with small-scale, protected, and well-managed data architecture systems.

Digital transformation in construction is not a matter of platforms, but rather a value agreement for the organizational future, something that, ultimately, many companies are already committed to.

***Declarations***

Experience in highly complex infrastructure projects shows that digitalization is not only a technological challenge, but also an organizational and cultural transformation. Transitioning from traditional practices based on manual records or fragmented systems to structured digital ecosystems requires recognizing the importance of analytical collaboration—where multidisciplinary teams, supported by advanced analytics, artificial intelligence, and emerging autonomous agents, transform dispersed data into actionable operational intelligence. In large-scale infrastructure projects, clarity is the most valuable asset; and clarity emerges from structured data, interoperable systems, and intelligent decision-support frameworks.

In this context, the proposed **Operational Data Intelligence Framework for Construction (ODIFC),** provides a structured approach to organizing, integrating, and activating data across the project lifecycle. Rather than focusing on isolated platforms or tools, ODIFC emphasizes the design of a coherent data architecture—where information flows seamlessly between systems, enabling consistency, traceability, and decision-making clarity. This approach shifts the focus from technology adoption to knowledge structuring, ensuring that data is not only available, but meaningful and actionable.

In many cases, digital initiatives begin as strategic concepts or preliminary ideas; however, their real impact depends on the technical and organizational capacity to evolve them into functional ecosystems. These ecosystems not only integrate information and reduce data fragmentation, but also incorporate predictive analytics, machine learning models, and agent-based automation capable of proactively identifying risks, optimizing workflows, and enhancing transparency and efficiency in project management.

Importantly, this transformation is not intended to increase technological complexity or overwhelm organizations with fragmented platforms. On the contrary, the purpose is to simplify, support, and augment human decision-making. Artificial intelligence and digital systems should act as enablers—filtering information, reducing cognitive load, and providing clarity—rather than generating noise or operational saturation. The value of digitalization lies not in the volume of tools implemented, but in their capacity to deliver structured insight and purposeful support to project teams.

Without a doubt, in global-scale organizations, this transformation is understood as a comprehensive and continuous effort. Leading experts in the field agree that the value of data extends beyond the construction phase: *it enables the development of intelligent systems that generate value during operations and maintenance (O&M), while simultaneously creating feedback loops that inform the design of future infrastructure. In this way, data evolves into a* *strategic asset, multiplying its impact exponentially across the entire asset life cycle.* (R. Munguía, personal communication, March 17, 2026)

In this context, digital transformation must also be analyzed in alignment with the United Nations 2030 Agenda for Sustainable Development, particularly Goal 9—"Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation"—and Goal 11—"Make cities and human settlements inclusive, safe, resilient, and sustainable." These principles reinforce the idea that digitalization is not an end, but a means to deliver long-term societal value through more resilient, transparent, and intelligent infrastructure systems.

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**Daniela M. Ledezma** holds a degree in Construction Management Engineering (2011) and Diplomate in Technical Inspection and Quality Management (2021). She is currently studying M.S. degrees in Global Smart City Management (2026). She has successfully overseen digital projects of varying sizes and complexities in: Venezuela, Chile and the United States of America. She is specialized in project planning, scheduling, and management control, supporting construction teams and stakeholders through structured project controls practices. Experienced in developing cost analyses, unit price evaluations, quantity take-offs, cost curves, baseline schedules, and budget control frameworks. She has a strong background in schedule monitoring, progress measurement, performance analysis, and KPI's development, ensuring alignment between physical execution and financial performance. Daniela is proficient in developing and leveraging digital tools and digital Transformation (BI-Bim-Data) to enhance reporting accuracy, project visibility, and decision-making efficiency.

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