Chapter 1
Intelligent Construction Monitoring Systems:
Foundations, Architectures, and Future Directions

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ABSTRACT

The rapid digital transformation of the construction industry has driven the adoption of intelligent construction monitoring systems to enhance safety, productivity, and risk management in complex and dynamic project environments. These systems integrate advanced sensing technologies, artificial intelligence, Internet of Things (IoT) platforms, and data analytics to enable real-time observation, prediction, and decision-making throughout the construction lifecycle. This chapter presents a comprehensive overview of the foundations, system architectures, and emerging trends in intelligent construction monitoring systems. It examines key enabling technologies, including computer vision, machine learning, digital twins, and

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cloud–edge computing frameworks, and discusses how these components are orchestrated to support real-time safety monitoring, environmental impact prediction, and proactive risk mitigation.

1. INTRODUCTION

The construction industry is undergoing a profound transformation driven by rapid advances in digital technologies, artificial intelligence (AI), and cyber-physical integration. Traditionally characterized by fragmented workflows, safety risks, cost overruns, and environmental uncertainty, construction environments are increasingly adopting intelligent monitoring systems to enable real-time visibility, predictive decision-making, and proactive risk mitigation. Intelligent Construction Monitoring Systems (ICMS) represent a convergence of sensing, communication, data analytics, and intelligent reasoning technologies that collectively support safer, more efficient, and more resilient construction processes (Irani & Kamal, 2014; Liu et al., 2022).

At the foundation of ICMS lies the evolution of intelligent systems research within the construction domain. Early efforts focused on rule-based expert systems and basic automation, but recent developments have shifted toward data-driven intelligence enabled by machine learning, deep learning, and distributed computing architectures (Lu, 2019; Sarker, 2021; Taye, 2023). These advances have been accelerated by the proliferation of wireless sensor networks (WSNs), smart sensors, and embedded systems capable of continuously capturing structural, environmental, and operational data from construction sites (Abdelhafidh et al., 2019; Preethichandra et al., 2023; Sonko et al., 2024).

The integration of Internet of Things (IoT) technologies has further expanded the scope and capabilities of construction monitoring. IoT-enabled architectures allow heterogeneous devices—such as wearable sensors, unmanned aerial vehicles (UAVs), ground vehicles, and smart equipment—to communicate seamlessly and operate within unified monitoring frameworks (Shafique et al., 2020; Saleem et al., 2019; Rane et al., 2023). These systems increasingly align with broader cyber-physical system (CPS) paradigms and smart city infrastructures, where construction sites function as intelligent nodes within urban ecosystems (Juma & Shaalan, 2020; Vinueza-Martinez et al., 2024; Mazzetto, 2024).

Artificial intelligence plays a central role in transforming raw construction data into actionable insights. Machine learning and deep learning models enable automated damage detection, structural health monitoring, safety risk prediction, and progress tracking with unprecedented accuracy (Mondal & Chen, 2022; Barbhuiya & Das, 2025; Wojciechowska et al., 2024). Computer vision techniques, often deployed through UAVs and fixed cameras, support real-time hazard identification,

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