


Chapter 4

Real-Time Environmental Risk Management and Safety Monitoring System for Modular Construction: A Framework for Enhanced Quality and Efficiency

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ABSTRACT

Modular integrated construction (MiC) offers faster, safer, and more sustainable building, but on-site environmental factors can reduce connection quality and productivity. This study presents a real-time risk management system using IoT

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sensors; thermometers, hygrometers, and anemometers; networked via MQTT to a central dashboard. The system continuously monitors temperature, humidity, and wind speed, comparing data to activity-specific thresholds for key MiC tasks. Risks are classified into three levels, triggering instant alerts and recommendations from “proceed with caution” to “stop work.” Simulations confirm reliable detection of hazards like high humidity, extreme temperatures, and unsafe winds. With AI helmet detection, the system reached 80% safety compliance, reducing misalignments and rework. This framework effectively mitigates environmental impacts, and future predictive analytics could further enhance proactive management.

1. INTRODUCTION

Modular construction (MiC) is transforming the landscape of the building industry by offering a more efficient, safer, and environmentally sustainable approach to project delivery. At its core, MiC involves the fabrication of building modules in controlled factory environments, which are then transported to the construction site for final assembly. This method exemplifies the highest form of prefabricated construction, representing the most complete and advanced implementation of off-site construction (OSC). In contrast to traditional construction methods that involve on-site assembly of all building components, MiC emphasizes the extensive off-site fabrication process; up to 80-90% of the design can be completed before modules reach the site. This significant shift from conventional practices has been driven by the need to improve project timelines, reduce costs, enhance safety, and promote sustainability Shen et al. (2025).

The advantages of MiC are well-documented and widely acknowledged across the industry. First and foremost, it offers a pathway to accelerate construction schedules. Because modules are built in controlled environments, weather-related delays; such as rain, snow, or high winds; are minimized, allowing projects to adhere more closely to planned timelines. This not only shortens project delivery but also reduces labor costs and mitigates the risks associated with on-site work. Additionally, the controlled factory environment ensures higher quality standards, as manufacturing processes are closely monitored, and defects can be identified early. This results in better overall product consistency and durability, reducing the need for repairs or rework after installation Chen et al. (2025).

Safety is another critical benefit associated with MiC. Traditional construction sites are inherently hazardous due to the presence of heavy machinery, high elevations, and unpredictable working conditions. By shifting a substantial portion of construction activity to factories, the number of workers exposed to on-site risks diminishes. This transition enhances worker safety, reduces accidents, and lowers

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