INNOVATIVE TECHNOLOGIES FOR THE DIFFUSE LOGISTICS OF URBAN CONSTRUCTION AND DEMOLITION WASTE

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Silton Luiz Pereira Proenca

ABSTRACT

The management of construction and demolition waste in urban environments represents a growing logistical and environmental challenge, particularly due to its diffuse generation pattern. Unlike centralized waste streams, construction debris is produced by numerous small and spatially dispersed sources, which complicates collection, routing, sorting, and recovery processes. This article examines the role of innovative technologies in improving the diffuse logistics of urban construction and demolition waste, with particular emphasis on drones, autonomous and semi-autonomous vehicles, and intelligent waste management systems. Drawing on recent academic literature, the discussion highlights how digital sensing, automation, artificial intelligence, and building information modeling can enhance traceability, optimize reverse logistics networks, and support circular economy objectives. At the same time, the analysis identifies key limitations related to regulatory frameworks, data interoperability, economic feasibility, and institutional coordination. The article argues that technological innovation, when integrated with governance mechanisms and market incentives, can significantly improve the efficiency and sustainability of diffuse construction waste logistics in contemporary cities.

Keywords: Construction and Demolition Waste. Diffuse Logistics. Urban Waste Management. Drones. Autonomous Vehicles. Circular Economy.

INTRODUCTION

Urban construction and demolition waste (C&DW) is a complex, spatially dispersed challenge for contemporary cities. Unlike municipal solid waste that often follows regular collection routes, construction debris arises from numerous small and geographically scattered sites, including renovation activities, informal repairs, small demolitions, and individual building projects. This diffuse generation pattern undermines economies of scale, increases vehicle kilometers traveled, complicates sorting at source, and creates incentives for illegal dumping, resulting in significant environmental and social impacts. Addressing these constraints requires a technological reconfiguration of logistics processes that incorporates digital sensing, advanced routing, automation, and integrated information systems capable of managing decentralized waste flows. Recent empirical studies and systematic reviews indicate that such technologies offer substantial efficiency gains, although their effectiveness depends on contextual and institutional conditions (Wang *et al*., 2024; Wu *et al*., 2025).

Drones, or unmanned aerial vehicles, have gained prominence as tools for monitoring and assessing diffuse construction waste generation. Equipped with high-resolution cameras, photogrammetry software, and LiDAR sensors, drones enable rapid mapping of construction sites and accurate estimation of debris volumes without requiring direct physical access. Research demonstrates that drone-based surveys significantly reduce the time and labor associated with waste inventorying, particularly in dense urban environments where ground-level access is constrained. Furthermore, the integration of computer vision and machine learning algorithms allows for preliminary classification of visible waste materials, supporting more informed decisions regarding collection scheduling and downstream sorting. Despite these advantages, drones face regulatory restrictions in urban airspace, limited payload capacity, and reduced effectiveness in identifying buried or mixed waste streams, which confines their role primarily to data acquisition rather than physical transport (Wang *et al*., 2024; Naranjo Hernández, 2023).

Autonomous and semi-autonomous ground vehicles represent another important technological pathway for improving diffuse waste logistics. These systems are designed to operate within construction sites or along predefined urban routes, transporting debris to local consolidation points or transfer stations. Studies focusing on autonomous haulers in construction and tunneling projects report improvements in safety, operational efficiency, and scheduling flexibility, as well as reduced dependence on manual labor. In the context of diffuse logistics, smaller autonomous vehicles can facilitate frequent and localized pickups, reducing illegal dumping and minimizing disruption to urban traffic patterns. However, technical challenges related to navigation in dynamic environments, sensor reliability, and localization in areas with limited satellite coverage remain significant barriers. Moreover, the economic viability of autonomous systems is strongly influenced by regulatory approval processes, labor costs, and the scale of deployment (Naranjo Hernández, 2023; Jahangiri *et al*., 2022).

The coordination of these physical technologies depends on robust digital infrastructure. Intelligent waste management systems that integrate Internet of Things sensors, geographic information systems, artificial intelligence, and building information modeling play a central role in orchestrating diffuse logistics networks. Sensors installed in containers and vehicles provide real-time data on fill levels and movement, while AI-based optimization models generate dynamic routing plans that reduce empty trips and fuel consumption. BIM and digital twin technologies further enhance traceability by embedding material information within building models, enabling the prediction of waste streams before renovation or demolition occurs. This proactive approach supports reverse logistics strategies aimed at maximizing reuse and recycling rates. Nevertheless, the literature emphasizes persistent challenges related to data fragmentation, lack of standardized material classifications, and limited interoperability between platforms operated by different stakeholders (Wu *et al*., 2025; Kaewunruen *et al*., 2025).

Automation in sorting and material recovery facilities is also critical for managing heterogeneous waste from diffuse sources. Advances in robotic sorting, sensor-based separation, and computer-vision-assisted systems improve the purity and consistency of recovered materials, increasing their market value and supporting circular economy objectives. These technologies reduce reliance on manual sorting and can be strategically deployed in decentralized transfer stations to shorten transport distances. However, high capital costs and variability in waste composition often necessitate hybrid logistics models that combine local pre-sorting with centralized automated recovery facilities. Policy support and financial incentives are frequently required to enable such investments, particularly in regions where landfill disposal remains economically attractive (Dodampegama *et al*., 2024; Jahangiri *et al*., 2022).

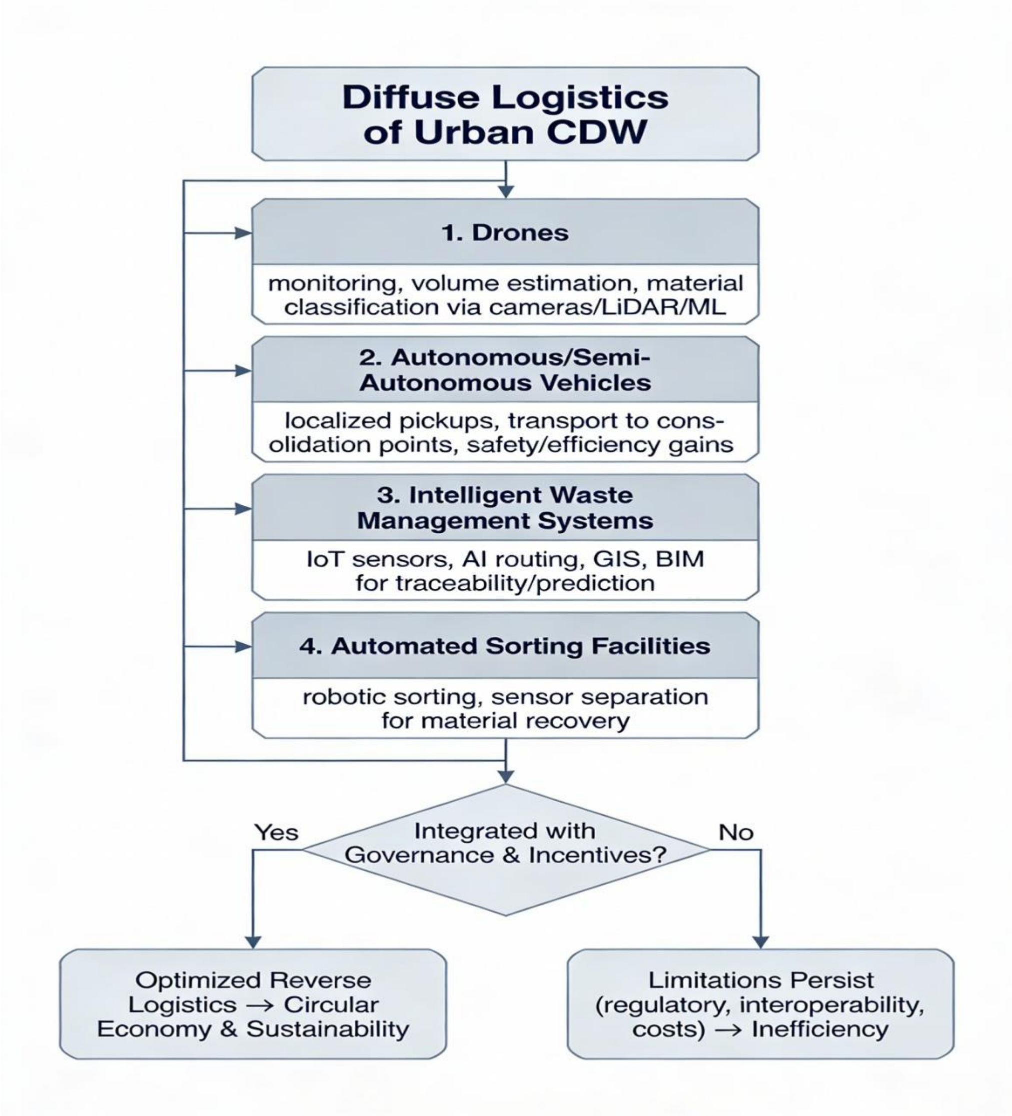
When integrated into coherent reverse logistics networks, these technologies facilitate a shift from linear disposal models toward resource-oriented waste management. Effective diffuse logistics systems require coordination among contractors, municipalities, recyclers, and technology providers, supported by transparent information flows and aligned incentives.

Modeling studies and pilot projects demonstrate that well-designed reverse logistics networks can achieve higher diversion rates and lower environmental impacts, provided that source segregation is encouraged and market demand for secondary materials is stable. Importantly, technological solutions alone are insufficient to overcome institutional fragmentation or weak regulatory enforcement, highlighting the need for complementary governance mechanisms (Kaewunruen *et al*., 2025; Dodampegama *et al*., 2024).

The flowchart, titled "Innovative Technologies for Urban CDW Diffuse Logistics," depicts the application of advanced technologies to address diffuse logistics challenges in urban construction and demolition waste (CDW) management, starting from the central node "Diffuse Logistics of Urban CDW" and branching into four key rectangular process nodes: Drones for site monitoring, volume estimation, and material classification using cameras, LiDAR, and machine learning; Autonomous/Semi-Autonomous Vehicles for efficient localized pickups and transport to consolidation points with safety and flexibility gains; Intelligent Waste Management Systems leveraging IoT sensors, AI-driven routing, GIS, and BIM for real-time data, traceability, and waste prediction; and Automated Sorting Facilities employing robotic systems and sensor separation to enhance material recovery and circular economy outcomes (see the generated image above). These technologies converge at a diamond decision node "Integrated with Governance & Incentives?", leading to two paths: "Yes" resulting in Optimized Reverse Logistics toward Circular Economy & Sustainability, or "No" perpetuating Limitations (regulatory barriers, data interoperability issues, high costs) and operational Inefficiency.

Figure 1

Innovative Technologies for Urban CDW Diffuse Logistics



Source: Created by author.

In conclusion, innovative technologies such as drones, autonomous vehicles, intelligent information systems, BIM-based traceability tools, and automated sorting infrastructure offer significant potential to address the diffuse logistics challenges associated with urban construction and demolition waste. Together, they enable decentralized collection, optimized routing, improved material recovery, and greater transparency across the waste management chain. However, their successful implementation depends on regulatory adaptability, economic feasibility, data standardization, and institutional coordination. Future research and policy efforts should therefore focus on integrated pilot projects that combine technological innovation with governance reforms, incentive structures, and circular economy principles to create scalable and resilient models for urban construction waste logistics (Wang et al., 2024; Wu *et al*., 2025; Jahangiri *et al*., 2022).

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