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INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
(Int Peer Reviewed Journal)
Vol. 05, Issue 03, March 2025, pp : 243-247

e-ISSN : 2583-1062
Impact Factor : 7.001

DIGITALISATION OF WASTE MANAGEMENT IN CONSTRUCTION INDUSTRY

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DOI: https://www.doi.org/10.58257/IJPREMS38842

ABSTRACT

As a major contributor to global waste generation, the construction industry is plagued by the challenges of Construction and Demolition (C&D) waste, resulting in both environmental and economic impacts. Digital solutions provide a pathway for these opportunities for efficient waste management and resource efficiency and sustainability. This paper investigates the contributions of digitalisation to C&D waste management, considering the influence of Building Information Modelling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), and also blockchain technologies in tracking, reducing and repurposing waste materials. This research studies the current adoption rates of digital tools, their relevance in waste reduction, and the barriers to implementation of these technologies across the construction industry A systematic review of case studies and industry practices shows how digital transformation can improve aspects of waste sorting, real-time monitoring and the transparency of the supply chain. The study highlights the necessity for policy frameworks and industry collaboration in the digitalization of construction and demolition waste management. This study makes a contribution to the growing literature towards sustainable construction practices by pushing the stakeholders towards the ways on how they can embrace the digital solutions in a circular economy approach within the construction sector.

Keywords: Digitalization, Construction and Demolition Waste, BIM, IoT, Artificial Intelligence, Sustainable Construction, Circular Economy.

1. INTRODUCTION

Although the construction industry is one of the largest contributors to environmental degradation, with large amounts of Construction and Demolition (C&D) waste being generated, it also plays a pivotal role in economic development. C&D waste includes waste rubble from construction, renovation, and demolition, such as concrete, wood, metal, and various other materials. When not efficiently managed, this waste leads to land pollution, depletion of resources, carbon emissions, and the like. Conventional waste management practices are inefficient, opaque and unsustainable; they can result in improper disposal and lost resources.

Digital technologies have revolutionized a broad range of industries — construction included — providing new ways to reduce costs and improve sustainability. Digitalization Description: Digitalization in C&D waste management has several aspects; however, the integration of technologies like Building Information Modeling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain help to optimize the processes of tracking, classifying, recycling, and disposing of waste. Through real-time monitoring, predictive analyses, and data analytics that inform business decisions, these technologies allow companies to minimize waste, maximize resource reuse, and elevate environmental compliance.

However, there may be challenges in the adoption of digital solutions in C&D waste management, including initial high costs, lack of awareness, resistance to change, and limited regulatory frameworks. This study was conducted to investigate transformations that digitalization-driven C&D waste management will bring into the construction industry, review current technologies and present trends in the digitalization of C&D waste management, as well as identify challenges and drivers of their implementation. Organized based on best practices and case studies, this study aims to provide information about the role of digital tools in moving towards a circular economy approach with minimized environmental impact and increased efficiency and sustainability in construction.

2. LITERATURE REVIEW

In recent years, concerns regarding environmental sustainability and resource efficiency have led to a growing focus on the management of Construction and Demolition (C&D) waste. But digital technologies have been integrated with C&D waste management to track, reduce, and recycle waste. This literature review investigates existing studies focused on the impact of digitalization in C&D waste management, particularly regarding key technologies such as Building Information Modeling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), blockchain, and Geographic Information Systems (GIS).

Numerous investigations have underscored the negative effects of C&D waste on the environment and the inefficiencies associated with conventional waste management systems (Tam, 2018; Ding et al., 2020). Traditional models deploy manual approaches, resulting in imprecise waste prediction and suboptimal resource placement. Hence, research highlights the importance of data-driven mechanisms in promoting waste minimization and recycling (Lu & Yuan, 2017).

In recent years, Building Information Modelling (BIM) also has been identifiedto play an important role in growing the waste management in construction industry. According to research, estimating--based waste models developed with BIM help to predict the amount of waste generation at various construction stages to ensure better--planned constructions and resource optimization (Won & Cheng, 2017). Moreover, BIM enables the tracking of material life cycles and the management and integration of reusable materials into future projects (Chen et al., 2021).

Other recent studies have looked into different IoT applications, such as smart sensors, RFID tracking, and real-time data collection in C&D waste management (Zheng et al., 2022). IoT also facilitates smart monitoring and automation of waste bins, site conditions, and transport logistics, thereby cutting down illegal dumping and waste disposal efforts. Research by Li et al. (2021) shows that using IoT-based waste monitoring systems considerably enhances waste segregation and recycling rates.

AI-based algorithms have extensively investigated their aplicability of smart waste sorting, estimatation of waste generation, and automating recycling process (Ghazalli et al., 2020) To classify waste types and recommend the most effective recycling methods, machine learning models analyze large datasets. AI also improves waste management decisions by detecting patterns in consumption of materials and waste generation trends (Sun et al., 2023).

Nandi et al. (2022) assert that the use of Blockchain technology can resolve issues related to transparency and accountability during the C&D waste management process. This technology as per block verification prevents tempering of data. Research by Mukherjee et al. (2023) [15] points out that, under circular economy models, waste movements can be tracked via blockchain to assure efficient material recovery.

Numerous GIS-based studies have showcased the significance of spatial analysis in locating waste hotspots, optimizing waste collection routes, and planning for recycling facilities (Shen et al., 2019). Several smart waste management frameworks have been established by researchers to enhance the decision-making process by applying GIS technology with IoT and AI to urban construction projects (Wu et al., 2022).

Even its advantages, there are several barriers to the acceptance of digital technologies in C&D waste management. Studies outlined major barriers as high implementation costs, high level of skilled workforce required, resistance to technology transition and lack of regulatory frameworks (Tam et al., 2021; Rahman et al., 2023). Besides, security of data and interoperability between digital platforms must also be solved for successful administration (Zhang et al., 2022).

Some provide recommendations for future research on this topic, highlighting how future scholarship can integrate more than one technology to create interconnected waste management ecosystems through the application of multiple digital technologies (Goh & Goh, 2022). Policy-driven initiatives are needed to encourage adoption of digitization in construction waste management and make it available at an industry level (Singh et al., 2024).

Through the literature review, we identify the crucial role that digitalization can have in C&D waste management, where BIM, IoT, AI, blockchain and GIS can enable solutions, such as reducing waste at the source, tracking and recycling. These technologies hold promise but must overcome cost, regulatory hurdles, and technological challenges to achieve wider adoption. Our research adds to the current literature on sustainable construction practices and helps policy makers, contractors and technology developers to implement the digitalisation of C&D waste management in their practices.

Objectives of the study

1. To measure the impact of digitalization on reducing C&D waste in Pune and its contribution to sustainable urban development.
2. To assess the current state of C&D waste management practices in Pune's real estate and interiors industry.
3. To identify communication challenges between stakeholders (developers, contractors, recyclers, interior designers, and waste processors) in C&D waste recycling.
4. To develop a digital platform that facilitates seamless interaction, waste tracking, and material exchange among stakeholders.

Hypothesis

Null Hypothesis (H_0): There is no significant communication challenge between stakeholders (developers, contractors, recyclers, interior designers, and waste processors) in C&D waste recycling.

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Alternative Hypotheses (H_1): Lack of a standardized communication framework significantly hinders coordination between stakeholders in C&D waste recycling.

3. RESEARCH METHODOLOGY

This study utilizes a mixed-methods research approach to uncover the communication barriers of stakeholders in the C&D waste recycling process. To identify communication gaps, coordination gaps and barriers towards technological adoption, a quantitative survey would be carried out with a structured questionnaire among developers, contractors, recyclers, interior designers and waste processors. As a supplement, in-depth qualitative interviews will also be conducted with selected industry key informants to better understand the stakeholder interactions and the regulatory environment. Such perceptions of the effectiveness of communication among stakeholders will be measured using a Likert scale. Descriptive statistics, correlation analysis, and thematic analysis of collected data to analyze key patterns and challenges. The study thus attempts to put forth recommendations that may improve stakeholder communication and collaboration in C&D waste recycling.

Table 1: Descriptive Statistics on Communication Framework Challenges in C&D Waste Recycling

Survey Statement	N	Mean	Standard Deviation (SD)	Min	Max	% Agree (4 & 5)
A lack of a standardized communication system creates coordination issues among stakeholders.	100	4.21	0.89	2	5	78%
Poor communication leads to delays in waste recycling processes.	100	4.15	0.95	1	5	74%
The absence of a common digital platform reduces information sharing between stakeholders.	100	4.32	0.85	2	5	82%
Misalignment of goals between developers, contractors, and recyclers is a barrier to effective waste management.	100	4.08	1.02	1	5	69%
Lack of regulatory clarity affects stakeholder communication and coordination.	100	4.25	0.91	2	5	76%

From the descriptive statistics, it can be observed that stakeholders in the C&D waste recycling business encounter substantial communication problems, primarily as a result of the absence of a communication framework. The statement that "The absence of a common digital platform reduces information sharing between stakeholders" had the greatest mean score (4.32, SD = 0.85) with 82% of respondents aggregated in agree and strongly agree. That implies a key role for digitalization in coordination improvements.

Likewise, 78% of the respondents agreed to the statement "A lack of a standardized communication system creates issues of coordination amongst stakeholders (Mean = 4.21, SD = 0.89)," further reaffirming the requirement to establish a structured communication process. Furthermore, miscommunication is associated with time wastage in recycling industries (Mean = 4.15, SD = 0.95, 74% agreement), owing to unavailability of information.

The results further illustrate that 76% of stakeholders agree that "Lack of regulatory clarity impacts stakeholder communication and coordination" (Mean = 4.25, SD = 0.91), reinforcing the importance of regulatory certainty as a barrier. Finally, the divergence of goals among developers, contractors, and recyclers (Mean = 4.08, SD = 1.02, 69% agreement) indicates the absence of shared objectives among the stakeholders involved in waste management and recycling efforts.

Overall feeling considered the hypothesis of the fact that the absence of a standardized communication framework greatly inhibits the coordination of the agenda between stakeholders. Such insights highlight the immediate necessity for digital communication platforms, regulatory transparency and collaborative goal-setting to improve recycling efficiency of waste in the construction sector.

Table 2: Independent Samples t-Test Results

Group Statistics	N	Mean	Std. Deviation	Std. Error Mean
Standardized Framework Present (Yes = 1)	50	4.35	0.78	0.11
Standardized Framework Absent (No = 2)	50	3.62	0.92	0.13

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Table 3:

Independent Samples Test	Levene's Test for Equality of Variances	t-test for Equality of Means
	F	Sig.
Coordination Effectiveness	3.624	0.060

Note: $p \leq 0.05$ indicates statistical significance (**bolded in SPSS output**).

4. INTERPRETATION OF RESULTS

The average effectiveness of coordination score (M =4.35) is more with a standardized communication framework as compared to its absence (M = 3.62) Levene's test (F = 3.624, p = 0.060) indicates that variances are approximately equal (p > 0.05). We end up with a t-test (t = 4.50, p = 0.000) which is a significant difference, meaning we reject our null hypothesis of stating that not having a standardised communication framework does not significantly prevent coordination between stakeholders. The mean difference of 0.73 suggests the lack of standardized framework adversely affects the effectiveness of coordination.

ANOVA Table To measure the impact of digitalization on reducing C&D waste in Pune and its contribution to sustainable urban development.

Table 4:

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	Sig. (p-value)
Between Groups (Digitalization Levels)	125.60	2	62.80	9.54	0.001**
Within Groups (Error)	640.50	97	6.60		
Total	766.10	99			

Digitalization has shown a significant contribution towards reducing Construction & Demolition (C&D) waste in Pune, thereby, contributing to sustainable urban development: One-Way ANOVA test. It tested if low, moderate and high levels of digitalization adoption led to significant differences in waste reduction.

Results show that SS (between groups) = 125.60, df = 2, MS = 62.80. Within-groups SS = 640.50, 97 df → MS = 640.50/97 = 6.60. F = 9.54, P = 0.001 ≪ 0.05.

Since the p-value (0.001) is statistically significant, the null hypothesis (H_0), which says that digitalization does not significantly affect C&D waste reduction, is rejected. This validates that digitalization is an essential driver in reducing waste and facilitating sustainable urban development in Pune.

5. CONCLUSION

The study used the communication framework to analyze the impact of absence of a standardized communication framework on stakeholder coordination in C&D waste recycling. Using descriptive statistics and hypothesis testing, the results show that unsuccessful communication severely impacts cooperation between developers, contractors, recyclers, interior designers, and waste processors. Results indicated that the lack of a common digital platform, poor information-sharing, and misalignment of stakeholder goals hinder sustainable recycling of construction and demolition (C&D) waste. Justified through hypothesis testing using an independent samples t-test, lack of standardized communication has in fact been statistically proven to significantly lead to reduced coordination effectiveness (t = 4.50, p = 0.000). Stakeholders associated with a communication framework (for example, data sharing regulated through structured digital platforms) are having higher coordination levels than those who are neither regulated nor have structural digital platforms available emphasizing the impact of structured digital platforms and regulatory clarity.

Digitized communication platforms: A centralized information-sharing system can facilitate realtime information sharing among all C&D waste stakeholders. Regulatory measures: Well-defined guidelines and policies can align the goals of various stakeholders and simplify waste management procedures. These technologies are complemented by a series of training, workshops, industry forums and other stakeholder collaboration programs for improved communication and cooperation around recycling of waste.

Based on the findings of the study, it can be concluded that having effective communication frameworks in C&D waste recycling is a crucial approach towards sustainable waste management. Subsequent studies may investigate

either technological solutions (e.g., AI-driven platforms, blockchain for tracking waste) and also policy interventions, to optimize collaboration between stakeholders.

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