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A Longitudinal Analysis of Construction Waste Recycling Performance in Peninsular Malaysia (2017–2024) Through Digital Monitoring Indicators

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Abstract

The construction sector in Malaysia is a major contributor to overall waste generation, underscoring the urgent need for sustainable waste management practices. Therefore, this study examines the longitudinal performance of Peninsular Malaysia's construction and demolition (C&D) waste management system from 2017 to 2024, focusing on the effectiveness of digital monitoring tools in assessing recycling and reuse outcomes. The data for this study were obtained from the Construction Waste Monitoring System (CWMS), administered by the Solid Waste and Public Cleansing Management Corporation (SWCorp). The study analyses trends across 11 Peninsular states and 2 federal territories. Key performance indicators, including the Recycling to Generated (CG), Reuse to Generated (RG), and Landfill to Generated (LG) ratios, were employed to evaluate waste diversion efforts. Findings indicate intermittent rather than sustained improvements in recycling and reuse, particularly in urban regions, alongside a continued heavy reliance on landfilling, with LG ratios frequently exceeding 80%. State-level disparities and implementation challenges, such as voluntary reporting, limited infrastructure, and enforcement capacity constraints, further hinder progress. The study concludes that while digital systems offer valuable transparency and accountability, they have not yet translated into consistent improvements in diversion performance. Recommendations include mandating digital reporting, offering performance-based incentives, expanding recycling infrastructure, and institutionalising digital indicators within compliance frameworks. These measures are crucial to supporting Malaysia's transition toward a circular economy in the construction sector.

1. Introduction

The global increase in construction and demolition (C&D) waste has emerged as a critical environmental and economic challenge [1]. Driven by rapid urbanization and economic expansion, escalating construction activities have generated substantial waste volumes, most of which continue to be disposed of through landfilling [2], [3]. This practice contributes to land degradation, groundwater contamination, and air pollution, while placing additional economic burdens on governments due to high costs associated with waste disposal and management [4], [5]. The situation is further exacerbated by the depletion of natural resources and ecological disruptions [6]. In response, integrating circular economy principles into construction waste management has been recognised as a vital strategy to promote sustainable resource utilisation and mitigate environmental harm [7].

Recent advancements in digital technologies have created new opportunities for more systematic and transparent tracking of construction waste flows, prompting several countries to revisit their waste governance structures [8], [9]. Globally, digital monitoring systems and data analytics are transforming the measurement and management of waste generation and recycling performance [10]. In the Malaysian context, a significant institutional shift occurred in 2018 with the introduction of the Construction Waste Monitoring System (CWMS), which was communicated through nationwide briefings to contractors and enforcement agencies. This marked the first formal rollout of a dedicated digital platform for the governance of construction and demolition waste in the country [11]. This system facilitates real-time data collection and tracking of waste management practices across construction sites, offering the potential for longitudinal assessment and evidence-based decision-making [10], [12].

Malaysia's construction sector has experienced significant growth over the past decade, leading to heightened challenges in managing C&D waste [13]. Despite growing awareness, the country continues to rely heavily on landfilling, with limited diversion to recycling or reuse [14]. A persistent challenge across developing economies is the absence of reliable, long-term empirical datasets for construction and demolition (C&D) waste, which undermines monitoring and system improvement efforts [15]. Most existing research focuses on short-term or project-specific assessments, failing to capture evolving trends or sustained impacts of policies and interventions [16], [17]. Consequently, the lack of longitudinal digital indicators restricts Malaysia's capacity to evaluate systemic progress and to identify persistent structural barriers within the construction waste management system [18].

Addressing this research gap requires a consistent, data-driven monitoring framework that can effectively evaluate construction waste management performance over time. Recycling indicators are globally recognised as essential tools for assessing the efficiency and circularity of waste systems [19]. Consequently, digital performance indicators such as the Recycling to Generated (CG), Reuse to Generated (RG), and Landfill to Generated (LG) ratios that offer robust tools for benchmarking system efficiency and tracking progress over time. However, in Malaysia, the current construction waste data landscape remains fragmented and largely dependent on voluntary reporting, particularly outside federally administered jurisdictions, thereby limiting comprehensive and consistent evaluation at scale [17].

Considering persistent challenges in construction waste management, this study undertakes a longitudinal analysis of Peninsular Malaysia's performance between 2017 and 2024 using digital monitoring indicators [20]. The primary objectives are to quantify annual trends through key metrics, namely the recycling to generated (CG), reuse to generated (RG), and landfill to generated (LG) ratios, identify patterns of improvement, stagnation, or regression in waste diversion, and examine structural and policy-related factors that constrain recycling outcomes. The findings offer evidence-based insights that inform strategic policy recommendations, including the institutionalization of mandatory digital reporting, the provision of fiscal incentives to promote recycling efforts, and the incorporation of diversion indicators into regulatory compliance frameworks [21]. By integrating digital tools into national waste governance structures, Malaysia can advance toward a more sustainable and circular construction economy [22].

2. Longitudinal Digital Monitoring in Construction Waste Management

The integration of circular economy (CE) principles into construction waste management has gained global momentum, driven by increasing environmental concerns and the growing imperative for sustainable development [23]. Recent research emphasizes the role of digital technologies in enhancing transparency, accountability, and evidence-based decision-making in waste management systems [24]. Case studies from Europe and parts of Asia demonstrate that digital tracking systems have significantly improved operational efficiency by enabling detailed waste flow analyses and supporting the real-time monitoring of recycling and material reuse activities [25]-[27].

In the Malaysian context, sustainable construction waste management is governed primarily through the Solid Waste and Public Cleansing Management Act 672, implemented in seven Peninsular states [28], and the Local Government Act 1976 (Act 171), which empowers local authorities to regulate construction waste in non-Act 672 states [29]. At the national level, the Circular Economy Blueprint for Solid Waste 2025–2035 outlines national priorities for improving material efficiency and expanding digital reporting across major waste streams [30]. Complementing these policies, SWCorp issues technical guidelines for managing construction waste at project sites [31], particularly under the Solid Waste and Public Cleansing Management Regulations (P.U. (A) 279/2018)

[32]. However, the implementation and enforcement of these regulatory instruments vary across states, resulting in uneven adoption of digital reporting and recovery practices.

Despite this policy architecture, a significant gap persists in the availability of comprehensive, empirical datasets that capture long term construction and demolition (C&D) waste treatment performance [33], [34]. Indicators such as the Recycling to Generated (CG), Reuse to Generated (RG), and Landfill to Generated (LG) ratios have been proposed as benchmarks, yet their application remains sporadic and primarily confined to pilot or voluntary reporting initiatives [34], [35]. As a result, observed performance trends may partly reflect system familiarity and reporting maturity rather than actual improvements in waste diversion outcomes. The slow adoption of advanced technologies, including GIS-based planning and predictive analytics, further constrains efforts to scale digital monitoring [36], [37]. This is consistent with persistent evidence that Malaysia's construction sector remains behind other major industries in digital transformation, especially in the area of environmental performance reporting [36], [38].

A key challenge in evaluating the effectiveness of waste management policies lies in the lack of consistent and longitudinal data [35]. Short-term or fragmented datasets fail to reveal structural inefficiencies or long-standing barriers to recycling and reuse [39], [40]. As emphasised by Gálvez-Martos et al. [41], the utility of any monitoring system is directly linked to the quality, granularity, and temporal continuity of its underlying data. Without multi-year digital records, policymakers and stakeholders lack the necessary insights to assess program effectiveness, adapt strategies, or track progress toward CE goals. Therefore, there is an urgent need for a unified, longitudinal digital monitoring framework that captures construction and demolition (C&D) waste performance in a consistent and standardised manner across administrative jurisdictions**.** Such a framework is particularly important for distinguishing between structural policy limitations, external disruptions (such as economic shocks), and genuine improvements in system performance over time.

3. Methodology

This study adopts a longitudinal quantitative research design to assess trends in construction and demolition (C&D) waste management performance in Peninsular Malaysia from 2017 to 2024. The analysis relies on secondary data obtained from the Construction Waste Monitoring System (CWMS), a national platform managed by the Solid Waste and Public Cleansing Management Corporation (SWCorp) [11], [42]. This system provides comprehensive monthly records on total waste generation, along with data on materials that have been recycled, reused, or disposed of in landfills [42].

In its initial phase between 2017 and 2019, CWMS reporting was dominated by the seven Act 672 states, where construction waste management falls under SWCorp's regulatory mandate [28]. During this period, submissions from non-Act 672 states were minimal, as CWMS use was not mandatory under local authority legislation [29]. From 2020 onwards, CWMS began receiving a wider range of project entries from across Peninsular Malaysia, although participation outside Act 672 areas remained voluntary and inconsistent. The East Malaysian states of Sabah and Sarawak are excluded from the dataset because they operate under separate solid waste legislation and do not utilise CWMS [43], [44]. This variation in regulatory coverage explains the uneven geographical distribution of data and influences the representativeness of broader national-level interpretation.

To evaluate waste treatment performance, three key indicators are calculated annually: the Recycling to Generated Ratio (CG), the Reuse to Generated Ratio (RG), and the Landfill to Generated Ratio (LG). These ratios are derived by dividing the amount of waste recycled, reused, or landfilled by the total amount of waste generated in a given year, and then multiplying by 100 to express the result as a percentage. These standardised indicators allow for consistent year-to-year comparisons and benchmarking across different waste treatment practices. The year 2018 is adopted as the analytical baseline, as it represents the first complete operational cycle of CWMS implementation under the Act 672 jurisdictions [11]. While data from 2017 are included for reference, they are treated cautiously due to their limited coverage. The data are analysed using descriptive statistical methods to observe trends and changes in the CG, RG, and LG ratios over time.

4. Results and Analysis

Building on the methodology outlined earlier, this section presents the aggregated performance outcomes derived from Malaysia's Construction Waste Monitoring System (CWMS). Covering the period from 2017 to 2024, the analysis draws on data reported by 11 Peninsular Malaysian states and two federal territories, namely Kuala Lumpur and Putrajaya. The study employs three key performance indicators: the Recycling to Generated Ratio (CG), the Reuse to Generated Ratio (RG), and the Landfill to Generated Ratio (LG). Calculated annually, these standardised indicators provide a consistent basis for assessing waste treatment outcomes over time. Collectively, they enable a longitudinal assessment of construction waste diversion trends within Peninsular Malaysia under the CWMS framework, with 2018 adopted as the analytical baseline corresponding to the first full operational year of digital monitoring.

4.1 Longitudinal Construction Waste Database

The dataset comprises aggregated annual figures on construction waste generation and treatment outcomes derived from the Construction Waste Monitoring System (CWMS). Table 1 presents a comprehensive overview of recycling, reuse, and landfill outcomes from 2017 to 2024 across Peninsular Malaysia, offering insights into the progression of waste management performance and highlighting shifts in sustainability practices within the construction sector.

Table 1 *Longitudinal recycle and reuse of construction waste*

Year	Total Waste (t)	Recycled (t)	Reused (t)	Landfilled (t)	Projects	CG (%)	RG (%)	LG (%)
2017	268,245	37,133	9,845	221,267	242	13.84	3.67	82.49
2018	1,456,459	23,059	2,178	1,431,222	59	1.58	0.15	98.27
2019	345,225	32,014	119,061	194,150	127	9.27	34.49	56.24
2020	36,188	4,516	10,571	21,101	165	12.48	29.21	58.31
2021	76,444	6,816	47,932	21,695	151	8.92	62.70	28.38
2022	42,424	21,934	3,188	17,303	101	51.70	7.51	40.78
2023	16,625	757	2,491	13,377	66	4.55	14.98	80.46
2024	7,706	1,175	2,422	4,109	102	15.24	31.43	53.32
Mean	281,164	15,925	24,711	240,528	127	14.70	23.02	62.28
STDEV	491,248	14,424	41,098	488,969	60	15.64	20.76	23.23

*CG (Recycling to Generated), RG (Reuse to Generated), and LG (Landfill to Generated) ratios

Table 1 provides a longitudinal overview of construction waste management from 2017 to 2024, focusing on the total waste generated, quantities recycled and reused, and the volume landfilled across various construction projects. The table also includes calculated ratios: CG (Recycling to Generated), RG (Reuse to Generated), and LG (Landfill to Generated), which help illustrate the efficiency and sustainability of waste management practices over time.

The data indicate that landfilling remains the dominant waste treatment method overall, with an average landfill-to-generated (LG) ratio of 62.28%, suggesting that a substantial proportion of construction waste continues to be disposed of in landfills. In contrast, the average recycling-to-generated (CG) and reuse-to-generated (RG) ratios are 14.70% and 23.02%, respectively, indicating that while diversion efforts have improved in certain years, circular practices remain unevenly adopted across the construction sector.

Notably, recycling and reuse ratios exhibited substantial variation over the study period, with particularly high reuse in 2021 (RG = 62.70%) and elevated recycling in 2022 (CG = 51.70%), reflecting project-specific recovery practices and reporting effects. However, the overall trend suggests inconsistent efforts across the years. For example, 2018 exhibits exceptionally high total waste volumes, coupled with very low recycling and reuse ratios. In contrast, other years, such as 2020, also showed weak diversion performance, despite comparatively low total waste generation.

The high standard deviations in total waste, recycled and reused quantities further indicate significant year-to-year variability, which may be attributed to differences in project scale, regulatory enforcement, or the type of construction activities involved. Despite a general decline in total waste volumes in recent years, such as only 7,706 tonnes recorded in 2024, landfilling continues to account for a substantial share of waste treatment. These patterns indicate the presence of structural constraints within the construction waste management system that cannot be addressed solely through digital monitoring.

Fig. 1 presents a horizontal bar chart comparing the ratios of landfilling (LG%), reuse (RG%), and recycling (CG%) of construction and demolition waste in Malaysia from 2017 to 2024. Each year is represented by three colour-coded bars: blue for LG (Landfill to Generated), green for RG (Reuse to Generated), and orange for CG (Recycling to Generated).

The visualisation indicates that landfilling remains the dominant waste treatment method throughout much of the study period, particularly during the early phase of digital monitoring. Substantial temporal variation is nevertheless observed. The highest landfill dependency occurred in 2018 (LG ≈ 98%), coinciding with the initial rollout of Malaysia's digital monitoring system. This spike likely reflects transitional reporting effects, whereby waste declarations were concentrated among a limited number of large projects during the system's early implementation phase.

Conversely, the recycling (CG) and reuse (RG) ratios exhibit pronounced year-to-year variability, with notably high reuse recorded in 2021 and elevated recycling in 2022. These fluctuations suggest that diversion performance is strongly influenced by project-specific practices and reporting coverage, rather than representing a consistently sustained system-wide improvement. Despite intermittent gains in recycling and reuse, landfilling remains a substantial contributor to overall waste treatment. Overall, the chart reinforces the quantitative findings by illustrating the persistent reliance on landfill disposal and the uneven, non-linear patterns of diversion performance under the CWMS framework.

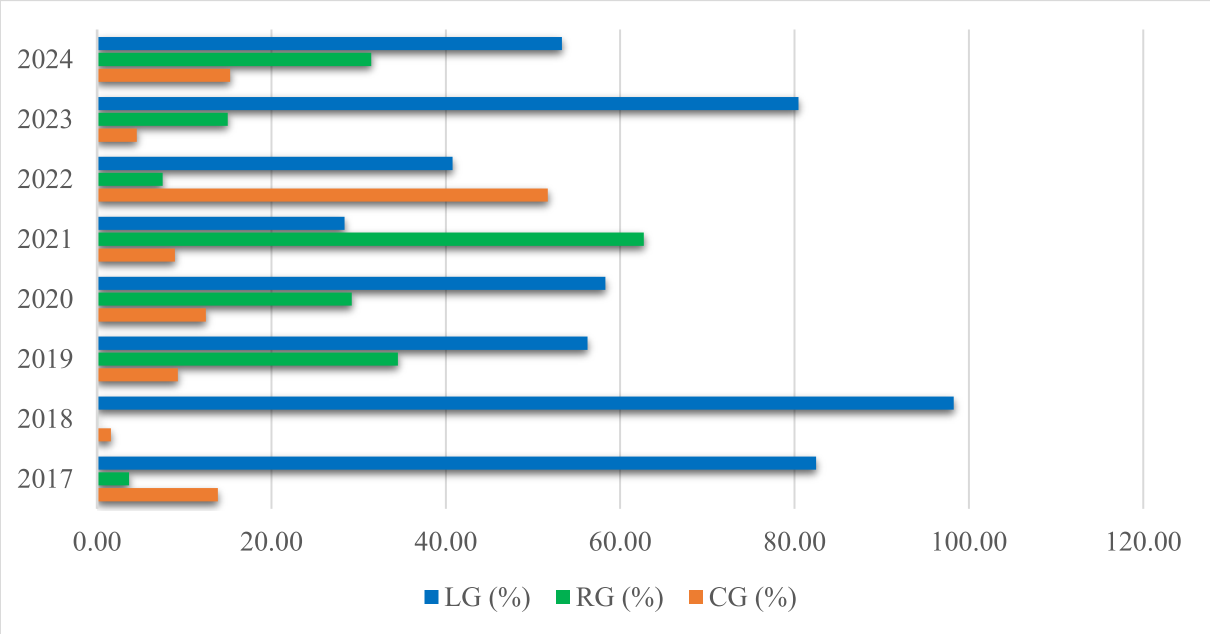

Fig. 1 *Ratio of recycle, reuse and landfill*

To further enhance the visual interpretation of longitudinal diversion patterns, a heatmap is introduced in Table 2 to illustrate the relative intensities of CG, RG, and LG ratios across years. The colour gradient facilitates the rapid identification of years characterised by landfilling versus periods of comparatively stronger recycling or reuse performance, thereby complementing the trend-based comparison shown in Fig. 1. Fig. 2 presents a heatmap visualisation of CG, RG, and LG ratios from 2017 to 2024, where colour intensity reflects the relative magnitude of each indicator. Warmer colours indicate higher ratios, allowing clearer identification of years with dominant landfill reliance or comparatively stronger recycling and reuse performance.

Year	CG (%)	RG (%)	LG (%)
2017	13.84	3.67	82.49
2018	1.58	0.15	98.27
2019	9.27	34.49	56.24
2020	12.48	29.21	58.31
2021	8.92	62.70	28.38
2022	51.70	7.51	40.78
2023	4.55	14.98	80.46
2024	15.24	31.43	53.32

Fig. 2 *Heatmap of recycling (CG), reuse (RG), and landfill (LG) ratios by year 2017–2024*

4.2 States Construction Waste Database (2017 to 2024)

To complement the aggregated Peninsular-level trends, a state-level analysis was conducted to uncover regional disparities in construction waste management performance. This granular approach highlights notable variations in waste diversion outcomes across different states and federal territories. Table 2 presents a summary of key indicators by state, including the total number of construction projects monitored and the calculated diversion ratios for recycling (CG), reuse (RG), and landfill disposal (LG). These indicators offer critical insights into the relative effectiveness of waste treatment practices at the subnational level, enabling targeted evaluation and benchmarking of state-level sustainability efforts from 2017 to 2024.

Table 2 *Distribution of recycling, reuse and landfill*

State	Total Projects	Total Waste (t)	Total Recycled (t)	Total Reused (t)	Total Landfilled (t)	CG (%)	RG (%)	LG (%)
Johor	160	1,557,589	33,841	6,327	1,517,421	2.17	0.41	97.42
Kedah	75	21,752	3,474	5,286	12,992	15.97	24.30	59.73
Kelantan	22	7,737	511	259	6,968	6.60	3.34	90.06
Melaka	113	40,526	12,777	1,882	25,868	31.53	4.64	63.83
Negeri Sembilan	52	7,321	1,034	666	5,620	14.13	9.10	76.77
Pahang	94	16,902	1,706	3,703	11,493	10.09	21.91	68.00
Pulau Pinang	25	80,749	5,931	47,401	27,417	7.35	58.70	33.95
Perak	33	6,019	1,344	1,029	3,645	22.33	17.10	60.57
Perlis	29	1,909	339	126	1,444	17.75	6.58	75.67
Selangor	67	119,760	8,674	10,839	100,246	7.24	9.05	83.71
Terengganu	20	3,049	579	89	2,380	19.00	2.93	78.07
W.P. Kuala Lumpur	63	268,782	34,661	117,133	116,988	12.90	43.58	43.53
W.P. Putrajaya	22	117,220	22,532	2,947	91,741	19.22	2.51	78.26
Mean	60	173,024	9,800	15,207	148,017	14.33	15.70	69.97
STDEV	43	422,917	12,576	33,133	413,494	7.89	17.70	17.77

*CG (Recycling to Generated), RG (Reuse to Generated), and LG (Landfill to Generated) ratios

Table 2 presents a detailed breakdown of construction and demolition (C&D) waste management performance across 11 states and two federal territories in Peninsular Malaysia, based on projects that actively declared waste data in the CWMS from 2017 to 2024. Overall, landfilling remains the dominant waste treatment method, with a mean landfill-to-generated (LG) ratio of 69.97%, indicating a continued reliance on disposal-oriented practices at the state level.

Recycling performance varies widely across the states. Melaka (31.53%), Perak (22.33%), and Putrajaya (19.22%) record the highest CG ratios, indicating relatively stronger recycling efforts. However, several states, such as Johor (2.17%), Kelantan (6.60%), and Selangor (7.24%), remain below the overall mean CG of 14.33%, highlighting considerable room for improvement. Reuse practices are similarly uneven. W.P. Kuala Lumpur (43.58%), Pulau Pinang (58.70%), and Kedah (24.30%) exhibit comparatively strong reuse activity, while most states fall below the mean RG of 15.70%, with exceptionally low reuse observed in Terengganu (2.93%), Putrajaya (2.51%), and Kelantan (3.34%).

There is a significant variance in the number of monitored projects across states, ranging from 20 in Terengganu to 160 in Johor. States with higher project numbers tend to generate larger waste volumes but do not consistently achieve better diversion outcomes. For instance, Johor, despite its high project count and the most significant total waste volume, records a CG ratio of only 2.17%, well below the state-level average. This suggests that diversion outcomes are more strongly shaped by infrastructure availability and enforcement capacity than by reporting volume or project familiarity alone. The mean CG ratio across states is 14.33%, with a standard deviation of 7.89, indicating moderate variability in recycling performance. In contrast, the RG ratio shows greater dispersion, with a mean of 15.70% and a standard deviation of 17.70, reflecting inconsistent adoption of reuse practices across states. The LG ratio, while dominant overall, has a mean of 69.97% and a standard deviation of 17.77, suggesting that although landfilling prevails, certain states are making more pronounced efforts to divert waste from landfill disposal.

To further support the interpretation of state-level disparities, a heatmap representation is presented in Fig. 3 to visualise the relative intensity of CG, RG, and LG ratios across states and federal territories. The colour gradients enable rapid identification of states with dominant landfill dependency versus those exhibiting comparatively stronger recycling or reuse performance, thereby complementing the numerical comparisons in Table 2.

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State	CG (%)	RG (%)	LG (%)
Johor	2.17	0.41	97.42
Kedah	15.97	24.3	59.73
Kelantan	6.6	3.34	90.06
Melaka	31.53	4.64	63.83
Negeri Sembilan	14.13	9.1	76.77
Pahang	10.09	21.91	68
Pulau Pinang	7.35	58.7	33.95
Perak	22.33	17.1	60.57
Perlis	17.75	6.58	75.67
Selangor	7.24	9.05	83.71
Terengganu	19	2.93	78.07
W.P. Kuala Lumpur	12.9	43.58	43.53
W.P. Putrajaya	19.22	2.51	78.26

Fig. 3 *Heatmap of recycling (CG), reuse (RG), and landfill (LG) ratios by state (2017–2024)*

The heatmap highlights stark contrasts in waste diversion performance across states. Johor, Kelantan, and Selangor are visually dominated by high LG intensities, indicating persistent reliance on landfill disposal. In contrast, Pulau Pinang and W.P. Kuala Lumpur exhibit strong RG intensities, reflecting comparatively mature reuse practices, whereas Melaka and Perak show stronger CG intensities, reflecting higher recycling activity. These visual patterns reinforce the uneven spatial distribution of waste diversion capacity across Peninsular Malaysia.

Overall, the results reveal a highly uneven landscape in C&D waste management across states and federal territories in Peninsular Malaysia. While selected federal territories, particularly W.P. Kuala Lumpur, demonstrate comparatively stronger waste diversion performance, most states continue to rely heavily on landfill disposal. These findings emphasise the need for state-specific strategies, improved enforcement of recycling policies, and more consistent waste reporting practices to support the broader transition toward a circular construction economy.

5. Discussion

Results from Table 1 outline the evolution of recycling, reuse, and landfill practices over the study period. A key anomaly is observed in 2018, when total C&D waste generation peaked at approximately 1.46 million tonnes. This corresponds with the pilot phase of the Construction Waste Monitoring System (CWMS), during which waste reporting was concentrated among a limited number of large-scale infrastructure projects, resulting in disproportionately high recorded volumes. Despite this irregularity, 2018 remains the analytical baseline, as it represents the first full operational year of digital reporting. When 2018 is excluded, the post-2018 trend (2019–2024) still indicates persistent landfill dominance and volatile diversion performance, confirming that the study's conclusions are robust beyond the pilot year. The sharp decline in recorded waste after 2019 likely reflects reporting coverage and compliance (voluntary participation), rather than an actual reduction in C&D waste generation in Peninsular Malaysia.

Consistent with this transition phase, recycling (CG) and reuse (RG) ratios were lowest in 2018, at 1.58% and 0.15%, respectively. Subsequent years exhibit substantial fluctuation rather than a linear improvement trend. Notably, reuse performance peaked in 2021 (RG = 62.70%), while recycling reached its highest level in 2022 (CG = 51.70%), reflecting project-specific recovery practices rather than sustained system-wide improvements. Yet this improvement did not persist, as subsequent years showed stagnation and regression in diversion performance. Between 2020 and 2022, diversion performance showed mixed and unstable patterns, which may partly reflect the disruptive effects of the COVID-19 pandemic. Movement restrictions, reduced site activity, limited audits, and interruptions to reporting continuity likely influenced waste declaration behaviour during this period[45]. Accordingly, trends observed in 2020–2022 should be interpreted as a combination of operational disruption and reporting discontinuity, rather than policy effectiveness alone.

Landfilling remains the dominant waste treatment method across much of the study period, particularly during the early years of digital monitoring. While LG ratios exceeded 80% in several years, with a peak of approximately 98% in 2018, subsequent years show greater variability, with temporary reductions observed in 2021 and 2022. Nevertheless, landfill disposal continues to account for a substantial share of overall waste treatment, indicating persistent reliance on linear disposal pathways.

While Malaysia saw marginal improvements over the years, intermittent gains in diversion performance have been observed, and overall progress remains uneven. Across the study period, CG and RG ratios exhibit pronounced volatility rather than steady growth, indicating that gains in recycling and reuse are not consistently sustained. For example, countries such as the Netherlands and Japan routinely exceed 70% in C&D waste diversion, reflecting mature regulatory frameworks and market-ready recycling systems [46], [47]. Thailand provides a contrasting benchmark, where scenario-based circular economy assessments using life cycle analysis (LCA) demonstrate the technical feasibility of near-complete recycling of construction waste, particularly concrete, alongside energy recovery pathways for timber waste [48]. Compared to Malaysia's predominantly monitoring-oriented approach, Thailand's framework integrates performance modelling directly into policy-relevant decision-making, resulting in substantially higher diversion potential.

5.1 State-Level Disparities in Diversion Performance

State-level analysis further reveals pronounced disparities in construction waste diversion performance. Table 2 summarises key indicators by state, including total project counts and calculated CG, RG, and LG ratios. This disaggregated view highlights significant disparities in digital system integration, regulatory enforcement, and access to treatment infrastructure. W.P. Kuala Lumpur and Putrajaya consistently recorded the highest volumes of recycled and reused construction waste. Their performance corresponds with earlier and higher adoption rates of digital reporting, as well as the concentration of large-scale urban projects. In contrast, high-waste-generating states like Johor and Selangor exhibited relatively low CG and RG rates, signalling inefficiencies in recovery infrastructure and system enforcement, despite high construction activity.

Kelantan presents a unique case. While some recovery was recorded in 2017 and 2018, the limited continuity and low volume of project declarations beyond the early CWMS phase indicate weak enforcement capacity and poor digital integration. Comparable limitations are observed in Sabah and Sarawak, which were excluded from this study due to their non-participation in the SWCorp-administered system [43], [44]. These disparities highlight the need for a more harmonised and inclusive policy approach that can elevate low-performing states and support more consistent waste recovery practices across jurisdictions.

5.2 Systemic Constraints and Policy Gaps

Despite the availability of digital infrastructure, several systemic challenges persist that hinder the effective implementation of construction and demolition (C&D) waste monitoring in Malaysia. A key issue is the voluntary nature of participation, with many contractors, particularly those operating in non-SWCorp-administered jurisdictions, failing to report their waste data consistently [28]. The absence of incentives further compounds this lack of engagement; without fiscal rewards or regulatory credits, contractors have little motivation to prioritise recycling efforts [49]. Additionally, the limited availability of recycling and reuse infrastructure, particularly in rural and semi-urban areas, significantly constrains material recovery efforts [49]. Enforcement capacity has similarly remained limited, as resource limitations have hindered routine audits and reduced the capacity for meaningful compliance follow-up [50]. These barriers align with international findings, which show that without strong policy frameworks, active enforcement, and well-structured market incentives, recycling programs tend to remain peripheral and underutilised [49], [51].

5.3 Strategic Recommendations

To effectively address the current gaps and advance Malaysia's construction sector toward achieving circular economy (CE) objectives, several strategic actions are proposed. First, digital reporting of construction and demolition (C&D) waste should be made mandatory for all projects that exceed a specific size or budget threshold. This would ensure consistent and comprehensive data collection across the industry. Second, contractors who demonstrate high recycling-to-generated (CG) and reuse-to-generated (RG) performance should be rewarded through tangible incentives, such as green certification bonuses or preferential treatment in project tender evaluations. Third, the government should prioritise the development and expansion of recycling and reuse infrastructure, especially in rural and underserved areas where such facilities are currently lacking. Lastly, the CG, RG, and landfill-to-generated (LG) ratios should be formally institutionalised as mandatory compliance indicators in project assessments conducted by the Construction Industry Development Board (CIDB) and local authorities. These measures, collectively, would create a more robust policy framework to promote sustainable waste management practices in the Malaysian construction industry.

5.4 Post-Baseline Improvements and Slow Progress

While the digital monitoring system has enabled a modest increase in recycling and reuse rates since 2018, the overall pace of improvement has been slow and inconsistent [52]-[54]. The initial drop in participation from 242 projects in 2017 to only 59 in 2018, highlights the challenges of transitioning to a new system, particularly without mandatory reporting. Although digital familiarity among contractors has improved over time and the number of reporting projects has partially recovered, participation remains insufficient and uneven across states, limiting the dataset's reliability and broader representativeness. This issue has also been identified in other countries, where voluntary systems yield weak compliance and poor data coverage [55].

5.5 Persistent Landfilling and Infrastructure Gaps

One of the most persistent findings is the overwhelming reliance on landfilling as a default treatment method [56]. Despite the system's rollout, landfilling remained the dominant waste treatment method across most years, with landfill ratios exceeding 80% in several years and peaking at approximately 98% in 2018. This trend reflects inadequate fiscal disincentives for landfilling and a systemic absence of viable recovery alternatives in many regions [57], [58].

5.6 Alignment with Circular Economy Policies

Although Malaysia's overarching policy framework, which includes the Twelfth Malaysia Plan and the National Solid Waste Management Policy that emphasises the integration of circular economy (CE) principles, the translation of these commitments into the construction sector remains limited [59], [60]. Instruments such as MyCREST provide sustainability metrics for building projects, yet their adoption is voluntary and not embedded within public procurement or CIDB regulatory requirements [61]. International evidence demonstrates that mandatory integration of recycling performance into licensing, contracting, and tender eligibility significantly accelerates industry-wide behavioural change [62]-[64].

Despite this national policy direction, the longitudinal C&D waste dataset indicates a misalignment between Malaysia's CE aspirations and the construction sector's actual waste recovery performance. While the national solid waste recycling rate has surpassed 30 percent in recent years, the C&D-specific recycling rate recorded through the CWMS system remains persistently low, fluctuating only between 5 and 7 per cent. This disparity indicates that the construction sector has not yet contributed meaningfully to overall recycling achievements. Instead, C&D waste continues to act as a structural bottleneck that limits Malaysia's ability to meet medium- and long-term recycling targets outlined in the Circular Economy Blueprint [30].

The Blueprint explicitly calls for enhanced recovery, improved material circularity, and digital transparency across all major waste streams [30]. Yet the construction sector's heavy dependence on landfilling, inconsistent reporting, and limited recovery infrastructure demonstrates a substantial implementation gap. Strengthening C&D waste recovery mechanisms, improving compliance consistency, and integrating CE-aligned performance indicators (CG, RG, and LG) into regulatory systems are therefore critical to realising the Blueprint's strategic goals.

5.7 Towards Institutionalised Digital Monitoring

The digital performance indicators, namely CG, RG, and LG, offer a valuable framework for tracking waste management performance. However, to unlock their full potential, they must be institutionalised within legal, compliance, and procurement structures [27]. Publicly accessible dashboards and real-time monitoring tools can improve transparency and support regulatory enforcement [65]. As highlighted by Rodrigo et al. [66], digitisation is not transformative unless it feeds directly into policy feedback loops and accountability systems. The longitudinal dataset offers a consolidated view of how Malaysia's construction and demolition (C&D) waste system has performed over eight years, and several clear patterns emerge when these results are assessed against the country's circular economy (CE) direction. The synthesis below integrates trends, state disparities, and the policy environment to explain the sector's structural position.

5.8 Synthesis of Findings in Relation to CE

The eight-year dataset demonstrates a consistent pattern: digital monitoring has improved visibility but has not shifted waste treatment behaviour. Recycling (CG) and reuse (RG) ratios remain low and stagnant, indicating that material recovery is still peripheral rather than integrated into routine project practices. Landfilling continues to dominate across most states, suggesting that disposal remains structurally embedded as the default option.

State-level contrasts reinforce this pattern. Urban territories with stronger institutional capacity record relatively better diversion outcomes, whereas several states exhibit weak reporting uptake and limited recovery infrastructure. This uneven performance reflects a broader misalignment between Malaysia's circular economy ambitions and the operational realities of the construction sector.

While the Circular Economy Blueprint sets national CE aspirations, it does not provide C&D-specific recycling indicators or modelling tools needed to drive measurable improvements [30]. As a result, despite enhanced transparency through digital monitoring, CG and RG performance have remained stagnant and weakly embedded within compliance routines. The absence of mandated reporting, incentives, and enforcement mechanisms further limits the system's effectiveness [67].

Collectively, these findings underscore the need for the institutional integration of diversion indicators, enhanced compliance mechanisms, and targeted capacity-building to accelerate Malaysia's transition toward circular construction practices.

6. Conclusion

The longitudinal analysis of construction and demolition (C&D) waste data in Peninsular Malaysia from 2017 to 2024 reveals modest improvements in recycling and reuse practices, but progress remains slow and uneven across states. Digital monitoring indicators such as CG (recycling-to-generated), RG (reuse-to-generated), and LG (landfill-to-generated) have enabled more transparent tracking of waste management outcomes. The results consistently show that landfilling continues to dominate treatment practices, with LG ratios remaining dominant across the eight-year period, frequently exceeding 80%. State-level data further emphasise regional disparities: while federal territories like Kuala Lumpur and Putrajaya demonstrate better diversion outcomes due to higher reporting uptake and project scale, states such as Johor and Selangor record comparatively lower diversion performance despite high project volumes [68]. In contrast, data gaps in Kelantan, as well as the exclusion of Sabah and Sarawak due to their separate regulatory systems, highlight systemic weaknesses in enforcement and reporting integration.

These findings highlight the urgent need for comprehensive policy reforms. Mandating digital waste reporting for all qualifying projects, incentivising high diversion performance, and expanding recycling infrastructure, particularly in underserved regions, are critical. Institutionalising CG, RG, and LG as compliance indicators within SWCorp, CIDB and local authority frameworks will further support accountability. Ultimately, while Malaysia's digital monitoring system has laid a foundational step toward sustainable construction waste management, more substantial institutional alignment, mandatory compliance mechanisms, and equitable development of recovery infrastructure are required to support Malaysia's circular economy (CE) targets. The findings advocate for systemic transformation that goes beyond data collection by leveraging digital tools to support behavioural change, strengthen compliance, and embed sustainability into the core of the construction industry.

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Author Contribution

The authors confirm their individual contributions to this paper as follows: ***Study conception and design:*** *Noor Fazierah Yaakub, Sasitharan Nagapan;* ***Data collection:*** *Noor Fazierah Yaakub;* ***Analysis and interpretation of results:*** *Noor Fazierah Yaakub, Ismail Abdul Rahman, Nur Amylia Izrin Mohd Saim;* ***Draft manuscript preparation:*** *Noor Fazierah Yaakub, Sasitharan Nagapan, Ismail Abdul Rahman. All authors reviewed the manuscript and approved the final version.*

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