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LEANER CONSTRUCTION AND DEMOLITION WASTE (CDW) MANAGEMENT: PRACTITIONERS' INSIGHTS

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ABSTRACT

The construction sector has a substantial impact on the environment, primarily due to its excessive resource and energy consumption, along with significant waste production. Construction accounts for a third of the world's total waste and around 40% of global CO_2 emissions. The phases of material production, construction, the facility's useful life, and end-of-life components have been widely studied for their role in environmental pollution. Whilst minimising waste holds the highest priority in construction waste management, understanding the sources of construction waste can support effective reduction strategies. This paper aims to explore the relationship between the origins of construction and demolition waste (CDW), lean practices, construction productivity, and the associated environmental impacts. A quantitative research method was adopted, using a survey questionnaire to identify correlations between CDW origins, construction productivity, and environmental impacts. Findings revealed that 62% of CDW origins have a greater impact on the environment than on productivity. Additionally, eight specific CDW origins showed statistically significant relationships with the tested environmental variables. These insights can promote evidence-based decision-making by construction practitioners in developing effective strategies for waste minimisation.

KEYWORDS

Construction and demolition waste, Lean construction, Construction productivity, Environmental impacts, Sustainability.

INTRODUCTION

In many countries, construction and demolition waste (CDW) represents a significant portion of total waste. Construction waste constitutes nearly half of all global solid waste generated,

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accounting for about 30 - 40% by weight (Lizárraga-Mendiola et al., 2022). China and the European Union (EU) are the leading contributors to global CDW production (Gao et al., 2023). In specific, China generated approximately 2.4 billion tonnes of construction waste each year (Hao et al., 2020; Wang et al., 2023). In 2022, the construction sector in the European Union (EU) generated the largest share of waste, contributing 38.4% (Eurostat, 2022). This figure accounts for more than one-third of all other types of waste produced. In other regions, rapid economic development and urbanisation have inadvertently increased the volume of construction activities and the resulting waste (Gao et al., 2023).

Construction waste primarily consists of inert and non-inert materials (Patil et al., 2024; Yuan et al., 2013). Certain solvents and asbestos, which are some of the constituents of construction waste, can be detrimental to the environment (Gualtieri, 2013; Roussat et al., 2008). While recycling and reusing construction waste is possible and practised, these processes can be cumbersome and require additional effort from various stakeholders after the construction project has concluded (Shooshtarian et al., 2020). Therefore, it is more effective to reduce waste generation during the construction process itself, making subsequent recycling and reuse easier to manage. This approach supports the principles of lean construction and contributes to sustainable development (Waheed et al., 2024).

Lean construction can, therefore, facilitate the improvement of processes and delivery methods for construction projects, thereby satisfying the needs of the client by reducing waste and other activities of minimal value (Ghosh & Burghart, 2021). Additionally, efforts to ensure the "*sustainability of construction projects*" and the "*innocuousness of construction waste*" form the basis of sustainable construction, which, in turn, can enhance the efficacy of lean construction (Francis & Thomas, 2020; Waheed et al., 2024). However, to realise the aforementioned, it is critical to identify and comprehend the factors that are the main culprits for construction waste generation. Only when the sources of waste are identified can proper action be devised to control, minimise, or eliminate waste of materials, effort, and time, leading to the attainment of lean construction (Koskela et al., 2002). Therefore, this study aims to identify the critical origins of CDW and their impacts on construction productivity and the environment.

BACKGROUND

CONSTRUCTION AND DEMOLITION WASTE (CDW) ORIGINS

The concept of lean construction relies on the minimal use of resources needed to initiate, propagate, and conclude a construction project (Formoso et al., 2020). In this context, waste refers to anything beyond the minimum necessary resources, which includes physical and non-physical wastes (Waheed et al., 2024). A key aspect of reducing construction waste is to minimise its generation "at source" by continuously identifying and eliminating process inefficiencies (Liu et al., 2020). However, the causative factors for CDW generation differ and are dependent on the construction's size, location, and methodologies. CDW may be produced at any stage of the project's lifecycle, from site clearance to project handover (Liu et al., 2020). Hence, the minimisation of CDW is only possible through harmonious coordination, communication, and cohesion between all construction stakeholders, who possess a deeper understanding of the various sources of construction waste.

Many studies have sought to identify the origins of construction waste production. Kaliannan et al. (2018) identified five recurring root causes of construction waste based on a review of 38 articles and validation by construction practitioners. These root causes, ranked in order of perceived significance, are constant design changes, incorrect material storage, poor material handling, the impact of weather, and ordering mistakes. Luangcharoenrat et al. (2019) posited other dominant factors based on relative importance indexes, including errors in construction planning and scheduling, workers' mistakes resulting from inattentiveness and incompetence, and delays in delivery due to issues with material ordering. Ayinla et al. (2022) further highlighted factors such as miscommunication leading to delays in information sharing, downtime while waiting to use equipment due to machine failure or unbalanced workflows, inefficient resource allocation between sites, misuse of machines resulting from poor staff-task assignments, and inefficient equipment processing. Other factors that contribute to construction waste generation include lengthy approval and processing times, as well as inadequate procedures related to overproduction (Igwe et al., 2022).

LEANER CONSTRUCTION WASTE MANAGEMENT

Construction waste management and lean construction are two sides of the same coin, which can significantly ameliorate the detrimental environmental and socio-economic effects stemming from waste generation. Reducing, recycling, and reusing process waste is the cornerstone for sustainable development in the construction industry (Ajayi et al., 2017). Lean-integrated project management should focus on minimising the occurrence and volume of CDW on-site, as the transportation and disposal of such waste incur extra costs, lower profit margins, and can lead to project delays, thereby causing a negative economic impact on the project (Eze et al., 2017). On the other hand, the accumulation of construction waste in landfills can have adverse effects on the health and well-being of society, particularly in close proximity, through pollution and land loss (Rodríguez et al., 2020).

By the end of 2020, construction waste contributed to over 30% of global carbon dioxide emissions, a figure that could rise to 52% by 2050 without effective mitigation policies (Baek et al., 2013; Mitigation, 2011; Omat & Kucukvar, 2020). Hence, by adhering to lean construction principles, construction companies can become role models for sustainability because reducing waste can concurrently enhance their carbon credits by lowering their carbon footprint (Mensah et al., 2024). Although waste reduction is one of the goals of lean construction, economic efficiency and timely project completion are sometimes considered the main success indicators (Chen et al., 2024). However, waste management and lean construction can cordially co-exist by aligning the project activities to certain recommendations, as follows: (1) Construction project teams can prioritise the development of strong relationships with producers and suppliers for efficient shipment of materials that will reduce delays and inventory accumulation (Ajayi & Oyedele, 2018; Bigwanto et al., 2024); (2) Using locally available materials/resources, ideally natural in origin, will simultaneously expedite the construction process and reduce environmental impact (Mensah et al., 2021; Treloar et al., 2003); (3) Organising training sessions for workers on the importance of waste management and the means to implement it will develop a skilled workforce where the concept of lean construction will be inherently present (Yang et al., 2020); and (4) Fostering enhanced collaboration amongst all the players, including the stakeholders, of the construction project will enable increased communication, cooperation, and trust, which can potentially eliminate a number of root causes of waste generation such as planning errors, information bottlenecks, and long waiting time for approvals (Ahmed & Ali, 2006). In summary, structuring the entire construction work to continuously and concurrently increase value and reduce waste at both the project planning and delivery levels is the route to achieving safer, timely, and high-quality projects.

RESEARCH METHODOLOGY

RESEARCH DESIGN

This study employed quantitative research approaches. With the origins of CDW as the independent variables, a survey questionnaire was developed to identify the most critical CDW origins during the construction phase. The identified CDW origins were then ranked according to their weighted importance based on two factors: productivity and environmental impact. The survey questionnaire consisted of multiple-choice questions, and responses were measured using the Likert scale.

SAMPLING AND DATA COLLECTION

In 2018, 750 online survey invitations were sent to construction practitioners worldwide. The sample was selected to represent a diverse group of multidisciplinary construction practitioners worldwide. Contacts were obtained from online directories and portals for construction practitioners across different countries. The invitation clearly outlined the inclusion criteria for participants, explicitly requiring knowledge and experience in the management of construction waste. A total of 750 practitioners were randomly sampled and approached for participation. Out of these, 250 responses were received, with 117 fully completed questionnaire surveys returned. The geographical distribution of responses is illustrated in Figure 1. Tables 1 and 2 show the classification of the respondents' companies and their years of experience.

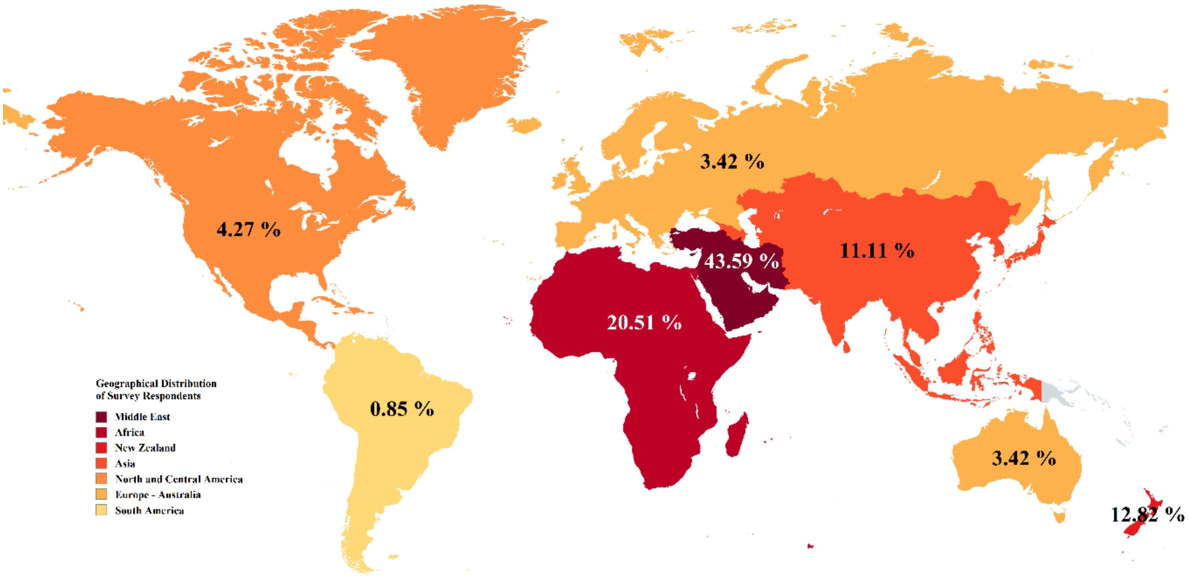

Figure 1: Maps of Survey Respondents (%)

Table 1: Classification of Respondents' Companies

	Number of Responses	Percentage of Responses
Contractor	59	50.43
Specialist Contractor/ Subcontractor	9	7.69
Developer	5	4.27
Government Agencies	27	23.08
Environment Consultant	3	2.56
Others (Academia and Telecommunication)	14	11.97
Totals	117	100

Table 2: Respondents' Years of Experience

Years of Experience	Number of Responses	Percentage of Responses
0 – 4	17	14.53
5 – 10	31	26.50
11 – 15	32	27.35
> 15	37	31.62
Totals	117	100

CORRELATIONS BETWEEN CDW ORIGINS, CONSTRUCTION PRODUCTIVITY, AND THE ENVIRONMENT

The origins of 13 CDW were identified through the literature and assessed based on two factors: construction productivity and environmental impact. To identify the most significant factors contributing to waste production during the construction phase, the frequency of each identified CDW origin was assessed, along with its level of importance, based on an index value. For clarity, the survey defined "frequency" and "importance" as follows: "frequency" referred to the probability of CDW origins occurrence. In contrast, "importance" indicated the impact of these CDW origins on on-site waste generation during the construction process. The index values of the frequency and importance of each CDW origin are multiplied by the formula below to obtain the variable's weighted importance:

$$\text{Weighted Importance} = \text{Frequency Index} \times \text{Importance Index}$$

CORRELATIONS BETWEEN CDW ORIGINS AND CONSTRUCTION PRODUCTIVITY

Table 3 presents five highlighted variables, along with their weighted importance relative to the average value of 16.337. These variables are confirmed as the critical origins of CDW on construction productivity.

Table 3: Weighted Importance of CDW Origins on Construction Productivity

	Frequency Index	Importance Index	Weighted Importance
Constant design changes	4.2906	4.3333	18.5926
Planning and scheduling errors	4.2393	4.2735	18.1167
Workers' mistakes	4.0684	4.1026	16.6908
Lengthy approval and processing times	4.1197	4.0085	16.5138
Incompetent workers	4.0171	4.0684	16.3430
Delivery delays	4.0855	3.9915	16.3070
Low machine output	4.0085	4.0513	16.2398
Poor storage	4.0000	4.0598	16.2393
Inadequate procedures	4.0085	4.0171	16.1027
Poor communication and coordination	3.8803	4.0256	15.6209
Poor site management	3.9316	3.9658	15.5921
Machine downtime	3.9231	3.9573	15.5247
Inclement weather	3.7778	3.8376	14.4976
		Average Value	**16.3370**

CORRELATIONS BETWEEN CDW ORIGINS AND THE ENVIRONMENT

Table 4 presents eight highlighted variables along with their weighted importance relative to the average value, which is 12.403. These variables are confirmed as the critical origins of CDW on the environment.

Table 4: Weighted Importance of CDW Origins on the Environment

	Frequency Index	Importance Index	Weighted Importance
Constant design changes	4.2906	3.3761	14.485
Planning and scheduling errors	4.2393	3.3162	14.059
Poor storage	4.0000	3.3333	13.333
Low machine output	4.0085	3.1880	12.779
Inadequate procedures	4.0085	3.1709	12.711
Workers' mistakes	4.0684	3.0684	12.483
Poor site management	3.9316	3.1624	12.433
Incompetent workers	4.0171	3.0940	12.429
Inclement weather	3.7778	3.1624	11.947
Delivery delays	4.0855	2.8889	11.802
Poor communication and coordination	3.8803	2.8462	11.044
Machine downtime	3.9231	2.8034	10.998
Lengthy approval and processing times	4.1197	2.6068	10.739
		Average Value	**12.4034**

Analysis of the Significant Correlation Between CDW Origins and The Environment

The findings revealed that a more significant percentage (62%) of the CDW origins have a greater impact on the environment than on construction productivity. Therefore, further analysis was conducted to examine the relationship between the origins of CDW and their environmental impacts. In this analysis, environmental waste is classified into two specific groups: excessive resource consumption (i.e., material, water, energy, and land) and excessive emissions released (i.e., air pollution, water pollution, hazardous waste, solid waste, and soil pollution). The environmental assessment design was aligned with the Building Research Establishment Environmental Assessment Method (BREEAM) and the Hong Kong Building Environmental Assessment Method (HK-BEAM) to comply with international standards and practices. In specific, survey respondents were asked to assess the environmental impacts caused by the 13 CDW origins using a rating system that categorised the impacts as none, little, moderate, great, or extreme.

Table 5 below shows the 13 identified CDW origins and their significance. The results suggested that eight origins of CDW impacted the tested environmental impact variables. In contrast, the other CDW origins, marked in grey, showed no correlation with the environmental variables. The correlations between the aforementioned variables were determined using R, based on the number of mentions and the likelihood that each factor could influence the construction process. The asterisks are interpreted as follows:

* = 0- ≤ 25%; ** = 25- ≤ 50%; ***= 50- ≤ 75%; **** =75- ≤ 100%

Table 5: Weighted Importance of CDW Origins on the Environment

CDW Origins	Environmental Impact								
	Excessive Resource Consumption				Excessive Emissions Released				
	M^a	W^b	E^c	L^d	A^e	WP^f	H^g	SW^h	S^i
Constant design changes	***						***	**	
Planning and scheduling errors							**	**	
Lengthy approval and processing times									
Inadequate procedures									
Workers' mistakes	**						**	***	
Incompetent workers							***	***	
Low machine output			***		***		***	***	
Machine downtime									
Delivery delays									
Poor site management							**		
Poor storage							***	**	
Poor communication and coordination									
Inclement weather							**		

M^a: Material waste; W^b Water consumption; E^c Energy consumption
L^d Land consumption; A^e Air pollution; WP^f Water pollution
H^g Hazardous waste; SW^h Solid Waste; S^i Soil Pollution

The findings indicated that various origins of CDW showed significant correlations with environmental impacts. For example, constant design changes and errors made by workers are closely linked to material consumption, as well as the production of hazardous and solid waste. Planning and scheduling errors, incompetent workers and poor storage also showed strong correlations with hazardous and solid waste. Furthermore, it was found that low machine output significantly influenced the energy consumption, air quality, and the production of waste and solid waste. Poor site management and inclement weather are associated with the production of hazardous waste.

DISCUSSION

The results of the investigation identified the major CDWs and how they impact both construction productivity and the environment. The CDW with the highest negative impact on construction productivity is constant design changes, with planning and scheduling errors as the close second. In fact, design changes are detrimental to both productivity and predictability of productibility (Ibbs, 2012), which can lead to re-work, re-sequencing of schedules, and delay or suspension of the project. Design changes can affect any construction project phase and usually have a cascading effect. Hence, it is critical that design changes are kept to a minimum in order to maintain a reasonable overhead cost, schedule, and thus, productivity. Planning and scheduling errors have a significant negative impact on construction productivity because it is challenging for contractors (especially the ones with less experience and knowledge) to envisage the resources and time needed for the entire construction project. The large amount of information and the interrelation between various construction elements make the decision-making process difficult, thus leading to the disorganisation of major aspects of the construction project (Waly & Thabet, 2003). The two aforementioned CDWs also have been revealed to have the highest environmental impact. It was found that more CDW origins (62%) are detrimental to the environment than to construction productivity. This includes, along with constant design changes and planning and scheduling errors, poor storage, low machine output, inadequate procedures, workers' mistakes, poor site management, and incompetent workers. This is because certain CDW origins (e.g., constant design changes and planning and scheduling errors) can affect the subsequent steps (e.g., re-work) (Mahamid, 2022) in the construction project and directly impact waste generation in terms of resource consumption and emissions. Other CDW origins, such as incompetent workers and their mistakes, can generate hazardous and solid wastes while consuming more material than needed for a task. Low machine output in a construction project would consume more energy to produce a certain volume of products. Low machine output is linked to the potential overordering of materials and process-flow inefficiencies, which can generate solid and hazardous wastes (Shaqour & Almashhour, 2020). Low machine output will lead to increased production time, thus indirectly causing more emissions in the form of air pollution. The current article has identified the main culprits in the form of CDW origins that are responsible for reducing construction productivity and causing environmental harm. Thus, practitioners can use the knowledge to adhere to a lean construction framework through proper planning to ensure waste resource minimisation throughout the construction project cycle.

CONCLUSIONS

This study aimed to identify the primary sources of construction and demolition waste (CDW) and relate them to construction productivity and environmental impact. In particular, it was found that three common CDW origins, namely, constant design changes, planning and scheduling errors, and workers' mistakes, were strongly correlated with negative construction productivity and environmental impact. The findings of this study are presented through the lens of construction practitioners worldwide, thus providing a holistic view of the effect of CDW on the construction industry. The findings of this study can help construction companies adopt new value chains that are conducive to lower waste and facilitate the development of sustainable business models. Construction companies can use the findings to establish on-site workflow guidance that allocates specific tasks to site workers and manages on-site resources, thereby eliminating waste related to delays, downtime, poor site management, and inadequate communication.

The study has identified the critical origins of CDW. Thus, construction companies can strategically avoid them during the procurement, design, construction, and post-construction phases to achieve higher productivity, meet customer needs, and gain a competitive edge over other companies. The findings can also enable construction companies to identify potential areas for improvement and sources of inefficiency in their current value chain. Finally, this study could facilitate the development of holistic and replicable solutions for circular, sustainable, and climate-neutral construction materials and activities that involve both upstream and downstream actors.

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