Waste Generation Factors and Waste Minimisation in Construction

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Abstract. The consistent growth of the construction sector during the last decades has generated massive waste that severely impacts the environment. Globally, construction activities generate around 30% of the overall waste annually, and the numbers are expected to increase due to population growth projections and the need for infrastructure developments. As a matter of fact, the causes of waste can be grouped into seven categories namely, design-related, procurement-related, human-related, handling and storage, site conditions, management-related, and due to other external factors, such as the effect of weather and accidents. In addition, construction waste types are influenced by project type, size, and construction method. To mitigate the impacts of construction waste, a plethora of practices have been recommended, including innovations for procurement, design, and construction. The present study scrutinises potential opportunities for minimising construction waste and proposes future sustainability enhancement related to construction activities. A pivotal contribution of this study is the creation of a matrix that links the identified causes of construction waste with sustainability practices, offering a comprehensive insight for effectively reducing waste and enhancing the sustainability of construction activities.

Keywords: Construction Waste · Waste Minimisation · Sustainability · Construction

1 Introduction

Construction waste (CW) is considered as a significant challenge in the building sector. Skoyles [1] defined CW as material waste that arises due to construction activities. Other sources define construction waste as the produced debris or discarded materials that occur during various construction activities and phases [2, 3]. Either way, construction waste is a major contributor to waste generation, harming the planet and impacting society and the economy [4, 5]. Consequently, it is widely acknowledged that addressing construction waste is a top priority issue.

Statistically, more than 32% of municipal waste is generated by construction activities worldwide [6]. In the EU, around 35% of the total waste is a construction source [7]. Similarly, CW represents 30–40% of the total municipal solid waste in the US, UK, and Australia, making the construction sector a primary source of materials dumping

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and landfilling [8]. In other regions, such as Jordan and Malaysia, CW amounts to more than 30 million tons and 9 million tons of waste on an annual basis, respectively [5].

Due to population growth and the excessive demand for construction and building projects worldwide [9], CW is anticipated to increase dramatically [6], among other reasons, as discussed in Loizou et al. [10], waste creation is inevitable in infrastructure projects with the current technology and construction methods. However, it can be mitigated through efficient management strategies. For instance, repurposing construction waste could improve environmental preservation and economic opportunities.

Waste minimisation is vital for sustainability, and focusing on waste sources is a critical step to reduce the environmental impact [8]. Several researchers investigated minimisation strategies and recommended multiple actions across various project stages that could be quantified throughout lifecycle assessments. Hence, this study aims to scrutinise the multifaceted causes of construction waste, and proposed strategies to mitigate it in the design, procurement, and construction phases, as informed by the existing literature. Subsequently, the causes of waste are associated with potential sustainability measures that could significantly contribute to its mitigation. Figure 1 shows the research process followed in this study.

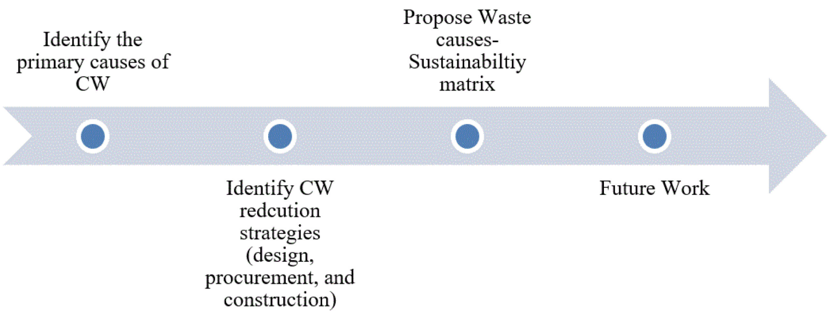

Fig. 1. Research process based on existing literature.

2 Construction Waste Generation

2.1 Causes of Construction Waste

The waste type and quantity in the construction sector are highly influenced by construction size, type, and technology used [11] while it is generated in different amounts during each project stage [12]. Researchers have found that CW multiplies due to design issues and errors, improper scheduling, reworks, lack of skilled labours, poor project management, materials storage and handling, and ill management of waste [5, 12–15]. Table 1 summarises the most common categorisations of construction waste.

It has been noted that the causes of construction waste generation are categorised differently by researchers. For instance, Al-Rifai and Amoudi [13] investigated the causes in

Table 1. Summary of the common construction waste factors in the literature.

Group	Construction Waste Causes	References
Design-related	Design complexity (W1)	[3, 15]
	Design documents errors (W2)	[3, 5, 13, 16]
	Design changes during construction (W3)	[3, 5, 15]
	Poor coordination & communication (W4)	[3, 5, 12–14]
Procurement-related	Ordering errors (W5)	[3, 13, 15]
	Buy low-quality materials (W6)	[3, 13, 15]
Human-related	Lack of experienced designers (W7)	[3, 13, 15]
	Lack of skilled workers (W8)	[3, 5, 13–15]
Handling and Storage	On-site transportation methods (W9)	[3, 13, 15]
	Inappropriate storage (W10)	[13–15]
Site Conditions	Leftover materials on site (W11)	[3, 13, 15]
	Poor site condition (W12)	[3, 5, 13, 15]
Management-related	Inaccurate planning and scheduling (W13)	[3, 12, 13, 15]
	Incapable site supervision (W14)	[3, 13, 14]
	Absence of waste management (W15)	[3, 5, 13, 15]
	Reworks (W16)	[3, 12, 13, 15]
External Factors	Weather (W17)	[3, 14, 15]
	Accidents in construction area (W18)	[3]
	Theft (W19)	[13, 14]

the Jordanian's building sector and classified waste factors in terms of their contribution to total amounts: high, medium, low, and very low. Obaid et al. [11] grouped construction waste into physical or non-physical, time and cost. Other researchers classified construction waste based on the construction stages [16]. For instance, they investigated waste minimisation in the design stage, procurement, and construction and classify waste accordingly [8]. Other studies categorised factors based on their origins; for example, Luangcharoenrat et al. [15] identified 28 factors contributing to construction waste and categorised them into four groups ranked from the most significant to the least significant: design and documentation, human-related, construction planning and methods, and materials and procurements. In addition, handling, site condition, and external factors are also identified as categories for construction wastes by Nagapan et al. [3].

CW cause factors are influenced by construction type and building techniques that also vary from region to region [15]. For example, a study by Al-Rifai and Amoudi [13] in Jordan found that construction waste is mainly driven by poor management and issues with the workforce. Instead, Nagapan et al. [17] identify poor site management and supervision as Malaysia's most significant construction waste factors. Hence, there is not yet a uniform categorisation criterion, which causes substantial delays in tracing the waste source and implementing the relevant strategies for waste reduction.

3 Construction Waste Minimisation

3.1 Design Stage

Engineering practitioners, academics, and scientists all emphasise the role of waste-efficient design, eco-design, and design for deconstruction to mitigate waste generation [18]. Ajayi et al. [19] place enhanced prefabrication techniques, pre-assembled components, and modular design as the core of waste reduction strategies in the design stage. Osmani [20] added to this by reporting on the current practices in the UK to minimise waste, which includes the standardisation of dimensions for steel and concrete profiles, prefabricated ancillary items, and design for disassembly. Olanrewaju and Ogunmakinde [21] further investigated strategies to reduce CW during the design stage and referred to Nigerian architects' most common strategies, including standard materials and products. Separate studies explore the effects of implementing BIM in construction projects and found that this facilitates sustainable construction and helps minimise waste by enabling design adaptability, which allows for more efficient planning and easier modifications, for example, Alasmari et al. [22]. We close this point by citing Laovisutthichai et al. [23], who state that the CW and construction cost could be reduced without compromising the design if we adopt the design for construction and waste minimisation (DfCWM) modern guidelines such as Wrap [24].

3.2 Procurement

Any improvement to design and management could not be separate from procurement. The main strategies suggested by the authors are on-time delivery, proper storage, purchasing products with little or no packaging, and over-ordering prevention [25]. Ajayi et al. [26] emphasised the importance of considering CW in procurement and identifying delivery management, supplier commitment to reduce waste, waste-efficient bill of quantity, and low waste purchase management as the main features in waste reduction during procurement. Furthermore, Nagapan et al. [27] identify ordering errors, shipping mistakes, and inaccurate quantity calculations as the causes of construction waste in the procurement stage. Thus, new reduction strategies could be developed to further integrate procurement into the production process.

3.3 Construction

Construction techniques can be improved through enhanced technologies, including using green materials, implementing relevant legislation, and implementing behavioural-based methods to increase worker efficiency [28, 29]. Additional on-site minimisation strategies are related to waste collection and reuse, although those are labelled as reactive strategies [30]. Waste source minimisation measures shall be considered in the construction phase under a rational structure, for example, through groups defined as field planning & management, and materials management [25, 26]. Hence, both the generated waste and its sources could be the focus to minimise sending materials to the landfill and maximise the benefits of the resource. Table 2 summarises waste minimisation practices in the current construction landscape.

Table 2. Summary of the common construction sustainability practices in the literature.

Construction Phase	Sustainability practice	References
Design	Waste-efficient design (D1)	[18, 26]
	Eco-design (D2)	[18]
	Design for deconstruction (D3)	[18, 20]
	Modular design (D4)	[19, 21]
	Prefabricated design (D5)	[19, 20]
	Standard design (D6)	[20, 21]
Procurement	On-time delivery (P1)	[25]
	Proper storage (P2)	[25]
	Purchasing products with little or no packaging (P3)	[25]
	Over-ordering prevention (P4)	[25, 26]
	Supplier commitment to reduce waste (P5)	[26]
Construction	On-site waste minimisation strategies (C1)	[30]
	Legislation (C2)	[28, 29]
	Behavioural approaches (C3)	[28, 29]
	Materials management (C4)	[25, 26]

4 Proposed Waste Causes- Sustainability Practices Matrix

The construction industry faces significant challenges in managing and reducing waste, raising concern for its environmental, economic, and societal implications. To address this, various sustainable practices have been proposed, targeting different waste causes in construction projects. Table 3 presents a linkage between common waste causes and sustainable practices, providing an insightful idea for enhancing sustainability in construction activities.

Table 3. Matrix linking sustainability practices to waste causes in construction projects.

Waste causes	Sustainability Strategies														
	D1	D2	D3	D4	D5	D6	P1	P2	P3	P4	P5	C1	C2	C3	C4
W1	√	√	√	√	√	√									
W2				√	√	√									
W3	√	√	√			√									
W4				√	√	√									
W5								√		√	√	√	√		√
W6								√			√				√
W7						√									
W8					√										
W9							√				√				√
W10							√	√	√	√	√				
W11	√	√		√	√	√						√	√	√	
W12											√	√	√	√	√
W13							√				√	√			√
W14											√	√	√	√	√
W15												√	√		√
W16				√	√	√					√				
W17							√	√		√					
W18											√				
W19										√	√			√	√

5 Conclusions and Future Work

The paper discusses the main issues related to construction waste (CW) and provides insight into the causes of construction waste. It goes on to address sustainability aspects and waste minimisation practices in construction projects.

The causes of waste have been previously investigated and categorised into defective planning, human errors, and design mistakes, including improper handling. These causes vary in their impacts based on the project's size, type, and technology used.

Strategies across the construction phases (design, procurement, and construction) are proposed from the literature to mitigate the risks associated with construction waste. Waste-efficient design, Design for Disassembly (DfD), and standard design practices minimise waste from the design phase. During procurement, key practices include avoiding over-ordering, reducing packaging, and ensuring supplier commitment. Meanwhile, in the construction phase, effective measures include on-site waste management and material management to mitigate construction waste.

The paper contributes to the field by identifying the leading causes of construction waste (CW) and underscores the importance of integrating sustainability practices into the main construction phases: design, procurement, and construction. Furthermore, this study contributes by constructing a matrix that links the identified causes of construction waste with sustainability practices, offering a comprehensive overview of effective ways to reduce construction waste. However, the study is limited to the existing literature, and empirical studies are needed to highlight the strategies' significance and impact on CW reduction.

Future studies should focus on quantifying the economic benefits of waste management, assessing the long-term social and environmental impacts, and validating the matrix through case studies to clearly outline the relationship between waste causation and sustainability practices, thereby ensuring a comprehensive understanding of the subject.

References

1. Skoyles ER (1987) Waste prevention on site. BT Batsford Limited, London
2. Davis P, Aziz F, Newaz MT, Sher W, Simon L (2021) The classification of construction waste material using a deep convolutional neural network. Autom Constr 122:103481
3. Nagapan S, Rahman I, Asmi A (2012) Factors contributing to physical and non-physical waste generation in construction industry. Int J Adv Appl Sci 1:1–10
4. Kabirifar K, Mojtahedi M, Wang C, Tam VWY (2020) Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: a review. J Clean Prod 263:121265
5. Alshdiefat AS et al (2023) Construction and demolition waste management in Jordan: a multifaceted perspective. Constr Innov. https://doi.org/10.1108/CI-08-2022-0221
6. Ginga CP, Ongpeng JMC, Daly MKM (2020) Circular economy on construction and demolition waste: a literature review on material recovery and production. Materials 13:1–18
7. European Union (2018) Construction and Demolition Waste. In: European Commission on the Environment. http://ec.europa.eu/environment/waste/construction_demolition.htm. Accessed 30 April 2023
8. Doust K, Battista G, Rundle P (2020) Front-end construction waste minimisation strategies. Aust J Civ Eng 19:1–11
9. Aslam MS, Huang B, Cui L (2020) Review of construction and demolition waste management in China and USA. J Environ Manag 264:110445
10. Loizou L, Barati K, Shen X, Li B (2021) Quantifying advantages of modular construction: waste generation. Buildings 11:622
11. Obaid AA, Rahman IA, Idan IJ, Nagapan S (2019) Construction waste and its distribution in Iraq: an ample review. Indian J Sci Technol 12:1–10
12. Zighan S, Abualqumbozm M (2021) A project life-cycle readiness approach to manage construction waste in Jordan. Constr Econ Build 21:58–79
13. Al-Rifai J, Amoudi O (2016) Understanding the key factors of construction waste in Jordan. Jordan J Civil Eng 10:244–253
14. Fitriani H, Ajayi S, Kim S (2022) Analysis of the underlying causes of waste generation in Indonesia's construction industry. Sustainability 15:409
15. Luangcharoenrat C, Intrachooto S, Peansupap V, Sutthinarakorn W (2019) Factors influencing construction waste generation in building construction: Thailand's perspective. Sustainability 11:3638

16. Katz A, Baum H (2011) A novel methodology to estimate the evolution of construction waste in construction sites. Waste Manag 31:353–358
17. Nagapan S, Rahman IA, Asmi A et al (2012) Identifying causes of construction waste-case of central region of peninsula Malaysia. Int J Integrat Eng 4:22–28
18. Akinade O, Oyedele L, Oyedele A et al (2020) Design for deconstruction using a circular economy approach: barriers and strategies for improvement. Prod Plan Control 31:829–840
19. Ajayi SO, Oyedele LO, Akinade OO et al (2017) Attributes of design for construction waste minimisation: a case study of waste-to-energy project. Renew Sustain Energy Rev 73:1333–1341
20. Osmani M (2011) Construction waste. In: Waste. a handbook for management, pp 207–218. https://doi.org/10.1016/B978-0-12-381475-3.10015-4
21. Olanrewaju SD, Ogunmakinde OE (2020) Waste minimisation strategies at the design phase: architects' response. Waste Manag 118:323–330
22. Alasmari E, Martinez-Vazquez P, Baniotopoulos C (2023) Adopting BIM to enhance sustainability. The Saudi Arabia construction projects case study. In: IOP conference series: earth and environmental science. IOP Publishing, p 012111
23. Laovisutthichai V, Lu W, Bao Z (2022) Design for construction waste minimisation: guidelines and practice. Arch Eng Des Manag 18:279–298
24. Wrap U (2020) Achieving good practice Waste Minimisation and Management. Guidance for construction clients, design teams and contractors. Practical solutions for sustainable construction Material change for a better environment. Waste Res Action Programme
25. Ajayi SO, Oyedele LO (2018) Waste-efficient materials procurement for construction projects: a structural equation modelling of critical success factors. Waste Manag 75:60–69
26. Ajayi SO, Oyedele LO, Akinade OO et al (2017) Optimising material procurement for construction waste minimisation: an exploration of success factors. Sustain Mater Technol 11:38–46
27. Nagapan S, Rahman I, Asmi A (2011) A review of construction waste cause factors. In: Asian Conference on Real Estate: Sustainable Growth Managing Challenges (ACRE), Johor Bahru, Malaysia, pp 967–987
28. Ajayi SO, Oyedele LO (2017) Policy imperatives for diverting construction waste from landfill: experts' recommendations for UK policy expansion. J Clean Prod 147:57–65
29. Ajayi SO, Oyedele LO, Bilal M et al (2017) Critical management practices influencing on-site waste minimisation in construction projects. Waste Manag 59:330–339
30. Ding Z, Yi G, Tam VWY, Huang T (2016) A system dynamics-based environmental performance simulation of construction waste reduction management in China. Waste Manag 51:130–141