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Construction Waste Minimisation: A Narrative Review

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Abstract: Colossal growth of construction waste (CW) generation worldwide, and its consequential environmental and economic impact, has ensured that construction waste minimisation (CWM) practice is critical. Notably, the largest proportion of waste generation that can be actively reduced within the sector lies within the construction /on-site activities stage. As such, a number of waste minimisation approaches have been utilised during construction, targeted reduce/ eliminate waste with the aim to support a more sustainable construction agenda. This paper provides a narrative review of related literature published in leading journals through Scopus, ScienceDirect and Web of Science databases, to understand the fundamentals of CW and to investigate CWM implementation levels and barriers during the construction stage. This will aid in identifying research gaps for future studies and highlight key findings which will help researchers and construction industry practitioners to understand the principles of, and the need for, CWM as well as the challenges facing its effective implementation in construction projects.

Keywords: Construction Waste, Construction Waste Minimisation, Construction Waste Management, Construction Stage, Sustainable Construction, Review.

1. Introduction

Sustainable development in construction, is increasingly mandated around the world. Sustainable construction supports social wellbeing in addition to environmental protection and economic prosperity, and in order to satisfy sustainable development in construction, it is important to attain the right balance between these pillars of sustainability (Li et al. 2018c). Construction waste (CW) is considered a serious and chronic problem affecting the attainment of sustainable construction. In recent decades, with rapid urban development, vast construction, renovation and demolition activities across the world, has resulted in increasing volumes of waste. The construction industry is considered the largest producer of solid waste (Figure 1), generating around 36% of the total waste worldwide, which equates to 2.5-3.5 billion tonnes each year (International Solid Waste Association, [ISWA], 2015). This presents a significant challenge to the sustainability of the construction industry, the country's economy at large and environmental sustainability worldwide (Bakshan et al. 2015). Increasing awareness by both researchers and practitioners in the construction industry has led to the development of waste minimisation as an important function of construction project management (Yeheyis et al. 2013; Ding et al. 2015), and a large body of literature has emerged dedicated since the 1980s to determine optimal methods to reduce CW.

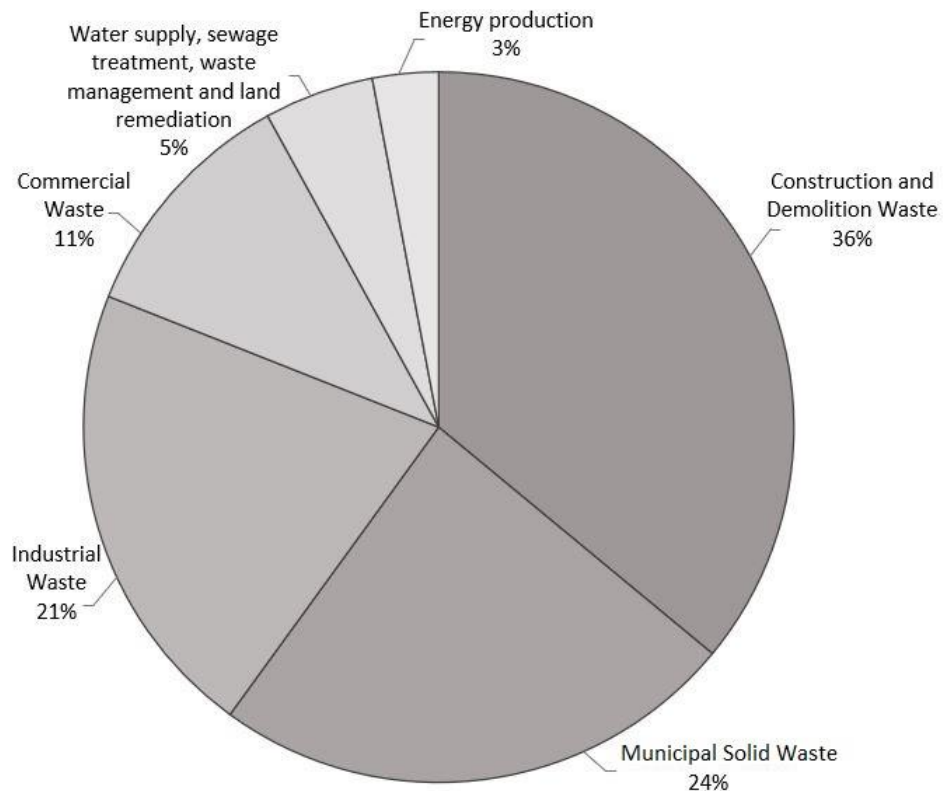


Figure 1: Categorisation of the Annual Global Waste Generation

Source: ISWA (2015)

Whilst it is acknowledged that CW can be minimised during both design and construction stages, waste generation is usually upmost during the construction stage since it includes a wide range of activities that may cause waste. The construction stage and its associated waste generation are commonly classified into: site clearance, material use, material handling, material non-use, human error, on-site management and planning, on-site operation, transportation, and finally, residual waste (Wang, Kang, and Wing-Yan Tam 2008; Al-Hajj and Hamani 2011; Nagapan, Rahman, and Asmi 2012b; Nagapan et al. 2012b; Villoria Saez et al. 2013; Najafpoor et al. 2014; Bakshan et al. 2015; Al-Rifai and Amoudi 2016; Ajayi et al. 2017a; Kolaventi et al. 2020). Consequently, numerous researchers have attempted to identify the most effective construction waste minimisation (CWM) approaches related to the construction stage. However, CWM has not always been successfully controlled due to several reasons, including: lack of awareness and poor knowledge of CW generally, lack of interest from construction stakeholders towards CWM, and the lack of strict regulations and governmental supervision (discussed in section 4.2). This concludes that more work is required to achieve an acceptable standard in CWM. Therefore, it is important to understand the fundamentals of CW and demystify the issues concerning its minimisation.

The aim of this paper is to provide important insights and highlight key findings of previous studies that relate to the implementation of waste minimisation approaches during the construction stage. This narrative review will aid researchers and construction industry practitioners to understand the principles of, and the need for, CWM as well as the challenges facing its effective implementation in construction projects.

2. Method

The narrative review presented in this paper provides a summary of the extant literature through exploring the fundamentals of CW and demystifying the issues concerning its minimisation during the construction stage. The literature review was undertaken by using Scopus, ScienceDirect, and Web of Science databases as they are considered as three of the leading and comprehensive bibliographic citation index organisations. The keywords used for this review were related to CW and its minimisation, therefore combining the term “construction waste” with: management, minimisation, reduction, quantifications, classification, origins, causes, impacts and sustainability. These terms were used to select any paper where it was found in the title, abstract and/ or keywords. The review period was May till August 2020. The criteria of this review study were primarily based on the direct relevance to the subject of published articles from 2000 to 2020 which were scribed in the English language only. The review was primarily focused on exploring the current uptake of waste minimisation in developed countries to garner best practices and challenges in CWM for potential application in developing countries, particularly as CW is very limited and modestly explored in developing countries. In total, 176 papers were identified following the selection criteria and are used to underpin this narrative review.

3. Construction Waste

Waste in construction is defined in many ways in the literature. For instance, Skoyles and Skoyles (1987, 17-18) defined it as “a material which needs to be transported elsewhere, due to damage, excess, or non-use or which cannot be used specifically due to non-compliance with the specifications, or which is a by-product of the construction process”; which focuses on waste which arises during the construction process. Shen et al. (2004, 472-81) went further by providing a more comprehensive definition in describing that waste that could arise from other stages and phases. They stated that “waste from construction can be in the form of building debris, rubble, earth, concrete, steel, timber, and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork, and building renovation... waste is often the mixture of inert and organic materials”.

Notably, both these definitions refer only to material waste, whereas other authors (e.g., Ekanayake and Ofori 2000; Alwi, Sherif, and Hampson 2002) define waste in construction projects in terms of material, labour and machinery waste which results in time, cost and quality losses. Based on these definitions, it can be noted that there are different types of waste in construction projects and therefore, it is important to identify its components to clarify the priority area to address.

3.1 Construction Waste Classification

Various types of wastes are generated throughout the construction project. The amount and classification of these wastes depends upon different factors, such as the nature and the stage of the construction project, and the methods of construction. Many categorisation models have been applied to classify the types of waste in construction projects, however, there is no universal classification system. Table 1 details the most common classifications of waste in construction projects.

Table 1: Classifications of Waste in Construction Projects

<i>Type of classification</i>	<i>Type of waste</i>	<i>Reference</i>
<i>Physical and non-physical waste</i>	Material Time Cost	Nagapan, Rahman, and Asmi (2012a) Nagapan, Rahman, and Asmi (2011).
<i>By their origin</i>	Design Construction Demolition	Shen et al. (2004), Kozlovská and Spišáková (2013), Polat et al. (2017).
<i>By their cost</i>	Labour Material Machinery	Ekanayake and Ofori (2000), Alwi, Sherif, and Hampson (2002), Yahya and Boussabaine (2006), Bølviken, Trond, and Koskela (2014).
<i>By their added value</i>	Transportation Inventory Motion Waiting Over-production Over-processing Defects	Ohno (1988), 68. Koskela, Bølviken, and Rooke (2013), Bølviken, Trond, and Koskela (2014).

Source: Alhawamdeh and Lee

In light of Table 1, the types of CW can be in the form of physical materials, time and cost losses or quality defects in construction works. However, existing literature focuses heavily on solid material waste, and has identified it among the top priorities in relation to CWM (e.g. Lau, Whyte, and Law 2008; Llatas 2011; Oko John and Emmanuel Itodo 2013; Ding and Xiao 2014; Villoria Sáez, Porrás-Amores, and del Río Merino 2015; Saidu and Shakantu 2016; Hossain, Wu, and Poon 2017; Arshad et al. 2017; Huang et al. 2018; Mulenga 2018; Menegaki and Damigos 2018; Liang et al. 2019; Wu, Yu, and Poon 2019; Bakchan and Faust 2019; Villoria-Sáez, Porrás-Amores, and del Río Merino 2020). A

number of governmental and professional bodies such as in the UK (i.e. Waste & Resources Action Programme [WRAP], Department for Environment, Food and Rural Affairs [DEFRA], and the Chartered Institution of Wastes Management, [CIWM]), in the USA (i.e. United States Environmental Protection Agency [EPA], and the Solid Waste Association of North America [SWANA]), in the European Union (i.e. European Environment Agency [EEA]) and internationally (i.e. ISWA, United Nations Environment Programme [UNEP]) have all raised concerns over the generation of significant volumes of solid material waste in construction projects. This type of waste is identified to be the most critical due to its impact on the environment, as well as the delivery and cost-overrun of projects, which will be discussed later in this review. Therefore, the scope of this study will be focused on solid material waste; the causes, impacts and minimisation approaches of such type of waste will be further discussed in this paper.

In a typical classification, solid waste from construction projects is often a mixture of inert and non-inert materials. Inert materials are the components that scarcely react in chemical reactions under common circumstances, such as: concrete, bricks, ceramics, plaster, asphalt, aggregate, rock or rubble and soil. Non-inert materials are readily engaged in chemical reactions, such as: ferrous and non-ferrous metal, timber, plastic, glass, paper, cardboard, wallboard and other organic materials (UNEP 2015a). The first step towards CWM is the identification of the origin and causes of CW, to understand how effective minimisation methods are and the challenges circumventing implementation.

3.2 Origins and Causes of Construction Waste

Both terms “origins of waste” and “causes of waste” are often used synonymously. However, for the purpose of this study, it is important to clarify the difference between these terms. In this context, the term ‘origins’ refers to the stage or level of activities that generate CW, whilst the term ‘causes’ refers to the reasons why CW is generated within the stage or level of activities.

CW is generated throughout the entire project lifecycle i.e., during the design, construction and demolition stages. The literature reveals a large number of past studies which have been conducted to identify origins based on the project stage or level activities. For instance, Gavilan and Bernold (1994) grouped the origins of CW according to the following: design, procurement, materials handling, operation, residual and others. This has also been reported by a number of other studies (i.e., Ekanayake and Ofori 2000, 2004). Osmani et al. (2008) added four clusters into these six groupings, including contractual, transportation, on-site management and planning, and material storage. Keys, Baldwin, and Austin (2000) adopted a slightly different categorisation system, their study classified the origins of CW under the headings of manufacture, supplier, procurement, designer, logistics, client, contractor and site management. Notably, Keys’ classification suggested that the origins of CW are not only associated with project activities but also with the project stakeholders. Another categorisation was proposed by Tam et al. (2007), who included the demolition stage in their grouping of waste origins namely design, procurement, material handling, construction/renovation and demolition.

Causes of CW are mainly associated with two stages of a construction project: the design and construction stages. As for the demolition stage, there are no causes that generate waste; the whole structure will be turned to waste once its torn down and is often considered as non-avoidable waste. Various issues that cause construction are highlighted in the literature, and they have different levels of significance and impact on CW generation. A number of researchers have come to this conclusion in their studies. Table 2 categorises and itemises common causes of CW generation which are identified in past studies.

However, it is important to note that CW generation is not only a technical issue but also a behavioural one, as human factors have a major effect on waste generation and minimisation in construction projects. This is because most common causes of CW generation are directly or indirectly affected by the behaviour of those working in the construction industry, and by changing perceptions and attitudes – most of these causes can be prevented (Osmani, Glass, and Price 2006; Kulatunga et al. 2006; Begum et al. 2009; Al-Sari et al. 2012; Udawatta et al. 2015; Ikau, Joseph, and Tawie 2016;

Bakshan et al. 2017; Wu, Yu, and Shen 2017; Li et al. 2015; 2018a; Yuan et al.,2018; Liu et al. 2019; Luangcharoenrat et al. 2019). Behavioural cause of CW is integrated with every stage and phase in construction projects, unlike technical causes which are related to a specific phase. For instance, Al-Sari et al. (2012) highlighted that due to the labour-intensive nature of construction activities, levels of waste generation are largely influenced by the behaviour of contractors. This was confirmed by Liu et al. (2019) who revealed that the extent to which reduction, reuse and recycling of CW can be attained, depends highly on motivational influences on the attitude of contractors, from management level to labourers. Wang, Kang, and Wing-Yan Tam (2008) revealed that CW generation during on-site activities such as on-site management, operating machines, materials ordering and material handling, is mainly attributed to contractors' behaviour. On the other hand, Osmani (2013) concluded that CW is largely caused by poor perception and understanding of designers and architects regarding design waste causes, origins and sources. Further, Li et al. (2015) and Wu, Yu, and Poon (2019) argued that passive perspectives and lack of interest from designers towards the issue of CW are regarded as significant factors contributing to its generation.

Table 2: Common Causes of Waste Generation in Construction Projects

<i>Group</i>	<i>Causes of CW</i>	<i>Reference</i>
<i>Design</i>	<ul style="list-style-type: none"> Errors in contract documents Blueprint errors Detailing errors Design changes Complexities in design Poor coordination and communication (late information, last minute client requirements, slow drawing revision and distribution) Unclear/unsuitable specification 	Nagapan, Rahman, and Asmi (2012a), Ajayi and Oyedele (2018a), Akinade et al. (2017), Osmani (2008, 2013), Banihashemi, Tabadkani, and Hosseini (2018), Polat et al. (2017), Al-Hajj and Hamani (2011).
<i>Procurement</i>	<ul style="list-style-type: none"> Shipping errors/ suppliers' error Ordering errors Late/incorrect timing of deliveries Leftovers due to over estimation Packaging materials Incorrect quantity estimation Use of low-quality materials 	Nagapan, Rahman, and Asmi (2011), Mahamid and Elbadawi (2014), Ajayi and Oyedele (2018b), Ajayi et al. (2017b), Kolaventi et al. (2020), Ajayi (2017), Parisi Kern et al. (2015).
<i>Handling of materials</i>	<ul style="list-style-type: none"> Improper storage/deterioration Improper handling (off-site and on-site) Materials supplied in loose form 	Mahamid and Elbadawi (2014), Nagapan, Rahman, and Asmi (2011), Oko and Emmanuel (2013), Najafpoor et al. (2014).

<i>On-site operations</i>	<ul style="list-style-type: none"> Rework due to errors Improper project planning Equipment malfunctions Use of incorrect material Poor workmanship Leftovers from cutting and shaping/ materials off-cuts Poor site conditions Poor supervision Lack of waste minimisation plans 	Udawatta et al. (2015), Al-Hajj and Hamani (2011) Bekr (2014), Al-Rifai and Amoudi (2016), Osmani, Glass, and Price (2006), Arshad et al. (2017), Polat et al. (2017), Oko and Emmanuel (2013), Kolaventi et al. (2020), Muhwezi, Chamuriho, and Lema (2012), Patil and Pataskar (2013).
Others	<ul style="list-style-type: none"> Poor weather conditions Environmental disasters Accidents Theft and vandalism 	Bekr (2014), Karunasena and Amaratunga (2016), Domingo and Luo (2017), Muhwezi, Chamuriho, and Lema (2012), Vasconcelos and Junior (2015).

Source: Alhawamdeh and Lee

4. Construction Waste Minimisation

As discussed, the construction stage is considered *the* most important stage in terms of CWM. This is because there are more opportunities to avoid waste and reduce at the origin, whereas demolition waste can be managed separately for reuse and recycling. According to several studies (e.g., Zhang, Wu, and Shen 2012; Wu et al. 2014; Akinade et al. 2015, 2017; Chen and Lu 2017; Yu et al. 2020), there are methods that can potentially salvage waste generated from demolition (e.g., deconstruction). However, the problem with this type of waste is that it is unavoidable, and the probability of producing it is significant. Wu et al. (2014) and Akinade et al. (2015) indicated that the majority of waste from the demolition of structures is unrecoverable and is eventually sent to landfills. Thus, waste minimisation is essential during the construction stage. According to numerous studies (e.g. Tam, Shen, and Tam 2007; Wang, Kang, and Wing-Yan Tam 2008; Al-Hajj and Hamani 2011; Nagapan, Rahman, and Asmi 2012b; Nagapan et al. 2012b; Villoria Saez et al. 2013; Najafpoor et al. 2014; Mahayuddin and Zaharuddin 2013; Bakshan et al. 2015; Gulghane and Khandve 2015; Sasidharani and Jayanthi 2015; Li et al. 2016; Al-Rifai and Amoudi 2016; Ajayi et al. 2017a; Arshad et al. 2017; Kolaventi et al. 2020), CW is generated throughout the construction stage where there is site clearance, onsite operation, material use, material handling, material non-use, human error, on-site management and planning, transportation, and finally residual waste. Therefore, even with an effective project design, there is still a high probability of producing a huge amount of waste if construction is poorly executed. Conversely, if on-site practices are effectively implemented, it could minimise any waste that originates directly from the construction stage and indirectly from other stages and phases of the project. Accordingly, mistakes and errors made during the design stage can be corrected and avoided in the construction stage (Lopez et al. 2010; Love et al. 2011, 2012).

The hierarchy of waste management is a well-known guide used in the evaluation of practices from the most favourable option to the least favourable one, for addressing waste minimisation in construction projects. Figure 2 represents the best practicable options that protects the environment alongside resource and energy consumption within the chain of priorities for waste management, starting from the optimal situation of waste reduction (also referred to as prevention) and extending up to waste disposal, which is the end-of-pipe solution. The waste hierarchy comprises the 3Rs of waste minimisation (i.e., reduction, reuse & recycling), followed by recovery of energy (e.g., incineration) and final disposal.

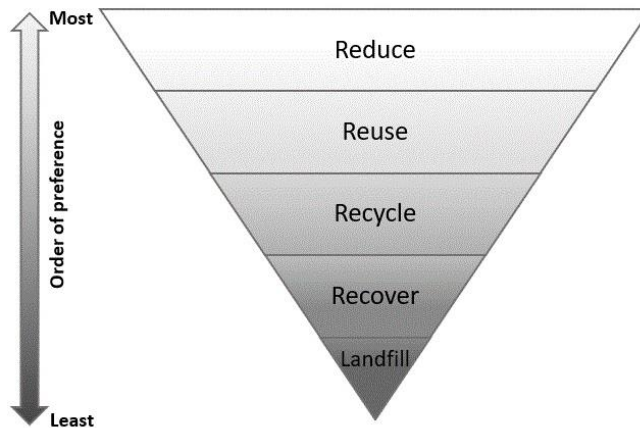


Figure 2: Waste Hierarchy

Source: Council Directive 2008/98/EC (2008)

Reducing CW is the paramount goal of the hierarchy, as source reduction usually results in the least environmental and economic costs because it requires no collecting or processing of waste, which in turn helps to reduce the cost of higher charges for waste transportation, recycling and disposal. Therefore, CW management must primarily aim to prevent waste generation from the start. However, when waste prevention is not possible, reuse of CW is the next most desirable option as suggested by the hierarchy. This step often requires collection but relatively little or no processing. Failing the above, recycling is most often the more preferred option than energy recovery in the hierarchy of waste management. However, both activities generally require collection and processing, thus, requiring additional energy and resources to reduce CW levels. CW disposal is the last resort in the waste management hierarchy and is only considered once all other possibilities have been explored due to its negative environmental impact.

Many governments worldwide have established a number of CW management plans and strategies following the guidelines of the waste hierarchical approach in order to effectively manage CW. However, despite the recognised effort for enhancing environmental sustainability, the amount of CW generation is still substantially high. In addition, the management of CW is still unsatisfactory as the amount of solid waste (including CW) disposed to landfills worldwide is approximately 60%; with little or no attempt at early recovery, see Figure 3 (World Bank 2018). Thus, CW is considered a chronic and ongoing concern.

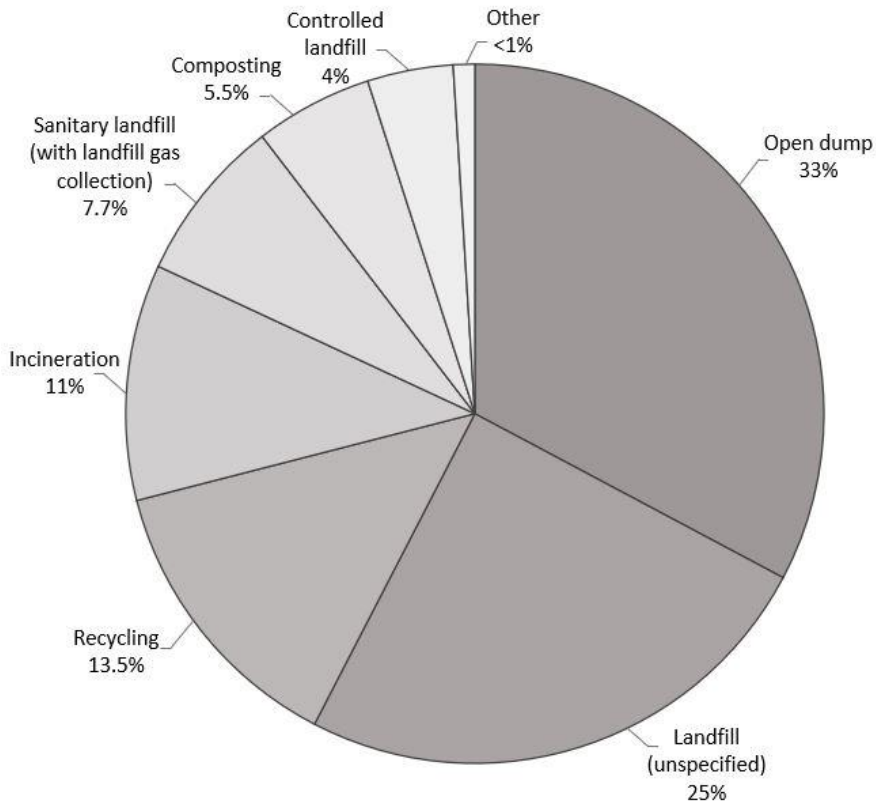


Figure 3: Solid Waste Treatment and Disposal Worldwide

Source: World Bank (2018)

4.1 The Need for Construction Waste Minimisation

The effects of CW can be classified into two levels: the project level and the national level. At the project level, CW impacts stakeholder's profits, and reputation as well as the project's performance and productivity. At the national level, CW causes national and even global environmental problems as well as a financial load on governments; dealing with CW and its related problems. Below are a number of significant environmental, economic and social problems resulting from CW extracted from the literature:

- **Diminishing landfill space:** Many countries worldwide are rapidly running out of landfill areas for dumping waste, especially in developing countries, yet the need for landfill space is ever growing. For instance, figures published by the UK government revealed that construction and demolition waste is around 130 million tonnes of waste per annum, which equates to almost two-thirds of total landfill waste (DEFRA, 2020). In the EU, over 800 million tonnes of construction and demolition waste is generated every year (Deloitte 2017), accounting for around 25-30% of all waste generated (European Commission 2018). The figure is more than 1.5 billion tonnes in China with only 5% being recycled (Huang et al. 2018). In the USA, the volume of CW increased to 569 million tonnes each year in 2017 (EPA 2019). It is a similar story in the Middle East region; inevitably the figures are lower but relative to the region's size and economic situation, they are still significant. The construction industry in the Gulf Cooperation Countries (GCC) generate around 66 million tonnes of waste every year accounting for around 55% of all waste generated (McElroy, 2012; Bhatia, 2016). Most of the collected waste in these countries is disposed of in

landfills and waste dumpsites on the outskirts of cities (Ouda et al. 2018). The UAE is no exception and is ranked as one of the largest producers of waste (per capita) worldwide where construction and demolition waste accounts for 70% of total waste generated (Al-Hajj and Hamani 2011).

- **High consumption levels of raw material resources:** The generation of CW also contributes to the depletion of the world's natural resources, including non-renewable sources of energy, as well as resources that are in danger of depletion, such as metal, timber and crushed stone (UNEP 2015b). Construction activities consume around 35% of the world's resources each year: including 12% of water, 25% of steel and more than 50% of crushed rock, gravel and sand (UNEP 2015b, 2019a, b, c). Additionally, the construction sector accounts for 36% of global final energy-use, including embodied energy (UNEP 2019a)
- **Pollution and contamination:** These are other significant problems attributed to increased volumes of CW worldwide. Existing research suggests that construction activities are a major contributor to environmental pollution, impacting air, water and soil contamination, resulting in adverse effects on flora and fauna (Ding et al. 2016; Ferronato et al. 2017). Globally, 33% of CW is still openly dumped in forests, open lands or waterways and this figure can rise to 93% in lower-income countries, since open dumping is a prevalent waste disposal practice causing soil and water contamination (World Bank 2018). Additionally, CW often contains solvents and volatile organic compounds which affect human health and can create fire hazards (Butera, Christensen, and Astrup 2014). Furthermore, CW leads to serious air pollution as 11% of the generated waste is treated through incineration worldwide (World Bank 2018), in addition to 11% of the total carbon dioxide (CO₂) emissions resulting from the associated energy usage of construction activities (UNEP 2019a).
- **Financial losses:** Waste increases the total cost of construction projects; around 15% (by value) of materials delivered to construction sites are wasted (Waste & Resources Action Programme, [WRAP], n.d.). The true cost of CW is not only reflected in materials purchasing costs, but also the cost of storage, transport, disposal, the cost of the time spent managing and handling the waste, and the loss of income from not salvaging waste materials (Mahpour and Mortaheb 2018; Hao et al. 2019). According to Osmani (2011), the true cost of waste in construction projects is estimated to be around 20 times the cost of the disposal of waste. Further, CW increases the tender price which affects the competitiveness of obtaining new projects (Yu et al. 2013). From a country's economic perspective, CW is of grave concern and a challenging issue faced by many economies around the world. Globally, 205 billion dollars was spent in 2010 on solid waste related challenges and this figure could rise to an estimated 375 billion dollars per year by 2025 (Asnap, 2012). In low- and middle-income countries, solid waste management comprises more than 20% of municipal budgets and around 50% of the local governments' investments (World Bank 2018). Therefore, managing CW and its related problems affect the financial sustainability of governments as funding must be balanced with the provision of other essential services such as healthcare, education and housing (ISWA 2017).

Based on the above points, it is clear that the social benefits of sustainable construction are strongly correlated with the minimisation of CW. Adopting sustainable construction through waste minimisation outlines the creation and management of a healthy built environment based on resource-efficient and ecological principles (Hussin, Abdul Rahman, and Aftab Hameed Memon 2013; Gan et al. 2015). This will result in achieving significant advantages of social sustainability for both society and the construction industry. In terms of a society perspective, sustainable construction enhances environmental performance through minimising pollution, salvaging natural resources, reducing the overall energy use and enhancing city landscapes by reducing open dumping. Additionally, sustainable construction enhances the economic performance of governments through reducing the costs of dealing

with CW and its related problems. Therefore, adopting sustainable construction through essential sustainability practices (e.g., CWM), will help improve the quality of life and increase the standard of those living in local communities.

From the construction industry perspective, the social benefits of adopting sustainable construction are reflected through responding to the needs of people over the project's lifecycle, providing satisfaction for customers and working closely with clients, suppliers, employees and local communities (Hussin, Abdul Rahman, and Aftab Hameed Memon 2013; Almahmoud and Doloi 2018). In other words, social sustainability in construction is best achieved by attaining satisfaction from the project stakeholders through conducting sustainable practices (e.g., CWM), which requires the collaboration of all parties involved in the construction process. In recent decades, the shift in the construction industry from the traditional paradigm towards sustainable development has received close global attention as a result of the significant impact of CW on the environment and society (Nagapan et al. 2012a). Therefore, it is important to integrate the three pillars of sustainability throughout the construction projects life cycle, with every stakeholder having a responsibility for carrying out sustainability practices including CWM (Gan et al. 2015).

4.2 Construction Waste Minimisation Approaches

Over the years, different approaches have been established to address waste minimisation during the construction stage, including on-site waste minimisation practices, technological approaches, legislation and behavioural approaches. However, CWM has not always been successful due to several barriers limiting the successful adoption of these approaches (see Table 4). Therefore, there is a real need to undertake a comprehensive review of common waste minimisation approaches adopted during the construction process. This is to gain a profound insight into the impact of such methods and highlight the barriers encountered in their application. Additionally, it will identify research trends and gaps that will support the critical need for improvement and the potential impact of this stage. Table 3 categorise common CWM approaches identified in past studies and Table 4 summarise the key barriers affecting their implementation.

Table 2: Common CWM Approaches Adopted in Construction Projects

<i>CWM category</i>	<i>Type of practice</i>	<i>Reference</i>
<i>On-site waste minimisation practices</i>	Waste collecting and sorting	Li Hao, Hill, and Yin Shen (2008), Wang et al. (2010), Yuan et al. (2011), Lu and Yuan (2012), Yuan, Lu, and Hao (2013), Ding et al. (2016).
	Waste reuse	Jin et al. (2017), Ajayi et al. (2017a), Wu et al. (2016), Huang et al. (2018).
	On-site planning and management: <ul style="list-style-type: none"> - On-site supervision - On-site planning and scheduling - Quality management - On-site communication - Maintenance of equipment and machinery 	Wang, Kang, and Wing-Yan Tam (2008), Hoonakker, Carayon, and Loushine (2010), Chin-Keng (2011), Mäki and Kerosuo (2015), Udawatta et al. (2015), Ajayi et al. (2017a, b), Ajayi and Oyedele (2018b), Mohideen and Ramachandran (2014)

	<p>On-site material management:</p> <ul style="list-style-type: none"> - Material procurement - Material delivery - Material storage - Material handling 	<p>Al-Hajj and Hamani (2011), Madhavi and Methew (2013), Patil and Pataskar (2013), JerutoKeitany and Richu (2014), Gulghane and Khandve (2015), Ding et al. (2016), Koriom et al. (2019).</p>
<i>Technological approaches</i>	<p>Soft technologies (i.e., information and communication technologies)</p>	<p>Adriaanse, Voordijk, and Dewulf (2010), Nikakhtar et al. (2015), Gulghane and Khandve (2015), Liu et al. (2015), Martínez-Rojas, Marín, and Vila (2016), Won and Cheng (2017).</p>
	<p>Hard technologies (i.e., innovative construction tools and equipment)</p>	<p>Zhang, Wu, and Shen (2012), Tam et al. (2015), Pan et al. (2018), Martin and Perry (2019).</p>
	<p>Modern methods of construction (MMC)</p>	<p>Lu and Yuan (2011), Zhang, Wu, and Shen (2012), Mesároš and Mandičák (2015), Rahman (2014), Tam et al. (2015), Martin and Perry (2019).</p>
<i>Legislation</i>	<p>Landfill disposal charges</p>	<p>Lu and Tam (2013), Yu et al. (2013), Poon et al. (2013), Li et al. (2018b), Hao et al. (2019), Li et al. (2020).</p>
	<p>Illegal dumping penalties and supervision</p>	<p>Lu and Tam (2013), European Commission (2016), Rahim et al. (2017), Wee et al. (2017), Li et al. (2018b).</p>
	<p>Waste management schemes</p>	<p>Tam (2008), Solís-Guzmán et al. (2009), Zaman and Lehmann (2011), European Commission (2016), Yukalang, Clarke, and Ross (2017), DEFRA (2020).</p>
	<p>Sustainable development strategies</p>	<p>Augenbroe et al. (1998), European Commission (2012, 2014), Yukalang, Clarke, and Ross (2017).</p>
<i>Behavioural approaches</i>	<p>Training and education of:</p> <ul style="list-style-type: none"> - CW causes and minimisation techniques - Environmental impacts and cost reduction 	<p>Wang, Kang, and Wing-Yan Tam (2008), Begum et al. (2009), Al-Hajj and Hamani (2011), Al-Sari et al. (2012), Yean Yng Ling and Song Anh Nguyen (2013), Bakshan et al. (2017), Li et al. (2018a).</p>

A Reward scheme motivation

Kulatunga et al. (2006), Tam and Tam (2008), Mills et al. (2012), Yuan (2013), Mahpour and Mortaheb (2018).

Waste management support

Rodriguez-Melo and Mansouri (2011), Tan, Shen, and Yao (2011), Oluwole Akadiri and Olaniran Fadiya (2013), Nagapan et al. (2012a), Bakshan et al. (2015).

Source: Alhawamdeh and Lee

On-site Waste Minimisation Practices

On-site waste minimisation practices are very important approaches due to their potential impact. These practices can be grouped into two types of waste minimisation measures. The first type is waste management practices which are employed after waste is generated (i.e., waste collecting, sorting and reusing). The second type is source reduction measures, which through their effective implementation, enhance the performance of the construction process and, thus, minimisation occurs in CW generation (see Table 3).

Waste collection and sorting are important approaches in on-site waste management as they are preliminary steps for achieving reuse, recycling and safe waste disposal. On-site collection and sorting play a large role on the quantity of recycled and reused waste; as the more waste materials are collected and sorted, the more waste there is to be recycled and reused (Yuan et al. 2011). Additionally, reusing and recycling could be largely influenced by how well the different components of CW are properly segregated (Ding et al. 2016). On-site sorting is often adopted to minimise waste disposal. As Lu and Tam (2013) have argued, if CW is unavoidably generated on construction sites, arranging on-site sorting is advisable for contractors. The benefits of conducting on-site sorting of CW typically include: reducing the cost of waste disposal, increasing the rates of reuse and recycling, prolonging the lifespan of landfills designed for receiving waste, and reducing the pollution resulting from the huge amount of disposable waste (Li Hao, Hill, and Yin Shen 2008; Ding et al. 2015; Wang et al. 2010). Although the sorting procedure of CW can be carried out on-site or by hiring a specialised company, a number of studies highlighted the benefits of on-site sorting since it requires less effort, results in better segregation and avoids the transport of refuse to sorting and recycling facilities (Lu, & Yuan, 2012). Contractors' attitude is regarded as one of the most critical factors, as according to Yuan, Lu, and Hao (2013) project stakeholders' attitude and management effort are perceived as being of major importance in the on-site collection and sorting practices.

In general, reuse is more desirable than recycling as reusing CW will avoid the cost of recycling and its associated energy usage (Wu et al. 2016). Reusing and salvaging waste materials reduces the quantity of disposed waste to landfill, which can be significant in some projects. This will protect the environment, and reduce further costs for both clients and contractors through reducing the cost of purchasing new materials, and avoiding the disposal and transport costs of waste materials (Yuan et al. 2011; Ajayi et al. 2017a, 2014). However, the practice of reusing CW is still in its infancy and there are key barriers to implementation as disputed in Table 4.

Site supervision is one of the vital on-site management measures that ensures time, safety, quality and cost-effectiveness of construction operations (Ajayi et al. 2017a, b). Site supervisors are mainly concerned with the planning, organising, monitoring and controlling of each phase of the construction process. In addition, they ensure communication of instructions and take action whenever necessary to deal with identified problems (Wang, Kang, and Wing-Yan Tam 2008; Mäki and Kerosuo 2015). Therefore, negligence of supervision in construction sites can disrupt the effective implementation of construction activities which would increase the probability of waste generation. However, according

to Alwi, Sherif, and Hampson (2002), the success of supervision is more likely to be dependent on the experience level rather than the number of supervisors involved in a project. Adequate on-site planning and scheduling is also an essential issue in CWM as efficient planning of construction activities ensure sufficient allocation of time, money, material and human resources (Ajayi, et al. 2017b). This will help avoid errors, minimise wasted resources, enhance work performance and increase the productivity of work. Additionally, with effective construction planning, the consequences of unforeseen situations can be easily controlled or even avoided (Mäki and Kerosuo 2015). Nonetheless, Udawatta et al. (2015) pointed out the importance of devoting adequate time for the on-site planning process to achieve successful outcomes.

Quality management (quality planning, assurance & control) is another on-site measure that provides a major contribution to CWM. It is a proactive measure to produce high quality work through eliminating defects at the source which reduces rework and ensures that the quality of the final work is controlled (Chin-Keng 2011). This can be achieved by identifying all the issues that might have an impact on the quality of work including the role of people and the quality of materials (Hoonakker, Carayon, and Loushine 2010; Ajayi and Oyedele 2018b). Therefore, obtaining high quality in construction work is heavily reliant on the utilisation of standardised materials, stakeholders' behaviour and the proficiency of workmanship (high experience and skills), which all have a direct effect on waste generation. One significant barrier against quality implementation in construction projects is that some contractors reduce their costs in order to obtain new tenders in a competitive bidding process. As a result, they may try to reduce allotted resources towards safety or quality management in order to maintain a healthy profit margin for the work (Hoonakker, Carayon, and Loushine 2010).

Furthermore, researchers have highlighted the importance of collaboration and clear communication between the different stakeholders involved in the construction process (Hoonakker, Carayon, and Loushine 2010). Effective collaboration and communication between stakeholders involved in the project will lead to more engagement in CWM by enhancing performance, increasing productivity, reducing conflicts, and reducing post-variations and rework (Wang, Kang, and Wing-Yan Tam 2008; Udawatta et al. 2015). One more typical on-site management measure is regular maintenance of construction equipment and machinery which can significantly contribute to CWM. Such a measure helps sustain the continuous and reliable operation of equipment and machinery in construction sites and, as a result, minimises equipment downtime, avoids interruptions and rework, increases productivity, improves quality and reduces the cost (Bashiri, Badri, and Hejazi 2011; Mohideen and Ramachandran 2014). Therefore, equipment and machinery maintenance are absolutely essential to maintain a trouble-free working environment and reduce the chance of CW generation.

Finally, researchers have emphasised the significance of on-site material management towards CWM. This is because ineffective material management is evident in many construction projects and causes considerable waste of time, money and materials (JerutoKeitany and Richu 2014). Material management is described as a coordinating function responsible for planning and controlling materials flow in a construction project (see Figure 4). This ensures that the right quality and quantity of material are appropriately selected, effectively delivered and safely handled on site in a timely manner and at a proper reasonable cost (Madhavi and Methew 2013; Gulghane and Khandve 2015). According to Nagapan, Rahman, and Asmi (2011), the management of procuring materials is a critical step and needs to be effectively planned and executed to avoid shortages or surpluses in the materials' inventory in construction sites. While shortages in the supply and flow of construction materials are often cited as major causes of project delay, productivity degradation and financial losses (Nagapan, Rahman, and Asmi 2011), excessive stocks are also subject to damage, deterioration, theft and vandalism and poor weather conditions (Muhwezi, Chamuriho, and Lema 2012).

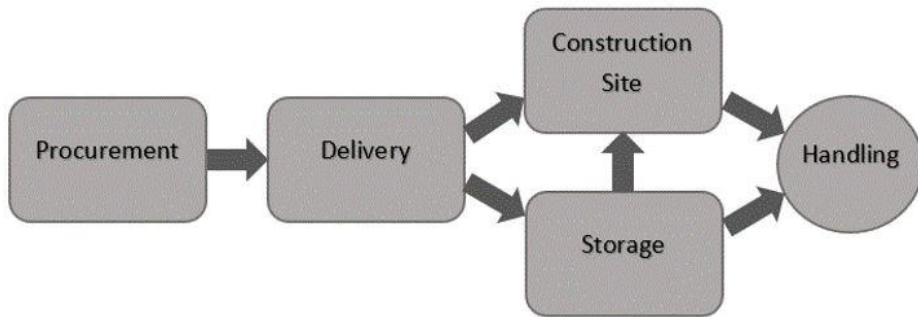


Figure 4: A Typical Material Management Process in Construction Projects

Source: Alhawamdeh and Lee

Ajayi et al. (2017b) revealed that Just-In-Time delivery supports a consistent flow of materials for production and is an effective CWM process. Additionally, improper storage of construction materials can cause material damage and loss which has a direct impact on CW generation (Najafpoor et al. 2014). Furthermore, Koriom et al. (2019) emphasised the importance of efficient material handling, as this practice encompasses all aspects of movements and distribution of raw materials, work in process, or finished goods on and off construction sites. Therefore, effective material management in construction projects ensures material safety and protection, increases work productivity, avoids schedule delays and enhances the overall project performance. Increasing awareness about the significance of every aspect of material management is almost essential as it helps trace the origins and causes of any failures (Al-Hajj and Hamani 2011; Patil and Pataskar 2013).

Technological Approaches

Low-waste technologies are not new to the building industry and are considered an important approach in CWM. Utilising low-waste technologies in the construction process optimises resource consumption which results in waste minimisation and increased value for a project's stakeholders (Jaillon, Poon, and Chiang 2009; Zhang, Wu, and Shen 2012). In general, low-waste technologies facilitate quicker construction and produce better quality work leading to a decrease in waste generation. In addition, there would be cost savings if construction materials can be reused or if mass production is required (Jaillon, Poon, and Chiang 2009; Tam et al. 2015).

Information and communication technologies, which are sometimes referred to as soft technologies, aid project managers to improve the processes and work performance during construction activities, thereby minimising CW generation (Martínez-Rojas, Marín, and Vila 2016). Such low-waste technologies improve collaboration, coordination and data exchange including data sharing, digital representation, and storage among the stakeholders involved in the construction process (Zhang, Wu, and Shen 2012; Martínez-Rojas, Marín, and Vila 2016; Won and Cheng 2017). For instance, Building Information Modelling (BIM) is a widely embraced information and communication technology that is used in architecture, construction and engineering. It contains a wealth of information, such as material resources and geometry which can be integrated with the project's schedule which, in turn, provides improved planning to help ensure Just-In-Time arrival of materials, equipment and labour (Won and Cheng 2017).

Hard technologies, such as innovative construction tools and equipment, are becoming more widely used by contractors on construction sites. Such low-waste technologies contribute to CWM through increasing the productivity and quality of work, providing a tidier and safer working environment, improving work performance, and reducing construction process duration and costs (Tam et al. 2015; Pan et al. 2018). One common example is Machinery Sprayed Plaster; the main difference between traditional cement mortar and mechanised plaster is that the former is applied and

trowelled smooth by hand, whilst the latter is mixed and applied mechanically. Therefore, utilising such a tool can provide high productivity of work, low labour demand, a tidier work space and less waste generation (Tam et al. 2015).

Modern methods of construction (MMC) is another typical approach of low-waste technologies and have a very broad application in the construction industry, especially in developed countries (Mesároš and Mandičák 2015). MMC are construction techniques that incorporate innovative designs and technological implementations which have a strong capability to minimise CW generation (see Figure 5). This type of low-waste technologies ensures an efficient management process, increases the precision of construction within a shorter time, optimises usage of resources, reduces the environmental impact and increases construction sustainability (Zhang, Wu, and Shen 2012; Tam et al. 2015; Mesároš and Mandičák 2015). For instance, an innovative formwork system such as Prefabricated Steel Formwork is one of the most commonly used methods in construction activities. It can provide higher stiffness and is more durable than traditional timber formwork since it can be erected repetitively as well as maintain a coherent concrete surface. This will aid in reducing the additional allocation of materials and labour in dealing with step joints and poorly cast surfaces. In addition, it will increase the precision and quality of the construction component which leads to reduced possibilities of CW generation. (Tam et al. 2015). There is often negative behaviour towards the implementation of low-waste technologies, as construction costs remain the most governing issue for project stakeholders when choosing a construction method (Abarca-Guerrero, Maas, and van Twillert 2017).

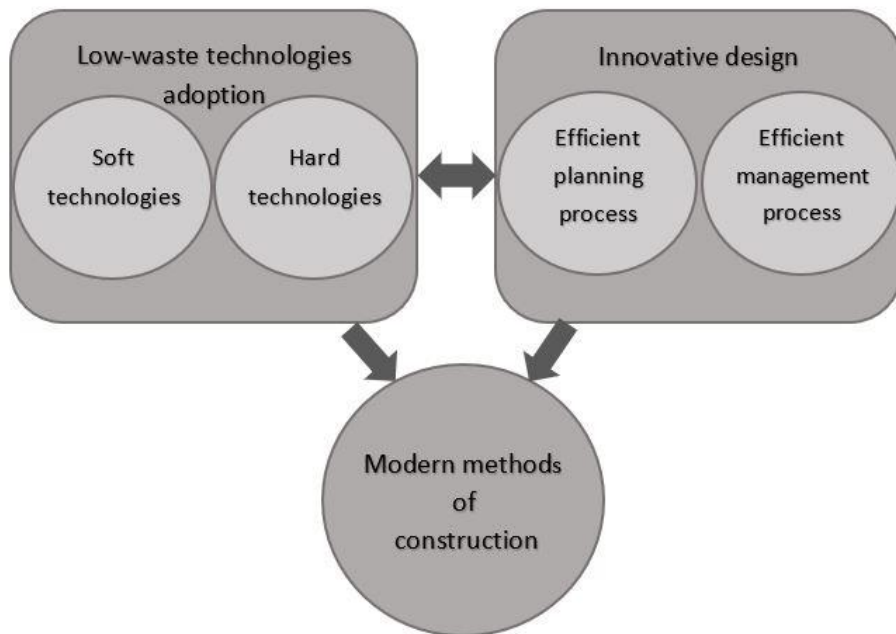


Figure 5: Criteria of Modern Methods of Construction (MMC)

Source: Alhawamdeh and Lee

Legislation

Government regulations and policies play a critical role in CWM by developing and fostering the regulatory environment. However, CWM legislation can exert a different level of influence: some are compulsory, and some are total or partial voluntary (see Table 3).

Over the past few years, local governments have been paying increased attention to the promotion of CWM through establishing and further reinforcing landfill charges. It is considered as one of the most typical legislative measures implemented by local governments worldwide due to the increasing amount of CW being disposed to landfill sites (Lu and Tam 2013). Landfill charges play a critical role in promoting economic incentives for contractors to minimise waste, as well as encouraging reuse and recycling as cost savings prevail as the primary motivating factor (Yuan et al. 2011; Hao et al. 2019). For instance, a landfill tax came into force in the UK in 1996 and has encouraged recycling and recovery, and this is now, in many cases, cheaper than sending CW to landfill (European Commission 2016). In Hong Kong, a significant minimisation of CW was achieved in the first three years (2006–2008) of the Construction Waste Disposal Charging Scheme (CWDCS) implementation (Yu et al. 2013). However, elsewhere landfill charges have not always exerted a strong influence towards motivating project stakeholders to minimise CW, as in many cases waste is being disposed of with little or no attempt at early recovery. The most likely reason is that some project stakeholders are reluctant with a laissez-faire attitude to CWM as according to Yu et al. (2013), lack of involvement in CWM results from sub-contractors being reluctant to change. Li et al. (2020) revealed that there is a negative correlation between stakeholders' perceptions of cost reduction and their willingness to pay for CW collection, sorting and recycling. Another reason is that sometimes project managers would rather pay the charges of CW disposal than invest time and money in CWM, because the former is perceived as being much cheaper (Li et al. 2018b; Li et al. 2020). Confirming this, a study by Poon et al. (2013) and Yu et al. (2013) revealed that at times the cost of landfill charges is not high enough to raise the awareness about waste minimisation on construction sites, as some contractors tend to increase their tender prices in order to absorb the extra cost for landfill charges.

Monitoring CW disposal and imposing penalties for illegal dumping is another key legislative measure towards controlling CW generation. Imposing financial penalties significantly promote economic incentives for project stakeholders towards minimising CW (Yuan et al. 2011). Many local governments are establishing strict measures for monitoring CW disposal further reinforcing their existing ones to discourage illegal dumping of CW. For instance, in the UK, local councils and environmental regulatory bodies have a responsibility towards controlling the illegal disposal of waste. They carry out a huge number of inspections of waste sites and have issued guidance for environmental offences. However, in the year 2013-2014, there were almost 18% of open dumping incidents from construction and demolition waste in the UK which indicated that further attention and effort should be placed on such issues (European Commission 2016).

Local governments worldwide are continuing to examine effective monitoring measures and enforce strict punishment to prevent the practice of illegal dumping of CW (Lu and Tam 2013; Rahim et al. 2017). However, implementation efforts are challenged by some difficulties as illustrated in Table 4. One significant barrier is the lack of moderation in CW related policies, as both strict regulations and looser regulations can lead to illegal dumping practices (Li et al. 2018b). For instance, higher landfill charges may trigger objections or uncooperative behaviour, such as illegal dumping, from related construction stakeholders because this policy will affect their financial interests. On the other hand, charge levels that are too low will not provide sufficient motivation for construction stakeholders to minimise CW.

Waste management schemes have been developed by many local governments worldwide as they are ultimately responsible for any related waste management strategies and waste prevention plans. Additionally, some plans provide specific targets to be met for waste reduction, reuse and recycling. For instance, Waste Management Plans (WMP) have been developed by UK governmental bodies within England, Scotland, Wales and Northern Ireland, which are responsible for any related waste management issues (European Commission 2016). One of the targets of WMP is for the UK to recover at least 70% of non-hazardous construction and demolition waste by 2020, which it is currently meeting (DEFRA, 2020). In 2019, the Ministry of Ecology and Environment decided to address the issue of enormous amount of solid waste generation in Chinese cities by introducing the concept of a

'zero waste city' (Lu, 2020). This concept includes 100% recycling of solid waste and 100% recovery of all resources from waste materials. In the UAE, the Centre of Waste Management, Tadweer, has been established by the government of Abu Dhabi in 2008. It is responsible for the implementation of solid waste management policies and strategies across the Emirate. In the first half of 2019, Tadweer has managed to collect 1.2 million tonnes of solid waste (including CW), and this was a relatively large figure considering the country's size and population (Gulf news 2019).

Furthermore, several governments worldwide initiated sustainable development strategies to coordinate participatory processes of thought and action in order to achieve economic, environmental and social sustainable construction objectives in a balanced and integrative manner. For instance, the "Construction 2020 Strategy" has been established in the EU in order to support the construction sector in its adaptation to key upcoming challenges, as well as to promote sustainable competitiveness in the sector. One of its main objectives is to improve resource efficiency, protect the environment and improve business opportunities (European Commission 2012, 2014). Another example is the USA, where a number of national sustainability initiatives have been established such as "Buildings for the 21st Century" and "Resource conservation strategies", in order to create a new generation of buildings that are energy-efficient, high quality, affordable and environmentally sustainable. These strategies hold tremendous potential and have attained successful outcomes over the past years (Augenbroe et al. 1998; EPA 2016). In 2016, Dubai launched the Dubai 3D Printing Strategy which adopted an emerging technology to help produce SC. This initiative has a vision to transform the Emirate as a 'leading hub of 3D printing technology' by 2030 and dictates that 25% of the buildings in the Emirate will be constructed using the technology by that year. The first project that was in line with such a strategy was "Apis Cor" which was completed in 2019, reported benefits of increased efficiency including time, cost and waste reduction (Arabian Industry 2020). Notably, a significant limitation to the successful of such strategies is that many construction organisations only seek to invest in waste minimisation to be legally compliant and, therefore, produce minimum performance outcomes (Simpson 2012).

Behavioural Approaches

The role of human factors has gained more attention from researchers in recent years. This is because behaviour is critical to the successful attainment of desired CWM outcomes. Hence, several behavioural approaches have been addressed to minimise waste in the construction industry.

The awareness of CW causes and minimisation techniques are significant issues in tackling CWM behaviour, and it can be addressed by providing adequate relevant training and education (Li et al. 2018a). Training on source-reduction procedures, reuse of materials and the underlying factors that can generate CW, can highly improve the level of knowledge and skills of CWM among contractors which in turn, would effectively improve CWM growth and performance (Al-Hajj and Hamani 2011; Yuan 2013; Abarca-Guerrero, Maas, and van Twillert 2017). Indeed, Luangcharoenrat et al. (2019) noted that poor implementation of CWM due to lack of experience and skills in assigned tasks, will cause rework and repairs. Further, increasing awareness of financial incentives (cost saving) is seen to be the most influential method of motivating stakeholders in taking effective action to minimise CW, as project stakeholders are mostly concerned with cost saving objectives (Udawatta et al. 2015; Bakshan et al. 2017). Moreover, environmental awareness which is a qualitative variable that influences the willingness of various construction stakeholders to minimise waste, can also be raised by highlighting the importance of CWM through providing relevant education (Wang, Kang, and Wing-Yan Tam 2008; Al-Sari et al. 2012; Yuan 2013).

A number of training schemes have been initiated by governmental bodies as well as private organisations with the aim of enhancing awareness in the construction industry towards sustainable development. For instance, ISWA has made a key contribution in knowledge build-up, action and awareness raising in waste minimisation and recycling (ISWA 2017). In the UK, a number of institutions such as WRAP, Construction Industry Research and Information Association (CIRIA) and

the Building Research Establishment (BRE), have been promoting sustainable construction through guiding the construction industry towards waste minimisation with the support of workshops, publications, best practice examples and guidance. It was evident that such institutions have helped businesses and individuals to develop sustainable practice and use resources in an efficient way (Oluwole Akadiri and Olaniran Fadiya 2013). For instance, BRE has established the 'Site Sustainability Manager Training scheme', which provides training and education that will equip site managers with the required knowledge for delivering the most sustainable development. Such a scheme ensures that a construction site will not only be managed in an environmentally efficient manner, but also gives the client and the site management team confidence that the project's design requirements are achieved. Despite the importance of education and training about CW issues, there is still a significant absence of the provision of such training by decision makers in the construction industry, especially in developing countries (Ling, & Nguyen, 2013; Mahdi and Ali 2019; Mahamid 2020)

A reward scheme is an effective performance-dependent approach that can motivate construction stakeholders, including both organisations and employees, to change their behaviour and increase their participation in waste minimisation (Osmani et al. 2008; Liu et al. 2019). Several reward schemes, which can be a financial or non-financial recognition, have been established by many governmental bodies and non-profit institutions for the promotion of SC. For instance, the Building Research Establishment Environmental Assessment Method (BREEAM) was established in 1990 in the UK and is the world's longest established method of assessing, rating and certifying the sustainability of buildings, including energy use and material waste. In more than 50 countries across the world, around 550,000 projects have been BREEAM-certified and over 2,250,000 projects are registered for certification (Giles, 2017). In addition, the KSA Award for Environmental Management (KSAEM) was established in Saudi Arabia in 2015. It is a financial award as well as an honorary recognition of outstanding achievements in the environment and sustainable development. So far, it has been awarded to many individuals and organizations in recognition of their substantial contributions to the environment (Ksaaem 2018).

Within the construction industry, an organisational strategy of rewarding construction employees is proven to raise willingness and motivation to be more engaged in CWM activities (Kulatunga et al. 2006; Wang, Li, and Tam 2014). Conversely, negative behaviour towards CWM may exist among some employees, particularly construction operatives, thinking that it is not worthwhile unless it is tied to personal financial benefits (Yuan 2013). The reward scheme can be in the form of bonuses, merit-related salary reviews, and recognition of individual/ team excellence rather than the length/ duration of service. For instance, the Stepwise Incentive System (SIS) scheme is used to measure the cost saved in purchasing materials and controlling CW generation (Tam and Tam 2008). The key importance of such a scheme is that it exploits employees' awareness of CWM by rewarding staff involved in projects who are producing lower CW levels. Tam and Tam's (2008) study showed that the effectiveness of SIS can result in CW being reduced by up to 23%. The absence of a rewarding system does exist within organisations when project managers do not perceive any short-term benefit from CWM, as sometimes the financial returns gained from minimising CW are too small (Wang, Li, and Tam 2014). It is noteworthy that incentive-based (e.g., rewards) and penalty-based (e.g., fines & charges) approaches are both important measures affecting CWM behaviour. However, a study conducted by Mahpour and Mortaheb (2018) provided evidence for the preference of incentivising over penalising construction employees in order to increase their motivation for minimising CW.

A number of non-profit organisations have emerged in the past decades to support the construction industry through the provision of guidance solutions and services that facilitate better waste management. For instance, in 2011, WRAP managed to help more than 600 construction companies succeed in halving their waste to landfills, which in turn, positively influenced construction to the value of more than 38 billion pounds (WRAP 2011). In the USA, the Building Materials Reuse Association (BMRA) is a non-profit organisation that provides guidance and services to facilitate the reuse of used or surplus building materials through an online directory website (EPA 2019). It can be

clearly seen that both reward schemes and waste management support schemes are key achievements in CWM.

Table 4: A Summary of the Common CWM Approaches and their Key Barriers

<i>CWM Approach</i>	<i>Barrier</i>	<i>Reference</i>
<i>Waste collecting and sorting</i>	Lack of on-site space Increased sorting cost Poor waste separability Poor market for recyclables Poor attitude and management effort in contractors	Li Hao, Hill, and Yin Shen (2008), Wang et al. (2010), Yuan, Lu, and Hao (2013), Ajayi et al. (2015).
<i>Waste reuse</i>	Non-compliance of specifications, Lack of knowledge and experience of reusing waste Lack of awareness of the short- and long-term advantages of reusing waste.	Park and Tucker (2017), Jin et al. (2017), Huang et al. (2018).
<i>On-site planning and management:</i>	Lack of skills and experience of site supervisors Insufficient time and money allocation for the on-site planning and quality management processes Poor material quality lack of experience and skills Lack of interest from project stakeholders	Alwi, Sherif, and Hampson (2002), Udawatta et al. (2015), Hoonakker, Carayon, and Loushine (2010), Ajayi and Oyedele (2018b).
<i>On-site material management:</i>	Lack of tools and techniques for managing construction materials Lack of awareness about the causes of failures in construction material management	Al-Hajj and Hamani (2011), Patil and Pataskar (2013), Gulghane and Khandve (2015).
<i>Low-waste technologies</i>	Higher low-waste technologies appliance design and investment cost Market limitations Limited fabrication facilities Lack of knowledge and familiarity with the low-waste technologies and their implementations Insufficient government support The governing culture of the construction industry Incompatibility with the requirements of the construction project Negative behaviour towards the acceptance of low-waste technologies	Jaillon, Poon, and Chiang (2009), Zhang, Wu, and Shen (2012), Rahman (2014), Abarca-Guerrero, Maas, and van Twillert (2017).

<i>Landfill disposal charges</i>	Reluctance to change Low disposal charges Increasing tender prices for absorbing the cost of landfill charges	Yu et al. (2013), Poon et al. (2013), Li et al. (2018b), Li et al. (2020).
<i>Illegal dumping penalties and supervision</i>	Limited government financing, Low staff technical capacity Ambiguity in the policies' guidelines Lack of moderation in policies	Wee et al. (2017), Li et al. (2018b).
<i>Waste management schemes and sustainable development strategies</i>	Insufficient infrastructure Weak strategic planning Lack of interest and engagement with programs Minimum legal compliance Poor staff capacity managing the schemes Poor information systems Strategies' system vagueness	Zaman and Lehmann (2011), Simpson (2012) Yukalang, Clarke, and Ross (2017).
<i>Training and education</i>	Lack of motivation Reluctance to change, Lack of management support	Al-Hajj and Hamani (2011), Ling, and Nguyen (2013), Lu et al. (2015).
<i>Reward scheme and waste minimisation good practices</i>	Lack of interest of project stakeholders Belief that CW is inevitable Belief that CWM is not cost and time effective Interest in delivering quality over CWM Absence of a rewarding system, especially when the financial returns from CWM are perceived as small	Jaillon, Poon, and Chiang (2009), Wang, Li, and Tam (2014), Ajayi et al. (2016), Jin et al. (2017), Wu, Yu, and Shen (2017).

Source: Alhawamdeh and Lee

5. Conclusion

This paper reported a narrative review of the existing literature on the fundamentals of CW, together with its definition, origins, causes and its minimisation methods. The purpose of this was to gain a theoretical understanding of the principles of, and the need for, CWM as well as to benefit from the challenges and experience of developed countries towards effective waste minimisation in construction projects. The following is a summary of the key findings:

- Construction waste can be broadly defined as any waste produced during the construction and demolition of structures, and it can be originated over the project lifecycle. It can be in the form of physical materials, time and cost losses or quality defects in construction works.
- Solid materials waste is a colossal problem for construction and is considered to be one of the major contributors to the total waste production, generating around 36% of the total waste worldwide. It was identified as most critical due to its impact on the three pillars of sustainability at the project, as well as, the national level. At the project level, CW impacts stakeholders' profits and reputation as well as the project's performance and productivity. At the national level, CW

causes national and even global environmental problems as well as a financial load on governments dealing with CW and its related problems.

- The construction stage is the most critical stage in terms of CWM. First, waste generation is usually upmost in the construction stage since it includes a wide range of activities that may contribute to waste generation. While it was acknowledged that design-out practices are important in terms of waste minimisation, the amount of waste generation can still be significant, if it is poorly executed, during the construction process. Conversely, effective implementation of on-site practices can minimise any waste that originates directly from the construction stage and indirectly from the design stage and, therefore, mistakes and errors made during design can be corrected and avoided. Second, waste generation can be avoided and reduced at the origin during the construction stage, whereas demolition waste is often considered as non-avoidable waste since there is a strong chance of producing significant amounts of it once the whole structure is demolished.
- Human factors play a major part in waste generation and minimisation in construction projects. This is because most common causes of CW are directly or indirectly affected by the behaviour of the personnel involved in the construction industry and, therefore, by changing their perceptions and attitudes, particularly that of contractors, it will lead to the avoidance of these causes.
- Different approaches have been established to address the issue of CW during the construction stage, including on-site waste minimisation practices, technological approaches, behavioural approaches and legislation. Despite the importance of these approaches and their relative benefits, waste minimisation in the construction industry has not always been successfully controlled due to a number of obstacles that constrain the successful adoption of such approaches. It was notable that behavioural issues such as lack of interest, poor attitude and perception, and lack of awareness and knowledge were the most common obstacles limiting the successful adoption of nearly most of the aforementioned CWM approaches.

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