Environmental Science and Pollution Research (2019) 26:13773–13784
https://doi.org/10.1007/s11356-018-2887-0

SUSTAINABLE ENVIRONMENTAL MANAGEMENT

A cost compensation model for construction and demolition waste disposal in South China

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Received: 3 May 2018 / Accepted: 31 July 2018 / Published online: 20 August 2018

Abstract

Construction and demolition waste (C&D waste) is a worldwide issue that concerns the sustainable development of the construction industry. In this paper, detailed formulas are listed for calculating the costs of four typical kinds of disposal routes of C&D waste. They are illegal dumping, controlled dumping (landfill), centralized recycling, and on-site recycling. Through the specific formulas, the costs of the new construction project in Guangzhou are also estimated. Then, a cost compensation model of construction waste disposal is constructed, which serves to calculate the amount of compensation that the government shall make to the contractor's disposal cost. The results of this study include the following: (1) steps taken to ensure the appropriate measures for C&D waste disposal sites and recycling centers; (2) the on-site recycling will become the future trend of C&D waste disposal due to its lowest cost; (3) the brick cement mortar and scattered concrete take a relatively larger proportion in the total C&D waste generated during the new construction project, and their disposal costs are higher; (4) we find that the cost of illegal dumping is the lowest among four varieties of waste treatment options if only the direct cost of waste treatment is taken account. However, the cost of on-site recycling becomes the lowest if the total cost is considered; (5) according to the case study, the full estimated cost of construction waste disposal is 9074.56 CNY and the total cost compensation is 15,084.21 CNY. The amount of compensation is greater than the disposal cost and contractors make a profit, thus stimulating them to recycle and reuse construction waste. Based on the empirical findings, we make several policy proposals. The research puts forward some operational advice as a reference for decision-makers of C&D waste management.

Keywords C&D waste management · Cost compensation model · Full-cost accounting

Introduction

With the accelerating process of urbanization in China, there is a huge amount of construction waste generated every year in the transformation of old towns, subway construction, and foundation pit excavation. Taking Guangzhou as an example, the amount of the construction waste generated in the urban renewal and subway construction has been growing year by year, reaching 34.6 million tons by the end of 2016 (as shown in Fig. 1). However, the comprehensive utilization rate of the construction waste in Guangzhou is very low, less than 60% (CAEPI 2009; Liu et al. 2017). Lots of construction wastes are transported by construction units to the outskirts of cities or villages without any treatment (Wang et al. 2011; Liu et al. 2014; Ding et al. 2016). During transport, the construction waste without the seal processing will inevitably cause problems like scattering dirt, flying dust and lime-sand, and other issues, seriously affecting the city's appearance and landscape (Wang and Zhao 2004; Pang and Yang 2006; Liu and Wang 2012; Jin et al. 2017). If the construction unit illegally buries the construction waste, not only will it use a lot of land, but also a large accumulation will cause damage to surface landscape and groundwater, thereby blocking the soil biological chain and causing serious environmental pollution (Wang et al. 2004; OGPCCM 2010; Lu et al. 2011; Calvo et al. 2014). Mismanagement even gives rise to serious security accidents. In a demolition waste treatment field of Hongao village, Guangming New District, Shenzhen, a landslide was triggered

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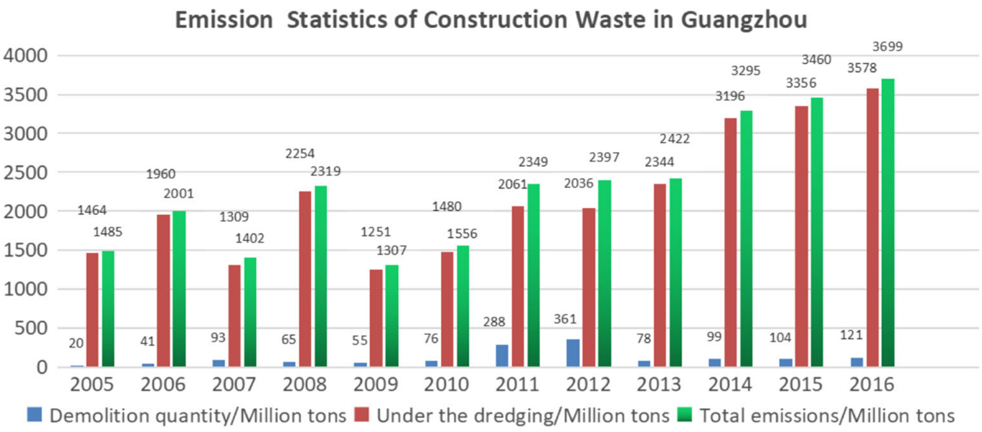


Fig. 1 Annual emission statistics of construction waste in Guangzhou (Hu et al. 2016a)

by collapse of construction debris on 20 December 2015, which served as a wake-up call for China's construction waste management (Yang et al. 2017).

The output of the construction waste in large cities in China is huge. Most of the demolition waste treatment fields are in remote suburbs, which will cause large costs of the transportation and disposal of construction waste, and increasing charges of demolition waste treatment fields (Huang et al. 2018). As a result, contractors will rather illegally bury the waste in spite of taking the risk of being punished. In view of the above consideration, many scholars have discussed the related issues of the construction waste disposal costs. For example, Hao et al. (2008) considered that construction waste disposal costs are low, as well as landfill charges, so construction waste producers are more willing to transport the waste to landfill. Yuan and Hao (2008) studied that the current fee standard for waste landfill in Shenzhen is about 5.88 CNY ($ 0.86)/t, which is much lower than Hong Kong's standard of 125 Hong Kong dollars ($ 16.13)/t. Construction waste producers are more willing to resort to recycling and resourcing, if the fee is higher. According to Begum et al. (2006, 2007), the maximum amount that a contractor is willing to pay for construction waste disposal is about 69.88 CNY/t. Larger contractors are more willing to pay for waste disposal than their smaller counterparts. Meanwhile, the amount those larger ones are willing to pay is relatively higher. The survey by Poon et al. (2001) showed that construction workers are reluctant to implement source-classified activities that exploit recycling, even though they are paid high fees because they think it is time- and labor-consuming. Excessive disposal fees sometimes lead to the preference of illegal dumping. Using the full-cost accounting method, Hu et al. (2011) carried out cost accountings of four disposal routes of construction waste in Chongqing: illegal dumping, controlled dumping, centralized recycling, and on-site recycling. The results showed that the cost of on-site recycling is the lowest, about 40 CNY/t. Liu and Wang (2013a, b) found that the cost of 1-ton construction waste's disposal in the Pearl River Delta is about 87.91 CNY; the cost of recycling 1-ton construction waste is about 76.33 CNY, and the cost of reusing 1-ton construction waste is about 27.29 CNY. Under the same condition, the cost of construction waste reusing is the lowest. The average maximum WTP (willingness to pay) is around HK$232/t for landfill disposal of C&D waste, HK$186/t for off-site sorting facility disposal, and HK$120/t for public fill reception facility disposal in Hong Kong (Lu et al. 2015). It is can be seen from the above literatures that costs of all these construction waste disposal methods are increasingly growing. Especially in large cities of developing countries, there are few demolition waste treatment fields in urban areas. Most of the disposal fields are built on the outskirts of cities, resulting in increasing transportation costs and disposal costs. More and more developing countries have realized this situation (Ye et al. 2012; Tam et al. 2014). In order to promote the recycling of construction waste more effectively, they make cost compensation (including tax breaks) to waste contractors or recycling companies (Tam 2007; Tam and Tam 2008). As the above, this paper calculates the construction waste disposal cost of different treatment methods by using the full-cost accounting method. Then, a model of construction waste disposal cost compensation is constructed, which can simply calculate the amount of compensation that the government shall make to the contractor's disposal cost. Finally, the research puts forward the relevant suggestions and countermeasures. The conclusions of the paper can provide decision-making basis for developing country governments to make the construction waste cost compensation (Fig. 1).

Research methodology

First of all, this paper uses the full-cost accounting method to calculate the cost of four typical types of construction waste disposal: illegal dumping, controlled dumping, centralized recycling, and on-site recycling. The full-cost accounting of construction waste treatment means accounting all the costs generated in the disposal of construction waste, including both direct and indirect costs. Many scholars have used this method to calculate waste disposal costs, as described by US EPA (1996, 1997), Antheaume (2004), Herbohn (2005), Karagiannidis et al. (2008), Lim (2011), Hu et al. (2011), Liu and Wang (2013a, b), Debnath and Bose (2014), D'Onza et al. (2016), and Hu et al. (2016a, b).

Then, appropriate and legitimate treatment methods of construction waste disposal are adopted to make cost compensation, and a cost compensation model of construction waste disposal is developed. Based on this model, after selecting the compensation object, the cost compensation of construction waste disposal is made.

Finally, the research takes a case for testing. According to the first and the second step, construction waste disposal cost compensation in this case is analyzed. This paper has investigated a new construction project—the main structure of laboratory building. The C&D waste data are collected within 1 year and the construction site has been surveyed 38 times. The related data of on-site C&D waste were recorded once a week. The records and collection include the category, quantity, and processing methods of C&D waste. In accordance with the statistical data on the volume of construction waste recovered during the year, this paper carried out cost estimates.

Identification of the full-cost factors of C&D waste management

Identification of the cost factors The reduction and resource of the C&D waste site are the most encouraging development orientation. Four typical routes that represent the present situation and the future development orientation of C&D waste disposal in China (Hu and He,2011; Liu 2013; Hu and Zhou 2018) are shown in Fig. 2.

(1) Route 1: illegal dumping. This route is an illegal disposal route, which represents the current situation of Chinese C&D waste disposal, i.e., most of the C&D waste is being illegally dumped (Wang et al. 2010; Zhu and Li 2011; Liu 2013). At present, most of China's city C&D waste disposal fields are planned unreasonably. The haul distance is long, which largely increases transportation costs and time. In order to reduce the costs, the contractors take the risk of breaking the law by the nearest dumping, such as nearby bottomland and river dumping. In this way, the contractors need not to pay waste dumping or disposal fees if their illegal activities are not found by the relevant governmental departments, so their direct cost will only contain the transportation cost of transporting the C&D waste to the illegal CDW disposal site. As a consequence, the government has to deal with the illegal dumping C&D waste and bear the indirect cost of dealing with the environmental and social influences caused by illegal dumping. The illegal dumping cost can be expressed in Eq. (1)

$$C_1 = C_{11} + C_{12} = L_f \times T + (W + L_Z \times T + Z_c) \quad (1)$$

where C_1 is the total costs of illegal dumping, C_{11} is the direct cost of illegal dumping, C_{12} is the indirect cost of illegal dumping, L_f is the haul distance of illegal dumping, T is the transportation cost per unit, W is the excavation cost, L_Z is the haul distance to centralized recycling, and Z_c is the cost of new construction and operation of the centralized recycling disposal site.

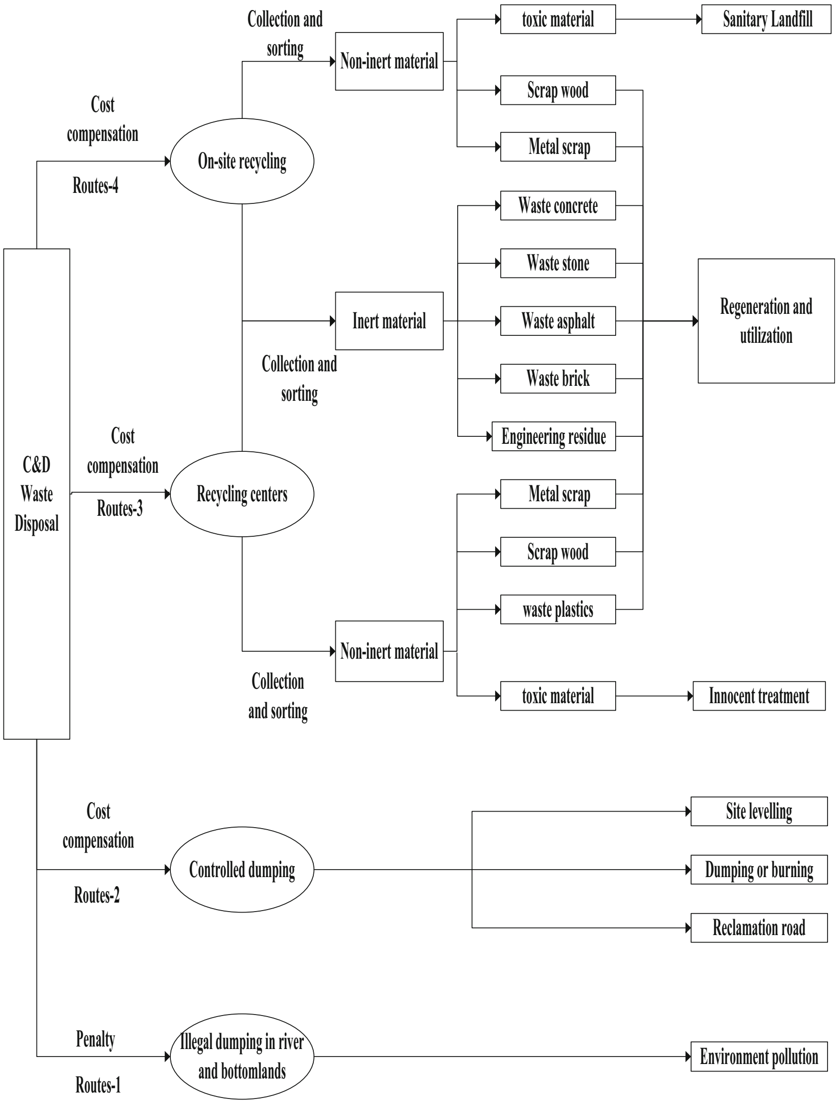
(2) Route 2: controlled dumping. This route is a legal one and also represents the current situation of China's C&D waste disposal (Hao et al. 2007; Wang et al. 2012; Yuan and Wang 2014). If there are some legal CDW disposal sites near the construction site, the contractors may transport the C&D waste into a CDW disposal site and pay the admission fee. Therefore, the direct cost of the route includes the transportation cost of transporting the C&D waste into the legal CDW disposal site and the admission fee. But the survey shows that the method of the controlled dumping is not perfect (Liu et al. 2017). After the C&D waste is taken into the CDW disposal site and simply burnt without other treatment, it will be directly buried into the CDW disposal site without seepage controlling, which will have environmental effects on the soil, air, and water of the surrounding region (Parthan et al. 2012a, b; Aleluia and Ferrão 2017). One of the approaches to avoid such effects is to properly dispose the C&D waste in the recycling center instead of the controlled dumping disposal site. The proper disposal cost of the C&D waste should include the actual cost of centralized recycling (landfill) of the C&D waste and the indirect cost of controlled dumping which exceeds the admission fee of the CDW disposal sites. The controlled dumping cost can be expressed in Eq. (2)

$$\begin{aligned} C_2 &= C_{21} + C_{22} = (L_x \times T + G) + (Z_c - G) \\ &= L_x \times T + Z_c \quad (2) \end{aligned}$$

where C_2 is the total costs of controlled dumping, C_{21} is the direct cost of controlled dumping, C_{22} is the indirect cost of controlled dumping, L_x is the haul distance to the legal CDW disposal site, and G is the admission fee of the CDW disposal site.

(3) Route 3: centralized recycling. This is the planned and proper route of the C&D waste disposal. The

Fig. 2 Typical Chinese C&D waste disposal routes



contractors transport the C&D waste into the centralized recycling disposal site (recycling plant) and pay the admission fee. Therefore, their direct cost contains the transport cost of transporting the C&D waste into the centralized recycling disposal site and the admission fee there. However, the survey on the reduction and resorting of Guangzhou city C&D waste shows that the planned construction cost of a centralized recycling disposal site is far higher than the proposed admission fee when considering the unit generated capacity of C&D waste. The insufficient part, if it is not supplemented by selling the resource products from the C&D waste, can only rely on governmental subsidies, resulting in social cost. The survey on some running centralized recycling projects shows that the current resource product market has not yet formed and their profits from selling are very limited (Liu et al. 2017). Therefore, the indirect cost for the centralized recycling disposal site is the centralized recycling cost minus the admission fee of centralized recycling disposal site. The centralized recycling cost can be expressed in Eq. (3)

$$\begin{aligned} C_3 &= C_{31} + C_{32} = (L_z \times T + Z) + (Z_c - Z) \\ &= L_z \times T + Z_c \end{aligned} \quad (3)$$

where C_3 is the total costs of centralized recycling, C_{31} is the direct cost of centralized recycling, C_{32} is the indirect cost of centralized recycling, L_z is the haul distance to the centralized recycling disposal site, and Z is the admission fee of the centralized recycling disposal site.

(4) Route 4: on-site recycling. This is a hypothetical C&D waste disposal route. From the perspective of the C&D waste management practice of Japan and western developed nations, the higher the level of the C&D waste management of the country is, the more

widely the on-site recycling equipment is applied and the higher the degree of its reduction and recycling (Wimalasena et al. 2010;Wimalasena 2011; Jacobsen et al. 2013; Chifari et al. 2017). Supposing route 4 is applied in the case of strict legal supervision and the widespread of on-site recycling technology, the contractors will definitely make every effort to carry out the on-site recycling disposal in order to reduce transport cost and the C&D disposal fees. For example, jaw crushers and other machines can be applied to crush the C&D waste such as concrete, bricks, and stones into coarse aggregate or fine aggregate for paving roads, backfilling, making bricks, on-site field leveling, or for sale. The on-site resource recovery rate is about 80%, and the remaining parts that cannot be recycled are sent to the recycling centers to be disposed together. Therefore, the direct disposal costs are the on-site recycling cost of the C&D waste that can be resourced plus the transport cost of transporting the remaining C&D waste to the recycling center and the admission fee of the recycling center. Because the C&D waste that cannot be resourced still needs to be disposed in the recycling center, when the resource market is not mature, the admission fee is not sufficient to pay the actual cost of disposal, which brings extra costs that can be calculated by the rate of non-resource recovery multiplied by the centralized recycling, then minus the admission fee of the recycling center. The on-site recycling cost can be expressed in Eq. (4)

$$\begin{aligned} C_4 &= C_{41} + C_{42} \\ &= [r \times C_{\mathrm{r}} + (1{-}r) \times L_z \times T + (1{-}r) \times Z] + (1{-}r) \\ &\quad \times (Z_{\mathrm{c}}{-}Z) \end{aligned} \tag{4}$$

where C_4 is the total costs of on-site recycling, C_{41} is the direct cost of on-site recycling, C_{42} is the indirect cost of on-site recycling, C_{r} is the on-site recycling cost, and r is the on-site resource recovery rate.

Cost calculating All the cost accounting is based on the unit disposal cost of 1-ton C&D waste. The cost accounting supposes all the C&D wastes that have been disposed properly, namely, they are carried out by resource utilization or safe landfill as planned. The quantization and basis of the key parameters are shown in Table 1.

Table 1 The quantization and basis of the key parameters

	Parameters	Quantitative basis and explanation
Haul distance (km)	Haul distance of illegal dumping (L_f)	According to market survey and expert consultation, we take L_f as 5 km.
	Haul distance to the legal dumping disposal site (L_x)	According to market survey and Guangzhou Building Bulk Material Management Ordinance, the receiving radius of the disposal site is 20 km and we take L_x as 20 km.
	Haul distance to the recycling center (L_z)	According to the market survey and expert consultation, the receiving radius of the recycling center is 25 km, we take$L_z$as 25 km.
Unit transport cost (CNY t^{-1} km^{-1})	Transport cost per unit (T)	According to Guangdong province 2010 Construction Quota (OGPCCM 2010), transporting 1000 m^3 of earthwork per km by the dump truck costs 1.70 CNY and soil density is 1.5 t m^{-3}, so we get that transport cost T is 1.13 CNY t^{-1} km^{-1}.
Admission fee (CNY/t)	Admission fee of the CDW disposal site (G)	According to Guangzhou Sanitation Paid Service Charging Regulations, the current admission fee of the CDW disposal sites is 15 CNY/t.
	Admission fees of the recycling center (Z)	According to Guangzhou Building Bulk Material Management Ordinance and expert consultation, the planned admission fee of the recycling center is 30 CNY/t.
Disposal costs (CNY/t)	Excavation cost (W)	According to Guangdong province 2010 Construction Quota (OGPCCM 2010), the excavation cost based on earthwork (including machinery costs, labor costs, management fees, and profits) is 2.67 CNY m^{-3}, conversed based on the soil density 1.5 t m^{-3},we get that the excavation cost W is 1.78 CNY/t.
	Cost of new construction and operation of the centralized recycling disposal site (Z_c)	According to the market survey and expert consultation, considering the costs of new construction and operation of recycling centers (including land-use fee, construction costs, equipment acquisition costs, labor costs, disposal costs, and so on), we get that the disposal cost Z_c is 100 CNY/t.
	On-site recycling cost (C_r)	No actual examples of on-site recycling could be found in Guangzhou, based on literature (Zhao et al. 2010, 2011; Liu and Wang 2013a, b); we count on-site recycling costs (including on-site machinery costs and labor costs) as 21.3 CNY/t.

Substitute the quantitative data of the parameters collected in Table 1 into the formulas (1)–(4); thus, we get the direct and indirect costs of the four typical routes of the C&D wastes disposal, as shown in Fig. 3.

As can be seen from Fig. 3, the total cost of illegally dumping construction waste (including direct cost and indirect cost) is up to 135.68 CNY/t, and the lowest total cost of on-site recycling is 34.69 CNY/t. Therefore, the on-site resource treatment of the new and demolition construction waste was encouraged at this stage. The total cost is representative in South China, however, it is not static, but dynamic. In the future, the cost of the four ways is likely to increase.

A cost compensation model of construction waste management

We have analyzed the costs of the construction waste management and offered four typical cost formulas of the construction waste management, including illegal dumping, controlled dumping, centralized recycling, and on-site recycling. Considering that illegal dumping will cause environmental pollution as well as damage to the society such as economic losses, it is not impossible for the government to make compensation but to impose punishment.

Suppose the government's standard cost to compensate the contractor (or construction waste processors) for the disposal of construction waste is W. Based on the actual situation of the contractor's construction waste management cost, the upper limit of the compensation standard is the government budget constraint:

$$W \times Q \le C \times Q - Y \times Q + F \qquad (5)$$

Among them, W means the compensation standard, subject to payment constraints; F means the government's disposable financial resources in construction waste management, Y means the maximum willingness of the contractor to pay for the waste disposal, Q is the estimated output of construction waste, and C is the unit disposal cost.

W is constrained by payment, and the government's disposable financial resources in construction waste management before the taxation are F and Y is the maximum willingness of the contractors to pay for the waste disposal, then the government's budget constraint is:

$W \times Q \le [C \times Q - Y \times Q, C \times Q - Y \times Q + F]$, that is, cost compensation for construction waste management is constrained by government financial resources and the difference between the cost of construction waste management and the contractor's maximum willingness to pay for the waste disposal.

Faced with a government with weak financial ability, assume that $F = 0$ and the government can only make compensation through the difference between the cost of construction waste management and the contractor's maximum willingness to pay for the waste disposal, that is: $W \times Q \le C \times Q - Y \times Q$; when a government owns strong financial ability, $F > 0$, the government can make compensation by exploiting certain amount of finance through the difference between the cost of construction waste management and the contractor's maximum willingness to pay for the waste, that is $W \times Q \le C \times Q - Y \times Q + F$. Based on both cases, the constraint is simplified as: $W \times Q \le C \times Q - Y \times Q + F$.

Taking Guangzhou as an example, suppose that $F = 0$ is the government's disposable financial resources in construction waste management, then the government can only compensate through the difference between the construction waste management cost and the contractor's maximum willingness to pay. That is, $W \times Q \le C \times Q - Y \times Q$, then the compensation standard is: $W \le C - Y$. According to our estimation results (Fig. 3), if 1 ton of construction waste is disposed by landfill in Guangzhou, the cost from on-site collection management to landfill disposal is about 122.60 CNY and the compensation standard is $W \le 122.60 - 67.54 = 55.06$CNY/t (of which the contractor's maximum willingness to pay is 67.54 CNY (Liu and Wang 2013a, b); if 1 ton of construction waste is disposed by centralized recycling, the cost from collecting and managing on the site to the disposal field is about

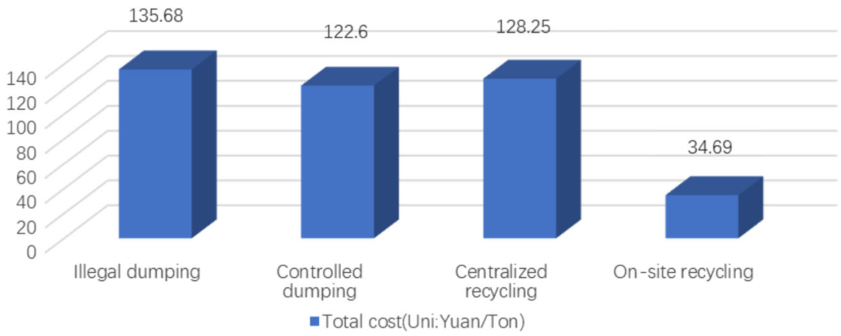


Fig. 3 Total cost of each C&D waste disposal route (unit: CNY/t, USD1 = CNY6.6 @ exchange rate of July 2018)

128.25 CNY, $W \le 128.25 - 67.54 = 60.71$/t. If 1 ton of construction waste is recycled on the site, the cost from collecting and managing on the site to the recycle processing in the plant is about 34.69 CNY, $W = -32.85$. $W \le 0$ means that through this kind of method, the contractor (or construction waste processor) can make profits on its own and the government does not need to provide subsidies.

Case study

Laboratory building II, the new construction project, is located in Wushan Campus of South China University of Technology (SCUT), Tianhe District, Guangzhou, covering a building area of 5959.5 m^2. It has a reinforced concrete frame structure and the total cost of the project is 12.4 million CNY. Most of the on-site C&D wastes are concrete formwork, concrete reinforcement, iron pieces, cement mortar, the packing, etc., as shown in Fig. 4. A preliminary classification scheme is made for the C&D wastes generated in the new project, which plans to collect the concrete formworks, battens, concrete reinforcements, and iron pieces regularly, and some locations are designated to stack the wastes. When the concrete formworks and battens reach a certain amount, they will be sent to the corresponding waste wood material receiving station by dump trucks. The longer on-site concrete reinforcements are picked out to be welded at the joints to reinforce the nodes or to be processed into stirrups to support reinforcements during concrete pouring. All the on-site scattered concrete, cement mortars, bricks, dregs, and the packaging are cleaned up after the main structure is completed. Some of the mixture of dreg, scattered concrete, cement mortar, and brick is used to backfill near the construction site, and the remaining is firstly collected in the center of the site and then delivered to other places (for Centralized recycling). Based on investigation and tracking the generation of the related C&D waste in the process of constructing the new project, the generation, disposal methods, and the costs of the main C&D waste are listed in Tables 2 and 3.

Table 2 The amount, rate and per unit yield the main C&D wastes (Zhou 2011; Liu 2013)

Concrete formwork & batten	236.564	–	–
Masonry & cement mortar mixture	32.465	3.32%	9.18
Site hardened concrete	44.208	1.21%	17.76
Concrete reinforcement	0.8044	1.94%	1.05
Steel structure piece	0.18	1.09%	–

Note: The amount of each waste is accumulated on the site and calculated by volume (unit: m^3), and the rate of waste material is the ratio between the amounts of each of the waste materials and the total amount of the used materials in the bill of quantities of the bidding documents. The cement mortar is estimated to account for about 40% of the mixture of masonry and cement mortar

In Table 2, the concrete formworks and battens are the largest in size, amounting to 236.564 m^3, followed by the cavity blocks and cement mortar mixture, up to 32.465 m^3. It is showed that the largest amount of waste is generated in the wood formwork engineering works and the part/section of engineering works, which needs to be given greater attention. As the wood formwork is a working material and cannot be turned into the construction entity, the rate of waste material cannot reflect the actual consumption of the wood formwork,

①Concrete formwork ②Concrete reinforcement & waste iron pieces ③ Scrap iron generated in steel reinforcement processing

④Brick &cement mortar ⑤Scattered concrete &mixture ⑥Waste PVC piles

Fig. 4 Main on-site C&D wastes (Zhou 2011; Liu 2013). ① Concrete formwork, ② concrete reinforcement & waste iron pieces, ③ scrap iron generated in steel reinforcement processing, ④ brick & cement mortar, ⑤ scattered concrete & mixture, ⑥ waste PVC piles

Table 3 The generation and disposal costs of the main C&D wastes during the new building project

Category	Amount (m^3, piece)	Disposal methods	Disposal costs	Cost compensation
Concrete formwork, batten, & sawdust	Stack volume is 236.564 m^3	Route 2, controlled dumping or burning. When the wastes reach a certain amount, they are sent to the special waste wood material receiving station within 20 km in Guangzhou by dump trucks, and chiefly used for fuel.	According to Guangdong province 2010 Construction Quota (OGPCCM 2010), calculate based on the dump truck transporting 1000 m^3 of earthwork per km, the required cost is 1.70 CNY, converse based on the soil density1.5$_t$ m^{-3}, we get that the transport cost T is 1.13 CNY·t^{-1} km^{-1}, as the concrete formworks have some economic value, they can be used to offset the centralized recycling costs of them. According to Formula (2), the disposal costs are calculated as $C_2 = L_x \times T + Z_c = 20 \times 1.13 + 0 = 22.60$ (CNY).	According to the research in this paper, the compensation standard for contractors and professional processors is 55.06 CNY/t; 236.57 $m^3 \times 0.54 \times 10^3$ kg m^{-3} (wood apparent density) × 55.06 CNY t^{-1} = 9033.79 (CNY)
Brick & cement mortar	32.465 m^3	Route 3, centralized recycling. By manual cleaning, the scattered cement mortar and bricks are shoveled up, collected by carts, and delivered to the recycling center 25 km away from the construction site by dump trucks.	Considering the costs of new construction and operation of recycling centers (including land-use fee, construction costs, equipment acquisition costs, labor costs, operational costs, and so on), based on the market research and interviews, the contractor is willing to accept the reasonable centralized recycling cost $Z_c = 100$ CNY/t. suppose 1 m^3 of brick weighs about 103 kg, then $C_3 = L_z \times T + Z_c = 25 \times 1.13 \times 19.479 + 100 \times 19.479 = 2498.18$ (CNY)	According to the research in this paper, the compensation standard for contractors and professional processors is 60.71 CNY/t; 32.47 $m^3 \times 1.7 \times 103$ kg m^{-3} (bulk apparent density) × 60.71 CNY/t = 3351.13 CNY
Scattered waste concrete	20.208 m^3	Route 3, centralized recycling. By manual cleaning, the scattered cement mortar and bricks are shoveled up, collected with carts, and delivered to the recycling center 25 km away from the construction site by dump trucks.	C20~C35 concrete is generally as 2.45 t/m^3, Therefore,$C_3 = L_z \times T + Z_c = 25 \times 1.13 \times 49.51 + 100 \times 49.51 = 6349.66$ (CNY).	According to the research in this paper, the compensation standard for contractors and professional processors is 60.71 CNY/t; 20.21 m^3 × 2.2 × 103 kg m^{-3} (C20~C35 concrete apparent density) × 60.71 CNY/t = 2699.29 (CNY)
Concrete reinforcement & iron pieces	Stack volume is 0.8476 m^3	Route 4, on-site recycling. Send the waste to relevant waste receiving stations.	Based on literature (Zhao et al. 2010; Liu and Wang 2013a, b), the on-site recycling costs (including on-site machinery costs and labor costs), C_r is 21.3 CNY/t. Supposing the on-site resource recovery rate r is about 80%, and 1 m^3 of iron pieces weights 7800 kg, then $C_4 = C_{41} + C_{42} = [r \times C_r + (1-r) \times L_z \times T + (1-r) \times Z] + (1-r) \times (Z_c - Z) = 80\% \times 21.3 + 20\% \times 1.13 \times 20 \times 6.61 + 20\% \times 100 \times 6.61 = 179.12$ (CNY)	On-site recycling of steel and iron pieces to some degree brings developers and professional processors some economic income. This does not need costs.
Packing bags	430 nr	Route 3, centralized recycling. When the packing bags reach a certain amount, they are sent to the recycling center 25 km away.	Because of light weight, we can transport the packaging bags with the bricks and concrete to the recycling center, and only calculate the admission fees of the recycling center 25 CNY/t, then $C_3 = 25.00$(CNY).	Due to the light weight, packing bags can be transported together with broken blocks and concrete to the recycling plant, without paying extra admission fees. Cost compensation is not necessary.
Total			9074.56 CNY	15,084.21 CNY

therefore, the rate of waste material has not been calculated in this paper.

In the case study, the full estimated cost of construction waste disposal is 9074.56 CNY and the total cost compensation is 15,084.21 CNY. The amount of compensation is greater than the disposal cost and the contractors make a profit, thus stimulating them to recycle and reuse construction waste.

Conclusions and recommendations

According to the survey and calculation by taking Guangzhou as an example, the results of the full-cost accounting of the different C&D waste disposal routes show the following: the direct cost of illegal dumping is the lowest, followed by on-site recycling, controlled dumping, and centralized recycling; as far as the total costs are concerned, the cost of the on-site recycling is the lowest, followed by controlled dumping, and centralized recycling. Meanwhile, it can be seen that the total costs and indirect costs of illegal dumping are the highest. The calculation method used in this paper is roughly in accordance with the method used by Hu et al. (2011) who focus on the C&D waste disposal costs in Chongqing. The calculations of the new engineering cases show that brick, cement mortar, and waste concrete take the larger proportion of the total C&D waste, and the calculated disposal cost is relatively high. In addition, the amount of compensation is greater than the disposal cost and the contractors make a profit, thus stimulating them to recycle and reuse construction waste.

According to the above analysis, the following recommendations are given on the C&D waste management in China.

(a) Developing centralized recycling and marketing the C&D waste disposal. The cost analysis shows that the centralized recycling costs and the controlled dumping costs in CDW disposal sites are roughly equal. Controlled dumping has a great impact on the surrounding environment, so its indirect cost is far higher than that of centralized recycling, while the centralized recycling route disposes the C&D waste more properly considering the resource utilization and environmental protection, which is consistent with the overall social benefits. However, the construction of the recycling centers is costly. Besides raising fees, we must develop resource market of the C&D waste and keep the operation of recycling centers with the help of the sale profits of recycled products. In the long run, developing centralized recycling and the C&D waste disposal market is the general trend to upgrade the C&D waste management.

(b) Promoting the reduction and adding the disposal costs of the C&D waste into bidding documents. The case calculation shows that, the total disposal cost of the C&D waste generated by the new construction project of subtropical science experiment building II, South China University of Technology is 9074.56 CNY, accounting for a small proportion of the total project cost. But the amount of the C&D waste is relevant to the size of the construction project. The larger the size is, the more the C&D waste. The costs of waste disposal and management cannot be ignored. Therefore, we suggest adding the disposal costs of the C&D waste to the bidding documents; namely, the developers write the C&D waste management measures into the bills of the project, and the contractors bid and offer the price. This helps developers make the reduction plan of the C&D waste so that the generation of the C&D waste will be cut down.

(c) Formulating corresponding support mechanisms for the disposal management of construction waste. The current charging system shall be improved further. The government should formulate corresponding support mechanisms for the disposal management of construction waste, provide preferential treatment for construction enterprises that recycle and reuse construction waste, and encourage enterprises to use the information exchange platform to achieve earthwork balance between construction projects so as to reduce the government's pressure to dispose construction waste and achieve self-balanced digestion of construction waste in the market. At the same time, the government should appropriately support the demolition waste disposal site according to the current situation of construction waste recycling in the construction project in order to ensure the normal operation of the disposal fields. Guangzhou municipal government's subsidy policies are worth learning. Subsidies are divided into the construction waste disposal subsidies and production land subsidies (CMC, GCHURCC and GCBF 2015): (1) Subsidies for construction waste disposal shall be subsidized according to the actual utilization of construction waste in the recycled building materials with the subsidy standard of 2 CNY/t; (2) Subsidies for production land applying to the plants of the enterprises that meet the subsidy demands (excluding free land provided by the government and land for mobile production projects) will be subsidized according to the production scale of enterprises, with the subsidy standard of 3 CNY per square meter per month.

(d) Establishing a "deposit" system for the construction waste disposal. Construction waste disposal deposit system refers that before the construction commencement, the owners pay the construction waste disposal deposit to the construction administrative department and the construction permit will be issued. After the completion of the project and before the issuance of the certificate of competency, according to the corresponding auditing standard of the completion of construction waste disposal, the issue of the return of the construction waste

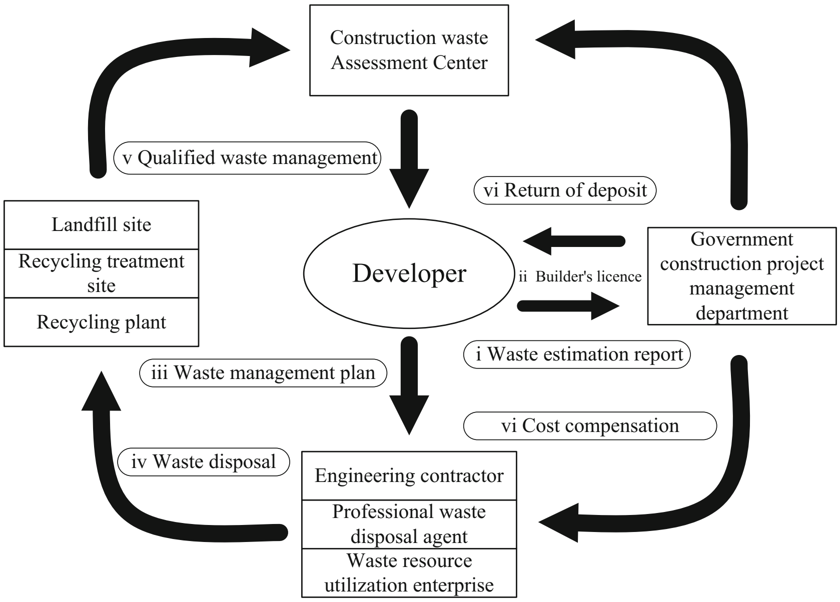


Fig. 5 Cost compensation management model for construction waste disposal (Liu 2013)

deposit paid initially or not will be decided, so as to ensure that the construction waste producers carry out construction waste management as required (Solís-Guzmán et al. 2009; Liu 2013). The implementation of "deposit" system has following steps:

(1) Firstly, the owner estimates the construction waste of the newly demolished project and then submits the waste assessment report to the governmental construction management department that will inform owners to submit a deposit. The amount of the payment depends on the type of the project involved and the waste assessment report.
(2) The owner submits a pre-deposit, and the government issues a construction permit for the construction or demolition of the project.
(3) Based on the construction waste assessment report, the owner will make a construction waste management plan in person, or by entrusting a contractor, a specialized processor, or a resource utilization enterprise, and the plan will be implemented by a contractor, a specialized processor, and a resource utilization enterprise.
(4) Contractors, specialized processors, and resource recovery enterprises treat the construction waste according to the construction waste management plan, such as transporting construction waste to construction waste disposal sites or on-site recycling.
(5) After the construction and demolition of the project are completed, the Waste Assessment Center will evaluate the waste treatment of the project and decide whether or not to issue the waste disposal certificate to the owner and contractor depending on the assessment results. Construction Waste Assessment Center is an organization belonging to the government construction project management department.
(6) The government construction project management department returns the pre-deposit to owners. In the meantime, the government shall make cost compensation or reduce the tax to the contractors, professional processors, and resource utilization enterprises. If the compensation is taken, the amount of compensation shall be multiplied by the appropriate proportion based on the construction waste estimate report and the disposal cost (Fig. 5).

"Deposit" system in construction waste disposal to some degree can prevent the illegal dumping of construction waste and encourage owners to recycle construction waste.

This paper has further improved the C&D waste management theory by providing a cost compensation approach. However, the paper also has some disadvantages. For instance, the assumptions imposed on the cost calculation are too strong. Although such a mechanism may promote recycling activities, it will not provide an incentive for waste reduction.

Acknowledgements The author would like to acknowledge the valuable suggestions of the editor and three anonymous reviewers. The authors would also like to thank Jiawen Zhou for his assistance during the data collection process.

Funding information The research was supported by the National Natural Science Foundation of China (71501052).

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