WESTERN SYDNEY UNIVERSITY

PREVAILING CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT PRACTICES: A CHINA STUDY

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This thesis is submitted for the degree of Master of Philosophy

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Declaration

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The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

Author's signature

Publications

A list of publications spawning from this research is presented as followed.

1. Submitted journal paper(s):
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Abstract

The construction industry is regarded as one of the largest generators of solid waste in the world. These large amounts of construction and demolition waste generated by continuous construction activities have harmful effects on the environment. China is the largest producer of construction and demolition waste, with an annual generation of 2.4 billion tonnes. Moreover, with the continued development of their construction industry, the total volume of construction and demolition waste generated in China is forecasted to reach 3.96 billion tonnes by 2020. However, without proper management, a significant amount of construction and demolition waste has inevitably occupied land resources. In the current age of enhanced environmental awareness, transformation to sustainable management in the construction sector is needed. Despite the increasing awareness of recycling in industry, the average recovery rate of construction and demolition waste in China is only approximately 5%. Few developed countries have a sustainable society with an orderly, reasonable, and effective construction and demolition waste management system. However, as most of the waste in China is directly dumped or landfilled, it lags far behind these high-performance countries.

The objectives of this study were to obtain information about the current status of construction and demolition waste management in China from comparative analyses and case studies, and to identify the obstacles to the promotion of recycling. Recovery rates of construction and demolition waste were collected from 35 countries, and the existing policies, standards, and official documents at a national level in China and seven selected countries with high performance (including Japan, South Korea, Germany, Austria, the Netherlands, Italy, and the United Kingdom) were reviewed. The comparative analysis revealed the reasons for China's unsatisfactory performance. These reasons included the following: (1) inadequate guidance on recycling, (2) an underdeveloped recycling market, (3) incomplete knowledge of stakeholders' responsibilities, (4) ineffective cooperation among governing bodies, (5) a lack of penalty for other stakeholders, and (6) an ineffective supervision system.

Few studies have been performed to evaluate construction and demolition waste management performance of different Chinese cities, although case studies have been performed on specific cities. In the present study, site visits to 10 different Chinese cities were conducted: Shanghai (Direct-administered municipalities), Hangzhou (Zhejiang Province), Suzhou (Jiangsu Province), Chongqing

(Direct-administered municipalities), Chengdu (Sichuan Province), Xi'an (Shaanxi Province), Changsha (Hunan Province), Shenzhen (Guangdong Province), Nanjing (Jiangsu Province), and Zhoukou (Henan Province). Construction and demolition waste management performance, as well as the obstacles for waste management, varies among these Chinese cities. These obstacles included the following: (1) a lack of sources of construction and demolition waste, (2) a lack of guidance on the application of building materials recycled from waste, (3) a lack of land use for fixed industries, (4) a lack of precise estimations of the waste amount and distribution, (5) a lack of guidance on the classification of construction and demolition waste, (6) unrestrictive landfilling, (7) inconsistent cooperation among different official governments, (8) inadequate research on the use of recycled products and waste separation, and (9) an incomplete waste traceability system.

If these obstacles are more fully understood, recommendations can be provided to enhance construction and demolition waste management in China. Policymakers in China can consider the following suggestions: (1) ensuring the stability of construction and demolition waste sources; (2) precise estimation of waste generation and distribution; (3) an effective waste tracing system; (4) improvements in related technology; (5) expanding financial incentives; (6) prioritising the recycling of waste and promoting waste reduction; (7) completion of waste classification and relevant standards; (8) strict landfill bans; (9) consistent cooperation among governmental departments; and (10) expansion of the recycling market.

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Chapter 1: Introduction

1.1 Background

A large amount of construction and demolition waste is generated owing to the rapid development of the construction industry (Nagapan et al., 2012). Of all the countries in the world, China produces the largest amount of construction and demolition waste, with an annual generation of 2.4 billion tonnes in 2015 (Duan et al., 2019). The total volume of waste generated in China is forecasted to be 3.96 billion tonnes in 2020 (China Association of Circular Economy, 2018). The construction industry in Australia generated a total of 19 million tonnes of construction and demolition waste in 2008 (Hyder Consulting, 2011). In 2016, the waste generated by the European Union (EU) amounted to 912 million tonnes, constituting 34.6% of the total waste from economic activities and households (Eurostat, 2017). In Germany, construction and demolition waste is considered one of the significant waste streams, with 222.8 million tonnes generated in 2016 (Federal Statistical Office (Germany), 2019). Generation of 246.7 million tonnes of the waste was reported in France, 180.1 million tonnes of which was soil (Deloitte, 2015g). The amount of construction and demolition waste produced annually in the United States is estimated to be 66.2 million tonnes (Duan et al., 2019). According to the Korea Waste Association (2018), the total volume of construction and demolition waste generated was approximately 196,262 tonnes per day in 2017, comprising 47.3% of the solid waste generated in South Korea.

The global construction industry continues to grow, because construction activities contribute to economic growth, the creation of wealth, and improvement of people's quality of life (Razak Bin Ibrahim et al., 2010). The generation of a large amount of construction and demolition waste can be associated with many factors, including large-scale urbanisation (Zehai et al., 2018), rapid population growth, regional planning, and local polices (Duan et al., 2015). Without proper management, massive construction and demolition waste has inevitably occupied land resources and destroyed natural habitats (Nagapan et al., 2012), as large amounts of waste are dumped or landfilled on useful land (Bravo et al., 2015). Considering the negative effects of the increasing volume of waste on the environment, effective and proper treatment is imperative. It is generally agreed that the principles of "reduce, reuse, and recycle" can contribute to a sustainable future (Huang et al., 2018). The contribution from waste management is positive and distinctive, compared with traditional treatments such as landfilling (Huang et al., 2018). Proper management of construction and demolition waste is expected to promote the efficient use of resources (Balachandra et al., 2010), reduce the utilisation of primary materials, and reduce landfilling (European Commission, 2016).

Orderly, reasonable, and effective waste management can be critical for developing a sustainable society. Some developed countries have established integrated regulations and developed an adequate regulatory system. For example, all the countries within the EU were bound by the Waste Framework Directive, which required them to achieve a minimum recycling rate of 70% before 2020 (Jeffrey, 2011). With the objective of improving resource efficiency, the European Commission established a set of standards for construction and demolition waste management across Europe. Some European countries have established additional policies and regulations owing to various geographical, cultural, and political factors. Seven countries had already fulfilled 70% recycling rate by 2010: Denmark, Estonia, Germany, Ireland, the United Kingdom, Italy, and the Netherlands (BIO Intelligence Service, 2011). Germany has directed efforts toward construction and demolition waste management for decades, and has one of the highest recovery rates in the world at up to 88% (Nakajima and Russell, 2014). In Japan, 96% of the waste generated in 2018 was recycled, which is expected to be maintained in the next few years (Ministry of Land Infrastructure Transport and Tourism (Japan), 2018).

With regard to construction and demolition waste management, China lags far behind these high-performance countries. China currently produces the largest amount of construction and demolition waste in the world. However, the average recovery rate of the waste was only approximately 5% in 2017, as most of the waste was directly dumped or landfilled (Huang et al., 2018). With rapid economic growth, the continuous increase in the amount of construction and demolition waste has accelerated the depletion of land (China Association of Circular Economy, 2018). A set of policies and regulations are being drafted in China to promote construction and demolition waste recycling, to address the environmental concerns of authorities and the public. Additionally, the government provides financial incentives and subsidies to stimulate the recycling business. Despite these efforts, the construction and demolition waste management in China is in a stage of infancy (Huang et al., 2018). Pressure from the large population and the limited living spaces (Jin et al., 2017) force China to learn from other countries with a high recovery rate and adopt sustainable management in the construction sector.

1.2 Problem statement

The idea of recycling is not new in China, but construction and demolition waste has not been utilised efficiently. Currently, approximately 75% of Chinese cities are surrounded by a large volume of construction and demolition waste (Huang et al., 2018). In addition to legislation, accurate estimation of construction and demolition waste generation can directly impact the effectiveness of waste management (Menegaki and Damigos, 2018). However, it is difficult to estimate the volume of construction and demolition waste generated in China because systematic data collection has not been

performed (Akhtar and Sarmah, 2018). Additionally, construction and demolition waste management performance varies among Chinese cities. The recovery rate of construction and demolition waste in most Chinese cities is between 3% and 10% (Huang et al., 2018). The best-performing cities, such as Shanghai and Shenzhen, have achieved recovery rates of >15% (Ghisellini et al., 2018). Furthermore, some municipal governments have set recycling goals and enacted a regional standard and legislation related to construction and demolition waste management, to establish an integrated recycling chain. For instance, Shenzhen is required to fulfil the recycling target of 30% from Guidelines in Green Construction (Shenzhen Housing and Construction Bureau, 2008). Management on Construction and Demolition Waste in Shanghai was enacted in 2017 and began to be enforced on 1 January 2018. This regulation classifies the construction and demolition waste in Shanghai, duties of stakeholders, and tracing systems (Shanghai Municipal People's Government, 2017).

In previous studies, the most critical obstacles to the promotion of construction and demolition waste management in China were investigated. Despite the variety among different regions, the inefficient waste management practices in China can be attributed to the following: inadequate regulations concerning related stakeholders (Yuan, 2013), limited recycling businesses and facilities (Akhtar and Sarmah, 2018), low landfill costs (Huang et al., 2018), uncontrolled dumping (Yuan, 2017), an underdeveloped market for recycled building materials (Zhao et al., 2010, China Association of Circular Economy, 2018), and a lack of an intermediate link between waste generation and the use of recycled materials (Zhao et al., 2010). Studies have been performed to analyse the construction and demolition waste management in developed countries with high recycling rates. These countries include Japan (Sakai et al., 2011, Yolin, 2015, Amemiya, 2018, Nitivattananon and Borongan, 2007), Europe (Menegaki and Damigos, 2018, Gálvez-Martos et al., 2018, Iacoboaea et al., 2019, Sakai et al., 2011, Tam and Lu, 2016), Singapore (Nitivattananon and Borongan, 2007, Chew, 2010, Bai and Sutanto, 2002), and South Korea (Yang et al., 2015, Sakai et al., 2011). Empirical studies on Chinese cities are increasingly being conducted. Jin et al. (2017) analysed the composition of the waste generated in Shanghai and suggested that proper management depends significantly on accurate estimation of the quantity and composition of the waste. Zhao et al. (2010) investigated the current status of construction and demolition waste management in Chongqing and provided recommendations to enhance the economic feasibility of recycling. Zhao et al. (2009) performed a lifecycle assessment to evaluate solid waste management in Tianjin. However, few studies have been performed to evaluate construction and demolition waste management from a global perspective or for different Chinese cities. Existing legislation, policies, standards, and guidelines at a regional level must

be reviewed to obtain an updated and accurate understanding of the status of construction and demolition waste management in China.

1.3 Research objectives

The research objectives of this thesis were as follows:

a. Investigate construction and demolition waste management policies worldwide;
b. Conduct site visits to evaluate the current status of construction and demolition waste management in different cities for thoroughly analysing the current status of construction and demolition waste management in China;
c. Identify the obstacles to the promotion of construction and demolition waste management in China; and
d. Provide recommendations for improving the construction and demolition waste management in China.

1.4 Research methodologies

In order to achieve the research objectives, following methodologies are adopted.

1.4.1 Literature review

A literature review provides a unified definition of construction and demolition waste for this study. Additionally, the recovery rates of construction and demolition waste for 35 countries in 5 continents are presented. A thorough review of the existing policies, standards, and official documents at a national level in China and selected countries (including Japan, South Korea, Germany, the Netherlands, Australia, Italy, and the United Kingdom) is also conducted.

1.4.2 Site visit

The site visit is an important tool used in this study. Researchers conducted site visits to 10 selected Chinese cities to obtain the most current and accurate information related to construction and demolition waste management in China.

1.5 Structure of the thesis

Chapter 1 presents the research background, as well as the research gap, research objectives, and a brief illustration of the research methodology.

Chapter 2 presents a literature review and a comparative analysis. This section defines construction and demolition waste in the context of the present study and presents the recovery rates of construction

and demolition waste for 35 countries. Additionally, the existing policies, standards, and official documents at a national level in China and seven selected countries, including Japan, South Korea, Germany, Austria, the Netherlands, Italy, and the United Kingdom, are reviewed.

Chapter 3 presents the case studies, where 10 recycling plants in 10 different Chinese cities are investigated to examine the current status of construction and demolition waste management in different cities. Based on the results, useful recommendations for policymakers in China are provided.

Chapter 4 presents the main conclusions of the study. Furthermore, recommendations based on the analysis presented in Chapters 2 and 3, the research limitations, intellectual value of this research and future research directions are presented.

Chapter 2: Comparative analysis of construction and demolition waste management policies worldwide

2.1 Introduction

Because of the uneven development of construction and demolition waste management around the world, there is possibility for China to learn from other high-performance countries, through comparing the current policies and formulating better policies (Nugroho et al., 2015). A comparative analysis is conducted in this chapter to investigate the current construction and demolition management in China and seven countries and identify the difficulties to the promotion of recycling in China.

This chapter consists of three sections. Section 2.2 defines construction and demolition waste. Currently, the definition of construction and demolition waste varies among regions, representing different waste management philosophies and priorities (Menegaki and Damigos, 2018). This section provides a unified definition for the present study.

Section 2.3 presents information from 35 countries in 5 continents, with a focus on the generation of construction and demolition waste and the recovery rate. Data on the construction and demolition waste generated in the different countries are obtained from governmental websites, including those of Eurostat; the Ministry of Land, Infrastructure, Transport and Tourism (Japan); and the Ministry of Environment (Korea). The literature was consulted when data were unavailable.

Section 2.4 contains a thorough review of existing policies, standards, and official documents at a national level in China and other countries concerning construction and demolition waste management. The current status of waste management in China, Japan, South Korea, Germany, the Netherlands, Australia, Italy, and the United Kingdom is investigated.

In section 2.5, comparative analyses are conducted with a focus on four dimensions: (1) general regulations, (2) incentives, (3) stakeholders' responsibilities, and (4) supervision and penalties. Four lists of factors based on these four dimensions are presented in Table 11-14. These factors are derived from the literature review in section 2.4. Additionally, the four tables are used to compare the construction and demolition waste management in China and the seven selected countries, as whether each factor is mentioned in these countries' waste management is identified in these tables.

2.2 Definition of construction and demolition waste

Construction and demolition waste is defined as waste generated from all types of construction, renovation, and demolition activities (Yuan, 2017). It contains many types of materials, including excavated materials, non-hazardous waste, and hazardous materials (

Table **1**). Herein, construction and demolition waste management includes regulations associated with waste generation, collection, transportation, recycling, and landfilling.

Table 1: Categories of construction and demolition waste (Deloitte, 2016)

Excavated materials	Topsoil, sand, gravel
Non-hazardous waste	Building debris, road rubble, concrete debris, site waste, building demolition waste wood, packing, metals
Hazardous waste	Asbestos and asbestos cement, contaminated oil, waste containing hydrochlorofluorocarbons, waste containing polychlorinated

The scope of this study is limited to non-hazardous and hazardous construction and demolition waste, excluding excavated materials. Although excavated soil accounts for a large portion of construction and demolition waste and has potential for backfilling, it is not included in the calculation of the recovery rate for most countries. Further, it is not included in the definition of construction and demolition waste in Japan (Ministry of Land Infrastructure Transport and Tourism (Japan), 2018). The Ministry of Housing and Urban-Rural Development of the People's Republic of China (1996) specifies that excavated soil is managed by a special environmental agency, and does not belong to the category of construction and demolition waste. Waste soil from excavation and construction activities requires treatment or landfilling, unless the stream is reused on-site (Hyder Consulting, 2011). Waste soil can be used in backfilling, flooring uplift, and landscaping in China. The reprocessing of waste soil into fire bricks is still in a stage of infancy, failing to satisfy the market requirements. This waste stream is not a focus of the present study.

2.3 Recovery rate

The construction and demolition waste recovery rates have large variability (Table 2). Construction and demolition waste is attracting increasing attention in Europe, under the Waste Framework Directive. Recovery rates of >95% were achieved by Japan, South Korea, and Singapore. However, gulf countries in the Middle East have the common issue of illegal dumping, presenting difficulties for both the tracing and recycling of construction and demolition waste (Blaisi, 2019). Additionally, the

estimation of the construction and demolition waste in China has uncertainty because of the unavailability of systematic data collection (Akhtar and Sarmah, 2018).

In section 2.4, countries that generate >10 million tonnes of construction and demolition waste (excluding soil) and have a recovery rate of >85% are investigated. The recovery rate is no longer the only consideration, because countries with a high recovery rate and a small quantity of waste have limited research value, as a high recovery rate can be achieved more easily with a small volume of waste. The status of construction and demolition waste management in Germany, Italy, the Netherlands, Austria, the United Kingdom, Japan, and Korea is examined in this study.

Table 2: Recovery rates of construction and demolition waste

Countries	Total construction and demolition waste (Million tonnes)	Construction and demolition waste exclude soil (Million tonnes)	Recovery rate (%)	References
Europe				
Bulgaria	1.5	0.199	90%*	(Deloitte, 2015b)
Czech Republic	13.4	4.5	92%*	(Deloitte, 2015c)
Denmark	8.06	3.88	92%	(Deloitte, 2015d)
Germany	201.3	82.2	88%	(Deloitte, 2015h)
Estonia	1.9	0.983	92%	(Deloitte, 2015e)
Ireland	3	1.02	97%	(Deloitte, 2015i)
Spain	-	27.7	79%	(Deloitte, 2015j)
France	246.7	66.6	63%*	(Deloitte, 2015g)
Italy	-	39	98%*	(Eurostat, 2019, Deloitte, 2015l)
Netherlands	-	25.71	98%	(Deloitte, 2015m)
Austria	40.3	10	88%*	(Eurostat, 2019, Federal Ministry for Sustainability and Tourism (Austria), 2017)

Countries	Total construction and demolition waste (Million tonnes)	Construction and demolition waste exclude soil (Million tonnes)	Recovery rate (%)	References
Sweden	7.67	3.45	61%*	(Eurostat, 2019, Deloitte, 2015k)
Norway	0.3	-	71%*	(Eurostat, 2017, Eurostat, 2019)
Finland	16	2.05	87%*	(Eurostat, 2019, Deloitte, 2015f)
United Kingdom	120	66.2	91%*	(Eurostat, 2017, Department for Environment Food and Rural Affairs (United Kingdom), 2019)
Asia				
Japan	213.48	72.6	96%	(Ministry of Land Infrastructure Transport and Tourism (Japan), 2012, Ministry of Land Infrastructure Transport and Tourism (Japan), 2018)
China	-	1930	<5%	(China Report, 2019) (Huang et al., 2018)
South Korea	68	66	97.2%**	(Ministry of Environment (South Korea), 2012, Somasundaram et al., 2015)
Thailand	-	-	7%	(Kofoworola and Gheewala, 2009)
Vietnam	-	1.9	0%	(Kien, 2013)
Singapore	-	1.6	99%	(National Environment Agency (Singapore), 2019)
Malaysia	-	-	15%	(Esa et al., 2017)

Countries	Total construction and demolition waste (Million tonnes)	Construction and demolition waste exclude soil (Million tonnes)	Recovery rate (%)	References
India	-	17	<10%	(Duan et al., Esa et al., 2017)
Oceania				
Australia	-	19	55%	(Hyder Consulting, 2011)
New Zealand	-	3.5–4.5	80%	(Inglis, 2007)
Middle East				
Egypt	4	-	-	(Zaki et al., 2013)
Israel	7	4	-	(Israel Ministry of Environmental Protection, 2015)
Jordan	2.6	-	-	(Alhyasat et al., 2014)
Saudi Arabia (Eastern Province)	0.143	-	-	(Blaisi, 2019)
Africa				
Algeria	11	-	-	(Youcef, 2014)
Libya (Projected)	3.6	-	-	(Ali et al., 2016)
Americas				
United States	-	191	70%	(Duan et al., 2019)
Canada	-	4	16%	(Brantwood Consulting, 2016)
Brazil	>70	-	6.14%**	(Tam et al., 2018, Contreras et al., 2016)
Chile	-	5.8	<40% (2009)	(Ossio and Castillo, 2012)

*) Only non-hazardous waste is considered.

**) Including soil.

2.4 Overview of current status of construction and demolition waste management

2.4.1 China

China is experiencing rapid economic development, with up to 9.8% annual growth in its gross domestic product (GDP) (Wang et al., 2010). With a large amount of construction activities, the construction sector in China accounts for nearly 40% of the worldwide consumption of cement and steel (Wang et al., 2010). The repeated construction and short lifespans of buildings in China have been blamed for the large volumes of construction and demolition waste (Wang, 2010). The average lifespan of residential buildings in China is 30 years, which is significantly shorter than that in developed countries (e.g., 74 years in the United States and 102 years in France) (Cai et al., 2015). Most of the construction waste in China is still directly dumped or landfilled.

While some Chinese cities have achieved recovery rates higher than the national average, e.g., 20% for Shanghai and 16% for Shenzhen (Ghisellini et al., 2018), these rates are significantly lower than those of developed countries. Since 2015, the Chinese Government has prioritised environmental protection (China Concrete and Cement-based Products Association, 2018). A set of policies related to environmental protection have been introduced, restricting the mining of natural materials to create markets for recycled building materials. The restriction of mining will cause the price of natural construction materials to increase (China Cement Association, 2018). Construction industries may turn to recycled products to replace natural materials.

In recent years, the Chinese government directed considerable effort toward encouraging waste reduction. The Plan for Comprehensive Utilization of Solid Waste (2011), the Green Building Plan (2015), the Circular Development Plan (2017), and the Experimental Programs of Construction Waste Management in Selected Provinces (2018) aimed to reduce the amount of waste resulting from design processes, extend the scale of recycling, and promote the development of recycling technology. Regarding the promotion of corresponding standards and regulations, developing an adequate regulatory system of waste recycling is one of the main challenges (Ghisellini et al., 2018). Landfilling and dumping are still considered the first choice for contractors needing to dispose of waste, owing to the low landfill fees (Huang et al., 2018). To encourage recycling, the Chinese government provides financial incentives for recyclers. Construction waste recycling projects can obtain financial support from the National Development and Reform Commission, with subsidies ranging from 8% to 12% of the project investment (Huang et al., 2018).

The Technical Specifications for the Application of Recycled Aggregates (2011) indicate different applications of recycled aggregates, together with their performance requirements and inspection, transportation, and storage methods. Since 2010, the Chinese standards GB/T 25177-2010, GB/T 25176-2010, and JGK/T 240-2011 were released successively, filling the long-term technology gap of recycled concrete in China and regulating the production of recycled aggregates (Zhao et al., 2011). GB/T 25177-2010 and GB/T 25176-2010 present classifications for recycled coarse and fine aggregates, respectively. JGK/T 240-2011 specifies the applications of recycled aggregates according to their classification. Several construction and demolition waste management-related documents have been issued by governing bodies. However, the cooperation between departments is inefficient (Huang et al., 2018). The duties of departments overlap and are unclear (Wang et al., 2015). The existing Chinese policies on construction and demolition waste management are presented in Table 3.

Table 3: Existing policies on construction and demolition waste management in China

Ref.	Law enacted	Year	Reference
C-1	National Guideline, Regulations for Construction Waste Management in Cities	1996	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 1996)
C-2	Notice on Promoting the Urban Sewage and Waste Treatment Industrialisation	2002	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2002)
C-3	Clean Production Act	2003	(Standing Committee of the National People's Congress (China), 2003)
C-4	Regulations on Urban Construction Waste Management	2005	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2005)
C-5	Circular Economy Promotion Law of the People’s Republic of China	2008	(Standing Committee of the National People's Congress (China), 2008)
C-6	Financial Subsidy for Recycled and Energy-saving Building Materials	2008	(Ministry of Finance of the People's Republic of China, 2008)
C-7	Value-added Tax on Comprehensive Utilization of Resources and Other Products	2008	(State Taxation Administration (China), 2008)
C-8	Responsibility of the Construction Waste Recycling Department	2010	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2010)
C-9	Recycled Fine Aggregates for Concrete and Mortar	2010	(General Administration of Quality Supervision Inspection and Quarantine of the

Ref.	Law enacted	Year	Reference
			People's Republic of China and Standardization Administration of the People's Republic of China, 2010b)
C-10	Recycled Coarse Aggregates for Concrete	2010	(General Administration of Quality Supervision Inspection and Quarantine of the People's Republic of China and Standardization Administration of the People's Republic of China, 2010a)
C-11	Technical Specifications for the Application of Recycled Aggregates	2011	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2011)
C-12	Guidance on the Comprehensive Utilization of Resources in the 12th Five-year Plan	2011	(Ministry of Education of the People's Republic of China, 2011)
C-13	Adjustment of Value-added Tax Policies	2011	(State Taxation Administration (China), 2011)
C-14	Plan for Comprehensive Utilization of Solid Waste	2011	(National Development and Reform Commission (China), 2011)
C-15	Green Building Plan	2013	(General Office of the State Council of the People's Republic of China, 2013)
C-16	Circular Economy Promotion Plan in 2015	2015	(Ministry of Commerce of the People's Republic of China, 2015)
C-17	Environmental Protection Tax Law	2016	(State Taxation Administration (China), 2016)
C-18	13th Five-year Plan for Construction in Cities	2017	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2017)
C-19	Circular Development Plan	2017	(National Development and Reform Commission (China), 2017)
C-20	Experimental Programs of Construction Waste Management in Selected Provinces	2018	(Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2018)

2.4.2 Japan

Japan is a crowded island nation with limited land area. The amount of construction and demolition waste is increasing rapidly (Nitivattananon and Borongan, 2007), exacerbating the problem of landfill shortages. This problem could be the key driver behind Japan's management policy (Yolin, 2015). The

depletion of natural resources obligates policymakers to be aware of the economic value of waste (Yolin, 2015). Japan produces approximately 70 million tonnes of construction and demolition waste per year, and 96% of the waste was recovered in 2018 (Ministry of Land Infrastructure Transport and Tourism (Japan), 2018).

Japan began to manage construction and demolition waste in the late 1960s. According to the Ministry of the Environment (Japan) (1970), the waste produced in Japan should be managed whenever possible. The basic principle of the regulations is the restriction of waste production. In 1977, standards for the use of recycled aggregates and concrete were issued to respond to the scarcity of landfill sites (Gonçalves and Brito, 2008). Since 1990, Japanese society has gradually shifted to a sustainable economic structure. The Japanese government promoted the 3R principles (Reduce, Reuse, and Recycle) in construction and demolition waste utilisation (Mansouri and Kacha, 2017, Nitivattananon and Borongan, 2007).

In Japan, construction and demolition waste is treated as a by-product from the construction site. It includes both municipal and industry waste (Tokyo Bureau of Environment, 2018). According to the Ministry of Land Infrastructure Transport and Tourism (Japan) (2014), recyclable components of construction and demolition waste (including concrete, asphalt, wood, and sludge) must be recycled. In recent years, the Japanese government formulated several standards for different recycled products. A series of regulations and guidelines were enacted to deal with the application of recycled aggregates in concrete, including JIS A 5021 Recycled Aggregates for Concrete – Class H (2011), JIS A 5022 Recycled Aggregates for Concrete – Class M (2006), and JIS A 5023 Recycled Aggregates for Concrete – Class L (2012). These standards are related to the classification of recycled concrete, along with its quality control and applications. Recycling plants have been developed across the country after the implementation of relevant policies (The Climate Group, 2014). The number of recycling facilities dealing with concrete debris and asphalt increased from 1790 in the year 2000 to 2531 in 2005 (Ministry of the Environment (Japan), 2008). In addition to recycled products, the Construction Material Recycling Law was enforced in 2002, outlining the obligation of the waste generator for end-of-life products, including control and reduction of waste generation and selection of trustworthy recycling companies.

Japan has directed considerable effort toward the monitoring of illegal dumping. In the Construction Recycling Promotion Plan (2014), the on-site inspection for the recycling status was strengthened, promoting efficient recycling. Moreover, details shared by the construction by-product information exchange system force concerned parties to respond properly to waste management (Ministry of the

Environment (Japan), 2019b). The number of illegal dumping incidents has been significantly reduced to 163 cases, with a total of 36000 tonnes in 2017 (Ministry of the Environment (Japan), 2019b). Numerous financial benefits from the government encourage the starting of new recycling businesses, including investment in facilities, hiring costs, employee training and welfare (Ministry of the Environment (Japan), 2019a), and tax deductions (Nakajima and Russell, 2014). Furthermore, tax revenues from waste generators are used to support technical improvements and recycling plants.

Existing policies on construction and demolition waste management in Japan are presented in Table 4.

Table 4: Existing policies on construction and demolition waste management in Japan

Ref.	Law enacted	Year	Reference
J-1	Waste Management and Public Cleansing Law	1970	(Ministry of the Environment (Japan), 1970)
J-2	Resource Utilization Promotion Act	1991	(Ministry of the Environment (Japan), 1991)
J-3	Construction Material Recycling Law	2000	(Ministry of the Environment (Japan), 2000b)
J-4	Basic Act on Promotion of Recycling Oriented Society	2000	(Ministry of the Environment (Japan), 2000a)
J-5	Proper Process on Construction and Demolition Waste	2002	(Ministry of Land Infrastructure Transport and Tourism (Japan), 2002)
J-6	Recycled Aggregates for Concrete – Class M	2006	(Japanese Standards Association, 2006)
J-7	Recycled Aggregates for Concrete – Class H	2011	(Japanese Standards Association, 2011)
J-8	Recycled Aggregates for Concrete – Class L	2012	(Japanese Standards Association, 2012)
J-9	Construction Recycling Promotion Plan	2014	(Ministry of Land Infrastructure Transport and Tourism (Japan), 2014)
J-10	Illegal Dumping in 2017	2019	(Ministry of the Environment (Japan), 2019b)
J-11	Governmental Funds for Waste Disposal	2019	(Ministry of the Environment (Japan), 2019a)

2.4.3 South Korea

South Korea is characterised as a very small but highly populated country, with a total area of 100,210 km^2 and a population in 2017 of 51 million (The World Bank, 2019). Owing to its rapidly developing economy, the country faces considerable pressure from urbanisation and industrialisation regarding the efficient use of the available land (Hong, 1999). Along with the demolition and reconstruction of old structures to accommodate the increasing population, land has become scarce in the urban cities. Additionally, large volumes of waste threaten the efficient use of land. Construction and demolition waste issues and landfill shortages have attracted attention from both the government and the public. According to the Korea Waste Association (2018), the total volume of construction and demolition waste generated in 2017 was estimated to be 196,262 tonnes per day, comprising 47.3% of the solid waste in South Korea. To effectively address the waste issue, the Korean government has shifted its focus to the minimisation of waste generation, through promoting the efficient use of natural resources and proper waste management (Ministry of Environment (South Korea), 2003).

The Construction Waste Recycling Promotion Act (2003) is fundamental for reducing construction and demolition waste and is based on the idea that producers should take responsibility for the waste generated. However, this legislation focuses on government obligations. Benign cooperation among three levels of governments is pivotal in construction and demolition waste management. The Ministry of Environment (South Korea), a special self-governing city government, and municipalities are involved in devising and applying measures to facilitate eco-friendly disposal and recycling. Mayors/province governors and heads of cities direct research on the status of construction and demolition waste, including the distribution and treatment. Subsequently, the Ministry of Environment (South Korea) prepares a nationwide "master plan" based on the results of statistical data. To keep pace with the rapidly changing society, the Ministry of Environment (South Korea) should review the feasibility of the master plan every 5 years and update the plan every 10 years, in accordance with the Construction Waste Recycling Promotion Act (2003). Establishment of the Korea Waste Association with approval from the Ministry of Environment (South Korea) led to environmental preservation and an increase in the adoption of eco-friendly practices in South Korea. Specialised training programs on waste policies, laws, and technologies have been conducted for local government officials and related industry workers, to build their expertise.

Additionally, an electronic information sharing system is employed to manage construction and demolition waste in a transparent and effective way. Information related to waste collection, transportation, recycling, and landfilling is recorded in the system automatically. This information is preserved for three years and can be verified and searched by authorised users. The Ministry of Environment (South Korea) (2008) specifies that contractors, transporters, and operators of recycling

plants should keep a record of details for disposed waste. Furthermore, construction and construction waste disposal businesses should submit an annual report to the Ministry of Environment (South Korea) concerning waste generation. Mayors/governors should report on the performance of waste management in the preceding year before the date prescribed by the ordinance of the Ministry of Environment (South Korea).

Policies enforcing the use of recycled aggregates and recycled-aggregate products are concerned with increasing the adoption of recycling and protecting local recyclers. According to the Construction Waste Recycling Promotion Act (2003), recycled aggregates must be used in the construction of roads and environmental infrastructure. Moreover, obligatory waste ratios specify the required usage of recycled aggregates in certain construction activities. However, to promote the use of recycled-aggregate products, the safety and quality of the recycled aggregates should be ensured by authorities. The Ministry of Land, Transport and Maritime Affairs (South Korea) published Recycled Aggregate Quality Standards for a set of aggregate products, including road pavement, concrete, and asphalt concrete. Additionally, an authorised recycling aggregate quality certification agency was established.

State governments may grant local subsidies for all or part of the expenses for installing waste recycling facilities, depending on their budgets (Ministry of Environment (South Korea), 2003, Ministry of Environment (South Korea), 2008). The Ministry of Environment (South Korea) can provide technical guidance on installation if necessary. Additionally, to encourage businesses to reduce waste generation voluntarily, a reward program was enacted for businesses with outstanding performance in waste reduction. However, the penal regulation is complex and strict in South Korea. Punishments for different violations are specified in Construction Waste Recycling Promotion Act (2007), including penalties for fly-tippers and unauthorised disposal companies. The existing policies on construction and demolition waste management in South Korea are presented in Table 5.

Table 5: Existing policies on construction and demolition waste management in South Korea

Ref.	Law enacted	Year	Reference
K-1	Business Waste Reduction Program	1996	(Ministry of Environment (South Korea), 1996)
K-2	Construction Waste Recycling Promotion Act	2003	(Ministry of Environment (South Korea), 2003)
K-3	Waste Control Act	2008	(Ministry of Environment (South Korea), 2008)

K-4	Act for the Promotion of Saving and Recycling of Resources	2010	(Ministry of Environment (South Korea), 2010)
K-5	Recycled Aggregates for Concrete	2014	(Korean Standards Association, 2014)
K-5	Enforcement Regulations for the Promotion of Construction Waste Recycling Act	2018	(Ministry of Environment (South Korea), 2018)

2.4.4 Germany

A set of European standards governs construction and demolition waste management, binding all the member states in the EU (Sáez et al., 2011). The main policy driver for the management in Europe is the Waste Framework Directive, which calls the member states to reuse or recycle 70% of their construction and demolition waste by 2020 (Jeffrey, 2011). The average construction and demolition waste recycling rate in Europe was estimated to be approximately 46% (BIO Intelligence Service, 2011). The recycling rates vary significantly among European countries, for geographical, cultural, and political reasons. Some European countries already recycle all the suitable construction and demolition waste, fulfilling the target (Korea Waste Association, 2018).

Germany has the most advanced construction and demolition waste management practices among the countries in Europe (Deloitte, 2015h). Large amounts of construction and demolition production were reported in this country (BIO Intelligence Service, 2011), reaching 222.8 million tonnes in 2016 (Federal Statistical Office (Germany), 2019). The total volume of construction and demolition waste produced in Germany has increased slightly over the past several years, with 199.5 million tonnes generated in 2011 (Figure 1).

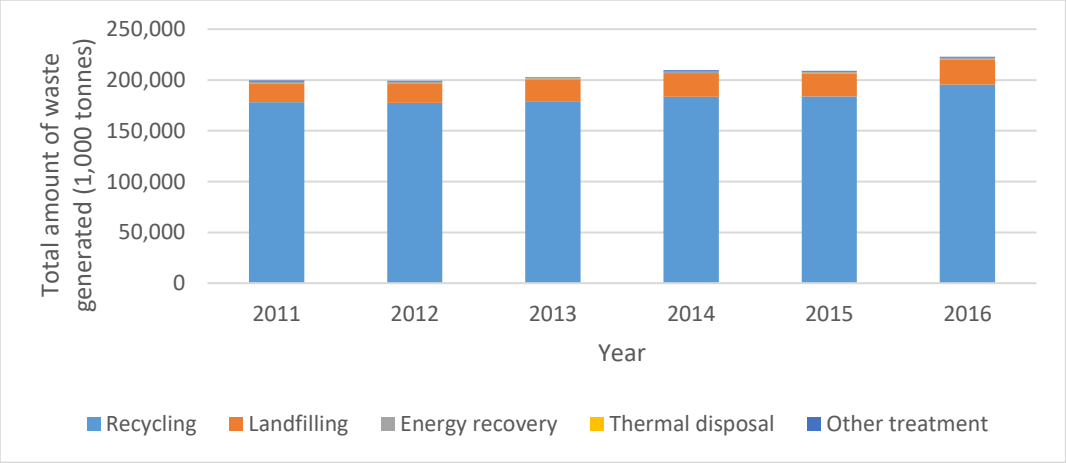


Figure 1: Waste treatment in Germany (Federal Statistical Office (Germany), 2019)

Germany has been involved in conserving natural resources through recycling and other recovery operations for decades. Among the world's countries, Germany has one of the highest waste recovery rates (up to 88%) (Nakajima and Russell, 2014); the number was 17% in 1994 (Del Río Merino et al., 2010). This remarkable increase was achieved via strict regulations regarding waste avoidance, recycling, and landfilling, to solve the problem of land shortages (Deloitte, 2015h). Only specific types of waste can be landfilled (German Federal Government, 2009). Additionally, all energy in the waste for landfilling must be exploited to the maximum extent possible (German Federal Government, 1994). In 2016, 195.5 million tonnes (87.7%) of construction and demolition waste was recycled, and only 11% of the waste (24.6 million tonnes) ended up in landfill sites (Federal Statistical Office (Germany), 2019).

The introduction of Acts for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal (1994) turns waste management into resource management, as recycled aggregates can be used for concrete production in the structural engineering sector (Jeffrey, 2011). This act was further developed in accordance with the European Union Waste Framework Directive in 2010. The basic obligations of related stakeholders to avoid waste production are expanded in closed-substance cycle waste management. For instance, contractors are required to pursue high-quality and appropriate recovery methods, according to their types and natures. Additionally, waste disposal should be compatible with public interests and occur within the country. The federal government is responsible for ensuring safe recovery, including placing restrictions on certain types of waste; mandating requirements regarding the separation, transport, and storage of waste; and supervising the performance of contractors. The federal government is in charge of delivering licenses for demolition and transportation companies and responding to questions from related parties.

It is not difficult to distinguish the waste hierarchy from governmental and official documents. Germany gives top priority to avoiding waste generation. According to the hierarchy established for waste treatment, waste avoidance is preferred over recycling, and recycling is preferable to landfilling. To achieve closed substance waste management, the German government encourages the design, development, production, and marketing of reusable and durable products. Related parties are responsible for utilising recoverable waste or secondary raw materials in the production process. Additionally, technologies for waste collection, transportation, and recycling have been gradually improved to reduce the amount of reconstruction and demolition waste in an eco-friendly manner. Landfilling of waste is only permitted when recycling is highly expensive or impossible and the generation of waste is unavoidable. Strict control of landfilling is an essential aspect of management.

Mixing one type of waste with other substances or types of waste is strictly prohibited. Furthermore, high landfill fees (US $112 to $190 per tonne in 2011) discourage waste disposal at landfill sites in Germany and contribute to the high recycling rate (Wonschik et al., 2014).

In Germany, the selective demolition of waste streams maximises the efficiency of recovery and recycling and ensures the production of clean and uncontaminated products (Wonschik et al., 2014). Quality marks are officially used to provide guidance for customers to verify the reliability of products and services. Only recycled products from construction and demolition waste that satisfy performance-specific quality criteria and obtain adequate quality marks can be used in industry. The DIN 4226-100 standard was developed to regulate the use of recycled aggregates in concrete production (Pellegrino and Faleschini, 2016). This standard specifies four types of recycled aggregates that are allowed for recycling and outlines the specific types used for concrete production (Pellegrino and Faleschini, 2016). The existing policies on construction and demolition waste management in Germany are presented in Table 6.

Table 6: Existing policies on construction and demolition waste management in Germany

Ref.	Law enacted	Year	Reference
D-1	Act for Promoting Closed Substance Cycle Waste Management and Ensuing Environmentally Compatible Waste Disposal	1994	(German Federal Government, 1994)
D-2	Waste Catalogue Ordinance	2001	(Federal Ministry of Justice (Germany), 2011)
D-3	Aggregates for Concrete and Mortar	2002	(German Institute for Standardisation, 2002)
D-4	Ordinance Simplifying Landfill Law	2009	(German Federal Government, 2009)
D-5	Ordinance on the Management of Municipal Solid Waste and Certain Construction and Demolition Waste	2017	(Federal Ministry of Justice (Germany), 2017)

2.4.5 The Netherlands

The requirements in the Waste Framework Directive were applied to the Netherlands, with the aim of achieving a recovery rate of 70% for construction and demolition waste before 2020. However, the country has already surpassed this requirement, achieving 100% recovery of construction and demolition waste in 2016 (Eurostat, 2019). Additionally, construction and demolition waste

management in the Netherlands is effective, integrated, and mature (Brantwood Consulting, 2016), and a high recovery rate has been maintained for decades.

This outstanding performance could be the result of strict regulations regarding landfills (BIO Intelligence Service, 2011). Landfilling is regarded as the least desirable approach for waste disposal in the Netherlands; thus, incentives are provided to reuse and recycle materials. A ban on landfilling is applied to all reusable, recyclable, and combustible waste. Landfilling is not allowed when there are technically and economically viable alternatives (Ministry of Infrastructure and Water Management, 2019). Additionally, tax legislation for landfill and incineration was reintroduced in 2014 (European Union, 2018). Companies and individuals must pay a waste tax when they receive waste. However, the waste tax is transferred to waste producers (Central Government of the Netherlands, 2019). The waste taxes in the Netherlands have increased sharply, reaching €32.12 (or US $35.12) per tonne in January 2019 (Figure 2) (Central Government of the Netherlands, 2019). The waste tax is relatively high for waste exported to other countries, in accordance with the rules stipulating that waste produced in the country should be processed in the country (Central Government of the Netherlands, 2019).

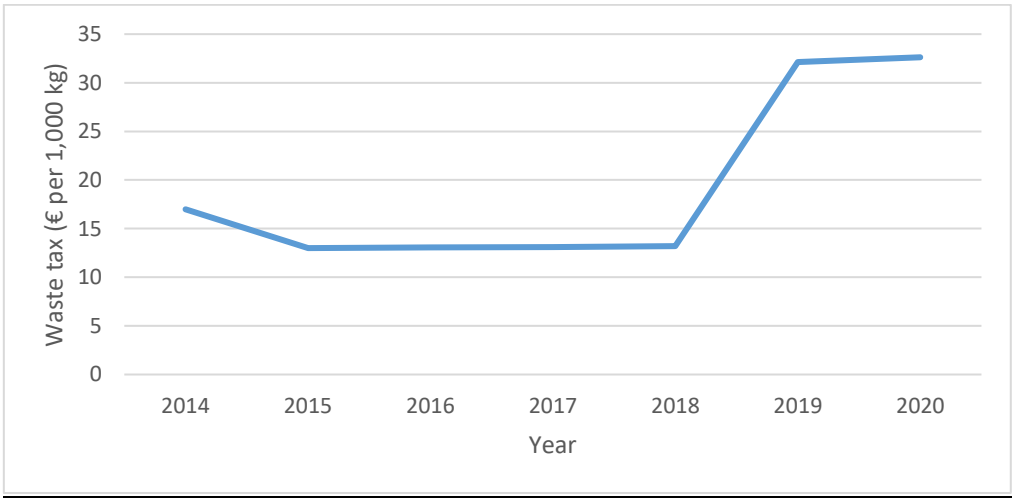


Figure 2: Waste tax in the Netherland (The Netherlands Tax Authority, 2019)

The 12 provinces of the Netherlands are responsible for adapting national policies established by ministers to a regional context, including regional policies and plans (European Union, 2018). Ministers, provinces, and municipalities are authorised to grant exemptions from certain prohibitions. For example, if there are temporarily no other processing options for certain types of waste to which the landfill ban is applied, the government may grant exemptions from the ban. Quarterly reports are obtained from demolition and waste processing companies to monitor disposal (BIO Intelligence Service, 2011).

NEN 5942, 5921, and 5930 (Tam et al., 2018) were enacted, specifying key quality control criteria for recycled aggregates and influencing the use of recycled aggregates. Cost reduction is an important driver for improving construction and demolition waste management (Deloitte, 2015m).

The Environmental Management Act is the basis for the regulation of construction and demolition waste management in the Netherlands. This act is in accordance with the Waste Framework Directive. It introduces the order of preference in construction and demolition waste management. Similar to other countries with high recovery rates, the Netherlands priories waste avoidance. National Waste Plan 3 was released in 2017, with the aim of reusing as much waste as possible (European Union, 2018). Furthermore, the plan provides detailed definitions for different classes of waste and instructions for transportation and treatment. Moreover, the Netherlands enacts strict regulation on related stakeholders. Waste can only be processed by authorised companies. All demolition, transportation, recycling, and landfilling companies must register with the National and International Road Transport Organization to be included in the official list.

Information on the existing construction and demolition waste management policies in the Netherlands (Table 7) was obtained from the Ministry of Infrastructure and Water Management, Royal Netherlands Standardization Institute and Netherlands Enterprise Agency.

Table 7: Existing policies on construction and demolition waste management in the Netherlands

Ref.	Law enacted	Year	Reference
N-1	Environmental Protection Act	1979	(Ministry of Infrastructure and Water Management (Netherlands), 1979)
N-2	Aggregates for Concrete - Determination of the Chloride Content	1988	(Royal Netherlands Standardization Institute, 1988)
N-3	Aggregates for Concrete - Determination of Sulphate Content	1990	(Royal Netherlands Standardization Institute, 1990a)
N-4	Aggregates for Concrete - Determination of the Composition of Granular Debris	1990	(Royal Netherlands Standardization Institute, 1990b)
N-5	National Waste Plan 3 (LPA3)	2017	(Ministry of infrastructure and Water Management (Netherlands), 2017)
N-6	Registration of Waste Transporters, Demolition Companies, Dealers, and Brokers	2019	(Netherlands Enterprise Agency, 2017)

Ref.	Law enacted	Year	Reference
N-7	Landfilling in the Netherlands	2019	(Ministry of Infrastructure and Water Management (Netherlands), 2019a)
N-8	Waste Tax	2019	(Ministry of Infrastructure and Water Management (Netherlands), 2019b)

2.4.6 United Kingdom

Annually reported data for the construction and demolition waste in the United Kingdom were collected from licensed waste management facilities, as well as other reputable sources, including industry data related to recycled aggregates and surveys (Deloitte, 2016). The volume of non-hazardous construction and demolition waste generated in 2016 was estimated to be 66.2 million tonnes, of which 59.6 million tonnes was generated in England (Department for Environment Food and Rural Affairs (United Kingdom), 2019). The Waste Framework Directive requires the United Kingdom to recover at least 70% of the waste from the construction and demolition industry by 2020. The United Kingdom currently satisfies the requirement; it achieved a recovery rate of 91% in 2016 (Department for Environment Food and Rural Affairs (United Kingdom), 2019). However, there is no specific legislation for construction and demolition waste. Overarching waste legislation is enacted in the United Kingdom, which applies to construction and demolition waste along with other types of waste. Moreover, the governing bodies in England, Wales, Scotland, and Northern Ireland have developed waste management plans, considering the current waste management status (Deloitte, 2016).

Waste regulations in England and Wales (2014), Northern Ireland (2011), and Scotland (2011) specify requirements for waste management plans and prevention plans. England has already fulfilled the recycling target from EU legislation, achieving a 93% recovery rate (Department for Environment Food and Rural Affairs (United Kingdom), 2013). A method for calculating the recovery rate of construction and demolition waste was developed for waste monitoring in England. Welsh and Scottish governments consider waste prevention in the construction sector as the most efficient approach and emphasise the use of recycled materials. Reduction of priority waste would contribute significantly to waste prevention. An annual prevention target of 1.4% (based on a 2006/2007 baseline) for construction and demolition waste managed off-site was set in Wales (Welsh Assembly Government, 2010). In 2010, 3.5 million tonnes of construction and demolition waste was generated in Northern Ireland, of which non-hazardous construction and demolition waste accounted for 1.2 million tonnes (Department of Agriculture Environment and Rural Affairs (Northern Ireland), 2013). The number is far smaller than that for England. Nonetheless, reduction of construction and demolition waste is

regarded as an important issue in Northern Ireland. A percentage of waste to landfill has been set for each year to encourage recycling. Additionally, contractors and demolition companies, transporters, recyclers, and operators of landfills are well-versed in waste regulations. For those involved in the treatment, recovery, and landfilling of construction waste, registrations and/or permits are required (Deloitte, 2016).

Encouragement from governmental programs aims to maximise use of recycled aggregates in construction, such as by setting targets for the use of recycled content in construction products. A minimum of 10% of recycled content should be included in governmental construction projects in Northern Ireland (Department of Agriculture Environment and Rural Affairs (Northern Ireland), 2013). Additionally, quality protocols outline criteria for the production of aggregates from inert waste. A uniform control process in production ensures sufficient waste recovery and greater use of recycled aggregate, with the aim of increasing market confidence in products manufactured using recycled waste (Civil Engineering Contractors Association, 2018). Additionally, investment from the government in the recycling sectors and an increase in the landfill tax in the United Kingdom have accelerated the transition to a more eco-friendly economy, owing to the reduced recovery costs (Deloitte, 2016). While various government policies have been introduced to develop the recycled-materials market, the demand for recycled materials is insignificant in the United Kingdom (Oyedele et al., 2014). Specifically, only 6.4% of aggregates for concrete came from secondary sources or recycled materials in 2015 (Gálvez-Martos et al., 2018). Apart from inadequate information regarding the recycled products, additional time is required for construction companies to source the products (Oyedele et al., 2014). Table 8 presents the existing policies related to construction and demolition waste management in the United Kingdom.

Table 8: Existing policies on construction and demolition waste management in the United Kingdom

Ref.		Law enacted		Year	Reference
U-1	Waste Regulations	England	Waste (England and Wales) Regulations	2014	(Department for Environment Food and Rural Affairs (United Kingdom), 2014)
		Wales			
		Northern Ireland	Waste (Northern Ireland) Regulations	2011	(Department of the Environment (Northern Ireland), 2011)
		Scotland	Waste (Scotland) Regulations	2011	(Scottish Parliament, 2011a)

U-2	Landfill Legislation	England Wales	Environmental Permitting (England and Wales) Regulations	2010	(Department for Environment Food and Rural Affairs (United Kingdom) and Department of Energy and Climate Change (United Kingdom), 2010)
		Northern Ireland	Waste Management Licensing Regulations (Northern Ireland)	2003	(Department of Agriculture Environment and Rural Affairs (Northern Ireland), 2003)
		Scotland	Waste Management Licensing (Scotland) Regulations	2011	(Scottish Parliament, 2011b)
U-3	Waste management plan	England	Waste Management Plan for England	2013	(Department for Environment Food and Rural Affairs (United Kingdom), 2013)
		Wales	Towards Zero Waste. One Wales: One Planet	2010	(Welsh Assembly Government, 2010)
		Northern Ireland	Delivering Resource Efficiency	2013	(Department of Agriculture Environment and Rural Affairs (Northern Ireland), 2013)
		Scotland	Zero Waste plan	2010	(Scottish Government, 2010)
U-4	European List of Waste			2000	(European Commission, 2000)
U-5	Aggregates for concrete			2012	(British Standards Institution, 2012)

2.4.7 Austria

The promotion of recycling of construction and demolition waste in Austria follows the characteristics of EU legislation. Similar to other EU members, the Austrian government must take existing EU standards on the quality of waste management into account. As public concerns regarding construction and demolition waste have increased significantly, Austria has become one of the most advanced countries with regard to waste management (Deloitte, 2015a). A detailed waste management plan that covers construction and demolition waste must be established or updated at least every six years, according to the Waste Management Act (2002). Moreover, there is a set of federal ordinances related to construction and demolition waste, including regulations on recycled construction materials, waste traceability, and landfills. Additionally, as of 2015, there were currently >418 recovery facilities available for processing construction and demolition waste (Deloitte, 2015a), and waste is expected to be reused or recycled whenever possible.

The Waste Management Act (2002) is the legal basis for sustainable solid waste management, including management of construction and demolition waste. Additionally, the Recycled Construction Materials Ordinance was enacted in 2015 and began to be enforced on 1 January 2016. This ordinance ensures environmental compatibility of recycled construction materials and provides legal certainty for manufactures and purchasers. Simultaneously, the Ordinance on the Separation of Materials Generated was replaced. The Recycled Construction Materials Ordinance (2015) specifies separation duties, appropriate treatments for construction and demolition waste, and limits the cost and required quality of secondary materials. Waste collection should be completed directly on the demolition site by authorised demolition companies (Federal Ministry for Sustainability and Tourism (Austria), 2017). Once the total amount of construction and demolition waste reaches 750 tonnes, examinations and separation for contaminants and undesirable substances must be conducted. Furthermore, recycling yards and material collection points of municipalities or local waste management associations have been established for citizens to dispose of small amounts of demolition waste. Regarding recycled aggregates, analytical examinations and evaluations should be conducted by an external authorised specialist or group on samples from each batch of recycled materials (maximum of 50 production hours, minimum of 200 tonnes). Only quality-assured recycled construction materials can be released into the market. However, there is a lack of financial incentives from the Austrian Government. Secondary building materials are unattractive to consumers, because of the low price of primary materials (Kleemann, 2010). Moreover, it is not mandatory to use recycled materials in Austria (Deloitte, 2015a).

The intention of the Austrian government is to maintain high waste management performance via legislation. Construction and demolition waste data from demolition and recycling companies have been directly transmitted to a central database since 2011 (Deloitte, 2015a). Improved statistical records have become important sources for the precise evaluation of the volumes of construction and demolition waste (Federal Ministry for Sustainability and Tourism (Austria), 2017). Under the Waste Management Act (2002), contractors are obliged to keep records of the types, quantities, and origins of generated waste, along with the waste codes. Moreover, demolition, transportation, and recycling companies must keep continuous electronic records. The waste quality is inspected before visits to landfill sites. It may be found that some of the waste is unsuitable for landfilling owing to unacceptable chemical characteristics (Ministry of Sustainability and Tourism (Austria), 2008). Landfill operators record detailed information, including the delivery dates, inspection results, and exact locations of waste at the landfill site. These records are kept for more than seven years and are accessible to the authorities.

The existing policies on construction and demolition waste management in Austria are presented in Table 9.

Table 9: Existing policies on construction and demolition waste management in Austria

Ref.	Law enacted	Year	Reference
A-1	Hazardous Waste Specification Ordinance	2000	(Ministry of Sustainability and Tourism (Austria), 2000)
A-2	Waste Management Act	2002	(Federal Ministry of Constitution Reforms Deregulation and Justice (Austria), 2002)
A-3	Waste List Ordinance	2003	(Ministry of Sustainability and Tourism (Austria), 2003)
A-4	Landfill Ordinance	2008	(Ministry of Sustainability and Tourism (Austria), 2008)
A-5	Waste Treatment Responsibilities	2009	(Federal Ministry of Agriculture and Forestry (Austria), 2009)
A-6	Austrian Ordinance for Tracking Waste	2012	(Federal Ministry of Agriculture and Forestry (Austria), 2012)
A-7	Dismantling of Buildings as Standard Method of Demolition	2014	(Ministry of Sustainability and Tourism (Austria), 2014)
A-8	Recycled Construction Materials Ordinance	2015	(Federal Ministry of Constitution Reforms Deregulation and Justice (Austria), 2015)
A-9	Recycled Aggregates for the Construction Industry	2015	(Austrian Standards Institute, 2015)

2.4.8 Italy

Italy largely follows EU legislation and is subjected to the Waste Framework Directive. In Italy, as one of the most significant waste streams (Mei et al., 2014), approximately 51.7 million tonnes of construction and demolition waste was generated in 2014, representing 32.5% of the waste produced from economic activities and households (Eurostat, 2017). The number was 48.5 million tonnes and 52.5 million tonnes in 2013 and 2012, respectively (Deloitte, 2015l). The large volume of construction and demolition waste generated in Italy requires public administrators to ensure that the waste is sustainably managed (Blengini and Garbarinoc, 2010). The recovery rate in Italy has been steadily maintained since 2010; it was 97% in 2010 and 98% in 2016 (Eurostat, 2019).

However, there is no waste management plan at the national level, as waste management plans and strategies are developed at the regional level (Deloitte, 2015l). Thus, various construction and demolition waste management plans exist across different regions and provinces in Italy. Regions and provinces are responsible for waste management and environmental protection. States, regions, provinces, and local bodies promote appropriate techniques for eliminating dangerous substances and separate collection of different types of waste. Planning and organisation of waste management at the provincial level, with periodic checks on waste management and trading activities, are important.

With the scarcity of nationwide policies and related documents, Decree from the Ministry of Environment and subsequent amendments may be the only example of legislation that can be used for investigating the construction and demolition waste management in Italy. Waste derived from construction and demolition is classified as "special waste" (pursuant to Chapter 184) because it constitutes a large volume of non-hazardous substances (98 vol.%) (Higher Institute for Environmental Protection and Research (ISPRA), 2016), which are treated in recycling facilities, as well as contaminants such as asbestos and other harmful substances, which must be treated in a different manner. Almost half of the hazardous waste generated in Italy is landfilled after proper treatment. The remaining portion is exported to other countries, such as Germany (Deloitte, 2015l).

A waste traceability control system (SISTRI) was developed by the Italian Ministry of Environment to trace hazardous and non-hazardous waste and obtain real-time information regarding the waste chain. However, the system is no longer used for non-hazardous special waste. Estimation of construction and demolition waste is based on annual declarations from waste treatment operators to the regional agencies (Borghi et al., 2018). Databases from ISPRA (Higher institution for environmental protection and research) concerning special waste (RS) at the regional and provincial levels provide a constantly updated overview of the construction and demolition waste management in various territories.

In Italy, the quality criteria set in the UNI EN 12620 standards regulate the use of recycled aggregates in concrete production (Borghi et al., 2018). However, recycled aggregates are not competitive, owing to their poor quality and a lack of taxes on quarrying activities (Deloitte, 2015l). To increase the recovery rate, it is crucial to increase the demand for recycled aggregates and thus increase the utilisation of recycled aggregates. Green Public Procurement was introduced. Building companies are required to use recovered and recycled materials in construction. Recycled products with the same characteristics as products from natural materials must account for >30% of the market for construction materials. Additionally, the price of recycled aggregates is strictly controlled. The price of recycled

aggregates is available in the official recycling dictionary and is lower than that of virgin aggregates. Table 10 presents the existing policies on construction and demolition waste management in Italy.

Table 10: Existing policies on construction and demolition waste management in Italy

Ref.	Law enacted	Year	Reference
T-1	Decree from the Ministry of Environment	2003	(Italian Ministry of Environment, 2003)
T-2	Green Public Procurement	2005	(Italian Ministry of Environment, 2005)
T-3	Legislative Decree	2006	(Authority for the Supervision of Water Resources and Waste (Italy), 2006)
T-4	Aggregates for Concrete	2013	(Italian National Unification, 2013)

2.5 Comparison of policies

2.5.1 General regulations

This section presents factors limiting the construction and demolition waste management performance in China compared with the aforementioned countries. In recent years, the awareness of construction and demolition waste management in China has increased, and a larger number of governmental policies related to construction and demolition waste have been formulated in China (Table 3) compared with the other selected countries. Although experimental projects have been implemented in a few cities (such as Beijing and Shanghai), national regulations are insufficient and inefficient. Specifically, regulation is a powerful factor driving the development of construction and demolition waste management, which frames markets for building materials recycled from construction and demolition waste (Edge Environment Pty Ltd, 2012). Efficient waste management practices in the interest of public cannot be achieved without governmental regulations (Napier, 2016).

Table 11 presents a comparison of the general regulations. Factors R-1 to R-23 are derived from the contents of national regulations in China and all the selected countries. 5 of the 23 factors are included in legislations in China, i.e., priority to reduce waste generation (R-1), centralized landfilling (R-17), development of recycling technology (R-19), enactment of experimental programs in leading cities (R-20), and cooperation with capitals (R-21). Meanwhile, in all the seven selected counties, separate collection and different treatments for different classes of construction and demolition waste are emphasised (R-6). According to Table 11, Japan, South Korea, Germany, Austria, the Netherlands,

and the United Kingdom have established integrated classification systems for construction and demolition waste (R-5). However, classification of construction and demolition waste is not uniformly defined in China (R-5).

Inadequate guidance on recycling

Japan, South Korea, Germany, the Netherlands, and Austria have adopted mandatory recycling (R-12). Mandatory recycling has specifically targeted recyclables, such as concrete, wood, and asphalts, to make waste disposal compatible with public interests (R-15). To reduce the dependence on landfilling, only specific types of (non-hazardous) waste can be deposited at landfill sites (R-13). The energy potential of waste that is transported to landfills should be exploited to the maximum extent, as in South Korea, Germany, the Netherlands, the United Kingdom, and Italy (R-16). In Germany, the Ordinance Simplifying Landfill Law (2009) defines landfill sites of Class 0, I, II, III, and IV for different codes of waste (R-14). Similar to Germany, the governing bodies in Austria and the United Kingdom define the types of landfills (R-14). Mixing one class of waste with another substance or class of waste is strictly prohibited in Germany, the Netherlands, Austria and Italy (R-8). In contrast to the mandatory recycling of recyclables (R-12) in selected countries, the construction and demolition waste produced in China is transported to storage centres to be landfilled together (R-17), as recycling and other treatments are unavailable.

In China, there is a lack of an intermediate link between waste generation and the use of recycled materials in the recycling chain, because of inadequate regulations and guidance on recycling. This is consistent with Lu and Yuan (2010), Liu et al. (2012) and Yuan (2017). Most current policies in China are not operable and not detailed enough to guide efficient construction and demolition waste management (Lu and Yuan, 2010). Specifically, one reason for the limited recycling capability could be a lack of proper guidelines on how to classify construction and demolition waste (Huang et al., 2018). According to Table 11, Japan, South Korea, Germany, Austria, the Netherlands, and the United Kingdom have established integrated classification systems for construction and demolition waste. For example, Japan issued legislation to stimulate recycling and identified approximately 20 classes of construction and demolition waste. The recycling rates for each class of waste were calculated separately (Nakajima, 2014). Additionally, the lack of a standard classification could lead to unorganised waste separation and collection (Zhao et al., 2010). Most waste is mixed in China, and recyclers must direct considerable effort and financial resources toward manual and machine sorting (Huang et al., 2018). In contrast to the selected countries, the construction and demolition waste produced in China is transported to storage centres to be landfilled together, as recycling and other

treatments are unavailable. The quantity and quality of recyclable materials can be maximised via the separate collection of waste (Calabrò, 2009), increasing the efficiency of recycling. In contrast to virgin aggregates, recycled aggregates cannot be produced and immediately used before their properties are carefully tested. Therefore, separate collection of selected class of waste with certain features, such as low concentration of contaminants, is essential for producing high-quality recycled-aggregate concrete (Torgal, 2013). Currently, most waste is mixed in China, and recyclers must direct considerable effort and financial resources toward manual and machine separation (Huang et al., 2018).

During the last few decades, fly-tipping of construction and demolition waste was prevalent. In recent ten years, landfilling starts to become a convenient and dominant solution to handle the waste (Duan et al., 2015). In 2014, approximately 84% (29.4 million tonnes) of construction and demolition waste generated in Shenzhen ends up in landfills (Duan and Li, 2016). A landfill ban for recyclable components and unsorted waste could help to deal with the waste sustainably and desirably (Ulubeyli et al., 2017). In 2002, German government issued a ban on landfilling, to encourage reuse and recycle of construction and demolition waste (Agamuthu, 2008). In Germany, the Netherlands, Austria and Italy, only specific types of (non-hazardous) waste can be deposited at landfill sites.

A national standard and legislation on construction and demolition waste should be released to establish an integrated recycling chain, requiring additional details on the classification of construction and demolition waste. Following the guidance, different classes of waste could be correctly separated and then transported to proper treatment facilities. Furthermore, based on a robust knowledge of classification, subsequent regulations, such as separate collection, a ban on mixing waste, mandatory recycling, acceptance criteria on waste in recycling and landfilling and classification of landfill sites could be enacted.

Minimisation of waste can address the issue of large volumes of waste and encourage waste reduction. China should find a better solution for waste reduction. China has regarded waste reduction as an objective in C-5, C-12 and C15 (Table 11). In China, application of prefabricated technology in construction industry is emphasised in the long-run national development plan (Gao and Tian, 2020). Since 1999, national policies have been issued successively to promote prefabricated construction (Gao and Tian, 2020, Chang et al., 2018). However, the immaturity of the prefabrication market has resulted in lagged adoption of prefabricated technology in construction industry (Zhu et al., 2018). With regard to waste reduction, other measures from selected countries can be considered. Japan strives to reduce the waste generation through selection of proper materials and techniques, as well as efficient demolition. Authorities in South Korea encourage businesses to reduce waste generation

voluntarily by considering environmental impacts throughout the processes of design, manufacturing, distribution, consumption, and disposal.

Table 11: Comparison of general regulations

Ref.	General regulations	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
R-1	Priority to reduce waste generation	C-5, C-15, C-18	J-1, J-2	K-1, K-2, K-3, K-4	D-1	N-1	A-2	U-1	T-3
R-2	Tax on generation of construction and demolition waste		J-2	K-3		N-8			
R-3	Higher waste tax for waste exported					N-8			
R-4	Mandatory waste management		J-2, J-4	K-1, K-2, K-4	D-1, D-5	N-1, N-5	A-2		
R-5	Detailed types of construction and demolition waste		J-9	K-4, K-6	D-1, D-2, D-5	N-1, N-5	A-3	U-4	
R-6	Separate collection		J-9	K-4, K-6	D-1, D-2, D-5	N-1, N-5	A-8	U-1	T-3
R-7	Quality inspection on waste						A-4, A-7		
R-8	Mixing ban on hazardous waste				D-5	N-1	A-2, A-8		T-3
R-9	Restricted waste imports		J-1						
R-10	Development of recycling-oriented economic system		J-2			N-1	A-8	U-1	
R-11	Development of closed substance cycle				D-1				
R-12	Mandatory recycling of the recyclables		J-2	K-4	D-5	N-1, N-5	A-7		T-3
R-13	Only specific types of waste can be landfilled				D-4	N-7	A-2, A-4		T-3
R-14	Detailed classification of landfill sites				D-4		A-4	U-2	

Ref.	General regulations	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
R-15	Waste disposal should be compatible with the public interest			K-2, K-4	D-1	N-1	A-2, A-4		T-3
R-16	Energy in the waste for landfilling should be exploited to the maximum extent possible			K-4	D-1	N-7		U-2	T-3
R-17	Centralized landfill	C-15							
R-18	Maintenance of waste recycling facilities		J-9						
R-19	Development of recycling technology	C-14	J-1						
R-20	Experiments in selected provinces and cities	C-16, C-19, C-20							
R-21	Cooperation between government and capitals	C-18							
R-22	National self-care (Duty of care for waste)		J-1		D-1	N-1		U-1	
R-23	Quality assurance for recycled building materials						A-8		

2.5.2 Incentives

Classification of incentives can provide motivations for stakeholders to take particular actions. In this study, incentive schemes are considered as drivers, whereby recyclers can receive benefits from the government, e.g., cost savings (Hu et al., 2012). Such incentives can contribute to the success of waste management (Armstrong, 2012). The study of incentives and motivation for recycling is important to obtain a comprehensive understanding of construction and demolition waste management.

Table 12 presents a comparison of the incentives among China and the selected countries. Continuous encouragement can motivate recyclers to actively participate in the recycling process (Manowong, 2012). The recent release of financial incentives in China indicated the intention of the Chinese government to foster the recycling business, including value-added tax (VAT) deductions (I-2), and BOT right (I-6) (Table 12). BOT (build-operate-transfer) is a financing mechanism, where private sector is given responsibility to finance, build, operate until the project is transferred back to public sector (Song et al., 2017, Shen, 2007). Enterprises who obtained BOT contracts can conduct operations within the scope of the franchise rights, including investing, implementing projects, and collecting waste transportation tariffs. The State Taxation Administration (China) (2008) introduced VAT exemptions with a focus on products, including concrete, bricks, and mortar, which account for >30% of construction and demolition waste. Additionally, funds for recycled material producers (I-3), subsidy for use of recycled materials (I-4), reduced prices for electricity (I-6) and land use (I-10) are employed as incentives in China. China can expand these incentives and apply regulations that have been used by the other selected countries. For example, Japan, the United Kingdom, and South Korea provide funds for new recycling businesses (I-8), for purchasing facilities, hiring, and employee training and welfare. Additionally, concessional loans are provided in Japan (I-10), aiming to attract increasing investments and trigger voluntary recycling activities from private companies. Research funds are provided to improve the recycling performance in Japan (I-9).

Underdeveloped recycling market

Although Chinese government has provided information and standards regarding the use of recycled aggregates (I-16) and encourage the use of recycled products (I-14), there is a lack of market incentives in utilising recycled materials. Some countries issued policies to promote the use of recycled products. It is obligatory for contractors to use recycled aggregates that satisfy the quality standards for construction works in South Korea (I-15). In Italy, recycled materials and products should account for >30% of the market share of the given type of product (I-11).

However, absence of market incentives in using recycled materials is a critical issue. There are differences between the properties of recycled aggregates and those of natural-aggregate concrete, because the properties of recycled aggregates are largely dependent on the source (Yehia et al., 2015). The use of recycled aggregates in China has been limited to road construction and the production of non-structural-grade concrete, owing to their low strength (Senaratne et al., 2017). Researches on widening the application of recycled aggregates in structural use could be conducted. Lu and Yuan (2010) identified research and development as a critical factor in implementation of construction and demolition waste, and government should cooperate closely with local universities and research

institutes to develop related technologies. There is limited interest in the replacement of natural resources with recycled aggregates in the recycling market, because of the unstable properties of recycled aggregates (Duan et al., 2019).The market calls for the availability of documents that provide detailed information regarding recycled aggregates (Oyedele et al., 2014). Governing bodies of all the selected countries have provided information and standards regarding the use of recycled aggregates (I-16), which outline the requirements for the properties and applications. Another important step in the establishment of a recycling program is to nurture a market for recycled products (Jin et al., 2017). China, Japan, South Korea, and Germany encourage the use of recycled products (I-14). Some selected countries forced contractors to use of building materials recycled from construction and demolition waste (Table 12). It is obligatory for contractors to use recycled aggregates that satisfy the quality standards for construction works in South Korea (I-16). ⩾35% recycled aggregates should be used for the establishment or expansion of road pavement (Allbaro System, 2019). In Italy, recycled materials and products should account for >30% of the market share of the given type of product. This framework ensures the diversion of construction and demolition waste from landfills and stimulates the market for recycled materials. Recycled building materials cannot be sold at a price higher or lower than the maximum or minimum price, respectively, set by governing bodies in South Korea (I-13). In Italy, the prices of recycled products can be checked in the recycling dictionary (I-14). The price restriction might stem from a desire to allow recyclers to earn an income and avoid a monopoly. Chinese government could move beyond voluntary use of recycled products and impose obligatory recycling content in building materials. In addition, the government could play a leading role as a customer, as recycled materials could be used in governmental programs and construction in fundamental facilities.

Table 12: Comparison of incentives

Ref.	Incentives	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
I-1	Awards for distinctive performance in clean production	C-3		K-1					
I-2	VAT exemptions for waste recycling operators	C-7, C-13							
I-3	Funds for recycled-material producers	C-2, C-6		K-3					
I-4	Subsidy for use of recycled materials		J-11						
I-5	BOT right or recycling businesses	C-2							
I-6	Lower price of electric power	C-2							
I-7	Funds for starting new recycling business		J-11	K-2				U-3	
I-8	Funds for research		J-11						
I-9	Concessional loans for recycling businesses		J-11						
I-10	Less expensive land use	C-2							
I-11	Recycled products should account for a certain percentage of the market share								T-2
I-12	Price control on recycled aggregates			K-3					
I-13	Price list for recycled building materials								T-2
I-14	Use of recycled products	C-5, C-12	J-2	K-2	D-1				
I-15	Obligatory use ratio for recycled building materials			K-2, K-4					

Ref.	Incentives	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
I-16	Instructions on applications of recycled aggregates	C-9, C-10, C-11	J-6, J-7, J-8	K-5	D-3	N-2, N-3, N-4	A-9	U-5	T-4

2.5.3 Stakeholders' responsibilities

The influence of stakeholders on the success of construction and demolition waste management is critical (Oppong et al., 2017, Yuan, 2017), because the participation of stakeholders is needed to maintain the recycling chain and achieve a sustainable environment. Construction and demolition waste management is sophisticated and involves several stakeholders, each playing a role in optimising the management. Therefore, stakeholders' responsibilities are considered in this study.

The responsibilities on different levels of government are specified by C-1 and C-8 (S-1, S-5, S-7 and S-10). Similar to the other selected countries, the Chinese central government makes important decisions on behalf of the country and has the responsibility of drafting national waste management plans with the highest priority (S-1). Technical assistance from central governments to lower governments is provided in Japan, Germany, and Italy (S-2), to effectively turn waste into resources and ensure safe operations. The central government in Germany incorporated recycling into the culture and defined a standard recycling process for waste facilities (S-3). Publicly notified assessments of the capability of recyclers to perform services are conducted by the central government in South Korea (S-4), to help contractors select qualified companies. Municipalities in Japan and South Korea promote voluntary efforts from business to reduce waste (S-8), extend the lifetime of buildings, and use recycled building materials.

Incomplete knowledge of stakeholders' responsibilities

Construction and demolition waste management is sophisticated and involves several stakeholders each playing a role in optimising the management. The influence of stakeholders on the success of construction and demolition waste management is critical (Yuan, 2017). In line with previous literature (Lu and Yuan, 2010), the responsibilities of stakeholders involved in construction and demolition waste recycling activities in China are ambiguous and not well-defined (Table 13). Only contractors' responsibility to formulate plans for waste disposal are determined in S -15 (Table 13). The responsibilities of other parties, such as demolition, transportation, recycling, and landfilling companies, are not specified. In China, construction waste reduction and environment protection

received little attention from industry stakeholders (Yuan, 2013). Seldom would contractors pay attention to the destination of construction and demolition waste, after it exits a construction site (Lu and Yuan, 2010). All the related stakeholders should be considered in the recycling chain. China can expand the responsibilities of different stakeholders based on the experience of the selected countries. Flowcharts of the waste processing among related stakeholders in Japan and Germany are presented in Figure 3 and Figure 4, respectively. These countries consider all the related stakeholders in the recycling chain, including contractors, demolition companies, and recyclers. It is common in the construction industry for a stakeholder to have dual roles. For example, enterprises can operate as a demolition or recycling company simultaneously. This study focused on the responsibilities of different roles, regardless of this specific situation. Waste reduction from design (S-14), and waste delivery to an authorised company (S-18) are important responsibilities of contractors in almost all the selected countries. Specifically, in Japan, South Korea, Germany, Austria, the United Kingdom, and Italy, legal regulations require contractors to consider the efficiency of the demolition of materials and select appropriate technology when designing building (S-14). In South Korea, ordering parties can require contractors to use recycled building materials (S-13). The primary duties of sub- contractors are to comply with the instructions of main contractors (S-21) and undertake construction in a safe and eco-friendly manner. In Italy and Germany, the concept of product responsibility was introduced. This means that suppliers of building materials should use recycled building materials or recoverable waste (S-35) and consider waste generation during production as well as subsequent use and recycling (S-34). Consumers are encouraged to protect, maintain, and extend the lifespan of buildings in Germany (S-36). The registration of demolition (S-22), transportation (S-37), and recycling (S-25) companies is mandatory in the recycling process. In the Netherlands, demolition, transportation, and recycling companies must register with the National and International Road Transport Organization and be included in the national list. To be able to register, related stakeholders must acknowledge liability and demonstrate compliance. Moreover, for recyclers in Austria (S-28, S-31), Italy (S-31), and Germany (S-31), visual inspections and assessments of construction and demolition waste are necessary to control and ensure the quality of waste for recycling and determine whether the waste can be recycled or should be landfilled. In Japan, self-improvement is required (S-30), with a focus on research and facility improvement.

Ineffective cooperation among governing bodies

For all the countries, a national plan forms the basis of legislation. Provinces are responsible for translating these basic policies into regional contexts, and municipalities take actions for proper waste management that are compatible with these regulations (Table 13). For instance, technical assistance

from central governments to lower governments is provided in Japan (Figure 4), Germany (Figure 6), and Italy, to effectively turn waste into resources and ensure safe operations. In South Korea, provinces and municipalities conduct research on the current waste status to provide the Ministry of Environment (South Korea) with basic information and materials that are necessary to establish a national waste management plan (Figure 5).

The responsibilities on different levels of government are specified by C-1 and C-8 (S-1, S-5, S-7). Figure 7 presents the responsibilities of government at different levels in China. Similar to the other selected countries, the Chinese central government makes important decisions on behalf of the country and has the responsibility of drafting national waste management plans with the highest priority. A national plan would further form the basis of legislation. Provinces are responsible for translating these basic policies into regional contexts, and municipalities take actions for proper waste management that are compatible with these regulations. As the current policies are too general to provide operable guidance, some local governments implemented construction and demolition waste management in their administrative areas (Lu and Yuan, 2010). However, whether a culture of efficient cooperation among departments has been achieved calls for additional robust research. Yuan (2017) stated that the efficient arrangement of their management activities had not been achieved, because responsibilities on different government departments were not properly determined. China can expand the responsibilities of different levels of government based on the experience of the selected countries. The central government in Germany incorporated recycling into the culture and defined a standard recycling process for waste facilities. Publicly notified assessments of the capability of recyclers to perform services are conducted by the central government in South Korea (S-4), to help contractors select qualified companies. Municipalities in Japan and South Korea promote voluntary efforts from business to reduce waste (S-8), extend the lifetime of buildings, and use recycled building materials. Additionally, Japan municipal governments organised a council for the promotion of waste reduction (S-9). Suitable promoters with social reputations and professional knowledge are selected to stimulate cooperation between businesses and municipalities.

Table 13: Comparison of stakeholders' responsibilities

Stakeholders' responsibilities		**Ref.**	**China**	**Japan**	**South Korea**	**Germany**	**Netherlands**	**Austria**	**United Kingdom**	**Italy**
Central government/	Provide national guidance on	S-1	C-1, C-8	J-1, J-3	K-2, K-3	D-1	N-1	A-2		T-3

Stakeholders' responsibilities		Ref.	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
Federal government/ Ministry	waste management									
	Promote related technology	S-2		J-1		D-1				T-3
	Define requirements for waste facilities	S-3				D-1				
	Assess capability of recyclers to perform services	S-4			K-2					
Prefectural government/ States/Provinces	Proper waste management in administrative area	S-5	C-1	J-1, J-3, J-5	K-2, K-3	D-1	N-1		U-1, U-3	T-3
	Provide technical advice to municipalities	S-6		J-1, J-3						
Municipalities	Take actions for proper management	S-7	C-1, C-8	J-1, J-3, J-4		D-1				T-3
	Promote voluntary activities	S-8		J-1	K-1					
	Organize a council for promoting waste reduction	S-9		J-1						
	Follow national policies	S-10	C-1	J-3, J-4		D-1				T-3
Ordering parties	Investigate surroundings	S-11		J-5						

Stakeholders' responsibilities		Ref.	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
	Plan for demolition and other operations	S-12		J-3, J-5						
	Require contractors to use recycled aggregates	S-13			K-2					
Main contractors /waste producer/waste holders	Reduce waste from design	S-14		J-1, J-3, J-4, J-5,	K-3	D-1, D-4, D-5,		A-2, A-6, A-8	U-1	T-3
	Make and submit waste disposal plan	S-15	C-1, C-4, C-15	J-3, J-5	K-2, K-3		N-1			
	Use recoverable or recycled building materials	S-16			K-2	D-1				
	Manage waste for whole lifecycle	S-17	C-15	J-3	K-2, K-3	D-1, D-4	N-1	A-2, A-8	U-1	T-3
	Deliver waste to authorised disposal companies	S-18			K-3	D-1	N-6	A-2		T-3
	Separate collection	S-19		J-3	K-4, K-6	D-1, D-2, D-5	N-1, N-5	A-8	U-1	T-3
	Report information of waste	S-20		J-1	K-2	D-1, D-5	N-1	A-2, A-6		
Sub-contractors	Follow instructions of main contractors	S-21		J-5						
	Register	S-22		J-3			N-1, N-6		U-1	

Stakeholders' responsibilities		Ref.	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
Demolition companies	Proper demolition work	S-23		J-3, J-5	K-2, K-3	D-1, D-5		A-6, A-8		
	Records on waste	S-24			K-2	D-1		A-2,		
Recycling companies	Register	S-25		J-1, J-5	K-2, K-3		N-1, N-6	A-6, A-8	U-1, U-2	
	Cooperate with municipalities	S-26		J-1						
	Proper, safe, and high-quality recycling	S-27			K-2, K-3	D-5				
	Visual inspections and assessments of waste	S-28						A-8		
	Keep records regarding waste	S-29			K-2	D-1	N-1	A-2	U-1	T-3
	Conduct research and improve facilities	S-30			K-2					
Landfill operators	Acceptance inspection of waste	S-31				D-4		A-4		T-3
	Organise landfill sites	S-32				D-4				
	Keep records regarding waste	S-33				D-4	N-7	A-2		
Suppliers of materials	Products designed for reducing waste	S-34		J-2, J-4		D-1				T-3
	Use recycled products	S-35				D-1				T-3

Stakeholders' responsibilities		Ref.	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
Consumers	Proper maintenance	S-36				D-1				
Transportation companies	Register	S-37			K-2		N-1, N-6		U-1	
	Record data on waste	S-38			K-3	D-1	N-1, N-6	A-2, A-6	U-1	T-3
	Comply with local regulations	S-39							U-1	T-3

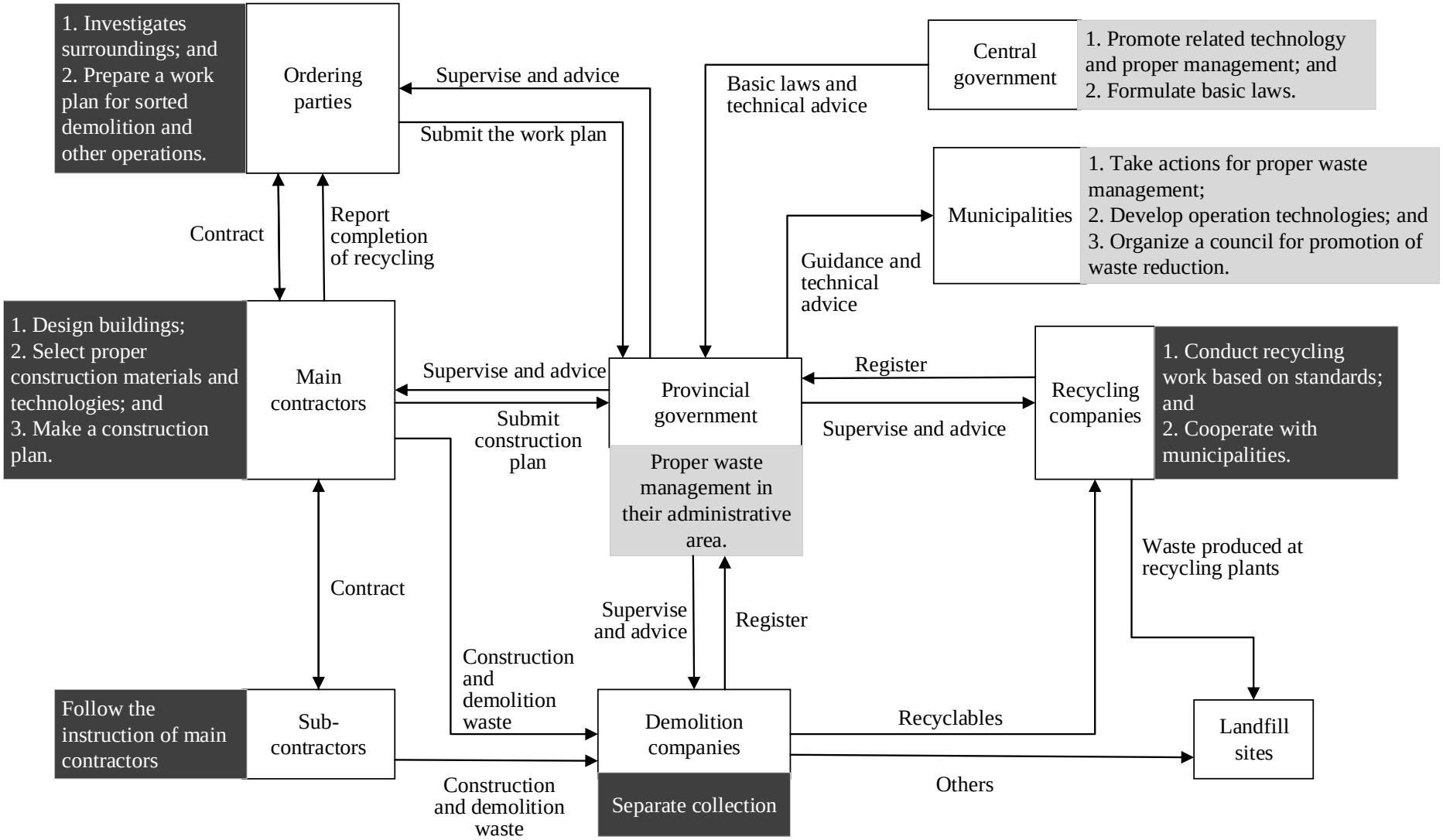


Figure 3: Responsibilities of related stakeholders in Japan

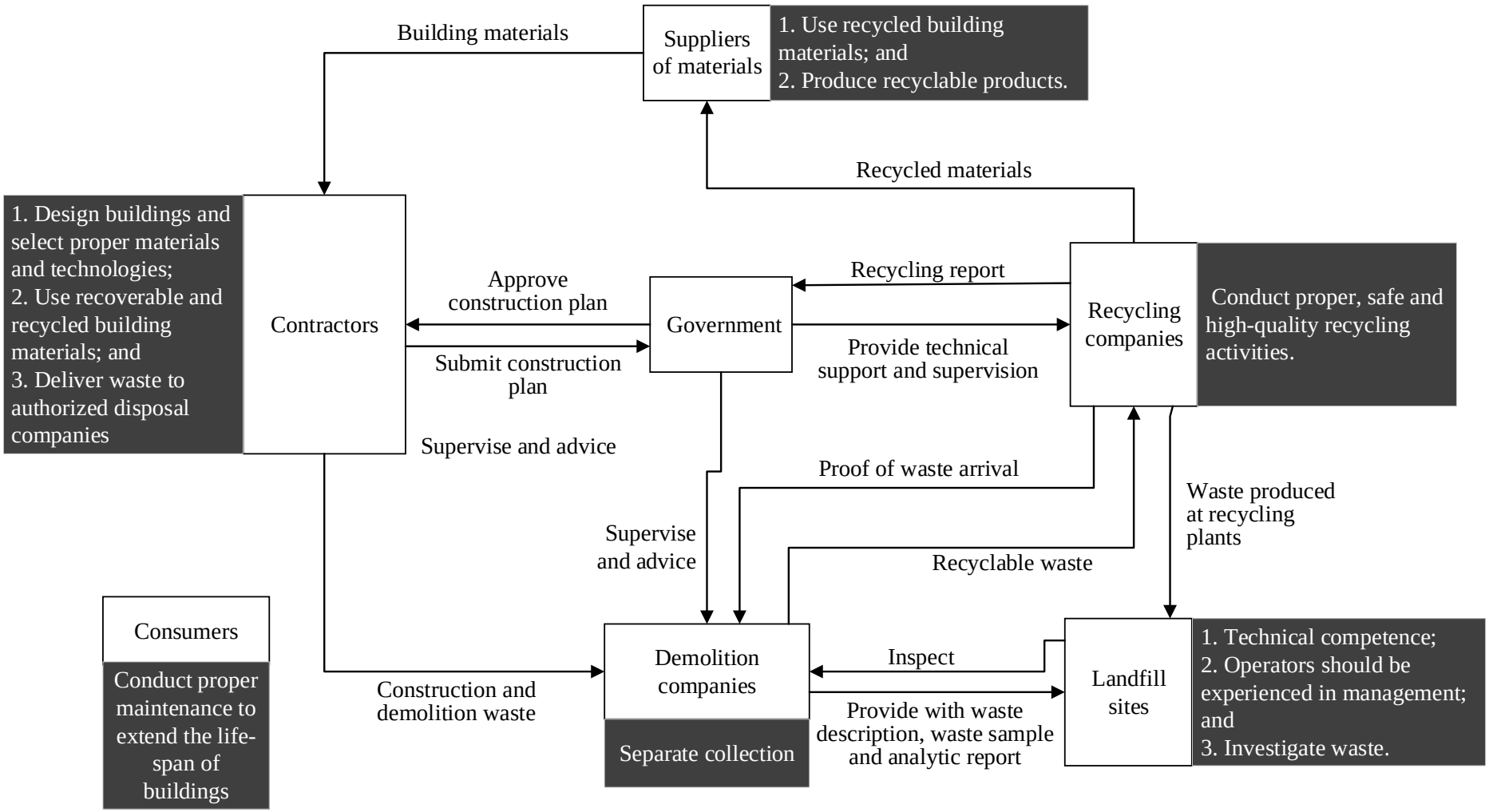


Figure 4: Responsibilities of related stakeholders in Germany

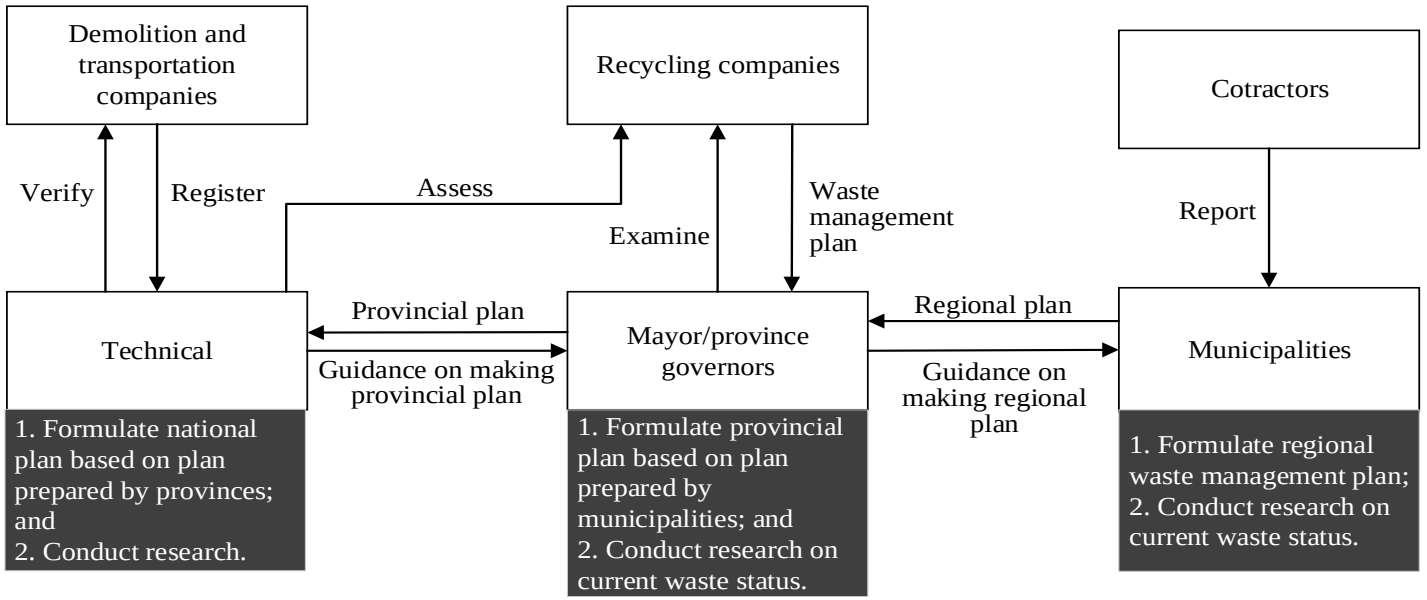


Figure 5: Government responsibilities in South Korea

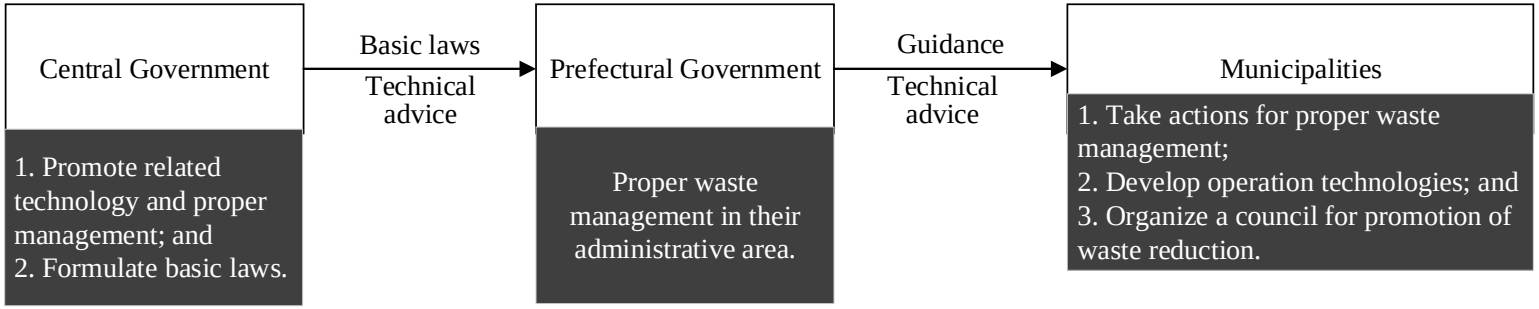


Figure 6: Government responsibilities in Germany

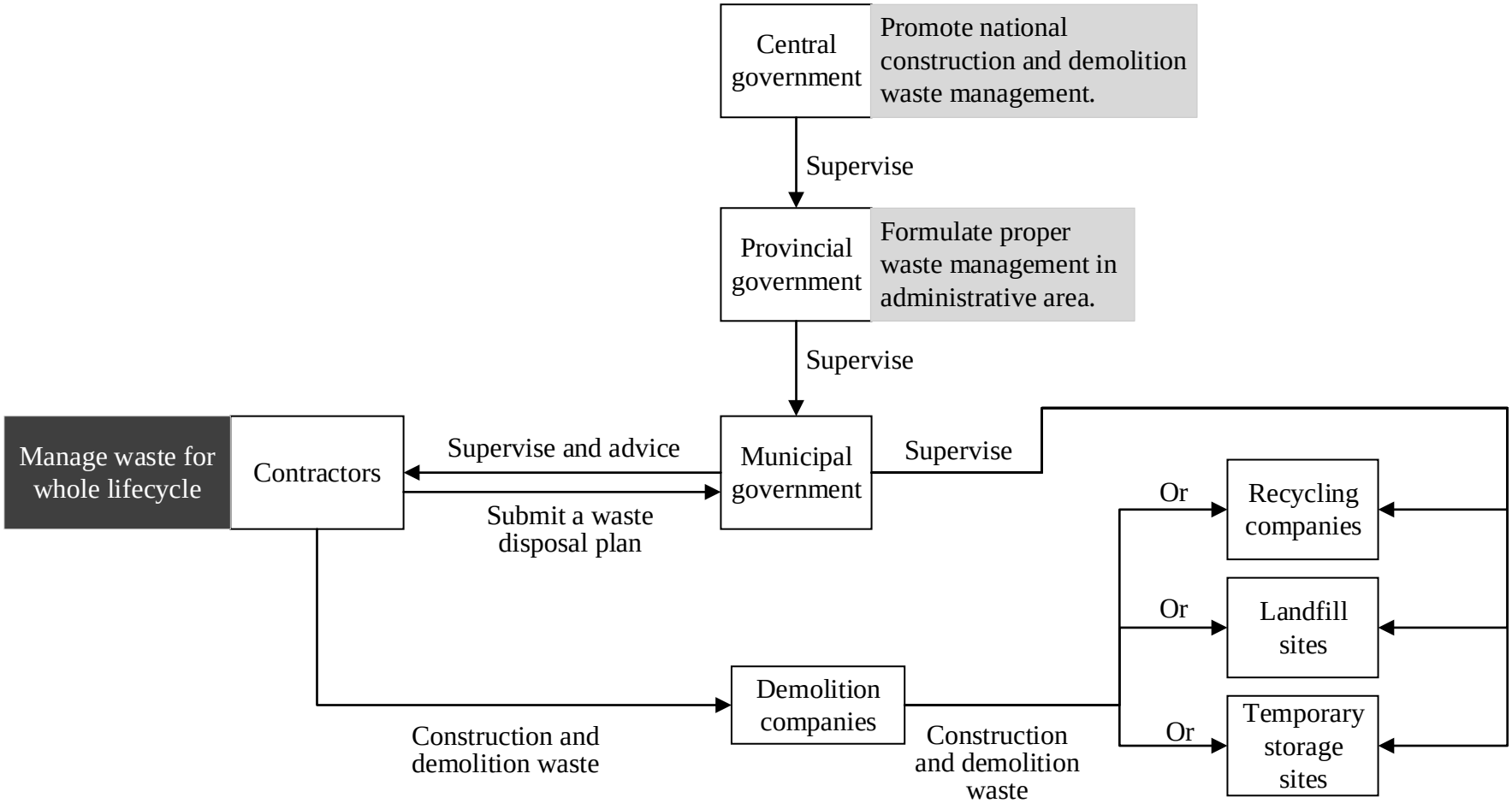


Figure 7: Responsibilities of governments in China

2.5.4 Supervision and penalties

Supervision and penalties are necessary to reinforce the obedience of related stakeholders. Appropriate use of penalties is critical for achieving high management performance (Maurer et al., 2003). Additionally, supervision is useful for evaluating the work performance (Nasution, 2017) and helps related stakeholders enhance their waste recycling performance. Supervision and penalties are considered as influencing factors in construction and demolition waste management.

Lack of penalty for other stakeholders

Table 14 presents a comparison of supervision and penalties. China conducts nationwide inspections targeting fly-tipping (P-1). However, the penalties faced by related stakeholders who fail to fulfil their responsibilities are not presented in the Chinese regulations at national level (P-2). Appropriate use of penalties could be used to reinforce the obedience of related stakeholders and trigger an efficient recycling chain. Japan, South Korea and Germany outline rules for violations by relevant stakeholders. For instance, the Waste Management and Public Cleansing Law (1970) in Japan has been continuously updated over the past 40 years. Recycling enterprises that undertake recycling as a business without approval from the provincial government are subject to fines of up to 100,000 yen (or US $927). China can fill gaps in the law with standard clauses and terms.

Inefficient supervision system

Supervision is useful for evaluating the work performance (Nasution, 2017). Waste monitoring, tracing, and reporting are critical parts to ensure that waste disposal is compatible with public interests. Information of construction and demolition waste production is a significant prerequisite to formulate an efficient waste management (Li et al., 2013). Governmental supervision (P-3, P-4, P-7) and information exchange system (P-5) are unavailable in China. In contrast to situations in China, in South Korea, Germany, the Netherlands, Austria, the United Kingdom and Italy, all the related parties, including contractors, demolition, transportation, and recycling companies and landfill sites, are required to keep a record book and submit their records to governing bodies for inspection (P-7). Regular data collection (P-3), on-site inspection (P-4), and information exchange system (P-5) are developed, allowing related stakeholders to properly manage disposal according to the waste profile. The SISTRI in Italy traces the entire lifecycle of waste, from production to disposal. The records of loading and unloading, together with the identified waste class, are used to prevent companies from

conducting unlawful activities that harm the environment. In Germany, special supervision is performed for contractors that produce >2000 kg of waste annually (P-6). The availability of records for construction and demolition waste makes it possible to investigate the efficiency of waste management, encourage proper treatment, and estimate the annual waste production.

Currently, it is difficult to estimate the volume of construction and demolition waste in China because of the unavailability of systematic data collection (Akhtar and Sarmah, 2018, Duan et al., 2015, Lu et al., 2017, Li et al., 2013).The availability of records for construction and demolition waste makes it possible to estimate the annual waste production and prevent companies from conducting unlawful activities. China should collect validated records and enhance on-site inspection to calculate total volumes of construction and demolition waste and trace the movement of waste. In order to better improve management efficiency, an electrical platform for data sharing could be developed. Contractors, collectors, recyclers, operator of landfill sites could login in the system and record the waste dynamically. The platform could be accessible to all the related stakeholders.

Table 14: Comparison of supervision and penalties

Ref.	Supervision and penalties	China	Japan	South Korea	Germany	Netherlands	Austria	United Kingdom	Italy
P-1	Penalty for illegal dumping	C-4	J-1	K-2	D-1				
P-2	Penalty for other violations		J-1	K-2	D-1				
P-3	Regular data collection for recycling status		J-9			N-1			
P-4	Enhanced monitoring and on-site inspection		J-9, J-10						
P-5	Information exchange system		J-9, J-10	K-2					T-3
P-6	Special supervision for contractors that produce large amounts of waste				D-1				
P-7	Related parties provide information and keep a record book			K-2, K-3	D-1	N-1	A-2, A-6, A-8	U-1	T-3

Chapter 3: Case studies

3.1 Introduction

As described in Chapter 2, although a set of documents and policies were issued at a national level to encourage recycling of construction and demolition waste, these documents are not detailed enough to further guide the practice of waste management. In China, the practice of construction and demolition waste management is dependent on the policies from the provincial or municipal governments (Menegaki and Damigos, 2018), which provide a more specific guidance on waste management (Huang et al., 2018). For instance, these documents specify the management responsibility of related stakeholders, detailed information of governmental incentives and regulations on following treatments (Huang et al., 2018). However, the performance of construction and demolition waste varies across different regions, e.g., 20% in Shanghai, 16% in Shenzhen (Ghisellini et al., 2018), and 5% in Chongqing (Zhao et al., 2010), because there are various factors, including different local policies and the number of recycling facilities, which would influence the practice of waste management (Jin et al., 2017). As systematic data collection is unavailable and official data are not documented (Akhtar and Sarmah, 2018), the current practice of the construction and demolition waste management in industry remains unknown. However, it is of great importance to understand the current industry practice, because it is tightly related to efficiency of regulations, which is critical to decision-making and further improvement in related regulations.

Case study is an ideal methodology when an in-depth investigation is needed (Tellis, 1997). In previous studies, case study is a major method for data collection in researches related to construction and demolition waste management (Yuan and Shen, 2011). An increasing amount of literatures conduct case studies to investigate construction and demolition waste management in different Chinese cities, including Shenzhen (Yuan, 2017, Yu et al., 2018, Lu et al., 2011, Wu and Yuan, 2016), Hong Kong (Tam and Tam, 2008, Au et al., 2018, Hao et al., 2011, Hao et al., 2008), Beijing (Shi et al., 2019), Shanghai (Jin et al., 2017), Tianjin (Zhao et al., 2009) and Chongqing (Xu et al., 2012, Wang et al., 2013, Yong et al., 2016, Zhao et al., 2010). Previous literatures evaluated construction and demolition waste management in the scope of different Chinese cities is however insufficient, while some case studies were carried out only in specific cities. With the increasing studies on the waste management in China, case study appears to be the most appropriate method to explore industry practice of construction and demolition waste management in its real-life context (Yuan and Shen, 2011).

In the Chapter 3, site visits to 10 different Chinese cities were conducted to examine the current status of construction and demolition waste management in China and provide useful recommendations for Chinese policymakers.

3.2 City selection

In 2018, the Ministry of Housing and Urban-Rural Development of the People's Republic of China (2018) selected 35 pilot cities to mandatorily promote construction and demolition waste management (Table 15). The 35 pilot cities in China (Figure **8**) were selected, as they are the most developed cities in economy, industry, commerce, and municipal strategies. The 35 pilot cities are required to follow the national guidance and to implement a series of policies for regulating construction and demolition waste production, transportation, and treatment. It is expected that successful implementation of construction and demolition management in these cities could provide useful references to other non-pilot cities when promoting the waste management to the whole country. Additionally, as construction activities are the major economic activities, these cities have a more urgent need to manage waste compared with other Chinese cities.

Table 15: 35 pilot cities (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2018)

Ref.	City	Location	Ref.	City	Location
1	Beijing Direct-administered municipalities	Northern China	19	Quanzhou, Fujian Province	Eastern China
2	Handan, Hebei Province	Northern China	20	Fuzhou, Fujian Province	Eastern China
3	Tianjin, Direct-administered municipalities	Northern China	21	Shanghai Direct-administered municipalities	Eastern China
4	Huhhot, Inner Mongolia Autonomous Region	Northern China	22	Xuchang, Henan Province	South-Central China
5	Qingdao, Shandong Province	Eastern China	23	Zhenzhou, Henan Province	South-Central China
6	Jinan, Shandong Province	Eastern China	24	Luoyang, Henan Province	South-Central China
7	Linyi, Shandong Province	Eastern China	25	Shangqiu, Henan Province	South-Central China
8	Tai’an, Shandong Province	Eastern China	26	Changsha, Hunan Province	South-Central China
9	Changzhou, Jiangsu Province	Eastern China	27	Guangzhou, Guangdong Province	South-Central China

Ref.	City	Location	Ref.	City	Location
10	Yangzhou, Jiangsu Province	Eastern China	28	Dongguan, Guangdong Province	South-Central China
11	Suzhou, Jiangsu Province	Eastern China	29	Shenzhen, Guangdong Province	South-Central China
12	Nantong, Jiangsu Province	Eastern China	30	Liuzhou, Guangxi Autonomous Region	South-Central China
13	Huainan, Anhui Province	Eastern China	31	Nanning, Guangxi Autonomous Region	South-Central China
14	Huaibei, Anhui Province	Eastern China	32	Xi'an, Shaanxi Province	Northwestern China
15	Bengbu, Anhui Province	Eastern China	33	Chengdu, Sichuan Province	Southwestern China
16	Jinhua, Zhejiang Province	Eastern China	34	Chongqing Direct-administered municipalities	Southwestern China
17	Hangzhou, Zhejiang Province	Eastern China	35	Yuxi, Yunnan Province	Southwestern China
18	Huzhou, Zhejiang Province	Eastern China			

Figure 8: 35 pilot cities (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2018)

In this study, 10 Chinese cities were selected as case studies (Figure 9), because they are the most populous and developed regions in China, which could be the representative sample in the current and future urbanization trend in this country. Eight of these 10 cities are among the 35 pilot cities: Shanghai (Direct-administered municipalities), Hangzhou (Zhejiang Province), Suzhou (Jiangsu Province), Chongqing (Direct-administered municipalities), Chengdu (Sichuan Province), Xi'an (Shaanxi Province), Changsha (Hunan Province), and Shenzhen (Guangdong Province). Shanghai and Chongqing are under the direct administration of central government, whose political status is higher than that of provinces. The other six cities are provincial administration headquarters with the highest GDP in their provinces. In the last couple of decades, policies related to construction and demolition waste management has been introduced in these cities. In addition to these eight cities, Nanjing (Jiangsu Province) and Zhoukou (Henan Province) were selected. Nanjing is capital city of Jiangsu Province, which is famous for its historic and cultural background. Although its construction and demolition waste recycling started late, local government is exploring an integrated construction and demolition waste management system. Zhoukou is located in Henan province and there are several scaled recycling enterprises in this city, which could provide information related to the current status of the waste management in this city. Recycling companies in these 10 cities consent requests from the research team for site visits and interviews and provided with access to recycling industries.

Figure 9: 10 selected cities

Eastern China: Shanghai, which is a commercial, financial, and political centre, is one of the most advanced cities in China with regard to construction and demolition waste management, with a recycling rate of 20% (Huang et al., 2018). The Shanghai Municipal People's Government (2017) enacted and updated related regulations in the past decade, but further improvement is needed (Ding and Xiao, 2014). To aid the development of the construction and demolition waste recycling industry, the Shanghai Municipal Government provides subsidies to recycling companies (Shanghai Municipal Development and Reform Commission, 2019b). In 2019, after governmental evaluation, one construction and demolition waste recycling company was selected for a subsidy of 1.57 million yuan (US $219,424) (Shanghai Municipal Development and Reform Commission, 2019a).

Hangzhou and Suzhou have two of the largest economies in the Yangtze river delta. These cities continuously improve their construction and demolition waste management systems and strengthen collaboration between departments and supervision systems (Tianjin Housing and Urban-Rural Construction Commission, 2019). The annual generation of construction and demolition waste in Hangzhou amounts to 12 million tonnes (Xu and Du, 2019). In recent years,

as environmental protection has attracted increased attention, construction and demolition waste management has been a top priority of the municipal government (Wang et al., 2016). Construction and demolition waste management to respond to the rapid economic urbanisation and the extensive construction activities in Suzhou are among the top concerns of the local government (Bao et al., 2019). Management on Construction and Demolition Waste in Suzhou was introduced in 2005, forming an integrated recycling chain (He et al., 2015).

With continuous urbanisation, Nanjing is at the peak of their construction activities. The amount of construction and demolition waste has continued to increase. The quantity of construction and demolition waste generated in 2020 is expected to be 16.68 million tonnes, including 3.75 million tonnes for infrastructure construction and 12.29 million tonnes for building construction (Liu, 2019). The present state of construction and demolition waste recycling in Nanjing exhibits a serious mismatch, as the legislation lags behind the market demand (Nanjing Municipal Commission of Housing and Urban-Rural Development, 2019). Management on Construction and Demolition Waste in Nanjing (Table 16) was issued in 2019 to adjust the regulations on waste management in Nanjing and simultaneously accumulate experience through experimental projects (Nanjing Municipal Commission of Housing and Urban-Rural Development, 2019). The existing policies related to the waste management in Nanjing are presented in Table 16.

Table 16: Existing policies on construction and demolition waste management in Eastern China

City	Law enacted	Year	Reference
Shanghai	Management on Construction and Demolition Waste in Shanghai	2017	(Shanghai Municipal People's Government, 2017)
	Recycling of Construction and Demolition Waste in Shanghai	2019	(Shanghai Municipal People's Government, 2019)
	Financial Subsidy for Circular Economy and Comprehensive Use of Resources	2019	(Shanghai Municipal Development and Reform Commission, 2019b)
Hangzhou	Plan for Construction and Demolition Waste Management in Hangzhou	2018	(Hangzhou Municipal Government, 2018)
Suzhou	Management on Construction and Demolition Waste in Suzhou	2005	(Suzhou Municipal Government, 2005)

City	Law enacted	Year	Reference
Nanjing	Management on Construction and Demolition Waste in Nanjing	2019	(Nanjing Municipal Commission of Housing and Urban-Rural Development, 2019)

Western China: Chongqing, Chengdu, and Xi'an are the three most populous cities in western China, forming the west triangle economic zone and accounting for 40% of western China's GDP (Zhang, 2009). There are two construction and demolition waste recycling plants in Chongqing. One is located in Heishizi district, and the other is in Nan'an district. They process 800,000 and 600,000 tonnes of waste per year, respectively (People's Daily, 2019). Because of the large number of governmental departments involved in construction and demolition waste management, it is difficult to supervise the whole waste disposal chain in Chongqing (Hu et al., 2011). Thus, governmental supervision focuses on waste transportation and whether the waste ends up at authorised disposal sites (Hu et al., 2011).

With a mature disposal approval system and numerous recycling businesses, Xi'an has developed an integrated construction and demolition waste recycling system (AECOM Asia Company Limited, 2018). Management on Construction and Demolition Waste in Xi'an (Xi'an Municipal Government, 2003), Regulation on Construction and Demolition Waste Management in Xi'an (Xi'an Municipal People's Congress, 2012), and Strengthening the Utilisation of Construction and Demolition Waste in Xi'an (Xi'an Municipal Government, 2018) were issued in succession, along with regulations related to transportation, supervision, and comprehensive evaluation (AECOM Asia Company Limited, 2018). There are 27 recycling companies in Xi'an, which are capable of recycling approximately 77,730 tonnes of construction and demolition waste per day (Shu and Zhang, 2019).

Governmental policies and regulations are being developed in Chengdu for encouraging the development of the recycling industry. The Chengdu Municipal People's Congress (2014) issued Management on Construction and Demolition Waste in Chengdu in 1998 and continuously upgraded the waste management system in the subsequent ten years, with a focus on waste recycling, transportation, and departmental cooperation. In 2016, target recycled-material contents of >15% and 5% were set for infrastructure and building projects, respectively (Jin et al., 2017, Chengdu Municipal Government, 2016). The existing policies related to construction and demolition waste management in Chongqing, Xi'an, and Chengdu are presented in Table 17.

Table 17: Existing policies on construction and demolition waste management in Western China

City	Law enacted	Year	Reference
Chongqing	Management on Construction and Demolition Waste in Chongqing	2014	(Chongqing Municipal Administration Commission, 2014)
Xi'an	Management on Construction and Demolition Waste in Xi'an	2003	(Xi'an Municipal Government, 2003)
	Regulations on Construction and Demolition Waste Management in Xi'an	2012	(Xi'an Municipal People's Congress, 2012)
	Strengthening the Utilization of Construction and Demolition Waste in Xi'an	2018	(Xi'an Municipal Government, 2018)
Chengdu	Management on Construction and Demolition Waste in Chengdu	2014	(Chengdu Municipal People's Congress, 2014)
	Financial Subsidy for Construction and Demolition Waste Recycling Industries	2016	(Chengdu Municipal Government, 2016)

South-Central China: Current management in Changsha might fail to follow the increasing pace of construction activities, as there were only two recycling enterprises in 2014 (Huang et al., 2018). The Bureau of Housing and Urban-Rural Development of Changsha (2019) formulated polices related to construction and demolition waste recycling, representing an urgent need to address the issue of waste generation. Changsha Municipal Government (2017) introduced a subsidy of approximately 3 yuan (US $0.43) per cubic meter of construction and demolition waste recycled.

Shenzhen—one of the economically developed cities in southern China—has begun to recycle construction and demolition waste into recycled aggregate and bricks, whereas some underdeveloped cities have not taken measures to treat the waste (Yuan, 2017). Over the past few years, Shenzhen has played a leading role toward achieving sustainable construction and demolition waste management in China, partly owing to its many recycling enterprises (AECOM Asia Company Limited, 2018).

Zhoukou is located in Henan province. High-speed construction forces Zhoukou governing bodies to take responsibility for waste management. In order to establish a recycling-oriented society, Zhoukou government spent a great effort learning construction and demolition waste

management from Xuchang, whose recycling rate is ahead in China (AECOM Asia Company Limited, 2018). Management on Construction and Demolition Waste in Zhoukou (2017) provides a background of current construction and demolition waste management in this city, which is featured for a franchise operation model. The existing policies related to construction and demolition waste management in Zhoukou are presented in Table 18.

Table 18: Existing policies on construction and demolition waste management in South-Central China

City	Law enacted	Year	Reference
Changsha	Regulation on Construction and Demolition Waste Transportation in Changsha	2015	(Changsha Municipal Government, 2015)
	Management on Construction and Demolition Waste in Changsha	2017	(Changsha Municipal Government, 2017)
	Construction and Demolition Waste Management in Changsha	2019	(Bureau of Housing and Urban-Rural Development of Changsha, 2019)
Shenzhen	Management on Construction and Demolition Waste in Shenzhen	2007	(Shenzhen Municipal Government, 2007)
Zhoukou	Management on Construction and Demolition Waste in Zhoukou	2017	(Zhoukou Municipal Government, 2017)

3.3 Site visits

There is a policy-practice gap between management on paper and industry practices (Wafula et al., 2014). Despite the introduction of municipal policies in the 10 selected cities, it seems that the industry practices of construction and demolition waste management have not been documented. For instance, information, such as the actual distribution of subsidies, methods used to calculate the waste volume or the role of each stakeholder in the waste tracing system, is unavailable in government documents. Therefore, direct investigation to visit recycling industries is needed to collect realistic data, in order to assess the obstacles to the promotion of construction and demolition waste management in different Chinese cities.

Ethical approval for this project was granted by the Western Sydney University Human Research Ethics Committee (HREC). The HREC operates in accordance with the National Statement on Ethical Conduct in Human Research of 2007 (Updated 2018). Approval of this

project is valid from 3 October 2019 to 3 October 2020. The HREC Approval Number is H13470. The letter for ethical approval has been included in the Appendix 1.

As part of the research design, the names and contact details (e.g., phone number, e-mail address, or WeChat number) of participants were recorded. Information collected from each site was linked with each participant, for organisational purposes. However, the links and private information are not disclosed in this thesis.

3.4 Data analysis

To evaluate the current status of construction and demolition waste management in China, 10 construction and demolition waste recycling plants in different Chinese cities were visited. Interviews were adopted during the site visits. The interviews were varied in duration between 1 hour to 1.5 hour long. Interview questions are presented in Appendix 2. The questions asked during the interviews are focused on: (1) basic information of recycling plants, (2) government incentives, (3) local policies, (4) supervision and penalties, and (5) difficulties faced by recycling industries. Photographs taken at different recycling plants are presented in Appendix 3. The details collected from the case studies can be supported by these pictures taken. For instance, these photos could imply information related to environment of workshops, area of industries, facilities, and main products. The original data collected from interviews are presented in Appendix 4. This chapter initiated analysing current construction and demolition waste management in different Chinese cities by organising and managing the original data into Table 19: Basic information collected from recycling plants, Table 20: Incentives provided by local governments, Table 21: Local policies, Table 22: Supervision and penalties and Table 23: Difficulties faced by recycling industries. It is important to mention that detailed information of VAT exemptions for waste recycling industries in Table 20 and penalty for illegal dumping in Table 22 are from review of local polices rather than interviews, because most interviewees were unable to tell the exact of tax deduction for recycling businesses and penalty for illegal dumping. Other data in these tables are originated from interviews. Based on these tables, another round of analysis is conducted to explain and assess the current waste management in the 10 selected cities from the perspectives of provision of incentives, governmental regulations, supervision and penalties and difficulties faced by recycling industries. Consequently, obstacles faced by the ten cities are identified.

3.4.1 Basic information

Table 19 presents basic information for the 10 recycling plants.

Table 19: Basic information collected from recycling plants

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
Area	78,000 m^2	1,066,667 m^2	2,991 m^2	1,000,000 m^2	5,000 m^2	2,000-2,667 m^2	30,000 m^2	65,333 m^2	2,500 m^2	1,066,667 m^2
State-owned or private company	Private	State-owned	State-owned	Private	Private	State-owned	Private	State-owned	Private	Private
Is demolition included in business	No.	No.	No.	No.	No.	No.	Yes.	No.	Yes.	No.
Source	Cooperation with local contactors	Contract with municipal government; purchase	Contract with municipal government; and purchase for free	Purchase; cooperation with local contractors	Cooperation with local contractors	Cooperation with local contractors; and waste from nearby small enterprises during down time	Contract with municipal government	Purchase	Contract with municipal government	Contract with municipal government
Quantity of waste recycled/day	4,000 tonnes/d	2,000 tonnes/d	30 tonnes/d	4,000 tonnes/d	7,000 tonnes/d	420–480 tonnes/d	10,000 tonnes/d	2,000 tonnes/d	1,500 tonnes/d	3,000 tonnes/d
Mobile or fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Mobile	Mobile	Fixed	Mobile	Fixed
Number of production lines	3 crush lines	3 crush lines	1 crush line	2 crush lines	2 crush lines	1 crush line	6 crush lines	2 crush lines	1 crush line	1 crush line
Products	Recycled aggregate; bricks; and red brick powder	Bricks	Coarse aggregate	Recycled aggregate; and recycled-aggregate concrete (C25 and below)	Recycled aggregate; light panel wall; and recycled-aggregate concrete (C30 and below)	Recycled aggregate; and bricks	Recycled aggregate; bricks; and recycled-aggregate concrete (C15 and below)	Recycled aggregate; and recycled-aggregate concrete (C5-8)	Recycled aggregate; bricks; and recycled-aggregate concrete (C20 and below)	Recycled aggregate

Private or state-owned company

These 10 recycling sites were investigated from December 2019 to January 2020. In Hangzhou and Nanjing, only state-owned companies are qualified to recycle construction and demolition waste. Hangzhou is divided into 10 areas by the authorities. Multiple construction and demolition waste recycling plants were nominated to recycle waste in each area. Specifically, in the Yuhang area, two state-owned recycling companies were nominated to treat waste. Approximately 100 private recycling companies would shut down permanently in Nanjing, most of which are small-scale business and operate without business license. At present, assessments of the production environment of fixed industry are extremely strict. Fixed recycling industries should be equipped with wastewater recycling systems, dust suppression spray systems, and sealed workshops. It is difficult for private companies to establish a standard production environment, which requires substantial funding. In Suzhou, the local government uses drones to supervise the production environment of recycling industries. Without proper environmental protection measures, tax deduction would be cancelled for 3 years. This recycling project in Nanjing is an experimental project, and the state-owned company can play a guiding role in promoting a standard operating procedure throughout the city. Seven fixed construction and demolition waste recycling plants are expected to be established in the next few years in Nanjing. The management, production, and operation of these recycling plants will follow the present recycling industry. Experience from this industry can be useful for the development of standards for construction and demolition waste management at a municipal level.

Source of construction and demolition waste

There are three primary ways to obtain the source of construction and demolition waste. (1) A few companies signed contracts with the local government to ensure a supply of construction and demolition waste, including Chengdu, Xi'an, Nanjing, Hangzhou, and Zhoukou. For instance, the construction and demolition waste produced in the Fengxi renovation area of Xi'an must be transported to the nominated plant for recycling. (2) Industries in Shanghai, Shenzhen, Changsha, and Suzhou cooperate with local contractors that pay for the transportation and recycling fees. (3) The industry in Chongqing must purchase construction and demolition waste from contractors to maintain operation. The remote location of this industry has significantly increased the transportation costs. The transportation cost increases significantly when the distance from demolition site to recycling plant is >25 km, and

contractors prefer to transport the waste to landfill sites for reducing the cost. However, the closet demolition site is 28 km from this recycling plant; thus, the industry faces a lack of a waste source.

Mobile or fixed industry

Different types of waste can be directly separated in the mobile industries in Chengdu and Changsha. Concrete can be demolished and crushed into recycled aggregates at a demolition site. In contrast to the Chengdu industry, in which demolition is included in the business, production in the Changsha industry is significantly influenced by the demolition speed. With the capability to deal with 150–200 tonnes of construction and demolition waste per hour, the Changsha industry can only recycle 70–80 tonnes of the waste, because of the downtime in demolition. Despite the lowest transportation cost from mobile industries, complaints from surrounding residents regarding noise and dust limit the growth of mobile industries in some cities, such as Chongqing. As the scale of city renovation has decreased, surrounding residents are affected by recycling activities. As urbanisation progress in Changsha remains continuous and numerous buildings are under reconstruction, recycling activities do not affect surrounding residents who have relocated. Without a city plan regarding land use for construction and demolition waste recycling, the development of a mobile industry appears to be a better choice for Changsha than the development of a fixed industry.

Products

The properties of recycled-aggregate concrete largely depend on the properties of the construction and demolition waste (Yehia et al., 2015). Converting construction and demolition waste into recycled aggregates for non-structural applications is the most common method for recycling the waste (Tam et al., 2009). As indicated by Table 19, a primary product from construction and demolition waste in most cities is recycled aggregate. In Xi'an, recycled aggregate is the only product in this industry and can be used for C20 concrete production. Coarse aggregates produced in the Nanjing industry are used in the subbase layer, as there is a large demand for road pavement. High-calcium stones are added to the construction and demolition waste during the crushing process in Chongqing, enhancing the strength of the recycled aggregates. Additionally, bricks—including water permeable bricks, grass bricks, and bricks for tactile paving—are industry-leading products. Specifically, the Hangzhou industry only produces bricks, because the standards for recycled aggregates vary among the different areas of Hangzhou. Recycled aggregates produced in this industry are difficult for customers

from other areas to accept. Recycled aggregates from construction and demolition waste are expected to replace part or all of the natural aggregates in concrete (Guo et al., 2018). In Chengdu, Shanghai, Shenzhen, and Zhoukou, recycled aggregates can replace part of the natural aggregates in low-strength concrete for non-structural applications. With appropriate mix design and construction, recycled-aggregate concrete can be safely used as a structural material in civil engineering (Xiao et al., 2012a, Dimitriou et al., 2018). However, to achieve wider use of recycled aggregate in structural applications, research and governmental promotion are needed. Red brick powder is a special product produced by the Suzhou industry. As broken red bricks transported to recycling plants cannot be processed into high-quality aggregates, crushing red bricks is an ideal recycling solution. The red brick powder is sold back to the market.

3.4.2 Governmental incentives

Table 20 presents information related to governmental incentives.

Table 20: Incentives provided by local governments

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
VAT exemptions for waste recycling industries	70% VAT deduction	100% VAT exemption	70% VAT deduction	50% VAT deduction	100% VAT exemption	70% VAT deduction	70% VAT deduction	70% VAT deduction	100% VAT exemption	50% VAT deduction
Subsidy for waste recycling	Yes. Subsidy for construction and demolition waste recycling is approximately 120 yuan/tonne (or US $17).	No.	No.	Yes.	No.	Yes. Subsidy for construction and demolition waste recycling is approximately 3 yuan/m^3 (or US $0.43).	No.	No.	No.	No.
BOT for recycling businesses	Yes. Two BOT rights were obtained by this company in 2019.	No, but there is a contract between this company and the local government to ensure a waste source.	Yes.	No, but there is a contract between this company and the local government to ensure a waste source.	No. BOT was cancelled to avoid monopoly.	No.	Yes, the company has had BOT rights since 2017.	No.	No, but there is a contract between this company and the local government to ensure a waste source.	No, but there is a contract with the local government to ensure a waste source.
Cheaper price of electric and water use	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
Cheaper land use	Yes. Local government allocated land for this company and provided a lower rental price.	Yes. Local government allocated lands to this recycling company and provided a lower rental price.	Yes. Local government allocated lands to this company and provided a lower rental price.	No.	Yes. Rental price is 1 yuan/m^2/year (or US $0.14).	No. Land use for construction and demolition waste recycling is not included in the city plan. There are no land resources for fixed industries.	No.	No.	Yes. Local government allocated lands to this company and provided a lower rental price.	No.
Mandatory use of recycled products	No. Local government encourages the use of recycled building materials. Recycled products are the first consideration in governmental projects.	No. Local government encourages the use of recycled building materials. Recycled products are the first consideration in governmental projects.	Yes. Nanjing local government has required mandatory use of recycled aggregates since 2019.	Yes. Concrete below C25 should use a least 15% recycled aggregates (since 2018).	Yes. 20% building materials recycled from construction and demolition waste should be used in construction.	No. Contractors who use the recycled products can obtain credits, which can be used for governmental funding or tax deduction.	No. Local government encourages the use of recycled building materials. Recycled products are the first consideration in governmental projects.	No. Contractors who use 30% building materials recycled from construction and demolition waste can obtain subsidies or tax deductions from local government.	No. Local government encourages the use of recycled building materials. Recycled products are the first consideration in governmental projects.	No. Local government encourages the use of recycled building materials. Recycled products are the first consideration in governmental projects.

Tax deduction

Regarding tax deductions, different cities follow different rules. For instance, recycling companies in Xi'an and Shanghai can claim 50% deductions in the VAT, according to the State Taxation Administration (2015). However, subsidies for construction and demolition waste recycling have not been implemented in most cities (exceptions include Shanghai, Changsha, and Suzhou). The Suzhou local government subsidises recycling of construction and demolition waste by 120 yuan/tonne. Although subsidies can provide immediate incentives to recycling industries, several cities have no recycling subsidies, because of financial constraints on the local government. In Changsha, a scoring system is used for companies that employ recycled aggregates in building-material production or construction and wish to apply for governmental funds or a concessional loan. In Chongqing, additional funds or tax deductions are granted to contractors who use $\geqslant$30% recycled building materials in construction.

BOT contract

BOT contracts can efficiently link the benefits or welfare of the private sector with the local government (Wang et al., 2018). Construction and demolition waste recycling in Nanjing, Zhoukou, and Suzhou is developed on a BOT basis. A BOT contract was awarded to the Zhoukou industry in 2017 and lasts for 30 years. Additionally, the Suzhou industry obtained two BOT contracts in 2019, which last for 20 years. One contract is related to construction and demolition waste transportation, and the other is related to construction and demolition waste recycling. Industries in Hangzhou, Shanghai, and Xi'an signed contracts with the local governments to ensure the source of construction and demolition waste. These contracts are similar to BOT contracts. In Shenzhen, the BOT was cancelled to avoid a monopoly and to stimulate the involvement of private recycling companies. The Changsha local government intends to award BOT contracts to six recycling companies, to ensure that there is one construction and demolition waste industry in each area.

Land use

Construction and demolition waste management is a complex system involving waste generation, transportation, recycling, disposal, and land use (Yuan, 2017). Land use is linked to waste storage, production, and product preservation. Large-scale land use imposes an economic burden. The Hangzhou, Nanjing, and Suzhou local governments have allocated land to recycling industries and reduced the prices for land rentals. The Shenzhen government

charges only 1 yuan/m^2 (or US $0.14) per year for land use, to encourage the participation of waste recyclers.

Mandatory use of building materials recycled from construction and demolition waste

Mandatory use of recycled materials from construction and demolition waste can increase recycling, improve social acceptance, and contribute to long-term operation. In Shenzhen, construction projects must employ 20% recycled materials from construction and demolition waste. In Shanghai, concrete below C25 should consist of ⩾15% recycled aggregates (since 2018). In Suzhou, Hangzhou, Xi'an, Chengdu and Zhoukou, recycled building materials are the first consideration in governmental projects, without mandatory requirements for local contractors.

3.4.3 Local policies

Table 21 presents information related to local policies.

Table 21: Local policies

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
Priority to reduce waste generation	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Forbidden exportation	No, but waste exportation requires governmental approval.	Yes. Waste produced in Hangzhou should be disposed of in this city.	No, but waste exportation requires governmental approval. A small amount of waste is transported to other provinces.	Yes.	No, but waste exportation requires governmental approval.	No. A small amount of waste is transported to Jiangxi Province.	No.	No.	No.	Yes. Waste produced in Xi'an should be disposed of in this city.
Classification of construction and demolition waste	Yes, a rough classification.	No.	No.	Yes, a rough classification.	No.	Yes, a rough classification.	No.	No.	Yes	Yes, a rough classification.
Separate collection	Yes.	No.	No	Yes.	No.	Yes.	No.	No.	Yes.	Yes.
Strict landfill policy	Yes, landfilling is not allowed.	Yes. Landfilling is normally not allowed and must be approved by local government	Yes. Landfilling is normally not allowed and must be approved by local government.	No.	Yes. Landfilling is normally not allowed and must be approved by local government. Unrecyclable waste can be landfilled but needs special treatment before landfilling.	No, there is no official check for landfilling. Numerous private landfill sites are not under supervision of local government.	Yes, landfill is not allowed.	No. Five landfill sites are under construction.	Yes. Only non-harmful waste can be landfilled.	Yes.

Priority to reduce waste generation

The focus of most cities is reducing the volume of construction and demolition waste. In recent years, building prefabrication (as an efficient approach to control waste generation) has been strongly promoted in China (Chang et al., 2018). Application of prefabrication technology in the construction industry can reduce the amount of waste generated and lead to sustainable urbanisation (Hong et al., 2018). In Chengdu and Nanjing, the local governments encourage waste reduction in design, material selection, and construction.

Waste exportation

In Shanghai, Hangzhou, and Xi'an, waste exportation is strictly prohibited. Construction and demolition waste produced in these cities should be disposed of within the same cities. Waste exportation should be approved by the local government in Nanjing, Xi'an, Shenzhen, and Suzhou. However, restrictions on waste exportation may lead to illegal dumping. When the Shanghai government banned waste exportation, there was a significant increase in illegal dumping (The Beijing News, 2016). Because the landfill capacity is nearly full, a small amount of construction and demolition waste produced in Changsha is transported to surrounding provinces, such as Jiangxi Province. There is no restriction on waste exportation in Chengdu, Zhoukou, or Chongqing, but the transportation costs for waste exportation to other cities and provinces are high.

Classification of construction and demolition waste

The Shanghai and Changsha local governments enacted policies to guide the classification of construction and demolition waste, including Management on Construction and Demolition Waste in Shanghai (Shanghai Municipal People's Government, 2017) and Management on Construction and Demolition Waste in Hunan Province (People's Government of Hunan Province, 2019). Although the operation conditions vary among industries, a common waste classification has been developed for managing waste. Construction and demolition waste can be roughly classified into three categories: (1) recyclables, (2) waste that can be burnt, and (3) waste that should be further studied. Steel, timber, and concrete waste belong to the first category. Steel should be separated from concrete waste at the demolition site and sold back to the market. In Chengdu, waste wood can be used to produce paper. Although construction and demolition waste cannot legally be mixed with municipal waste before landfilling or recycling, it is difficult to separate clean concrete waste from other class of waste. For instance, concrete waste from road renovation is mixed with asphalt, which would reduce the strength of recycled

aggregates. The second category comprises municipal waste, which will end up in incineration plants. Proper methods to handle waste that is unrecyclable or incombustible should be developed, such as aerated blocks. Manual sorting combined with magnetic separation plays an important role in the crushing process, to separate concrete waste from other types of waste.

Landfill ban

A landfill ban on unsorted construction and demolition waste and mandatory recycling of recyclables can increase the recycling activity (Jin et al., 2017). Currently, the construction and demolition waste generated in Chongqing, and Shanghai can lawfully end up in landfills. Five landfill sites are under construction in Chongqing. As long as the cost of disposing waste at landfills is lower than the cost of recycling, landfill will be the most common form of waste disposal in Chongqing. Disposing of construction and demolition waste at landfills is strictly forbidden in Chengdu, Hangzhou, Nanjing, Shenzhen, Zhoukou, Suzhou and Xi'an. In Xi'an, 2–3 landfill sites are established only for unrecyclable components of construction and demolition waste, and the local government prioritises waste recycling. Waste landfilling must be approved by the local government. It is difficult to determine how many landfills exist in Changsha, as many are privately owned and not under governmental supervision.

3.4.4 Supervision and penalties

Table 22 presents information related to supervision and penalties.

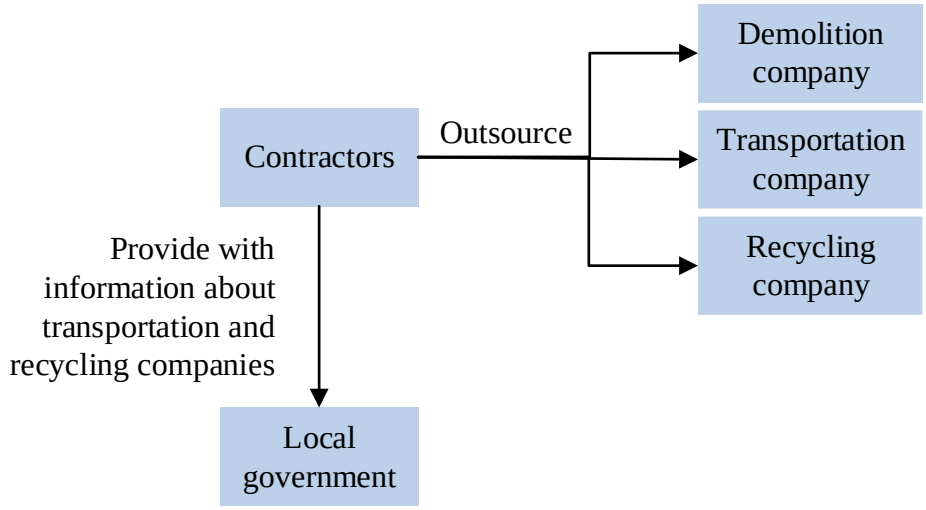
Table 22: Supervision and penalties

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
Penalty for illegal dumping	(1) Violators would be fined 10,000 yuan (or US $1,430); and (2) Violators would be sentenced, if the waste significantly harms the environment.	Violators would be fined 5,000–50,000 yuan (or US $716–$7,166).	Violators would be fined 10,000 yuan (or US $1,430).	Violators would be fined 5,000–50,000 yuan (or US $716–$7,166).	(1) Violators would be fined 5,000–50,000 yuan (or US $716–$7,166); and (2) Violators would be sentenced, if the waste significantly harms the environment.	Violators would be fined 5,000–50,000 yuan (or US $716–$7,166).	Violators would be fined 5,000–50,000 yuan (or US $716–$7,166).	Violators would be fined 5,000–50,000 yuan (or US $716–$7,166).	(1) 10,000–30,000 yuan (or US $1433–$4300) for non-hazardous waste/truck; (2) 30,000–50,000 yuan (or US $4300–$7167) for slightly hazardous waste/truck; and (3) 50,000–100,000 yuan (or US $7167–$14333) for hazardous waste/truck	Violators would be fined 10,000 yuan/truck (or US $1,430).
Penalty for stakeholders' violation	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Planned route for waste transportation (using GPS)	Yes.	Yes.	Yes. An online application is designed to trace trucks.	Yes. Waste can only be transported by special green trucks.	Yes.	Yes.	Yes.	Yes. Waste can only be transported by special yellow trucks.	Yes.	Yes.
Method to calculate waste quantity	The calculation of the waste quantity	The calculation of the waste quantity	The calculation of the waste quantity	The calculation of the waste quantity	The calculation of the waste quantity is	The calculation of the waste quantity is	The calculation of the waste quantity	The calculation of the waste	The calculation of the waste quantity is	The calculation of the waste quantity is

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
	is based on demolition amount in disposal plan.	is based on demolition amount in disposal plan.	is based on demolition amount on disposal plan.	is based on demolition amount on disposal plan.	based on demolition amount on disposal plan. landfill sites.	based on demolition amount on disposal plan. However, the calculation is not accurate, as a large number of small projects are not required to submit a disposal plan to the local government.	is based on demolition amount on disposal plan.	quantity is based on demolition amount on disposal plan.	based on demolition amount on disposal plan.	based on demolition amount on disposal plan.
Waste traceability	Card access system (Figure 13).	A 3 duplicated-bill system (Figure 12).	Card access system (Figure 14).	Figure 11.	An electronic bill system (Figure 15).	Figure 14.	Figure 11.	Figure 14.	Figure 14.	A 4 duplicated-bill system (Figure 16).
Report from public	Yes, by phone.	Yes, by phone.	Yes, by phone.	Yes, by phone, e-mail, or mail.	Yes, by phone.	Yes, by phone.	Yes, by phone.	Yes, by phone.	Yes, an application is designed for public reporting.	Yes, by phone.

Illegal dumping

In Chengdu, Suzhou, and Shenzhen, the penalties for illegal dumping depend on the how the dumping affects the environment. In Chengdu, the penalty is divided into three levels. Violators are fined 10,000–30,000 yuan (US $1433–$4300) per truck for non-hazardous waste, 30,000–50,000 yuan (US $4300–$7167) per truck for slightly hazardous waste, and 50,000–100,000 yuan (US $7167–$14333) per truck for hazardous waste. In Shenzhen and Suzhou, violators can be sentenced in cases where the environmental damage is significant. The Municipal Comprehensive Law-enforcing Bureau of City Administration decides the penalty, according to the location of the illegal dumping, the potential risks, and the waste volume. The other seven cities follow their local rules or the national guidance (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2005). Waste flipping violators are fined 5,000–50,000 yuan (US $716–$7166). Citizens can report violations by phone, e-mail, or mail. In Chengdu, an online application was designed for citizen reporting. Users can upload pictures and share locations and other details regarding illegal dumping. However, most contractors outsource the dumping of waste, making it difficult to identify the offenders involved in illegal dumping (Figure 10).



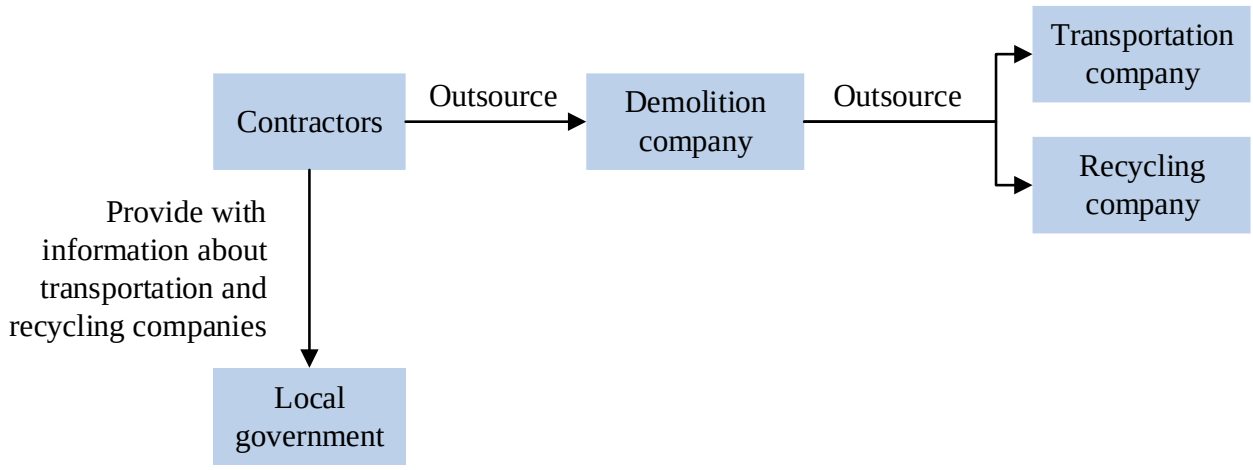


Figure 10: Outsourcing model

Additionally, in most cities, penalties for illegal actions of stakeholders, including contractors, transportation companies, recycling companies, and landfill sites are specified in official documents. For example, in Shanghai, only governmentally approved construction and demolition waste can be transported; if this is violated, the business license of the transportation company is cancelled. In Nanjing, contractors who consign the waste to unauthorised recycling companies are fined up to 100,000 yuan (or US $14,302). The unauthorised recycling companies are subject to fines of up to 150,000 yuan (or US $21,453).

Waste traceability

Optimising waste logistics is fundamental to waste management (The Waste and Resources Action Programme, 2015). Figure 11–16 provide information on the waste traceability throughout the recycling chain in different cities. All the vehicles used for transporting waste should be equipped with a global positioning system (GPS), follow an approved route, and be supervised by a tracing system. In Xi'an, a special green truck with a solid top cover was designed to transport construction and demolition waste to recycling plants, which forbid unapproved waste transportation. The calculation of the annual generation of construction and demolition waste is based on demolition amount noted in the disposal plan of contractors. This number is verified by recycling companies or landfill sites, according to the number of trucks and the truck volume (or by using a weighing scale). In Xi'an, trucks used for waste transportation should be equipped with a solid cover on top. The capacity of each waste truck is approximately 20 m^3. In Chongqing, trucks are equipped with sensors to avoid overloading. However, it is difficult to estimate the amount of waste produced in Changsha, as numerous small projects are not required to submit disposal plans to the local government. The amount

of construction and demolition waste produced in Changsha would be significantly underestimated.

Normally, before waste removal, contractors should submit a construction and demolition waste disposal plan to the local government and obtain permits for waste disposal. The disposal plan should include the (1) project name, location, and demolition area; (2) information about the contractors, transportation companies, and recycling companies or landfill sites; (3) types and volume of construction and demolition waste; and (4) detailed information about the transportation and disposal measures (Bureau of Housing and Urban-Rural Development of Changsha, 2019). In Shanghai and Zhoukou (Figure 11), contractors should make an advance payment to an authorised account for disposal and transportation fees, according to the approved demolition amount in the disposal plan. The final payment can be made only after completion of transportation and governmental verification. The transportation and disposal fees are transferred directly from the governmental account.

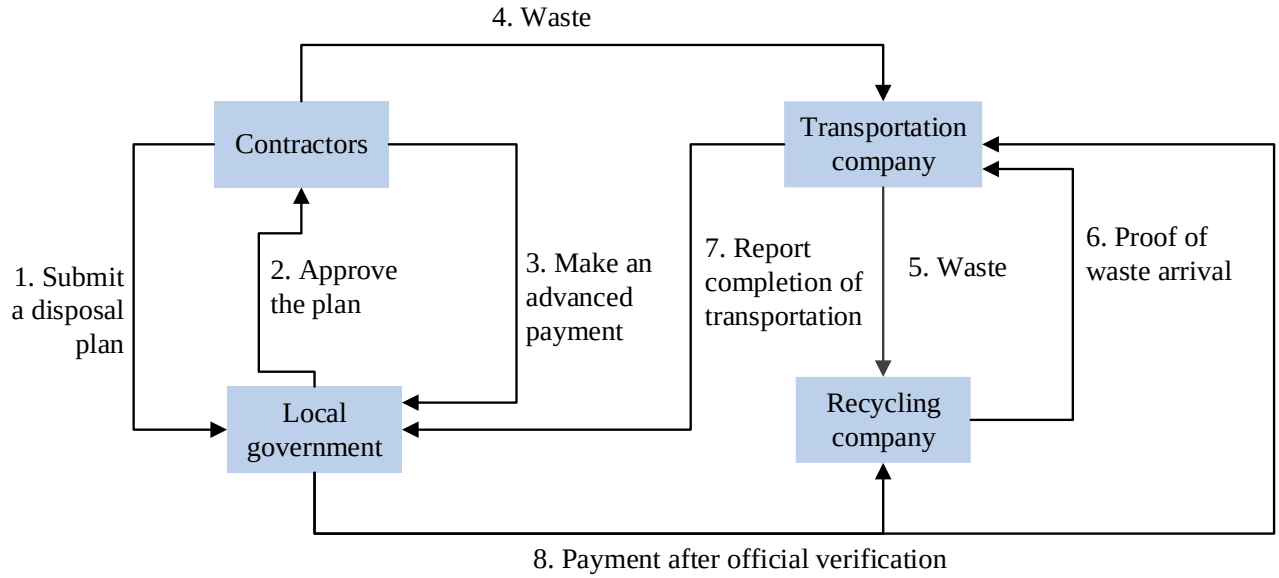


Figure 11: Waste tracing system in Shanghai and Zhoukou

A three duplicated-bill system is used in Hangzhou to trace construction and demolition waste (Figure 12). When the disposal plan is approved by local government, three duplicated-bills will be created and filled with relevant information. Government will keep one of the three duplicated-bills and deliver the two remaining bills to contractors. When transportation and recycling companies receive these bills, they should check the waste class, verify the waste

volume, and sign the bills. Government will verify the quantity of waste recycled through comparing the original bill and the bill submitted by transportation company.

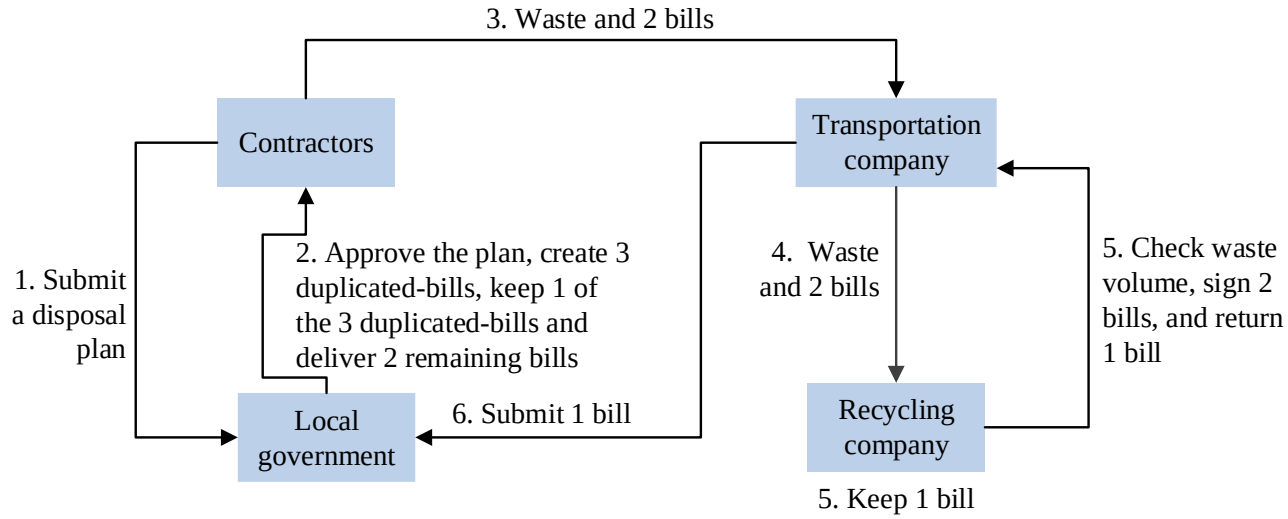


Figure 12: Waste tracing system in Hangzhou

The definition of construction and demolition waste in Suzhou is slightly different from that in other cities. In Suzhou, construction and demolition waste refers to clean concrete waste. In other cities, construction and demolition waste consists of concrete, bricks, timber, glass, and furniture, which is defined as renovation waste in Suzhou. The recycling subsidy is only provided to industries that recycle renovation waste. The local government would block the demolition site and decide whether the waste produced is categorised as renovation waste (Figure 13). After the assessment, the recycling industry can transport the waste to the recycling plant. For consistency, the term "construction and demolition waste" is used to replace "renovation waste" in Suzhou.

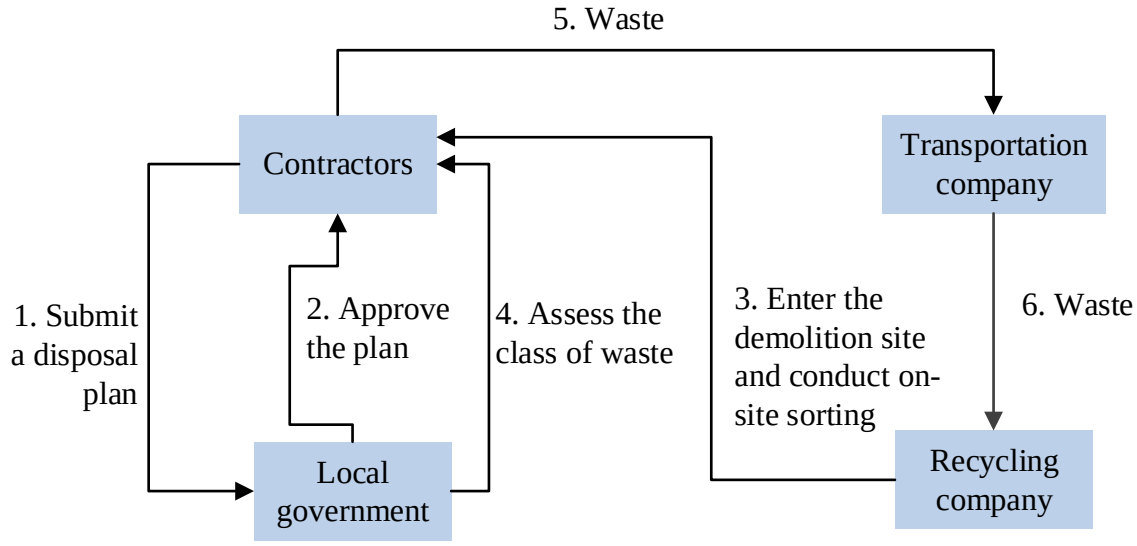


Figure 13: Waste tracing system in Suzhou

Figure 14 presents the construction and demolition waste traceability in most Chinese cities. A card access system is used in Nanjing and Suzhou. A special card is given to transportation companies. Transporters are required to scan their cards when trucks exit a demolition site or enter a recycling site. Waste transportation trucks are prevented from entering a recycling site if it is not the site nominated for them.

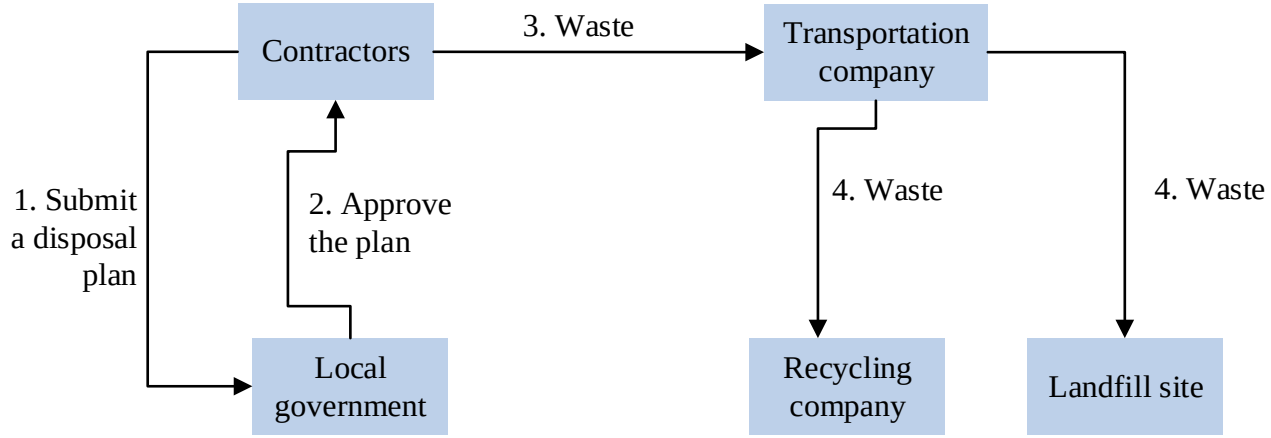


Figure 14: Waste tracing system in Changsha, Chengdu, Nanjing, and Chongqing

In Shenzhen, an online bill system is used (Figure 15). When the disposal plan prepared by contractors is approved by the Shenzhen local government, an online form is automatically created in a governmental system. Recycling companies must verify the total waste volume and sign the online form when construction and demolition waste arrives at the recycling site.

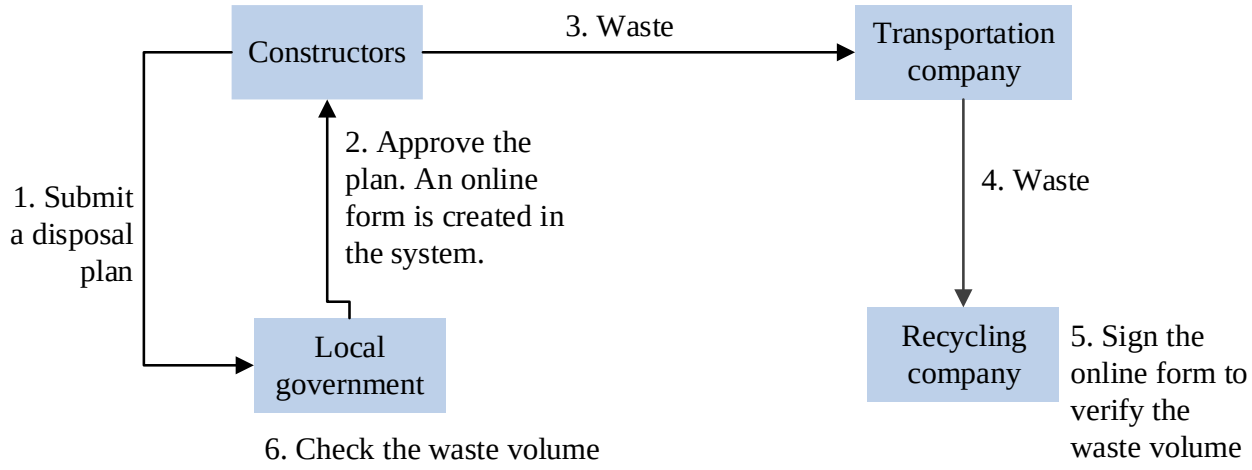


Figure 15: Waste tracing system in Shenzhen

Similar to Hangzhou (Figure 12), the local government in Xi'an uses a four duplicated-bill system to trace construction and demolition waste (Figure 16).

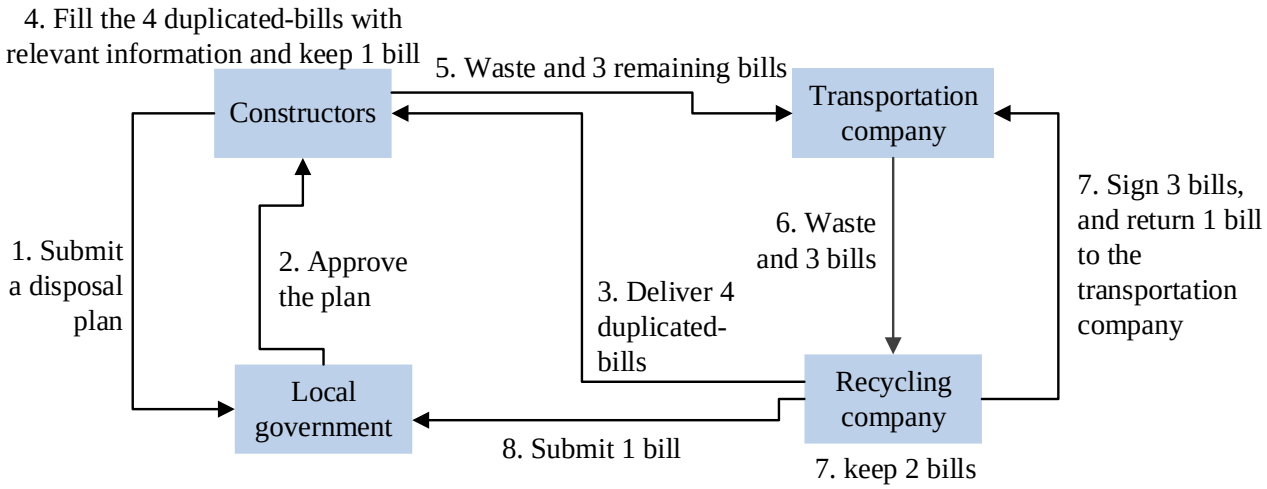


Figure 16: Waste tracing system in Xi'an

3.4.5 Difficulties faced by recycling industries

Table 23 presents the difficulties faced by recycling industries in China.

Table 23: Difficulties faced by recycling industries

	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
Difficulties	(1) A lack of guidance on waste classification.	(1) Standards for recycled aggregates vary among different areas in Hangzhou.	(1) A lack of guidance on waste classification; (2) A lack of standards on application of recycled building materials; (3) A lack of confidence in using recycled aggregates; and (4) It takes a long time to promote waste recycling to the whole city.			(1) A lack of standard costs for construction and demolition waste recycling and transportation; and (2) Inconsistent cooperation among different official departments.	(1) Inconsistent cooperation among different official departments; (2) A lack of classification of construction and demolition waste.	(1) A lack of classification of construction and demolition waste; (2) How to separate clean concrete waste from other types of waste? and (3) A lack of quality requirements.		(1) A lack of resources, because of the decrease in the amount of construction and demolition waste.

Inconsistent cooperation among official departments

Fostering cooperative relationships among various departments is complex, as each department plays a different role and has different responsibilities (Figure 17). For example, the Municipal Commission of Housing and Urban-Rural Development formulates municipal acts and regulations on construction and demolition waste recycling, leading engagements with other departments, e.g., subsidies for recycling industries from the Finance Bureau or tax deductions from the Municipal Tax Service. However, the Financial Bureau has the right not to follow an act issued by the Municipal Commission of Housing and Urban-Rural Development, because they are at the same administrative level. Additionally, financial constraints restrict governmental expenditures on construction and demolition waste recycling.

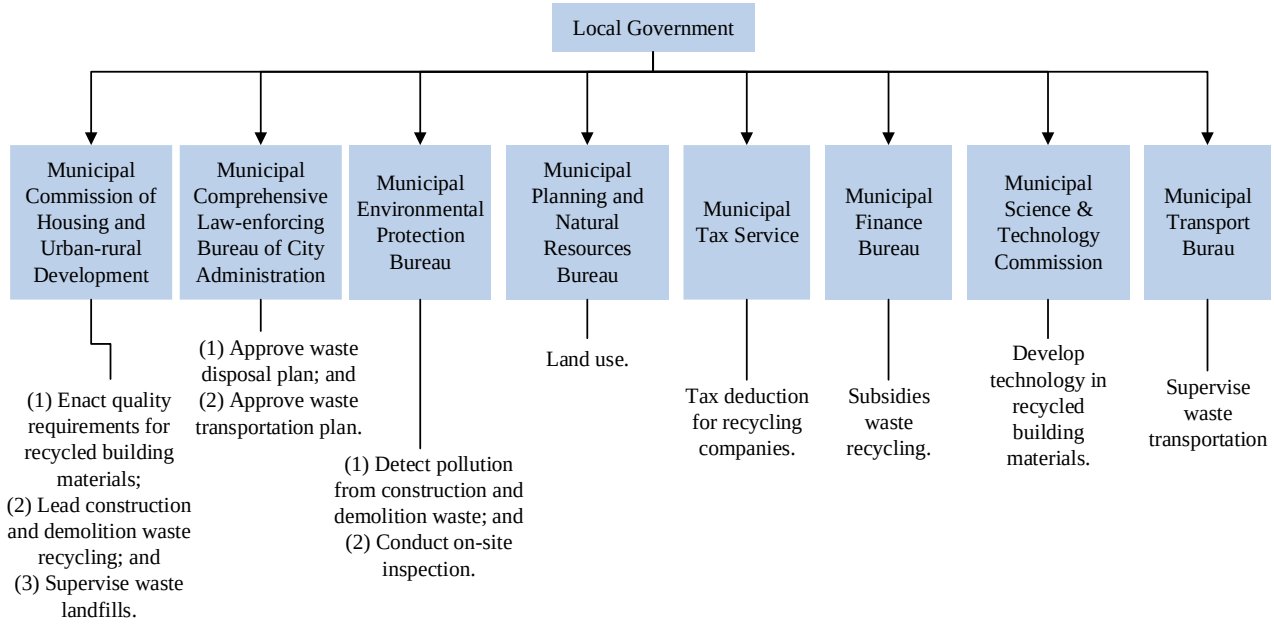


Figure 17: Responsibilities of governmental departments in Changsha

Guidance on classification, application of recycled materials, and standard price

A lack of guidance on waste classification and a lack of national standards on building materials recycled from construction and demolition waste are two critical challenges that can cause a lack of confidence in the use of recycled materials. Construction and demolition waste management in China is still in a stage of infancy (Huang et al., 2018). Most Chinese cities are searching for a suitable method to manage construction and demolition waste. The industries in Changsha expect that a standard price for construction and demolition waste transportation and recycling will be announced by the local government. The price of recycling largely

depends on contractors, without a standard price for recycling set by authorities. Additionally, separating concrete waste from other types of waste is a challenge for the Chongqing industry. For example, concrete waste from road renovation is always mixed with asphalt, significantly affecting the quality of recycled aggregates.

Long-term operation

Another issue is maintaining long-term operation as the production of construction and demolition waste decreases. The reduction in construction and demolition waste is a concern for the Xi'an industry. The focus of this business might shift to renovation waste and landfilled construction and demolition waste. The Hangzhou industry stores a large amount of construction and demolition waste to deal with this issue, and research may be conducted in the future on renovation and landfilled waste recycling. Additionally, a reduction in construction and demolition waste might cause the amount of recycling products to fall short of market demand. Few municipal governments have mandated percentages for the use of recycling building materials in construction, which ensure sales of recycled products. In the future, owing to the reduced volume of waste, the mandatory use of recycled products may not be feasible.

3.5 List of identified obstacles

This section summarized obstacles hindering promotion of construction and demolition waste management in the 10 selected cities (Table 24).

Table 24: Summary of obstacles in construction and demolition waste management in the ten selected cities

Obstacles	Eastern China				South-Central China			Western China		
	Suzhou	Hangzhou	Nanjing	Shanghai	Shenzhen	Changsha	Zhoukou	Chongqing	Chengdu	Xi'an
A lack of source of construction and demolition waste						×		×		×
A lack of guidance on waste classification	×		×				×	×		
A lack of subsidies for recycling activities		×	×		×		×	×	×	×
A lack of land use						×				
Waste reduction is not considered	×	×	×	×	×	×	×	×	×	×
Loose landfill policy						×		×		

A lack of precise estimation of waste volume						×		×		
Unavailability of waste tracing system			×			×		×	×	
Inconsistent cooperation among different official department						×	×			
A lack of related technology								×		
Various standards for recycled aggregates in one city		×								
A lack of standard costs for recycling activities						×				

Chapter 4: Conclusions

4.1 Introduction

This chapter presents the major conclusions of the study, based on the results of the comparative analyses and case studies. According to the current status of construction and demolition waste management in China, recommendations for Chinese policymakers are presented. Intellectual value of this study and future research directions are suggested.

4.2 Conclusions of this study

In the current age of enhanced environmental awareness, transformation to sustainable management in the construction sector is imperative. Despite the increasing awareness of recycling in industry, the average recovery rate of construction and demolition waste in China is only approximately 5%.

Chapter 1 of this thesis presented the research background. Considering the negative effects of the increasing volume of construction and demolition waste on the environment, effective and proper treatment is urgently needed. Proper construction and demolition waste management is expected to promote the efficient use of resources, reduce the utilisation of primary materials, and prevent landfilling.

Chapter 2 reviewed the existing policies, standards, and official documents concerning construction and demolition waste management in China and seven selected countries: Japan, South Korea, Germany, Italy, Austria, the Netherlands, and the United Kingdom. Comparative analyses were performed on the waste management in these countries, with a focus on four perspectives: general regulations, incentives, stakeholders' responsibilities, and supervision. The findings indicated the reasons responsible for China's unsatisfactory performance: (1) inadequate guidance on recycling, (2) an underdeveloped recycling market, (3) incomplete knowledge of stakeholders' responsibilities, (4) ineffective cooperation among governing bodies, (5) a lack of penalty for other stakeholders, and (7) an ineffective supervision system.

Chapter 3 presented information collected from site visits in 10 different Chinese cities, including Shanghai, Hangzhou (Zhejiang Province), Suzhou (Jiangsu Province), Chongqing, Chengdu (Sichuan Province), Xi'an (Shaanxi Province), Changsha (Hunan Province), Shenzhen (Guangdong Province), Nanjing (Jiangsu Province), and Zhoukou (Henan Province). The current status of construction and demolition waste management in China was examined in detail. The construction and demolition waste management performance varies among

Chinese cities, and the obstacles to waste management also vary among the cities. These obstacles include the following: (1) a lack of sources of construction and demolition waste, (2) a lack of guidance on the application of building materials recycled from waste, (3) a lack of land use for fixed industries, (4) a lack of precise estimations of the waste amount and distribution, (5) a lack of guidance on the classification of construction and demolition waste, (6) unrestrictive landfilling, (7) inconsistent cooperation among different official governments, (8) inadequate research on the use of recycled building materials and waste separation, and (9) an incomplete waste traceability system.

4.3 Recommendations for Chinese policymakers

The analyses presented in Chapters 2 and 3 were performed from national and municipal perspectives, respectively. A summary list of all obstacles identified in comparative analysis (Chapter 2) and site visits (Chapter 3) and corresponding recommendations are presented in Table 25. Specifically, these recommendations are explained in detail in the following paragraphs.

Table 25: A summary list of all obstacles identified in previous chapters and corresponding recommendations

Obstacles	From which chapter(s)	Recommendations
A lack of source of construction and demolition waste	Chapter 3	1. Stability of construction and demolition waste sources could be ensured through issue of BOT rights or cooperation with local contractors; and 2. Governmental subsidy for waste transportation could be provided.
Inefficient supervision system	Chapter 2 and Chapter 3	1. Precise estimation of waste generation and distribution is needed; and 2. An effective waste tracing system should be developed.
A lack of related technology	Chapter 3	1. Related technology should be improved; and 2. Applications of products recycled from construction and demolition waste should be widen.
A lack of market incentives in utilising recycled materials	Chapter 2 and Chapter 3	1. Policies associated with quality assurance of recycled building materials should be formulated; 2. Recycled products should be considered as prior choice in governmental projects; and 3. Financial incentives could be enriched.
Inadequate guidance on recycling	Chapter 2 and Chapter 3	1. Recycling should be prioritised, and waste reduction should be promoted; 2. Waste classification and relevant standards should be completed; and 3. A strict landfill ban should be introduced.

Inconsistent cooperation among different official department	Chapter 3	1. A higher-level governmental department should assume leadership; 2. Municipal government should manage inconsistencies in policies across different areas.

(1) A lack of source of construction and demolition waste

Ensuring the stability of construction and demolition waste sources

One challenge faced by recycling industries is ensuring the stability of the waste sources and maintaining long-term operation. According to information collected from site visits, government contracts, franchise rights, or stable cooperation with local contractors can ensure a source of waste. Because some industries signed a contract with a municipal government, the construction and demolition waste produced in certain areas should be transported to nominated recycling plants. Additionally, a governmental subsidy can be provided for construction and demolition waste transportation. In some cities, the remoteness of industries significantly increases the transportation costs, reducing the amount of waste transported to recycling sites. The government paying part of the transportation cost can help to shift transportation companies' preference from landfilling to recycling.

(2) Inefficient supervision system

Precise estimation of waste generation and distribution

Importantly, estimation of waste generation is required before contract enactment. Currently, estimation of annual waste generation is based on the waste disposal plans submitted by contractors. Furthermore, recycling companies and landfill sites check the number of vehicles to verify the waste quantity. In Changsha, the actual amount of construction and demolition waste might be underestimated, because waste produced in small projects is not included in the calculation. The waste generation of small projects should be strictly regulated. Furthermore, local government must identify the waste distribution in each administrative area and allocate resources reasonably, considering the land use needed for recycling, the number of recycling plants needed in each area, a reasonable transportation routine, and efficient governmental supervision.

Effective waste tracing system

The performance of integrated construction and demolition waste management largely relies on an effective waste tracing system. The four duplicated-bill system in Xi'an, the three

duplicated-bill system in Hangzhou, and the electronic bill system in Shenzhen are good examples to follow. In these waste tracing systems, bills are delivered to contractors from recycling companies or local governments. Contractors should fill these bills with relevant information such as the waste class, appearance, amount, and treatment. When transportation companies receive these bills, they should check the waste class, waste quantity, and drop-off location. Recycling companies and landfill sites should visually inspect waste, determine whether the waste can be lawfully accepted, verify the waste volume, and sign the bills. To improve the management efficiency, an electronic bill system for data sharing was developed in Shenzhen. Contractors, transportation companies, recycling companies, and landfill sites can log in to the system and record the waste details. The platform is accessible to all the related stakeholders.

The waste traceability system in Shanghai and Zhoukou, which features advanced payments for transportation and recycling, can ensure the proper treatment of waste and prevent illegal dumping. Local governments in other cities can assess these waste tracing systems and formulate a suitable approach for construction and demolition waste tracing.

(3) A lack of related technology

Improvement in related technology

Use of building materials recycled from construction and demolition waste is mandated in a few cities, to address the lack of market demand for recycled building materials. However, before issuing such a mandate, the local government should calculate the average annual yield of recycled building materials and evaluate the feasibility of mandatory use. Additionally, the mandatory use of recycled products presents challenges because it is difficult to balance the supply, which is influenced by the amount of source material, with the construction demand for recycled products. At present, numerous Chinese cities encourage the use of building materials recycled from construction and demolition waste, instead of promoting mandatory use of these materials in construction or production.

The use of recycled aggregates is limited to non-structural applications. Local governments can cooperate with universities or institutes to widen the use of recycled products. Additionally, the components of construction and demolition waste are complex. For example, concrete waste from road renovation is always mixed with asphalt, significantly affecting the quality of recycled aggregates. Separating concrete waste from asphalt is technically difficult, and the related technology needs improvement.

(4) A lack of market incentives in utilising recycled materials

Extension of the recycling market

Although there is already a market for recycling building materials, the government should stimulate investment and expansion of the market. Policies associated with quality assurance of recycled building materials should be formulated to encourage the wider application of recycled materials. Additionally, the government can play a leading role as a customer, as recycled materials can be the first consideration in governmental programs.

Expanding financial incentives

Financial incentives can motivate stakeholders to engage in construction and demolition recycling. However, for a few cities, it is difficult to reduce rental prices for land use to the Shenzhen level (1 yuan/m^2/year or US \$0.14/m^2/year), because of financial constraints. Enterprises who obtained BOTs can be sheltered from competition, and the stability of their waste sources can be ensured. Companies can profit from BOT rights. However, the volume of construction and demolition waste produced in one city is remarkable and is beyond the recycling capacity of monopolies. As one of the best-performing cities with regard to waste recycling, Shenzhen cancelled BOT contracts to avoid a franchise monopoly, to encourage the involvement of private recycling companies and recycle as much waste as possible. Therefore, local authorities should consider not only the financial situation of the city but also the possible effects of a BOT contract.

Environmental protection is becoming increasingly important, at both the national and municipal levels. Chinese cities reduce the VAT by at least 50% for construction and demolition waste recycling industries. In addition to the financial incentives presented in Table 20, China can expand incentive policies and apply regulations that have been used by the other selected countries, such as concessional loans and funding for new recycling businesses, for purchasing facilities, hiring, and employee training and welfare.

(5) Inadequate guidance on recycling

Prioritising the recycling of waste and promoting waste reduction

Adoption of a waste hierarchy is critical for transitioning to a sustainable and recycling-oriented society. The pressure from the large volume of construction and demolition waste and the rapid depletion of lands in China may be difficult to address completely through recycling and landfilling alone. Compared with recycling, waste reduction can use less energy. Waste

contractors should be held responsible for the full lifecycle of the waste and should take the technology and material selection into account. Taxes can be levied on waste generation. In recent years, China has investigated prefabrication technology that can significantly influence the waste reduction and subsequent waste handling activities (Li et al., 2014). However, the immaturity of the prefabrication market presents a challenge to the current practice of precast construction in China (Hong et al., 2018). Numerous Chinese cities have realised the seriousness of the problem of construction and demolition waste and issued regulations related to waste recycling. This recycling industry will gradually mature and become integrated, and waste management standards will be established. Prioritising the recycling of waste might be appropriate at this stage.

Completion of waste classification and relevant standards

A national standard and legislation for construction and demolition waste should be released to establish an integrated recycling chain. This requires additional details regarding the classification of construction and demolition waste. Classification of the waste can be regarded as an initial step, as it can contribute to organised separate collection. By following the guidance, different classes of waste can be correctly separated and then transported to proper treatment facilities. Furthermore, according to a robust classification system, subsequent regulations, such as a ban on mixing waste, mandatory recycling, acceptance criteria for waste in recycling, and classification of landfill sites, can be enacted. Defining the classification of construction and demolition waste can improve the efficiency of on-site sorting and subsequent treatments. For instance, steel can be sold back to the market, and concrete waste can be used to produce recycled aggregates. Additionally, completion of the guidance on the use of recycled building materials, as well as a standard cost for waste recycling and transportation, is needed. The price of recycling should not be higher or lower than the maximum or minimum price set by governing bodies, respectively.

Strict landfill ban

Recycling is not the only method to deal with construction and demolition waste. Promotion of recycling combined with strict landfill restriction can stimulate the recycling industry. Landfill bans in European countries, such as Germany and Austria, have been in existence for decades (Dawkins and Allan, 2010) and provide strong guidance to limit the types of waste deposited at landfill sites. These bans can apply to all types of waste, except for particular streams (such as non-hazardous and unrecyclable components), according to the waste

classification and required treatments. Additionally, landfilling should not be permitted without approval from the local government. Mixing one class of waste with other substances or classes of waste should be strictly prohibited. Landfill operators should conduct visual inspections and record detailed information, including the class and appearance of the waste, whether the waste is acceptable, the quantity, the date of delivery, and the exact location of the waste at the landfill site. These records should be accessible to authorities. Additionally, economic penalties such as a high landfill-tipping fee can prevent waste disposal to landfills and increase the recycling rate.

(6) Inconsistent cooperation among different official department

Consistent cooperation among governmental departments

Internal inconsistencies arise when the leading departments of construction and demolition waste management are at the same administrative level. This is because of a lack of guidance and resources from a higher-level government for the introduction of new regulations. As numerous departments are involved in the waste management chain and are responsible for different aspects, fostering cooperative relationships among the various departments is complex. Specifically, the Municipal Commission of Housing and Urban-Rural Development plays a leading role in waste management, but other departments at the same administrative level can ignore their guidance. Therefore, a higher-level governmental department should assume leadership, such as the Municipal People's Congress. Its responsibility includes leading subordinate departments, clarifying the duties of each department, promoting information sharing, formulating powerful legislation, and strengthening cooperation among different departments.

Additionally, an inconsistency exists when a standard in one area is in conflict with a standard in another area. For example, each area in Hangzhou has a different standard for recycled aggregates; thus, recycled aggregate with the same quality can be used in one area but not in another. Managing inconsistencies across different areas is another issue.

However, not all the strategies are suitable for China. The advantages and disadvantages should be evaluated according to practical experience.

4.4 Intellectual value of this research

Along with the dramatic increase in construction activities, construction and demolition waste management becomes a global concern which increases international researches in related

fields. This study gave a comprehensive review of existing national polices in relation to construction and demolition waste management and provided the conditions of industry practice in different Chinese cities. Although additional efforts should be put into long-term work in the management of construction and demolition waste, it is foreseeable that China is gradually moving to a sustainable society. The findings of this study could expand the knowledge on the construction and demolition waste management in China. For practice, the obstacles identified in this study could inform policy makers to observe and consider related issues, in order to conduct best practices of waste management. Recommendations provided in this study could be helpful to improve performance of construction and demolition waste management.

As described in previous chapters, the national guidance in China is not detailed enough and the promotion of construction and demolition waste management is based on the provincial or municipal policies. The 10 cities selected in this study are more populous and developed than other Chinese cities. However, in less developed Chinese cities, landfilling or dumping are still the major treatments and recycling is not considered as an option in construction and demolition waste management. As China is undergoing a continuous urbanization, these cities will be confronted with increasing amount of construction and demolition waste. The case studies in Chapter 3 could help these less developed regions to learn the experience from the 10 cities and provide insights to policy makers in formulating related strategies and polices. Additionally, the findings in this study could be applicable to crossing countries. Because of the uneven development of construction and demolition waste management around the world, there is possibility for developing or underdeveloped countries to learn from other high-performance countries, through comparing the current policies and formulating better policies. Comparative analysis in Chapter 2 was performed to analyse the construction and demolition waste management in developed countries with high recycling rates. This chapter offers a comprehensive literature review of policies and regulations in relation to construction and demolition waste management in high performance countries, which provides references to countries who urgently need to manage the waste.

4.5 Limitations of this study

The current status of construction and demolition waste management in China was investigated via comparative analyses and case studies, and the obstacles to the promotion of recycling were identified. However, this study had the following limitations:

(1) Seven countries with high recovery rates and relatively large quantities of construction and demolition waste were selected for the study. However, the waste volume produced in some countries, such as Italy and Austria, is very small compared with that produced in China. The experiences of other countries can provide guidance to China but may not be applicable to the Chinese situation.

(2) Site visits to 10 different Chinese cities were conducted. These cities should have been the most prosperous cities in China, to represent the current status of construction and demolition management in the country. However, because of a lack of contacts and access, the research team failed to visit some of the best-performing cities, such as Beijing and Xuchang. Additionally, the construction and demolition waste management in Northern China was not investigated.

(3) Interviewing was the main approach for obtaining information. Some recycling companies did not disclose certain information, such as information about customers or technology. In Xi'an, the recycling industry obtained a patent related to the production process. Researchers were not allowed to enter the sealed workshop but conducted observations outside the production line. Additionally, under pressure from the company, participants may have provided biased answers to certain questions.

4.6 Future research directions

The current status of construction and demolition waste management in China was investigated, and the obstacles to the promotion of recycling were identified. This research can be extended to analyse the market for the commercialisation of CO_2 concrete in China and to evaluate the characteristics associated with recycled-aggregate concrete for explaining its market price.

In the current age of enhanced environmental awareness, sustainable development of the concrete industry is urgently needed (Xiao et al., 2012b). Recycled aggregates from construction and demolition waste can replace part or all of the natural aggregates in concrete (Guo et al., 2018). Their significant potential to prevent problematic landfills can contribute to environmental preservation and sustainable development (Guo et al., 2018). However, the production of recycled-aggregate concrete in China has not yet reached a commercial scale, because the properties of recycled-aggregate concrete largely depend on the properties of the construction and demolition waste (Yehia et al., 2015). The use of recycled aggregates in China has been limited to road construction and the production of non-structural concrete, owing to their low strength (Senaratne et al., 2017). Numerous studies have indicated that the strength of recycled-aggregate concrete is adequate for structural use (Dimitriou et al., 2018). To

produce similar products to natural-aggregate concrete, recycled-aggregate concrete requires supplementary strengthening measures. CO_2 concrete is a new type of recycled-aggregate concrete with carbon dioxide injected into the recycled aggregate to improve its bonding and thus the performance of the recycled-aggregate concrete. Normally, the strength of recycled concrete is approximately 30% lower than that of natural concrete. The CO_2 injection can endow recycled-aggregate concrete with mechanical properties similar to those of natural-aggregate concrete. Additionally, for CO_2 concrete, the production cost is 10% lower than that for natural concrete, while the same strength is achieved.

Environmental protection is a fundamental concern in China. In 2015, a set of policies regarding environmental protection was introduced, which restricted the mining of natural materials, such as sand and stones. The restriction of mining has increased the price of natural construction materials in several cities (China Cement Association, 2018). Therefore, recycled aggregates from construction and demolition waste are expected to replace part or all of the natural aggregates in concrete. However, construction-industry practitioners are concerned that the purchase price of the concrete may increase because it has more additions than natural concrete (Senaratne et al., 2017). Because a 10% cost reduction can be achieved, it is possible for CO_2 concrete to become profitable and favoured by the Chinese market.

This study provides a background of the current recycled-aggregate concrete applications in China. Additionally, it identifies intrinsic and extrinsic characteristics that can affect the price of CO_2 concrete in China and contributes to further research in this area.

Appendix 1: Letter for ethical approval

WESTERN SYDNEY
UNIVERSITY

HUMAN RESEARCH ETHICS COMMITTEE

3 October 2019

Professor Vivian Tam

School of Computing, Engineering and Mathematics

Dear Vivian,

Project Title: "On the prevailing construction and demolition waste management practices: A China study"

HREC Approval Number: H13470

Risk Rating: Low 1 - LNR

I am pleased to advise the above research project meets the requirements of the National Statement on Ethical Conduct in Human Research 2007 (Updated 2018).

Ethical approval for this project has been granted by the Western Sydney University Human Research Ethics Committee. This HREC is constituted and operates in accordance with the National Statement on Ethical Conduct in Human Research 2007 (Updated 2018).

Approval of this project is valid from 3 October 2019 until 3 October 2023.

This protocol covers the following researchers:

Vivian Tam, Mingxue Ma, Khoa Le

Summary of Conditions of Approval

1. A progress report will be due annually on the anniversary of the approval date.
2. A final report will be due at the expiration of the approval period.
3. Any amendments to the project must be approved by the Human Research Ethics Committee prior to being implemented. Amendments must be requested using the HREC Amendment Request Form.
4. Any serious or unexpected adverse events on participants must be reported to the Human Research Ethics Committee via the Human Ethics Officer as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the Committee as a matter of priority.
6. Consent forms are to be retained within the archives of the School or Research Institute and made available to the Committee upon request.

7. Approval is only valid while you hold a position or are enrolled at Western Sydney University. You will need to transfer your project or seek fresh ethics approval from your new institution if you leave Western Sydney University.

8. Project specific conditions:

There are no specific conditions applicable.

Please quote the registration number and title as indicated above in the subject line on all future correspondence related to this project. All correspondence should be sent to humanethics@westernsydney.edu.au as this email address is closely monitored.

Yours sincerely

Professor Elizabeth Deane

Presiding Member,
Western Sydney University Human Research Ethics Committee

Appendix 2: Interview questions

Appendix 2 provides the interview question list.

Table 26: Interview questions

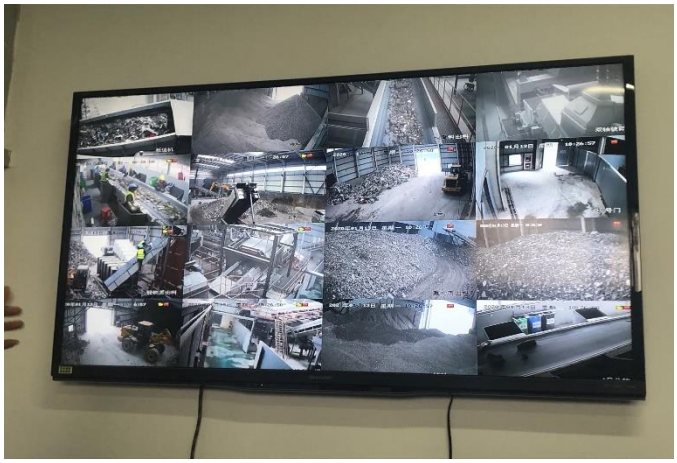
Basic information of the company or project	1. What is the area of the site? 2. Is the project run by private or state-owned company? 3. Is demolition included in their business? 4. Information about production: a. How much construction and demolition waste are recovered per day? b. How many production lines? c. Is the industry mobile or fixed?
Source	1. Where is construction and demolition waste from? Does the company have a contract with local government? Is the waste purchased from contractors? 2. How to address the problem of decreasing quantity of construction and demolition waste in China? How to ensure the long-term operation of the company?
Products	1. What kind of recycled products are produced in this company? 2. What are the costs and prices of a certain product? 3. Who are the customers?
Governmental incentives	1. Is there tax reduction on construction and demolition waste recycling? 2. Is there a BOT contract enacted? 3. Are cheaper land and water use provided by government? 4. Is there requirement for certain content of recycled aggregate included in construction products? 5. Would recycled aggregates be used in governmental projects?
Local policies	1. Are there guidelines for construction and demolition waste classification? 2. Is there on-site separate sorting? 3. Is there a ban on landfilling? Could the waste be exported to other provinces or cities? 4. Should waste holders or producers be responsible for the whole life of construction and demolition waste?
Supervision	1. Is waste transported in a planned route, and followed by GPS? 2. How to calculate and check the quantity of the waste? 3. Is there on-site inspection from government? 4. How could public report violations, such as illegal dumping? 5. Is there a shared-information system between government, demolition and recycling plants? 6. Is there penalty on illegal dumping?
Contact details	
Location	

Appendix 3: Photographs taken from site visits

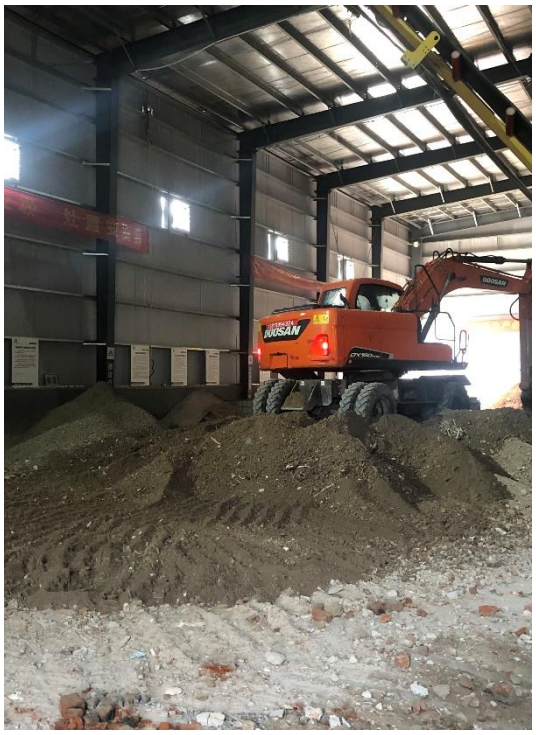
1. Photographs taken from Shanghai recycling plant

2. Photographs taken from Hangzhou recycling plant

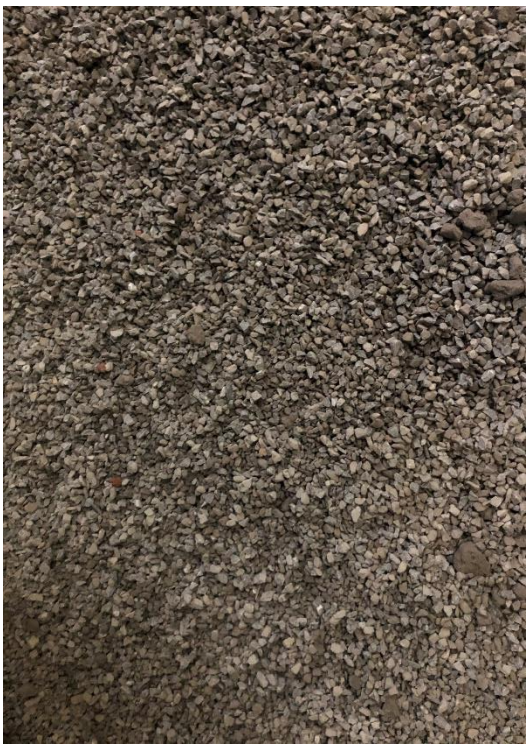
3. Photographs taken from Suzhou recycling plant



4. Photographs taken from Nanjing recycling plant


DOOSAN

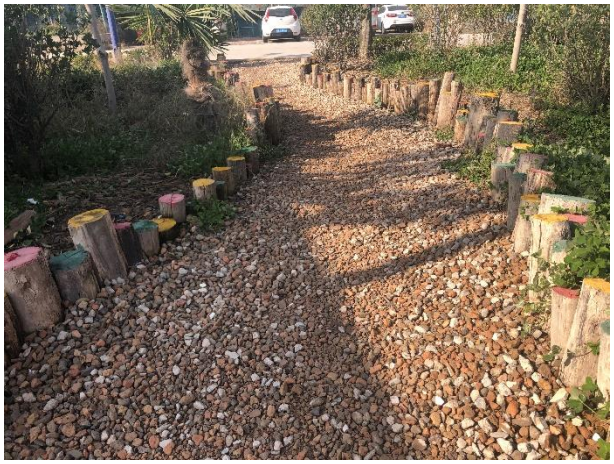
5. Photographs taken from Chongqing recycling plant



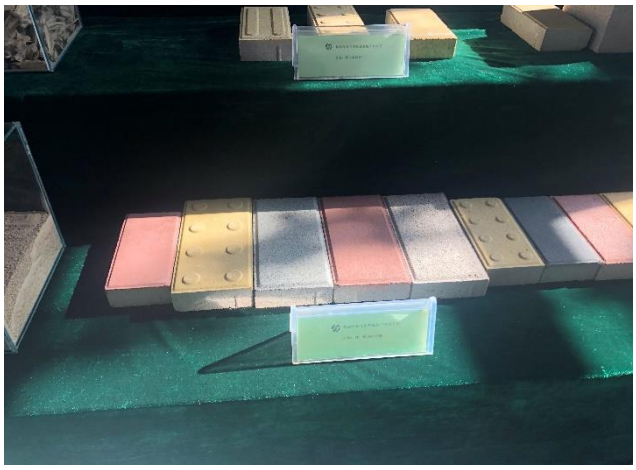
6. Photographs taken from Chengdu recycling plant


扬尘治理
许可证查
违法查询
工地查询
车辆查询
企业查询
车辆事故
历史扫描

7. Photographs taken from Xi'an recycling plant




原始建筑垃圾



8. Photographs taken from Changsha recycling plant

9. Photographs taken from Shenzhen recycling plant

10. Photographs taken from Zhoukou recycling plant








Appendix 4: Original data

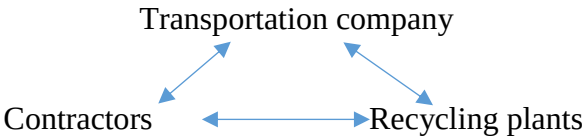
1. Information collected from Shanghai recycling plant

Introduction	1. Private company; 2. Area: 1,000,000 m^2; 3. Business: construction and demolition waste recycling; 4. Fixed industry; 5. Production: a. 2 production lines: and b. 4000 tonnes of construction and demolition waste could be recovered per day.
Waste classification and treatment	1. Waste soil: landfill 2. Waste from renovation: manual sorting; landfilling or recycling; 3. Construction and demolition waste: recycling.
Source	1. Contract with local government: construction and demolition waste should be transported to authorised recycling plants to ensure the source of waste. 2. Purchase. 3. Construction and demolition waste produced in Shanghai might be disposed in Shanghai. Exporting the waste to other provinces and landfilling is forbidden.
Products	1. Recycled aggregates: a. 0–5 mm b. 5–16 mm c. 16–31.5 mm 2. Recycled concrete (C25 and below, not for structural applications)
Governmental incentives	1. VAT tax exemption: 50% VAT deducted. 2. Mandatory use of recycled aggregates. At least 15% of recycled aggregates should be used in concrete below C25. 3. Recycled building materials should be the first consideration in governmental projects.
Supervision	1. Illegal dumping: violators would be fined 5,000–50,000 yuan. 2. The waste would be transported along a planned route (outside the city), by trucks with GPSs. 3. Municipal solid waste cannot be mixed with construction or demolition waste. 4. An advanced payment system: a. Contractors should submit a disposal plan to the local government;

	b. After local government approves the plan, contractors should make an advance payment for transportation and waste recycling to a governmental account; c. When waste arrives at recycling plant, recycling company delivers proof of waste arrival to transportation company, which is submitted to local government by transportation company to report completion of transportation; d. Payment is transferred from governmental account to recycling company and transportation company.
Other details for Shanghai	1. Approximately 14 authorised recycling companies in Shanghai, but the quantity of products varies. Some small companies might fail to satisfy the requirements for production. 2. Regulation on construction and demolition waste was issued from 2016/2017, which is earlier than that for other cities and provinces. 3. Waste producers should manage waste for whole lifecycle.

2. Information collected from Hangzhou recycling plant

Basic information	1. Area: approximately 1,066,667 m^2; 2. State-owned company; 3. Demolition is not included in business; 4. Fixed industry; 5. Production: a. 2000 tonnes/d of construction and demolition waste are recovered; and b. 3 lines for crush; 4 lines for bricks production.
Source	1. Purchase.
Products	1. Bricks only: a. There are different requirements for recycled aggregates in the 10 areas of Hangzhou. Recycled aggregates might satisfy the standards in the Gongshu area but not those in the Yuhang area.
Governmental incentives	1. 100% VAT exemption. 2. Rights similar to BOT. Only two state-owned companies could recycle construction and demolition waste. Private companies are not allowed to treat the waste.

	3. Land use. Local government allocate land to the company for a cheaper rental price.
Long-term operation	The focus of this company shifts from construction and demolition waste recycling to renovation waste recycling. Additionally, the company stores a large quantity of construction and demolition waste.
Supervision	1. Illegal dumping: Violators would be fined 5,000–50,000 yuan; 2. Landfilling and waste exportation should be approved by the local government; 3. The waste should be transported along a planned route (outside the city), by trucks with GPSs. 4. Three duplicated-bill system:  a. Local government delivers 3 duplicated-bills, recording quantity of construction and demolition waste which would be treated; b. Local government would give 2 bills to contractors and keep 1 bill; c. Contractors would pass 2 bills to transportation company, recording quantity of trucks (not the precise weight of construction and demolition waste), license number, and plate number; d. Recycling company would check the waste quantity, sign the 2 bills when waste arrives at recycling plant, and return 1 bill to transportation company; and e. Transportation company would submit the bill to local government for further supervision.
Other details for Hangzhou	1. Development of recycling companies in Xihu and Fuyang areas is better than that in the other 8 areas. The area government provides funds for these companies. In addition, local government contract with these companies to ensure their source of waste.

3. Information collected from Suzhou recycling plant

Basic information	1. Area: approximately 78,000 m^2. 2. Private company. 3. Demolition is not included in their business. 4. Fixed industry. 5. Production: a. Approximately 500 tonnes of construction and demolition waste would be recovered by one crush line in 1 h. b. 2 crush lines
Source	1. Definition of construction and demolition waste and renovation waste: a. Definition of construction and demolition waste: waste concrete only. b. Definition of renovation waste: Waste from on-site demolition: This kind of waste contain various components. 2. When there is building demolition: Local government would block the demolition site (Contractors should pay government for waste inspection) -----Recyclers enter the site and conduct on-site sorting ------ local government would define the waste and see whether the waste is renovation waste ----- waste would be transported to recycling plants. 3. Waste is classified into three classes: (1) Recyclables; (2) Waste should be further studied; (3) Waste could be burnt.
Products	1. Red bricks from old buildings would be crushed into powder, and would be further produced into red bricks; 2. Bricks; 3. Recycled aggregate.
Governmental incentives	1. 70% Value-added tax exemption. 2. Subsidy for renovation waste recycling: 120 yuan/tonne. However, there is no subsidy provided for construction and demolition waste recycling. 3. BOT is enacted. This company received 2 BOTs in 2019, including construction and demolition waste transportation and recycling. This right would last for 20 years. 4. Land use: local government allocated land for this company for a lower rental price. 5. Promotion in use: Company who use the building materials recycled from construction and demolition waste could obtain 1–3 extra credits, which could be used for applying governmental funding. However, there is no practice in reality.

Landfilling and exportation	1. Landfilling is not allowed. 2. Waste exportation should be approved by local government. However, the transportation cost is very high.
Supervision	1. There is no detailed classification for construction and demolition waste, only a rough and non-official definition of the waste. 2. Violators for illegal dumping would be fined 10,000 yuan or imprisoned. 3. GPS is used to trace trucks. When trucks exit demolition site or enter recycling site, drivers should scan cards. The volume of one truck is constant, i.e., approximately 25 tonnes. 4. Waste volume estimation: contractors should submit waste disposal plan to local government. Calculation of waste quantity is based on the disposal plan. 5. Public can call the local government to report illegal dumping.

4. Information collected from Nanjing recycling plant

Introduction	1. State-owned company; 2. Area: 2991 m^2; 3. 20,000 tonnes of construction and demolition waste could be recovered per year; 4. This industry is for temporary use, which would only operate for 2 years. The operation started on 05/2019; 5. 1 crush line; 6. Demolition is not included in business; 7. Fixed industry.
Source	1. Contract with local government: waste produced in Hongshan Road should be transported to this industry for recycling. 2. Construction and demolition waste is purchased by the company for free.
Products	1. Coarse aggregates only.
Governmental incentives	1. 70% VAT exemption; 2. BOT contract. Private companies would be illegal to deal with construction and demolition waste; 3. Land use. Local government allocate land to this company for a cheaper rental price; 4. Mandatory use of recycled aggregates.

Long-term operation	This project plays an important role in leading construction and demolition waste recycling across the whole Nanjing. This project only lasts two years. They do not have a long-term plan.
Supervision	1. The waste would be transported in planned route (outside the city) and by trucks with GPS. 2. Waste volume calculation: Contractors should submit waste disposal plan to local government. The local government would calculate the weight based on the plan. Recycling companies could check the quantity, based on number of trucks and truck volume. 3. License and card for transportation: (1) Exporting waste to other provinces should be approved by local government; (2) Card system: When trucks exit demolition site or enter recycling site, drivers should scan cards. 4. Landfilling for construction and demolition waste is not allowed in Nanjing. Violators for illegal dumping would be fined over 10,000 yuan.
Other details for Nanjing	1. Approximately 100 private recycling companies exist in Nanjing. Some companies are small and do not have an operation license. Those private companies would be prohibited by local government. Business related to construction and demolition waste recycling would be taken by a few state-owned companies. 2. Seven fixed construction and demolition waste recycling industries would be established in the future.
Difficulties to promote recycling in Nanjing	1. A lack of national standards for waste classification; 2. A lack of standards for the application of recycled building materials; 3. A lack of confidence in using the recycling building materials from construction and demolition waste; 4. It takes a long time to promote recycling throughout Nanjing.

5. Information collected from Chongqing recycling plant

Basic information	1. Area: approximately 65,333 m^2. 2. State-owned company. 3. Demolition is not included in business. 4. Fixed industry. 5. Production:

	a. 2,000 tonnes of construction and demolition waste could be recovered per day; b. 2 crush lines.
Source	1. Purchase. 2. Unspoken rules: If the distance from demolition site to recycling industry is within 25 km, contractors must pay fees, which include transportation and recycling fees. However, the closest demolition site is 28 km from the recycling plants. Contractors are unwilling to transport the waste to this recycling industry, owing to the significant increase in the transportation cost.
Products	1. Recycled aggregates: the construction and demolition waste is mixed with high-calcium stones during the crushing process, to improve the strength of the recycled aggregates.
Governmental incentives	1. 70% VAT exemption. 2. Credits: If contractors use 30% recycled building materials, they can obtain funding or a tax deduction from the municipal government.
Landfilling and exportation	1. Five landfill sites are planned to be constructed in Chongqing. 2. The price for landfilling (approximately 2,000 yuan/truck) is lower than that for waste recycling. 3. There are no restrictions on landfilling or waste exportation.
Supervision	1. Illegal dumping: Violators would be fined 5,000–50,000 yuan; 2. GPSs are used to trace trucks. Special yellow trucks are used for construction and demolition waste transportation. 3. Calculation of the volume of construction and demolition waste is based on disposal plans from contractors. However, the estimations are inaccurate.
Difficulties to promote construction and demolition recycling in Chongqing	1. A lack of national standards on classification of construction and demolition waste; 2. A lack of powerful regulations regarding construction and demolition waste management in Chongqing; 3. Inadequate cooperation among different departments at the same municipal level; 4. A lack of technology to separate concrete waste from other types of waste; 5. A lack of national standards for the application of building materials recycled from construction and demolition waste; and 6. Job conflicts among different governmental departments.

6. Information collected from Chengdu recycling plant

Introduction	1. Private company; 2. Demolition and recycling are included in business; 3. Area: 2,500 m^2; 4. Mobile industry; 5. Production: a. 1,500 tonnes of construction and demolition waste could be recycled per day; b. 1 crush line.
Products	1. Recycled fine/coarse aggregate; 2. Recycled-aggregate concrete for C20 and below; 3. Bricks: water permeable bricks;
Governmental incentives	1. 100% VAT exemption; 2. Cheaper fees for land use; 3. Recycled building materials are competitive and would be the first consideration in governmental projects.
Source	1. Contract with Chengdu local government to ensure the source of construction and demolition waste.
Supervision	1. Landfill: Landfilling in Chengdu becomes stricter than before. Only waste which is not harmful to environment could be landfilled. In addition, landfilling should be approved. 2. The waste should be transported in planned route (outside the city) and by trucks equipped with GPS. 3. Components of construction and demolition waste which is unable to be landfilled should be transported to authorised recycling plants. 4. Information exchange system: App was developed for the public to track the waste. The public could report the illegal dumping to local government through the application. This app allows the public to upload pictures and share locations and other details. 5. Estimation on waste volume: The estimation is based on the disposal plans submitted by contractors.
Punishment for illegal dumping	For one truck (approximately 20 m^3) construction and demolition waste: 1. 10,000–30,000 yuan (no harm to the environment); 2. 30,000–50,000 yuan (slight/medium harm to the environment); 3. 50,000–100,000 yuan (significant harm to the environment); 4. Local government decides penalty, according to risk posed by waste.

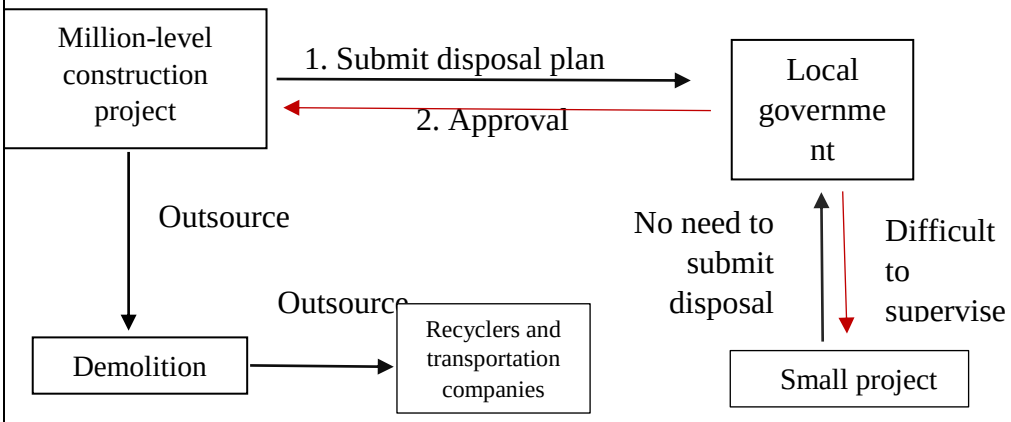
7. Information collected from Xi'an recycling plant

Basic information	1. Area: approximately 1,066,667 m^2; 2. Private company; 3. Demolition is not included in business; 4. Production: a. Approximately 3,000 tonnes of the waste is recovered per day. b. 1 crush line. 5. Fixed industry.
Source	1. Contract with local government: All the construction and demolition waste produced in Fengxi new city should be transported to the company for recycling. Waste producers should afford transportation cost. 2. Production line was not allowed to be visited, as this company obtained a patent for purifying the waste and producing high-quality recycled aggregates. Only 1% light components could be included in recycled aggregate, based on the requirement. Recycled aggregates produced in this industry only contain 1/10000 light components.
Products	1. Recycled aggregates only, most of which are used in governmental projects for pavements. a. Steels, waste timber, and clean concrete blocks are selected during the demolition process. b. Concrete waste from road renovation is mixed with asphalt, significantly affecting the quality of the recycled aggregates.
Governmental incentives	1. 50% VAT deduction. 2. No price reductions are provided for land, water, or electricity. 3. Building materials recycled from construction and demolition waste are the first consideration in governmental projects.
Long-term operation	The reduction in demolition waste is one concern for this industry. The focus of this company is shifting from construction and demolition waste to renovation waste or landfilled construction and demolition waste*. *Landfilled construction and demolition waste: The company would dig out the demolition waste landfilled in previous years.
Supervision	1. The waste would be transported along the planned route (outside the city), by trucks equipped with GPSs. 2. Illegal dumpers would be fined up to 10,000 yuan/truck. 3. On-site inspections are conducted by the local offices, to check whether the environmental assessment satisfies the requirements.

	4. Public could call 12345 to report illegal dumping. 5. Four duplicated-bill system: a. Recycling company would deliver 4 bills to contractors, who should record quantity of construction and demolition waste; b. Contractors and keep 1 bill and deliver 3 bills to transportation company; c. Recycling company would check the waste quantity, sign the 3 bills when waste arrives at recycling plant, and return 1 bill to transportation company; and d. Recycling company would submit 1 bill to local government and keep 1 bill. 6. Waste estimation: a. The green trucks for waste transportation should be equipped with lid. The volume of one truck remains 20 m^3. b. Waste holders would report the quantity of the waste transported to recycling plant in the waste disposal plan; c. Recyclers would calculate the number of trucks to verify the quantity of waste.
Landfilling and waste exportation	1. There are 2–3 landfill sites for construction and demolition waste in Xi'an. The cost for landfilling is around 800 yuan/m^3. Waste exportation is forbidden.

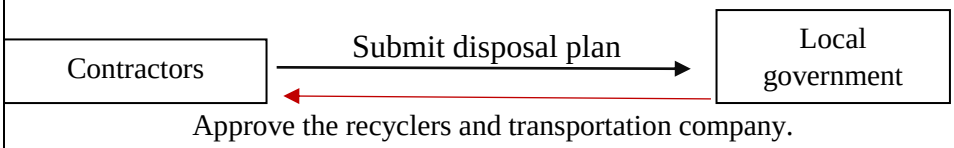
8. Information collected from Changsha recycling plant

Basic information	1. Area: approximately 3–4 mu (approximately 2,000–2,667 m^2); 2. Public company; 3. Demolition is not included in business. 4. Mobile industry. Land use for construction and demolition waste recycling is not included in the local plan. Additionally, the cost for fixed industry is high. 5. Production: c. 150–200 tonnes per hour for plan. However, they could only treat 70–80 tonnes of the waste per hour, because their production largely depends on the demolition speed. d. 4 lines for crush; 6. Approximately 8 business hours per day, including 2-hour device cleaning. Only 6 hours are used for crush and product production.
Source	1. Construction and demolition waste is from local contractors. This recycling company cooperate with a demolition company. These demolition companies are willing to ask them to recycle the waste; 2. Waste from nearby small demolition sites during downtime;

	3. Cost for waste recycling and transportation in Changsha: 65 (Subsidy for demolition) = 20 (demolition cost) + 38 (transportation cost) + 7 (landfill cost) = 20 (demolition cost) + 35 (on-site recycling cost) + 10 (profit). Contractors prefer to pay 35 yuan for on-site recycling and gain a profit of 10 yuan. 4. However, there is no standard cost for recycling. The cost for recycling estimated by government was only 15 yuan, without considering the delay of demolition, device depreciation, weather, and other factors. 5. Outsourcing (see the flowchart blow): 
Products	1. Recycled aggregates. The price of recycled aggregates is approximately 40 yuan/tonne. The price of natural aggregates is approximately 170 yuan/tonne. The price of manual sand is approximately 70–80 yuan/tonne. 2. Bricks; 3. Light components are burned with municipal waste, and steel is sold back to market.
Governmental incentives	4. 70% VAT deduction; 5. Subsidy for construction and demolition waste recycling: 3 yuan/m^2. 6. BOT is expected to be enacted. (1) Investors prefer to understand whether the BOT for waste recycling is investment-worthy. The government should provide information about standards for costs, the production process, the devices required, the size of the industry, the application of recycled products, and what types of support are available, including land use, stable waste sources, and customers. 7. Land use: Land use for construction and demolition waste recycling is not included in the local plan. 8. No financial support for use of water or electricity.

	9. Government encourages the use of recycled products: Companies who use recycled products can obtain 1–3 credits, which can be used for tax deductions or governmental funding.
Landfill and export	1. Construction of new landfill sites is included in city plan. In addition, there are landfill sites which operate without governmental approval. 2. There is no check for landfilling. Small projects should be added into supervision. 3. A small amount of waste would be transported to other cities or provinces, such as Jiangxi province, because capacity of some landfill sites is full and operators refuse to receive the waste. Transportation cost to other provinces is relatively high.
Supervision	1. GPSs are used to trace trucks. 2. It is difficult to estimate the amount of construction and demolition waste generated per year accurately, as small projects are not required to submit waste disposal plans to the government. 3. On-site inspection would be conducted by local government for demolition. 4. Public can call the local government for illegal dumping. Violators would be fined 5,000–50,000 yuan.
Other details for Changsha	1. There is a rough classification of construction and demolition waste in Hunan Province; 2. There is a decrease in construction and demolition waste annual generation. However, quantity of recycled products might fail to meet the demand for mandatory use of recycled products; 3. Government should release a standard cost for construction and demolition waste recycling and waste transportation; 4. Cooperation among different governmental departments is not consistency, because they are at same level and one department does not have a right to ask other departments to follow it. For example, the Municipal Commission of Housing and Urban-Rural development is leading construction and demolition waste management. They want the Municipal Finance Bureau to provide subsidies for waste recycling. However, the Finance Bureau can refuse to provide the subsidies, because they are at the same municipal level.

9. Information collected from Shenzhen recycling plant

Basic information	1. Area: 5,000 m^2; 2. Private company; 3. Production: a. 7,000 tonnes of waste could be recycled per day; b. 2 lines for crush; 4. Demolition is not included in business. 5. Fixed industry.
Source	1. Waste produced within 20 km; 2. Waste recyclers, transportation company should be approved by local government (see the flow chart blow):  3. Waste holders have a responsibility to deal with construction and demolition waste produced. They are required pay the transportation cost. 4. Light components, including timber, should be discarded on-site, to ensure the quality of recycled aggregates. Non-recyclable components would be landfilled.
Products	1. Fine and course recycled aggregates. Recycled aggregates are used to produce other products, according to customers' requirements; 2. Light wall panels; 3. Recycled-aggregate concrete (C30 and below);
Governmental incentives	1. 100% VAT exemption; 2. BOT was cancelled, to stimulate the involvement of more recycling companies, avoid monopoly, promote competition and solve the problem of large volume of construction and demolition waste; 3. Cheap land use: 1 yuan/m^2/year. 4. No financial support for use of water or electricity 5. Local government encourages use of building materials recycled from the waste.
Landfilling and exportation	1. Landfilling should be approved by local government. 2. Waste exportation to other cities or provinces should be approved by local government. 3. Some waste would be transported to temporary storage sites, and then waste there would be recycled by nearby recycling plants.

Supervision	1. Illegal dumping: Violators would be fined 5,000–50,000 yuan. If this illegal dumping brings potential risks to environment, violators might be imprisoned. 2. Public can call the local government to report the illegal dumping. 3. Electronic-bill system: When waste holders submit disposal plan and report waste quantity for recycling, an online bill is created in official system. Recyclers need to check the vehicle license plates, record the number of trucks (he volume of the truck remains 12 m^3), and sign the online bill when the waste arrives at waste recycling site.
Other details for Shenzhen	1. There are 42 construction and demolition waste recycling companies in Shenzhen, half of which are mobile industries. 2. A list of qualified recycling companies is available on the official website, to promote construction and demolition waste recycling. 3. Recycling is the first choice to treat construction and demolition waste in Shenzhen.

10. Information collected from Zhoukou recycling plant

Basic information	1. Area: 30,000 m^2. 2. Private company. 3. Demolition, transportation and recycling are included in business. Subsidy for demolition is approximately 3,450 yuan/m^2. 4. Mobile industry. 5. Production: c. 10,000 tonnes of waste could be recovered per day. d. 6 lines crush lines;
Source	1. The company obtained a BOT contract in 2017 and is responsible for recycling the construction and demolition waste produced in this city.
Products	1. Different types of bricks; 2. Recycled aggregate: the size of aggregates is within 0–70 mm; 3. Recycled-aggregate concrete (C15 and below); 4. Light components such as wood and plastics would be sold and recycled. Some non-recyclable materials would be burnt for electricity.

Governmental incentives	1. 70% VAT exemption; 2. Subsidy for demolition: Approximately 3,450 yuan/m^2; 3. BOT issued: The BOT started in 2017 and lasts for 30 years. 4. No financial support for land, water, or electricity. 5. Prior use in governmental project, such as pavement.
Landfill and export	1. Landfilling should be approved by local government. 2. Illegal dumping is not popular in this city.
Supervision	1. Illegal dumping: Violators would be fined 5,000–50,000 yuan. 2. Cooperation among different departments at same governmental level is insufficient. 3. Estimation of waste volume: The calculation is based on the disposal plan from contractors. When the waste arrives at the recycling plant, recyclers check the waste volume according to the number of trucks. However, it is difficult to estimate the waste volume accurately. 4. On-site supervision on recycling environment by local government. 5. Advanced payment system.
Other details for Henan	1. There is a lack of classification of construction and demolition waste. 2. At present, the quantity of construction and demolition produced is large. The company stores a small amount of the waste to deal with the situation of reduced demolition in the future.

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