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Output 4 - Synthesis Report
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1 Synthesis

1.1 Project Rationale

1.1.1 Objectives of Technical Assistance Study

The Government of the People’s Republic of China (PRC) has requested policy and advisory technical assistance (TA) from the Asian Development Bank (ADB) to enhance the PRC’s policies and practices related to the management and recycling of construction and demolition waste (CDW).

The impact of the TA will be improved CDW management policies and practices in the PRC, and the outcome will be an agreed set of policy recommendations to regulate CDW management and promote CDW recycling.

1.1.2 Scope of Technical Assistance Study

The scope of the study comprises:

- An assessment of CDW management in China. This will be carried out through literature review, questionnaire surveys, and case studies of CDW recycling success stories in PRC cities, the policies and current practices of CDW management at construction and/or demolition sites, the perceptions in relation to recycled and conventional construction materials, and the barriers to increased application of recycled materials. The assessment will include an economic analysis to identify the probability of a CDW market failure in the PRC.

- A review of international good practice in CDW management and recycling. This will include in-depth case studies to be conducted in selected advanced economies with high CDW recycling rates, as well as a study tour to one of these countries. The international good practice report will document hindering and enabling factors for sustainable CDW management and recycling.

- Development of a set of policy recommendations for the regulation of CDW management and the promotion of CDW recycling in the PRC (including cost–benefit analysis). This will consist of
  
i. policy recommendations to regulate CDW supply, including technical guidelines for CDW segregation and processing, and capacity-building needs to improve CDW management at construction or demolition sites; and
  
ii. a set of policy instruments to promote demand for, and increase uptake of, recycled CDW in the construction industry. The policy recommendations will be identified and formulated in consultation with relevant ministries and professional associations. A cost–benefit analysis will quantify how much the implementation of these recommendations could benefit the PRC.

- Preparation of a synthesis report, which will be prepared which will summarise and present the outputs of this TA.

1.2 Project Background

1.2.1 Overview of Construction Waste Issues in China

The continuous economic growth of the PRC since the start of its economic reforms in 1978 has been accompanied by rapid urbanization. Increased urbanization will remain an essential pillar supporting future growth and development in the PRC, but it also poses a variety of environmental challenges. One of the problems is the large quantities of CDW being generated as a by-product of the construction boom.

CDW quantities in China are projected to increase significantly over the next 2 decades with the lifetime of buildings expiring; and a comparison with international per capita CDW data suggests that, if China
follows the pattern of waste generation in Europe, quantities are likely to be in the region of 2 billion tonnes or more. Currently, most of this waste is delivered unsegregated (i.e., mixed with other waste streams) to suburban or rural areas for disposal in open storage or landfill.

The CDW reduction performance of construction contractors in the PRC is still poor, as it is mainly driven by short-sighted economic and practical considerations rather than environmental and resource efficiency concerns. However, a small-scale private sector business is thriving for the direct reuse of valuable construction materials such as copper, aluminium, reinforcing steel, wood, and others. However, these materials are likely to form only a relatively small proportion of the overall CDW quantities, most of which comprises inert materials such as concrete, brick, asphalt and excavated soil and rock.

Market potential for CDW recycling in the PRC is significant. According to the National Bureau of Statistics, in 2013 (the latest year for which annual data is published) 11.2 billion square metres of buildings were under construction and 3.9 billion square metres of buildings were completed (National Bureau of Statistics of China, 2013). A widely reported statistic claims that China used more concrete between 2011 and 2013 than was used in the USA during the whole of the twentieth century (Gates, 2014). Cement production in China in 2013 was 2.4 billion tonnes, which (assuming cement forms around 10 to 15% of concrete) is equivalent to around 16 to 24 billion tonnes of concrete (National Bureau of Statistics of China, 2013).

Despite its great potential and the government’s effort to promote it, CDW recycling rates do not exceed 5%–10%. Actual demand for recycled materials is relatively low in the absence of incentives to buy recycled materials (as compared to natural aggregates), and concerns over the quality assurance of recycled materials. CDW recycling centres have been established in several cities in the PRC, but these often struggle to make a profit.

1.2.2 Approaches to Construction Waste Management

Although entirely avoiding CDW generation is impractical, there are alternative management approaches which can reduce the negative impacts of CDW.

As with other types of waste, the approach to CDW management is best considered using the internationally accepted framework of the “waste hierarchy”. The waste hierarchy is enshrined in regulations such as the European Union Waste Framework Directive (European Union, 2008) and aims to improve the sustainability of waste management operations by apply as a priority order the following waste management hierarchy, which prioritizes waste prevention, re-use and recycling over disposal, as shown in Figure 1-1.

![Figure 1-1: The Waste Management Hierarchy](image)

National and municipal governments around the world are enacting legislation that encourages recycling of CDW. In Europe, the Waste Framework Directive has been revised by the European Union to include a requirement that 70% of each member state’s CDW be reused or recycled by 2020. Countries such as Denmark, Germany, Ireland, the Netherlands, and the United Kingdom have already surpassed the 70%
benchmark. Asian economies that have achieved very high CDW recycling rates include Hong Kong, China; Japan; Singapore; and Taipei, China.

1.3 Current PRC Practice Review

1.3.1 Methodology

This report studies the CDW management policies and current status in the PRC through literature review, questionnaire survey and interviews with key stakeholders, and case studies of five Chinese cities that have made significant improvement in CDW management and recycling; and analyzes the obstacles to application of recycled building materials and the feasibility of market-based solutions for incentivising CDW recycling.

1.3.2 Waste Types and Quantities

This study focuses on the types of CDW which are the responsibility of MOHURD, and therefore does not include wastes from road, hydraulic and hydropower structures, railways and tunnels. The main types of CDW are:

- Waste from excavation
- Waste from demolition of old buildings
- Waste from construction sites, and
- Waste from building fit-out and decoration.

The types of CDW generated depend on construction methods and the types of buildings being demolished. Modern buildings are primarily constructed from reinforced concrete, whereas buildings currently being demolished in China, dating from the 1960s to 1990s, include a large proportion of bricks.

Among the above CDW components, a mature recycling system has been developed for asphalt blocks, and there is also active recycling and reuse of waste metal, plastics, wood and glass. The remaining large amount of surplus spoil, scrap bricks and tiles, waste mortar and concrete blocks have become the current focus of CDW management and recycling. From environmental protection and disposal safety perspectives, management of surplus spoil is one of the key issues, but there is no mature recycling technology for this material.

Although there are no official statistics of CDW production at the national level, according to several survey results, CDW production shows an upward trend each year, with the annual CDW production currently being over 1.5 billion tons. A recent study\(^1\) estimated that CDW production will reach over 2.5 billion tons per year in 2020.

1.4 Laws and Regulations

1.4.1 Laws

At present, the PRC government has not formulated specific laws for CDW management and solid waste management-related provisions are only covered by subordinated laws, including:

- Environmental Protection Law
- Cleaner Production Promotion Law
- Solid Waste Pollution Prevention Law
- Circular Economy Promotion Law
- Building Law

However, the provisions of these laws are expressions of principle, low in operability, and therefore they do not adequately provide guidance or deter illegal behaviour: they can only provide a basis for policy formulation. This study recommends that there should be a series of supporting administrative laws,

\(^1\) Construction Waste Recycling and Reuse Policy Research Report, the PRC Architecture Design Institute (CADI)
regulations and systems that can truly provide guidance for CDW management and recycling. CDW are regional materials, and therefore provincial, municipal and county governments should also be able to formulate CDW management methods, but currently only 21.7% of the provinces and cities in the PRC have issued local regulations and policies on CDW management and recycling.

1.4.2 Standards
There are 16 CDW recycling related standards, including those already issued and those under formulation, and 8 local standards that are already issued.

1.5 CDW Management and Recycling Authorities

1.5.1 National Level
The Notice on Roles and Responsibilities for CDW Utilization issued by the State Commission Office of Public Sector Reform in 2010 (No. [2010] 106) clarifies the responsibilities of central government departments, including the Ministry of Housing and Urban-Rural Development (MOHURD), the National Development and Reform Commission (NDRC), the Ministry of Industry and Information Technology (MIIT), the Ministry of Environmental Protection (MEP), the Ministry of Science and Technology (MOST), the Ministry of Finance (MOF) and the State Administration of Taxation (SAT). MOHURD is the leading authority in CDW management and recycling. The following issues were identified during a survey of CDW management functions of the above ministries:

- Lack of coordination

Although all departments performed their duties specified by State Commission Office of Public Sector Reform, their duties are separated. MOHURD is in charge of the management of source and final use of CDW; whilst MIIT is responsible for management of CDW recycling companies. The evaluation and auditing system is developed by NDRC. The responsibilities are separated and there is a lack of coordination mechanisms at the ministerial level.

- Enforcement performance varies at the local level.

At the Central Government level MOHURD has been clearly defined as leading unit, but in local governance, the construction department is divided into housing construction bureaus and urban management bureaus (city appearance and environmental sanitation) to perform different duties; but there is lack of effective management and coordination with respect to CDW management.

- Lack of clear positioning of recycling enterprises

CDW recycling enterprises are regarded as “common enterprises” when the State Commission Office of Public Sector Reform defined the responsibilities. According to the “Notice on urban domestic waste treatment charging system and promoting waste treatment industrialization” (NDRC [2002]872 ), urban solid waste explicitly included CDW and spoil, therefore, construction waste recycling facilities should be regarded as “public utilities”. Referring to the solid waste management, urban infrastructure shall be managed by the centralized construction department, which is conducive to the implementation and enforcement of policies.

1.5.2 Local Government Level
The CDW recycling management of local governments involves different government administration departments (including development and reform commission, land resources, housing and construction, planning, municipal administration and landscape, transport, environmental protection, industry and information technology and finance) with their respective administration privileges and responsibilities. Currently in the PRC, the urban management department is the major CDW authority in most cases. At the local government level, the issues are similar to those at national level. The following specific issues were identified during the survey:

- The CDW administration authority and enforcement authority are separate.
The authority of the urban management department has no control over demolition and construction sites. It has the right to approve CDW transportation licenses but does not have right to regulate overloading of vehicles; to do this requires joint law enforcement of 5~6 departments. There is a low level of efficiency in enforcement, which causes difficulties in source control of CDW generation and sorting, and failures in back-end support for promotion and application of recycled products.

- Construction waste management is not linked with existing administrative licensing of construction projects.

The permits and license required for construction projects have no requirement for CDW recycling, therefore CDW recycling is usually ignored for both new construction projects and demolition. Uncontrolled dumping is common.

- Government responsibilities do not match with the construction waste recycling industry supply chain.

Existing functions are based on the management of permits and integrated considerations from upper, middle to downstream industry chain, so as to make it impossible for integrated management. The CDW recycling enterprises are often short of raw materials and find it difficult to sell their products. Policy development is also only for producer or consumer. The policies are difficult to implement.

### 1.6 Stakeholder Analysis

Stakeholders relevant to CDW management including central government bodies, local governments, developers, construction companies, construction waste disposal companies, transportation companies and the general public; this report includes surveys and analysis covering the aspects of CDW recycling awareness, CDW recycling promotion, CDW recycled products application and price, issues in CDW recycling, and suggestions to promote CDW recycling, which are summarized as follows:

#### 1.6.1 Upstream Industry – Sources of CDW

- **Gaps of legal system and lack of supervision of the market**

It is generally believed by stakeholders that CDW is inert material, non-toxic and odorless, and public complaints are minor. The environmental and resource conservation awareness is weak, and impacts on public safety are not considered. For example, the Building Law and government solid waste announcements don’t consider CDW at all, and there are no provisions on building demolition. The administration and management only care about construction while demolition is overlooked. There is a lack of waste prevention and minimisation concepts. There is no CDW generation statistical system or unified calculation standard. The existing regulations don’t have any quantitative targets on CDW emission, recycling and disposal, or standards and requirements on CDW pollution control, which bring difficulties in the actual management. The existing management is basically following the mode from the era of planned economy, i.e. the CDW administrative units bear the responsibilities of qualification approval and also shoulder the tasks of supervision and law enforcement. This kind of arrangement mixes administration and enforcement and weakens the effectiveness of macro management functions, which has seriously limited development of CDW recycling.

- **Lack of appropriate provisions, randomly dumping hard to stop**

At present, the PRC’s “Housing construction and decoration quote” does not include construction waste disposal costs but has construction waste removal fees only, which has not changed for many years and is generally low. At the same time, random dumping of construction waste has not been recognized as a serious crime, attracting just simple low fines, and most contractors are more interested in short-term profits. Most CDW is dumped directly despite the fact that the CDW recycling enterprises suffer from a lack of materials.

- **Unsorted CDW affects resource treatment costs and product quality**
Currently, waste demolition is separated from recycling and reuse: the management of demolition waste is not regulated, and there is lack of evaluation of both construction and demolition waste and detailed management. Specifically, engineering demolition is generally done by a demolition company. Due to the absence of regulation on sorting and storage, (except metals), demolition enterprises will store waste concrete, broken brick, soil, wood, and plastic together, sometimes also with domestic garbage. The CDW recycling enterprises have to sort the wastes. This significantly increases the treatment cost and the quality of recycling products is also affected.

### Stakeholder Analysis

The project owner, construction unit, design institute and government are involved in source generation. The project owner is the major player during demolition and construction; at the source generation stage, the project owner is in the center. The major concerns of design institutes include incorporating their ideas into the building while meeting the requirements of the project owner, completing as many works as possible in the shortest time, and accomplishing work which comply to standards. The construction unit is concerned about how to complete the construction at the fastest rate and with least resources and cost inputs. The government expect less CDW generation. Their expectations, responsibilities and obligations should be properly coordinated.

#### 1.6.2 Midstream Industry - Recycled CDW products

### Management of construction waste transportation industry

The construction waste disposal administrative licensing and other construction licenses are not bound to each other. Approval documents, engineering drawings and other relative materials of construction project shall be submitted to the approval authority, i.e. the Urban Management Administrative and Law Enforcement Bureau for the CDW disposal administrative license. However, the relative procedures and filings have not been done appropriately in compliance with the regulations. Meanwhile, some vehicles are modified in order to save transportation expenses and carry more CDW, which increases the safety risks during the transportation. Uncontrolled dumping of CDW in areas where CDW recycling plants suffer from shortages of material is quite common.

The mutual cooperation and linked enforcement mechanism is insufficient between functional departments. Traffic police, public security, housing construction, urban management and highways departments are all involved in the CDW transportation. Nevertheless, the departments lack mutual cooperation and information sharing, which results in low efficiency.

### Difficulties in land use approval for CDW recycling

At present, CDW land use is not guaranteed. The high cost of CDW transport results in reliance on nearby land. However, the CDW recycling land is not included in the urban construction plan in many cities and the investment for the CDW recycling does not meet the marketization standard. Thus, the land problems hinder the CDW recycling development.

### Environmental assessment approval for CDW recycling project is difficult

The products of CDW recycling enterprises are mainly building materials, belonging to the “construction and processing enterprise” category. Building material processing enterprises are forbidden to build factories in urban area by the environment departments of many local governments in compliance with the laws and regulations, which may add difficulties for the factories to obtain authorization under the EIA process. Meanwhile, to demonstrate the environmental-friendliness of CDW recycling, as well as to facilitate the administrative permit, if the word “waste” remains in the project name, the local residents disagree with the construction of such facilities and the negotiation with the residents is difficult.

### High costs and investment of CDW recycling

At present, the CDW recycling industry is still in the primary stage. Due to the diversity and complexity of the raw materials of CDW, the underdevelopment and high cost of relative disposal technologies and
equipment, as well as the costly environment investment, recycled CDW products are high price and consequently cannot achieve good sales. Although it may involve the government administrative departments, demolition unit, transport enterprises, construction unit, using unit for the development of CDW recycling, the industrialization for the CDW recycling needs negotiation and coordination among the entire industry chain.

1.6.3 Downstream Industry - Utilization of Recycled CDW Products

- **Lack of mandatory regulations for recycled CDW products**

Many provinces and cities require that the infrastructure engineering investment by governments (including roads, landscaping, public toilets, garbage buildings, pavements, river channels and embankments) shall use a certain percentage of recycled CDW products according to the relative proportion of the city. However, the execution of the regulations remains to be improved, in which the recycled CDW products are in excess of demand and products for public infrastructure are unavailable. Meanwhile, the above regulations restrain the application scope of recycling products, which hinders the actual application.

- **Lack of completed standards for recycled CDW products**

Although the production standards are generally complete, the corresponding evaluation and product certification standards for recycled CDW products are incomplete and insufficient, which prevents construction units from judging the current products correctly, resulting in reduced use of recycled CDW products.

- **Lack of price competitiveness for recycled CDW products**

Screening, crushing and other relative treatment processes are needed for the recycled CDW products, which increases the labor and relative processing costs. Also, the promotion costs are rising considering the lack of subsidies, which decreases the price competitiveness of recycled CDW products.

- **Traditional conception hinders the use of recycled CDW products**

Recycled CDW products are mainly recycled aggregate, recycled brick, and recycled concrete, which illustrates the products characteristics well. But this kind of nomenclature is not in accordance with any current standards, which increases the engineering difficulties. Also, developers do not agree to use words like “recycled” and “garbage” when describing construction materials, as it is unacceptable for the public and may influence the sales of houses..

1.6.4 Obstacles in Promoting Recycled CDW Products

Based on the above analysis, the obstacle to market promotion of CDW recycling comes from various parts of the industrial chain, involving not only influences of macro-level policies, but also micro-level problems arising in the development of enterprises..

1.7 Economic Analysis of the PRC CDW Recycling Market Failure

The economic analysis under this Study is carried out by means of empirical analysis and whole industrial chain comparative analysis. The cost elements of CDW generation and sorting, CDW removal and transportation, CDW digestion and CDW beneficial use are analyzed from the perspective of the whole production process of CDW recycling. Cost computation and comparative analysis are conducted by means of standardized processing of data sampled from the individual cases of fixed crushing CDW recycling, mobile crushing CDW recycling and CDW landfill. Costs of different CDW recycling technologies as well as prices of recycling products and common construction material products are compared and analyzed.

The analysis shows that construction waste recycling technology generates marginal economic benefits. Without proper policies and instruments on subsidizing, it is very hard for all types of recycling facilities
to be financially viable. Products of fixed treatment technology have better marketing advantage despite their higher investment cost than mobile treatment technology that is limited by process equipment.

The financing costs of different types of enterprises have not been considered in the study, i.e. all the investment is considered made by the enterprises fully with their own capital. If such financing costs are taken into account, the economic benefits of both fixed and mobile technologies are expected to be lower, which is one of the obstacles to market application of construction waste recycling technology.

According to the study, due to the absence of measures for mandatory dumping and transportation of construction wastes, there is not a stable source of materials for construction waste recycling enterprises, resulting in the absence of stability of revenue for enterprises engaged in, for example, fixed construction waste recycling and also bringing certain impacts on their market sustainability.

Sales price in the market is not an obstacle influencing market application of recycled CDW products because there are occasions when their prices are lower than ordinary construction material products. It is more a factor of market acceptance of recycled CDW products. Their narrow application and the absence of a uniform quality certification and accreditation identification system in the sector cause some problems of marketing.

1.8 Current Status of Urban Construction Waste Utilization and Management in the PRC

1.8.1 Selection of Case Study Cities

Typical cities have the following features:

- Adequate CDW source management
- Scaled CDW recycling and sustainable enterprise operations
- Effective marketing of recycled CDW products
- High CDW recycling rate
- Different types of cities which can provide lessons and experience for each other

1.8.2 Cities Selected for Case Studies

Shenzhen — an emerging large city which has an early start in CDW recycling with many recycling enterprises that in sustainable operation. Shenzhen is playing a leading role in CDW recycling among the major cities in the PRC.

Xi’an — a famous historic and cultural city which has established a mature disposal approval system, with adequate source management and large-scale recycling enterprises in sustainable operation.

Xuchang — a small to medium city which has achieved adequate whole process management of CDW recycling, there are scaled recycling enterprises with sustainable operations. Its CDW recycling rate is ahead in the country.

Wujin District of Changzhou City — one district of a medium city, its CDW recycling has a late start but the promotion is strong and effective, there are already scaled recycling enterprises.

Beijing — a megacity of the PRC, even though great importance is attached to CDW recycling, the performance is not satisfactory, a brief introduction is provided in this study for comparison with other cities.

1.8.3 Summary of Successful Experiences

- **Shenzhen**

(1) Laws and regulations of Construction Waste Reduction and Utilization
On October 1st 2009, Shenzhen issued the first legal regulation on construction waste reduction and utilization in the PRC, specifying 9 innovation systems, including the review and record of construction wastes, reduction and disposal proposal, labels of recycled products, emission tariff, disposable residence decoration, mandatory use of the construction waste recycled products, exchange and utilization of construction spoil, on-site classification of the construction waste. The regulation provides clear legal basis to cut down the sources of construction waste.

(2) Government counterpart and strong supervision

Under the supervision of the legal regulations, two record systems namely construction waste reduction and utilization are established. The system of reviewing construction waste content in the designed drawings specifies the requests that the design unit shall have reduction design, the drawing review institute shall report to the administrative competent department after the approval of relevant content for record; The system of construction waste reduction and utilization indicates that reduction design and utilization plan should be prepared in the construction of new projects, demolition of existing architectures, structures and municipal roads. The construction unit shall report to the competent department before the commencement of the project.

(3) Market-driven and industrial upgrading

Shenzhen has developed 5 integrated construction waste utilization enterprises successively and explored the business model of integrated construction waste utilization, namely “site-plant combined mode”, temporary land use mode, on-site disposal mode. The site-plant combined mode is defined that, the recycling treatment facilities and receiving site will be constructed jointly for the purpose of eliminating the stored wastes; Temporary land use mode is defined that, the land use for recycling disposal facilities is used temporarily, mainly eliminating the waste for street demolition; On-site disposal mode is defined that, the recycling facilities are constructed on the demolition site, so as to realize “zero emission” of construction waste and reuse the recycled products in project construction.

(4) Technique support and innovation upgrading

In 2012, the first construction disposal emission technical standards was released in the PRC and clarified the standards of construction waste emission, detailed requirements of waste reduction design and construction reduction. It is very critical to the design institutes in optimizing the construction design, reducing the consumption of building materials, generation of the construction waste, guiding the construction unit to recycle the construction waste.

(5) Promotion and Social Recognition

Shenzhen attaches great importance to the promotion and guidance of construction waste recycling. With various channels such as newspapers and magazines, Shenzhen has special feature report to show the hazards of construction wastes compared with the social and environmental benefits of waste recycling. Also it shows the technique and recycled products to the public. Through promotion and guidance, the construction waste recycled products have achieved social recognition and good market acceptance.

- Xi’an

(1) Serious Governmental Recognition

Leaders of the CCP Municipal Committee and the Municipal Government have conducted field studies and held multiple special meetings. In 2010, a steering group headed by the responsible leader of the Municipal Government and comprising of members from the municipal authorities of city appearance, city administration and traffic police was established; in the meanwhile, 15 joint inspection teams comprising of members from the municipal authorities of city appearance, city administration and traffic police were established for daily inspections and strict strike of various violations in terms of construction waste transportation.

(2) Assurance from Legislative System
Xi’an has set up an integrated and complete construction waste management system consisting of local legislations, government specifications and sector regulations. Construction Waste Management Regulations of Xi’an City defined the responsibilities of the government authorities of city appearance, city administration and traffic police and others involved as well as at the management levels of district, county and community and described in full detail the rights, obligations and responsibilities of government departments and individuals in terms of construction waste generation, transportation, digestion, recycling and legal responsibilities, including specific and strongly operable measures.

“Methods for Appraisal and Evaluation of Construction Waste Transportation Companies in Xi’an City”, “Provisional Requirements on Charges of Construction Waste Disposal in Xi’an City” and “Methods of Accountability Investigation in Construction Waste Management in Xi’an City” were issued in succession, along with series of rules and regulations on daily reporting, site supervision, comprehensive evaluation, market withdrawal, recycling company registration, traffic safety registration, “uniform management in 7 aspects” and joint inspection.

(3) Appropriate Enforcement of Actions and Measures

Xi’an City has been implementing discharge permit and daily reporting in a strict way making sure that producers of construction wastes must apply for and obtain a “Construction Waste Disposal (Discharge) Permit and that the construction waste transportation permit shall not be granted until the procedures of reporting, generation verification and disposal fee payment are fulfilled. In practice, a daily report of the transportation vehicles at night time is required, with the reported information shared by the city administration and traffic police authorities via the Comprehensive Management System of Construction Wastes. The concerned government authorities carry out their respective duties and responsibilities based on the reported information.

Xi’an City has specific requirements on transportation capacity and site scale for the purpose of strictly managing the qualifications and competence of transportation operators. Vehicles transporting construction wastes are managed under the category of special vehicles and the vehicles, drivers and corporate owners are subject to traffic police registration and “uniform” management. Transportation operators are subject to monthly evaluation and year-end appraisal for quantitative rating. Those with poor performance in monthly evaluation will be suspended for improvement while those with unacceptable performance will be disqualified and instructed to withdraw from the construction waste transportation sector, with their Construction Waste Disposal (Transportation) Permit revoked.

Xi’an established a recycling enterprise registration system. Registered enterprises are included in the comprehensive management system of construction wastes and the city appearance authorities of the various districts and development zones, upon approval of construction sites, will assign demolition wastes based on the production needs of the enterprises to support their production activities.

Thanks to the effective implementation of a series of management measures, effective interaction is achieved of the stages of construction waste generation, transportation and disposal to ensure that the construction wastes are transported to the digestion sites or recycling enterprises, destination of construction wastes is effectively controlled and development of construction waste recycling industry is facilitated.

(4) Strengthened Supervision and Appraisal

In order to make sure that the various measures are enforced, the Municipal Joint Inspection Team carries out zone-based and group-based night tours around the City while the City Appearance and Gardening Bureau organizes at least 2 non-notified inspections per week focusing on site control at the entrances and exits of construction sites with waste generation. Transportation permit approval is, in the first instance, suspended for sites with problems discovered in such inspections and then evaluation scores of the respective jurisdiction are deducted, with news published on Xi’an Daily, Xi’an Evening News and other media.

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Xuchang

(1) A special management body is established to facilitate effective management.
Both the Municipal CCP Committee and People’s Government of Xuchang attach consistent and great importance to construction solid wastes management. Early back in 1999, Xuchang City established the Construction Solid Waste Management Office and was then approved in 2014 by the People’s Government of Xuchang City as a permanent government body, which plays an extremely important role in facilitating the management and beneficial use of construction solid wastes in Xuchang.

(2) Powerful supports were provided through policy improvement.

Xuchang City consecutively issued the “Methods for Management of Urban Construction Solid Wastes in Xuchang City”, the “Detailed Rules of Implementation of Urban Solid Waste Management in Xuchang City” and the “Standard on Collection of Urban Solid Waste Treatment Fee in Xuchang City”, the “Methods of Management of Construction Materials and Construction Solid Wastes on Construction Sites” and the “Opinions on Comprehensive Use of Construction Solid Wastes”, specifying the full process of management and beneficial use of construction solid wastes from source declaration, collection, transportation, disposal and promotion and application of regenerated products of construction solid wastes. The adequately detailed and strongly operable requirements included in such policies guaranteed their effective implementation.

(3) Franchised operation model was developed to increase the impetus of industrial development.

As of Year 2008, the People’s Government of Xuchang City initiated “franchised operation” of integrated collection, transportation and beneficial use of construction solid wastes in the urban area. The franchised enterprise has the exclusive right of investing in and constructing, operating and maintaining projects of construction solid waste transportation, disposal and utilization within the scope of franchised operation and collecting construction solid waste transportation tariff according to the tariff standard approved by the People’s Government of Xuchang City. This enterprise undertakes construction projects of construction solid wastes treatment plants to realize recycling and reuse of construction solid wastes and fulfills the public benefit tasks and other obligations assigned by the government. With clearly assigned rights and obligations, the franchised enterprise experienced high-speed development, and the CDW recycling industry in Xuchang has reached a relatively high level.

(4) Joint efforts from multiple government departments contribute to effective supervision.

Xuchang established its joint law enforcement mechanism, under which, the Municipal Government, as the leading organization, is responsible for organizing joint law enforcement participated in by the government departments of city management, public security, housing and urban construction, transportation and highway administration. The key purpose of such joint action is to control and manage construction sites, debris transportation vehicles and commodity concrete transportation vehicles. In addition, improvements were made to the supervision, examination, reward and penalty and accountability mechanisms, accompanied by stronger efforts in inspection and penalty. These actions have effectively addressed the problems of spillage of construction solid wastes and pavement contamination by muddy vehicles. In order for closer partnership between the franchised enterprises and the management authorities, joint management teams were established to increase the frequency of routine inspections and assure that all the construction solid wastes are transported to designated disposal sites.

(5) S&T innovations become a driver of sector development.

The franchised enterprise established Henan’s first engineering and technology research center specialized in R&D of construction solid wastes. Thanks to its all-round efforts of S&T research in classified collection, disposal, key processes and technologies and new product development in terms of construction solid wastes, technological, process, equipment and management models were developed for the sector of beneficial use of construction solid wastes, laying a solid foundation for nationwide duplication of “Xuchang Jinke Model”. The franchised enterprise was certified in 2014 as a national hi-tech enterprise.

(6) Policy and technology supports assured market application.

The Municipal Government provided supports to comprehensive use of construction solid wastes through comprehensive use of public financing, taxation and investment and other economic levers and
incorporating regeneration products of construction solid wastes into the scope of government procurement and regarding such incorporation as one of the prerequisites of financial settlement and fund disbursement. Projects failing to use construction solid waste regenerated products according to the design shall not be permitted for final acceptance and registration upon completion. Such policy supports opened the gate to market application of regenerated products. Construction solid wastes regeneration products have already been widely applied in construction projects of urban roads, gardens, plazas, houses, rivers and water conservancy facilities in Xuchang.

- **Wujin District, Changzhou City**

(1) Demonstrative Role in Green Development

Changzhou follows the concept of green development, and has made requirements for CDW recycling enterprises on classified dismantling, regulated transportation, enclosed production, high recycling rate, zero pollution and zero discharge.

(2) Policy supports enabling the formation of a closed industrial chain

Changzhou City has consecutively issued the "Implementation Plan for Special Actions in Controlling and Regulating Construction Wastes in Changzhou City", the "Announcement on Strengthening Management of Municipal Construction Waste Disposal", the "Opinions on Implementing the "Municipal Construction Waste Management Regulations", the "Minutes of Meeting on Further Strengthening Beneficial Use of Construction Wastes" (No. 2013-88) and the "Minutes of Meeting on Coordinating Efforts in Facilitating the Work of Management and Harmless Disposal of Construction Wastes" and integrated the efforts of all concerned departments to set up a comprehensive management system and formed a closed industrial chain integrating the generation, collection, transportation, disposal and recycling and application of construction wastes.

(3) Four development goals achieved through departmental interaction

Changzhou Urban Administration Bureau, in coordination with Wujin District government departments and offices of urban administration, housing, finance, reform and development, taxation, economic and IT, science and technology, collection, transportation, water conservancy and public security, has set up a comprehensive coordination and management mechanism for construction waste recycling. "Admission thresholds" are established for vehicles and enterprises to be engaged in construction waste transportation to regulate the process of construction waste transportation and avoid "spillage and leakage" during transportation. A sound construction waste management system that is led by the government, participated by the social public and managed by the competent industrial department and involves cooperation from all concerned sides shall be set up, and incorporate construction waste recycling into modernized development plan of building industry and truly realize reduction, harmless and beneficial use and industrialization of construction wastes.

(4) Franchised enterprises established using PPP model

In Changzhou Wujin District Green Building Industrial Zone, franchised construction waste enterprises are established using PPP model for the sake of moderate integration of market competition and government regulation. State-owned and private account for 70% and 30%, respectively, for Franchise enterprise, and project land use is unified transfer. Economic benefits are realized simultaneously with social benefits to bring profits to the enterprises.

(5) Green production achieved through technological research and innovation

The franchised enterprise has developed excellent partnership of technological development with a number of scientific research institutes and colleges and universities. In addition, it has set up the Construction Waste Green Recycling Engineering Technology Research Center and Jiangsu Province Graduate Work Station. Advanced process technologies and equipment were imported, and automation and integration of diversified product promotion modules were realized and green production achieved in construction waste recycling.
(6) Recycling product market expanded by diversified means

It is pointed out in the Minutes of Meeting on Coordinating Efforts in Facilitating the Work of Management and Harmless Disposal of Construction Wastes that construction waste recycling products should be included into the catalogs of green construction materials, the catalogs of government procurement and the engineering cost information for preferential promotion and application in construction projects. Construction waste recycling products should be utilized as a top priority in green buildings and the construction project design stage. Construction projects financed with state-owned fund or by the national government must use construction waste recycling products to expand the scope of application of construction waste recycling products. The franchised enterprise has sped up the R&D and promotion of new technologies, new processes, new equipment and new materials, in particular, the development of new regenerated construction materials and raw materials oriented towards the current hot directions of industrial development.

1.8.4 Comparison of Case Study Cities

There are various factors influencing urban CDW management, in terms of the case studies stated above, there are general practices of CDW recycling and reuse among different case study cities and also differences. In general, the key success factor for CDW management and utilization are primarily government policies and promotions, as well as actively participation by enterprises in the local market, secondly tailored measures based on its own features.

Shenzhen is the first city in the nation that has CDW utilization legislation, although some items in Shenzhen Construction Waste Reduction and Utilization Regulations are not in details, it is the first time in the nation that regulations are set out for CDW source reduction and utilization, which is demonstrative action for the legislation of CDW recycling and reuse in the whole nation.

Xi’an Construction Waste Management Regulations are in adequate details and provide legislations for the implementation of urban CDW management, it is highly practical and provides strong support to monitoring of CDW disposal and transportation for Xi’an.

Methods for Management of Urban Construction Solid Wastes in Xuchang City provides legislation condition for establishing franchise mode, Xuchang became the first city that implements CDW recycling and reuse Franchise.

Although there has been no legislation established in Changzhou, regulations for CDW recycling and reuse management are developed through 2 meeting minutes, which set out policy support for CDW disposal and transportation enterprise franchise, and the implementation of disposal and transportation government subsidies.

Advices on promotion of CDW Recycling and Reuse Comprehensive Management in Beijing includes all aspects, however, it is at macro level and not practical.
2 International Good Practice Review

2.1 Methodology

The Methodology for this Good Practice Review has comprised a desk-based review of available information in the English language. Sources of information have included:

- Papers and reviews in a range of national and international journals and conferences;
- Information published by regulatory authorities, including waste strategy and legislation;
- Information published or made available by other stakeholders, including construction companies, waste management companies and industry bodies.

Information has been collated and assessed around the following key topic areas, for each of the case study countries:

- Roles and responsibilities – identifying the relevant bodies which are responsible for setting regulations, enforcement and issuing guidance.
- Construction waste statistics – identifying how the CDW system performs, in terms of total quantities generated and recycling rates, and discussing the infrastructure for CDW recycling.
- Legislation – discussion of relevant legislation, including that covering waste generation, licensing of waste facilities, prevention of illegal dumping, and any mandatory recycling targets.
- Fiscal Instruments – the use of taxes, subsidies and other fiscal instruments to incentivize improved CDW management
- Specifications and client requirements – how improved CDW is implemented at a practical site-based level, for instance by preparing specifications for the use of recycled materials and how clients (including public sector clients) can influence CDW management by setting their own targets and requirements
- Technical guidance – how the construction industries are assisted in improving CDW management by the development of technical guidance, best practice notes and case studies.

2.2 Definitions of Construction Waste

In order to discuss international CDW practices, it is necessary to understand and define the various terms used to describe wastes arising from the construction industry.

The European Union’s Encord Construction Waste Measurement Protocol project (Encord, 2013) has recommended the following definitions for waste from construction:

- Demolition waste – Unwanted material arising from the demolition or strip out of an existing structure.
- Excavation waste – Unwanted material resulting from excavation activities such as a reduced level dig and site preparation and levelling, and the excavation of foundations, basements, tunnels, and service trenches, typically consisting of soils and stones.
- Construction waste – Any other unwanted material produced at the construction site, which is not classified as Demolition or Excavation waste.

According to EU definitions, uncontaminated soil (and other naturally occurring material) excavated in the course of construction activities, where it is certain that the material will be used for the purposes of construction in its natural state on the site from which it was excavated, is not considered as a waste.
This type of material is excluded from consideration in the 70% recycling target set in the Waste Framework Directive.

A large proportion of CDW comprises hard inert\(^2\) material which can be recycled as an aggregate (i.e. a granular material used in a variety of construction activities and which forms the main constituent of concrete and asphalt). Aggregates can be classified as:

- Primary aggregate: produced directly from quarries and comprising sand, gravel and crushed rock;
- Secondary aggregate: produced from by-products of industrial processes, such as incinerator bottom ash and blast furnace slag; and
- Recycled aggregate: produced from processing of construction and demolition waste.

The European Waste Catalogue (EWC) identifies the following categories and sub-categories of CDW (Table 2-1). Producers and disposers of waste in the EU are required to use this classification scheme for reporting. Hazardous wastes are underlined and carry an EWC code marked with an asterix (*).

Table 2-1: European Classification Scheme for CDW

<table>
<thead>
<tr>
<th>EWC Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 01 concrete, bricks, tiles and ceramics</td>
<td></td>
</tr>
<tr>
<td>17 01 01</td>
<td>concrete</td>
</tr>
<tr>
<td>17 01 02</td>
<td>bricks</td>
</tr>
<tr>
<td>17 01 03</td>
<td>tiles and ceramics</td>
</tr>
<tr>
<td>17 01 06*</td>
<td>mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing hazardous substances</td>
</tr>
<tr>
<td>17 01 07</td>
<td>mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06</td>
</tr>
<tr>
<td>17 02 wood, glass and plastic</td>
<td></td>
</tr>
<tr>
<td>17 02 01</td>
<td>wood</td>
</tr>
<tr>
<td>17 02 02</td>
<td>glass</td>
</tr>
<tr>
<td>17 02 03</td>
<td>Plastic</td>
</tr>
<tr>
<td>17 02 04*</td>
<td>glass, plastic and wood containing or contaminated with hazardous substances</td>
</tr>
<tr>
<td>17 03 bituminous mixtures, coal tar and tarred products</td>
<td></td>
</tr>
<tr>
<td>17 03 01*</td>
<td>bituminous mixtures containing coal tar</td>
</tr>
<tr>
<td>17 03 02</td>
<td>bituminous mixtures other than those mentioned in 17 03 01</td>
</tr>
<tr>
<td>17 03 03*</td>
<td>coal tar and tarred products</td>
</tr>
<tr>
<td>17 04 metals (including their alloys)</td>
<td></td>
</tr>
<tr>
<td>17 04 01</td>
<td>copper, bronze, brass</td>
</tr>
<tr>
<td>17 04 02</td>
<td>aluminium</td>
</tr>
<tr>
<td>17 04 03</td>
<td>lead</td>
</tr>
<tr>
<td>17 04 04</td>
<td>zinc</td>
</tr>
<tr>
<td>17 04 05</td>
<td>iron and steel</td>
</tr>
<tr>
<td>17 04 06</td>
<td>tin</td>
</tr>
<tr>
<td>17 04 07</td>
<td>mixed metals</td>
</tr>
<tr>
<td>17 04 09*</td>
<td>metal waste contaminated with hazardous substances</td>
</tr>
<tr>
<td>17 04 10*</td>
<td>cables containing oil, coal tar and other hazardous substances</td>
</tr>
<tr>
<td>17 04 11</td>
<td>cables other than those mentioned in 17 04 10</td>
</tr>
</tbody>
</table>

---

\(^2\) In the context of the EU Waste Framework Directive, waste is classified as inert if:

(a) it does not undergo any significant physical, chemical or biological transformations;
(b) it does not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health; and
(c) its total leachability and pollutant content and the ecotoxicity of its leachate are insignificant and, in particular, do not endanger the quality of any surface water or groundwater.
2.3 Significance of Construction Waste

2.3.1

In many countries, construction and demolition waste (CDW) is one of the largest waste streams by quantity. For instance, the European Union as a whole, CDW is the single largest waste stream accounting for 33% of all waste in 2012, 821 million tonnes in total (European Union, 2015). The CDW waste quantities for the 28 member of the EU and selected individual countries are shown in Table 2-2 below.

Table 2-2: CDW Generation in Selected Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Total waste from economic activities and households (million tonnes)</th>
<th>Construction &amp; demolition waste (million tonnes)</th>
<th>Proportion of CDW</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU-28</td>
<td>2,514</td>
<td>821</td>
<td>33%</td>
<td>(European Union, 2015)</td>
</tr>
<tr>
<td>Germany</td>
<td>368</td>
<td>197</td>
<td>54%</td>
<td>(European Union, 2015)</td>
</tr>
<tr>
<td>Spain</td>
<td>118</td>
<td>26</td>
<td>22%</td>
<td>(European Union, 2015)</td>
</tr>
<tr>
<td>France</td>
<td>344</td>
<td>246</td>
<td>72%</td>
<td>(European Union, 2015)</td>
</tr>
<tr>
<td>Italy</td>
<td>162</td>
<td>52</td>
<td>33%</td>
<td>(European Union, 2015)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>241</td>
<td>100</td>
<td>42%</td>
<td>(European Union, 2015)</td>
</tr>
<tr>
<td>Australia</td>
<td>48 (approx.)</td>
<td>18 (approx.)</td>
<td>38%</td>
<td>(Australian Government, 2013)</td>
</tr>
<tr>
<td>Japan</td>
<td>380</td>
<td>75</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>South Korea</td>
<td>382</td>
<td>186</td>
<td>49%</td>
<td>(Statistics Korea, 2014)</td>
</tr>
</tbody>
</table>
2.3.2 Impacts

The adverse impacts of CDW management may include:

- Local environmental nuisance from unregulated dumping;
- Increased demand for virgin construction materials;
- Loss of value in waste materials if they are not recycled or recovered.

The Australian “Sustainable Aggregates” organisation lists the benefits of recycling aggregate (one of the major CDW streams) as follows (Sustainable Aggregates South Australia, n.d.):

- Reduced resource consumption – substitution of new products for recycled means conserving new quarried aggregates for future generations
- Diversion of waste materials from landfill – which can mean less biodiversity, amenity and transport emission costs
- Reduced quarrying – means less amenity costs and biodiversity loss
- Reduced greenhouse gas emissions – recycled aggregates can have lower embodied energy in addition to reduced transport emissions, especially where recycled materials are reused in close proximity to the site of reprocessing.

2.4 Key Aspects of Successful CDW Management Systems

In order to achieve a high rate of CDW recycling and establish stable and competitive markets for recycled CDW materials, there are a number of critical factors that need to be addressed as a matter of policy. Any stable market requires a balance between supply and demand, and policy measures play an important role in ensuring a supply of recycled CDW materials of adequate quality, and also encouraging and supporting customer demand for these materials, recognising that government itself is often one of the largest customers for recycled CDW materials, in its role as the ultimate client for public infrastructure.

The critical factors are considered in this report under three main headings, which are briefly discussed below and analysed in more detail in subsequent sections of this report:

- Technical factors.
- Regulatory factors.
- Economic factors.

In general it is difficult to establish direct quantitative links between specific CDW policy measures and outcomes (e.g. improvements in recycling rates). This is because, in most countries, a package of policy measures have been introduced over a period of time, making it difficult to disentangle the specific impacts of a particular. In addition, the construction industry in most countries is highly cyclical, with construction activity slowing down sharply whenever GDP growth reduces. This in turn affects the amount of CDW arisings and can limit the demand for recycled construction materials. Nevertheless, in some cases it is possible to identify the major policy measures that have been introduced over a given period of time, and quantify the change in recycling rate over the same period, and examples are provided in this report.

Concrete is the largest single component of CDW, and considerable world-wide effort has gone into developing ways of recycling concrete. The Cement Sustainability Initiative, supported by the World Business Council for Sustainable Development, has assessed the global situation for concrete recycling and identified the following key issues as summarised in

Table 2-3 below (The Cement Sustainability Initiative, 2009). Although this information was produced specifically for recycling of concrete, the issues have a wider application to recycled CDW materials in general.
<table>
<thead>
<tr>
<th>Issues</th>
<th>Barriers</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material cost vis-à-vis natural aggregate</td>
<td>Low economic cost of virgin aggregate in some countries.</td>
<td>Aggregates levies and transportation costs for natural aggregates can be higher. Overall project costs can be reduced as less landfill taxes/fees are paid on CDW as the material is recovered instead of being landfilled.</td>
</tr>
<tr>
<td>Availability of material</td>
<td>Non-regular supply of CDW.</td>
<td>CDW is usually found in urban areas near construction and development projects. Virgin materials often need to be transported over greater distances.</td>
</tr>
<tr>
<td>Processing infrastructure</td>
<td>CDW on-site waste management plans are needed. CDW may need to be sorted. High-value recovered concrete requires costly processes.</td>
<td>Once infrastructure is established mobile sorting units and dedicated facilities can provide good returns.</td>
</tr>
<tr>
<td>Public attitudes</td>
<td>Misconception that recovered concrete is of lower quality. New materials are perceived as being of better quality.</td>
<td>Increasing environmental concerns leading to increased demand for eco-friendly products and reuse of materials.</td>
</tr>
<tr>
<td>Laws, regulations and industry accepted standards</td>
<td>Classification of recovered concrete as waste can increase reporting and permit requirements. Extra limitations can be placed on use.</td>
<td>Positive recycling laws, landfill taxes and green procurement policies by large users can all promote recycled concrete use.</td>
</tr>
<tr>
<td>Environmental impacts</td>
<td>Processing technology for recovery of concrete should consider possible air and noise pollution impacts as well as energy consumption, although there is little difference to natural aggregates processing.</td>
<td>Within a life cycle analysis, use of recovered concrete can lower overall environmental impact.</td>
</tr>
<tr>
<td></td>
<td>• Failing to use recovered materials increases landfill and associated environmental and health costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Failing to use recovered materials means virgin materials are used instead • Recovered concrete is generally inert</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• In some cases, transportation needs for recycled concrete can be lower than virgin materials (often not located in urban development areas) and as such fuel consumption, CO2 emissions and road and vehicle use can be reduced.</td>
<td></td>
</tr>
</tbody>
</table>
### Issues

<table>
<thead>
<tr>
<th>Physical properties</th>
</tr>
</thead>
</table>

For specialized applications (e.g. high performance concrete) there are some limitations on fitness for use. Technology can also limit recycling options.

<table>
<thead>
<tr>
<th>Benefits</th>
</tr>
</thead>
</table>

For most uses, recycled concrete performs well.

### 2.4.1 Technical Factors

Technical factors on the supply side ensure that sufficient quantities of recycled CDW material are produced that is of an adequate quality for its intended market. CDW must be segregated where possible and collected from construction sites, and facilities must be established (whether fixed or mobile) to process CDW into recycled materials to recognised standards, with consistent properties, and which can substitute for primary materials.

On the demand side, technical factors determine whether or not potential users of the recycled CDW material have the necessary confidence and ability to use this material. Specifications must allow recycled CDW materials in place of primary materials, and construction clients and contractors have an important role to play in promoting or requiring the use of recycled CDW materials.

### 2.4.2 Regulatory Factors

Regulatory factors are those which require or prohibit certain actions or behaviours by law. Waste regulations can take many forms, sometimes specific to CDW and sometimes relating to all wastes.

Regulatory measures can include mandatory recycling targets, landfill bans for certain materials, prohibitions on waste dumping, and requirements for source-separation of waste. Regulatory factors can also include non-statutory guidelines or accreditation schemes (such as requirements under various green building schemes), and measures for monitoring and measuring CDW performance. Because of the complex supply chain in the construction industry, unauthorized waste disposal (“fly-tipping”) can be a significant problem, which also requires regulation and enforcement.

### 2.4.3 Economic Factors

Economic factors include instruments which are intended to stimulate or support markets in recycled CDW materials. A fundamental difficulty with establishing markets for recycled CDW materials is that, in the absence of policy instruments:

- CDW waste disposal costs are low,
- CDW processing can require considerable plant and labour costs, and
- Primary construction materials are usually inexpensive.

Economic instruments can address these barriers by:

- increasing disposal costs by means of landfill taxes;
- subsidising processing costs either directly or via some form of public-private partnership (PPP), and
- taxing primary construction materials or incentivising the use of recycled CDW materials.
2.5 Technical Factors

2.5.1 Waste Types and Classification

Excluding excavated soil\(^3\) and asphalt\(^4\), the main constituents of CDW are:

- Hard inert materials (concrete and brick);
- Wood;
- Mixed waste.

The majority of construction waste in most countries comprises hard inert material, such as concrete and bricks. In terms of improving the amount of CDW that is recycled, this hard inert portion is generally prioritised because:

- This fraction forms the majority of CDW in most countries; and
- Recycling technologies and markets for the smaller fraction of CDW such as plastic and metal are relatively well-established.

Other fractions of CDW which are present in smaller quantities but which have received specific attention include:

- Wood – this can form a significant proportion of CDW, depending on construction methods in specific countries\(^5\);
- Gypsum (e.g. plasterboard/drywall) – landfill disposal is problematic due to its potential to generate toxic hydrogen sulphide;
- Hazardous materials such as asbestos.

In order to assess the effectiveness of CDW policy, it is necessary to measure CDW performance, which requires a robust and consistent framework for data collection. In the European Union, the European List of Wastes presents a clear and consistent framework for classifying different types of construction waste. A European construction industry organization has developed guidance on how to measure and report waste arisings and reuse/recycling/recovery from construction, demolition and excavation activities on construction projects throughout the EU (Encord, 2013), with the objective of ensuring consistency. In many countries, the mandatory use of waste transfer notes enables the regulator to monitor construction waste types and quantities, and therefore to calculate recycling rates (e.g. transfer notes are required as part of Hong Kong’s construction waste charging scheme).

2.5.2 Supply-side Technical Factors

The technical factors affecting the supply-side of CDW recycling can be grouped into two categories:

- Effectiveness of source-separation to produce relatively clean and consistent sources of material which is suitable for processing; and
- Effectiveness of processing to produce recycled material suitable for use.

In some countries, source-separation is mandatory for all but the smallest construction projects (e.g. Japan). In other countries, source-separation is encouraged either by regulators or clients. For instance, public sector clients in the UK often require contractors to prepare and implement Site Waste

\(^3\) Excavated soil is often excluded when considering CDW, as its management is relatively straightforward and usually simply a matter of identifying projects requiring fill material which can use the excess cut material from other projects.

\(^4\) MOHURD noted during the inception stage that asphalt recycling is outside the scope of this project.

\(^5\) For example, wood is used extensively in domestic construction in Japan; and bamboo is used for scaffolding in Hong Kong.
Management Plans\(^6\), which will normally include provision for source-separation of the main types of CDW. Hong Kong’s public sector clients also require similar commitments to CDW source-separation.

The primary recycling route for hard inert CDW is back into the construction industry, as a recycled aggregate. Most recycled aggregate is used as general fill or sub-base\(^7\), and the basic procedure for recycling hard inert material is relatively straightforward, consisting of crushing and screening (Hyder Consulting, 2011). More advanced techniques are available, which are intended to produce a higher-quality aggregate which may be used in more demanding applications, such as in concrete.

For instance, a European Union (EU) project investigated waste concrete streams and optimised recycling processes that yield fine cement paste, coarse aggregate and fine binding materials. This was achieved through lab tests, simulations and experiments, as well as through a case study involving industry partners. Tests showed that end-of-life concrete can be recycled with excellent results, although contaminants such as wood or plastic must be removed at an early stage (CORDIS, 2015).

The UK has successfully developed a “Quality Protocol” for recycled aggregates. CDW treatment facilities which accept certain types of waste, and produce recycled aggregate to a recognised specification and following defined quality control procedures are entitled to sell their outputs as a construction product, and it is no longer regulated as a waste. This has helped to build confidence in the market, and reduced regulatory burdens associated with waste legislation (Mineral Products Association, 2011).

In the case of mixed CDW, a UK study into good practice CDW recycling at Materials Recycling Facilities (MRFs) noted that various sorting equipment is available recovering material on the basis of size, mass and other physical and chemical properties, but the level of automation in MRFs varies markedly (WRAP, 2009). Technologies used may include:

- Screening equipment – the most important initial step of a CDW MRF, which uses trommels, vibrating screens or star screens to separate material by size.
- Hand picking – hand separation of mixed waste still remains common in many countries.
- Magnets – to extract ferrous metal.
- Water separation equipment – flotations tanks can be used for separating wood from heavier aggregates.
- Air separation equipment - air- or wind-separation equipment can optimise the quality of aggregate outputs by removing lighter contaminants (such as paper, plastic and wood) from the heavier rubble leaving the picking cabin, or from fines separated out by trommels or vibratory screens.
- Shredders - wood-shredding machines to reduce the space taken up by recovered wood and thus increase transport efficiency, and shredding can also be used for other waste streams.
- Advanced equipment - some highly automated plants used equipment such as ballistic separators (to separate light from heavy fractions), optical sorting technology (applicable to separating several types of materials), and eddy current separators (to remove aluminium).

A study into the potential of Near Infrared (NIR) sorting technology to improve the quality of mixed recycled aggregates carried out tests using samples of mixed recycled aggregates collected in different EU countries (Germany, Sweden, Spain and Italy). Constituents, total sulphur content, acid soluble sulphates, total heavy metals and metal leaching were determined before and after the use of the NIR sorting technology. The results clearly indicate that the problematic fractions (organic material, gypsum and AAC) in the mixed recycled aggregates can be significantly reduced or even eliminated during the NIR sorting treatment, boosting a greater use of recycled aggregates in high grade applications such as concrete manufacturing (Vegasa, Broosb, Nielsen, Lambertz, & Lisbona, 2015).

\(^6\) Site Waste Management Plans were previously a legal requirement in England: although no longer legally required, they are frequently made a contractual requirement.

\(^7\) In highway engineering, sub-base is the lowest layer of aggregate, which is placed on top of the soil and which is overlain by the base- and wearing courses of the road.
Although many different technologies are available, the use of specific advanced technologies is not generally identified as a critical factor in achieving a good CDW recycling rate. Provided the necessary regulatory and economic drivers are in place, relatively simple recycling technology should be capable of generating recycled outputs that are suitable for use.

### 2.5.3 Demand-side Technical Factors and Client Requirements

Ensuring an adequate supply of source-separated CDW is only part of the solution: if markets are not available, this material cannot find a use. For instance, Hong Kong has been very successful in diverting CDW from landfill, but less successful in finding alternative outlets for this material. Most countries report some difficulties in the acceptance of recycled CDW: often it is perceived as being of low quality. Measures to address this negative perception have included:

- Development of specifications for use of recycled aggregates;
- Publicising case studies which illustrate the technical and economic benefits of using recycled CDW;
- Encouraging or requiring the use of products with a high recycled content;
- Carrying out research into higher value-added CDW recycling.

For example, the Cement & Concrete Association of New Zealand have published a detailed best practice guide for the use of recycled concrete which includes model specifications (Cement and Concrete Association of New Zealand, 2011), and the British Standard for Concrete, BS 8500, applies product-specific, and specification-specific, conditions on the use of recycled aggregates in new concrete construction (Mineral Products Association, 2013). A review of CDW management in Australia concluded that recovery rates are highest in those regions where there is strong market demand for recycled C&D materials, with well-defined and well-publicised specifications supporting the use of recycled products (Hyder Consulting, 2011).

A large amount of research has been carried out into use of recycled CDW, and is published in a wide range of international journals and conferences (for example, the organisation RILEM supports many such events (RILEM, 2011).)

Government or government-owned bodies are the clients for a large proportion of construction projects, particularly in the infrastructure sector. Government can set CDW performance requirements in their construction contracts, and select only contractors who can deliver these requirements. When selecting contractors, Government can show preference to those who can demonstrate achievements in sustainable CDW management. For instance, major contractors in the UK monitor and publicise their CDW recycling performance. For example, Carillion (a large UK-based contractor) has a commitment to sending zero non-hazardous waste to landfill by 2015 and achieved their 2014 target to divert 95% of waste from landfill. Measures included collaborating with the supply chain, designing out waste and strengthening relationships with waste management specialists (Carillion plc, 2015). In Japan, the Kajimi Corporation (a major construction contractor) has adopted a company-wide target for its final

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8 RILEM (Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages), in English the “International Union of Laboratories and Experts in Construction Materials, Systems and Structures”
disposal rate (i.e. the percentage of total waste material that is not recycled) of under 5% (Kajimi Corporation, undated).

Contractors on major infrastructure projects in the UK are typically required to measure and report their CDW recycling performance to a high level of detail. Project targets for CDW recycling are established at an early stage and continually monitored. For example, on the Crossrail project (Europe’s largest construction project) the Environmental Objectives for 2015-16 include: “Implementing the waste hierarchy by achieving 90% (or greater) reuse or recycling of our construction and demolition waste and 95% (or greater) reuse or recycling of our clean excavated material and achieving at least 15% of the total value of our construction materials from reused or recycled content” (Crossrail, not dated). This is turn is reflected in the contractual requirements of the project.

An Australian study recommended that the wider adoption of sustainable procurement practices, particularly through government agencies, would help increase market demand for recovered C&D materials, and also recommended that Government agencies should favour procurement of material containing recycled C&D content where they meet defined performance criteria / specifications (Hyder Consulting, 2011).

2.5.4 CDW Management in the Project Cycle

Countries which are already achieving relatively high levels of landfill diversion for CDW are increasingly turning their attention to:

- Improving the standard of recycling – i.e. using recycled materials for more value-added applications (such as using recycled aggregate in structural concrete, rather than as general fill); and
- Minimising construction waste at source, for example by designing out waste and better on-site management of materials.

For example, in the UK the government-funded organization WRAP carried out an active programme of developing guidance for the construction sector between 2000 and 2015.

Although it is important to provide effective “end-of-pipe” solutions for recycling of CDW, there are measures to reduce the quantities and increase the recycling rate of CDW that can be taken at all stages of the construction cycle. This included issuing practical guidance to the construction industry on how to manage CDW at all stages of the project cycle, following the principles of “reduce-reuse-recycle” (also known as “3Rs”). Advice from WRAP’s publication “Achieving good practice Waste Minimisation and Management” relevant to waste minimization is summarized below (WRAP, n.d.):

Design solutions

- Building form – design building size and space to eliminate unnecessary elements, and to reduce off-cuts resulting from the construction process, and ensure compatibility between market supply and specification.

- Design flexibility – ensure flexibility in design for future building expansion, adaptation and dismantling.

- Design complexity – reduce the complexity of the design to standardize the construction process and reduce the quantity of materials required.

- Specifications – avoid over-specification and minimise variation in components and joints; evaluate the reuse and recycling opportunities for the specified materials before specification.

Demolition

Stimulating demand for recycled CDW products is often challenging. Part of the answer is technical, and can be addressed by research and development of specifications and protocols. Part of the answer relates to perception, and can be addressed by case studies and demonstration projects. Clients can stimulate demand by requiring the use of a certain proportion of recycled material in projects.
Avoid the disposal of reusable materials and building elements; maximise the use of reclaimed materials on site.

**Logistics**

- Logistic Plan – development of a logistic plan at the early stages of the project will ensure that due consideration is given to material requirements through the construction phase of the project, enabling efficient management of the delivery and storage of materials and that the most effective logistic methods are adopted.
- ‘Just-in-time’ delivery – improving the movement of materials to the site and within the site to alleviate space constraints for storage and site congestion.
- Construction Consolidation Centres – these provide effective supply chain management solutions enabling the safe and efficient flow of construction materials and equipment from supplier to site.

**Modern Methods of Construction (MMC)**

- Improvements in the products or processes employed in the construction industry, ranging from innovative components to be used on site through to whole building systems manufactured off-site.
- Off-Site Manufacturing – utilise prefabrication, factory assembly, preassembly, off-site assembly/manufacture, panelised or modular volumetric construction where possible, for example, staircases, lift assemblies, architectural steelwork and toilet blocks for hotels, prisons and student accommodation. Waste Minimisation is realised due to the controlled environment and the “production line” type process where there is repeatability in construction.

**Materials procurement**

- Materials ordering – reduce the amount of surplus materials by ordering the correct amount of materials at the right time.
- Material storage – material storage areas should be safe, secure and weatherproof to prevent damage and theft.
- Supply chain manager – will develop relationships and partnerships with suppliers during construction who can implement waste minimisation at source.
- ‘Take-back’ schemes – setting up schemes with suppliers to take back surplus materials.

**Packaging**

- Reduce and reuse – engage with the supply chain to supply products and materials that use minimal packaging, and segregate packaging for reuse.

Countries that have been successful in achieving a high CDW recycling rate are increasingly looking to increase the quality of recycling, and minimize the amount of CDW generated in the first place.

Effective CDW waste minimization requires early and continued efforts throughout the project cycle, involving clients, designers and contractors.

### 2.6 Regulatory Factors

#### 2.6.1 Waste Regulations and Targets

Some countries have specific regulations relating to CDW, whereas others have broader regulations which apply to all wastes. Successful waste regulations generally require:

- Licensing of waste management facilities and waste transport companies;
- Environmental assessment for waste facilities;
- Manifest system to track the transfer of waste between parties; and
- Penalties for illegal dumping of waste.

Measuring the success of CDW recycling policies requires detailed information about the quantities and destinations of CDW. Whilst not straightforward to implement, countries see data collection and management as an important aspect of their overall CDW management programme, and this aspect has been addressed at an EU level (Encord, 2013). In the European Union, over-arching waste policy is set out in a series of Directives which are then passed into law by member countries. CDW is covered by the general requirements for managing waste as set out in the Waste Framework Directive, and there is a specific target that member countries should recycle at least 70% of CDW by 2020 (European Union, 2008). Where problems have been identified, these relate to fragmented and inconsistent approaches. For example, in Germany the lack of a nationwide regulation for secondary building materials, which resulted in many different legislations on state level, is considered as one of the major barriers for sustainable CDW management (Deloitte, 2015).

It is also important that the regulatory roles and responsibilities are clearly defined and understood by all parties. These responsibilities vary between different countries and there is no particular regulatory model that has been adopted globally. It is however important that these responsibilities are coordinated: the regulatory tasks may include:

- Promulgating CDW regulations.
- Licensing and regulating activities of CDW management facilities.
- Regulating activities on construction sites, including controlling environmental emissions from these sites.
- Licensing and regulating vehicles transporting CDW.
- Collecting and publishing data and statistics.
- Advising on the practical aspects of good-practice CDW management.
- Researching new ways of managing and recycling CDW.
- Setting standards for building materials made from recycled CDW.

In some countries, industry bodies have developed in order to advise, from an industry perspective, on aspects of CDW management and how to ensure that regulations are clearly and consistently applied (e.g. the UK’s “Green Construction Board”). From a regulatory perspective, bodies with a role to play may include:

- Environmental agencies or departments.
- Construction and building control departments.
- Transport departments.
- Police and traffic control agencies.
- Universities and research agencies.

There is little information in the literature which deals with inter-agency coordination, but the fact that so many agencies are potentially involves leads to the conclusion that there must be consistency and a clear strategy in place, to ensure there are no weaknesses in the regulatory environment; and that policy, implementation and enforcement are well-coordinated.

Control measures should extend from the site of production to the site of treatment/disposal, but should also include those responsible for transportation.

Many agencies are involved in regulating the CDW supply chain, and their activities need to be coordinated to ensure there are no loopholes or weaknesses.
2.6.2 Controlling Illegal Dumping

In many countries, CDW forms the largest proportion of waste that is illegally dumped. This illustrates the importance of regulating the entire waste “supply chain”, including transportation. Several countries are trialling or have introduced electronic manifests, which allow for wastes to be tracked easily. Even in highly regulated countries, illegal disposal of CDW is not unknown. Measures to reduce the scale of the problem include:

- Publicising cases to act as a deterrent;
- Applying high financial penalties (which may include fines but also exclusion from bidding for Government contracts);
- Enhancing surveillance and counter-measures against known or suspected illegal activities;
- Enforcing liability on the main contractor, to ensure that they are responsible for the actions of their sub-contractors and have a “duty of care” for the waste generated on their site.

2.6.3 Landfill Bans or Mandatory Recycling

Some countries or jurisdictions have introduced either bans on sending certain types of CDW to landfill, or mandatory requirements for recycling.

In Japan, the Construction Material Recycling Law was enacted in May 2000, aiming at recycling and reuse of prospected construction materials in view of ensuring efficient use of resources.

The Construction Material Recycling Law promotes recycling by requiring contractors to sort out and recycle wastes generated in construction where one or more of the following criteria are met:

- in case of demolition work of building, the total floor larger than 80 m$^2$;
- in case of construction work or enlargement work, the total floor area is larger than 500 m$^2$;
- in case of repair work or remodeling, contract fee exceeds 100 million yen; or
- in case of demolition work or construction work other than building, contract fee exceeds five million yen.

The materials that are required to be sorted and recycled are set out in Table 2-4.

Table 2-4: Mandatory CDW Sorting and Recycling Requirements in Japan

<table>
<thead>
<tr>
<th>Designated construction material</th>
<th>Example recycling facilities</th>
<th>Recycling method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Crushing facilities</td>
<td>Use as a (raw) material</td>
</tr>
<tr>
<td>Construction materials consisting of concrete and iron</td>
<td>Crushing facilities</td>
<td>Use as a (raw) material</td>
</tr>
<tr>
<td>Wood (wood generated in construction)</td>
<td>Crushing or incineration facilities</td>
<td>Permissible forms of recycling are: [1] Use as a (raw) material and [2] Thermal recycling, in order of priority</td>
</tr>
<tr>
<td>Asphalt concrete</td>
<td>Crushing facilities</td>
<td>Use as a (raw) material</td>
</tr>
</tbody>
</table>
CDW recycling performance in Japan has improved significantly since this law was passed, as illustrated in Figure 2-1.

In the US, the city of Seattle has passed regulations meaning that certain CDW must be recycled and may not be put in containers for disposal in landfills. Before receiving a permit from the Seattle Department of Construction & Inspection (SDCI), building permit applicants with projects more than 750 square feet and all demolition projects need to submit a Waste Diversion Report. In addition, a Salvage Assessment is to be filled out for whole building removal projects by a salvage verifier. Once a project is completed, all demolition permits and all new construction and remodeling projects that are $30,000 or more in value need to submit a Waste Diversion Report to SPU. This report documents where construction materials were delivered for reuse, recycling and disposal (Seattle Public Utilities, undated). Seattle is planning to phase in bans on landfiling certain types of CDW (including asphalt paving, bricks, and concrete; metal; cardboard; gypsum; untreated wood; carpet; plastic film; and asphalt shingles).

In the Netherlands there has been a national ban on the disposal of re-useable C&D waste since 1997. As a result only certified C&D crushers and sorters are allowed to dispose of non re-useable C&D waste. Under Dutch law only rubble contaminated with coal tar, asbestos and other forms of chemical contamination are considered non-re-useable (Construction Resources and Waste Platform, 2007).

2.6.4 Non-Statutory Guidelines

Many counties have certification schemes for environmentally friendly construction. Schemes include LEED (USA), BREEAM and CEEQUAL (UK), and HKBEAM (Hong Kong). These schemes typically have a waste management element, and points can be gained from achieving a certain level of landfill diversion or recycling, by separating CDW on site, and by using materials with a high recycled content. Clients may choose to make certification a mandatory requirement, which can drive sustainable CDW management.

Industry- and government-funded bodies issue guidelines to assist contractors with CDW recycling. This includes detailed technical guidelines for designers, but also practical guidelines for site agents, foremen and operatives (Environmental Protection Department, undated). Tools have also been developed to assist designers and contractors both during design and construction, such as the SmartWaste tool developed in the UK (BRE, 2015). In the UK, the Government funded the Waste Resources Action Programme (WRAP) to develop a wide range of supporting materials, which included practical “how to” guides, technical reports on construction waste recycling plant operations, and best-practice case studies.

2.7 Economic Factors

2.7.1 Background

The economics of recycling CDW (particularly inert material) is faced with two fundamental problems. On one hand, virgin aggregate is widely available and inexpensive; whereas recycled CDW requires relatively costly processing and transport. On the other hand, landfill disposal of CDW is inexpensive even if authorised facilities are used, and even less expensive if dumped illegally.
Some countries have adopted an almost entirely market-based approach to CDW, using economic instruments rather than detailed regulations in order to encourage desired behaviour. The UK provides a good example of this, where environmental taxes are one of the main drivers of improved CDW management. However, economic instruments alone are unlikely to be effective unless illegal disposal is strictly policed, since illegal disposal will always be cheaper than using legitimate facilities.

### 2.7.2 Raising the Cost of Disposal

Landfill is a relatively low cost operation, requiring land but relatively little plant and equipment. Engineered landfills with gas and leachate collection systems are more costly than inert waste landfills, and the “void space” (i.e. the disposal capacity) at a mixed waste landfill is therefore a more valuable resource than void space at an inert waste landfill. One of the aims of sustainable CDW management is to minimise the amount of waste that is landfilled at all, but also to minimise the amount that needs to be sent to a mixed waste landfill. This means incentivising the separation of CDW into inert and non-inert fractions.

In most developed countries it is usual practice to pay a “gate fee” for the use of a waste treatment or disposal facility. In the absence of specific economic instruments, the gate fee for landfill tends to be relatively low, compared to alternative treatment techniques. Countries use economic instruments to:

- Increase the cost of landfill disposal, thereby making alternative treatment or recycling more cost-competitive; and
- Differentiate between the costs of mixed waste and inert waste disposal, thereby incentivising source-separation of waste.

The current rates of UK Landfill Tax (in 2016) are:
- Lower rate (inactive waste): £2.65 per tonne
- Standard rate (active waste): £84.40 per tonne

The landfill tax was introduced in the UK in 1996 at a relatively low level (£7/tonne for active waste and £2/tonne for inactive waste), but has been progressively increased at a pre-determined rate (the “landfill tax escalator”). The effects of the landfill tax on the overall waste generation and disposal routes in the UK are shown in Figure 2-2.

In Hong Kong, the gate fees for disposing of CDW at various facilities (in 2016) are:
- Public fill reception facilities (inert CDW only): HK$27 per tonne
- Sorting facilities: (> 50% by weight of inert CDW): HK$100
- Landfills (< 50% by weight of inert construction waste): HK$125
Hong Kong recognized the potential for increased illegal disposal when charging for CDW disposal was introduced, and stepped up measures to prevent this and to catch offenders (Advisory Council on the Environment, 2007). The CDW charging scheme in Hong Kong was introduced in 2005, and a significant reduction in CDW waste sent to landfill was immediately apparent, as shown in Figure 2-3.

An Australian study also concluded that, where the cost of landfill disposal is sufficiently high, the cost to dispose of mixed waste will be high compared to the cost to reprocess uncontaminated streams of specific C&D waste materials. This provides a strong incentive for high volume and regular generators of C&D waste to source separate materials and allow for easier reprocessing. The study also noted that high landfill disposal costs provide an incentive to process mixed C&D waste in order to recover certain high value and high volume components, and avoid landfill disposal costs (Hyder Consulting, 2011).

### 2.7.3 Taxation of Primary Aggregates

The UK has also attempted to address the price differential between recycled and primary aggregates by means of a tax on primary aggregates, the “Aggregate Levy”. The tax is set at GBP 2.00 (CNY 18) per tonne of aggregate, and recycled aggregates are exempt. The tax forms a significant proportion of UK aggregates cost, which are reported to be approximately GBP 5.00 exclusive of tax (ex quarry). An EU study (European Commission, 2011) concluded that the UK’s Aggregate Levy has encouraged the use of recycling and secondary material, which has led to a decrease of the aggregates output. However, views on the effectiveness of the levy are mixed and critical points mentioned in the literature are the lack of measurement of the impacts on environment externalities, larger transport distances and stockpiling of unsold but locally available lower quality primary aggregates increasing at quarries (European Commission, 2011).

A study in Switzerland concluded that the demand for recycled concrete was found to be most sensitive to changes in construction stakeholders’ awareness of the recycling option and price differences between conventional and recycled material. The scenario analysis showed that a combination of extensive information campaigns and small price advantages for recycled materials would lead to a maximal reuse of construction and demolition waste (Knoeri, Nikolic, Althaus, & Binder, 2014).

A study investigated how taxes on primary raw materials used in construction in Denmark, Sweden and the UK have reduced the use of these resources (Söderholm, 2011). It concluded that in Sweden, a tax on natural gravel (introduced in 1996) to promote the use of crushed rock and recycled materials encouraged substitution with other materials, although the tax is applied uniformly across the country, even in regions where shortages in natural gravel is less of a problem. In Denmark, a tax on extracted raw materials (sand, gravel, stones, peat, clay and limestone) introduced in 1990 in conjunction with a waste tax has produced a greater demand for recycled substitutes: in 1985 only 12% of construction and demolition waste was recycled, compared with 94% in 2004. In the UK, a tax on aggregates (sand, gravel and crushed rock used in construction) was introduced in 2002 and has encouraged a higher recycling rate in the UK.

### 2.7.4 Subsidising Waste

A study investigated how taxes on primary raw materials used in construction in Denmark, Sweden and the UK have reduced the use of these resources (Söderholm, 2011). It concluded that in Sweden, a tax on natural gravel (introduced in 1996) to promote the use of crushed rock and recycled materials encouraged substitution with other materials, although the tax is applied uniformly across the country, even in regions where shortages in natural gravel is less of a problem. In Denmark, a tax on extracted raw materials (sand, gravel, stones, peat, clay and limestone) introduced in 1990 in conjunction with a waste tax has produced a greater demand for recycled substitutes: in 1985 only 12% of construction and demolition waste was recycled, compared with 94% in 2004. In the UK, a tax on aggregates (sand, gravel and crushed rock used in construction) was introduced in 2002 and has encouraged a higher recycling rate in the UK.

![Figure 2-3: CDW generation and disposal in Hong Kong, 1991-2009](image)
In Europe, facilities for managing CDW are generally run by the private sector without significant subsidies, although Governments have provided financial assistance with research and development, for example the various work in the UK funded by the organisation WRAP.

Outside of Europe, some countries subsidise the cost of CDW treatment. In Hong Kong, CDW recycling and disposal facilities are provided by Government but operated by the private sector under “Design-Build-Operate” contracts. These facilities do not operate on a full cost-recovery basis, and hence there is some element of public subsidy. Japan provides subsidies for recycling industries in certain “Eco Towns” (Ministry of Economy, Trade and Industry, 2008).

2.8 Conclusions

Based on a review of international practice in CDW recycling, the main conclusions are:

- Source-separation is mandated in many countries and enables higher quality recycled materials to be produced at lower cost. Various well-established technologies can be used for separating mixed CDW, but the emphasis should be on segregation at source.

- Although a variety of technologies are available, the basic processes for recycling that largest fraction of construction waste (hard inert material) are relatively simple.

- The use of protocols or standards for recycled CDW materials builds confidence in the market by providing a consistent product.

- Stimulating demand for recycled CDW products is often challenging. Part of the answer is technical, and can be addressed by research and development of specifications and protocols. Part of the answer relates to perception, and can be addressed by case studies and demonstration projects. Clients can stimulate demand by requiring the use of a certain proportion of recycled material in projects.

- Countries that have been successful in achieving a high CDW recycling rate are increasingly looking to increase the quality of recycling, and minimize the amount of CDW generated in the first place.

- Control measures on CDW should extend from the site of production to the site of treatment/disposal, but should also include those responsible for transportation.

- Controlling illegal waste dumping is one of the most important elements of sustainable CDW. If waste can be dumped for free and with impunity, this undermines the market for legitimate CDW management. A range of penalties can be applied, but effective surveillance is necessary to ensure that the risk of being caught is high.

- Landfill bans or mandatory recycling policies have been introduced in several countries and can be effective, but require effective monitoring to ensure compliance.

- Voluntary measures have a role to play but are unlikely to be sufficient on their own to alter CDW behaviour across the sector.
Technical guidance on how to comply with regulations or best practice is helpful to designers, contractors and site operatives. This guidance should be practical rather than theoretical, and supported by case studies.

The public sector can act as a role model for sustainable CDW management. Government can require their contractors to prepare CDW management and to provide accurate reporting of CDW management.

Raising the cost of waste disposal provides a strong incentive for recycling. Differential pricing for inert and non-inert wastes encourages waste producers to segregate at source. However, landfill taxes only work if they can’t be easily avoided by illegal dumping.

Taxes on primary construction material such as the UK’s Aggregate Levy can help recycled aggregate gain market share, but implementation may not be straightforward.

Subsidies can support CDW facilities where they would otherwise be uneconomic; but in the absence of sufficient demand for recycled CDW materials they may struggle to find outlets for their products. Direct provision of, or subsidy to, CDW processing facilities is unusual in Europe and the US.

Table 2-5 below summarises they key success factors in CDW management that have been identified in this review, and their potential applicability in Asia. International experience suggests that none of these measures on their own will produce an optimal CDW recycling system, but instead there is a need for an integrated approach, using a range of policy tools.

Table 2-5: Summary of Key Success Factors

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Main Features</th>
<th>Example Countries where Applied</th>
<th>Effectiveness in Strengthening CDW Management</th>
<th>Potential Applicability in Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory source-separation of CDW.</td>
<td>Requirement for all CDW to be separated into different fractions at the construction site.</td>
<td>Japan, Seattle (USA)</td>
<td>Effective if properly enforced at the site level, and if suitable management facilities and markets are in place for the separated materials.</td>
<td>Potentially applicable: requires high level of enforcement and oversight of construction sites and significant changes in behaviours.</td>
</tr>
</tbody>
</table>

The UK’s Aggregate Levy has helped recycled aggregate gain market share, but its implementation has not been straightforward.
<table>
<thead>
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<th>Potential Applicability in Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill bans.</td>
<td>Prohibition on the disposal of certain types of waste (typically unsorted CDW) to landfill.</td>
<td>Netherlands</td>
<td>Effective, but requires a range of behaviours and infrastructure to be established in order to be effective.</td>
<td>Difficult to implement without first establishing a network of CDW recycling facilities as an alternative to landfill.</td>
</tr>
<tr>
<td>Tax on landfill disposal.</td>
<td>Tax or mandatory charging scheme for disposal of waste to landfill, often with different bands for mixed and inert wastes.</td>
<td>UK, Denmark, Hong Kong</td>
<td>Very effective in developing alternatives to landfill, but with risk of increased fly-tipping if enforcement is poor. Likely to stimulate the supply of recycled CDW materials, but may not increase demand if material quality concerns remain.</td>
<td>Potentially applicable: requires strong enforcement against illegal disposal.</td>
</tr>
<tr>
<td>Tax on primary aggregates.</td>
<td>Tax on primary aggregates in order to make recycled aggregates more cost-competitive.</td>
<td>UK, Sweden</td>
<td>Helpful in stimulating the market for recycled aggregates.</td>
<td>Potentially applicable: may be opposed by aggregates and construction sectors as introducing additional costs to the industry.</td>
</tr>
<tr>
<td>Enforcement of prohibitions on illegal dumping.</td>
<td>Active enforcement of penalties on illegal dumping, with fines or other punishments at a level which are a proper deterrent to illegal behaviour.</td>
<td>UK, Hong Kong, Japan, Germany, Denmark and most other developed economies.</td>
<td>Essential in order to allow other economic measures to take effect.</td>
<td>Potentially applicable, but requires strong and transparent law enforcement.</td>
</tr>
<tr>
<td>Licensing of waste hauliers and use of trip tickets/transfer notes/manifests.</td>
<td>CDW can only be transported by licensed hauliers and all consignments of waste must be accompanied by a note (physical or electronic) which describes source, type and quantity of waste.</td>
<td>UK, Hong Kong, Japan, Germany, Denmark and most other developed economies.</td>
<td>Allows for improved data collection, better control of CDW management, and aids enforcement.</td>
<td>Applicable.</td>
</tr>
<tr>
<td>Instrument</td>
<td>Main Features</td>
<td>Example Countries where Applied</td>
<td>Effectiveness in Strengthening CDW Management</td>
<td>Potential Applicability in Asia</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Targets for CDW recycling on Government-funded projects.</td>
<td>Many infrastructure projects are either funded or directly built by Government; this gives Government the opportunity to set targets for CDW recycling and for the use of recycled CDW materials.</td>
<td>UK, Hong Kong, Denmark, Germany.</td>
<td>Helps to kick-start the market for recycled products by providing a secure outlet. Establishes positive behaviours in CDW management that can then be replicated in the private sector.</td>
<td>Applicable.</td>
</tr>
<tr>
<td>Subsidies to CDW processing facilities.</td>
<td>Provision of subsidy to operators of CDW processing facilities, for example by paying the capital costs of facility establishment, or guaranteeing the supply of CDW material or outlets for recycled products.</td>
<td>Hong Kong, Japan (to a limited extent).</td>
<td>Can help to establish facilities which are able to recycle CDW as an alternative to landfill disposal, if markets otherwise would not be viable.</td>
<td>Potentially applicable; if markets for recycled materials rely on subsidy, government may be committed to providing on-going subsidies, and there is a risk of producing material for which there is insufficient market demand.</td>
</tr>
<tr>
<td>Technical guidance, specifications, and best-practice guides.</td>
<td>Production of a suite of guidance documents, aimed at all levels in the construction industry (site operatives, contractors, designers and clients), which explain how to comply with regulations and highlight examples of best practice, and which provide clear specifications for recycled CDW materials.</td>
<td>UK, Hong Kong, Japan, Germany, Denmark and most other developed economies.</td>
<td>Important in ensuring that regulations are translated into practical actions, and in building confidence in the construction industry to use recycled materials.</td>
<td>Applicable.</td>
</tr>
<tr>
<td>Instrument</td>
<td>Main Features</td>
<td>Example Countries where Applied</td>
<td>Effectiveness in Strengthening CDW Management</td>
<td>Potential Applicability in Asia</td>
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<tr>
<td>Protocols or standards for recycled CDW materials.</td>
<td>Published standards or protocols which set out the procedures and quality standards for production of recycled materials from CDW and identify the point at which waste management controls can cease.</td>
<td>UK</td>
<td>Helps to build confidence in recycled CDW materials and hence develop markets.</td>
<td>Applicable; can be integrated with existing standards and specifications for construction materials.</td>
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</table>
3 Study Tour

The study tour took place between 4th and 11th May 2016, when a delegation from the PRC visited the United Kingdom and Denmark.

The delegation comprised:

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hongyi Yang</td>
<td>Supervisor, Urban Environment Management Division</td>
<td>Ministry of Housing and Urban-Rural Development</td>
</tr>
<tr>
<td>Dongsen Lu</td>
<td>Director, Circular Economy Division</td>
<td>Department of Environment and Resources, National Development and Reform Commission</td>
</tr>
<tr>
<td>Jiazhen Tian</td>
<td>Director</td>
<td>Ministry of Finance</td>
</tr>
<tr>
<td>Xiaoli Luo</td>
<td>Technical Specialist, Department of Resource Conservation and Environmental Protection</td>
<td>Ministry of Industry and Information Technology</td>
</tr>
<tr>
<td>Qingsheng Chang</td>
<td>Director</td>
<td>Henan Provincial Department of Housing and Urban-rural Development</td>
</tr>
</tbody>
</table>

The delegation was accompanied by the TA Deputy Team Leader, Dr Chen. The TA Team Leader, Mr Bains, accompanied the delegation during their stay in the UK.

The purpose of the study tour was to allow PRC delegates to meet with those involved in all stages of the CDW recycling supply chain, from regulator to processor, in order to better understand how these aspects are managed in the relevant country. The itinerary is summarised below:

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Individual &amp; Organisation Met</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 4, Wednesday</td>
<td>-</td>
<td>Travel – Beijing to London</td>
<td></td>
</tr>
<tr>
<td>May 5, Thursday</td>
<td>Morning</td>
<td>BRE Bucknalls Lane Watford</td>
<td>BRE is an independent and impartial, research-based advisory, testing and training organisation, offering expertise in every aspect of the built environment and associated industries. BRE works extensively in the field of CDW and has developed tools including “SMARTWaste” to help manage CDW. BRE staff described the tools commonly used in the UK to manage CDW.</td>
</tr>
<tr>
<td></td>
<td>Afternoon</td>
<td>Graham Winter</td>
<td>The Environment Agency is</td>
</tr>
<tr>
<td>Date</td>
<td>Time</td>
<td>Activity</td>
<td>Details</td>
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</tr>
<tr>
<td>May 6, Friday</td>
<td>Morning</td>
<td>Simon Little, Powerday Waste &amp; Recycling Centre</td>
<td>Powerday is a leading UK CDW processing and recycling company. The facility visited manages approximately 1.6 million tonnes per year of CDW from the London area. A site tour was provided, and the company’s commercial director provided an overview of the business drivers governing CDW management and recycling in the UK.</td>
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<td></td>
<td></td>
<td>John Bradshaw-Bullock, Mineral Products Association</td>
<td>The Mineral Products Association is the industry body for producers of both primary and recycled aggregates in the UK. The MPA’s technical lead for recycling provided an overview on the UK market for recycled aggregate.</td>
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<tr>
<td>May 7, Saturday</td>
<td></td>
<td>Rest</td>
<td></td>
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<tr>
<td>May 8, Sunday</td>
<td></td>
<td>Travel – London to Copenhagen</td>
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</tr>
<tr>
<td>May 9, Monday</td>
<td>Morning</td>
<td>Visit to Amager Resource Center</td>
<td>Resource Center is responsible for the domestic waste disposal and CDW disposal with the principle of source reduction, and prevention first. The Resource Center is neighboring the city center. The Resource Center can dispose 436 thousand ton waste per annual with only 2% waste landfilled, most waste is recycled or fueled for power generation.</td>
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<td></td>
<td></td>
<td>Visit to relevant building construction waste treatment Guo Li</td>
<td>The EPB of Copenhagen Municipal Government is a sustainably developing and planning department, introducing the waste disposal status of Copenhagen. The government has the obligation to establish policies and planning, implement inspection, and consult residents. The collection of residential waste is responsible by government, while the industrial waste is responsible by enterprises. In 1996, several activities were began to carry out with law issued, including waste</td>
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</table>
classification, data collection and analysis, qualification required for waste disposal, and promotion policies for waste classification and recycling. Currently, 87% of CDW has been recycled and reused.

<table>
<thead>
<tr>
<th>May 10, Tuesday</th>
<th>Morning</th>
<th>Visit to Danish building research institute, Aalborg University Copenhagen Du Guangli Aalborg University (Copenhagen) A.C. Meyers Vænge 15, DK 2450 København SV</th>
</tr>
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<tbody>
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<td></td>
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<td>In 2006, Danish building research institute was incorporated to Aalborg University to promote the combination of production and research in compliance with governmental requirements. During the visit, Danish building research institute introduced its basic information and major study scope, and the newly identified pollution and treatment of PCB in recent years. In their perspective, PCB could be fully reused after extracting the hazardous ingredients.</td>
</tr>
<tr>
<td></td>
<td>Afternoon</td>
<td>Return flight</td>
</tr>
<tr>
<td>May 11, Wednesday</td>
<td>Arrive in Beijing</td>
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4 Policy Recommendations

4.1 Awareness Raising

Studies and research on CDW management and recycling try to develop solutions to managing construction and demolition wastes, focussing on the issues at the last stage of building’s life. But to be effective, CDW management needs to take account of the whole lifecycle of a building and consider processes from design and construction, as well as broader areas such as environment and resources, new-type urbanisation and sustainable development. Over the past years, a large number of studies have been done on the planning, project identification, design, construction, structure and materials, energy saving and safety, etc, resulting in a series of procedures and standards to be followed strictly. However, less attention has been paid to the deconstruction or demolition of buildings, and the generation and disposal of CDW. Therefore, there are many problems in the management of CDW, including lack of data, unclear definitions, absence of demolition management, and insufficient awareness and understanding of CDW management leading to the current disordered and illegal dumping that risks public health and safety. Hence, it is critical to raise the awareness and understanding of both authorities and the public on the management and recycling of CDW.

Despite their limited size on the earth’s surface, the development of cities exert immense demands and pressure to the environment. Within the limits of our planet, recyclable and sustainable development is the only solution to urbanisation. The generation and treatment/disposal of CDW should be treated as a necessary part of urbanisation and the treatment and disposal facilities for CDW should be included as one of the components of city infrastructure during the early stage of preparation of the master plan and land use plan of the city.

The management and recycling of CDW should cover the life span of building, and address the whole processes of construction and the full chain of CDW treatment and disposal.

There is no contradiction between the harmless treatment and recovery or recycling of CDW. Harmless treatment is a prerequisite for reusing the recycled or claimed CDW, while CDW recycling provides a pathway to achieve harmless treatment. One supplements another, and none of them prevails. Ideally, all wastes should be recovered and recycled as much as possible, and safe storage and harmless treatment should be done for the rest that cannot be made for resource recovery with current technologies. Principles guiding CDW treatment and disposal include adjusting and tailoring to local environment and conditions, holistic planning and design, inclusive treatment and disposal and achieving a comprehensive solution to all problems.

4.2 Improve Legislation and Regulations

Legislations and regulations provide the legal basis and guidance for practitioners and entities to follow and have deterrent effects. Due to years of neglect of CDW management, there is very little or even no sections about the CDW in relevant legislations in China. In contrast, the management of domestic wastes has been specifically described in relevant legislations, e.g. the “Environmental Protection Law and the Prevention and Control of Environmental Pollution by Solid Waste”. Equal attention should be paid to the management of CDW. Especially, requirements on CDW management should be written into key relevant legislations, for example, to the “Construction Law,” adding ‘prepare holistic CDW treatment and disposal plan and report to relevant authorities for the record’ as another prerequisite of the Ground-breaking Permit, and articles to promote purchase of recycled products from CDW, such as ‘using C&D materials and recycled content products for new construction is encouraged by the national government’.

It is recommended that Administrative Regulations on Construction and Demolition Waste Management should be prepared and issued, based on the current Provisions on the Administration of Urban Construction and Demolition Waste, to clearly specify how to implement the principle of ‘producer...
responsibility' with details, incorporate or further clarify the ideas of ‘holistic planning, investment in infrastructures, whole process management, recovery and recycling, and buying of recycled product, etc.’, with practical measures, and to increase penalties for non-compliance and violations and improve the legal management of CDW.

In view of the current situation of ‘build it forget the demolition’ and lack of basic data, it is recommended to establish an appraisal and register system for building demolition, set up data collection and processing system, associate the CDW management with the current administrative permit system for construction project, incorporate requirements on CDW management and recycling into the review criteria those will be reviewed against when issuing ‘one report and two permits’ for construction projects, and to issue ‘expiry certificate’ of buildings based on existing files and records. The lifecycle management of buildings should be promoted to improve the management and recycling of CDW, and to prolong the useful life of building.

In order to better manage CDW from the source, avoid misreporting to sanitation and/or city administration authorities, and collect data on CDW generation and type, a declaration and registration system for CDW management should be set up to enhance the reporting and inspection of CDW streams. Before construction or demolition, entities who produce CDW should be required to report the types, generation, stops and destinations, storage and disposal, etc. to the local responsible authority for CDW disposal above the county level. The governance of authorities on the generation, transportation and disposal of CDW should be strengthened at all levels. The application materials in written form, as required, should be reviewed carefully and approved strictly. When necessary, a third party should be designated to check on site. All activities to be conducted by owners, contractors and entities responsible for CDW transportation and disposal should only be started with approvals. In large to medium size cities, authorities for environmental protection should release information on generation, disposal and other matters about CDW to the public at regular intervals to facilitate supervision and government by the public and related agencies.

The charging system for CDW should be improved, based on principle of ‘producer pays’: costs and fees relating to the collection, transportation and disposal should be paid by the entity that produces the corresponding wastes. Costs of CDW disposal should be included into the “Quote for Budgeting Building Construction and Finishing Project”. With subsidies for cost recovery and allowing for rational profit for the operator, charging rates should be determined by the city government according to local conditions and references as for service suppliers. In this way, subsidies will be not only for the disposal entities, but also benefit entities who purchase used C&D materials and recycled products.

4.3 Management Reform

A uniform appellation and definition should be agreed at the national level. Supported by careful analysis and tradeoffs, the Chinese terminology could be decided as either “C&D waste” (‘laji’), “C&D residual material” (‘feiqi wu’) or “construction castoff” (‘Qiwu’). In Chinese, the name ‘laji’ follows historical practices, although can mislead the audience to treat such materials as useless. C&D ‘Qiwu’ is more objective, indicates they are castoffs and residuals rather than wastes generated during construction, and likely to indicate a better acceptance of recycled products made from them. Formalizing the name or terminology will relate to many issues, such as administration permit and tax exemption, etc., and would require dissemination nationally and at all levels. Roles and responsibilities of each ministry/committee/commission should be further clarified based on sector positioning and from the perspective of the whole chain and overlaps and linkages between agencies should be carefully managed. The current management arrangements were decided by State Commission Office of Public Sectors Reform (SCPPSR) in 2010 based on understandings by that time. According to MIIT’s strategy, CDW recycling enterprises are treated and managed as enterprises producing new building materials. Since CDW arises from city infrastructures, it may be more rational for them to be manged by MOHURD and its departments. Management complications need to be reviewed and balanced. It is therefore essential to set up an effective coordination mechanism at national level.

At the local level, roles and responsibilities for managing and recycling CDW should be clearly identified, led by local government with administrative and technical guidance provided by the provincial HURD. The authority or association of several authorities, normally the city administrative department according to present practices, should be set up or appointed by the government at municipal level. Within the integrated and accountable management system, the full chain from CDW generation to purchase of
recycled products will be managed. Public supervision and complaint routes should also be enhanced by sharing information with departments of public security, transportation and others, improving inter-agency cooperation and coordination, strictly implementing designated duties and achieving synergies. This will improve public supervision and grievance redress. Government performance evaluation, such as issuing of city name-cards, should include indicators reflecting the performance of CDW management and recycling. By getting more attentions from the key governors at city level, CDW management and recycling would be facilitated.

4.4 Whole Process Management

4.4.1 Promote Source Reduction

Policies should be introduced to further implement the “Green Building Action Plan” nationwide, promote prefabricated buildings, and identify development targets of the proportion of prefabricated buildings (in percentage terms) in various places. Through concept propaganda, training, and education, project research should be carried out to establish relevant technical standard and other measures. This will encourage design institutes and designers to consider CDW source reduction and include direct reuse measures during the design stage. Construction companies, or contractors, should practice “Green Construction”, include costs for CDW disposal, reduction plan and other relevant costs into their engineering project management. Generation of CDW and the reduction and disposal plan should be included in the project identification, and should be part of the design document and construction plans. At the construction stage, construction companies, consulting firms and design institutes should thoroughly consider the balance of cut and fill, and adopt reusable construction materials with long service life and ease of maintenance. The choice for technique and auxiliary materials for excavation should consider the feasibility of recovery and recycling of CDW, to minimise the potential harm. Government should promote development and construction of a good standard of primary decoration in housing, to reduce the need for secondary fit-out, and at the demolition stage, should regulate the demolition process. Where possible, contractors should use mobile facilities for direct reuse locally or recycling processing of CDW.

4.4.2 Implement Sorting and Separation

Owners and construction companies should classify, store and transport CDW according to approved plans for sorting and recycling, including earth, broken concrete, tiles and bricks, metals, wood, plastics, and others. Mixing of toxic and harmful wastes and domestic wastes with CDW is prohibited, and the CDW should be handed over to entities with relevant qualifications for treatment and disposal. Demolition of buildings and structures of building for manufacture, storage and usage of materials for chemical industry, metallurgy, pesticides, electroplating, and dangerous chemicals should be conducted after the environmental risk appraisal and completion acceptance of environmental protection by local environment department or bureau. For unsorted or poorly-sorted CDW, the receiving entity could increase charging rates based on market prices to recover the costs for sorting them out properly.

4.4.3 Construction Site Management

Construction companies, or contractors, should practice “Green Construction”, and before construction starts, prepare CDW disposal and reduction plans, and budget for associated costs. Generated CDW during construction should be stored separately by type. Mobile facilities could be used to directly reuse as much materials as possible on site, minimizing the CDW transported.

The requirements on separation storage, harmless treatment and on-site reuse should be included in the criteria and indicators for evaluation of “Civilized Construction Site” and other competitions.

4.4.4 Transportation and Disposal

Reasonable dynamic referential prices for transporting CDW should be identified according to local economic development. Source management should be strengthened to avoid illegal trucks being used for CDW transport. Entities providing CDW transportation should make sure all vehicles are installed with proper covering facilities, camcorder, measurement and monitoring facilities and GPS. A regulatory platform should be established, employing tools of internet and manifests, etc., to prevent secondary pollution caused by releases of CDW and dumping on illegal sites, avoiding corresponding social cost. Training of drivers should be enhanced to avoid over-loading, speeding and red-light running. Relevant
agencies should collaborate and enhance the implementation of legislation and regulations jointly, and conduct dynamic management of the transportation firms and drivers. Adoption of the new type of smart and environmentally-friendly haulage vehicles should be promoted. Large and professional firms for CDW transportation should be encouraged and supported to achieve integrated operation, dispatching and management.

4.4.5 Disposal Facilities

Due to the properties of CDW (particularly the large quantity and variability of material), the transporting distance should be reasonable; and the long chain of processing requires a large land footprint CDW management facilities. Land use for CDW disposal facilities should be included into urban construction and development plans in order to ensure that suitable land is secured, and land should be provided with preferential rates and conditions when compared to other industrial uses. It is recommended to manage CDW treatment and disposal facilities as an important component of urban infrastructure, speed up the planning and construction and improve the treatment capacity and quality. Studies and preparation of planning for CDW treatment and disposal facilities should be done by local authorities for CDW management together with authorities for construction management to optimize the layout of disposal, landfill and recycling facilities. Locating the disposal and recycling facilities at one site is encouraged. Recycling facilities for CDW should be incorporated into the master plan, land use plan, planning for circular economy and the specialized plan for city aesthetics and sanitation, to make the land use secured. In addition, the establishment of mobiles CDW treatment facilities should be encouraged. The construction and management of CDW disposal sites, no matter whether permeant or temporary, should follow relevant standards and ensure the minimum environmental impacts and safety.

For the EIA process, it is recommended to prepare criteria in favour of CDW recycling firms, and adopt different evaluation methods for fixed and mobile facilities. Current requirements on environmental protection benefiting the environment and eliminating secondary pollution should be maintained, and at the same time, be practical and realistic, and able to differentiate the CDW management facilities from normal manufacturing and processing companies for building materials.

4.4.6 Process Monitoring

Declaration and registration systems for CDW management should be set up to enhance the reporting and inspection of CDW streams. An independent third party should be employed for the inspection. In the inspection documents, information should be clearly written including the total generation of CDW and the types from the project, name of entities for transportation, time and route; name of consignor of transportation and its qualification; the name, location, qualification and the disposal or recycling plans for each type of wastes of the receivers to transfer, disposal site and/or recycling facilities. All activities to be conducted by owners, contractors and entities responsible for CDW transportation and disposal, should only be started with approvals. It is recommended to establish a Management Information System (MIS) for CDW, using information tools to manage manifests from the generation of CDW, to discharging, transportation and disposal to allow for tracking of sources, prediction of destinations, and accountability of responsibilities.

4.5 Application and Promotion

4.5.1 Protocols or Standards for Recycled Materials

Recovery and recycling of CDW is a systematic process, and normally has a broad range from producing, collection, transportation, storage, to sorting, treatment, recycling and reclaiming and marketing, etc., involving many stakeholders along its long processing cycle. The CDW recycling industry in China is in an early stage of development. It is essential to establish a technical standards system covering the entire processes, in order to ensure the quality and effects of the CDW recycling. The system could target three main aspects:

- firstly, clearly identify the relationships between different agencies, procedures and processes;
- secondly, quality control of recycled products and materials; and
- thirdly, the market admittance criteria and applications.

Based on experience and requirements of CDW recycling in China, four key stages could be identified as:
- source,
- collection and transportation,
- processing and recycling, and
- recycled products and application.

Source reduction, and standards guiding the engineering design, construction and demolition, etc. for easier recycling will be managed at the first stage of ‘source’. In the second stage, collection and transportation, standards will focus on the sorting and collection of CDW, higher efficiency of recycling and low carbon transportation, etc. to achieve effective management of CDW and lower economic cost of recycling. The third stage of processing and recycling is mainly concerned with designing of the treatment to ensure the quality of products and green production. The last stage focuses on the quality of recycled products and their large scale applications, including standards of the recycled aggregates, powders, intermediate products, and different kind of products made with the intermediate products entirely or partially replacing natural materials, such as concrete, mortar, bricks, and blocks, etc., as well as the technical standards of using the aforementioned materials and products in construction.

Experiences from countries with well-developed CDW recycling systems indicate that standardization contributes to establishing confidence in recycled CDW products, and helps with market exploration and promotion of source reduction. In its early stage of the development of CDW recycling, China has been establishing standards for CDW recycling, although there are only a few standards for some products and their applications, and none for the upstream design, construction, demolition and transportation. The absence of many required standards, and the limited effectiveness of existing ones, has resulted in a slow development of the CDW recycling.

 Considering the development potentials of CDW industry and existing standards, future works could be done in the following areas to supplement and complete the standards system:

- based on the 3R principles, preparing Standard for Basic Terminology for CDW Recycling, Technical Specifications for CDW Recycling and Application, and Technical Code for CDW Reduction, etc.;
- in order to match the properties of recycled aggregates and needs for application, revising the existing Recycled Fine Aggregate for Concrete and Mortar, and Recycled Coarse Aggregate for Concrete, etc.;
- preparing more standards to supplement existing ones for recycled products, including standards for products difficult to be included and described in existing standards, such as Recycled Powder from CDW and Filing Materials recycled from CDW, and for those with similar properties with other materials and could be included in existing standards, incorporating sections about the recycled material into existing standards and the indicators could be adjusted slightly, such as standards for recycled blocks and mortar;
- revising the existing Technical Specification for Application of Recycled Aggregate to enhance the requirements by applying recycled aggregates for producing other building materials;
- to meet the diverse demands by application of recycled aggregate, preparing technical standards for application of other main recycled products, such as Technical Specification for Application of Recycled aggregate and Inorganic Mixture, Technical Specification for Application of Recycled Controlled Low Strength Materials, or Technical Specification for Application of CDW in Concrete;
- and preparing certification standards for recycled products to help users selecting from the list and to include recycled products into the recommended list for green building materials, creating enabling environment for engineering design, application during construction and successful completion acceptance.

### 4.5.2 Pilot and Demonstration Projects

Compared to traditional materials, recycled materials have a few limitations, however, from a technical point of view, the requirements for application in construction could be fully met with feasible design and quality control of recycled materials. In reality, lack of confidence in the quality of recycled materials impedes the application and promotion of recycled materials. Due to educational factors and traditional views on waste materials, sceptical attitudes over material recycled from wastes are prevalent, with recycled materials viewed as being ‘poor quality’. These negative perceptions have limited the reuse of
recycled materials in new constructions and slowed development of the whole industry. International experiences has shown that demonstration and piloting is an effective trigger that can stimulate and boost the market for recycled materials.

Selecting pilot regions and constructing pilot projects could both increase understanding and awareness of the public on CDW recycling and enhance public confidence, and also demonstrate relevant technical and economic benefits, and improve the enthusiasm for promoting CDW recycling and technical competence in different areas. Furthermore, pilot construction and dissemination of experiences and lessons, which could be replicable to other places in China, is of important significance to the CDW recycling industry in China.

Administrative methods could be prepared to provide detailed guidance and requirements on source declaration and data collection, sorting and transportation, disposal ratio, technologies and rates for CDW recycling for the pilot and demonstration projects. It is recommended to establish 10 pilot provinces and cities with 20 pilot projects during the period of 13th Five Year Plan (FYP) demonstrating the benefits, and replicate the successful experiences in other places in China, promoting the CDW recycling and application gradually.

4.5.3 Contract Requirements

At present, effective, practical implementation measures with sufficient details and policies that encourage CDW recycling and reuse of its products are absent in China. It is still the early stage of CDW recycling in China, where a comprehensive system covering the entire chain from collection, transportation, processing to the quality control and marketing of recycled products is not in place. Although China has included the recycling and reuse of urban solid wastes including CDW into national strategies, effective industrial policies and the holistic management system has not been issued and established so far. From experiences of recycled CDW products in China, it could be seen that effective policy that promotes reuses of recycled materials is lacking, therefore marketing of recycled materials is impeded by the insufficient governance.

Experience overseas indicate that policies can boost the reuse market effectively and ensure the entering, buying and adoption of the recycled products in the market, and in turn enable the scaling up of the recycling facilities. According to the current status of CDW management and construction, promotion of recycled product could be done from the following four areas:

1) Include recycled materials and products into the green category of the government procurement list, and for projects financed by government projects, impose compulsory conditions on using recycled materials during the design and construction stages and identify targets for CDW recycling generated by the project and for using recycled materials, which provides a direct marketing channel and helps with opening the market for recycled materials;

2) Include use rate of recycled materials as one of the criteria for the green building evaluation, to explore the market for private sectors;

3) promote use of recycled products from city administrative aspect, for example, the recycling and reuse targets could be added into the criteria system for competitions on National Garden City, National Environmental Protection Model City, National Civilized City and Nationally Recognized Clean City, etc.;

4) according to local conditions, practical methods for promoting use of recycled materials are to be prepared and issued by local government.

4.5.4 Technical Guidance

The most important issue of CDW management and recycling is to achieve promotion and application of the recycled CDW products. Therefore it is necessary to establish a comprehensive system of technical guidance, regulated by corresponding laws and policies. The technical guidance could include basic requirements, recycling and reuse plan, source reduction, demolish, sorting, transportation, recycling, recycled product and its reuse, and information management etc., and will provide introduction about the best practical case nationwide.
Through establishment of the technical guidance, it is possible to provide a full set of executive guidance about each section of the CDW resource management. This guidance, based on clarification of the Laws and policy documents of each section, can define the technical content of each section and provide support on relevant CDW management and recycling work of all aspects of building industry (management unit, client, design, construction, recycling contractors etc.). At the same time, presentation of the best practice cases would provide beneficial references for local government management and contractors’ project operation.

Good understanding and implementation of the technical guidance from the public will be beneficial to promote integrated management of CDW, centralized disposal, reuse, reduction, harmless treatment and recycling level.

4.6 Economic Instruments

Economic instruments which can be used to improve CDW management in China include:

- Fully using existing funding sources to enhance investments in CDW management and recycling, and use capital from central government for infrastructure and relevant special funds to support the building and operation of CDW recycling facilities.
- Continue to implement preferential taxation policies for imported key components and raw materials for important technical equipment for CDW recycling.
- Support research on CDW recycling technologies and equipment through the national or local technology development plans, including special funds and specific projects.

4.7 Training and Dissemination

Recommended training and dissemination measures include:

- Fully utilize the existing various training regimes and improve on-the-job training of all levels of the regulatory body.
- Increase respective types of work in *Occupational Classification of People’s Republic of China*.
- Carry out professional training program for workers.
- Fully utilize media such as magazines, radio, television, and internet, through student education, various employee training, conference etc. to improve advertisement of the management and recycling of CDW.
- Propagate ideas on reduction of CDW, recycling and harmless disposal.
- Carry out regular monitoring and propagation of the project using recycled materials, in order to obtain understanding, support, and participation of the general public.
- Set up respective disciplines and establish a construction waste engineering technology research centre or experimental base, etc. which could integrate production, learning, research and application all together.

4.8 Cost-Benefit Analysis

A cost-benefit analysis was carried out, based on the assumed financial performance of example CDW recycling facilities in PRC, and assuming that the proportion of CDW recycled increases to 35% by 2020.

Based on this analysis, it is concluded that under the current situation in China, the CDW market in China will be unprofitable without any policy support. Firstly, all return rates of investment are below 100%, which demonstrates no beneficial value of investment could be gained from the project; in addition, all net profit counts of project are below zero, which indicates the CDW enterprises will be in long-term unprofitable situation without any policy support on CDW recycling project, which is the justification for establishing the following policies on promoting the development of market for CDW recycling:
(i) Strengthen and ensure the review policies as well as the price of land use for CDW enterprises. The computation was carried out with the data sourced from the prices in the National Minimum Price Standard for Transfer of the Land of Industrial Use, however in the practical implementation, land use shortage and high product price has become the most critical problem for the cost of many CDW recycling enterprises. The situation for the existence of CDW recycling enterprises will be aggravated without ensured enforcement of above policies.

(ii) Enforce subsidy policies for recycled CDW products. In this study, all types of CDW recycled products have not received subsidies and tax reduction or exemption from government, which will be reflected in the product prices. With the enforcement of the policies, the competitiveness of CDW recycled products will be significantly strengthened in the market, and the achievement of targeted economic benefit can be ensured.

(iii) Strengthen the market promotion policies for CDW recycled products. Assuming 100% sales could be achieved for CDW recycled products in the market, in fact the sales of CDW recycled products is obstructed in the market currently, which needs the mandatory promotion and incentive policies from the government to achieve the estimated sales, hence, the implementation of relative market promotion policies should be strengthened during the policy enforcement.

(iv) Develop a technical standard systems for CDW harmlessness and recycling. Relative technical standard systems should be further improved in China, and the relative technologies and products should become more reliable, besides, the best overseas practice and experiences should be learned to develop the CDW recycling technologies, and to reduce the cost for CDW recycling and landfilling technologies.

(v) Improve the demonstration project of and support for CDW recycling. Currently the CDW recycling rate is still low in China, and the estimated CDW recycling rate in this study was set under the premise of the smooth enforcement of the relative policies, therefore the investment to the demonstration project and program should be increased to ensure the economic benefit of above policies, as well as the achievement of the CDW recycling target.
4.9 Policy Recommendations

Policy recommendations for the CDW management are summarized in below Table 4-1, and details are provided in the above sections.

Table 4-1: Summary of Policy Recommendations

<table>
<thead>
<tr>
<th>Legislation and Policy Recommendations</th>
<th>Reason</th>
<th>Responsibility</th>
<th>Timeline</th>
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<tr>
<td>1. In the “Construction Law”, include ‘prepare holistic CDW treatment and disposal plan and report to relevant authorities for the record’ as another prerequisite of the Ground-breaking Permit, and articles to promote rebuying of recycled products from CDW, such as ‘using C&amp;D materials and recycled content products for new construction is encouraged by the national government’</td>
<td>To provide legal basis to the improvement of source management and utilization of recycled product</td>
<td>MOHURD, NPC</td>
<td>Long term</td>
</tr>
<tr>
<td>2. Similar with domestic waste, specify sorting, treatment and disposal, and recycling and reuse of CDW in the “Environmental Protection Law”</td>
<td>To provide legal basis to the separation and recycling of CDW</td>
<td>MOHURD, NPC</td>
<td>Long term</td>
</tr>
<tr>
<td>3. Similar with domestic waste, identify the definition of CDW and describe requirements on preventing pollution by CDW in the act of “Prevention and Control of Environmental Pollution by Solid Waste”</td>
<td>To provide legal basis to the enhancement of CDW management and recycling</td>
<td>MEP, NPC</td>
<td>Long term</td>
</tr>
<tr>
<td>4. Revise Administration of Urban Construction and Demolition Waste, and prepare “Administrative Regulations on Construction and Demolition Waste Management”, elaborate or further clarify the ideas of ‘holistic planning, investment in infrastructures, whole process management, recovery and recycling, and buying of recycled product, etc.’, with practical measures.</td>
<td>Update to current situation with better operability</td>
<td>MEP, NPC</td>
<td>Short term</td>
</tr>
<tr>
<td>5. Issue “Guiding Opinions on the Management and Recycling of CDW” as soon as possible</td>
<td>Urgent to specify</td>
<td>MOHURD</td>
<td>By 2016</td>
</tr>
<tr>
<td>6. Issue “Regulatory Conditions of the CDW Recycling Industry”</td>
<td>Urgent to specify</td>
<td>MOHURD</td>
<td>By 2016</td>
</tr>
<tr>
<td>7. Include CDW into the taxable items under the “Environmental Protection Tax”, allowing CDW suitable for landfill and recycling to be taxed at rate of zero.</td>
<td>To stimulate recycling and reuse</td>
<td>MIIT</td>
<td>Short term</td>
</tr>
<tr>
<td>8. Include rational costs of CDW disposal in the “Quote for Budgeting Building Construction and Finishing Project”</td>
<td>Secure budget for CDW management and recycling</td>
<td>MEP, MOF, SAT</td>
<td>Short term</td>
</tr>
<tr>
<td>9. Improve the charging system for CDW, such that costs relating to collection, transportation and disposal, etc., should be paid by the waste producer</td>
<td>To enforce the principle of ‘producer responsible’</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>10. Use capital from central government to support the building and operation of CDW recycling facilities.</td>
<td>To facilitate recycling</td>
<td>Local government</td>
<td>Complete</td>
</tr>
<tr>
<td>Recommendation</td>
<td>Reason</td>
<td>Responsibility</td>
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<tr>
<td>11. Include imported facilities for CDW recycling into the preferential taxation lists for imported key components and raw materials for important technical equipment.</td>
<td>To promote localization of processing facilities</td>
<td>NDRC</td>
<td>Short term</td>
</tr>
<tr>
<td>12. Support research on CDW recycling technologies and equipment through the national or local technology development plans</td>
<td>To promote technology innovation and development</td>
<td>MOF, NDRC, MIIT, GAC, SAT, NEA, MOST</td>
<td>Launched</td>
</tr>
<tr>
<td>13. CDW recycling facilities should be incorporated into the master plan, land use plan, planning for circular economy and the specialized plan for city aesthetics and sanitation, to make the land use secured</td>
<td>To secure land and infrastructure required by recycling</td>
<td>Local government</td>
<td>Short term</td>
</tr>
<tr>
<td>14. Establish appraisal and register system for building demolition, set up data collection and processing system, issue ‘expiry certificate’ of buildings based on existing files and records</td>
<td>To enhance demolition management and improve data collection toward to fine management</td>
<td>MOHURD, local government</td>
<td>Short term</td>
</tr>
<tr>
<td>15. Promote concession system, and leverage private capital with PPP mechanism</td>
<td>To establish feasible business model</td>
<td>Relevant agencies</td>
<td>Launched</td>
</tr>
<tr>
<td>16. Pilot CDW management and recycling projects in selected provinces and cities, as well as CDW disposal projects</td>
<td>To learn from</td>
<td>MOHURD, NDRC</td>
<td>Launched</td>
</tr>
<tr>
<td>17. Strengthen performance evaluation of local government on CDW management and recycling by introducing related indicators.</td>
<td>To call attention from government on CDW management, to support efforts from line agencies.</td>
<td>Related agencies</td>
<td>Short term</td>
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### Management Arrangements

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<th>Recommendation</th>
<th>Reason</th>
<th>Responsibility</th>
<th>Timeline</th>
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<tbody>
<tr>
<td>18. Agree on definition of CDW. Clarify roles and responsibilities of each ministry/committee/ commission and manage the overlaps and linkages between agencies. Establish effective coordination mechanism at national level</td>
<td>To improve management and recycling of CDW all over China</td>
<td>State Council, MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>19. Led by the local government, identify the authority(s) for CDW management, establish responsible and accountable integrated management system covering the whole chain from CDW generation and reuse of recycled products.</td>
<td>To specify responsible authority and establish accountability system</td>
<td>Local government</td>
<td>Short term</td>
</tr>
<tr>
<td>20. Share information and work with relevant departments, improving inter-agency cooperation and coordination, strictly implementing designated duties and achieving synergies. Improve public supervision and grievance redress.</td>
<td>To form synthesis</td>
<td>Local government</td>
<td>Short term</td>
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### Standards

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<th>Recommendation</th>
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<th>Timeline</th>
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<tbody>
<tr>
<td>21. Establish the standards system for CDW management and recycling.</td>
<td>To perfect standard system</td>
<td>MOHURD</td>
<td>Short term</td>
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<tr>
<td>Recommendation</td>
<td>Why</td>
<td>Responsibility</td>
<td>Timeline</td>
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<tr>
<td>23. Set up product standards in documents such as “Recycled Powder from CDW” and “Filtering Materials recycled from CDW”</td>
<td>To exploit the application of recycled product</td>
<td>MOHURD, MIIT</td>
<td>Short term</td>
</tr>
<tr>
<td>25. Set up certification criteria for recycled products.</td>
<td>To supplement relevant policy</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>26. Prepare EIA criteria appropriate for CDW recycling firms.</td>
<td>To promote recycling with minimum environmental impacts</td>
<td>MEP</td>
<td>Short term</td>
</tr>
<tr>
<td>27. Revise existing standards including “Technical Specification for Application of Recycled Aggregate”, “Recycled Fine Aggregate for Concrete and Mortar” and “Recycled Coarse Aggregate for Concrete”</td>
<td>To match current situation and demands</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>28. Incorporate articles on on-site CDW reduction and reuse in relevant technical standards of construction, such as ‘Code for Quality Acceptance of Concrete Structure Construction’.</td>
<td>For better on-site CDW reduction and recycling</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>29. Prepare ‘Technical Code for Building Deconstruction’ specifying compulsory conditions and requirements on demolition procedures and on-site sorting, etc.</td>
<td>To facilitate resource management and separation, reduce costs for recycling and ensure quality of recycled product</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>30. Prepare ‘Technical Specification for CDW Transportation’.</td>
<td>To regulate CDW transportation</td>
<td>MOHURD</td>
<td>Short term</td>
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**Whole Process Management**

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<th>Recommendation</th>
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<th>Responsibility</th>
<th>Timeline</th>
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<tbody>
<tr>
<td>31. Establish declaration and registration system of CDW: local governments should publish information on CDW production and disposal.</td>
<td>Required by laws and regulations, to ensure source reduction, and to raise attention from local government and improve public supervision</td>
<td>MOHURD, MEP, local government</td>
<td>Short term</td>
</tr>
<tr>
<td>32. Add inspection requirements of CDW management and recycling into the construction project management.</td>
<td>By linking with existing administrative permits, to promote CDW management and recycling</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>33. Push forward research on waste minimisation in design and construction.</td>
<td>To promote prevention and reduction</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>34. Enforce CDW separation on site. Include the requirements on separate storage and on-site reuse into the criteria and indicators for evaluation of “Civilized Construction Site” and other competitions. Set up major professional CDW transport company.</td>
<td>To promote source separation and manage sources and outflows</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>35. Implement dynamic qualification management on the transport company, vehicles, and drivers. Promote usage of new vehicles.</td>
<td>To reduce fly-tipping and secure collection.</td>
<td>MOHURD</td>
<td>Short term</td>
</tr>
<tr>
<td>36. Promote construction of CDW disposal infrastructure. Prioritize resource facility</td>
<td>To ensure collection and increase treatment</td>
<td>MOHURD,</td>
<td>Short term</td>
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<tr>
<td>37. Establish CDW information management system, make use of internet and data mining tools to carry out real-time monitoring on CDW production, emission, transport, disposal and application etc.</td>
<td>By making use of advanced tools, to enhance management and secure recycling</td>
<td>NDRC, MIIT</td>
<td>Short term</td>
</tr>
<tr>
<td>38. Establish construction waste engineering technology research centre/experimental base etc.</td>
<td>To boost technology innovation and provide technical supports</td>
<td>NDRC, MOST</td>
<td>Short term</td>
</tr>
<tr>
<td>39. Carry out professional training program for employees from various industries. With the help of media, promote propaganda of CDW management and recycling.</td>
<td>To strengthen capacity of professional, increase awareness and understanding of community and mobilize public participation</td>
<td>Relevant agencies</td>
<td>Short term</td>
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5 Best Available Techniques for CDW Recycling

5.1 Source Reduction

CDW reduction is a comprehensive process to reduce waste production and discharge through management of the volume, mass, type, or toxicity of waste, supporting the efforts to promote clean production. It requires not only to reduce waste volume and mass, but also to minimize its types and reduce harmful substances from waste, and eliminate or reduce impacts to the environment essentially. China’s old practice of waste management focuses on the end - the so called ‘Abatement After Pollution’ – and it induces huge environmental impacts and implies higher treatment costs. While treatment and disposal are important methods to manage waste once waste has already been generated, source reduction prevents waste from being generated in the first place and reduces costs and environmental impacts throughout the whole chain from resource mining, manufacture to transportation. Source reduction of CDW incorporates lifecycle management of building industry, ranging from design, construction to demolition.

Currently, the understanding of China’s construction industry on source reduction of CDW has not yet been deep enough to actively adopt appropriate technologies to promote clean production. Therefore, in order to achieve better reduction management of CDW, proper guidance should be provided by relevant government departments or agencies through policies which promote and support clean production, encourage development of advanced construction technology and equipment, and facilitate sustainable use of raw materials, etc. Sections below show best available technologies for CDW recycling from three aspects of design for source reduction, construction and demolition in detail.

5.1.1 Design

CDW is generated in each process along the life chain, from building construction, maintenance, facility replacement, demolition even to the recycling and reuse of CDW. Therefore, cutting the CDW generation should be incorporated into processes from building design, construction management to demolition, etc. CDW-reduction design is a way of building design applying waste reduction concepts and methods to minimize CDW generation and to reuse CDW already generated during construction. In practice, those design concepts are not commonly adopted by Chinese architects, those concepts include:

Design for adaptability

‘Designing for adaptability’ is considering potential adaptabilities of buildings and reserves flexibilities for possible maintenance and renovation in the design. The building should be designed to local conditions and can reduce waste and extend its useful life, whilst taking other factors into account, such as material durability and risk to damage, etc.

Design for disassembly

Disassembly is a key step towards effective recycling, and will have to be considered in early stage of product design. With focuses on reuse, remanufacture and recycle, ‘designing for disassembly’ is to recycle raw materials for reuse at the minimum costs. It shows that sale of valuable recycled materials can far offset the additional labor costs of building disassembly. Disassembly provides an alternative for building demolition that not only reduces environmental impacts, but also opens new business opportunities for building demolition, recycling and transportation of demolition wastes, and remanufacture and resale of structure component. Designing a building to support disassembly can increase recycling rate of CDW from the current about 20% to 70% and above. Considering 50% of the total CDW are from building demolition and renovation, proper application of disassembly could create huge benefit space.

Design for green building materials
China's building industry heavily relies on traditional and low-performance construction materials, such as concrete, bricks, tiles and mortar, etc., and CDW accounts for 70% of the total municipal wastes in weight. In contrast, green materials use less natural raw materials and as a result of which pollution discharge and energy consumption during its production process are reduced. Adoption of green materials is eco-friendly and without harm to human health. Green materials are easier to be recycled and reused after disassembly, which could further eliminate pollutions to the ecosystem. Therefore, giving priority to green materials in material selection not only serves for CDW source reduction, but also promotes eco-friendly production in the building industry.

**Promote prefabricated structure system design**

Cast-in-situ reinforced concrete structures have been prevailed in the building industry and have become one of the traditional ways of construction. In terms of the structural mechanics, cast-in-situ concrete structures have good structural stability and good seismic performance, however, the CDWs generated with cast-in-situ structure construction are also considerable. As one of the key components in source reduction design, promoting prefabricated structure could heavily reduce CDW generation right from the source.

Currently, prefabricated structures are not commonly used in China and most constructions still adopt traditional techniques. From the perspective of design agencies, the design concept should be adapted to suit pre-fabricated structures and to match technical requirements by assembly-type construction. In terms of construction enterprises and material suppliers, they should increase the professional level of their production and facilitate the standardization of assembly-type components, to meet the needs of industrial development.

### 5.1.2 Construction

Construction processes generate CDWs most directly for various reasons, for example, due to improper management or lacking awareness of conservation by the contractor, material over budgeting resulting in unused or leftover materials; increased CDW due to inappropriate construction techniques or operations taken by workers; and waste of materials due to absence of detailed management of contractor on procurement and its consequences, including ordered materials not meeting design requirements, over-or-under order of material, and poor management on site, etc. Since many activities during construction stage could affect CDW generation directly, strengthening of waste reduction management during construction can’t be overstressed. Based on China’s experience and practice, CDW reduction could be achieved by taking pathways during construction, as described from different angles shown below:

**From management**

The considerable CDWs generated from building construction site are partly due to the unclearly stated and poorly followed management rules and regulations. An inclusive and sound on-site management regulations and its enforcement is essential to reduce CDW effectively. Although the contractor plays an important role in cutting CDWs down, coordination and cooperation between agencies and entities are needed to implement those aforementioned control measures and achieve the goal. On the one hand, government and its department should strive to create enabling environment for setting up system that could reduce CDW. On the other, in addition to follow regulations and systems, to enhance site management and achieve proactive CDW reduction, awareness and understanding of contractors on CDW management should be improved, including management measures of CDW reduction, on-site reuse measures, and awareness on centralized off-site waste treatment and disposal.

**From technologies**

Waste generation from construction has a close relationship with construction and engineering management. Generally, good management could effectively reduce CDW generation. CDW reduction could be achieved by improved management capacities of the contractor.

**From cost management**

To the contractor, CDW reduction or control will fundamentally fall on cost management. Construction and demolition wastes are/were all construction materials, which cost the largest proportion from the total, normally as much as 70%. Additional costs will be needed for waste treatment and disposal, and
procure and process the same amount of building materials to be used for construction, if deconstruction materials are treated as wastes. Therefore, reasonable limitation on costs and budget of contractor would encourage reuse of CDW on site, which will help to reduce CDW generation.

5.1.3 Demolition

After certain serving years, buildings will be demolished. Demolition process closes the old building’s functions and more often opens a new era for new ones. There are two methods used for reducing CDW during demolition: one is to discover and salvage residual values of the old building, preserving existing buildings rather than constructing new ones; another is the eye caught new technology changing the deconstruction from the traditional ‘demolition’ to ‘disassembly’. Based on practical engineering experience, demolition technologies could be improved from two aspects to reduce CDW generation from demolition, as follows:

Promote old building disposal appraisal and preserving

A rational appraisal method has decisive significance to determine a wise disposal plan of the old building and to reduce CDW generated from old building demolition and/or new building construction. Demolition the old building and constructing new ones is the common practice in China. Since the current appraisal method rarely, or never considers the potentials of CDW reduction, demolition plan will more often be selected. In order to reduce CDW in the future, it is necessary to incorporate parameters relating to CDW generation into the appraisal matrix.

Comparing to ‘demolition and reconstruction’, refurbishing old building and prolonging its useful life saves energy, building material and resources, also reduces CDW generation. Based on its characteristics, such as historical and cultural features, structure, ambient environment, material, function and space, etc., the residual values and potentials of the old building should be explored for reuse after proper renovation and refurbishing, where careful evaluation, planning, design and construction will be required. Actually, new building construction only takes a small proportion in the building industry in many developed countries, in which renovation and expansion of old buildings prevail. Utilization and reuse of old buildings are advocated. However, demolishing the old building and reconstructing new ones are still normal practice in China, and it’s partly because the absence of a sound method for old building appraisal and the weak awareness on reuse and reclamation. Preserving and reusing old buildings should become one of the targets contributing to the overall goal of CDW reduction.

Optimize demolition or deconstruction with techniques

With the opposite order to construction, selective demolition disconnects and separates components from structures. According to experience on old building demolition, typical sequencing steps include interior stripping and cleaning, separating and deconstructing, cutting down and separating, and transporting. Some of the deconstructed materials should be kept size and shape unchanged, like wood frame and metal components, to make the direct reuse easier. In addition, toxic and hazardous materials should be disassembled before the deconstruction starts to avoid mixture, allowing for the followed up recovery, reuse and processing.

Deconstruction demolition, sometimes called disassembly or dismantlement, similar to selective demolition, also supports dis-connection and separation of building materials. Higher technical requirements and emphasis on direct recovery and reuse of large-sized component makes it different from selective demolition. With deconstruction techniques, higher recovery and reuse rate of material could be expected and the recycling rate of building material could be increased from 20% to 70%. Hence, CDW need treatment and disposal will be significantly reduced.

The non-destructive features of the selective demolition and deconstruction demolition both can be seen clearly. In view of the technical requirements of deconstruction, dissemination and application of deconstruction techniques are significantly limited by current building design methods, which haven’t considered and are not responding to potential deconstruction practices. In contrast, selective demolition is more commonly used since it’s flexible and can be adjusted to local conditions much easier.
5.2 Sorting and Transportation

Sorting and separation of CDW could be done according to the source building, waste type, and disposal and recovery methods. In order to sort out CDW more efficiently, several bins should be placed on construction and deconstruction site to collect different type of CDW separately. According to waste composition, CDW could be collected separately as concrete and bricks (including tiles), earth and rock, metals and wood. According to sorting experience in China, improvement of sorting and separation of CDW at source would be done by taking measures shown below:

1) Based on waste type and characteristics, the separation collection of CDW should be achieved gradually. The collection method should match with the end disposal and treatment plan of that type.

2) According to their source, type and feature, CDW should keep separate at each stage from piling, deposition, transportation to treatment or disposal. Mixture with domestic waste and toxic or hazardous waste is forbidden in the whole process, from collection to disposal. Unsorted CDW should be treated at disposal site before it flows into the recycling processes.

3) Single-type and clean CDW could be recycled directly without pre-treatment. Mixed or uncleaned CDW will require pre-treatment. Process and facilities used for pre-treatment should be selected based on CDW features: bulk and massive wastes are better sorted mechanically, smaller size and amount of wastes could be sorted manually; to CDW contain mixed constituents, such as earth, wood and plastic, etc., mechanical sorting is recommended where different streams can be separated by vibration, gravity, airflow and screens, etc.

Transportation vehicles for CDW should not transport other types of waste. Especially for type of concrete and bricks & tiles, transportation tank should be covered or closed during operation, to avoid pollution to the environment. In addition, mixing already separated waste streams for transportation is not allowed. Separated CDW should be transported separately.

5.3 Recycling Processes

5.3.1 Processing methods

In China, waste treatment started late and many problems exist in the current treatment industry, including the predominant collection of mixed CDW without sorting and separating, poor reuse rate, weak technical capacity for recovery and recycling and low harmless treatment capacity. There are two type of processing methods for CDW before recovery and reuse: fixed and mobile.

Fixed processing plant is generally properly planned with larger footprint and more complete facilities. Compared to mobile types, it takes longer time for the planning and construction of the fixed plant, which is more expensive and capable to deal with bulk CDWs. Fixed processing plant requires large capital investment and resources, but it's not rare that the plant is running at a loss or closed due to multiple reasons, including incomplete legislation system to govern CDW treatment and weak enforcement of the regulations, insufficient supports from the government, transported CDW are not enough to match the treatment capacity and high level of heterogeneity of CDW, etc.

In contrast, the new type mobile processing features reliable performance, maintenance friendly, light in weight, flexible and adaptable, etc. However, the treatment capacity of mobile facilities, e.g. jaw crusher, impact crusher and cone crusher, are relatively small and not designed for bulk and centralized processing. The pre-treated CDW, which meet the diameter requirements, will be transported to the feeding machine by digger. Small and fine scraps will be filtered out, while large-sized materials will be fed into the impact crusher. Located above the output conveyer, the magnetic iron separator will remove steel bars from the stream and remainder flows into the screening station, from where large-sized materials will be sent back to the impact crusher and small-sized ones be sent to the product stockpiles by conveyers.

After processing, massive CDWs will be separated into different types. Especially, among the CDWs, materials like concrete, sand and stone, bricks and asphalt, etc. could be recycled and reused, reducing pressures to the environment effectively. Recycling and reuse of different materials is introduced in following sections.
(1) Recycling and reuse of concrete

Broken concrete account for 35% of the total CDW and is the major part of urban CDW. Recycling and reuse of broken concrete is of great value. The processed waste concrete could be used for producing reclaimed concrete and cement, and for roadbed and ram pile after mixed with rubble and lime.

(2) Recycling and reuse of bricks

Brickbat, or broken bricks, takes 15 to 20 percentage of the total CDW generated in urban area and is one of the major components of CDW. Experiments show that light blocks and hollow blocks could be made from the mixture of brickbat and mortar. With proper mixing ratio, produced blocks are able to meet all requirements by relevant regulations. In addition, mixture of brickbat and lime could be used for roadbed construction.

(3) Recycling and reuse of asphalt

Mortar accounts for about 2% of the urban CDW and it's mainly from road rehabilitation and roof removing works. Asphalt could also be recycled. After crushing and screening the asphalt materials collected from roads and roofs, reclaimed asphalt concrete could be made by mixing the processed recycled asphalt with recycling agents, aggregate and fresh asphalt at a proper ratio, and be used for either surface or base of road pavement. Roof asphalt could be recycled and reused for road pavement. In addition, practice shows that mixed asphalt could be used for lower grade road pavement or roadbed after simple treatment, and good performance could be expected.

5.3.2 Process and equipment

The process of reclaiming aggregate from broken concrete is selecting and sequencing different facilities, such as those for cutting and crushing, screening, conveying and impurity removing (in general wasted concrete contains steel bars, wood, plastics, glass and gypsum, etc., inevitably), to process the wasted concrete and produce recycled coarse and fine aggregates that meets relevant quality requirements. Traditional processing procedures are simple, only able to sort out material with limited sizes and have poor performance, resulting in insufficient classification. The crushing processes are also dusty and could have negative impacts to ambient environment. As a result, the gradation of recycled aggregate is bad, limiting product application and hardly being accepted by the market.

Normally, the aggregate production procedures include pre-treatment of wasted concrete, crushing, and post-treatment of aggregate. Pre-treatment procedures include sorting, impurity removing and homogenizing. Multiple levels of crushing and screening are used during crushing. Post-treatment includes physical strengthening and chemical strengthening of aggregate. Performance of aggregate is very important to the quality of product concrete, and the quality, or performance of aggregate is greatly affected by its production processes.

5.4 Use of Recycled Materials

5.4.1 Recycled aggregates

The main way to recycle and reuse CDW in China is producing recycled aggregates from CDW and making reclaimed concrete. The fact is that concrete strength of most of the concrete structures those have been demolished is less than grade C30. After proper crushing of wasted concrete, massive aggregates which could be recycled, which are separated from the aggregate-mortar interfaces and with the surface roughness significantly improved and similar shape, comparing to the conditions before mixture, which provides good basis for reuse. However, the recycled aggregates are surrounded with certain amount of mortar with high porosity and angularity, comparing to natural aggregates, recycled aggregates are at disadvantages of low apparent density, low bulk density, high water absorption and high crushing value, etc. Furthermore, the properties of recycled aggregates vary a lot with the strength, mixt ratio, age, living environment, producing process and other properties of the old concrete from which recycled aggregates are made.

5.4.2 Recycled concrete

Recycled concrete is that new concrete made with cement, water, other ingredients and aggregates, which are produced from waste concrete and properly grade-mixed after crushing the old concrete, washing and grading, instead of natural aggregates (mainly coarse aggregates), entirely or partially.
The combinations could be all with recycled aggregates, coarse recycled aggregates with natural sand, coarse natural gravels or peddles with fine recycled aggregates, or recycled aggregates replacing part of the coarse or fine aggregates.

5.4.3 Reclaimed mortars

Actually, the usage of mortar is much greater than one expected. It’s reported that quantities of sand used for mortar account for one third of the total usage of sands for construction, and cement used for mortar account for 25%-40% of the total consumption. After CDW crushing and screening, recycled fine aggregates, also called recycled sands could be used to produce mortar replacing natural sands, entirely or partially. It saves natural resources meanwhile eliminates the environmental impacts by solid wastes. Furthermore, using recycled fine aggregates contributes to the green development of the construction industry. According its application, mortars made with recycled fine aggregates could be classified as reclaimed masonry mortar, plastering mortar and screeding mortar. There are numerical experiments and studies conducted on the performance and properties of reclaimed mortars overseas. In terms of the working behavior, experimental results can be concluded as follows:

- The behavior differences between mortars made with recycled aggregates from different sources are small and negligible. It is suitable to produce recycled mortar from old concrete and bricks.

- Water demands of reclaimed mortar are higher than that of traditional mortar, but with better water holding capacity, the workability of reclaimed mortar is satisfied. In a real world application, more water could be added and secondary mixing method could be adopted when producing recycled mortar.

- The impact on mortar strength is negligible by replacing natural sands with recycled sands in good grading (also called find aggregates).

- The shrinkage of reclaimed mortar is higher than that of traditional mortar, and the shrinkage rate increases as the fine aggregate replacement rate increasing. In practice, surface coverage or water spray curing should be adopted for plastering mortar to minimize the potential impacts of higher shrinkage introduced by reclaimed mortar.

5.4.4 Reclaimed concrete products

Reclaimed concrete products are concrete products made with reclaimed concrete. Table 5 5 lists the basic characteristics of recycled concrete products, as well as recommendations based on practical engineering experiences.
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