Science of the Total Environment 724 (2020) 138264

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Developing efficient circularity for construction and demolition waste management in fast emerging economies: Lessons learned from Shenzhen, China

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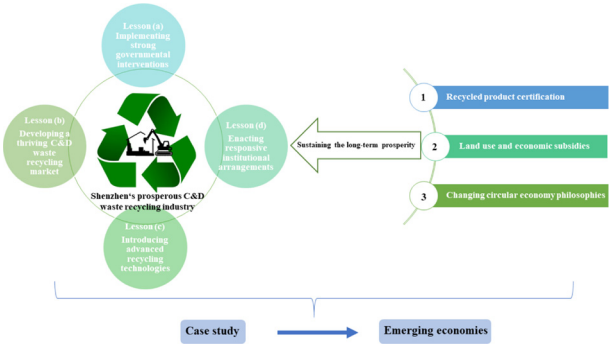
HIGHLIGHTS

- Some lessons learnt from Shenzhen's C&D waste recycling industry are summarized.
- The lessons are useful for emerging economies to develop efficient circularity.
- Some further improvements to sustain the long-term prosperity are also reported.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 February 2020
Received in revised form 23 March 2020
Accepted 26 March 2020
Available online 27 March 2020

Editor: Huu Hao Ngo

Keywords:
Construction and demolition waste
Waste management
Circular economy
Emerging economies
Shenzhen
China

ABSTRACT

Proper management of construction and demolition (C&D) waste is a key challenge amid global advocacy of the circular economy. This is of particular urgency in fast-emerging economies, where economic development induces massive construction without the capacity to manage the associated waste. This paper reports lessons learned from Shenzhen, China, which has witnessed exciting economic growth in the past few decades but also been compelled to rapidly develop an effective C&D waste circular economy from a low base. The research adopts a mixed-method approach combining case study, site investigations, and interviews in Shenzhen. It is discovered that Shenzhen's success can be attributed to (a) implementing strong governmental interventions; (b) developing a thriving C&D waste recycling market; (c) introducing advanced recycling technologies; and (d) enacting responsive institutional arrangements. Further improvements related to (1) recycled product certification, (2) land use and economic subsidies, and (3) changing circular economy philosophies, inter alia, are desired to sustain the long-term prosperity of this circular economy. The research provides a reference which can be adapted to the unique context of other emerging economies in developing effective circularity.

1. Introduction

Construction materializes the built environment, creates a myriad of jobs, and contributes significantly to economic growth. At the same

Abbreviations: R&D, research and development; CE, circular economy; ETC, Environmental Technology Co. Ltd; C&D, construction and demolition.

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https://doi.org/10.1016/j.scitotenv.2020.138264
0048-9697/

time, it is inherently environmentally unfriendly. It consumes non-renewable natural resources, generates solid waste, dust and gas emissions, and noise pollution, and causes land depletion and deterioration (Shen et al., 2007). Particularly, the problem of disposal of construction and demolition (C&D) waste has long plagued the global construction industry. Here, C&D waste, sometimes simply called construction waste, refers to the solid waste arising from construction, renovation, and demolition activities (Kofoworola and Gheewala, 2009; Lu et al., 2019). It is usually a mixture of surplus materials arising from site clearance, foundation, construction, refurbishment, renovation, and demolition (HKEPD, 2015; Chi et al., 2020).

Urbanization and urban regeneration produce huge amounts of C&D waste globally. In developed economies, the construction industry generally accounts for around 25–30% of the total solid waste disposed of (Lu et al., 2017). Various measures have been devised to manage C&D waste sustainably under the widely adopted 3Rs (i.e., reduce, reuse, and recycle) principle. Going beyond the 3Rs is the concept of the circular economy. Defined as "an industrial economy that is restorative or regenerative by intention and design" (EMF, 2013), it critiques the traditional linear economy and advocates proactive strategies, such as zero-waste design, restoration, and regeneration, organized in a closed loop. While achievement of the circular economy is a long way off, considerable progress has been made in developed countries. In Europe, for example, some countries have achieved zero or near zero landfilling, such as UK (Phillips et al., 2011), Netherlands (Scharff, 2014) and Germany (Aniekan and Ikechukwu, 2016).

In emerging economies such as China, India, and Brazil, the conflict between economic expansion and environmental degradation is especially conspicuous (Yang et al., 2019; Zhao et al., 2019). Massive construction activities generate huge amounts of waste, but these economies lack sufficient C&D waste management capacity to achieve sustainable development goals. This study aims to report some lessons on developing an efficient circular economy for C&D waste management in fast-emerging economies. We do so by conducting a case study in Shenzhen, an economically prosperous municipality in China. The paper is structured into seven sections. Following this introductory section are two literature review sections, one reviewing the literature on a circular economy for C&D waste management, the other C&D waste management in emerging economies. The fourth section describes our mixed-method approach combining case study, site visits, and interviews. The fifth section outlines the lessons learned from the case study, section six discusses possible further improvements and implications for other fast-emerging economies, and conclusions are drawn in the seventh section.

2. A circular economy for C&D waste management

As defined above, a circular economy offers an alternative to the conventional linear "take-make-use-dispose" economy which severely degrades the environment by removing its natural capital or diminishing this capital through pollution from waste (Murray et al., 2017). A circular economy responds to increasing pressure from expanding economic development and resource scarcity. It aims to bridge production and consumption activities by making a closed loop (Witjes and Lozano, 2016) and offers enormous benefits, such as reducing pressure on the environment, improving the security of raw material supply, increasing competitiveness, stimulating innovation, boosting economic growth, and creating jobs (European Parliament, 2018; Ghisellini et al., 2018).

Various governments, organizations, and businesses have elevated the circular economy to the top of their agendas. Along with developed economies such as Japan, the UK, France, and the Netherlands, some emerging economies have begun to launch circularity-accelerating policies. For example, China has recognized the concept of the circular economy in its national legislation (Mathews and Tan, 2011). A series of circular economy-related practices have been implemented across fields with the construction industry often highlighted in initiatives, for example in the European Union's *Action Plan for the Circular Economy*, the Netherlands' *Circular Dutch Economy by 2050*, and China's *Circular Development and Leading Action*.

Of paramount importance to achieving a circular economy is C&D waste management that ensures material flows in a closed loop. According to Stephan and Athanassiadis (2018), the key for the construction industry in transitioning towards circularity is recycling C&D waste into secondary resources to extend output flows. Ghaffar et al. (2020) also emphasize C&D waste recycling, allowing for new models of consumer behavior to new ways of turning waste into a resource. The importance of C&D waste circularity is also reflected in the 3Rs principle.

3. C&D waste management in emerging economies

Emerging economies "are striving to become advanced economies through increased production, development of regulatory bodies and exchange, and increasingly sophisticated markets" (Sraders, 2018). They are usually undergoing a transition from a low income, less developed, pre-industrial economy towards a modern, industrial economy with higher living standards (Chappelow, 2019). Organizations such as Morgan Stanley Capital International (MSCI) and the International Monetary Fund (IMF) have devised indices to determine whether an economy is emerging or not. Despite discrepancies between indices, some countries are commonly recognized as emerging. Brazil, Russia, India, China, and South Africa are representative emerging economies which have enjoyed brisker economic growth compared with their developed counterparts. The first letters of their economy names form a "BRICS", which refers to an international association consisting of these five leading emerging economies globally.

Brisker economic growth in the BRICS economies has to be sustained by proportionate construction activities, such as infrastructure, housing, and building development, which inevitably generate profuse C&D waste. It is estimated that China, for example, produces about 1.5 billion tons of C&D waste every year (Lu et al., 2017), >2.6 times the 569 million tons of the U.S. (SCMP, 2019; EPA, 2019). However, emerging economies lack sufficient C&D waste management knowledge and capacity. In some developed economies, the C&D waste reuse and recycling rate is 70–95% while in China it is just 5%, causing a situation known as "waste siege" (Huang et al., 2018). In India and Brazil, due to lack of recycling facilities, illegal dumping of C&D waste can be seen everywhere (Córdoba et al., 2019; Gayakwad and Sasane, 2000). Eventually, C&D waste-related issues are bound to impede the sustainable development of these economies.

The circular economy, which includes the C&D waste recycling industry, is relatively new to emerging economies. Even in most European countries, the origins of C&D waste recycling go back no farther than the 1990s (Rodríguez et al., 2015). Governments have explored how to develop a C&D waste recycling industry towards a circular economy, exploring institutional arrangements and marketization with minimum government intervention. However, pure marketization is seemingly not an option in some developing economies. This is due to C&D waste recycling industry characteristics such as high initial investment, low profitability, and high risk, all of which attract very few investors. In response, applying a public private partnership (PPP) procurement model to this industry in some Chinese cities has recently begun to be been explored (Bao et al., 2019).

Technologies, particularly recycling technologies, which can facilitate a circular economy are also being explored. The inadequacy of C&D waste recycling plants has been reported in economies such as Brazil and China (Lu and Yuan, 2011; Bao et al., 2019), and it is generally accepted that economic viability is the underlying barrier. For example, Nunes et al. (2007) found that it was economically not viable for the private sector to invest in the Brazilian recycling industry. Wang et al. (2004) revealed that the C&D waste recycling industry in China was economically viable only when supplying waste wood for waste-to-energy plants. The recycling industry cannot survive without

government subsidies, yet relying on transfusions from the government is unsustainable. How to develop a C&D waste recycling industry in emerging economies is a conundrum, calling for more studies to be conducted.

4. Research methods

This study adopts a mixed-method approach with a combination of case study, site investigations, and interviews.

4.1. Case description

The case study is deemed a suitable method as it can focus on a particular issue, feature, or unit of analysis, enabling researchers to understand complex real-life activities (Noor, 2008). Patton (1987) also describes it as being particularly appropriate to probe into an area of interest in depth. A combination of qualitative research methods to supplement the case study should be adopted for the sake of providing a broader picture (Yin, 2017; Noor, 2008; Wang et al., 2019).

The subject of our case study is the southern Chinese city of Shenzhen. Established as an experimental Special Economic Zone (SEZ) in the 1980s as part of China's reform and opening up, Shenzhen has transformed from a small fishing village to one of four Tier 1 cities in China after Beijing, Shanghai, and Guangzhou (Yang et al., 2020). According to the Statistics Bureau of Shenzhen Municipality (SBSM) (2019), in 2018 Shenzhen had an area of 1997 km^2 and a population of around 13.03 million. Its Gross Domestic Product (GDP) reached CNY 2469.1 billion in 2018, ranking third in China (NBS, 2019). To support its economic growth, massive construction activities have been initiated in Shenzhen, generating huge amounts of C&D waste. It is estimated that annual C&D waste generation in Shenzhen is about 100 million m^3 (Shenzhen Daily, 2019). The city's C&D waste issues, if not properly managed, will mount to an extent to impede its economic development.

Since a C&D waste landslide in 2015 destroyed over thirty buildings and caused over seventy deaths (Perlez, 2016), C&D waste management has moved to the top of the Shenzhen government's agenda. Meanwhile, economic growth and construction activities cannot be jeopardized for any reason, including C&D waste management. Shenzhen is building >10 subways, each generating a huge amount of excavated soil, and after 40 years' high-speed urbanization, is now reaching the urban renewal stage with a lot of demolition and new construction activities expected. Recent observations reveal that Shenzhen has made progress towards an efficient circular economy in its construction sector from a relatively poor past. According to the Housing and Construction Bureau (HCB) of Shenzhen, there are 42 officially registered C&D waste recycling enterprises, and some construction sites have achieved zero waste. Notably, this has occurred while economic growth has been sustained, with a GDP increase of 6.7% in 2019 (SBSM, 2019).

4.2. Site investigations

A site investigation is a systematic study of original data gathered from a real setting (Edmondson and McManus, 2007). It is usually characterised by a detailed understanding of the operations in a particular firm, business, or industry (DeHoratius and Rabinovich, 2011). In this study, the aim of the site investigations was to gain a more intuitive understanding of the Shenzhen C&D waste recycling industry. The focus of our site investigations was Environmental Technology Co. Ltd. (hereafter ETC), a leading C&D waste recycling company. Initiated in 2010, ETC has been widely recognized as one of the four largest companies of its kind in Shenzhen, with nearly 100 employees and occupying an area of around 80,000 m^2. It produces a variety of recycled products for sale, mainly using recycled aggregates of pavement brick, light foam brick, curbstone, sanded brick, recycled concrete, and dry-mixed mortar.

Traditional yet still prevailing waste processing (e.g., recycling) practice is to transport all waste to centralized recycling plants for treatment (Lu and Yuan, 2012), called off-site or stationary recycling in this paper. Shenzhen, however, has seen a growing practice of decentralized, on-site waste treatment, which we also refer to as on-site or portable recycling. C&D waste recycling companies in Shenzhen are either stationary, portable, or a combination of the two. Our two site investigations conducted in November 2019 looked at both: one investigation was conducted at ETC's stationary C&D waste recycling plant, the other at a portable waste recycling facility under the remit of ETC.

4.2.1. ETC's off-site C&D waste recycling plant

This site investigation comprised two parts. The first involved direct observation of the production of recycled products from C&D waste (see Fig. 1). Fig. 1(a) shows the storage spot where untreated C&D waste as the raw material is roughly sorted based on size. Fig. 1(b) shows the equipment used for finer sorting and crushing. First, impurities such as metal and timber are removed. Second is the crushing process where fine and coarse recycled aggregates are obtained. By utilizing aggregates of different grades, various recycled products can be made. The grades of recycled aggregates are usually characterised by the sizes of their diameters. Fig. 1(c) shows the manufacturing workshop where various recycled products are produced, and Fig. 1(d) shows the equipment used for producing recycled concrete.

This part of the site investigation took about an hour, during which personnel explained the step-by-step process and roles of different equipment and technologies in producing various recycled products. The detailed answers we received to our questions throughout the visit significantly deepened our understanding. In the second part of this site investigation, also taking about an hour, the general manager of the company led a group discussion in the office addressing the state of the market for recycled products and the prospects of the company.

4.2.2. ETC's on-site C&D waste recycling facility

The second site investigation took place 1 week later at a demolition site surrounded by residential buildings. At this site, the waste is treated immediately on-site rather than being transported to a C&D waste recycling plant (see Fig. 2). Fig. 2(a) shows the untreated C&D waste on-site. Preliminary manual sorting has already been conducted to eliminate hazardous materials, such as timber and plasterboard. Processing of the C&D waste is then conducted in two stages using remote controlled equipment imported from Europe. The first stage is further sorting (see Fig. 2(b)) with magnet pads to segregate metals such as steel and aluminium. The second stage is crushing the waste into aggregates of different grades (see Fig. 2(c)). Fig. 2(d) illustrates the two grades of recycled aggregates produced on-site. One grade is in a size of 13 mm in diameter (left in Fig. 2(d)) and the other is in a size of 24 mm in diameter (right in Fig. 2(d)).

This site investigation took about 2 h. We were accompanied by a project manager who elaborated on the process and equipment used for recycling, and also answered in detail our targeted questions. There was also a discussion on the strengths and weaknesses of portable C&D waste recycling.

4.3. Interviews

To garner more insights into Shenzhen's C&D waste recycling industry, we conducted semi-structured interviews with wider stakeholders including policymakers, practitioners, and researchers. The semi-structured interview is a qualitative research method where the researcher asks informants a series of predetermined, open-ended questions (Given, 2008). It has been widely applied to explore perceptions and opinions on complex issues (Barriball and While, 1994). It is

(a) Storage spot allocated for untreated C&D waste

(b) Equipment for sor ting and crushing C&D waste

(c) The manufacturing workshop for producing recycled products

(d) Equipment for producing recycled concrete

Fig. 1. ETC's stationary C&D waste recycling plant in Shenzhen.

considered suitable for this study as it can supplement and add depth to other approaches in mixed-methods research (Newcomer et al., 2015).

We conducted nine semi-structured interviews in December 2019. Table 1 shows the basic profiles of the interviewees. All are very experienced in the field and qualify as good informants of diverse and deliberately selected backgrounds. For example, Interviewees 1 and 2 were selected to provide insights into stationary and portable C&D waste recycling, respectively. Interviewee 3, as a representative of the government, surveys one or two C&D waste recycling companies every week and is very familiar with the status quo of the recycling industry in Shenzhen. It was expected that he could provide us with an overall picture of the industry. Scholar interviewees were selected on the basis

(a) Untreated C&D waste on-site

(b) Equipment used for processing the C&D waste on-site (stage 1)

(c) Equipment used for processing the C&D waste on-site (stage 2)

(d) Two grades of recycled aggregates produced on site

Fig. 2. ETC's portable C&D waste recycling facility in Shenzhen.

that they could provide relatively objective professional insights. Basically, there are two criteria for the selection of the interviewees. First, the backgrounds of the interviewees should cover different streams of C&D waste management as wide as possible. Second, all the interviewees must have abundant experience in C&D waste management, preferably holding high positions in their work units. Although the sample size of this interview study is only nine, the goal of the attainment of saturation has been generally achieved. All of our semi-structured interviews were conducted face-to-face in two rounds to capture more accurate and rich information. In the first round, the questions were more open-ended with a view to developing an overall picture of the C&D waste recycling industry in Shenzhen, e.g.:

- Can you briefly introduce the development of C&D waste recycling in Shenzhen?
- What are the pros and cons of the two types of C&D waste recycling in Shenzhen?
- How do C&D waste recycling companies in Shenzhen source their C&D waste?
- What are stakeholders' attitudes towards the adoption of recycled products in Shenzhen?

In the second round of interviews, the questions were more specific and targeted, e.g.:

- How profitable is the C&D waste recycling industry in Shenzhen generally?
- Has the government applied some interventions to stimulate the recycling industry?
- What are the main sources of the income for Shenzhen's C&D waste recycling industry?
- What prospects and challenges does the industry face?

Each interview lasted about 2 h and was audio-recorded with consent. Based on the recordings, detailed notes were taken in a separate script for each interviewee labelled with their names for distinction. Telephone calls were also made to the interviewees for clarification where necessary to ensure accuracy of the data collected. When nine scripts of all the interviews were completed, the authors then conducted the text analysis to find the content that was highly mentioned by multiple interviewees. Then the results presented in this paper were all mentioned by at least three interviewees. Through this way of cross-referencing, the results obtained are believed with high accuracy.

Table 1
Profiles of interviewees.

No.	Role	C&D waste management experience
1	General Manager (GM), Shenzhen ETC	>10 years
2	On-site project manager of a demolition project	>8 years
3	C&D waste management expert, HCB of Shenzhen	>6 years
4	GM of a local C&D waste recycling company	>10 years
5	Engineer, deputy GM of another local C&D waste recycling company	>8 years
6	C&D waste management expert of a leading regional architectural institute	>10 years
7	Project manager of a municipal construction project in Shenzhen	>5 years
8	Scholar, C&D waste management expert in a local university	>15 years
9	Scholar, construction soil & residue expert in a local university	>15 years

5. Lessons learned

To achieve a circular economy in construction, our Shenzhen case study highlights the importance of (a) implementing strong governmental interventions; (b) developing a thriving C&D waste recycling market; (c) introducing advanced recycling technologies; and (d) enacting responsive institutional arrangements. They are elaborated by supporting the first and secondary data as follows.

5.1. Implementing strong governmental interventions

The Shenzhen government has implemented a series of strategies to stimulate the C&D waste recycling industry. First, it has closed all landfills in Shenzhen except one which accepts renovation waste only. This radical policy, prompted partly by the landslide tragedy in 2015 and partly by a lack of sufficient treatment technologies, sent a clear signal to the industry. The “easy life” of landfilling is over, and construction clients must now rely on the recycling industry to process C&D waste. These clients cannot even obtain a building permit without first showing sufficient waste disposal capacity.

To further expand the market space of the C&D waste recycling industry, the government has released China's first C&D waste discharge quota with effect from January 2020. This stipulates the amount of C&D waste allowed to be transported out of a site, dependent on whether the project is new construction, renovation, or demolition. For example, no >10% of demolition waste can be transported out of a site. As a result, engaging the C&D waste recycling industry becomes a necessity.

In addition to interventions which could be considered “sticks”, the government has deployed “carrots” in the form of incentive policies targeting recycled products. Interviewee 1 said:

We are very grateful for the government's support as >80% of the recycled products produced in our company are used in public projects, such as schools and hospitals.

Interviewee 3 added:

The incentive policies are specific for recycled products. For example, if the recycling company produces one piece of recycled brick, the government may give back the company CNY 1. For other types of recycled products, the reward may vary. If the public project using recycled products receives good feedback, the government may directly reward the company CNY 1 million or two and put it as an exemplary.

While enjoying the incentives, C&D waste recycling companies also face great pressure. They must hand over the project to the client on schedule with no waste or recycled products on-site, or else suffer an economic penalty. Interviewee 4 explained:

The economic penalty is considerably high and almost intolerable for some small and medium-sized waste recycling companies. As far as I know, the economic penalty is at least CNY 10,000 per day delay of delivery.

Interviewee 3 echoed:

It makes sense why such a clause of huge economic penalty for delay of project delivery is stipulated in the contract. As many stakeholders take out a huge loan from the bank for property development with the site, delaying for even one day means they have to pay the bank a huge interest, likely leading to their direct failure of their project due to the broken capital chain.

5.2. Developing a thriving C&D waste recycling market

In addition to governmental interventions, some market-driven measures have been devised to foster the circular economy. First, to control the quality of recycled products, many C&D waste recycling companies in Shenzhen have implemented a staged charging scheme depending on the composition of the C&D waste received (see Table 2). Interviewee 1 reflected that:

On the one hand, this system aims to encourage related stakeholders to conduct on-site sorting for the sake of receiving good quality C&D waste and further producing good quality recycled products. On the other hand, charging the C&D waste sent to us constitutes an important source of our income.

Waste recycling in Shenzhen benefits from Guangdong province regulations prohibiting quarrying of river sand and stone, which have caused the prices of aggregates crushed from virgin materials to rise significantly in recent years. Consequently, the prices of recycled products have a comparative advantage over virgin materials. Interviewee 5 explained that:

The price of river sand was about CNY 30/m^3 in 2015, but now the price has been increased to about CNY 300/m^3. Thanks to that, the prices of recycled products are now 10–30% low than those made with virgin materials, depending on the percentage of C&D waste added into the recycled products. The more you add, the greater advantage in prices the recycled products will have.

In a thriving market, recycling companies can earn their income by selling the recycled products such as aggregates. Interviewee 7 said that:

The recycled aggregate produced on-site is usually used as filling materials for foundation pits in other construction projects nearby. Experience tells us the range for selling the recycled aggregate is usually limited to within 5 km due to extremely high transportation costs. The price of recycled aggregate usually fluctuates between CNY 20 and CNY 30 per ton. In rainy seasons the price is slightly higher, usually ranging from CNY 30 to CNY 40 per ton due to higher demand.

Recycling companies have also formulated tendering strategies to assure profitability for the company. Interviewee 1 said:

Before tendering for a certain demolition project, we will normally assess whether there are enough construction projects nearby to estimate the demand for recycled aggregate. If the demand is high, we will lower the service fee charged. Otherwise, we will raise the service fee. In short, we need to guarantee the sum of the two sources of income can guarantee the company is profitable.

It can be seen that the Shenzhen government-led and market-driven interventions work together to expand the market space, allowing for reasonable profit margins in the C&D waste recycling industry and fostering the circular economy.

5.3. Introducing advanced recycling technologies

Shenzhen's recycling industry has also relied on technologies to develop its circular economy, specifically the waste processing technologies that empower the market division of on-site/portable and off-site/stationary waste treatment (See Figs. 1 and 2). Companies searched the world for these technologies and adapted them to Shenzhen's conditions, e.g., its site conditions, business scale, and need for efficiency. The co-existence of two types of recycling creates a buffer for the recycling companies and gives them greater flexibility. On-site waste recycling has advantages such as lower investment, lower transportation cost, easier management, and less dust and noise pollution due to its on-site processing. However, this type of recycling must be supplemented by stationary recycling plants due to its weaknesses which include limited capacity, site space constraints, project duration, and equipment availability.

Since 2018, the Shenzhen government has made it compulsory to use a new type of vehicle to transport C&D waste. Interviewee 3 explained:

The government has significantly subsidized the C&D waste transporting companies to help them gradually replace their traditional vehicles with the new ones. The price of a traditional vehicle is CNY 100,000, and the new one is valued CNY 300,000. Our subsidy will meet the difference.

There are several advantages to using these new vehicles to transport C&D waste. First, they are better covered. Second, because the space is well designed the vehicles can normally contain 8–11 m^3 of C&D waste but no more, eliminating the possibility of overload. Third, the new type of vehicles minimizes illegal dumping potential as explained by Interviewee 3:

The new type of vehicle is very intelligent with a GPS monitoring system installed. In this way, the driver of the vehicle is only allowed to drive a designated road to transport the C&D waste. Otherwise, the system will alert us.

The C&D waste recycling industry has invested heavily in research and development (R&D), with a view to shaping their unique market competitiveness. Interviewee 4 reflected:

Our company has partnered with several local universities to probe into the R&D of C&D waste. Thanks to that, our company has achieved >30 patents. More than half of our company's recycled products are unique to other companies. This gives us more power to determine the market prices of these products to further contribute to our profitability.

Interviewee 3 further explained that:

Based on my survey results, most C&D waste recycling companies in Shenzhen have their own unique recycled products. I am not surprised to see this phenomenon as it is the main advantage of marketization.

The government encourages R&D by counting patents among other key performance indicators to allocate subsidies to companies. Although inevitably this means some companies seek patents without actually using them, overall, a healthy culture of R&D has been developed.

Table 2
The staged C&D waste charging scheme adopted by ETC.

Waste charge (CNY per vehicle)	Composition of C&D waste
100	Pure concrete block
150	Concrete blocks but with >30% of stone powder
250	With steel but not exceeding 8 cm in diameter
300	With small asphalt blocks
Rejection	With dry sand, mud blocks, wet waste, or >30% of asphalt blocks

5.4. Enacting responsive institutional arrangements

Shenzhen is a young city set up as a SEZ to emulate capitalist Hong Kong, and as a site for public policy experimentation in socialist China. It is genetically programmed to enact institutional arrangements responsive to changing social, economic, technological, and environmental conditions. To foster the recycling industry, Shenzhen has enacted a bilateral binding mechanism between recycling and demolition companies not before seen in any other economy. It comes from a specification promulgated by the HCB of Shenzhen in 2017 called *Measures for the Management of House Demolition Projects in Shenzhen*, which stipulates that any demolition project with a gross floor area of >500 m^2 must report first to the HCB for approval. The demolition company must join with a recycling company to tender for the demolition project as a unit. If successful, these two companies are then required to enter the site as a unit to ensure the waste is treated properly.

This bilateral binding mechanism provides tremendous benefits for Shenzhen's recycling industry. First, the recycling company has a key role in this mechanism, minimizing traditional risks such as sporadic waste supply. Meanwhile, it ensures the waste is treated properly, and that high-quality recycled products are obtained. Interviewee 1 said:

The recycling company is responsible for supervising the demolition company to conduct the demolition work properly so that the demolition waste is of high enough quality to produce the recycled products. For example, we usually require the demolition company to conduct the on-site sorting rigorously to eliminate some hazardous materials, such as furniture and pipeline, which will lower the quality of the recycled products.

Interviewee 1 further added that:

With our expertise, we can supervise the demolition company to conduct very targeted on-site sorting. For example, we know red brick slag is very detrimental to the quality of recycled products. Therefore, we usually require the demolition company to eliminate the red brick slag as much as possible.

This mechanism is the key to guaranteeing the profitability of recycling companies through two sources of income. One is the service fee usually paid by the stakeholder according to the amount of waste processed on-site. The other is sale of recycled products, normally recycled aggregate, to a third party. Interviewee 3 reflected:

Based on my experience, the total cost to conduct on-site recycling is no more than CNY 15 per ton. In comparison with the service fee charged by the C&D waste recycling company normally between CNY 20 and CNY 30 per ton, there must be a profit margin even without counting the income by selling the recycling aggregate.

6. Prospects and challenges

Although Shenzhen's C&D waste recycling industry has developed efficiently, further improvements are needed to sustain its prosperity in the long term.

6.1. Changing attitudes towards recycled products

Currently, the vast majority of recycled products are used in public projects only. Increasing the percentage of recycled products used in private projects is vital for the industry's long-term prosperity. The private sector is reluctant to adopt recycled products due to concerns about quality, and these deep-rooted attitudes towards recycled products need to be changed. To this end, more R&D should be conducted, e.g., to ascertain properties such as porosity, strength, and durability compared with virgin materials.

Based on these properties, a recommended measure is to set clear standards for recycled materials/products. The government has already taken some measures. Interviewee 3 said:

We are now compiling a standard for recycled products. In the future, we conceive of engaging a professional third party to certify the recycled products. The third party will take the responsibility to test various parameters of recycled products; once the recycled product passes the test, a certification will be issued to this recycled product.

By introducing a certification system, recycled products can be traded like any other virgin materials. The government should also initiate promotional activities via the media to change the general public's attitudes towards recycled products. The government may also organize some regular training on changing the industry stakeholders' attitudes.

6.2. Land use and economic subsidiaries to make a business case

Currently, the sustainability of the C&D waste recycling industry in Shenzhen is subject to further policy support and economic subsidies. Interviewee 3 said:

According to my estimation, most recycling companies can achieve at least 20% of profit margins. Some can achieve up to 30%. So overall, it is a profitable industry in Shenzhen. Currently, more companies are joining. However, most emerging industries show prosperous development at their infancy. Once the limelight passes, all the businesses will just collapse. Therefore, how to sustain the long-term prosperity of Shenzhen's recycling industry poses a real challenge for us.

Recycling industry land use is a long-standing problem in Shenzhen. Currently, many investors rent a piece of land to operate their recycling plant. After several years of operation, they may have to surrender this land when the landowner decides to take the land back for other purposes. The government is taking some measures to alleviate this dilemma. Interviewee 3 said:

We are now coordinating with the Bureau of Land Resources of Shenzhen to allocate a certain amount of land to C&D waste recycling industry. In the future, we plan to allocate 200,000 m^2 land for every district in Shenzhen from the public domain specifically for the recycling industry.

6.3. Changing philosophy on the circular economy

In the early stages of Shenzhen's growth, the government and its executive arm seemed reactive in its strategies dealing with growth-related environmental crises. Through trial and error, they have now developed the belief that economic growth can run in parallel with environmental protection. While a C&D waste recycling industry is the most effective point of departure, it is, after all, end-of-the-pipeline processing. More proactive strategies compliant with the circular economy philosophy, such as conservation and preservation of existing facilities, should be considered (Yang, 2018). In some dilapidated districts such as Luohu, urban renewal has incorporated the circular economy philosophy and C&D waste is consciously managed (Shenzhen Luohu Government, 2018).

Currently, companies are more often than not reactive to the government's C&D waste management incentive schemes. While sustaining amenable policies, companies should be educated to embrace the circular economy as a business axiom so that the whole construction industry can run in a virtuous circle that sustains long-term prosperity. It might be impractical to change industry stakeholders' bias against the circular economy overnight, but these efforts should be paid along the way the nexus between growth and environment is harmonized.

7. Implications for other emerging economies

One may be skeptical about the transferability of Shenzhen's experiences. Benefiting from its hi-tech industry, Shenzhen's GDP per capita is climbing quickly, allowing it to set C&D waste management goals (e.g., zero waste site, 10% of waste transported out from a demolition project) too ambitious even for its peer Hong Kong, let alone developing economies. But Shenzhen has developed from a low base, adopting a coarse management mode corresponding to its economic development level at the time. Of particular inspiration is that Shenzhen has always looked at quality peers and learned from them. In doing so, it has developed a healthy economy allowing resources to remediate the downside, i.e., the negative environmental impacts, of its growth.

One may also consider that Shenzhen's advantage of strong governmental intervention cannot be replicated elsewhere, particularly in emerging economies which often suffer poor administrative experience and enforcement power. Indeed, this advantage is an inherent strength of Shenzhen, which was developed within China's overarching planned economic system. All economies in China have a tradition of strong governmental intervention. In recent years, the Shenzhen government has focused on enacting various C&D waste management-related standards, implementing incentive policies, and stressing policy enforcement. It also counts on market-driven measures to supplement these interventions to achieve its C&D waste management goals. As an experimental SEZ, Shenzhen is flexible enough to adjust its strategies, and is forward-looking in attempting bold policy measures.

Shenzhen's experiences show a virtuous circle between economic growth and environmental protection. The environment and the economy are not adversaries but allies. To get the ball rolling, policymakers, practitioners, scholars, and the general public should act positively in their respective spheres. Emerging economies can derive confidence from Shenzhen's experiences showing that environmental protection policies, properly devised and enacted, can sustain economic development. They can also be encouraged by Shenzhen's experiences showing that difficulties of financial, technological, administrative, and environmental resources can be overcome. Instead, they could be elevated

like an ascending spiral to improve the difficulties that hinder the development of a CE.

The observations derived from this study might only reflect the tip of the iceberg of Shenzhen's experiences of developing a circular economy. Neither, the experiences reported in this paper should be treated in a piecemeal fashion. There is no one-size-fits-all formula that emerging economies can use to address their environment and growth dilemmas, and Shenzhen's experiences of developing an efficient circular economy for C&D waste management can only be treated as a reference. Emerging economies must devise their own strategies by thoroughly considering their own unique political, economic, social, and technological contexts.

8. Conclusion

How to deal with C&D waste is a conundrum for emerging economies. Economic growth necessitates construction, but these economies generally have limited capacity to deal with the resulting waste. This research investigated Shenzhen's experience of this predicament, with a view to providing a reference for other fast-emerging economies. Shenzhen has successfully developed a circular economy for C&D waste management from a low base. Triggered by several social-economic events, the city set this ambitious goal of circularity. To achieve this goal without impeding economic momentum, the government has introduced a series of strategies, including implementing strong governmental interventions; developing a thriving C&D waste recycling market; introducing advanced recycling technologies; and enacting responsive institutional arrangements. For the long-term sustainability of the circular economy, it is envisioned that several improvements, e.g., recycled product certification, land use and economic subsidies, changing philosophies on economic growth and environmental protection, should be made.

In developing their circularity, emerging economies often face challenges, such as insufficient finance, primitive technologies, and inefficient administrative experience. While the Shenzhen government appears to have unlimited finances to achieve its goal of a circular economy, the city in its early years suffered every hindrance seen in emerging economies now. The virtuous circle between economy, technology, administration, and environment could be elevated like an ascending spiral. Shenzhen's experiences shed light on this elevation process. However, these experiences cannot be simply sold “off the shelf” to other economies. Instead, emerging economies should absorb the experiences and adapt them to their particular development and environment context. Future research is recommended to explore the “epidemiologic link” of knowledge between the contexts of different economies.

CRediT authorship contribution statement

Zhikang Bao: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing - original draft.**Weisheng Lu:**Funding acquisition, Resources, Supervision, Validation, Visualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research is supported by Public Policy Research (PPR) (Project No.: 2018.A8.078.18D) and Strategic PPR (Project Number: S2018.A8.010) Funding Schemes from the Policy Innovation and Coordination Office of the Government of the Hong Kong SAR.

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