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Implementing on-site construction waste recycling in Hong Kong: Barriers and facilitators

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HIGHLIGHTS

• Identified five major barriers to on-site C&D waste recycling in Hong Kong;
• Developed four facilitators to promote on-site C&D waste recycling in Hong Kong;
• The facilitators discussed may serve as useful reference for other economies.

GRAPHICAL ABSTRACT

ABSTRACT

Construction and demolition (C&D) waste recycling constitutes an indispensable component in the overall waste management strategy. Unlike the traditional recycling approaches whereby C&D waste is transported to off-site facilities for treatment, construction managers are actively exploring the possibility of on-site recycling where C&D waste is treated directly at source. This study reports the barriers and facilitators of implementing on-site C&D waste recycling by contextualizing it in Hong Kong. It does so by adopting a mixed-method approach combining case study, site visits, and interviews. It is discovered that the barriers include (1) site space constraints, (2) narrow window of opportunity to trade recycled products, (3) vulnerable business case, (4) lack of support from off-site recycling, and (5) lack of government policy support. A series of facilitating measures are also proposed, including (1) developing customized on-site recycling equipment, (2) establishing a demand-supply information-sharing platform, (3) developing more thriving off-site recycling, and (4) providing more government support. This study probes into the real-life on- and off-site waste recycling practices in Hong Kong’s prominent C&D management system. It can also provide useful references for others in developing their own C&D waste recycling strategies by rationally deploying on- and off-site recycling.

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1. Introduction

The construction industry has long enjoyed rapturous applause for its significant contribution to materializing the built environment, creating job opportunities, and maintaining economic growth. Meanwhile, with the increasing embracement of sustainability globally, a surge of criticism has been overtly targeted at construction, which is perceived
as the culprit of environmental degradation, non-renewable natural resources consumption, gas and dust emission, solid waste generation, noise pollution, as well as land depletion and deterioration (Lu et al., 2016; Yang et al., 2019, 2020). Particularly, significant attention has been paid to construction and demolition (C&D) waste in recent years, discerning it a pivot to indicate the degree of sustainability. Here, C&D waste, sometimes used interchangeably with construction waste for simplicity, means the solid waste arising from construction, demolition and renovation projects (Lu et al., 2019; Wu et al., 2019; Chi et al., 2020). It often comprises surplus materials from excavation, site clearance, construction, demolition, renovation, refurbishment, and road works (HKEPD, 2015). The classification of C&D waste varies with territorial contexts. For example, the U.S. Environmental Protection Agency (USEPA) (2018) categorizes C&D waste into seven types, including concrete, gypsum wallboard and plaster, brick and clay tile, asphalt concrete, asphalt shingles, wood products, and steel. C&D waste can also be classified into either inert or non-inert, depending on whether it has stable chemical properties or not (HKEPD, 2019). Inert materials include earth, soil, rocks, slurry, and broken concrete, while non-inert waste includes predominantly organic materials, such as packaging waste, bamboo, timber, and vegetation (HKEPD, 2015).

In major economies, C&D waste normally accounts for about one quarter of the total amount of solid waste being landfilled (Lu et al., 2017). Given the non-trivial volume and its adverse impacts, researchers and practitioners have spared no effort in managing the waste. Various measures have been devised. These measures can be summarized by the “3R” principle, i.e., reduce, reuse, and recycling. Reduction means to prevent C&D waste from being generated. It usually includes employing low waste technologies, minimizing waste by design, enacting amenable government legislations, and so on (Lu and Yuan, 2011; Wang et al., 2014). Reuse refers to the practice of using applicable materials again, either for the original purpose or a new purpose (Wang et al., 2010). For example, timber waste can be reused as interior fixtures and furniture whereas plastic waste can be reused for other purposes, including material protection (Tam, 2011). Recycling is the process of remanufacturing new materials with C&D waste being the raw material. Through recycling, C&D waste can be turned into new resources for use, such as recycled aggregates and bricks (Mak et al., 2019; Bao and Lu, 2020). Regardless of how well reduction and reuse are being conducted, certain amount of C&D waste will inevitably be generated. Under this circumstance, recycling is the final option before proceeding with disposal as a last resort.

C&D waste recycling can be divided into two types. Traditionally, C&D waste is transported to off-site and centralized recycling plants for treatment. While this off-site/centralized recycling is still popular, many economies are actively exploring the possibility of an on-site/decentralized recycling strategy where the waste is treated directly at source. Indeed, off-site recycling plants would adopt high technologies to achieve higher efficiency, such as easier on-site management (Vyncke and Vrijders, 2010). Burgoyne (2003) deemed on-site waste recycling as one of the most efficient recycling strategies for significantly saving transportation, storage and processing costs. Similarly, Earle et al. (2014) considered on-site recycling as a highly promising means of developing an economically viable waste recycling industry. However, some studies pointed out certain drawbacks of on-site recycling, such as the poor quality of recycled products produced due to limited availability of cleaning facilities as well as vulnerability to possible noise and dust pollution to residential areas nearby (Ulubeyli et al., 2017; Kühlen et al., 2016). Overall, on-site C&D waste recycling has great potential while the drawbacks cannot be neglected.

2. C&D waste recycling

The academy still lacks a consensus on what is meant by “C&D waste recycling” despite the fact that there are already some scattered studies trying to define it. For example, Blengini and Garbarino (2010) defined C&D waste recycling as a process where C&D waste is broken down into “homogeneous material for a lesser value application or introduction as replacement feedstock for remanufacturing of components”. Moreover, Kumbhar et al. (2013) stated that C&D waste recycling comprises collection, sorting, recycling, storage, transportation, and disposal. Basically, it is the process of turning waste into new resources for use. Its level depends on how the waste is finally used. If it is for low-level use such as backfilling or land reclamation, then C&D waste recycling may simply involve the process of on- or off-site sorting, or crushing waste into smaller pieces with reference to municipal solid waste recycling, e.g., curbside and drop-off recycling (Bohm et al., 2010). If it is for high-level use such as for producing new materials, C&D waste may undergo further sophisticated treatment which is similar to organic waste recycling, both with the assistance of advanced technologies (Guo et al., 2019).

Generally, C&D waste recycling can be divided into two types: off-site/centralized and on-site/decentralized recycling. Fig. 1 illustrates the relationship between on- and off-site recycling. When C&D waste is generated on-site, sorting/segregation is often conducted quickly to decide whether on-site reduction/reuse/recycling can be performed or not. Otherwise, the segregated waste, in particular the non-inert portion, will be landfilled, and the inert portion will be sent to public fill banks. In many cities, it is also possible to send mixed C&D waste to off-site sorting and/or recycling facilities for segregation and further treatment. Sometimes, off-site recycling facilities are located in designated eco-parks. These off-site facilities receive recyclable wastes from construction sites, off-site sorting facilities, or even public fill banks. The recycled materials manufactured will then enter the material market. Here, the focus is on-site recycling.

On-site C&D waste recycling refers to the process of treating waste directly on-site so as to minimize the nuisance associated with transporting it to off-site facilities. It can also instigate other benefits, such as cost reduction, minimization of greenhouse gas emissions, avoidance of traffic congestion, less dust and noise pollution, as well as easier on-site management (Vyncke and Vrijders, 2010). Burgoyne (2003) deemed on-site waste recycling as one of the most efficient recycling strategies for significantly saving transportation, storage and some processing costs. Similarly, Earle et al. (2014) considered on-site recycling as a highly promising means of developing an economically viable waste recycling industry. However, some studies pointed out certain drawbacks of on-site recycling, such as the poor quality of recycled products produced due to limited availability of cleaning facilities as well as vulnerability to possible noise and dust pollution to residential areas nearby (Ulubeyli et al., 2017; Kühlen et al., 2016). Overall, on-site C&D waste recycling has great potential while the drawbacks cannot be neglected.

3. Research methods

This study adopts a mixed-method approach by combing a case study with a series of site visits and semi-structured interviews. Intended to focus on a particular issue, feature or unit of analysis, case study is a qualitative research method incorporating multiple sources of evidence
Fig. 1. The relationship between on-site and off-site recycling.
promoting on-site C&D waste recycling in Hong Kong were being discussed.

3.3. Interviews

To garner more insights on the topic, the authors had conducted a series of semi-structured interviews. Being one of the most commonly adopted qualitative research methods, respondents of semi-structured interviews are often required to answer a series of predetermined though open-ended questions (Given, 2008). Its versatility has been widely recognized for probing into the opinions and perceptions of interviewees on complex issues with a view to deriving further information and clarification (McIntosh and Morse, 2015). The application of semi-structured interviews can help elicit the opinions of a wider range of stakeholders on barriers and facilitators of implementing on-site C&D waste recycling in Hong Kong.

Eighteen semi-structured interviews were conducted between November 2019 and May 2020 in Hong Kong. Table 1 displays the basic profiles of the interviewees. There are two basic criteria for selection of interviewees. One is that they are all highly experienced in C&D waste management and thus are expected to provide insightful opinions on the topic. The other is that the backgrounds of the interviewees are as diverse as possible, covering different streams of C&D waste management in Hong Kong for providing a rounder picture. The sample size of the semi-structured interviews is considered acceptable for this study as the goal of attaining data saturation has been generally accomplished. Some semi-structured interviews were conducted face-to-face, while others were through telephone due to the outbreak of the COVID-19 pandemic. All interviews were conducted in two rounds for the purpose of capturing richer information. During the first round, the questions were open-ended to develop an overall picture of C&D waste management in Hong Kong, e.g.:

- Could you please briefly introduce some C&D waste management practices (reduce, reuse, and recycling) being adopted in construction projects of Hong Kong?
- What is/are the usual practice(s) of contractors in Hong Kong in treating C&D waste generated from projects?
- From your knowledge, how many C&D waste recycling plants are there in Hong Kong?
4.1. Site space constraints

It is not surprising that on-site C&D waste recycling is being constrained by site space in Hong Kong. Being one of the most densely populated regions in the globe, the spaces of construction sites in Hong Kong are usually limited (Jaillon and Poon, 2010). Regarding on-site recycling of C&D waste, an initial stage is to conduct sorting to eliminate non-inert materials, otherwise the quality of the recycled products made from C&D waste would be adversely affected. Given that recycled products produced from on-site recycling occupy space which could otherwise have been allocated to other trades, planning and allocating stockpile space in advance for placement of recycled products manufactured on-site has become a prerequisite to on-site recycling. As explained by Interviewee 5:

"On-site C&D waste recycling in Hong Kong is more applicable to civil projects, such as tunneling and road projects, with larger site space available, in comparison to building projects where site spaces are usually smaller."

Interviewee 3 added:

"As far as I know, the redevelopment project of Kai Tak Airport had adopted on-site C&D waste recycling by introducing a complete set of equipment. Site space is quite abundant given that it was an airport previously."

As echoed by Interviewee 6:

"I know there is an ongoing tunneling project, the Tseung Kwan O–Lam Tin Tunnel project, which had introduced some equipment for on-site recycling. Usually, larger rocks are processed into smaller sizes during the tunnel drilling stage, which can be used for backfilling at the later stage. Moreover, tunneling projects usually have relatively larger space to allow for on-site sorting, placement of recycling equipment, and stockpile of recycled products."

Unlike civil projects, sites of building projects are often highly congested and more challenges need to be overcome in order to conduct on-site waste recycling. Interviewee 1 reflected that:

"For public housing projects in Hong Kong, we did have enough site space to conduct on-site recycling of C&D waste during the early years due to the relatively large scale of projects. In recent years, due to the shortage of public housing, although we have been initiating new projects, all such projects are in small scales. For example, we may add one or two more buildings on the edge of existing public housing estates where space would be just enough."

Interviewee 2 further added:

"In Hong Kong, due to the lack of space for stockpiling of inert C&D waste, some contractors prefer paying an additional cost to deliver the C&D waste to government waste disposal facilities even though they may have demand for inert waste at subsequent stage(s) for purposes such as site formation and backfilling. Usually, where such future need arises, they prefer buying new materials to catch up with the deadlines."

Generally, on-site C&D waste recycling is more applicable to public projects, which have to follow Environmental, Transport and Works Bureau Technical Circular (Works) No. 19/2005 whereby on-site sorting of C&D waste is rigorously regulated. The private sector is mainly involved in high-end real estate projects. Since Hong Kong is a highly developed and urbanized city, most recent real estate projects are redevelopment sites positioned in congested neighborhoods, leaving little space for on-site recycling. However, such practice is appealing to them. The Government’s technical circular can always serve as a good foundation for on-site recycling for the private sector.

This finding resonates with past studies pinpointing the barrier of site space constraints for on-site recycling. For example, Guyer (2018) and Lauritzen (2018) pointed out that on-site recycling requires allocation of space for the equipment and recycled products. Nevertheless, this study identified some new knowledge. For example, on-site recycling..."
recycling is more applicable to civil and public projects than private building projects. We also discovered that the situation of site space for recycling varies significantly from one site to another, even they are within the same city or district.

4.2. Narrow window of opportunity to trade recycled products

If one site implements on-site C&D waste recycling to produce recycled products, it is important to find outlets to receive these recycled products in time. Otherwise, it is highly likely that the recycled products will still be treated as secondary waste and transported to government waste disposal facilities. As emphasized by Interviewee 18:

In Hong Kong, all construction projects are strictly bound by contracts, where different working stages are connected very compactly with each other. This implies that the recycled products have to be sold out before the deadline of the project under the contract, otherwise huge penalty for late completion in the form of liquidated damages can be incurred.

Apart from that, various difficulties in trading recycled products have been identified from the interviews. Interviewee 6 explained:

Most stakeholders attach great importance to the quality of the construction projects. In Hong Kong, every construction material adopted for public projects must be accompanied with a “birth certificate” to prove the source of material. For example, if there is no certification for river sand, it is likely to be faked by sea sand, which would undermine the durability of the project. Similarly, it is somehow difficult to track the source and quality of the recycled products produced from on-site recycling, for which many stakeholders in Hong Kong may be reluctant to receive them for use.

Interviewee 15 echoed:

The most common recycled product from on-site recycling is recycled aggregate, which can be used for site formation and backfilling. However, if the sizes of the recycled aggregates are not appropriate enough to interlock with each other, causing the voids to become too large after site formation or backfilling, differential ground settlement of the structure built on the ground is likely to be resulted.

Basically, whether the recycled products can be traded in a timely manner is largely dependent on the communication between construction sites as the most common recycled product, i.e. recycled aggregate, is most likely to be demanded by construction sites. However, it seems that the communication between sites in Hong Kong is not so straightforward. As reflected by Interviewee 3:

In Hong Kong, we normally follow a principle called “cut and fill” in managing construction soil & residue in a single construction project, which means contractors are encouraged to self-balance construction soil & residue within the project. However, in most construction projects, construction soil & residue are either in surplus (cut > fill) or shortage (cut < fill). Under such circumstances, successful cases are still rarely seen.

Interviewee 4 further added:

We indeed expect matching of construction soil & residue between different construction projects (i.e. sites in surplus supply sharing their soil & residue with sites in need of soil & residue) can be achieved more easily for the sake of relieving the pressure of government waste disposal facilities, which will be in full capacity in just a few years’ time. Therefore, we will pass some information on the possible suppliers and demands to contractors of public projects. However, such information is gathered based on our personal network with limited effect.

From the above discussion, it can be envisaged that stakeholders are likely to encounter similar obstacles during the trading of other recycled products. Obviously, it is almost impossible to achieve real-time trading by just relying on personal networks, thus calling for the development of more effective measures. The finding presents some new knowledge. Previous studies have sporadically mentioned the similar barrier. For example, Silva et al. (2017) suggested using on-site recycling when C&D waste can be processed and used on the same site. Richardson (2013) expressed the concern that the creation of a continuous supply chain for the recycled products may be a barrier to on-site recycling. On the top of previous studies, ours provides greater details in the context of Hong Kong, such as the concern about project deadline, the concern about the quality of recycled products, and asymmetric information between demander and supplier.

4.3. Vulnerable business case

The balance between cost and benefit is always one of the most important criteria for decision making pertinent to recycling or otherwise. This is particularly true for stakeholders in Hong Kong in deciding whether on-site recycling should be adopted. As indicated by Interviewee 8:

I had the experience of learning the lessons from Shenzhen in mainland China where on-site recycling is really vigorous. Generally, the cost of on-site recycling covers the fixed cost of purchasing the equipment, regular maintenance cost, and labor cost for equipment operation. The fixed cost of purchasing the simplest equipment, mobile crusher, which can turn the C&D waste into recycled aggregates of different sizes is normally about HKD 1 to 2 million if imported from overseas.

Interviewee 8 further added:

Considering the practical situation of Hong Kong, I think a complete set of supportive equipment, including conveyor belts and concrete batching machines, is required for the purpose of conducting on-site recycling, for which additional cost may be incurred.

In terms of the maintenance cost, Interviewee 9 reflected:

The maintenance cost mainly includes the fuel cost of driving the equipment and the cost of replacement of broken component(s). Usually, the equipment is driven by diesel. With the reference from Shenzhen, for normal equipment with a daily (8 h) treatment capacity of about 1000 tons, the fuel cost is about HKD 700 to 800 per day. Considering the price level difference between Shenzhen and Hong Kong, the fuel cost could be doubled in Hong Kong.

Interviewee 9 further explained:

Regarding the cost arising from replacement of broken component(s), indeed, the components themselves are inexpensive. However, as many components may have to be imported from overseas, this may lead to project delay for a few days in the worst-case scenario. Therefore, the time cost is much more expensive, particularly in Hong Kong.

Additionally, the labor cost of operating the equipment would discourage stakeholders from practicing on-site C&D waste recycling in Hong Kong. Interviewee 10 reflected:

Actually, on-site recycling is not a labor-intensive work. It may just demand 6 to 7 workers to do some supportive work, such as on-site sorting and machine operation. However, the wages of construction workers in Hong Kong are too high. The average daily wage of a general construction worker is almost HKD 1000.

Contrastingly, the benefit of implementing on-site recycling in Hong Kong is uncertain. The most attractive benefit is that it can help stakeholders to reduce the cost of legal disposal under the CWDCS. Interviewee 3 explained:
As the disposal charges are getting more expensive, many stakeholders do have the economic intention to explore how to save the cost. On-site recycling is a good alternative, but the premise is that the recycled products can be traded timely. Otherwise, disposing C&D waste at government waste disposal facilities may still be unavoidable. This uncertainty poses stakeholders a risk.

Generally, implementing on-site recycling in Hong Kong is relatively costly while the potential benefits remain in doubt, thereby hindering stakeholders from introducing on-site recycling. The findings are new to existing literature as it is the first study of this kind to emphasize the cost of on-site recycling with such detailed data provided as most studies just attach the importance to the benefits of on-site recycling, such as Silva et al. (2017), Siddique and Cachim (2018), and Hoang et al. (2020).

4.4. Lack of support from off-site recycling

Although on-site recycling is perceived as promising with a series of demonstrated benefits, it is not suitable to stand alone but should better be supported by off-site recycling as a backup (Bao and Lu, 2020). However, the development of Hong Kong’s off-site recycling has long been stagnant due to the lack of policy support from the government. Interviewee 13 said:

Currently, there are only three off-site recycling plants in Hong Kong, one for recycled concrete blocks and pavers, one for recycled aggregates, and another for recycled paving blocks. The development of off-site recycling in Hong Kong is seemingly stagnant during the past decade.

Interviewee 14 further added:

Even for these three recycling plants, the type of their recycled products is rather limited, with each focused on only one or two, which is far lagging behind their counterparts in Shenzhen. Moreover, these recycling plants are all established by large groups in Hong Kong, with C&D waste recycling being just one of their businesses. With the main purpose of establishment being undertaking social responsibility, there is no commercial gain from operating such recycling plants.

The dilemma of off-site recycling in Hong Kong can be attributed to the lack of policy support from the government. As indicated by Interviewee 13:

Currently, two most important initiatives provided by the government are land rental cost reduction and promotion of the local green building rating system of BEAM Plus. The first initiative refers to the industrial park called “Ecopark” established by the government and exclusively designed for waste recycling and environmental engineering, which offers recyclers long-term land at affordable rents together with a whole package of facilities.

Interviewee 13 further added:

The second initiative is that the government has been strongly encouraging stakeholders to apply for certification of Hong Kong’s green building rating system, BEAM Plus, by providing them with gross floor area concessions where the adoption of recycled products is an important criterion.

Despite the fact that the government has provided some incentives for C&D waste recycling plants, it is utterly inadequate to sustain the economic viability of these recycling plants. Interviewee 14 explained:

The vast majority of the recycled products are purchased by the government but at very low market prices as the construction materials made from virgin materials are even cheaper despite the fact that the processing cost of recycled products is particularly high.

A sustainable C&D waste recycling industry should allow the coexistence of on- and off-site recycling for two reasons. First, when on-site recycling cannot treat all the C&D waste or recycled products cannot be traded in time, then off-site recycling plants can play the role of temporary storage or further treatment. Second, the recycled products produced from the recycling plants are usually with more varieties and of higher quality, which can provide customers with greater flexibility and further promote the development of the recycling industry. Therefore, the lack of support from off-site recycling is also a barrier impeding the deployment of on-site recycling in Hong Kong.

By identifying this barrier, this study is one of the very few studies that articulates the nexus between on- and off-site recycling. Although the study conducted by Bao and Lu (2020) also mentioned that on- and off-site recycling are mutually supplementary in the context of Shenzhen, China as an emerging economy, this study is novel as it is the first to elaborate the nexus between the two in the context of Hong Kong wherein C&D waste management systems have been well-developed.

4.5. Lack of government policy support

Lastly, the lack of policy support from the government is identified as another barrier to promoting on-site recycling in Hong Kong. Interviewee 10 said:

On-site recycling will incur a certain level of noise and dust pollution, which is against the regulations in Hong Kong, such as Air Pollution Control Ordinance and Noise Control Ordinance, both of which are enforced by HKEPD. To conduct such industrial activities, e.g. on-site recycling, it is a must to apply for a license from the government.

However, the process of applying for that license is also a nuisance. Interviewee 10 further added:

Applying for such a license is extremely time-consuming, involving a series of procedures, such as control measures, monitoring, consultant engagement, and accreditation for approval. The whole process, which possibly takes about 6 to 12 months, has prevented stakeholders from further exploring on-site recycling.

Moreover, Interviewee 14 also recognized the importance of the government’s role in promoting on-site recycling in Hong Kong. He emphasized:

I strongly support promoting on-site C&D waste recycling in Hong Kong as it aligns with the core value which Hong Kong has long been adhering to - efficiency. To maximize the value of on-site recycling, the government should take the lead to first introduce on-site recycling in some large-scale public projects. However, one recognized drawback that the government has been widely criticized for is its conservative attitude towards environmental protection.

Interviewee 13 also echoed:

For most of the time, to foster the birth and development of a new thing, you may need some courage to go through the process of trial and error first for further improvement. If you intend to seek consent from everyone before decision making, then it is highly likely that the opportunity will be missed. Unfortunately, this is Hong Kong’s tradition.

Additionally, as on-site recycling is often conducted in residential areas, particularly in highly urbanized cities like Hong Kong where the boundary between urban and rural areas is blurred, the noise and dust pollution arising from on-site recycling will possibly arouse the disgust of residents in the vicinity. As reflected by Interviewee 18:

Influenced by the western mindset of “not in my back yard”, Hong Kong residents are extremely antipathic to some “dirty” activities in the vicinity of their residences that may affect their quality of life. Therefore, the long-standing culture of complaint may arouse resistance to promoting on-site recycling in Hong Kong. Generally, I think the Hong Kong society
lacks such inclusiveness to accept on-site recycling from a holistic point of view.

Either for the violation of existing regulations, or the culture of complaint, the lack of policy support from the government is definitely an intractable barrier to promoting on-site recycling in Hong Kong. Although there have been some scattered studies stating that on-site recycling is a “newcomer” in the field of C&D waste management (Pacheco-Torgal and Ding, 2013; Richardson, 2013; Tam, 2011), these studies have overlooked the role of support from the government. Contrastingly, in this study, the barrier of lack of government policy support is compelling as it is probably the first study to indicate the role of the government in promoting on-site recycling in Hong Kong with its uniqueness, such as the mindset of “not in my backyard” and the culture of complaint.

5. Facilitating measures to boost on-site recycling

Based on the barriers identified, a series of targeted facilitators are proposed to promote on-site C&D waste recycling in Hong Kong (see Fig. 3). Each facilitator is detailed separately below.

5.1. Developing customized on-site recycling equipment

The current on-site recycling equipment available in the market (see Fig. 4) may not fit into Hong Kong’s context mainly for two reasons. First, due to the limited site space, the size of the existing on-site recycling equipment is likely to be oversized for Hong Kong. Second, the level of noise and dust pollution caused by the current equipment is relatively high, which is against the regulations and likely to arouse the disgust of the residents in Hong Kong. Therefore, to overcome these barriers, it is sensible to develop customizable on-site recycling equipment to adapt to Hong Kong’s context. The customized on-site recycling equipment is supposed to be smaller in size, more environment-friendly, and smarter for operation. Interviewee 8 suggested:

I think the government can increase investment specifically for research and development (R&D) of the on-site recycling equipment. For example, the government can establish a sort of so-called “recycling fund” for local tertiary institutions to develop the equipment.

Interviewee 9 further explained:

My expertise can tell that the development of such kind of customized on-site recycling equipment for Hong Kong should be technically sound. The equipment is not only beneficial to Hong Kong, but also applicable to other regions around the world, such as Singapore. It is definitely worthy of being explored.

One may argue that Hong Kong overall is a small market which may not allow an economy of scale for such on-site recycling equipment customization. The point is not for Hong Kong only. There are many other cases around the world, which may not always have the luxury of a spacious site for large-scale on-site recycling equipment.

Additionally, it is crucial to fully consider the time efficiency of the on-site recycling equipment as an important criterion during its development. Particularly in some highly developed economies like Hong Kong, the first priority is to renovate the old structures rather than replacing with new ones. The normal practice is that the structure is still under normal operation alongside the renovation. In such cases, to minimize the disruption of renovation activities to the normal operation of the structure, the importance of the time efficiency of the on-site recycling equipment is suggested to be highly emphasized during its development.

5.2. Establishing a demand-supply information sharing platform

For the barrier of the narrow timing for trading recycled products, an effective facilitator is to establish a demand-supply information sharing platform in Hong Kong. Such a platform can help alleviate the longstanding issue of asymmetric market information in the recycled products trading market, which can further boost the free circulation of recycled products. There have been some practices to establish such a platform.

Fig. 3. A summary of the barriers and facilitators of on-site recycling in Hong Kong.
Notably, the Shenzhen Government established an information sharing platform specifically for construction soil & residue and recycled products in 2018. Yet, the effect of this platform is unsatisfactory. Interviewee 16 reflected:

*Only qualified members of Shenzhen's construction industry can access this platform. After the platform was put into operation, they realized that it is rather difficult to match the supply and demand due to limited options available, and now most people have stopped using the platform.*

Therefore, with reference to the defective case in Shenzhen, it is important to lower the threshold of accessing this platform in order to attract more potential suppliers and demanders of recycled products. Contrastingly, the platform for construction soil & residue established by the Japanese government seems more successful. Interviewee 17 reflected that:

*The platform in Japan requests all the project managers to report the status of their construction projects as detailed as possible, such as identity of construction soil & residue supplier/demander, the quantity of the construction soil & residue supplied/demanded, the quality of the construction soil & residue supplied/demanded.*

This successful experience learned from Japan can be applied to Hong Kong's platform if it intends to be established. All the information on the recycled products should be as detailed as possible and updated timely in the platform to increase the possibility of matching supply and demand successfully. Furthermore, to increase public credibility, the Hong Kong Government should play a pivotal role in monitoring and maintaining the platform by continuously injecting funds.

### 5.3. Developing more thriving off-site recycling

Hong Kong’s stagnant development of off-site recycling has significantly hindered the promotion of on-site recycling from a certain stance. Although the efforts devoted by the government have been well acknowledged in developing off-site recycling, such as rental cost reduction and promotion of REAM Plus, there is still a large room for improvement. For example, the market for recycled products should be further extended to cover more private projects. To achieve this purpose, a key strategy is to certify these recycled products. Therefore, some clients do not think the quality of the recycled products is reliable and are reluctant to use them.

Therefore, the government is suggested to designate a professional third-party, such as the Hong Kong Construction Industry Council and Hong Kong Productivity Council, to devise the standards for recycled products. If the recycled products can be certified with a set of normalized standards, this information can also be incorporated into the supply-demand information sharing platform, which can be much helpful to demanders. Moreover, to overcome the barrier of the uncompetitive prices of recycled products due to high handling costs, the government can implement some supportive policies, such as tax reduction for the adoption of recycled products or tax imposition for the use of virgin materials. Furthermore, to increase the competitiveness of Hong Kong’s off-site recycling plants, more R&D funds can be established to stimulate them to investigate the cutting-edge technologies of producing recycled products accompanied with recognition of the limited types of existing recycled products produced by them. More research seminars are also suggested to be organized between Hong Kong and Shenzhen for knowledge exchange and discussion on C&D waste recycling.

### 5.4. Providing more government support

Providing more government support is an indispensable facilitator for promoting on-site recycling in Hong Kong. First, the government should simplify the process of applying for the license required for conducting on-site recycling. Interviewee 12 said that:

*If the government can release such a positive sign by simplifying the application procedures of the license, I believe more stakeholders would desire to practice on-site recycling as it is really adaptable to the context of Hong Kong.*

Moreover, it is important for the government to consider the backup of on-site recycling such that even if there are difficulties in trading the recycled products produced from on-site recycling timely, there are still outlets available for storing them temporarily to avoid sending them to government waste disposal facilities. Interviewee 7 recommended that:

*I am considering whether it is possible for the government to allocate a certain area of land from the public domain as the backup of on-site recycling. If unfortunately, the recycled products cannot be traded in*
time, the government can still allow the stakeholders to rent the land at an affordable cost.

Furthermore, to widely promote on-site C&D waste recycling in Hong Kong, the government can consider adopting some more effective but extreme strategies. Interviewee 6 explained that:

In recent years, there has been an emerging trend of adopting the concept of “zero waste site” in some developed countries. Theoretically, the government can actually do more through legislation. For example, we can limit the amount of waste being sent from construction sites to government waste disposal facilities, forcing stakeholders to adopt either on-site or off-site recycling. However, we have to evaluate the policy implications and balance the interests of different parties, which is not easy in Hong Kong.

Notably, in pursuit of a new initiative like on-site recycling, the path will never be as straightforward as expected. It needs more courage and strong determination to reform, as there is no making without breaking. Similarly, to promote on-site recycling in Hong Kong, the government should not begin to consider it until all the parties are well prepared as it is almost impossible in Hong Kong.

6. Conclusion

Issues pertinent to C&D waste have plagued the global construction industry for long. Great importance has been attached to C&D waste recycling, which has long been relied on the traditional off-site means. However, such off-site means have seen many drawbacks in various regions, which have driven researchers and practitioners to explore on-site recycling options. However, there are a series of barriers preventing on-site recycling from being widely adopted, and these barriers are yet to be fully explored, particularly in a specific context. Therefore, this study aimed to investigate the barriers and facilitators of promoting on-site C&D waste recycling in Hong Kong using a mixed-method approach.

The results indicate that the barriers include (1) site space constraints, (2) narrow timing of trading recycled products, (3) vulnerable business case, (4) lack of support from off-site recycling, and (5) lack of policy support from the government. To overcome such barriers, a series of facilitating measures are also proposed, including (1) vigorously developing customized on-site recycling equipment, (2) effectively establishing a regional information sharing platform, (3) further developing off-site recycling, and (4) continuously providing additional government support. This study can provide useful references to others in developing their own C&D waste management strategies by rationally deploying on- and off-site recycling.

There are mainly three limitations in this study. First, as sites adopting on-site recycling are rather rare in Hong Kong, this study chose to conduct site visits and interviews to retrieve experienced practitioners' "wish-list" as the research data. If possible, in-depth investigation into real-life on-site recycling cases should be arranged in future with a view to providing more intuitive experiences. Second, this study qualitatively identified five barriers of implementing on-site recycling in Hong Kong, but the relative importance of each barrier is still unclear, which could be difficult for policy-makers to devise more targeted facilitators. Therefore, it is suggested to further this study to quantitatively assess each barrier by applying some numerical methods, e.g., structural equation modelling. Third, this study only focuses on on-site recycling, but a sustainable C&D waste recycling should allow the coexistence of on- and off-site recycling. Future studies taking on- and off-site recycling as a whole are highly desired to have a holistic and dynamic view.

CRediT authorship contribution statement

Zhikang Bao: Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft. Wendy M.W. Lee: Data curation, Formal analysis, Writing - review & editing. Weisheng Lu: Funding acquisition, Conceptualization, Supervision, Formal analysis, 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.

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