Innovative Management of Construction Waste in Hong Kong

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ABSTRACT

The generation of construction waste is inevitable in coping with the rapid economic growth of municipalities worldwide. Proper construction waste management is critical, as it contributes a significant proportion of waste materials disposed of in landfills. The situation is particularly acute for economies such as the Hong Kong Special Administrative Region (HKSAR), China where land resources for landfilling are scarce. Most economies would thus maximize the reuse and recycling of construction waste to minimize the quantity of construction waste disposed of in landfills. The Government of the HKSAR adopted an innovative approach using information and communications technology (ICT) to achieve the goal. In addition to the quantity maximization and quality control of inert materials in construction waste for reuse and recycling, the approach also prevents illegal dumping of construction waste. Details of the approach and implementation are presented in this paper.

1 INTRODUCTION

Coping with the economic development and living quality improvement, demolition of old facilities and construction of new facilities are inevitable in most economies. Because of demolition and construction activities, tremendous amount of construction and demolition waste is generated. If such waste is disposed of in landfills, not only it is a waste of natural resources, it is also a waste of landfill space. If land resources available for landfills are scarce, the situation becomes more acute. However, the slowing down of demolition and construction activities may hinder the economic development of an economy. The need for proper measures to reduce the amount of construction and demolition waste is evident. The most effective measures to achieve the goal is to increase the amount of reuse and recycling of construction and demolition waste. From a government policy standpoint, incentives must be given to the stakeholders of the construction industry to encourage such activities and penalties be given to those who choose not to perform such activities deliberately. Moreover, monitoring of construction site activities is required to ensure that the incentives have not be abused and illegal activities have not been performed to avoid the penalties. An approach using information and communications technology (ICT) to accomplish these objectives is presented in this paper.

2 BACKGROUND

The Environmental Protection Department (EPD) of the Government of the HKSAR broadly classifies the waste generated in the HKSAR into 8 categories: (1) municipal solid waste; (2) food waste; (3) construction waste; (4) chemical waste; (5) clinical waste; (6) waste cooking oils; (7) special wastes include animal

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carcasses, livestock waste, radioactive waste, grease trap waste, sewage sludge and waterworks sludges; and (8) other solid waste comprises dredged mud and excavated materials.

The Waste Disposal (Charges for Disposal of Construction Waste) Regulation (Cap. 354N) of the law of the HKSAR defines "construction waste" as *any substance, matter or thing that is generated from construction work and abandoned, whether or not it has been processed or stockpiled before being abandoned, but does not include any sludge, screenings or matter removed in or generated from any desludging, desilting or dredging works.* It is usually a mixture of surplus materials from site clearance, excavation, construction, refurbishment, renovation, demolition, and road works. In the HKSAR, the inert materials in construction waste are denoted as "public fill". Public fill includes debris, rubble, earth, and concrete suitable for land reclamation and site formation. When properly sorted, materials such as concrete and asphalt can also be recycled for use in new construction. The remaining non-inert substances in construction waste include bamboo, timber, vegetation, packaging waste, and other organic materials. In contrast to public fill, non-inert substances in construction waste are unsuitable for land reclamation. After reusable/recyclable items have been extracted, these non-inert substances are disposed of in landfills. In this paper, these non-inert substances disposed of in landfills are denoted as "C&D waste" (Construction and Demolition waste) to distinguish themselves from the reusable "public fill". Therefore, maximization of the quantity of public fill and the extraction of reusable/recyclable items from non-inert substances of construction waste is necessary for proper construction waste management. Disposal of public fill at public fill reception facilities and mixed construction waste at sorting facilities have been the primary approaches for construction waste management implemented by the Government of the HKSAR.

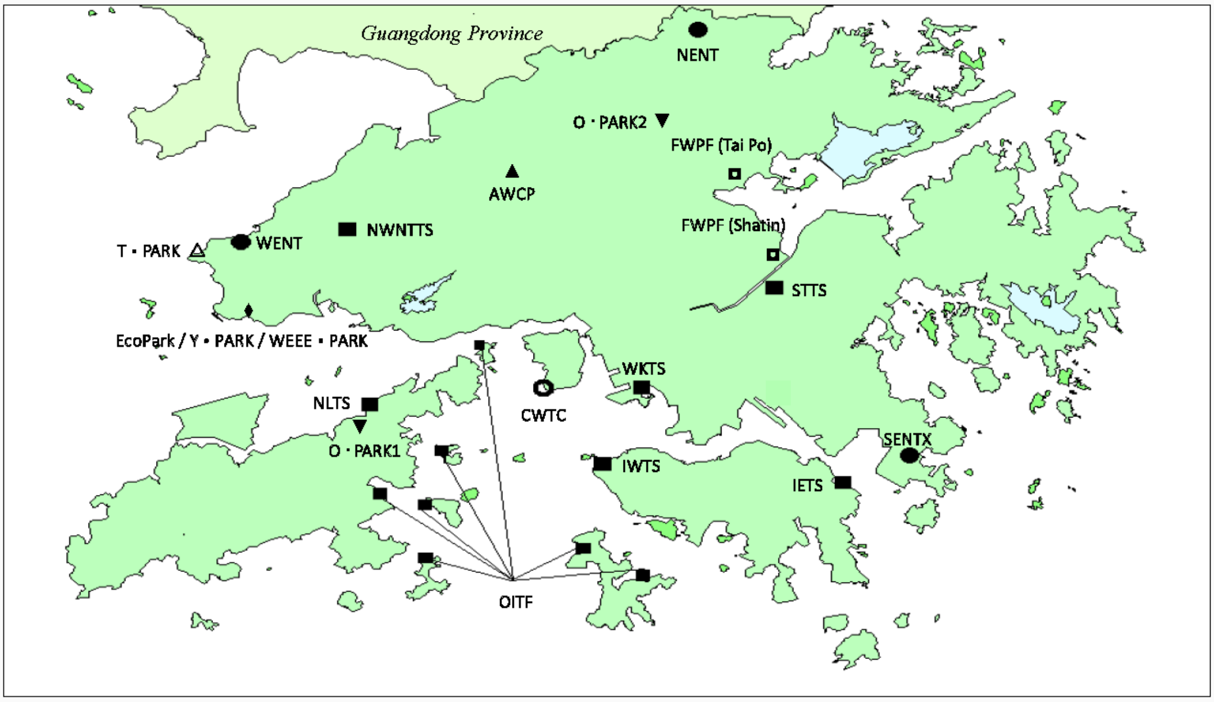
Public fill reception facilities managed by the Civil Engineering and Development Department (CEDD) of the Government of the HKSAR include: (1) public filling areas – designated parts of a development project that accept public fill for reclamation purposes, (2) public filling barging points – strategically located public fill reception facilities that utilize barges to transport public fill, (3) public fill stockpiling areas – newly reclaimed land where public fill is temporarily stockpiled as the surcharging material to accelerate the consolidation settlement process, (4) fill banks – areas allocated for temporary stockpile of public fill for future use, and (5) C&D material recycling facilities – facilities process hard inert materials into recycled aggregates and granular materials for use in construction projects. Four public fill reception facilities are now in operation: Tseung Kwan O Area 137 Fill Bank, Tuen Mun Area 38 Fill Bank, Chai Wan Public Fill Barging Point, and Mui Wo Temporary Public Fill Reception Facility, as shown in Figure 1.

The historical generation rates of public fill and C&D waste are depicted in Figure 2. The generation rate of public fill is the sum of the public fill stored at public fill reception facilities for future use and that reused directly in construction projects. C&D waste includes waste concrete generated in concrete batching plants and disposed of in landfills. It can be observed in Figure 2 that more than 90% of construction waste generated in the HKSAR is recovered as public fill stored at public fill reception facilities or reused directly in construction projects.

The Waste Disposal (Charges for Disposal of Construction Waste) Regulation (Cap. 354N) came into operation on 1 December 2005. Construction waste producers, such as construction contractors, renovation contractors, or premises owners, must open a billing account with the EPD and pay for the construction waste disposal charges before using government waste disposal facilities, i.e., the Charge Scheme. The main contractor undertaking construction work under a contract with a contract sum of $1 million or above must open a billing account solely for the contract. The charge rates, as promulgated by the law, are tabulated in Table 1. It can be observed that the charge rates provide significant financial incentives for construction waste producers to reduce, sort, and recycle construction waste to preserve our valuable landfill space.

3 WASTE MANAGEMENT CHALLENGES IN THE HKSAR

Although more than 90% of construction waste generated in the HKSAR is recovered as public fill, the remaining C&D waste still contributes approximately 25% of the solid waste deposited in landfills, as depicted in Figure 3. Landfill space shortage and the lack of proper operation of the Charge Scheme remain problems facing the Government of the HKSAR. While expansions for the West New Territories (WENT) Landfill and North East New Territories (NENT) Landfill are underway, the additional capacity is projected to accommodate the waste disposal demands of the HKSAR only through the 2040s.



Landfill	●	WENT	- West New Territories Landfill
		SENTX	- South East New Territories Landfill Extension (1)
		NENT	- North East New Territories Landfill
RTS	■	IETS	- Island East Transfer Station (2)
		IWTS	- Island West Transfer Station (2)
		WKTS	- West Kowloon Transfer Station (2)
		OITF	- Outlying Islands Transfer Facilities (2)
		NLTS	- North Lantau Transfer Station (2)
		STTS	- Shatin Transfer Station (3)
		NWNTTS	- North West New Territories Transfer Station (3)
Waste treatment / recycling facilities	○	CWTC	- Chemical Waste Treatment Centre
	▲	AWCP	- Animal Waste Composting Plant
	◆	EcoPark / Y · PARK (4) / WEEE Treatment and Recycling Facility (WEEE · PARK)	
	▼	Organic Resources Recovery Centre (O · PARK) (5)	
	△	Sludge Treatment Facility (T · PARK) (6)	
	◘	Food Waste Pre-Treatment Facilities under Food Waste / Sewage Sludge Anaerobic Co-digestion Trial Scheme	

Notes :

1. From 21 November 2021 onwards, SENTX has replaced SENT to accept C&D waste.
2. Waste from IETS, IWTS, WKTS, OITF and NLTS was transferred to WENT by sea.
3. Waste from STTS and NWNTTS was transferred to NENT by road.
4. From June 2021 onwards, Y · PARK has commenced operation to convert suitable yard waste into various recyclable products such as wood chips, wood boards and wood beam through the processes of sorting, cutting, shredding, etc.
5. O · PARK1 at Siu Ho Wan and O · PARK2 at Sha Ling have commenced operation in July 2018 and March 2024 respectively to convert food waste into biogas for electricity generation whilst the residues from the process be produced as compost for landscaping and horiculture use.
6. From April 2015 onwards, dewatered sewage sludge from major sewage treatment works managed by Drainage Services Department has been treated by incineration at T · PARK, and the residue and ash of incineration have been disposed of at WENT.

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Figure 1: Waste management facility in the HKSAR (after EPD 2024)

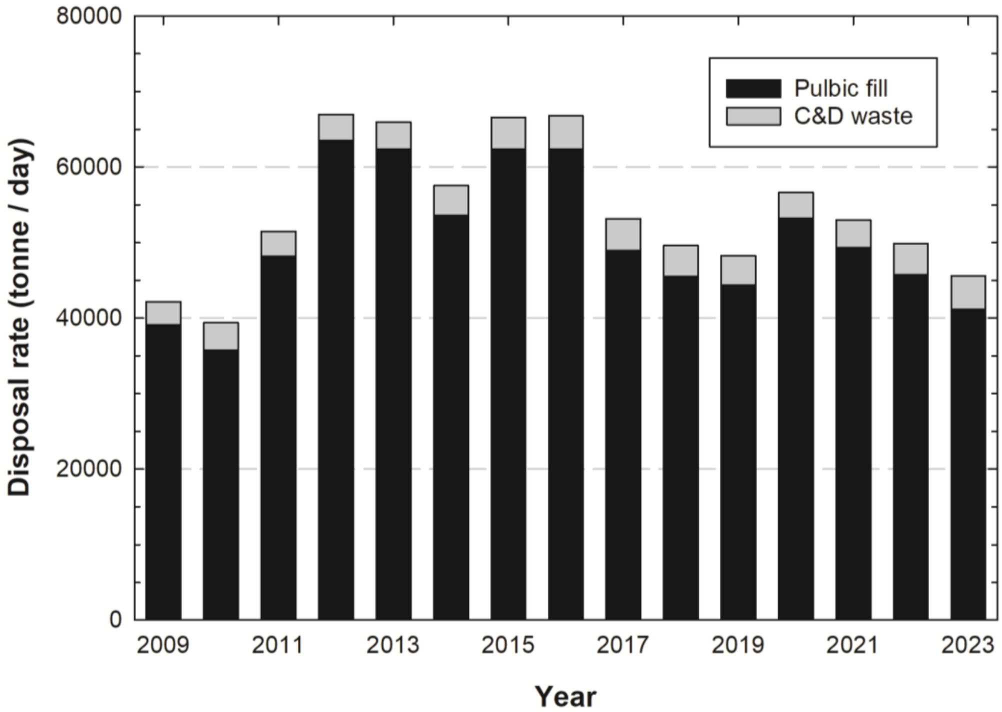

Figure 2: Historical generation rates of public fill and construction waste in the HKSAR

Table 1: Charge rates for construction waste disposal at different government waste disposal facilities

Government waste disposal facilities	Type of construction waste accepted	Charge / tonne
Public fill reception facilities	Consisting entirely of inert materials	$71
Sorting facilities	Containing more than 50% by weight of inert materials	$175
Landfills	Containing not more than 50% by weight of inert materials	$200
Outlying islands transfer facilities	Containing any percentage of inert materials	$200

3.1 Shortage of reclamation sites and landfill space

The total land area of the HKSAR, China, is 1,114.57 km^2, accommodating a population of 7.53 million (as of mid-2024) and a world-class financial, trading, and business center. However, most of the population is housed in 215 km^2 of urban development because of steep natural terrain and stringent planning controls. Over 400 km^2 of land have been designated protected areas, including country parks, special areas, and conservation zones. The concentration of population and economic activities in such a small area exert intense pressure on the environment. Thus, proper waste management is a significant challenge facing the Government of the HKSAR.

In May 2013, the then Environment Bureau of the Government of the HKSAR published the *Hong Kong blueprint for sustainable use of resources 2013–2022*, which develops a comprehensive strategy, targets, policies, and action plans for waste management for the upcoming 10 years to tackle the waste crisis of the HKSAR. It aims to reduce the per capita municipal solid waste (MSW) disposal rate by 40% by 2022. It proposes policies and actions in three areas to achieve the goal: (1) to undertake multiple and concurrent actions to drive behavioral change to reduce waste at source through policies and legislation, (2) to roll out targeted territory-wide waste reduction campaigns, and (3) to allocate resources to enhance waste-related infrastructure. Examples of newly launched waste-related infrastructure projects include the West New Territories Landfill Extension (WENTX) in Nim Wan, Tuen Mun, and Integrated Waste Management

Facilities (IWMF) Phase 1 and 2 on an artificial island near Shek Kwu Chau and at the middle ash lagoon at Tsang Tsui, Tuen Mun, respectively.

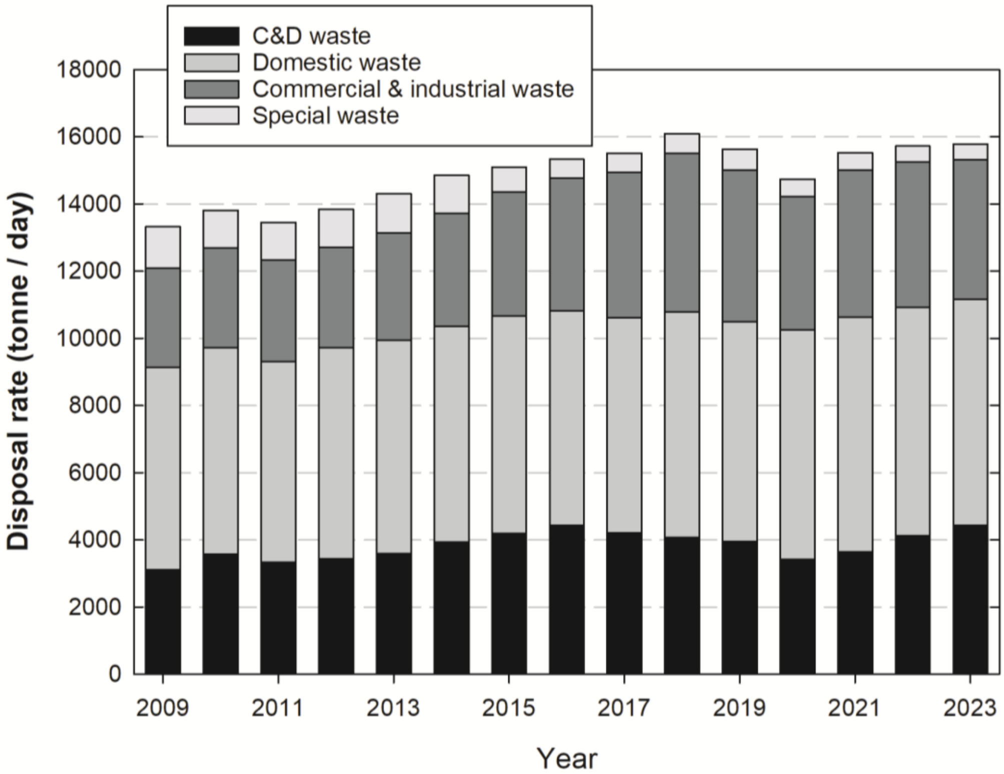

Figure 3: Historical disposal rate of total solid waste at landfills in the HKSAR

In February 2021, building on *Hong Kong: Blueprint for sustainable use of resources 2013-2022*, the then Environment Bureau announced the *Waste blueprint for Hong Kong 2035* (the Blueprint) to set out the vision of "Waste Reduction • Resources Circulation • Zero Landfill." The Blueprint outlines the strategies, goals, and measures to tackle the waste management challenge up to 2035. Under the vision, the Government will work with the industry and the community to move towards two primary goals. The medium-term goal is to gradually reduce the per capita MSW disposal rate by 40-45% and raise the recovery rate to approximately 55% by implementing MSW Charging, while the long-term goal is to move away from the reliance on landfills for direct waste disposal by developing adequate waste-to-energy facilities. The Government of the HKSAR will promote actions in six key areas to achieve these goals: (1) waste reduction, (2) waste separation, (3) resource circulation, (4) industry support, (5) innovation and cooperation, and (6) education and publicity, leading the advancement of various policies and measures and building a circular economy and a sustainable green living environment.

The HKSAR is running out of reclamation sites and landfill space to handle construction waste. If public fill storage capacity is insufficient and construction waste reduction measures are ineffective, more public fill will probably be diverted to landfills for disposal, and the useful lives of landfills will be further shortened. For sustainable development, the HKSAR cannot rely solely on reclamation sites to accept most of the inert construction waste. Therefore, the need for reduction, reuse, and recycling of construction waste is evident. Nevertheless, there will still be a substantial amount of materials that require disposal, either at public fill reception facilities or in landfills.

3.2 *Quality control of public fill*

It can be observed in Table 1 that there are significant financial incentives for main contractors to dispose of their construction waste at public fill reception facilities or sorting facilities in lieu of landfills. However, they may have to adjust their work processes to sort the inert materials from their construction waste. As a result, the quantity of construction waste disposed of in landfills has decreased tremendously since 2006. However, the disposal quantity fluctuates with the economy and the number of ongoing construction projects.

The Charging Scheme requires that construction waste disposed of at public fill reception facilities be 100% inert materials, i.e., rock, boulder, earth, soil, sand, concrete, asphalt, brick, tile, masonry, or used bentonite. Even construction waste disposed of at sorting facilities must contain more than 50% by weight of inert materials.

During large-scale construction projects, trucks continuously deliver waste to public fill reception or sorting facilities. Moreover, the numbers of public fill reception and sorting facilities are significantly less than the number of construction sites in progress. Therefore, each government waste disposal facility must support many construction sites simultaneously. It is challenging for the resident site staff at these facilities to determine the quality of construction waste, i.e., the proportion of inert materials in the construction waste delivered in trucks. Some unethical contractors may even mix other waste with construction waste to dispose of at public fill reception or sorting facilities to reduce waste disposal costs. However, verifying its original proportion of inert materials is impossible once the construction waste is dumped at these facilities. Mixing non-inert substances with public fill would jeopardize the future use of public fill as construction materials for new construction projects. Therefore, verifying the quality of construction waste is a practical implementation challenge of the Charging Scheme.

3.3 Quantity control of public fill

As tabulated in Table 1, the main contractor is charged by the weights of construction waste disposed of at different government waste disposal facilities. Therefore, it is necessary to determine the weights of construction waste disposed of at different government waste disposal facilities and to register the proper charges to the billing accounts of the main contractors efficiently and accurately. The issue is further complicated as the main contractor of a site may operate many trucks to deliver construction waste to different public fill reception facilities, sorting facilities, or landfills simultaneously depending on the proportion of inert materials in the truckload of construction waste and the progress of the construction work on site. Moreover, a main contractor may also have separate billing accounts for different construction sites as the legislation requires. As a result, it is always a challenge to keep track of the quantities of construction waste of different proportions of inert materials delivered to different facilities by a main contractor accurately.

3.4 Land filling and fly-tipping

Construction waste is sometimes dumped illegally on government or private land without the consent of the concerned landowners. Even the dumping activities are on private land with the consent of the concerned owners, they are still in breach of the town planning, environmental, buildings, drainage, public health, or public safety legislation if such activities contravene the statutory plans, cause adverse environmental impacts or hygiene problems, or result in unstable slopes affecting the safety of adjacent buildings or land. There are also cases where the dumped construction waste becomes an eyesore and has caused environmental degradation in the rural New Territories. There is increasing public concern and calls for the government to extend further control on such irresponsible and illegal activities and to enhance inter-departmental coordination in tackling the problem. Such illegal activities can be broadly classified into two types: (1) land filling, and (2) fly-tipping.

Land filling refers to dumping construction waste as fill material on land to raise the ground level elevation. It also includes filling watercourses, such as stream courses, ponds, etc. Land filling activities are usually carried out for purposes of filling up ponds; leveling off uneven ground surfaces; forming sites for development, e.g., landscaping, roads, village houses, car parks, or recreation facilities; stockpiling in the form of a fill bank; or placing construction waste onto land as dumping ground. Illegal land filling takes place when it contravenes the relevant legislation or is carried out on land without proper authorization of government authorities and/or consent from the land owners/occupiers.

Fly-tipping refers to the illegal dumping of construction waste, often associated with haphazard and casual dumping from vehicles. Fly-tipped construction waste is usually scattered, left in heaps and in small quantities. Most illegal dumping activities occur in urban built-up areas and rural locations with good vehicular access, such as at curbsides or side roads branched off from main roads.

4 THE REAL-TIME ICT SOLUTIONS

Given the practical implementation problems of the Charging System, real-time ICT management systems were developed and implemented simultaneously at public fill reception facilities, sorting facilities, and construction sites. The objectives of these ICT systems are to: (1) control the quality of public fill, (2) improve the efficiency and accuracy of the Charging Scheme, (3) maximize the quantities of reusable and recyclable materials extractable from construction waste, and (4) combat illegal land filling and fly-tipping of construction waste.

Two separate but similar systems co-exist: (1) for delivery of construction waste from construction sites to public fill reception facilities, and (2) for delivery of construction waste from construction sites to sorting facilities. The standard ICT features of the two systems are: (1) delivery truck identification system, (2) entrance and exit records of delivery trucks, and (3) truck weighing system. Different operating features of the two systems are: (1) quality of construction waste, (2) treatment of construction waste upon arrival at the facility, and (3) routing systems of delivery trucks.

Specific computer software has been developed to operate all these ICT features for the two systems. As the computer software is used by resident site staff who may not be proficient in computer operations, the software must be extremely robust and easy to use to minimize the need for troubleshooting and/or human errors. These features are elaborated in detail as follows:

4.1 Delivery truck identification system

A credit-card-sized RFID (radio-frequency identification) tag of unique identification is installed on the windshield of every construction waste delivery truck. Detailed information about the truck, such as its license plate number, ownership, net weight, etc., is recorded on the computer system, as identified by the RFID. Therefore, the RFID tag serves as a unique identifier of the truck, which can be read wirelessly by an antenna when the truck is within a specified range of the facility. The arrangement allows the truck to simultaneously deliver construction waste from different construction sites to various facilities. The truck's information is stored in an on-site notebook computer and a cloud storage system. The data can be accessed by authorized personnel instantaneously through a password-protected system. However, manual verification is required to confirm the RFID tag is installed on the corresponding construction waste delivery truck that is registered.

4.2 Entrance and exit records of the delivery truck

At each construction site exit, an antenna pointing towards the construction site, two cameras, and a weighing bridge are installed. The hardware must be properly selected so that it can be seamlessly integrated. Moreover, it must be weather-resistant. When a delivery truck leaves the construction site with a truckload of construction waste, the antenna reads the RFID tag and extracts the truck's information from the computer system, a camera takes photographs of the license plate of the truck for further verification if needed, and a camera takes photographs of the truckload automatically. The weighing bridge measures the total weight of the truck. The exit time of the truck from the construction site is recorded. All the data are processed, integrated, and recorded by an on-site notebook computer using the specifically developed software and uploaded onto the network cloud server in real time. The specifically developed software also verifies the consistency of the data collected. The data can be accessed by authorized personnel for random manual checking.

Delivery trucks enter or exit the public fill reception or sorting facility through traffic lanes controlled by gates. Two antennas pointing opposite directions, three cameras, and a weighing bridge are installed at each traffic lane of the facility so that the traffic lane can serve as either an entrance or exit. The hardware must be properly selected so that it can be seamlessly integrated. Moreover, it must be weather-resistant.

When a delivery truck enters the facility, one antenna reads the RFID tag to extract the truck's information from the computer system, and the gate is opened automatically upon verification of the truck's information. A camera takes photographs of the truck's license plate for further verification if needed, and a camera takes photographs of the truckload or the truck bed. The weighing bridge measures the total weight of the truck. The

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truck's entry time is recorded. All the data are processed, integrated, and recorded by an on-site notebook computer using the specifically developed software and uploaded onto the network cloud server in real time. The specifically developed software also verifies the consistency of the data collected.

When a delivery truck leaves the facility, the other antenna reads the RFID tag to extract the truck's information from the computer system, and the gate is opened automatically. A camera takes photographs of the truck's license plate, and a camera takes photographs of the truckload or the truck bed. The truck's exit time is recorded. All the data are processed, integrated, and recorded by the on-site notebook computer and uploaded onto the network cloud server in real time. The data can be accessed by authorized personnel for random manual checking.

4.3 Real-time processing of data recorded

The photographs of the license plate of the delivery truck can be used to check the truck's identity by the software and/or manually whenever necessary. It also provides redundant data to supplement the data provided by the RFID tag in case of malfunctioning of the antenna.

The travel time of the delivery truck between the construction site and the facility can be determined from the exit time of the truck from the construction site and the entry time of the truck into the facility. It indicates the traffic conditions and whether the truck has been driven elsewhere or stopped unnecessarily.

The truck's total weight leaving the construction site and entering the disposal facility can be compared to evaluate whether the truckload of construction waste increased or decreased during transportation without authorization.

The travel time and weight records can deter illegal land filling and/or fly-tipping by the truck driver.

The weight of the construction waste can be determined from the total weight of the truck entering the facility measured by the weighing bridge and the weight of the empty truck leaving the facility or vice versa. The weight of the empty truck is also used to confirm/update the net weight of the truck in the records. The data are also used to monitor the inventory of public fill in the public fill reception facility or the quantity of C&D waste going to the landfill.

The photographs of the construction waste taken at the construction site's exit and the facility's entrance can be used to perform a visual evaluation and/or computerized image processing of the quality of the construction waste whenever necessary.

4.4 Routing of construction waste delivery trucks serving public fill reception facilities

As tabulated in Table 1, the construction waste delivered to public fill reception and sorting facilities is of different quality. Moreover, construction waste delivered to sorting facilities must be processed for further delivery to other facilities. As a result, the delivery trucks going to these disposal facilities are taking different routes.

Construction waste delivered to public fill reception facilities is 100% inert materials, i.e., public fill. The public fill is delivered from construction sites to public fill reception facilities. The empty truck returns to the construction site after unloading the public fill at a public fill reception facility. As a result, the delivery trucks are routed from the construction site to the public fill reception facility and return.

4.5 Routing of construction waste delivery trucks serving sorting facilities

Construction waste delivered to sorting facilities contains more than 50% of inert materials by weight. The construction waste is delivered from construction sites to sorting facilities. The construction waste is sorted into public fill and non-inert substances at the sorting facility. Afterward, public fill is delivered to a public fill reception facility, and non-inert substances are delivered to a nearby landfill. As a result, there are three routes of delivery trucks serving sorting facilities: (1) from the construction site to the sorting facility and return; (2) from the sorting facility to the public fill reception facility and return; and (3) from the sorting facility to the landfill and return.

Construction waste is delivered from the construction site to the sorting facility by a group of trucks (Group 1), and empty trucks are returned to the construction site upon unloading. A second group of trucks

(Group 2) delivers public fill from the sorting facility to the public fill reception facility, and empty trucks are returned to the sorting facility. A third group of trucks (Group 3) delivers non-inert substances from the sorting facility to the landfill, and empty trucks are returned to the sorting facility. The main contractors of construction sites operate Group 1 trucks. The operating contractor of the sorting facilities operates Group 2 and Group 3 trucks. As these three groups of trucks deliver construction waste of different proportions of inert materials from different starting points to various destinations, they must be clearly identified. More importantly, they belong to different contractors. Group 1 trucks can be easily identified as they enter the sorting facility with a truckload of construction waste and leave it with an empty truck bed. However, Group 2 and Group 3 trucks must be differentiated with extreme care as they deliver public fill and non-inert substances from sorting facilities to public fill reception facilities and landfills, respectively. Moreover, they leave the sorting facility with a truckload of public fill or non-inert substances and enter with empty truck beds. As the two sorting facilities in the HKSAR are near the public fill reception facilities and landfills, shown as SENTX in Figure 1, Group 2 and Group 3 trucks are relatively few and can be easily identified.

5 RECENT AND FUTURE DEVELOPMENTS

Although the systems are running smoothly now, there is always room for improvement. Recent advances and recommendations for future developments may include:

5.1 Deployment of GPS technology for real-time tracking of truck locations

As every truck can be identified by an RFID tag, its real-time location can be monitored by a GPS (Global Positioning System). This can further prevent illegal land filling and/or fly-tipping of construction waste, as the truck's location can be monitored in real time. Moreover, the trucks can be steered to use the most efficient routes under current traffic conditions for delivery of construction waste to the appropriate facility, resulting in considerable savings in time and fuel. In recent years, GPS installation and use for truck monitoring have been tried and progressively implemented.

5.2 Image processing of the truckload of construction waste

The photographic images of the truckloads of construction waste can be processed for two purposes. Firstly, the top surface profile of the truckload can be used to estimate the volume of construction waste in the truck. Using the weight measured by the weighing bridge, the unit weight of the construction waste in the truck can be estimated. As the inert materials in the construction waste are typically denser than the non-inert substances, the unit weight of the truckload provides a reasonably good indication of the proportion of inert materials in the construction waste. Moreover, computer visioning can process the images to identify non-inert materials. As a result, the quality control of public fill can be further improved.

5.3 Other future developments

With the rapid advent of ICT, there can be numerous potential developments, such as establishing and utilizing big data and Internet of Things (IoT) technologies to manage public fill. Nevertheless, these developments must be cost-effective to be adopted to improve public fill management. The continuing development of ICT presents opportunities for cross-disciplinary collaborations with academic institutions alongside valuable training for research personnel and engineers.

6 CONCLUSIONS

These conclusions are drawn from the projects of applications of ICT to construction waste management in the HKSAR:

(1) Two automated management systems using ICT have been successfully developed and implemented for the management of construction waste in the HKSAR of China to:

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(a) control the quality of public fill;
(b) improve the efficiency and accuracy of the Construction Waste Disposal Charging Scheme;
(c) maximize the quantities of reusable and recyclable materials extractable from construction waste; and
(d) combat illegal land filling and fly-tipping of construction waste.

(2) The 1st system controls construction waste delivery to public fill reception facilities, and the 2nd system to sorting facilities. Both systems have been installed at multiple public fill reception facilities, sorting facilities, and construction sites. Necessary hardware must be carefully selected so that they can be properly integrated. Moreover, they must be weather-resistant as they are installed outdoors.

(3) Computer software has been specifically developed to operate the two systems. The software must be robust and easy to use to minimize the need for troubleshooting and human errors.

(4) The systems have been successfully operated in the HKSAR for years with necessary routine maintenance. Nevertheless, recommendations for possible future developments are identified and discussed.

(5) It is demonstrated that ICT can effectively manage construction waste in the HKSAR. Moreover, the systems developed can be adapted for other applications in logistics, construction, mining, and other related industries.

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