An anatomy of waste generation flows in construction projects using passive bigger data

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Abstract

Understanding waste generation flow is vital to any evidence-based effort by policy-makers or practitioners to successfully manage construction project waste. Previous research has found that accumulative waste generation in construction projects follows an S-curve, but improving our understanding of waste generation requires its investigation at a higher level of granularity. Such efforts, however, are often constrained by lack of quality "bigger" data, i.e. data that is bigger than normal small data. This research aims to provide an anatomy of waste generation flow in building projects by making use of a large set of data on waste generation in 19 demolition, 59 foundation, and 54 new building projects undertaken in Hong Kong between 2011 and 2019. We know that waste is generated in far from a steady stream as it is always impacted by contingent factors. However, we do find that peaks of waste generation in foundation projects appear when project duration is at 50~85%, and in new building projects at 40~70% of total project time. Our research provides useful information for waste managers in developing their waste management plans, arranging waste hauling logistics, and benchmarking waste management performance.

Keywords: Construction waste management; waste generation flow; building projects; bigger data

1. Introduction

Construction waste, also referred to as construction and demolition (C&D) waste, is the solid waste resulting from construction, renovation, and demolition activities (HKEPD, 2018; Lu, 2019). In the US, it is estimated that 548 million tons of C&D debris, more than twice the amount of municipal solid waste, were produced in 2015 (USEPA, 2018). According to WRAP (Waste and Resources Action Programme) (2019), the construction industry is the UK's largest user of natural resources and generates 100 million tons of waste annually; over a third of the country's total waste. In China, it is estimated that C&D waste production will reach over 2.5 billion tons in 2020 (AECOM, 2018). In major economies worldwide with robust construction sectors, 25~30% of solid waste landfilled comes from C&D activities (Hyder Consulting, 2011; MoE, 2014; HKEPD, 2017). Given the adverse environmental impacts (e.g., greenhouse gas emissions, leachate) of landfilling and its occupation of precious land that could otherwise be used for urban development, it is clear that construction waste management is of vital importance.

Measurement of construction waste generation is key to any effort to properly manage it (Lu et al., 2016). Numerous studies have been conducted to quantify construction waste generation at project, regional, and national level. In a comprehensive review, Wu et al. (2014) classify these studies into six types: site visit, waste generation rate, life cycle analysis, classification accumulation, variables modeling, and other. At regional or national level, quantification studies can be used to help plan a city's landfilling and other waste management facilities (HKEB, 2013), estimate material stock in buildings (Kleemann et al., 2017), and approximate waste recycling potential (Wang et al., 2019). However, most studies are conducted at project level (De Guzmán Báez et al., 2012; Bakchan and Faust, 2019; Šomplák et al., 2019), where C&D waste quantification has significant practical implications. It can provide critical information for devising a waste management plan before construction has commenced, which is becoming a standard practice in many economies (De Guzmán Báez et al., 2012; Šomplák et al., 2019). It can also be used to extrapolate waste generation in a future project, with a view to planning waste transportation logistics, or bidding for the project (Lu et al., 2016).

Nevertheless, quantification of C&D waste generation at project level is onerous and very often constrained by lack of quality data. Prevailing construction practices do not require record-taking of waste generation. Obtaining secondary data from a central source is not always feasible, so researchers often have to collect firsthand data themselves. They can only do so from a relatively small sample owing to the difficulties of conducting surveys of large-scale building projects over a long period (Lu et al., 2018a). Difficulties also lie in the transient nature of building projects (Demian and Walters, 2014). Unlike municipal solid waste generated by households or a community in a steady stream, a building site ceases to generate construction waste upon project completion. The project team, together with sporadic construction waste data, is soon dispersed. An exceptional case is Lu et al. (2016), who managed to collect a set of very good, "passive" data from 138 building projects in Hong Kong. Using the data, they discovered that the accumulative waste generation as a project progresses follows a sigmoidal or S-curve. While inspiring, this research has two shortcomings. First, it does not cover foundation or demolition projects, which are non-negligible C&D waste generators. Second, assessing waste generation flow (WGF) at a higher level of granularity and at regular intervals, e.g., on a weekly or daily basis, is required for the in-depth understanding needed to devise a comprehensive construction waste management plan. An anatomy of construction WGF in various types of building projects is thus highly desired.

This research aims to offer an improved understanding of WGF in construction projects. It does so by exploiting a large set of highly structured data on C&D waste generation from construction projects in Hong Kong. The research is significant in that (a) improved understanding of WGF is fundamental for construction waste management plans, e.g., onsite and offsite treatment; and (b) the data analytics adopted will reveal useful information that cannot be discovered with small data and encourage exploration of bigger data in construction waste management research. The remainder of the paper is organized as follows. Section 2 is a review of big and small data. Section 3 presents the materials and methods. Section 4 elaborates the analyses of the intra- and inter-groups of demolition, foundation, and building (both residential and commercial building) projects and presents the results and findings. Section 5 discusses the usage and significance of the results and findings and the methodological implications of the study. Our conclusion is drawn in Section 6.

2. Literature review: Bigger data vs. small data

"Big data" is rapidly emerging in research disciplines including business, finance, management, ecology, and medicine. It is a multifaceted concept subject to multiple definitions. Big data can be understood by comparing it with "small data"; it is bigger. It is a collection of data so large and complicated that it is difficult to process using traditional small data management tools. Strictly complying with this definition, most so-called big data are just bigger data. While many researchers stress the volume of big data, others, including Lu et al. (2018b), argue the "relativeness" of big data. The volume of big data, be it gigabytes, or zettabytes, is a moving target, depending on data generation capacity of the era (Everts, 2016); its strength is its ability to present a fuller picture so as to have a closer claim of objective truth (Bilal et al., 2016; Lu et al., 2018b).

The big data phenomenon can also be understood by differentiating passive and proactive data. Chen et al. (2016) refer to the data of active solicitation (e.g., surveying or interviewing subjects) as small data, and data generated unintentionally but with potential research uses as passive (big) data. Currently, many big data sets are an unintended byproduct of business (Ekbia et al., 2015), created for example by people traveling around with GIS-embedded devices, communicating using smartphones, or purchasing through e-commerce (Bakchan and Faust, 2019). Since this passive big data is not carefully curated, it can better reflect an objective truth as it happened (Lu et al. 2018b). Big enough, the data set can honestly record general business done as well as randomness or outliers.

Traditional research on construction waste generation tends to rely on actively solicited, carefully curated small data. Such data risks reflecting a small sample or a mere snapshot of waste generation. This paper endeavors to collect and analyze bigger construction waste generation data sets. Although not big enough to be called big data, they are definitely bigger than small data and are expected to offer more confident or insightful research findings.

3. Materials and method

2.1 Data Collection

Since 2006, based on the polluter pays principle, the Hong Kong Environmental Protection Department (HKEPD) has operated a Construction Waste Disposal Charging Scheme (CWDCS). The CWDCS mandates that all construction waste, if not otherwise reused or recycled, must be disposed of at government waste facilities (i.e. landfills, offsite sorting facilities [OSFs], and public fill banks). The main contractor is charged a tipping fee of HK$125 for every ton of inert waste it dumps in landfills; HK$100 per ton for mixed inert and non-inert waste accepted by OSFs; and HK$27 per ton for inert waste accepted by public fills. Prior to using these government waste disposal facilities, a main contractor undertaking construction work under a contract valued HK$1 million or above is required to open a billing account with the HKEPD solely for the contract, providing basic information including contract name, contract sum, site address, type of construction work, etc. When the construction waste is disposed of at the facilities, information on every load is recorded, including vehicle number, time, weight of the vehicle upon entry and exit, and vehicle billing account. The CWDCS thereby passively generates a big data set allowing investigation of many aspects of construction waste management, including WGF. Appendix 1 illustrates the structure of the big data set, which contains four types of databases as follows.

(1) The *Project* database contains all projects that have dumped waste in government facilities. Recorded in this database are a total of 27,536 construction projects, with information on site address, clients, project type, and other details.

(2) The *Facility* database contains all government construction waste management facilities, e.g. landfills, OSFs, and public fills.

(3) The *Vehicle* database contains 9,863 waste hauling vehicles involved in construction waste transport.

(4) The *Waste Disposal* database records every truckload of construction waste received at the government waste management facilities. A total of 7,866,085 disposal records were generated from all construction projects carried out during the eight-year period from 2011 to 2018, with around 3,500 records being added every day.

Properly harnessed, this data set offers a better chance of investigating WGF because it provides almost full coverage of waste generation from all sites in Hong Kong over the past eight years. We obtained the data from the HKEPD's general inquiry services and in recent years developed a VBScript applet to automatically download the transaction records to a local database for easier data access and storage. Receiving the passive data is a "trawling" exercise and we developed "crawlers" to collect data from other sources, e.g., the Buildings Department's monthly project digest, as shown in the *Building* database in Appendix 2. We can link our databases using indices. With this data on a longitudinal scale, we can track and analyze WGF in different projects as they progress.

A set of qualifying projects was sourced from the pool according to the following criteria:

(1) building projects, either demolition, foundation, or new superstructure, as they form the major physical structure of modern cities;

(2) sizeable projects of above-average contract sum for their kind, as they allow more regular patterns than smaller counterparts; and

(3) must be completed and waste disposal activities recorded in the data set, i.e., started after 2011 and finished before 2019.

The projects are divided into three groups: demolition of old buildings or facilities, foundation for new buildings, and new building construction (see Appendix 2). Comparison and interpretation of projects' WGF is conducted both intra- and inter-group.

3.2 Data preparation

3.2.1 Standardizing time

Since all projects differ in duration, the first step in data processing is to standardize time to make them comparable. We count the time of a project from its first record of waste disposal. For example, if the first record of Project A is week 27 of 2015, we calculate the project duration according to this baseline. Supposing Project A ends at week 10 of 2017, then the duration of Project A is 87 weeks (one year 52 weeks). Different projects may start from different time points, which means their baselines are different. The time is then standardized by percentage using formula (1) below:

$$T_i\% = {t_i}/{T} * 100\% \quad (1)$$

Where t_i is a time point of the project; T is the total duration of the project. Taking Project A as an example, if T = 87 weeks, the standardized time of the second week is $T_2\% = {2}/{87} * 100\% = 2.3\%$. The standardization method is set on a weekly basis as a monthly basis is too sparse. While the data available allows looking into WGF on a daily basis, having so many days makes this "over-engineered". It is too sparse to examine WGF on a monthly basis, although the data also allows doing so.

3.2.2 Standardizing waste generation

As the weight of generated waste varies radically from one project to another depending on size and other factors, the second step is to standardize waste generation. We treat the total weight of waste generation of a project as 100%, and weekly generation as a percentage of the total waste generation. We refer to this as waste generation ratio (WGR). The weekly waste generation for a given project in a certain week is assessed by adding the weight of construction waste truckloads (under the same billing account number) during that week. The weight of weekly construction waste is also used to calculate accumulative WGR to a time point. The WGR in a corresponding week of the project is calculated using formula (2):

$$r_i\% = {w_i}/{W} * 100\% \qquad (2)$$

where r_i is the weekly WGR in week i, w_i is the total waste generated in week i, and W is the total waste generated in a project.

The accumulative WGR till week j is calculated using formula (3):

$$AP_j\% = \sum_1^j r_i * 100\% \qquad (3)$$

where Ap_j is the accumulative waste generation ratio till week j, r_i is the ratio of total waste generation in week i, and i ranges from week *1* to week j.

3.2.3 Weekly and accumulative WGF curves

With the standardized time (T_i%) as the-x axis, weekly WGR (r_i) as the-y axis, the weekly WGF curve of a project can be drawn, as shown in Appendix 3(a). Replacing the weekly WGR (r_i) with accumulative WGR ($Ap_j\%$), the accumulative WGF curve as the project progresses can be portrayed, as shown in Appendix 3(b).

3.2.4 Scaling up

When the same approach is applied to all other projects, the weekly and accumulative WGF curves of multiple projects can be sketched, as shown in Appendix 3(c) and 3(d), respectively. Projects of the same group are arranged together. Consequently, a representative curve epitomizing the general trend of projects of the same type is outlined for better interpretation and comparison.

3.2.5 Inter-group curve

To compare individual and accumulative WGFs of the projects across their respective groups, we need to develop a "representative" WGF curve for each group. A simple methodology is adopted to produce the representative curves. At every 0.1% of the timeline, the waste generation percentages of all projects within the same group are averaged to derive a point. By plotting the points, the representative WGF curve of that group of projects is derived. We repeat this methodology to derive the representative curves of all three groups.

3.3 Data analytical platform

Windows Microsoft Excel 2016 is capable of dealing with big data when the data is structured, meaning that every record follows a standardized format. In Excel, our well-structured data comprising 12,828 rows can be converted between different worksheets and calculated easily using simple formulas embedded in the software, and figure plotting and manipulation is also very convenient. Therefore, Excel 2016 is used to handle the data set extracted using the VBScript applet from the raw data sets. The data is disaggregated first based on project group and then project ID. Data preparation and analysis is conducted at individual project level and then repeated for every project. For comparison purposes, all figures for each group of project are integrated into one figure for group analysis.

4. Data analyses, results, and findings

In this section, weekly and accumulative WGFs of demolition, foundation, and new building projects are analyzed within their respective groups. An inter-group analysis is also conducted to compare the similarities and differences between different types of projects.

4.1 Demolition projects

Waste generation data for 19 demolition projects was collected for analysis. The shapes of the WGF curves of these projects vary with some obvious outliers (see Fig. 1). There are three WGFs (D1, D2, and D3) with only three points changing dramatically. Upon checking the project database, we learned that they are projects with a relatively small contract sum, i.e., a few million HKD compared to tens of millions for other projects, with projects D1 and D2 for re-roofing and demolition of market stalls in two public housing projects, respectively, and D3 demolition and hoarding works in a private demolition project. Most of the projects have similar WGRs, generating around 10% of the total waste every 5% of the project time. Within each demolition project, it is hard to detect any stages that generate more waste than others. In other words, waste generation in demolition projects is a steady stream that is more or less evenly distributed from start to end.

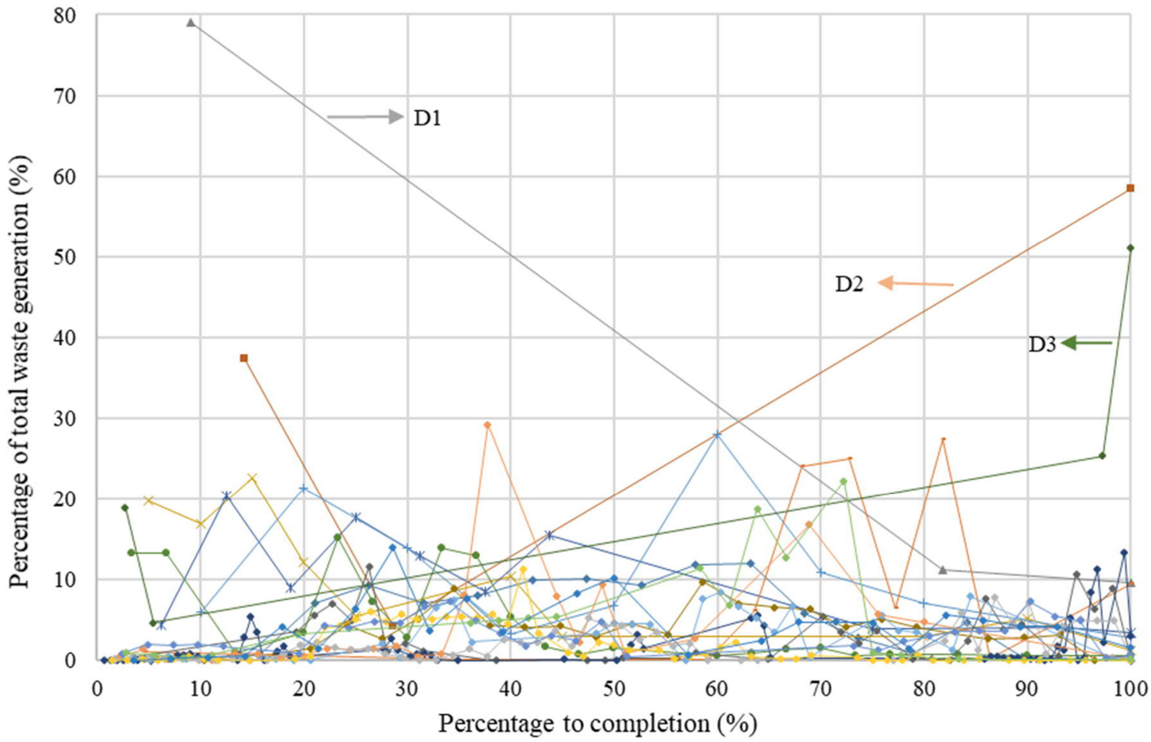

Fig 1. Weekly waste generation flows of 19 demolition projects

The accumulative WGFs of the demolition projects are shown in Fig 2. These accumulative WGFs follow an S-curve shape, starting slowly at the start, accelerating in the middle, and then tailing off when a project nears its end (PMI, 2013). However, the shapes of the S-curves are different from each other. Some of them are steep while others very smooth. There is one special case (D1 in Fig. 2) where nearly 80% of the waste was disposed of in the first week. This is because it is a small demolition project producing only 54.43 tons of waste in total with 43.01 tons generated in the first week lasting for only 12 weeks. Another outlier (D4 in Fig. 2) is the demolition project for a standard 24-classroom, 6-floor primary school in a housing estate and erection of associated hoarding and a covered walkway for residential use. At 60% project duration, it had produced less than 2% of its total waste.

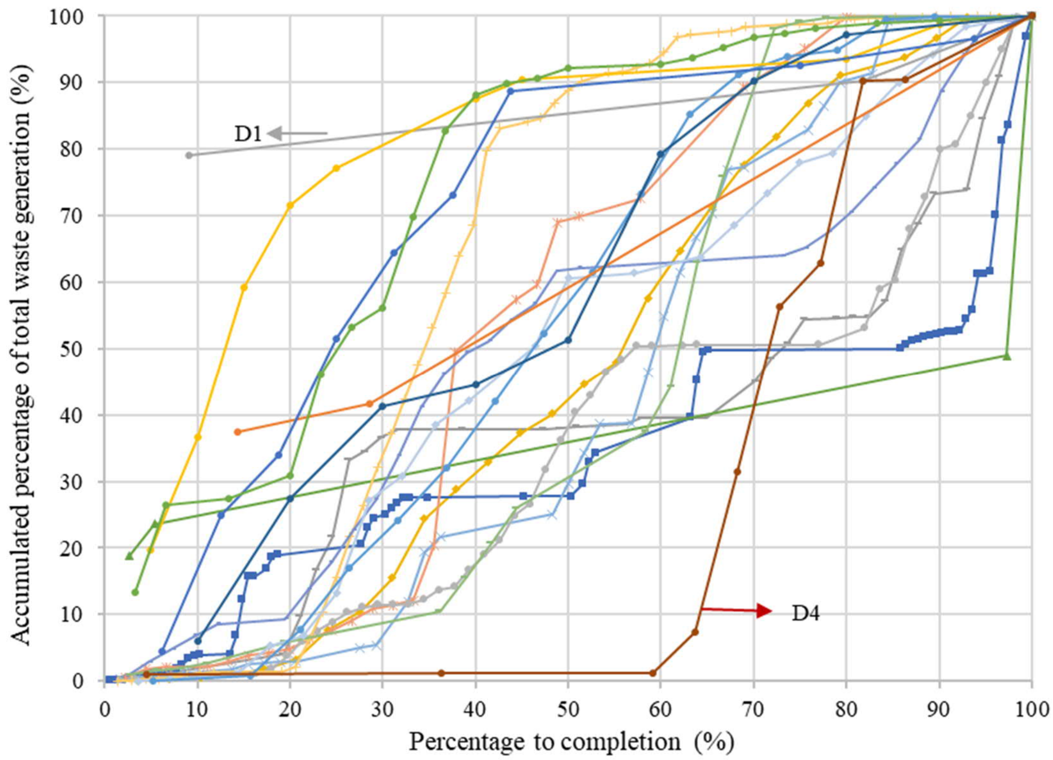

Fig 2. The S-curves of accumulative waste generation of 19 demolition projects

Further analyses were conducted to examine accumulative waste generation at critical time points. At 25% project duration, seven out of the 19 projects had generated more than 25% of total waste and four more than 50%. At 50% project duration, 11 projects had produced more than 50% of total waste, four of which had already produced nearly 90% of their total waste. At 75% project duration, 13 projects had generated more than 75% of their total waste. These figures clearly show that different demolition projects produce waste at different speeds. However, for most, waste generation in the middle stage is faster than in early and late stages. Monitoring this critical time point can help predict and control waste generation for both waste management facilities and contractors.

4.2 Foundation projects

Waste generation data for 59 foundation projects was extracted from the data set. Their WGFs are shown in Fig 3. Some patterns are significant. The WGRs of most projects are under or around 10%, mainly due to the long duration of foundation projects. On average, the foundation projects took around 78 weeks to complete (see Appendix 1), so weekly waste generation is lower than demolition counterparts which averagely last 40 weeks. Moderate in the early stages, WGRs of foundation projects peak between 50% and 85%. Originally, it was thought that most waste is produced during the early stages when evacuation and piling occurs. However, the WGFs in Fig. 3 illustrate that the middle to later stages, when backfilling and demoulding take place, generate the most waste. A possible explanation is that the evacuated soil can be used for backfilling. Hence, in projects where a storage area exists, the soil will be kept until backfilling is complete. Moreover, demoulding will inevitably create piles of mouldboard waste. Where the site area is limited, waste has to be disposed of promptly. There are some outliers in the WGF curves. A particular case is project F1 as highlighted in Fig. 3, where the waste percentage remains at a higher level (above 20%) during 75~80% of total project duration. More than 74% of F1's waste was disposed of in three continuous weeks, a possible explanation being that intensive evacuation works can generate a large amount of waste in a short period of time.

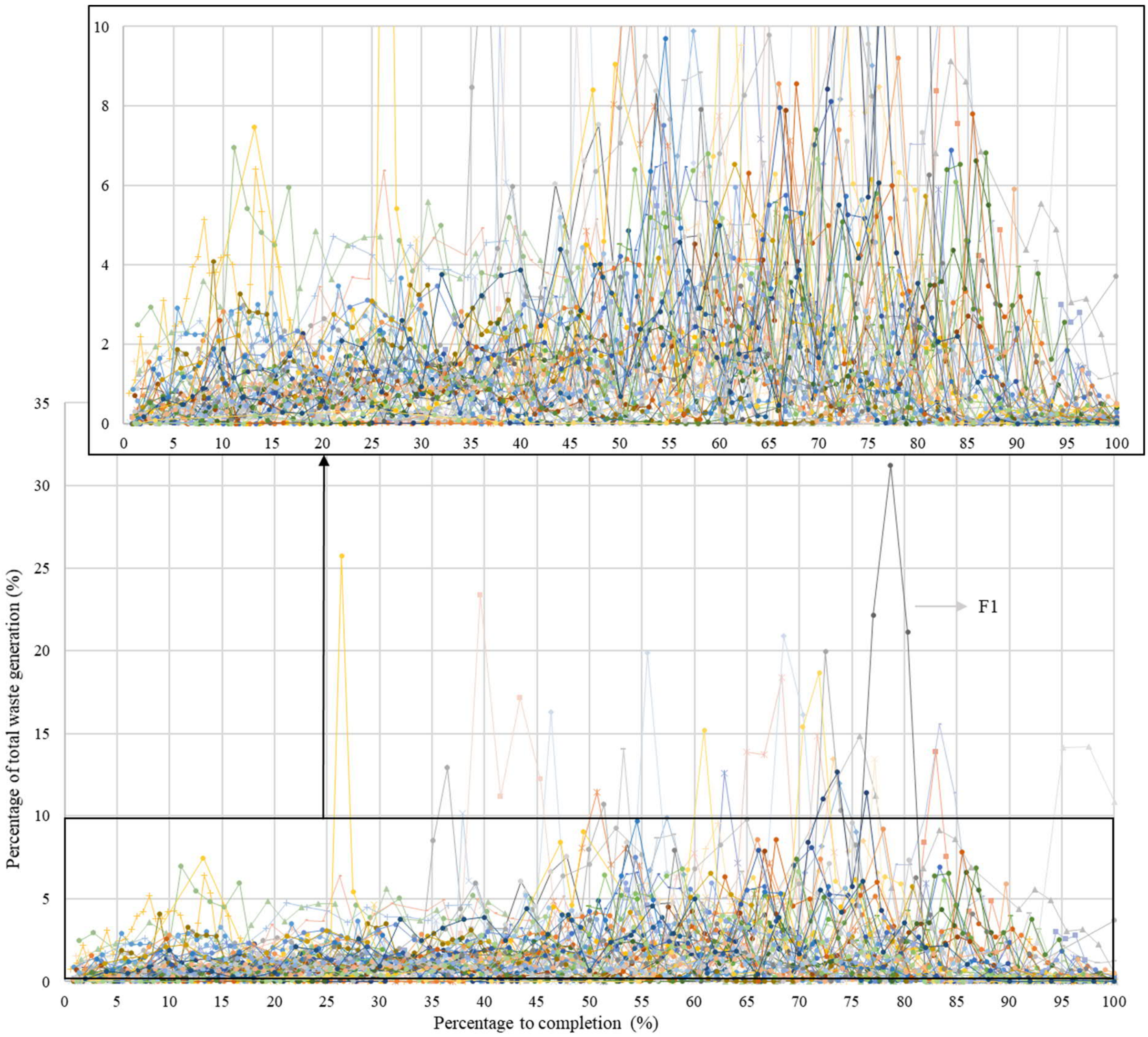

Fig 3. Weekly waste generation flows of 59 foundation projects

The accumulative WGFs of foundation projects are shown in Fig 4. The shapes of the S-curves do not overlap, proving that no two projects are the same and even though they have been standardized. Some patterns can be easily detected. For most projects, the curves grow slowly in the first 30% and final 20% of total time but climb quickly in the middle stages. An outlier in Fig. 4 is F2, a massive piling foundation project with a contract sum of HK$279 million which had generated 92% of its total waste at 18% of project time. Another notable outlier, F3, with a contract sum of HK$216 million only generated 1% of waste in the first 55% of project time. Another project, F1, only generated 0.42% of waste within the first 44.4% of project time. In some other special projects the S-curves have a flat line segment. One foundation project for public rental housing development had almost no waste increase from 40% to 67% of the time, after which its curve takes nearly a steep shape. This can be explained by the fact that in some foundation projects, preparation works take months before evacuation work takes place.

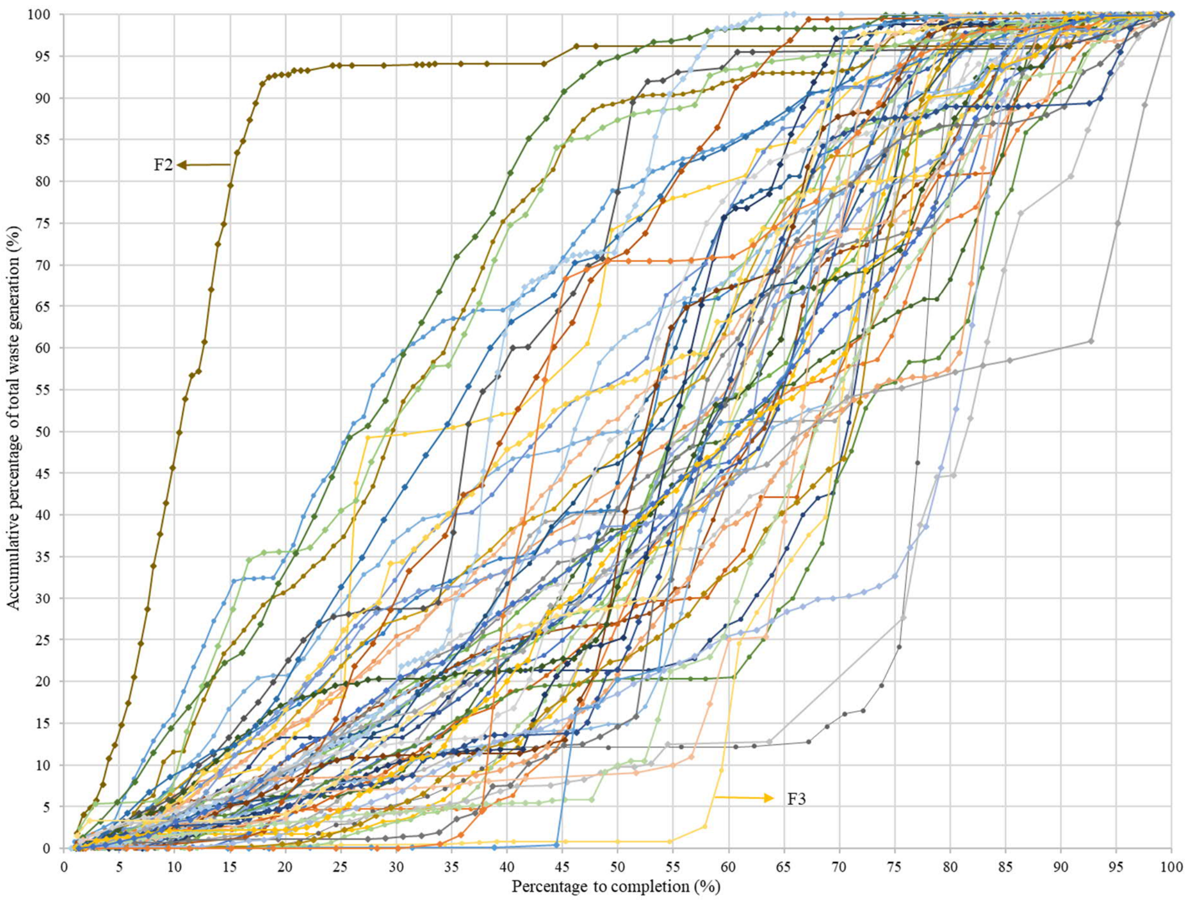

Fig. 4. The S-curves of accumulative waste generation of 59 foundation projects

Further analyses were conducted to examine accumulative WGFs at some critical time points. As shown in Fig. 4, at 25% of the time, only 9 out of 59 projects had produced more than 25% of their total waste; at 50% of the time, 15 projects had produced more than 50% of waste; and at 75% of the time, 13 projects had generated more than 75% of waste. For 54 (more than 91.5%) projects, the WGR is over 90% at 90% of the time. For the majority, waste generation is relatively slow for the first half of the project.

4.3 New building projects

Waste generation data of 54 selected new building projects was obtained. Their WGFs are shown in Fig. 5, where some patterns are noticeable. Apart from several outliers, the distribution of the ratios is more converged than for demolition and foundation projects. The highest WGRs of most new building projects, at less than 5%, are smaller than those of foundation projects. This is primarily due to the difference in completion time between new building projects (average 199.2 weeks) and foundation projects (average 77.9 weeks), as shown in Appendix 1. Unlike foundation projects with relatively concentrated peaks between 50% and 85% of project duration, these peaks appear in new building projects mostly between 40% and 70%. The WGFs of new building projects also have an early peak at 20% of the project time because site leveling works at the start of new building projects generate a large amount of waste.

The four observable outliers are: B1 (very early peak), B2 (peak value 36.75%), B3 (shorter time with dramatically changing value), and B4 (two high peaks). B1 is a residential development project comprising 17 blocks of 6-storey, low-rise buildings on Lantau Island. Simple construction requirements and a relatively capacious site made construction waste storage possible at the start of the project, leading to disposal of about 22% of total waste (mainly from site levelling) in one week at around 6% of progress. B2 is an 88-week residential building project with a contract sum of HK$239.8 million. At week 85, 36.75% of its total waste was disposed of in one week, much different than others that dispose wastes consistently. B3 is also a residential building project with a contract sum of HK$368.9 million and a duration of 52 weeks. No waste was disposed of from weeks 2 to 13, but with a dramatical changes of waste disposal amount at middle stages. B4, a 63-week project with a contract sum of HK$251 million is located in Yuen Long, a relatively rural and expansive area allowing some waste storage on site for disposal once for a long interval, leading to the two high peaks at the WGF.

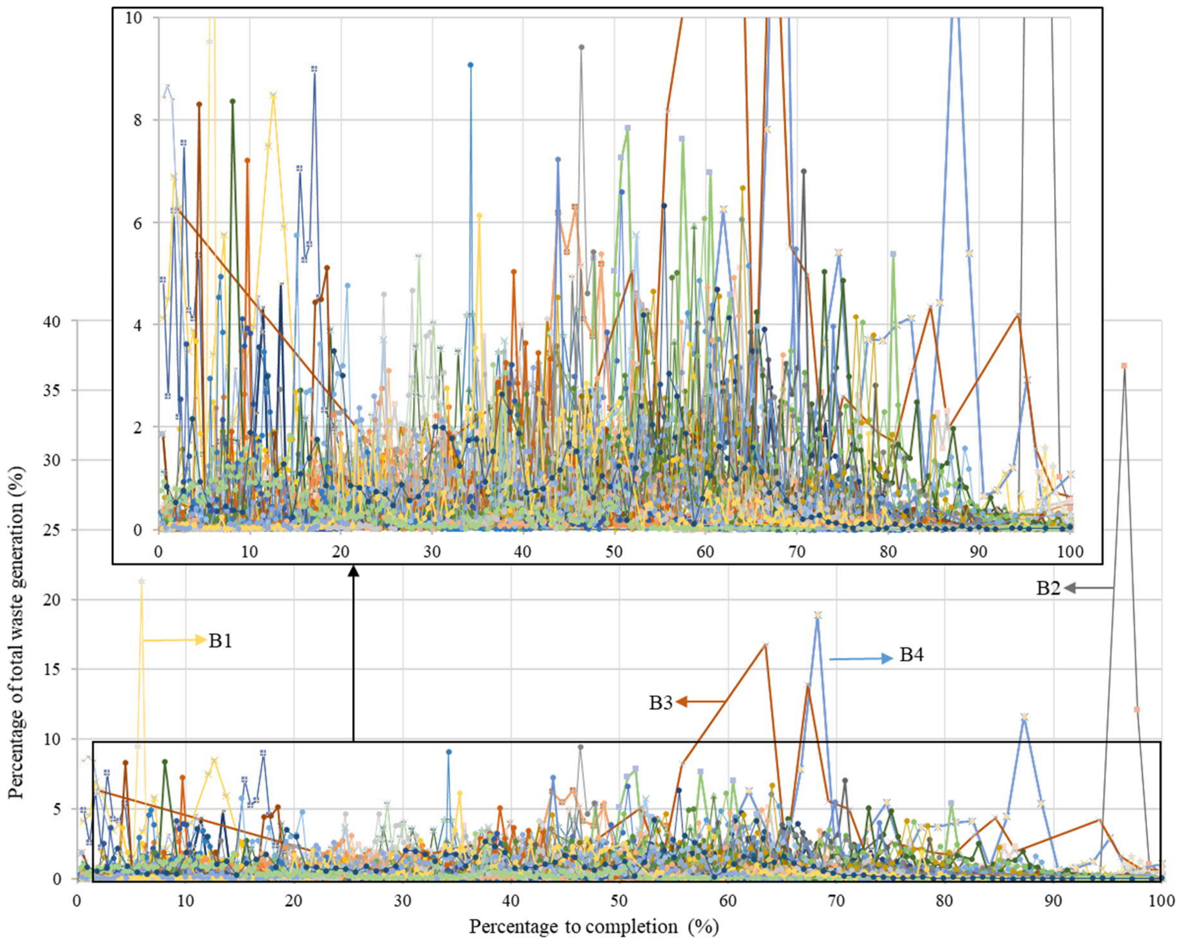

Fig. 5. Weekly waste generation flows of 54 new building projects

The accumulative WGFs of new building projects are shown in Fig. 6. Some general patterns can be observed. Although the shapes of the S-curves differ, most are parallel at the middle stages. This means the accumulative WGF patterns are similar. This pattern implies that Hong Kong contractors are quite adept at superstructure building projects, which are usually less impacted than other groups of projects by contingent factors such as design change, road congestion, or extreme weather. In the first 30% and final 30% of project time, the WGRs of most projects are moderate. There are 11 projects (nearly 20%) that produced more than 60% of total waste in the first 30% of the time and only 5 (less than 10%) that had produced less than 70% of total waste at 70% of project duration.

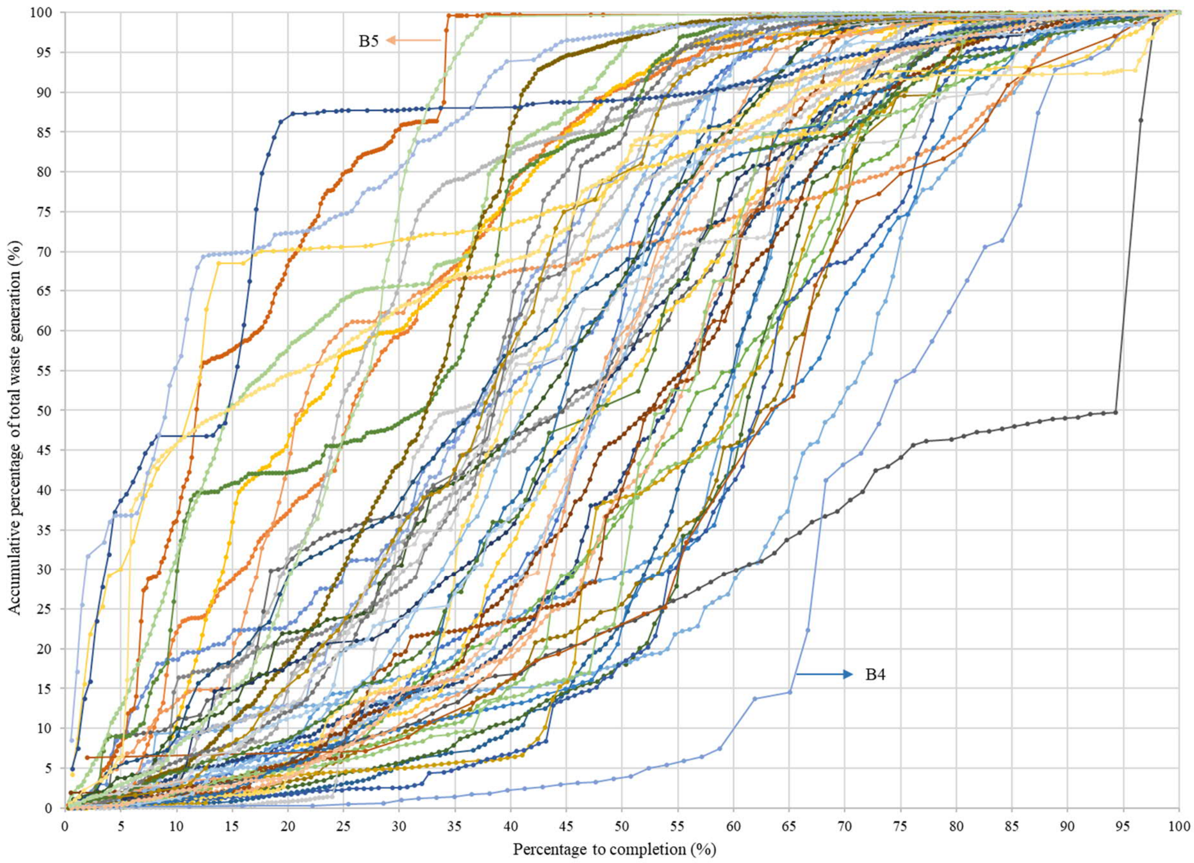

Fig. 6. The S-curves of accumulative waste generation of 54 new building projects

From the horizontal perspective, at 25% of project time, 16 out of 54 projects (nearly one-third) had produced more than 25% of their total waste. At 50% of project time, 37 projects (more than half) had produced more than 50% of their waste. At 90% of time, 53 projects (more than 98%) had generated more than 90% of their total waste. Most projects generated waste very quickly in the period 25% to 75% of project time. Unlike our casual remarks that waste generation in a high-rise superstructure building project would be a steady stream, WGFs actually concentrate in the middle 40~70% stage. An outlier in Fig. 6 is B5, which only took 34.5% of the time to produce 99.5% of its waste. B5 is a massive public rental housing development project with a HK$1.75 billion contract sum and lasting four years. It adopted prefabricated components and precast elements such as fabric reinforcement, semi-precast slab, precast façade and staircases, and also volumetric precast kitchen and bathroom, the implementation of which reduced wastage when constructing standard floors. Another outlier is the earlier-mentioned B4, where only 6% of waste had been disposed of at 55% of completion time because the wide site allowed for waste storage.

4.4 Inter-group analyses

This section compares individual and accumulative WGFs of the projects across their respective groups, as shown in Figs. 7 and 8.

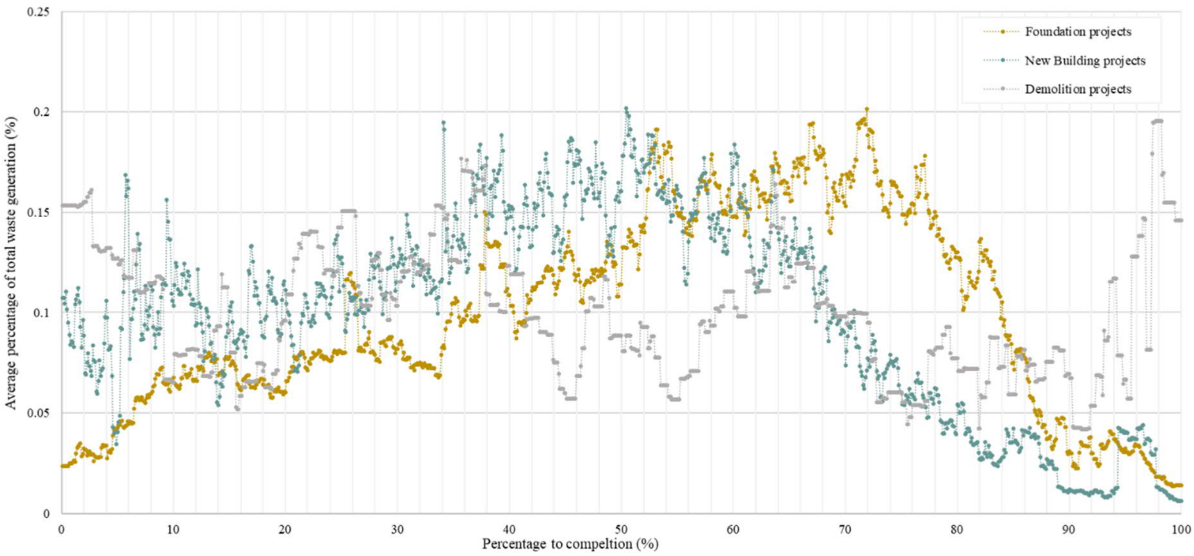

Fig. 7. Comparison of average individual WGFs of three types of projects

Several patterns are observed in Fig. 7, as follows:

(1) Generally, the three types of projects present different patterns of WGFs. The WGFs of foundation and new building projects display a reversed U shape as the projects progress while the WGF of demolition projects fluctuate randomly. The peak of the reversed U in foundation projects happens at around 70% of progress while in new building projects it happens earlier near 50%. In contrast, demolition projects generate a large quantity of waste at their final stage.

(2) Demolition projects' WGF fluctuates the most among the three types of projects. These projects generate waste more randomly at different stages of the project. The individual WGFs shown in Fig. 1 reveal no consistent pattern. There is no "standard" construction waste management method for demolition projects; rather, it depends on the nature of the project, the site, and the demolition methods adopted.

(3) Foundation projects generate most construction waste in their middle and later stages, especially during 55~85% of project time. This can be explained by excavation, backfill, and residual of waste materials being typical waste generation processes in foundation construction.

Based on this pattern, contractors and waste management facilities should reserve enough capacity to store, transport, and dispose of waste that is quickly generated at a later stage of these projects.

(4) New building projects generate large quantities of waste at the early stage, i.e. 5~10% of project time. Most construction waste is generated in the middle stage, at 40~70% of project time. Afterwards, the WGR declines until the final stage of the project. In this regard, contractors need to pay attention to the WGFs and arrange their waste management plans accordingly.

It will be informative to compare the cumulative WGF curves of the projects across their respective groups. By repeating the methodology as described above for individual WGF curves, the representative accumulative WGF curves of the three groups are derived, as shown in Fig. 8.

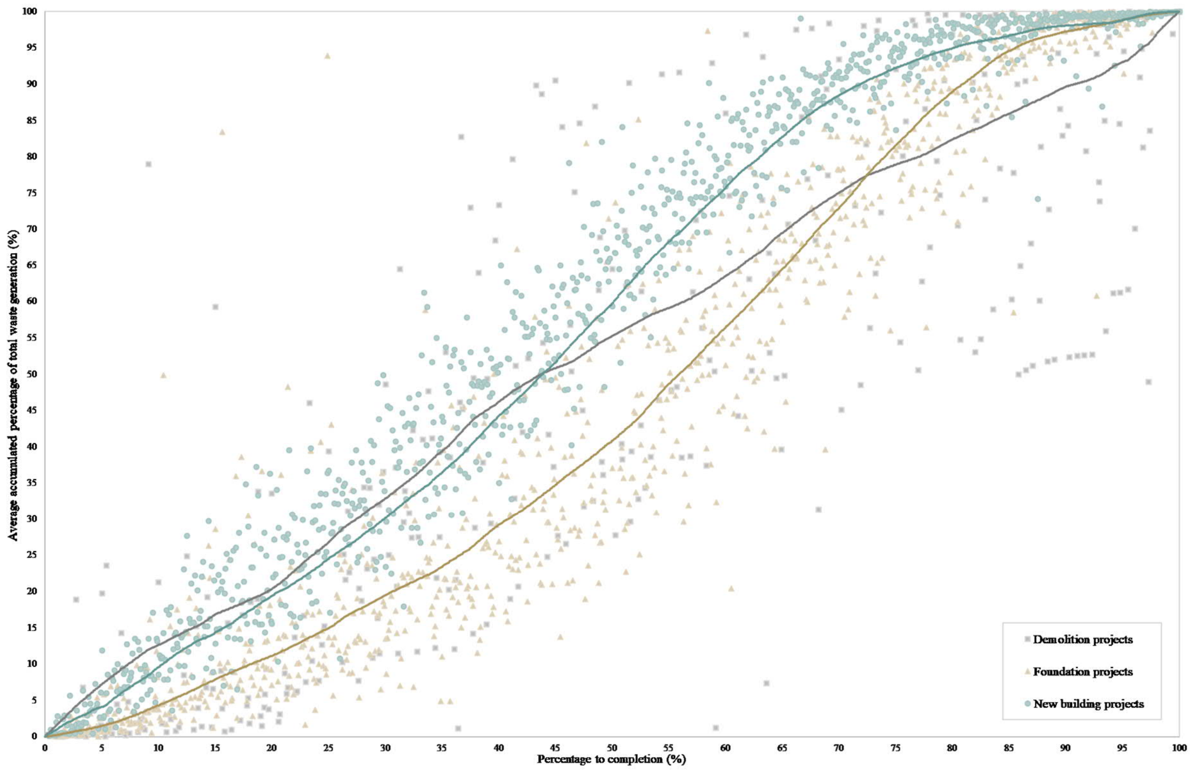

Fig. 8. Comparison of average accumulative WGFs of the three groups of projects

As illustrated in Fig. 8, all curves are S-curves but their shapes differ. Patterns observed are:

(1) Generally, the curve of new building projects is higher than that of foundation projects (except at the final stage). The gap between the new building and foundation project curves is small at the beginning and increases and then narrows until they converge at around 90% of progress. New building projects produce a bigger share of waste than foundation projects. New building projects generate more waste at the early stage (the first half of progress) while foundation projects produce more waste at the later stage (the last half of progress).

During the first 44% of project progress, demolition projects generate waste faster than new building projects but the generation ratios gradually decrease. At 56% to 87% of project time, new building projects accumulate 10% more waste than demolition projects. Demolition projects also produce waste faster than foundation projects in the first 72% of project time. The gap remains larger than 10% during the period 22% to 55% of project progress. For the last 28% of the time, foundation projects generate more waste than demolition projects. The gap is the widest at 86% of project time.

(2) The difference between different groups of projects changes over time. In the first 25% of time, the accumulated waste percentage for demolition, foundation, and new building projects is 26.8%, 15%, and 24.5% respectively. At 50% of progress, new building projects have generated nearly 60% of their total construction waste, demolition projects 55%, and foundation projects 42%. At 75% of project time, the accumulated waste percentage for demolition, foundation, and new building projects is 79%, 82%, and 92%, respectively. Demolition projects produce waste quickly in the early stages; new building projects create more waste in the early-middle stages; and foundation projects generate most of their waste at the middle and later stages.

5. Discussion

5.1 Improved understanding of construction waste generation

Findings of this research well resonate with previous studies. Particularly, the findings of this research echo Lu et al. (2016) in finding that the accumulative WGFs in building construction indeed follow an S-shape curve. A new finding is that the WGFs in demolition and foundation projects also follow an S-shape curve. Furthermore, the S-curves, compared either intra- or inter-group, show some interesting patterns previously unknown. From an inter-group perspective, new building and foundation projects have generated around 50% of their total waste when they approach 50% of the project schedule, while demolition projects as a whole have generated only 40% of the total waste at the same point in time. Knowing that construction waste generation in a project is a non-linear process with a steady stream (De Guzmán Báez et al., 2012), a construction project is often impacted by all kinds of factors, including design change, material shortage, accidents, road congestion, and extreme weather, and the WGFs reflect this. However, the overall patterns of different groups of projects are intriguing, which might be explained by the general nature of the projects. Probing the accumulative WGFs of each group, it is noticed that their accumulative waste generation varies significantly from one project to another, with some really distributing as outliers. Some may have generated more than 70% of total waste halfway through the project, while others may have generated only 30% at the same point. To understand the factors (e.g., project characteristics) that cause the difference would be interesting.

This research also looks at individual WGFs at regular intervals. The results show a difference in WGFs across the three groups of construction project. WGFs of demolition projects fluctuate with no outlier peaks; foundation projects have one major peak between 50~85% of progress; new building projects have a minor peak at 20% and a major peak during 40~70% of the project progress. Different demolition projects may generate construction waste at different speeds throughout their progress. This is dependent on demolition methods which are, in turn, determined by site condition and volume of demolished buildings or structures. For foundation projects, since the foundation types of residential buildings are not diverse, WGF remains moderate during evacuation and piling works and peaks during backfilling and demolding in the middle to later part of the project. This finding contradicts the claim in Yu et al. (2013) that the earthworks stage in a foundation project produces most of the waste. In new building projects, site leveling at the initial stage creates tons of waste soil, causing a minor peak in WGF. Afterwards, waste is created slowly. Although the individual and accumulative WGFs of a project are mutually convertible, the individual WGFs as discovered in this paper can better improve our understanding than previous similar studies using linear or sigmoidal models.

5.2 Applications of the results

Our research findings contain some latent knowledge that can inform practical waste management applications. For example, the WGF and accumulative WGF curves can help predict the generation of waste at different stages of different types of projects, enabling planning of materials, workforce, and vehicles in advance. For top-down demolition projects using manual methods or machines, an opening will usually be made to allow machines to be lifted to the top floor (see Appendix 4 for details). This opening can then also be used to transport demolition waste from upper to lower floors, which can be used as a buffer for storing the waste. Disposing of the waste thus becomes less of a pressing issue and more attention can be paid to other issues, e.g., safety, noise, and vibration hazards frequently reported in demolition projects. Intensive waste hauling services can be planned when demolition projects approach 90% of their progress.

Foundation projects, especially deep foundations for high-rise buildings widely seen in Hong Kong, need careful planning of piling, excavation, anchoring, and backfilling in what is normally a very much confined site area (see Appendix 5). Space for temporarily storing waste must compete with space allocated for other activities such as placing materials or installing machinery. The WGF curves of foundation projects as shown in Fig. 4 are distributed widely. These projects are often impacted by contingent factors, such as unexpected geotechnical conditions, water leakage, and uneven settlement (Canonico & Söderlund, 2010). On the other hand, reuse of excavated soil is desired to save construction costs. The WGFs are not only to provide a converged pattern for waste management but also do warn of the potential impacts of contingent factors that should be given careful consideration.

For new buildings projects, what is against our casual remarks is that waste generation amount is not as much as their demolition or foundation counterparts. There is a minor peak at 20% of project duration, mainly owing to site formation and non-standard floor construction. After the project enters the standard floor construction, some of the built-up floors can be used for temporary storage. The waste generated in upper floors can be moved to lower floors or ground floor storage directly through a debris chute (see Appendix 6). The curves shown in Fig. 5 demonstrate that major waste generation peaks at 40~70% of the project progress. Therefore, careful planning of onsite storage and waste hauling services should be targeted in this period.

In prevailing practice, a waste management plan is formalized as a project document before a project commences. However, the knowledge for making such plans often resides in the mind of experienced managers and is not necessarily accessible to others. It is not uncommon for managers to alter old waste management plan for a new project. The improved understanding of waste generation flows derived from our data analytics can help to make more effective plans to manage this waste.

Our results are transferrable to projects both in and outside Hong Kong. The large volume of the sample studied could reduce the unique characteristics of individual projects and keep the common waste generation pattern of all projects of the same kind, while the same types of construction projects have similar practical procedures and methods. However, to validate the findings, further studies using the same research methods are desired to compare the results of this paper with practices from elsewhere. Specifically, for example, future research may investigate how different materials and technologies across different geographic contexts impact the waste generation flows and patterns.

5.3 Applications of bigger data

Passive bigger data is useful for achieving an anatomy of the WGFs of completed construction projects. In comparison with small data, bigger data can mitigate the unique features of different projects, alleviate the impacts of outliers and reveal regularities. Without passive bigger data, immense effort would have to be spent on collecting firsthand data for just a single curve, let alone the 132 curves of this paper, and an understanding of WGFs in different types of projects would be extremely difficult to achieve.

Looking at the curves drawn, the outliers are even more informative than the converged curves. For example, we know that project B5 in Fig. 6 adopted a series of low-waste construction technologies. However, without the bigger data to paint a fuller picture, B5 would not stand out in terms of WGF. However, bigger data does not complete the picture. For example, the bigger data showed that project B2 in Fig. 5 disposed of 1812.7t of waste in a week. Google Maps reveals that the project is located on a compact site. Without project knowledge, it is not possible to interpret this huge volume of waste disposal in such a short time period. To fully harness the power of big data analytics, one needs to combine bigger data with “thick data”: meaningful qualitative data on behavior and its underlying motivations (Rasmussen and Hansen, 2015).

Bigger data use has a potential caveat. It is assumed that the waste disposal represents how waste is generated when a trade is made. This hypothesis is established under the special conditions of Hong Kong, where construction sites have little to no space for waste storage on-site, so waste generated has to be disposed of as soon as possible. With this potential caveat, the bigger data and its analytics demonstrate a compelling technique to probe into construction waste generation, with a view to providing better decision-making information for waste management.

5.4 Limitations

The first limitation of this study is the context of the analyzed projects. Since all the data are collected from Hong Kong projects, the findings best report waste generation patterns of Hong Kong projects. Although the study can work as a reference and guidance for similar projects in other contexts, validation is needed for further confirmation. The second limitation is that no two projects are the same. Although we tried to select comparable projects, they are still different to a greater or lesser extent. Meanwhile, the big sample makes it difficult to investigate the detailed characteristics of individual projects. These two weaknesses limit the findings of the study. Further research will be done to overcome them by triangulating bigger data with small thick data.

6. Conclusion

Using a set of passive bigger data on waste disposal in Hong Kong, the authors provide an anatomy of waste generation in three types of construction project: demolition, foundation, and new building projects. We find that the WGFs of each group show quite different patterns. The WGFs of demolition projects fluctuate with no outlier peaks; foundation projects have one major peak at 50~ 85% of project progress; and new building projects have a major peak during 40~70% of progress and a minor peak at the first 20%. Demolition projects may generate different but largely steady streams of waste throughout their progress. WGFs in foundation and new building projects largely follow a reversed U shape as the projects progress. Unexpectedly, WGFs in foundation projects remain moderate during piling and evacuation works, but reach their peak during the middle to the later stage of the projects when backfilling and demolding takes place. In new building projects, site leveling at the initial stage will cause a minor peak in WGFs. Afterwards, waste generation reaches a major peak during 40~70% of the total project schedule.

This research echoes previous studies to confirm that accumulative waste generation in construction projects follows an S-curve. We find that the shapes and trends of the S-curves of the three types of project have considerable differences. New building and foundation projects have more stretched curves than demolition projects. The accumulative WGFs in foundation and new building projects have fewer radical changes compared to demolition projects. In most foundation projects, half of the total waste is created quickly in the middle and later stages (at 50~75% of project progress). For most new building projects, 25~90% of total waste is generated in less than one-quarter of the project time, concentrating at 40~65% of project time.

This anatomy offers an improved understanding of WGFs in demolition, foundation and new building projects. It provides insightful information that can be used for, e.g., extrapolating waste generation, developing waste management plans, and arranging waste hauling logistics. Some outlying cases or anomalies are vividly visualized against the rest of projects for benchmarking performance or indicating areas for further investigation.

We use typical big data analytics processes, such as data collection, cleansing, processing, and visualization. The paper does not involve cumbersome statistical methods but relies on visualization, offering superior explanatory power that cannot be derived using small data. Bigger data can reveal regularity amongst a multitude of cases by alleviating the impacts of outliers to show the general patterns, and helps us investigate the collective WGFs of different types of projects. Outliers in bigger data are not often considered but are actually informative. However, without bigger data to paint a full picture, these outliers would not be standing out to notice without the comparison with others. Bigger data is not a silver bullet. It can allow some useful information to surface. To understand the causes behind the various patterns, one needs to combine bigger data with small, quality, informative "thick data" by further investigating the subject matter. Specifically, for example, future research may investigate what factors underlie the differences in waste generation curve shapes, and how different materials and technologies across different geographic contexts impact these shapes.

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