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Waste Generation Predictions and On-Site Waste Management: A Danish Perspective

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Abstract: Multiple methodologies exist for the calculation, estimation, and simulation of waste generation in the construction industry as means for planning and conducting waste management. The reliability and usability of such methods has, nonetheless, not previously been evaluated. This study, therefore, investigated the existing methodologies for waste prediction through a literature review and an analysis of the identified methods using two construction cases from Denmark. Semi-structured interviews were, additionally, utilised to explain how and why waste behaviour is the way it is in the Danish construction industry. The results showed that waste management is affected by multiple factors, which are not reflected in the current methodologies for waste estimation, and that waste behaviour as well as organisational factors are key contributors. In addition, the study concluded that existing estimation methodologies for waste generation tend to be either high in complexity or low in accuracy, limiting the benefits achievable from using them, and that projects of the same type within close proximity can be significantly different from another, highlighting a clear limitation for the development of waste estimation methodologies.

Keywords: waste management; construction management; waste management evaluation; sustainability

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1. Introduction

Construction activities are regarded as one of the main sources of solid waste, responsible for approximately 35% of the world's industrial waste [1,2]. Construction and demolition waste (CDW) is usually a mixture of surplus materials produced during new construction and the renovation and demolition of buildings and other structures [3–7], comprised of materials such as concrete blocks, various types of wood, steel, mortar, and tiles [8]. Construction waste is, additionally, considered one of the main factors impacting the environment [9].

Beyond excessive natural resource consumption, the construction industry is responsible for massive amounts of construction and demolition (C&D) waste directed to landfills each year, amounting to approximately 20–30% of all waste worldwide [10–12]. Some of the adverse effects of construction activities can, however, be mitigated through the 3Rs principle: reduce, reuse, and recycle [13].

In 2021, [14] Eurostat reported that 976 million tons of construction and demolition (C&D) debris was generated in European countries (37% of the total waste generated in Europe) in 2018. Construction and demolition waste also make up the majority of the total waste generation in Denmark, amounting to 58%, of which soil accounts for approximately 7 mil. tons, equivalent to 38% of the total construction waste.

In an attempt to protect the environment and to improve the sustainability of the construction industry, many countries and regions have, therefore, developed various regulations and initiatives to minimise waste [15]. In Denmark, 87% of C&D waste is recovered, representing a limited alternative to raw materials [16].

Proper construction and demolition waste (CDW) quantification, including the identification of waste generation rates (WGRs) and waste composition, plays an important role in developing appropriate and effective approaches for CDW management [17–20]. Hence, the estimate of construction waste generation is key decision-making information for policy-makers and construction managers, amongst others, to devise well-informed waste management strategies [21]. Additionally, quantifying construction and demolition waste allows policy-makers and stakeholders to understand the true internal and external costs of construction [22].

Multiple studies have been published presenting various methods for the prediction of waste generation on construction projects in different countries. None, however, have focused on the Danish construction industry, and only brief accounts have been presented with respect to how planned waste management performs compared to the actual waste management on construction projects. Finally, a gap in knowledge exists in the discussion of existing methodologies for estimating and quantifying waste during pre-construction and how accurate such methodologies are, as well as why such tools so far have proven insufficient in waste management planning.

To fill this gap in knowledge, this study therefore investigated the existing methods for waste generation prediction through a structured review of the scientific literature, presented in Section 2. This is followed by a comparative analysis of two governmentally financed mega-projects in Denmark and semi-structured interviews conducted with site and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) managers on construction sites across Denmark and the construction sites of the two mega-projects, in order to attain qualitative information about how waste management is conducted in Denmark and the factors affecting it.

The literature and results from the study are subsequently discussed in Section 4, followed by the presentation of the limitations of the study in Section 5, whilst the conclusion of the study is presented in Section 6.

2. Literature Review

The review of the literature was divided into two parts in order to structure the knowledge available in the existing body of scientific literature. The first part of the literature review focused on the identification of methods for construction waste quantification, whilst the second part focused on presenting methods for calculating the waste generation rate. The studies identified in the review were indexed as shown in Table 1 based on their focus and key findings.

2.1. Construction Waste Quantification Methods

Information about waste generation is a prerequisite for many waste management strategies, including planning landfill space, determining levies for polluters or subsidies for recyclers, and scheduling companies' waste management policies [23]. Therefore, the estimation of construction waste generation (CWG) at the field scale is a crucial but challenging task for effective construction waste management (CWM) [24].

Multiple studies have been conducted to quantify construction waste generation. Llatas [25] presented a model to estimate construction and demolition (C&D) waste during the design stage according to EU guidelines. In this model, a systematic structure for the construction process was provided to identify the elements and their materials. Based on this, a waste classification system was prepared to obtain a list of waste coded according to the European Waste List (EWL). The proposed model was implemented in a single case study of a four-floor building containing 26 apartments, wherein estimated data and actual data of waste generated were compared to test the validity of the model. The results showed that the rate of construction waste (CW) (without soil) generation was 0.1388 m^3/m^2 (95% of the actual amount of waste) [25].

In their paper, Li et al. [15] presented a model based on the mass balance principle to estimate the amount of waste generated per gross floor area (GFA) for building construction. In this paper, the purchased amount and actual material waste rates (MWRs) of major materials, the total waste generation per gross floor area (WGA), and the WGA for each major component were estimated, and the WGA for a newly constructed residential building was calculated at 40.7 kg/m^2, with concrete waste being the largest contributor to the index [15].

A study by Ding and Xiao [26] proposed a model to quantify the amount of C&D waste generated by building construction. In this study, material flow (or material balance) analyses and the waste weight per area method were used. The results showed that the figure for waste bricks and blocks in demolition waste was the highest (63.8%) [26]. Parisi Kern et al. [27] proposed a statistical model to determine the amount of waste generated in the construction of high-rise buildings by assessing the influence of the design process and production system. In this model, multiple linear regression was used to analyse the amount of waste generated. This model was implemented in the construction of 18 residential high-rise buildings, with the results illustrating that approximately 69% of the factors involved in the generation of waste were accurately predicted [27].

Lu et al. [11] developed an S-curve model to illustrate accumulative waste generation as a function of project progress. Then, the S-curve model was linked to project characteristics using artificial neural networks (ANNs) to predict the amount of waste generated on future projects [11]. Wu et al. [28], on the other hand, proposed an approach to predict the amount of demolition waste generated based on the gross floor area (GFA) and building type, applying the Gray theory to predict the amount of waste generated. The gross floor area (GFA) of demolition work in Shenzhen was obtained from the Urban Planning, Land and Resources Commission of Shenzhen Municipality [28].

Bakchan and M. Faust [4] calculated the amount of CW generated from actual CW data collected from 535 waste-hauling tickets; then, they assessed the influence of the construction stage on these quantities [4]. Furthermore, a study by Yu et al. [29] proposed a method to estimate the amount of waste generated during urban renewal based on the waste generation rate (WGR) and gross floor area (GFA). To obtain the GFA, image recognition technology and Google Earth were applied. In the same study, 200 buildings were assessed as samples to verify the accuracy of the GFA [29].

In another study, Guerra et al. [12] proposed time-based algorithms applying the mass balance principle and automated using BIM-based quantity take-off (QTO) to predict the amount of concrete and drywall waste generated for on-site reuse and off-site recycling with 4D-BIM integration. As the proposed model was validated by two nonprecedential cases, the results showed that the difference between the estimated concrete waste and the actual waste generated for case studies A and B were 11.1% and 16.7%, respectively [12].

In their research, Maués et al. [21] presented an approach based on a fuzzy logic model to predict the amount of construction waste generated. This model was implemented on a case study that comprised 23 residential buildings, and the accuracy of the proposed model was 66.7% [21].

Finally, Huang and Koroteev [30] proposed a machine-learning-driven predictive analytic framework (MLDPAF) to predict the amount of waste. The results of their study showed that the amount of waste generated was reduced by 90%. Landfill waste was reduced by 40%, and transportation was reduced by 15% [30].

2.2. Waste Generation Rate (WGR)

The waste generation rate (WGR) is usually used as a key performance indicator (KPI) to benchmark construction waste management (CWM) performance, with a view to improving the performance continuously; moreover, WGR also illustrates the performance of construction workers' skills on construction sites [20,31–33].

The WGR can be measured fairly easily by the weighing and registration of waste during the construction phase. This approach has a high accuracy, but it is both time-consuming and complex to implement. Moreover, it only allows one to apply the WGR as a benchmark for making strategic or informed project and design decisions, and an approximation of the expected WGR is often needed before the project is commenced. A number of studies have, therefore, looked into how the WGR can be estimated.

Lu et al. [31] proposed a method to calculate WGRs by weighing in four ongoing construction projects, in which the WGRs ranged from 3.275 to 8.791 kg/m^2. In their research, a methodology was implemented for conducting the on-site sorting, weighing, and classification of C&D waste into different categories. The GFA in kg/m^2 calculated from the floor drawings provided by the site manager was adopted as the main measure for construction waste, since it facilitated the identification of the waste generated [31].

In the work conducted by Lu et al. [33], an approach was presented to calculate the WGRs to obtain a set of more reliable KPIs/WGRs by using a big dataset. In this study, the GFA was used to estimate the WGRs, and R software (for statistical computing and graphics) was applied for removing the outliers through a boxplot approach [33].

Mah, Fujiwara, and Ho [22] proposed a method to predict the construction project waste generation rate (CDWGR) using waste disposal truck size and number and waste volume and composition, and the data were obtained through interviews. In this paper, the WGR based on the GFA was calculated for both the conventional construction method (CCM) and the mixed-construction method (MCM) (the cast-in-situ method in combination with the CCM). This study showed that the CCM generated more waste per square metre than the MCM [22].

Xu et al. [34] analysed a large dataset related to waste generation in 132 construction projects to calculate WGRs and waste generation flow. In their paper, the data were obtained from the Hong Kong Environmental Protection Department's general inquiry services using a VBScript applet. Excel 2016 was then used to handle the dataset extracted. This analysis was, furthermore, performed based on the projects' duration [34].

In another study, Hoang et al. [20] presented an approach to obtain WGRs and calculate the amount of waste generated. To identify construction and demolition waste (CDW) composition, image processing was applied to recognize components. To reveal CDW flows, interviews with contractors were conducted at construction and demolition sites. To evaluate the performance of the method, this approach was additionally tested on 15 buildings [20].

Lu et al. [35] re-evaluated the effects of prefabrication to minimise the amount of construction waste generated by investigating a quantitative dataset stemming from 114 sizable high-rise building projects. In this study, the WGR of each project was calculated by dividing the total amount of waste generated (in tons) by the GFA (in m^2) of the project. Independent-samples t-tests using IBM SPSS were additionally applied to investigate the effect of prefabrication on CWM among different types of projects. Furthermore, Spearman correlation analyses were conducted to reveal the contributions to CWM of adopting different types of prefabricated components [35].

Hoang et al. [36] proposed an approach to assess potential CDW recycling by estimating the amount of waste generated and the WGRs. A weight-per-construction-area estimation method was applied to estimate the amount of waste, and the WGRs of each project were calculated based on the per floor area (kg/m^2) [36].

Table 1. Indexing of the focus and key findings of the identified literature.

Study	Country/Year	Focus	Key Findings	Applied Waste Quantification Calculation
[3]	Thailand 2009	Waste management and calculation of CWG.	- The use of waste wood for electric energy presented the largest contribution to the total energy savings (at about 89%), while the down-cycling of concrete to aggregates contributed about 3%. - Of all waste disposed of (whether in landfills or in open dumps), 7.7% was construction waste.	The quantity of construction waste material: $Q_x = A \times G_{av} \times P_x = Q_p \times P_x$
[25]	Andalusia 2011	Identification of CWs, with a focus on packaging waste, remains, and soil.	- The rate of CW (without soil) generation was 0.1388 m^3/m^2 (95% of the actual amount of waste). - The rate of packaging waste generation was 0.0819 m^3/m^2. - The rate of remains generation was 0.0569 m^3/m^2. - The rate of soil generation was 0.2805 m^3/m^2.	The expected volume of CW: $CW = \sum CW_{SBEj} = \sum CW_{Bei} = \sum CW_{pi} + \sum CW_{Ri} + \sum CW_{si}$
[17]	China 2013	Calculation of the WGA by weight.	- The total WGA was 40.7 kg/m^2. - Concrete was a major contributor to the total WGA (43.5%), while the WGA for tiles was considerably smaller (1.2%).	Calculation of the overall WG: $WG = \sum Mi \times r_i + W_0$ Calculation of the WGA: $WGA = WG/GFA$
[26]	China 2014	Estimating WGA with a focus on demolition and construction waste.	- The percentage of waste bricks and blocks in demolition waste was comparatively high (63.8%). - Waste concrete was the second major waste (representing 42.9% of the demolition waste and 22.6% of the construction waste). - More than 80% of the building-related waste was concrete, bricks, and blocks.	The average WGA (tons/m^2): W = CW + DW = CA.Gc + DA.Gd Demolition waste: DW = DWr + DWnr Construction waste: CW = CW r + CW nr
[27]	Brazil 2015	Identifying CW and estimating the accuracy of a regression model.	- The deviation between the forecasts and the actual CW was less than 30 for 83.33% of the sample. - More than 80% of the building-related waste was concrete, bricks, and blocks.	-
[11]	Hong Kong 2016	Approximating CWG using S-curve models.	- The deviation between the forecasts and the actual CW was less than 30 for 83.33% of the sample. - The best S-curve form used for fitting the CWG S curve was: $Y = \frac{e^{a+b^x}}{1+e^{a+b^x}}$	-
[28]	China 2016	Waste management with a focus on waste collection, transportation, utilisation options, and landfill planning.	- The proposed model showed that the amount of DW was projected to rise from 14 million tons in 2015 to 40 million tons in 2030.	The amount of waste generated for each type of material: $G_x = \sum GFA_{ij} \times WGR_{ijx}$

Table 1. *Cont.*

Study	Country/Year	Focus	Key Findings	Applied Waste Quantification Calculation
[4]	USA 2019	Identification of CW of each waste stream using waste-hauling tickets.	- The concrete/masonry waste stream yielded the highest amount (48.5%), with a median of 40 tons per month. - The highest amount of recycled material was concrete/masonry, comprising 52.2% of the total recycled CW on the site. - The WGA was approximately 69 kg/m^2, with the concrete/masonry and wood waste streams having the highest generation rates of 33.61 kg/m^2 and 28.21 kg/m^2, respectively.	WGA in kg per m^2 of built-up area per waste stream was estimated using: $\mathrm{WGR_i = WGi/TBA}$; The total WGA was estimated using: $\mathrm{WGR} = \sum \mathrm{WGR_i} + \mathrm{W_0}$
[29]	China 2019	Forecasting CW using average WGR. The gross floor area of buildings determined using image recognition technology and Google Earth. Calculating the total weight of waste generated.	- The biggest waste stream was concrete, at 51.01%, while the figures for ceramic, aluminium, plastic, granite, glass, copper, and timber were the lowest, at 5.90%.	The total construction and demolition waste: $\mathrm{TG} = \sum \mathrm{WGR_{ij}} \times \mathrm{GFA_{ij}}$
[12]	USA 2020	Calculation of CW with a focus on concrete and drywall waste.	- The difference between the concrete recycling estimate and the actual data for case study A was 15.4%, and for case study B it was 29.3%. - The WGR of concrete for each case study was 18.1 kg/m^2 and 29.2 kg/m^2, respectively.	The CW generation estimate for the entire project: $\mathrm{CW_{Estimated}} = \sum_{\mathrm{Purchased;SectionA}} - \sum_{\mathrm{Needed,\ SectionA}}$ The backbone of the proposed model was: $\mathrm{CW_{\sum Estimated}} - \mathrm{CW_{\sum Reused}} - \mathrm{CW_{\sum Recycled}} = \mathrm{CW_{Landfilled}}$
[22]	Brazilian 2020	Fuzzy set theory was used to estimate CWG.	- The developed model had an accuracy of 66.67%	-
[30]	Russia 2021	An artificial neural network was utilised to estimate the amount of weekly waste generated.	- The amount of hazardous waste was decreased from 80% to 95%. - The simulation analysis showed that the quantity of waste, landfill use, and transportation reduced by 90%, 40%, 15%, respectively.	$-1\mathrm{A} + \mathrm{T1B}$
[34]	China 2011	Calculation of WGR by conducting on-site waste sorting and weighing in four construction projects.	- Project A: concrete and timber accounted for the major waste types (WGR 2.387 and 1.678 kg/m^2, respectively). - Project B: the WGR was highest for concrete, brick, and mortar (WGR: 3.34 kg/m^2). - Project C: the WGRs were highest for mortar, concrete, and miscellaneous brick and mortar (WGRs: 1.587 and 1.14 kg/m^2, respectively). - Project D: timber had the highest WGR (1.905 kg/m^2).	The WGRs of different waste materials: $\mathrm{WGR^j{}_i} = \frac{\sum_{i=0}^{n} \mathrm{Mi}}{A}$
[33]	China 2015	Identification of mass density functions of WGRs at project level based on CW per turnover of 5764 projects.	- The WGRs varied between 0.005 and 7115.12 ton/million HKD (t/mHKD). - The median WGR for all projects was about 15 t/mHKD, with 3 t/mHKD for non-inert and 12 t/mHKD for inert waste. - Civil and foundation works generated much inert waste but little non-inert waste.	The WGR per turnover: $\mathrm{WGR} = \frac{Waste\ ne\ Weight\ (ton)}{Project\ contract\ sum\ (million\ HK\$)}$

Table 1. *Cont.*

Study	Country/Year	Focus	Key Findings	Applied Waste Quantification Calculation
[23]	Malaysia 2016	Calculation of WGR using the number of trucks, the truck size, and the amount of waste.	- The average WGR for the six conventional construction projects was: 9.88 t 100 per m^2. - The average WGR for the four mixed-construction projects was 3.29 t 100 per m^2. - In all projects, concrete was the biggest waste source.	The WGR formula: WGR(k) = ([total waste disposed(m^3)] × [waste(k) composition (%)] × [waste(k) density (tm^{-3})])/Floor area (m^2)
[35]	Hong Kong 2020	Calculation of weekly WGR based on project progress.	- In foundation projects, the WGR peaked when the project was between 50 and 85% completed. - In new building projects, the WGR peaked when the project was between 40 and 70% completed.	The WGR formula (per week) was: ri% = wi/W × 100%
[21]	Vietnam 2020	The WGR was calculated based on construction and demolition waste (CDW) layout, image analysis, and interviews to reveal CDW flows.	- Soil had the highest WGR among all CDW components. - The average WGRs of small-and large-scale construction sites were 79.3 and 1030 kg/m^2, respectively. - The average WGRs of small-and large-scale demolition sites were 610 and 318 kg/m^2, respectively. - The results of the interviews indicated that merely 10% of the total CDW flows were recycled and reused.	Total CDW weight: W = ∑Wi = ∑V/S × D × Ci × Bi Formula for the WGR of each CDW component: WGR = Wi/A
[36]	Hong Kong 2021	The impacts of prefabrication on waste minimisation.	- The average WGRs of conventional and prefabrication building projects were 0.91 and 0.77 ton/m^2, respectively. - Compared with conventional construction, prefabrication logged a 15.38% waste reduction.	
[37]	Vietnam 2021	The calculation of WGR for construction and demolition activities in residential buildings.	- The average WGRs for concrete waste: small demolition sites: 353 kg/m^2; large demolition sites: 204 kg/m^2; small construction sites: 2.88 kg/m^2; large construction sites: 62.8 kg/m^2.	The estimated total concrete waste amount (kg): $EW = EW_C + EW_D = WGR_C \times FA_C + WGR_D \times FA_D$
[24]	China 2021	Identification of WGRs.	- Inorganic non-metallic waste had the highest WGR (i.e., 10.12 kg/m^2).	The WGRs at different stages: $WGR^j{}_i = \frac{\sum_{t=0}^{n} Qt}{A}$

In their research, Hu et al. [24] proposed a model to estimate the amount of construction waste generated (CWG) by integrating improved on-site measurement (IOM) and support vector machine (SVM)-based WGR prediction models (SWPMs). To evaluate the proposed method, 206 construction sites were investigated to obtain the predictor values and waste generation rates (WGRs), with results showing that the SVM-based WGR prediction model (SWPM) obtained more accurate prediction results [24].

3. Methods

In order to investigate the waste generation and behaviour of the construction industry internationally and in Denmark, a literature review was conducted, as well as empirical data collection, quantitative data analysis, and a series of semi-structured interviews.

3.1. Literature Collection

The literature was collected using a relevant keyword search in the Scopus database. This was followed by a title and abstract review, in order to find literature focussing specifically on waste generation prediction and waste management procedures internationally published within the past 15 years, with a focus on the most recent papers.

3.2. Quantitative Data Collection

The quantitative data collection consisted of two primary components: (1) project turnover and (2) the registration of waste disposal in relation to fractions and weight. The first component, project turnover, was registered on a yearly basis and originated from each project's internal financial management system. The second component was based on invoices from the subcontractor responsible for the removal of the on-site waste containers. Based on the invoices, the date of transport, the waste fraction, and the tonnage were retrieved; in total, 18,551 invoices were examined. The quantitative data collection was carried out with outset in two construction cases.

Case I was a construction project of a major hospital in Denmark. The new-build hospital is being constructed in a 920,000 m^2 plot located in the outer city and will be the newly built primary hospital of one of the six Danish regions, taking over the operations and service of two existing hospitals. The hospital project received its final approval in 2007, and the initial visionary work started in 2010, whilst the architectural tender was completed in 2012. The construction was initiated in 2013, whilst the main project was started in 2015, together with the common waste disposal centre. The project is expected to be completed in early 2023. The project includes solely the construction of a 170,000 m^2 new hospital on an open-field building site, with no demolition work and thereby no demolition waste. The hospital project has a budget of USD 832 million (DKK 4990 B in 2020, using an exchange rate of 600). The hospital will have a yearly capacity of 54,000 hospitalisations and 564,000 ambulant treatments. The project's key characteristics are summarised in Table 1.

Case II was another major hospital project in Denmark. The hospital was constructed on a 1,250,000 m^2 plot located at an existing hospital area in the outer city. The project was an expansion of an existing hospital, with four city hospitals being consolidated into one major hospital, and entailed both the construction of brand new buildings as well as the demolition and renovation of old buildings. The project's design phase was initiated in 2005, while the construction started in 2010 and was completed in 2019. The common waste disposal system was linked to the main project and was in operation from 2013 to 2016. Because the project was an expansion, it included a new build of 250,000 m^2, the integration of an existing 160,000 m^2, and the reconstruction of 30,000 m^2, with a total budget of USD 1238 billion (DKK 7433 B in 2018, using an exchange rate of 600). The new hospital will have a yearly capacity of 100,000 hospitalisations and 800,000 ambulant treatments. The project's key characteristics are summarised in Table 2.

Table 2. Key details regarding the two projects and their waste disposal.

	Case I	**Case II**
Project type:	New build	Reconstruction and new build
Construction period:	2013–2023	2010–2019
Contract type:	Prime contracts	Prime contracts
Contract sum:	USD 832 M	USD 1238 B
Waste disposal centre:	2015–2021	2013–2016
Invoices (waste removal):	1895	16,656
Total tones waste handled:	4370	20,636

3.3. Qualitative Data Collection

Qualitative data were collected using semi-structured interviews, as described by Brinkmann and Tanggaard [37], utilising conversation as the medium for the acquisition of empirical data. Additionally, the interviews were, following Tanggaard and Brinkmann [38], based on active participation from both interviewer and respondent. However, the interviewer was the facilitator of pertinent information, and not the co-producer of it [39].

The semi-structured interview form was selected as the method for the collection of qualitative data in this study, as it allowed the interviewer to use both pre-determined questioning as well as questions arising from the conversation during the interview. The use of semi-structured interviews furthermore allowed the respondent to speak using narratives, describing not only what and when something occurred, but also reflections regarding why, providing fuller descriptions of context and expectations in the scenarios described.

In all, six respondents were interviewed regarding waste management and waste documentation in the Danish construction industry. All respondents were male and represented design and construction companies in various regions of Denmark. The respondents were additionally all responsible for waste management on projects in their company. Two of the respondents were project participants in the two analysed case projects, providing a contextual understanding of the waste management data, whilst the remaining four respondents were from other construction projects in various Danish regions, providing an industry-wide contextual understanding of waste management.

To ensure a deep understanding and correct interpretation of the interviews, data familiarity was crucial [40]. In the present research, data familiarity was ensured by following five steps, i.e., the same researcher had to be: (I) present at the interview, (II) listening through the recordings, (III) transcribing their essence, (IV) reading and re-reading the transcription, and (V) carrying out the coding.

Four of the six interviews were sound-recorded and transcribed, as recommended by [38], to lay the foundation for a thematic condensation of the interview data, whilst the fifth interview was conducted as a phone call documented through hand-written notes, which were ultimately digitised for used in the coding of the qualitative data. The sixth and final interview was conducted in writing as an email correspondence between the interviewer and the respondent.

The interview data were analysed using qualitative content analysis; the direct approach with the following predefined categories was applied: (1) waste sorting, (2) waste dumping, (3) general waste behaviour, and (4) organisational factors affecting waste management. The coding followed the immediate approach, with statements highlighted in relation to the predefined categories, which was carried out while transcribing, reading, and re-reading the transcript [41]. Afterwards, the statements were sorted in relation to the four categories and displayed in arrays to cross-compare the statements made by the different respondents [42].

4. Results and Discussion

Even though the two projects analysed in this study were similar in terms of type and organisation, the data showed an obvious difference between the two projects in overall waste generation, considering both the waste generation per turnover and per square metre. This could be due to the fact that one project included renovation, whilst the other project was solely the construction of a new building, meaning demolition waste was only present on one of the projects. This, however, only seemed to explain the discrepancy between the projects on a project level.

The waste generated as part of case I was 4370 tons, registered by the common waste disposal centre, which was only in operation the first four years, resulting in an average waste generation per year of 1093 tons. Case I was a 170,000 m^2 hospital; thus, the waste generation per square metre was equivalent to 27.70 kg/m^2. In case II, 20,636 tons of waste was generated. The common waste disposal centre was incorporated in case II after seven years, resulting in an average waste generation per year of 5159 tons. Case II included a 250,000 m^2 new build, a 160,000 m^2 integration with an existing hospital, and 30,000 m^2 of reconstruction, totalling 440,000 m^2; the overall waste generation per m^2 (ignoring the difference in type) was equivalent to 46.90 kg/m^2.

Case II produced close to five times as much waste as case I, and close to double the amount per square metre.

When calculating the total waste generated per USD, we found that case I generated 7.50 g/USD (4370 tons/USD 583 M), whilst the total waste generated per USD in case II was 30.93 g/USD (20,636 tons/USD 667 M). Thus, the waste generated per turnover was more than four times higher in case II. The overall waste generated per turnover for the two case projects is shown in Figure 1.

A more detailed view of the waste generation is illustrated in Figure 2, which allows a direct comparison of the normalised WGRs at the fraction level.

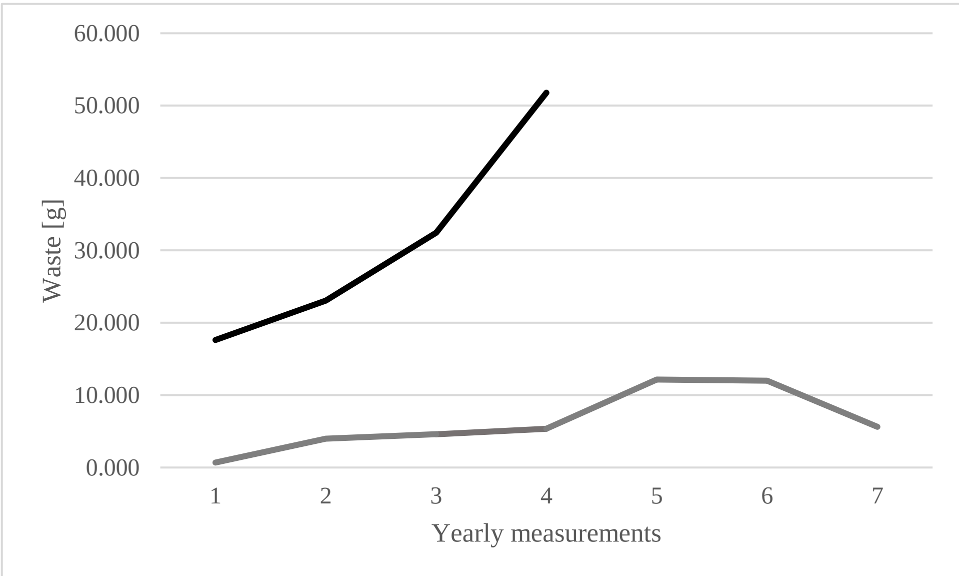

Figure 1. Total generated waste (in grams) per USD turnover. The grey line is case I, and the black line is case II.

In total, 18 different waste fractions were included in the analysis of waste for both projects. The key statistics regarding the WGR for each fraction are shown in Table 3. Even though similar fractions were utilised for indexing the waste, no data were available describing if the waste was actually sorted into the right fractions or not, which was another factor explaining the discrepancy in waste generation between the two projects when analysing the waste generation on the fraction level.

Table 3. Key statistics regarding WGR per fraction.

	Case I	Case II
Mean WGR per fraction:	242.76 tons	1146.45 tons
Standard deviation in WGRs:	551.85 tons	1312.312 tons

To make the WGRs comparable, the rates were normalised. The normalised WGRs per fraction are shown in Figure 2.

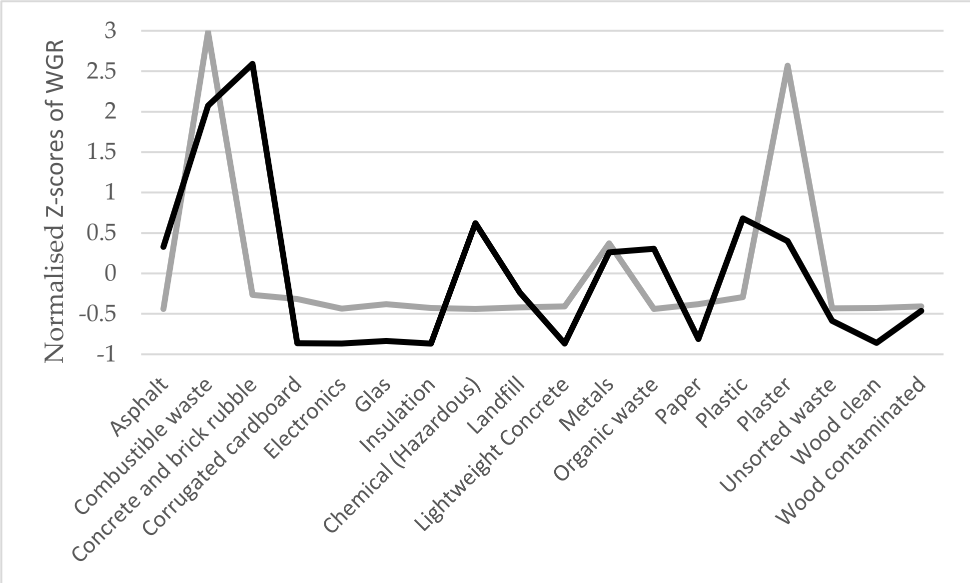

Figure 2. The normalised Z scores of the WGRs per fraction. The grey line is case I, and the black line is case II.

In both analysed cases, the amount of combustible waste was significantly higher than expected. In fact, combustible waste was the biggest fraction in case I (close to three standard deviations away from the mean), whilst it was the third highest in case II (close to two standard deviations away from the mean, cf. the Z scores). A quick comparison between the waste generation in the two cases identified a huge fluctuation in waste generation, with only a few waste categories (metals and contaminated wood) appearing to have a similar WGR. The biggest difference in WGR was observed for concrete and brick rubble, with the WGR being dramatically higher in case II, while the generation of plaster waste in case I was much higher compared to case II.

In this regard, it was again not possible to conclude if the combustible waste generated by each project was different due to one project having more combustible waste than the other, or because the sorting of waste was performed differently on the two projects. As the naming of the fractions both in the analysis and in the actual projects might not have reflected the waste intended for the container, errors in sorting are to be expected in the data; that said, intention or meaning can change from project to project.

Concrete and brick rubble were waste types that were also significantly higher than expected in the two case projects, with case I, which included renovation, having the largest amount of such waste, which was in line with other research [4,19,28]. The authors of these studies also found concrete, bricks, and masonry to be the largest fractions of waste in their projects. This indicated a similarity between projects across building types and global regions with respect to certain types of waste. However, not all types of waste can be estimated in the same way across projects, organisations, and countries.

4.1. The Applicability of the WGR Approximations

The approximation of waste quantities is key for well-formed waste management strategies at both the government and construction levels. A number of different approximation models exist, as shown in Table 1. A simple approach for forecasting waste is to identify the average WGR; this approach was applied in many of the identified studies, resulting in various WGRs. In Table 4, the expected waste quantities were calculated using the identified WGRs.

Table 4. Using WGRs to forecast expected waste for case I and case II.

Study	Waste Generation Rate	Case I (Generated: 4370 tons)	Case II (Generated: 20,636 tons)
3	WGR = 21.38 kg/m^2	CW = 170,000 m^2 × 21.38 kg/ m^2 = 3634 tons	CW = 440,000 m^2 × 21.38 kg/m^2 = 9407 tons
25	WGR = 0.1388 m^3/m^2	CW = 170,000 m^2 × 0.1388 m^3/m^2= 23.6 m^3	CW = 440,000 m^2 × 0.1388 m^3/m^2= 61.1 m^3
17	WGR = 40.7 kg/m^2	CW = 170,000 m^2 × 40.7 kg/m^2 = 6919 tons	CW = 440,000 m^2 × 40.7 kg/m^2 = 17,908 tons
4	WGR = 69.31 kg/m^2	CW = 170,000 m^2 × 69.31 kg/m^2 = 11,783 tons	CW = 440,000 m^2 × 69.31 kg/m^2 = 30,496 tons
12	$WGR_{concrete}$ = 18.1 to 29.2 kg/m^2	$CW_{concrete}$ = 170,000 m^2 × 18.1 to 29.2 kg/m^2 = [3077, 4964] tons; Actual = 95 tons	$CW_{concrete}$ = 440,000 m^2 × 18.1 to 29.2 kg/m^2 = [7964, 12848] tons; Actual = 4546 tons
34	WGR = 3.275 to 8.791 kg/m^2	CW = 170,000 m^2 × 3.275 to 8.791 kg/m^2 = [557, 1494] tons	CW = 440,000 m^2 × 3.275 to 8.791 kg/m^2 = [1441, 1494] tons
33	WGR = 15,000 kg/ mHK$	CW = 832 million USD × 15,000/(7.84) kg/million USD = 1592 tons	CW = 1238 million USD × 15,000/(7.84) kg/million USD = 2369 tons
23	WGR = 98,8 kg/m^2	CW = 170,000 m^2 × 98.8 kg/m^2 = 16,796 tons	CW = 440,000 m^2 × 98.8 kg/m^2 = 43,472 tons
21	$WGR_{construction}$ = 1030 kg/m^2 $WGR_{demolition}$ = 318 kg/m^2	CW = 170,000 m^2 × 1030 kg/m^2 = 175,100 tons	CW = 440,000 m^2 × 1030 kg/m^2 + 30,000 m^2 × 318 kg/m^2 = 462,740 tons
37	$WGR_{construction}$ = 62.8 kg/m^2 $WGR_{demolition}$ = 204 kg/m^2	CW = 170,000 m^2 × 62.8 kg/m^2 = 10,676 tons	CW = 440,000 m^2 × 62.8 kg/m^2 + 30,000 m^2 × 204 kg/m^2 = 33,752 tons

Considering the waste forecasts presented in Table 4, the expected waste generation for case I ranged from 557 tons to 16,796 tons (disregarding the outlier of 175,100 tons); compared to the actual waste generation of 4370 tons, the deviation ranged from 13 to 384% of the actual waste generation. Additionally, the generation of concrete waste was estimated to vary between 3077 and 4964 tons, with an actual generation of 95 tons, showing a deviation ranging from 3239 to 5225%.

In case II, the expected waste generation ranged from 1441 to 43,472 (disregarding the outlier of 462,740 tons); compared to the actual waste generation of 20,636 tons, the deviation ranged from 7 to 211% of the actual waste generation. Additionally, the generation of concrete waste was estimated to vary between 7964 and 12,848 tons, with an actual generation of 4546 tons and thus a deviation ranging from 175 to 283%.

In this regard, the uniqueness and complexity of construction are, again, a huge challenge for creating a reliable model for quantifying construction waste. As waste generation is affected by numerous country- and project-specific static and dynamic factors, this makes it hard to create a single measurement for approximating the WGR. The two cases had very different project characteristics, with case I comprising solely the new building of a hospital in an open field, whilst the second case covered both the demolition and renovation of existing buildings and the construction of new-built hospital facilities, all whilst the existing hospital was still in use. In both cases, the ranges of the waste predictions in the forecasting were too wide to provide applicable estimates.

Of the two construction cases, case I was the simplest, also producing less waste per square metre. In relation to the forecasted WGR, this entailed that the actual waste generation was at the lower end of the spectrum, whereas only three out of nine forecasts (in tons) were lower than the actual waste generation. It was expected that the more complex case II would be at the higher end of the spectrum, but only five out of nine forecasts (in tons) were lower than the actual waste generation. Thus, it seemed that the waste generation rates tended to overestimate the waste generation, especially when applied in a

Danish construction context. Most of the forecasting methods identified in this study were developed in Asia, which might explain the overestimations in the Danish context, due to country-specific characteristics, differences in production methods, or a higher focus on waste in the Danish construction industry.

In the context of construction waste generation, the currently applied on-site waste management strategies and waste behaviours have received only very limited attention, despite these representing the dynamic and human factors that affected the identified WGRs and thereby their accuracy.

As shown in Table 1, many of the studies concerned with waste management focused on the simple calculation of waste generation based on gross floor area [15], whilst others focussed on developing complex statistical models [27], applying fuzzy logic [20], or the utilisation of building information model data [12,13]. However, no one method seemed to facilitate an accurate estimate of the waste generation. It can furthermore be quite complex to estimate the waste generation of construction projects, making the methodologies unfeasible for use by designers and construction managers when planning or constructing buildings.

Most of the identified models (shown in Table 1) focused on either average waste per square metre, multiplying the WGR by the constructed square metres, or the average waste per material type, multiplying the WGR per material by the material quantities collected from 3D models.

As described by Guerra et al. [12,13], BIM is a process that can be utilised for planning and estimating waste generation. According to the respondents, such models are, nonetheless, rarely used in a waste management context on site. In the analysis of the two case projects, it was only possible to apply methods found in the literature review that were based on average waste per square metres. The calculations were carried out with the WGR identified and indexed in Table 4.

The results revealed a huge deviation between the expected waste generation values, and most forecasts did not even come close to the actual waste generation values. Keeping the huge range in expected waste values in mind, these models could at best be used to provide a very vague indication of waste, rendering the actual value of these measurements questionable.

Using actual material quantities extracted from building models to quantify expected waste of course entails that the project on hand be considered to a much higher degree. In this approach, the forecasted waste quantity depends on:

- The quality of the 3D model for extracting the correct quantities.
- The processing or prefabrication degree of the used material. The processing degree of the delivered materials expresses the degree to which production is carried out off or on site. Moving activities away from the site of course reduces the on-site WGR, while the off-site waste generation is increased.
- The actual quantities delivered to site, i.e., the amounts ordered by the contractors, taking expected dwindling and waste into account.
- The WGR at the fraction level, which once again depends on numerous country- and project-specific static and dynamic factors. In other terms, using a mean value for the WGR oversimplifies the approximation, because it does not consider the actual variability of waste generation and the factors affecting it.

However, the only place to find the expected values of building materials and thereby the potential waste is in the tender documents and CAD and BIM models, which, as previously mentioned, are rarely utilised on projects in the Danish construction industry. Wyke et al. [43] described how building information is often fragmented and stored and exchanged in various formats and representations, making the use and re-use of building information difficult, even though such knowledge would allow for better-informed planning on a project [44].

To emphasise the project-specific nature of how waste management is carried out and what affects sorting, waste behaviour, and organisational factors in construction projects in Denmark, interviews were conducted, presenting the qualitative experiences of the respondents. These experiences were derived from their work with waste management on different types of projects, including the two case projects utilised in the quantitative analyses.

4.2. Waste Sorting

According to one of the respondents, waste sorting is often a focal matter in construction projects, due to the prospects of financial gains achieved through the better and more specific sorting of waste, as well as the possibility of selling "clean" waste. All containers on the building sites described by the respondents therefore always had signage specifying the content of the containers. Signage, however, can differ both between projects and between phases of the same project, depending on who holds the responsibility for waste disposal in a project.

Furthermore, according to multiple respondents, waste sorting is often not carried out properly on Danish construction sites, even in projects with an enhanced focus on waste management, such as DGNB-certified projects. One respondent specifically noted that "Waste management is often not prioritised, even when the project must achieve DGNB certification".

This was in line with Hu et al. [24], who described how it can be a challenge to estimate the waste generation in construction projects.

The categories of waste in a building project are usually described as part of the tender documents for the construction project that the waste management contractor bid on. In this regard, one respondent described how it was possible to acquire containers for new categories during the building period if new and unforeseen waste disposal scenarios arose. Such new categories were discussed and approved during monthly site meetings.

Another way of handling waste categories is through planning the construction project with waste as an included focal area.

4.3. General Waste Behaviour

One respondent described how their company had the employed waste disposal company come onto the construction site and train the different workers in waste management and waste sorting twice during the building period, in 30 min sessions, which was a service they provided as part of their "off the shelf" waste disposal solution. This was again carried out to ensure clean waste in the site's containers, because well-sorted waste is cheaper to dispose of, and the re-selling of certain waste types can yield a better selling price.

According to multiple respondents, waste management was often managed on the site level, with the main contractor handling all waste for all contractors. This organisational structure of responsibility was implemented on many sites to present the building owner with the best price possible with respect to waste disposal, and in order to make the documentation of waste disposal easier. This documentation was, according to most respondents, often provided by the disposal companies, which sold "off the shelf" solutions whereby they weighed and controlled the waste they collected and documented it in a report, which the site or waste management team could request.

Waste dumping was another element of waste behaviour mentioned by the respondents.

According to one respondent, who was describing a construction site with a waste management team responsible for the cleaning and removal of litter across the site: "Sometimes a pile of trash/ waste appeared, with no obvious owner of it".

According to another respondent, it could be hard on construction sites to get all contractors involved in the waste management process, especially secondary contractors or subcontractors. On the construction site described by this respondent, all contractors were, therefore, urged to contact the site management team regarding questions of which containers to use for different types of waste, in order to better guide the waste-sorting process and keep the waste "clean" with respect to type or category.

However, waste dumping could, according to one of the respondents, be a result of "the areas for waste disposal/management being either missing or too small, and often placed in the worst location (as such location is often the only one available)". This raised the question of how much waste was removed from the construction site due to inconveniences for the construction workers regarding time limitations or even due to spite.

4.4. Organisational Factors Affecting Waste Management

According to one respondent, the waste management policies on one project created some dissatisfaction with a group of steelworkers, as steel waste customarily belongs to the contractor, which can then sell the waste and earn some extra money from the project. However, due to the extra focus on waste sorting and waste management on the site level, all waste was disposed of in the site's containers, removing the steelworkers' usual ability to increase their earnings through selling steel waste.

Another result of having the waste management happen on the site level is that it is not always possible to monitor how the waste is sorted. Today, for most quality-control systems and sustainability certification strategies, documentation of how waste is sorted is required. This is, according to most respondents, often achieved through photographing the containers on a construction site and their contents, as well as requesting a documentation report from the waste disposal company. However, as one respondent described, "You can pay the waste disposal plant for managing and sorting such waste—it costs approx. $130 an hour, which incentivises sorting waste on the site instead". It is, nonetheless, not a guarantee that the price will motivate all actors on a construction site to sort all their waste properly, as another respondent noted, "some of the people do not sort waste properly". Another respondent further explained that "we (the site management team) are responsible for the sorting of waste. It is possible to just have one container in which all waste is placed. That is, nonetheless, not optimal". Furthermore, paying the fee for waste disposal is, according to one of the respondents, not the contractors', but the building owner's responsibility.

As the price for having an external actor sorting waste is relatively low, it might lead to some construction workers ignoring the processes for waste sorting in construction projects, and as waste is generally the responsibility of the building owner in construction projects, bad waste behaviour seems to be hard to sanction in a way that incentivises better waste behaviour.

It is, nonetheless, essential for construction projects to sort waste as earnestly as possible, to allow for the re-use and recycling of materials and to ensure that as little waste as possible ends up in a landfill, which would cause not only the potential contamination of soil and groundwater, but also the generation of a large amount of methane and CO^2, impacting the environment. Finally, one respondent noted that "It is problematic that experiences and learning is not shared between projects, so that you have to start over, every time a new project starts, both regarding tender and bidding as well as collaboration", calling for better means of collecting data, information, and knowledge from and between projects, which could be shared between actors in the construction industry in order to improve waste sorting, behaviour, and organisational factors affecting waste management on site.

5. Limitations

The present research project only performed one key-word search of the literature, without performing a secondary search and without using snowballing techniques. Some methodologies for estimating and calculating waste generation might, therefore, not have been found.

In this study, we only compared and analysed two construction projects, which might have limited the generalisability of the study's results. In addition, both projects were from the Danish construction industry, and both projects were governmentally financed, limiting the generalisability of the study for private-sector projects and international construction projects.

6. Conclusions

As construction projects account for approx. 35% of all generated waste, even slight improvements with respect to waste sorting and waste disposing can be expected to result in significant environmental effects, as more re-use and recycling can be achieved whilst also limiting the disposal of waste in landfills.

Existing estimation methodologies for waste generation tend to be either high in complexity or low in accuracy, which limits the benefits achievable from using them. This study showed that similar projects within close geographical proximity can have significant differences in waste generation, with respect to not only the amount, but also the type of waste. This presents a general limitation for waste estimation, as construction projects generally tend to be one-of-a-kind projects with respect to what is built, the actors participating, and how such participants sort and behave regarding waste.

Based on this study, the one-of-a-kind nature of construction projects seems to outweigh the similarity of projects of the same type, as how procedures are conducted affects the waste generation and behaviour more than projects with similar geometries, materials, and functionalities. This is, furthermore, also the case with respect to signage on containers on construction sites, which seem to be understood differently between construction projects, which explains why some projects have significantly more combustible waste, glass, etc., than others.

Data regarding how well waste is sorted into fractions on construction sites were not analysed in this study but would be a valuable addition to the analysis. However, as such data are not available, such an analysis could not currently be conducted.

To increase the understanding of waste generation on site, research is needed regarding the quantification of the drivers that affect waste generation. By identifying the important drivers and their impact, better approximations to the WGR can be generated. As a part of this, the quality of the waste quantities needs to be examined, for instance, by assessing the amount of dumped waste and the quality of the sorting. Finally, future studies need to take the variability in the WGRs into account, for instance, by generating mass density functions. This will allow simulations of on-site waste generation, resulting not in an exact amount of waste, but in a probability distribution function explaining the expected generated waste.

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References

1. Hao, J.; Chen, Z.; Zhang, Z.; Loehlein, G. Quantifying Construction Waste Reduction through the Application of Prefabrication: A Case Study in Anhui, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 24499–24510. [CrossRef] [PubMed]
2. Solís-Guzmán, J.; Marrero, M.; Montes-Delgado, M.V.; Ramírez-de-Arellano, A. A Spanish Model for Quantification and Management of Construction Waste. *Waste Manag.* **2009**, *29*, 2542–2548. [CrossRef] [PubMed]

3. Kofoworola, O.F.; Gheewala, S.H. Estimation of Construction Waste Generation and Management in Thailand. *Waste Manag.* **2009**, *29*, 731–738. [CrossRef] [PubMed]
4. Bakchan, A.; Faust, K.M. Construction Waste Generation Estimates of Institutional Building Projects: Leveraging Waste Hauling Tickets. *Waste Manag.* **2019**, *87*, 301–312. [CrossRef] [PubMed]
5. Chen, Z.; Li, H.; Wong, C.T.C. An Application of Bar-Code System for Reducing Construction Wastes. *Autom. Constr.* **2002**, *11*, 521–533. [CrossRef]
6. Yuan, H.; Shen, L. Trend of the Research on Construction and Demolition Waste Management. *Waste Manag.* **2011**, *31*, 670–679. [CrossRef]
7. Wang, Z.; Li, H.; Yang, X. Vision-Based Robotic System for on-Site Construction and Demolition Waste Sorting and Recycling. *J. Build. Eng.* **2020**, *32*, 101769. [CrossRef]
8. Janani, R.; Kaveri, V. A Critical Literature Review on Reuse and Recycling of Construction Waste in Construction Industry. *Mater. Today Proc.* **2020**, *37*, 3077–3081. [CrossRef]
9. Tam, V.W.Y.; Tam, C.M.; Zeng, S.X.; Ng, W.C.Y. Towards Adoption of Prefabrication in Construction. *Build. Environ.* **2007**, *42*, 3642–3654. [CrossRef]
10. Srinivas, H. Waste Management: Fact Sheet. Available online: http://www.gdrc.org/uem/waste/waste-factsheet.html (accessed on 3 January 2023).
11. Lu, W.; Peng, Y.; Chen, X.; Skitmore, M.; Zhang, X. The S-Curve for Forecasting Waste Generation in Construction Projects. *Waste Manag.* **2016**, *56*, 23–34. [CrossRef]
12. Guerra, B.C.; Leite, F.; Faust, K.M. 4D-BIM to Enhance Construction Waste Reuse and Recycle Planning: Case Studies on Concrete and Drywall Waste Streams. *Waste Manag.* **2020**, *116*, 79–90. [CrossRef]
13. Guerra, B.C.; Bakchan, A.; Leite, F.; Faust, K.M. BIM-Based Automated Construction Waste Estimation Algorithms: The Case of Concrete and Drywall Waste Streams. *Waste Manag.* **2019**, *87*, 825–832. [CrossRef]
14. Eurostat. *Generation of Waste by Waste Category, Hazardousness and NACE Rev. 2 Activity*; Eurostat: Luxembourg, 2021.
15. Li, J.; Ding, Z.; Mi, X.; Wang, J. A Model for Estimating Construction Waste Generation Index for Building Project in China. *Resour. Conserv. Recycl.* **2013**, *74*, 20–26. [CrossRef]
16. OECD. *Environmental Performance Reviews: Denmark—Chapter 4. Waste, Materials Management and the Circular Economy*; OECD: Paris, France, 2019.
17. Bergsdal, H.; Bohne, R.A.; Brattebø, H. Projection of Construction and Demolition Waste in Norway. *J. Ind. Ecol.* **2008**, *11*, 27–39. [CrossRef]
18. Katz, A.; Baum, H. A Novel Methodology to Estimate the Evolution of Construction Waste in Construction Sites. *Waste Manag.* **2011**, *31*, 353–358. [CrossRef]
19. Nagapan, S.; Rahman, I.A.; Asmi, A.; Adnan, N.F. Study of Site's Construction Waste in Batu Pahat, Johor. *Procedia Eng.* **2013**, *53*, 99–103. [CrossRef]
20. Hoang, N.H.; Ishigaki, T.; Kubota, R.; Tong, T.K.; Nguyen, T.T.; Nguyen, H.G.; Yamada, M.; Kawamoto, K. Waste Generation, Composition, and Handling in Building-Related Construction and Demolition in Hanoi, Vietnam. *Waste Manag.* **2020**, *117*, 32–41. [CrossRef]
21. Maués, L.M.F.; do Nascimento, B.D.M.O.; Lu, W.; Xue, F. Estimating Construction Waste Generation in Residential Buildings: A Fuzzy Set Theory Approach in the Brazilian Amazon. *J. Clean. Prod.* **2020**, *265*, 121779. [CrossRef]
22. Mah, C.M.; Fujiwara, T.; Ho, C.S. Construction and Demolition Waste Generation Rates for High-Rise Buildings in Malaysia. *Waste Manag. Res.* **2016**, *34*, 1224–1230. [CrossRef]
23. Bao, Z.; Lee, W.M.W.; Lu, W. Implementing On-Site Construction Waste Recycling in Hong Kong: Barriers and Facilitators. *Sci. Total Environ.* **2020**, *747*, 141091. [CrossRef]
24. Hu, R.; Chen, K.; Chen, W.; Wang, Q.; Luo, H. Estimation of Construction Waste Generation Based on an Improved On-Site Measurement and SVM-Based Prediction Model: A Case of Commercial Buildings in China. *Waste Manag.* **2021**, *126*, 791–799. [CrossRef] [PubMed]
25. Llatas, C. A Model for Quantifying Construction Waste in Projects According to the European Waste List. *Waste Manag.* **2011**, *31*, 1261–1276. [CrossRef] [PubMed]
26. Ding, T.; Xiao, J. Estimation of Building-Related Construction and Demolition Waste in Shanghai. *Waste Manag.* **2014**, *34*, 2327–2334. [CrossRef] [PubMed]
27. Parisi Kern, A.; Ferreira Dias, M.; Piva Kulakowski, M.; Paulo Gomes, L. Waste Generated in High-Rise Buildings Construction: A Quantification Model Based on Statistical Multiple Regression. *Waste Manag.* **2015**, *39*, 35–44. [CrossRef]
28. Wu, H.; Duan, H.; Zheng, L.; Wang, J.; Niu, Y.; Zhang, G. Demolition Waste Generation and Recycling Potentials in a Rapidly Developing Flagship Megacity of South China: Prospective Scenarios and Implications. *Constr. Build. Mater.* **2016**, *113*, 1007–1016. [CrossRef]
29. Yu, B.; Wang, J.; Li, J.; Zhang, J.; Lai, Y.; Xu, X. Prediction of Large-Scale Demolition Waste Generation during Urban Renewal: A Hybrid Trilogy Method. *Waste Manag.* **2019**, *89*, 1–9. [CrossRef]
30. Huang, J.; Koroteev, D.D. Artificial Intelligence for Planning of Energy and Waste Management. *Sustain. Energy Technol. Assess.* **2021**, *47*, 101426. [CrossRef]

31. Lu, W.; Yuan, H.; Li, J.; Hao, J.J.L.; Mi, X.; Ding, Z. An Empirical Investigation of Construction and Demolition Waste Generation Rates in Shenzhen City, South China. *Waste Manag.* **2011**, *31*, 680–687. [CrossRef]
32. Zheng, L.; Wu, H.; Zhang, H.; Duan, H.; Wang, J.; Jiang, W.; Dong, B.; Liu, G.; Zuo, J.; Song, Q. Characterizing the Generation and Flows of Construction and Demolition Waste in China. *Constr. Build. Mater.* **2017**, *136*, 405–413. [CrossRef]
33. Lu, W.; Chen, X.; Peng, Y.; Shen, L. Benchmarking Construction Waste Management Performance Using Big Data. *Resour. Conserv. Recycl.* **2015**, *105*, 49–58. [CrossRef]
34. Xu, J.; Lu, W.; Ye, M.; Webster, C.; Xue, F. An Anatomy of Waste Generation Flows in Construction Projects Using Passive Bigger Data. *Waste Manag.* **2020**, *106*, 162–172. [CrossRef]
35. Lu, W.; Lee, W.M.W.; Xue, F.; Xu, J. Revisiting the Effects of Prefabrication on Construction Waste Minimization: A Quantitative Study Using Bigger Data. *Resour. Conserv. Recycl.* **2021**, *170*, 105579. [CrossRef]
36. Hoang, N.H.; Ishigaki, T.; Kubota, R.; Tong, T.K.; Nguyen, T.T.; Nguyen, H.G.; Yamada, M.; Kawamoto, K. Financial and Economic Evaluation of Construction and Demolition Waste Recycling in Hanoi, Vietnam. *Waste Manag.* **2021**, *131*, 294–304. [CrossRef]
37. Brinkmann, S.; Tanggaard, L. *Kvalitative Metoder—En Grundbog*, 3rd ed.; Hans Reitzels Forlag: Copenhagen, Denmark, 2020; ISBN 978-87-412-7726-4.
38. Tanggaard, L.; Brinkmann, S. Interviewet: Samtalen Som Forskningsmetode. In *Kvalitative metoder: En Grundbog*; Hans Reitzels Forlag: København, Denmark, 2020; pp. 33–64. ISBN 978-87-412-7726-4.
39. Gubrium, J.F.; Holstein, J.A. Narrative Practice and the Transformation of Interview Subjectivity. In *The SAGE Handbook of Interview Research: The Complexity of the Craft*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2012; pp. 27–44.
40. Rose, K.; Webb, C. Analyzing Data: Maintaining Rigor in a Qualitative Study. *Qual. Health Res.* **1998**, *8*, 556–562. [CrossRef]
41. Hsieh, H.F.; Shannon, S.E. Three Approaches to Qualitative Content Analysis. *Qual. Health Res.* **2005**, *15*, 1277–1288. [CrossRef]
42. Voss, C.; Tsikriktsis, N.; Frohlich, M. Case Research in Operations Management. *Int. J. Oper. Prod. Manag.* **2002**, *22*, 195–219. [CrossRef]
43. Wyke, S.; Lund Jensen, R.; Svidt, K. Design Rationale Documentation and Exchange in the Danish AEC Industry. In Proceedings of the 38th International Conference of CIB W78, Luxembourg, 13–15 October 2021; pp. 549–557.
44. Wyke, S.; Lindhard, S.M.; Larsen, J.K. Using Principal Component Analysis to Identify Latent Factors Affecting Cost and Time Overrun in Public Construction Projects. *Eng. Constr. Archit. Manag.* **2023**, ahead-of-print. [CrossRef]