Data Collection Challenges in Waste Diversion Assessment: A Building Demolition Case Study

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Abstract

Optimizing waste diversion in construction and demolition projects is often indeterminate, imposing difficulties on deciding whether to reuse, recycle, or dispose of the materials. While data can be used to help bring objectivity to this process, the data collection process imposes numerous challenges (e.g., missing data, non-standardized data, different reporting requirements, etc.). To address waste diversion data collection difficulties, data requirements are first investigated based on a real-world case study of a building demolition project. Three challenges are then identified: isolated data management, propagation of uncertainty, and lack of standards and guidelines. Additionally, recommendations for data collection strategies including enhancing waste management plans, waste tickets, legal requirements, and incentive programs are provided. This study serves as a guideline for project managers on data definition and collection strategies in practice.

Keywords –

Data collection challenges; Waste diversion; Demolition; Economic assessment; Environmental assessment

1 Introduction

600 million tons of construction and demolition (C&D) debris is generated every year, more than double the annual municipal solid waste production [1]. Accordingly, strategic waste management is crucial to mitigate environmental pollution as well as landfill deficiency and save natural resources [2]. Spurred by a growing consciousness of sustainable C&D waste management and its urgency, waste diversion has garnered significant attention in the Architecture, Engineering, Construction, and Facility Management (AEC-FM) industry.

Waste diversion refers to redirecting materials from landfills through three major strategies: reduction, reuse, and recycling. Reuse and recycling are mainly considered in this study as reduction may not be applicable for some unavoidable waste [3]. To identify the optimal waste diversion solution, assessing the costs and benefits of each method is required [4]. Specifically, economic and environmental impacts, the two primary contributing factors, should be evaluated for effective decision-making.

Previous research using quantitative waste diversion analysis has commonly highlighted the significance of data in the process [5]. Mohareb et al. (2011) compared the methods used to calculate greenhouse gas (GHG) emissions, underlining the influence of onerous data requirements on the method selection [6]. Ratnasabapathy et al. (2020) examined the current status of waste diversion rate applications and illustrated the considerable importance of data quality [7]. Guerra et al. (2024) explored data mining technologies that are relevant to the existing data to predict project-level waste diversion rates [8]. Despite the agreement on the importance of the data, their availability was largely assumed to be present, yet in practice remains a significant challenge.

In contrast, general barriers and opportunities to C&D waste management have been investigated in multiple studies. For example, Yuan et al. (2017) holistically analyzed the drawbacks of current C&D waste management practices [9]. Jin et al. (2017) identified challenges in practitioners' perceptions of C&D waste diversion [10]. Although existing research has provided valuable insights into the practical adoption of waste diversion, they are focused on general challenges, not specifically on data. Therefore, further investigation into the data collection process is needed to address the basis of the waste diversion assessment.

This study aims to identify data collection challenges during the waste diversion assessment based on an actual building demolition case study project. Data requirements, typical data sources, and challenges are identified in order to evaluate the environmental benefits and economic costs of reusing, recycling, and landfilling three building materials in the case study. Data collection challenges are then categorized with recommended strategies.

2 Case study

The Frank Erwin Center (ERC) demolition project is a case study used to investigate data collection challenges in waste diversion assessment. The Erwin Center, a large multi-purpose arena, was initially built in 1977 in Austin, Texas, United States. Its demolition commenced in July 2023 and was completed in October 2024. Environmental and economic impacts of three building components (i.e., doors, ceiling tiles, and carpet tiles) in the ERC were assessed. A widely adopted unit-based quantification algorithm is used in which total impact is the multiplication of the total quantity by the sum of unit cost, instead of a rough order of magnitude estimation for a more detailed analysis [11]. Cost items for all waste processing methods are identified from previous work but common expenses (e.g., sorting) are excluded for simplicity [12,13]. The authors (with an academic background in civil engineering and life cycle assessment experience in the industry) performed the case study.

3 Data sources and requirements

3.1 Data for waste quantity take-off

The total quantity of the target building components is required to assess both economic and environmental costs using the unit-based approach. As shown in Figure 1, which summarizes the data sources of cost items, the quantity take-off (QTO) can be done manually or retrieved from existing documents (e.g., inventory, bill of materials). Another method is automated QTO using building information modeling (BIM) or QTO software for 2D drawings. Notably, the quantity should be extracted in the unit of the impact factors. Unit conversion formulas would be necessary if the exact match is not available.

For the case study, doors were manually counted from 2D CAD since a BIM model was not provided. In contrast, the number of ceiling and carpet tiles was inferred from the summation of the area of rooms with tile finishing divided by tile size. Relevant rooms were filtered based on the site visits and room types denoted in floor plans. Existing construction documents that summarized the areas of all rooms in the building were used to map their areas. The tile sizes are defined as the standard dimension (carpet tiles 18”x18”; ceiling tiles 2’x2’). The case study also changed the unit. The doors, for instance, were first counted [EA] but converted to weight [kg] based on a rough estimate of the average door weight to follow the landfill cost unit [$/kg].

Item	Data source	Doors	Ceiling Tiles	Carpet Tiles
Quantity	Manual survey	•		
	Existing documents		•	•
	Automated QTO (BIM/CAD)			
Economic: Landfill	Landfill website	•	•	•
	Regional average cost			
Economic: Recycling	Manufacturer’s recycling program		•	
	Recycling company	•		•
Economic: Reuse	Secondary market			
	Deconstruction company	•	•	•
Environmental	Environmental Product Declaration (EPD)	•	•	•

Figure 1. Data sources of waste diversion assessment cost items. The data sources for each building component of the case study are marked on the right.

3.2 Data for economic cost assessment

Unit economic costs involved in each waste processing method should be collected for the economic evaluation. Firstly, landfilling requires unit disposal charges and labor cost data. These can be obtained from the official dataset from the Environmental Protection Department [14, 15] or project-specific surveys such as adjacent landfill’s web pages [16].

In terms of the recycling cost, basic recycling charges and extra transportation costs were identified. General recycling costs can be discovered from websites about deconstruction or demolition, considering material type and regional characteristics. More detailed cost data can be scrapped from a product-specific recycling program operated by manufacturers. For example, the case study applied detailed cost data for ceiling tiles from the recycling program of Armstrong, one of the leading ceiling and wall system design and manufacturing companies [17]. However, due to data accessibility, carpet tile data were extracted from the cost analysis report by a carpet tile recycling organization [18].

The economic cost of reuse denotes the estimated resale price subtracted from the sum of transportation and installation costs. This information can be obtained from deconstruction service websites similar to recycling or by reviewing the prices posted on secondary market platforms such as Rheaply [19].

3.3 Data for environmental impact assessment

The environmental impact assessment requires the material’s environmental product declaration (EPD) that covers the unit global warming potential (GWP) of all relevant life cycle stages. The overall concept of the environmental impact assessment complies with a general life cycle assessment (LCA) method. The impact is calculated by multiplying the total amount of materials and the sum of the applicable life cycle stages' GWP extracted from the corresponding EPD.

The relevant life cycle stages differ by the waste processing method as illustrated in Figure 2. The GWP from the life cycle stages encompasses those from the next life cycles in addition to the current ones. The A4-A5 (Construction) and B (Operation) stages are commonly eliminated from the calculation, assuming all waste management options have identical values. The environmental impact of landfilling, serving as the baseline, indicates the emission from the C (End-of-life) of the current and A1-A3 (Product) phases of the next life cycle. The current D (Beyond) stage is not but the next life cycle's A1-A3 are considered because the material is directly disposed of and it should be remanufactured from scratch. The recycling involves C1-C2 and D of the current and A3 from the next life cycle. C3-C4 stages are not considered because D is incorporated instead, replacing the need to extract raw materials (A1-A2). Similarly, reuse incorporates C1-C2 and D of the current lifecycle but even A3 of the next cycle is not added.

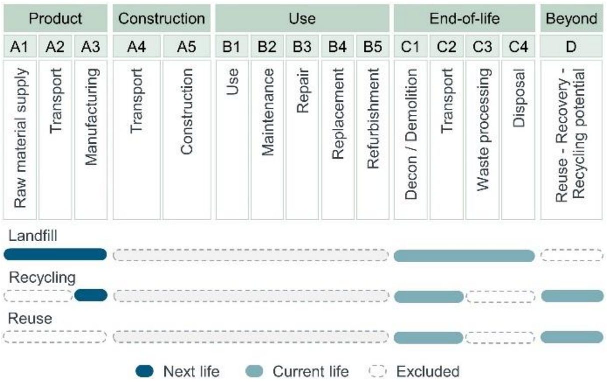

Figure 2. Classification of life cycle stages for the environmental impact assessment by the waste processing method. Different phases of current and next life cycles are applied to calculate the environmental impact of landfilling, recycling, and reuse.

In the case study, the specifications of the building components were unknown and EPDs with detailed information were unavailable. As a result, specific material's lower-level GWP (e.g., A3) was roughly approximated from the upper-level GWP (e.g., A) of a similar product's EPDs provided by its manufacturer.

4 Data collection challenges

Data collection challenges should be clearly identified to prevent them from cascading to future waste management practices which require reference data points to predict and validate the estimations. This section examines the challenges and outlines recommended data collection strategies.

4.1 Isolated data management

A poorly designed documentation plan for waste-related data in the earlier building life cycle phases adds obstacles to information retrieval. A great number of documents have already been generated through the existing practices. However, they cannot be used for the assessment as C&D waste management is not prioritized in the process [13, 20]. Accordingly, readily available documents lack details for waste diversion assessment and are difficult to search.

BIM models, often created during the design and construction phases, are more likely to be unavailable for demolishing buildings. A labor-intensive and error-prone manual QTO is thus prevalent, making the data collection more challenging.

Inventories and specifications generated for building construction and maintenance do not contain the data for waste (e.g., EPD, corresponding quantity, and the construction project manager's comments on future waste management plans). Finding an appropriate EPD that includes information for the end-of-life phase, for example, is challenging without enough description that only the design engineer or installer can provide. Even when the information exists, it is not organized well to search easily. Unstructured pieces of information were often scattered around the hundreds of pages in the case study.

Table 1. Insufficient data fields in the waste tickets from the ERC demolition project

Data Types	Fields
General	Contractor Project Manager
Logistics	Hauler Facility Date
Material Type	Metal Concrete Manifest Trash Trash
Analysis	Total Tons Total Recycling Recycling Rate

Moreover, waste tickets alone rarely support the process although they are required to be submitted. They usually do not designate the work type (e.g., new construction, demolition, renovation) and classify waste by only a few materials (e.g., concrete, metal, brick, wood, cardboard) instead of functional units as illustrated in the waste ticket data of the case study (Table 1).

Furthermore, waste tickets are restricted to the weight of recycled and landfilled waste. This discrepancy in the stakeholders' interests between the earlier phases and waste diversion blocks smoother and integrated data collection.

4.2 Propagation of uncertainty

Vast uncertainties exist in numerous variables of waste diversion, including item quantity, quality, historic value, and changing market needs [21,22]. The target level of detail of the assessment is one of the factors defining the variables. Waste recycling cost, for example, can be calculated at a high level based on the estimated waste type and regional recycling cost. However, it can also be decomposed into details by selecting a specific recycling facility of interest considering the distance from the site, accepted waste type, waste diversion rate, and more accurate waste estimation [14]. As the applicable variables differ by data requirements of the target level of detail, the degree of uncertainty changes accordingly.

Managing the uncertainty becomes more complicated as the uncertainty in one aspect of waste diversion is multiplied by assumptions from other variables. It is difficult to define an allowable range of differences for data collection. For instance, resale price includes uncertainty stemming from a market need for a specific material type; at the same time, material quantity can affect the pricing policy. The Erwin Center case had to consider three major compounded sources of uncertainty to calculate the reuse cost of ceiling tiles: 1) quantity unit conversion from area to weight, which propagates to estimating 2) the labor cost for tile removal that also varied by the project location, which affects 3) the resale price as it differs by the quantity, regional demand, and item condition. Concluding whether the final variance imposed from multiple sources is tolerable is difficult, and these ambiguities can therefore bring verbosity to waste diversion estimation.

4.3 Lack of guidelines and standards

Missing guidelines and standards, that could assist the data gathering on behalf of experienced human experts, impede the collection process. Skilled experts in waste diversion can use their own database or find the most suitable data sources but most experts still need assistance for the best practice. Due to the lack of well-established standards and guidelines in the waste diversion field, data collection efficiency is compromised [10,5].

In the case study, experienced experts' advice and standardized processes were mostly restricted or did not exist. Even the authors studying waste diversion had difficulties in determining a realistic resale price for reuse as the price changes by the fluctuating demand. Furthermore, an unstandardized dataset intensified the problem. There was no well-established guideline or standard listing crucial considerations and possible database to find the relevant data such as EPDs that perfectly match the material of interest. Unit conversion formulas and assessment methods also had to be modified multiple times following different EPD formats. When selecting EPDs of ceiling tiles, carpet tiles, and doors for the case study, the research team decided to prioritize EPDs that separately documented the global warming potential of Product stages (A1-A3) in addition to other basic requirements. These criteria for reasonable decision-making were developed from scratch as readily available resources were difficult to access and the EPDs were all distributed across different manufacturer's websites in varying formats.

It is currently infeasible to locate data sources that match all project attributes and variables. Hence, clear directions defining what is acceptable and how to adapt the data are necessary to ensure the reliability of the assessment. A centralized database and standardized criteria are needed to make the waste diversion assessment more accessible.

4.4 Recommendations

This research introduces four recommendations to enhance the data collection practices. The first strategy is to require contractors to submit a comprehensive waste management plan (WMP) in advance of a construction or demolition project. A WMP allows integrated data generation and management, addressing the limitation of isolated data management. The stakeholders can incorporate waste diversion in their plans before the project begins to minimize missing data and redundancy. Terminologies can also be standardized with WMP, which can contribute to communication efficiency. Furthermore, incorporating quantitative impact analysis and supply-demand simulation of reclaimed materials will enable WMP to play a more strategic and proactive role in waste diversion [23].

Restructuring the C&D waste post-reporting framework is also needed. Explicit descriptions of processing types, such as demolition/new construction and reuse/recycling/landfill, should be added to waste tickets. Categorization of materials in detail (e.g., plastic/furniture/contaminated, link to drawings/BIM elements) is also suggested for further analysis. This enables reducing uncertainty due to the lack of well-documented data.

Advanced legislation is another recommendation to motivate the execution of the strategies, and eventually, promote the better establishment of waste diversion guidelines and standards. Previous studies in waste recovery have demonstrated that financial incentives are effective but need further support for practical implementation [24,25]/landfill, should be added to waste tickets. Categorization of materials in detail (e.g., plastic/furniture/contaminated, link to drawings/BIM elements) is also suggested for further analysis. Internal motivations of general contractors, demolition, or waste management specialists can drive the efforts but legislative actions can facilitate the change. In practice, the C&D ordinance has already been published or is under development in multiple states and cities to enhance the C&D waste management practices [26-28]. Recycle Colorado, a nonprofit organization to advance circular economies in Colorado, also provided a toolkit for policy development [29].

Similarly, enhancing certification programs such as Energy and Environmental Design (LEED) can provide societal and indirect financial motivations by providing constructive instructions. Indeed, the U.S. Green Building Council has already started a discussion to include Building and Materials Reuse credit in their new LEED v5 rating system to encourage more material reclamation and reuse [30]. Clear legislative and certification processes, accompanied by knowledge exchange and assistance from organizations such as Build Reuse Wiki [31], will accelerate the improvements in data collection.

5 Conclusions

This study analyzed data collection challenges for the environmental and economic assessment of waste diversion methods based on a case study. Calculating the impacts of landfilling, recycling, and reuse of building materials in a sample demolition project revealed data collection challenges (i.e., isolated data management, propagation of uncertainty, and lack of standards and guidelines). Recommendations for improved data collection are also presented according to the analysis.

This research analyzed practical difficulties experts can encounter when gathering data for the quantitative waste diversion assessment, a task often left to individuals to resolve. The findings will serve as a guideline to establish improved data collection strategies. It is also expected to assist the project managers and future studies in implementing them for more waste diversion.

Still, the study has a limitation in that it focused on investigating the case study-specific data collection challenges. The identified problems might not apply to other projects, or different difficulties can be identified in new regions and authorities. Future research is necessary to discover possible solutions for data collection in practice. Their feasibility and effectiveness should also be interpreted theoretically and through real-world applications.

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