Check for updates

Original article

WM&R

Waste Management & Research
2026, Vol. 44(9) 1445–1459
© The Author(s) 2026
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/0734242X261451605
journals.sagepub.com/home/wmr
Sage

Demolition waste characterization from post-earthquake controlled demolitions in Türkiye: A field-based study

Kadir Özçelik[1], Serra Selin Övez[1], Kadriye Elif Maçin[1] and Osman Atilla Arıkan[1]

Abstract

Determining the composition of demolition debris is crucial for effective waste management and post-disaster recovery planning. This study had two main objectives: (i) the characterization of demolition waste (DW) originating from post-earthquake controlled demolitions (as opposed to collapsed buildings), and (ii) the investigation of how building age and seismic codes influence on debris composition. A field investigation was conducted in Malatya, one of the provinces affected by the 6 February 2023 earthquakes in Türkiye, to evaluate the valorization potential of DW. Debris from nine controlled demolitions representing buildings constructed before 2000, between 2000 and 2011, and between 2011 and 2018 was collected and characterized. Additionally, three truckloads of mixed piles were sampled from the temporary storage area. In total, 490 tonnes of material were analysed by mass percentage. The results show that mineral fractions consistently dominate (≈94–97% by mass), whereas iron exhibits the highest variability depending on construction period (1.69–3.48%). Other fractions such as wood, textiles, plastics, paper and cardboard, metals and electronics, and bulky items collectively account for less than 5% of total mass. This systematic field study provides an essential baseline for understanding DW composition in post-earthquake controlled demolition contexts and supports future research on the valorization and sustainable management of construction debris in Türkiye and other earthquake-prone regions in the world.

Keywords

construction and demolition waste, concrete, mineral waste composition, valorization potential, waste characterization

Received: 14 November 2025; accepted 2 May 2026 by Editor in Chief Arne Ragossnig.

Introduction

The amount and characterization of construction and demolition waste (CDW) in post-earthquake controlled demolition contexts are important for effective waste management and post-disaster recovery planning. The volume of debris from earthquakes can be 5–15 times the annual waste generation of affected areas (Reinhart and McCreanor, 1999). For instance, Türkiye generated approximately 35 million tonnes of municipal solid waste (MSW) in 2021 (Turkish Statistical Institution, 2022). Estimates of debris generated by the 6 February 2023 earthquakes in Türkiye vary widely – Xiao et al. (2023) reported 450–920 million tonnes, United Nations Environment Programme (2023) estimated 116–210 million tonnes, and Temelli et al. (2025) suggested approximately 396 million tonnes – yet all exceed annual MSW generation in Türkiye.

In addition to post-disaster CDW debris, Türkiye generates an estimated 4 million tonnes of CDW annually, a figure expected to double or more as a result of ongoing urban renewal initiatives (Buzkan and Erman, 2020). Türkiye is currently undergoing an extensive urban transformation process driven by seismic risk mitigation and the need for building renewal. In Istanbul (the country's largest and most densely populated city) alone, CDW generation from urban renewal projects is projected to reach 132–158 million tonnes in 20-year period (SKD, 2024).

Globally, CDW represents one of the largest and fastest-growing waste streams. In developed countries, CDW can account for up to 35% of total solid waste, whereas in developing countries this proportion may rise to as high as 50% (Cha et al., 2023; Tissera et al., 2022). In the United States, approximately 600 million tonnes of CDW are generated annually, with 40–50% being recycled (USEPA, 2020). In the European Union (EU), CDW reached about 860 million tonnes in 2022, accounting for 38.4% of total waste (Eurostat, 2024). In China, annual CDW generation is estimated at approximately 2.6 billion tonnes (Ma and Hao, 2024). Another major challenge is the implementation of

[1]Department of Environmental Engineering, Istanbul Technical University, Maslak, Türkiye

Corresponding author:
Kadir Özçelik, Department of Environmental Engineering, Istanbul Technical University, Istanbul, Maslak 34469, Türkiye.
Email: ozcelikk@itu.edu.tr

circular economy principles in practice (Esa et al., 2017). For instance, in China, CDW accounts for approximately 30–40% of total municipal waste (Huang et al., 2018).

Beyond its quantity, the composition of CDW can vary considerably depending on several factors, including the types of building materials used (e.g. concrete, wood, etc.) and the demolition method applied (e.g. controlled or selective demolition). In addition, demolition waste (DW) characteristics would change due to the alterations in seismic codes which includes structural design requirements, material specifications, and construction practices. Concrete and masonry materials (bricks, tiles, ceramics, and other mineral wastes) constitute the largest fraction of CDW. The buildings in Türkiye are mainly reinforced concrete and masonry structures. The increasing global focus on sustainable urban development has increased the valorization potential of a circular economy. Zhao et al. (2021) showed that recycled aggregates from CDW can effectively replace natural aggregates in applications like road construction, while helping to conserve natural resources. Singapore has a remarkably high recycling rate of 99%, demonstrating the success of its policies and systems (Oliveira et al., 2021). In contrast, China has significant challenges, with its recycling and reuse rates for CDW reported to be less than 5% despite the waste constituting a large portion of its total municipal waste (Huang et al., 2018). Therefore, China has begun to implement new government policies to improve CDW recycling, highlighting the importance of legislative support in transitioning to a circular economy (Li et al., 2023). Similarly, the EU has set a target to recycle a minimum of 70% of non-hazardous CDW by weight (Bassani et al., 2017). However, many regions still face significant challenges, including a lack of adequate infrastructure, economic challenges, and insufficient public awareness (Karanafti et al., 2022). The adoption of circular economy principles remains inconsistent across jurisdictions, reflecting these varied capacities and regulatory environments (Huang et al., 2018). A case study from Brazil shows the importance of multi-stakeholder partnerships and community involvement in creating effective reverse supply chains for CDW (Brandao et al., 2023).

While global efforts towards CDW valorization continue to advance (Bayram et al., 2025), post-disaster waste management presents additional challenges that are often more complex and urgent. Despite numerous studies on post-earthquake CDW (İlcan, 2025), there is a notable lack of systematic, field-based research investigating how building age, construction type, and local regulations influence waste composition, particularly in Türkiye and other developing countries. The recent earthquakes in Türkiye have underscored the critical importance of understanding DW composition, where institutional capacity and recycling infrastructure may be limited. Research following the 2023 Türkiye earthquakes indicates that the waste stream was predominantly composed of concrete (up to 59%) and bricks (approximately 28%; Alkan et al., 2025; Xiao et al., 2023), with metals and wood present in smaller quantities. The high proportion of concrete and masonry presents primary sources for recycling into new aggregates, reducing the demand for virgin materials and lowering environmental costs (Alkan et al., 2025). The use of industrial by-products such as fly ash can further improve the quality of these recycled aggregates, enhancing their suitability for new construction (Alkan et al., 2025).

The study aimed at two objectives: (i) the characterization of DW originating from post-earthquake controlled demolitions and (ii) the investigation of the impact of the building's age on DW characterization in accordance with the Turkish Building Earthquake Code (TBEC) implemented in Türkiye, and to identify materials fractions that can be valorised within the scope of the circular economy. This study also provided the methodological framework for similar studies aimed at observing the impact of building stock on DW composition. Addressing this knowledge gap is critical for informing both developing and developed countries. Despite the importance of DW characterization in waste management, comprehensive studies considering building age remain limited in the literature. To address this, a systematic field study was conducted in Malatya, one of the cities most severely affected by the 6 February 2023 earthquakes in Türkiye, selected due to its proximity to the epicentre of the second earthquake. Conducting systematic field investigations, such as this study, represents a significant step towards understanding the valorization potential of CDW. In addition, the impact of different factors, such as various types of buildings, construction materials, and demolition types, on recycling activities should be investigated for future perspectives.

Materials and methods

Study area

Türkiye's southeastern region experienced 2 major earthquakes on 6 February 2023, causing severe impacts across 11 provinces, including Hatay, Kahramanmaraş, Malatya, Adıyaman, Gaziantep, Diyarbakır, Osmaniye, Adana, Şanlıurfa, Elazığ, Kilis, Kayseri, and Niğde (Figure 1). According to the Strategy and Budget Office of the Presidency of Türkiye, approximately 14 million people, 16.4% of the national population of 85.7 million, were affected (SBO, 2023). Furthermore, the Ministry of Environment, Urbanization, and Climate Change of Türkiye (MoEUCC) reported that 279,000 buildings and 821,302 independent residential units sustained damage requiring demolition to ensure safety and structural integrity (MoEUCC, 2023). The field study was conducted in Malatya, one of the cities most severely affected by the 6 February 2023 earthquakes in Türkiye. The city was selected due to its proximity to the epicentre of the second earthquake (Figure 1, red dot) and because it implemented controlled demolition and debris management in the most organized manner following the disaster.

A multi-stage field study was conducted to assess the composition of DW resulting from heavily and moderately damaged concrete buildings in the 2023 earthquakes (Figure 2). The first stage of the study covers the data collection from local

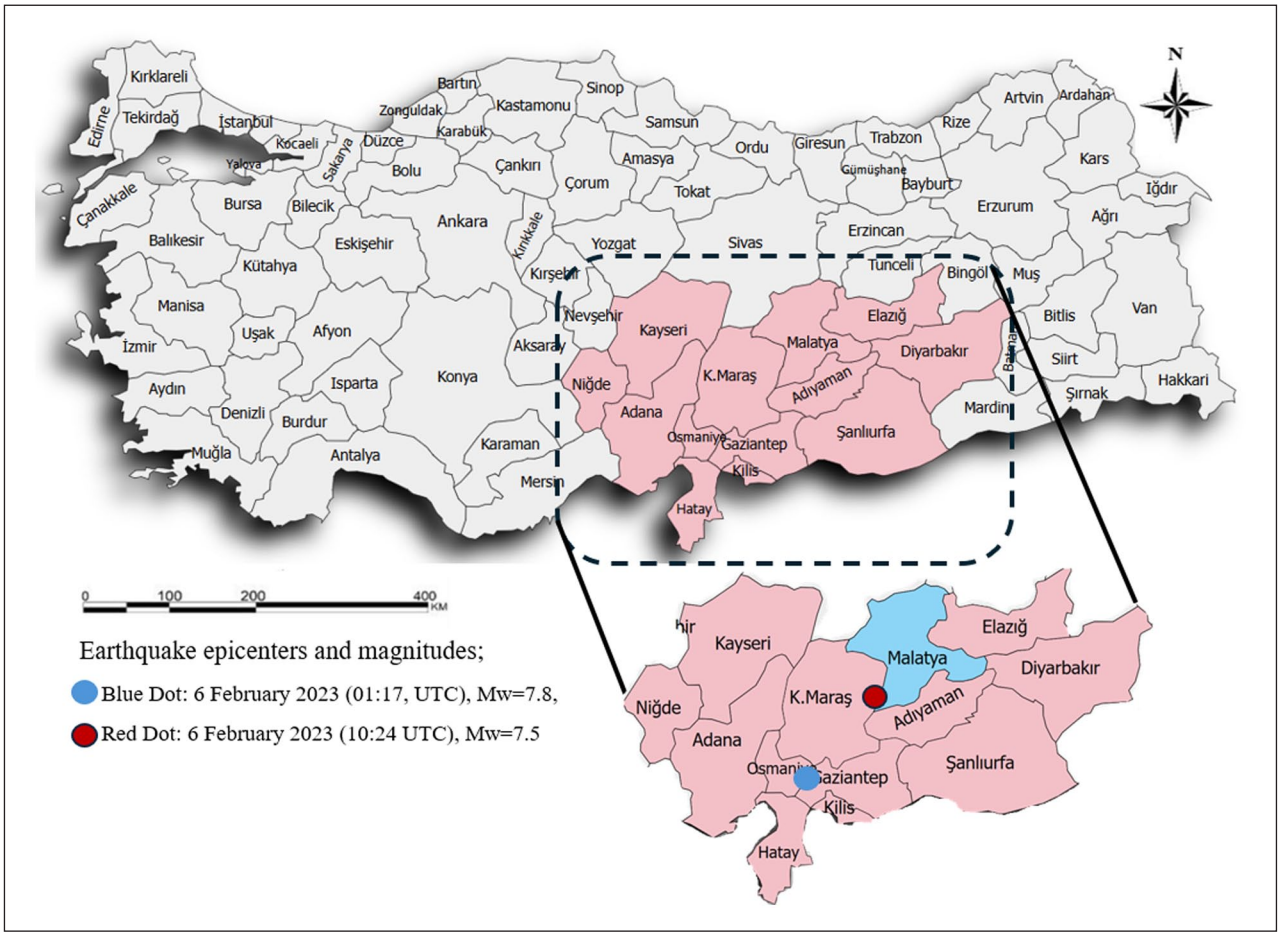


Figure 1. Türkiye's map with the 13 provinces affected by the earthquakes on 6 February 2023.

governments/district municipalities. The collected data involves the structural project plan, year of construction, gross area, location, building material, and number of independent units. Based on the collected dataset, buildings from three construction periods (pre-2000, 2000–2011, and 2011–2018) were selected to represent different construction periods. The second stage focused on the selection of samples for the characterization study. The selected buildings-controlled demolishing was carried out. At the end of the demolition process, excavation debris was removed via trucks. Each truck loaded with debris was weighed to determine the carried debris amount. After that, five loaded trucks were randomly selected to unload their waste to specified area. Each pile (unloaded debris) was marked with a number plate in order to prevent interference of each other. Then, three piles were randomly selected to proceed characterization study. The final stage of the study was to characterize the mixed debris and debris originated from buildings excavation in order to obtain material compositions.

Stage 1: Data collection and selection of buildings

This stage of the study involved collecting data from local authorities/district municipalities for building selection. The collected information about the buildings included the following data: structural plan, construction year, gross area, location, building material, and the independent unit number of the buildings. Information regarding the buildings was obtained from Yeşilyurt and Battalgazi District Municipalities, based on their locations. The heavily damaged buildings were in different neighbourhoods. The research team followed to the administration's demolition plan. Therefore, heavily damaged reinforced concrete buildings scheduled for demolition were selected for this study. The selection of the buildings was based on the collected data. Initially, the year of construction was crucial to observe the effect of the TBEC on Türkiye's building stock and the composition of the debris. The study aimed to observe the impact of changing seismic codes and regulatory practices on DW characterization by dividing Turkey's building stock into three construction periods: pre-2000 (representing the 1975 seismic code), 2000–2011 (post-1999 reinforced concrete regulations; for example, the increasing adoption of ready-mixed concrete), and 2011–2018 (constructed in compliance with the 2007 seismic code and subject to mandatory building inspection after 2011). The reason for choosing the different year period was to examine the seismic design code changes in Türkiye over the last five decades. Türkiye's building stock can be classified into three main groups based on construction periods and the

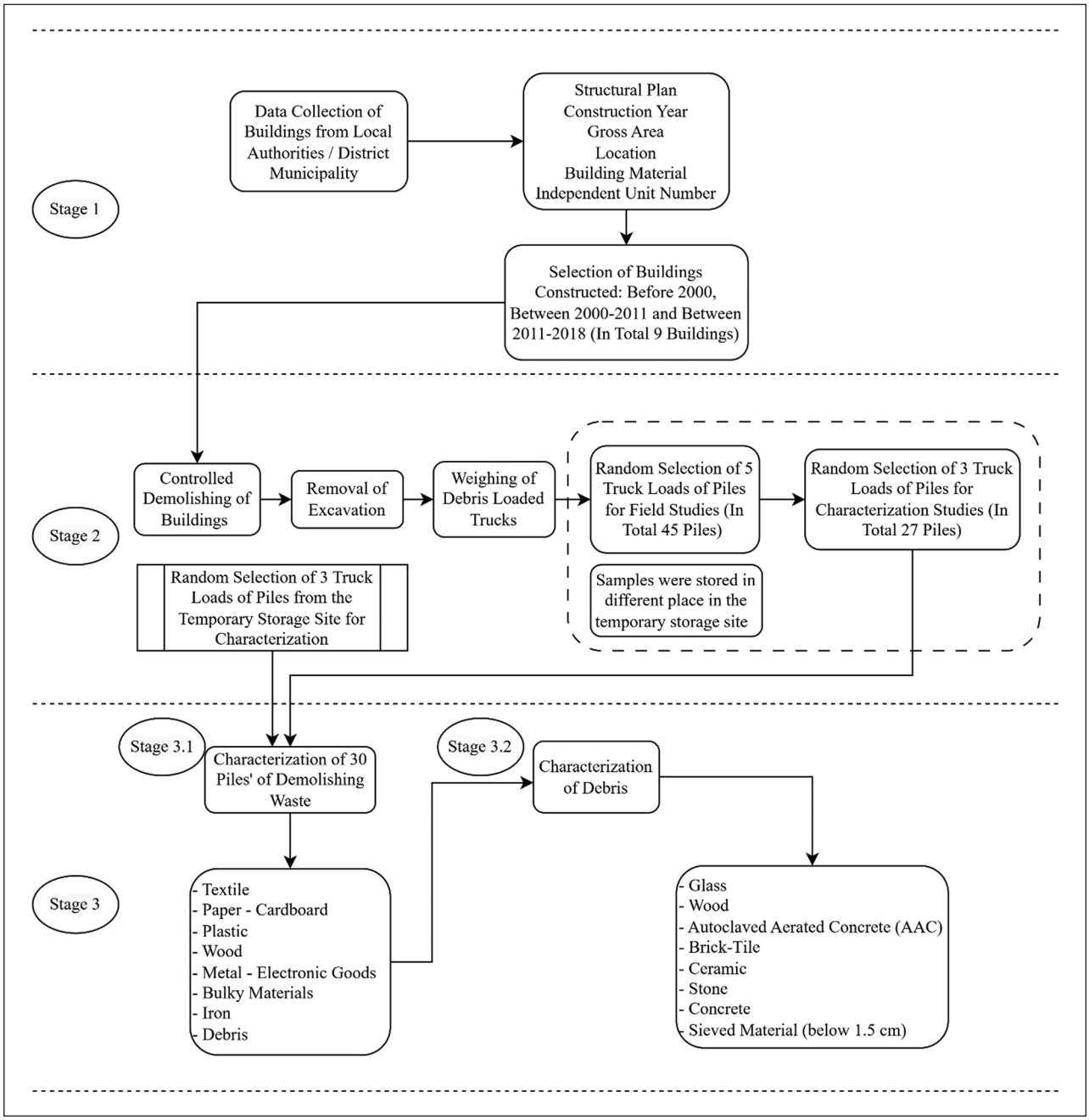


Figure 2. Methodology of the study and main stages.

evolution of seismic regulations. Structures built before 2000 were designed according to the 1975 seismic code. After the 1999 Gölcük earthquake, significant revisions were made to construction regulations; for instance, the use of ready-mixed concrete was mandated after 2000. Additionally, the current seismic regulation, the TBEC was issued on 18 March 2018 (Earthquake Quick Fact Sheet, 2019). Heavily damaged reinforced concrete buildings (built before 2000, between 2000 and 2011, and between 2011 and 2018) requiring urgent demolition were selected ($n=3$ per construction year period in a total of nine buildings) to represent construction year periods (Supplemental Figure S1). After that, buildings were named B1, B2, and B3 built before 2000, B4, B5, and B6 built between 2000 and 2011, and B7, B8, and B9 built between 2011 and 2018. The presence of basements, often used for various purposes such as storage, and the foundational structures of some buildings were also examined. Prior to demolition, household items such as furniture and appliances had been removed by the homeowners. In addition, research team conducted a pre-study on the demolition of severely-damaged building, which was built before 2000, with involving personal belongings of houseowners. In this pre-study, 10% of total amount of building's DW was characterized. Results showed that the composition was involving; approximately 94.8% mixed debris, 2.3% iron, 1.1% metals and electronics, 0.98% wood, 0.34% plastic, 0.31% textile, 0.1% paper and cardboard, and 0.1% was bulky items. Therefore, personal

belongings influenced the distribution only 2% at max. Consequently, the demolition predominantly involved only the reinforced concrete structure and the roof of the buildings (Supplemental Figure S2). To enhance the representativeness of the study, an attempt was made to select buildings with similar structural characteristics. For instance, all selected buildings constructed before 2000 are 4-storey high, although their gross areas differ. Notably, Buildings 1 and 3 are similar in terms of structural design but have different gross areas. Among the buildings constructed between 2000 and 2011, Building 4 is 5-storeys high, whereas the rest are 4-storeys. Furthermore, Buildings 4 and 6 have a basement, whereas Building 5 does not. Among the buildings constructed between 2011 and 2018, Buildings 7 and 8 have a basement. These buildings were constructed with raft foundations and are 7 and 8 storeys high, respectively. Building 9, however, has column foundations, similar to those in buildings constructed before 2011.

Stage 2: Demolition of selected buildings and sample selection

A structured and systematically controlled sampling strategy was implemented and closely supervised by the research team throughout the fieldwork to minimize potential sampling bias. Prior to demolition, the total amount of DW expected from each building was estimated by the research team using building inventory data obtained in Stage 1 (Figure 2), including the number of storeys, number of independent units, gross floor area, and structural characteristics. Based on these data, the total potential waste amount and the corresponding number of truckloads required for each building were predicted. Based on the estimated total number of truckloads per building (e.g. approximately 50 truckloads), a systematic sampling interval was defined prior to the start of demolition. To ensure representative coverage of waste generated during the early, middle, and late stages of demolition, one truckload was randomly selected from each predefined interval (e.g. 1 truck per 10-truck interval). For buildings with higher predicted waste volumes (e.g. approximately 100 truckloads), the sampling interval was adjusted accordingly (e.g. 1 truck per 20-truck interval), while maintaining a consistent sampling frequency of five truckloads per building distributed over the entire demolition timeline. The contracted companies conducted a controlled demolition of the selected buildings. The removal of the debris from demolished buildings was provided (Supplemental Figure S3). All trucks involved in the removal of the excavation were weighed to determine the amount of debris (Supplemental Figure S4). At first, each unloaded truck was weighed as empty to differentiate between those loaded with debris. After that, each loaded truck with debris was weighed, and the difference between the loaded and unloaded weighing results showed the net amount of debris for each truck (Supplemental Figure S5). The weighing of each truck was important not only for knowledge of selected samples' waste amount but also for establishing an informed and unbiased sampling framework. After that, 5 unloaded debris piles from debris trucks were randomly selected for each building (5 piles for 9 buildings, totalling 45 piles). All piles were numbered to obtain random selection while having the knowledge of the weight of piles. A secondary randomization step was then applied to select three piles per building for detailed characterization. This selection was performed using a random number generator in MS Excel. As a result, 3 piles out of 5 were chosen randomly for characterization studies, yielding a total of 27 piles across the 9 buildings (Supplemental Figure S6). Sampling from temporary storage site enabled a comparative assessment between building-scale and aggregated waste streams, helping to reduce potential sampling bias and to validate whether material characteristics remain consistent after transportation and short-term stockpiling. The temporary storage site was serving especially for DW originating from controlled demolitions, and the disposal of other waste types such as MSW was restricted. However, minor traces of municipal solid waste may occasionally be present due to personal belongings left in buildings prior to demolition. This possibility was considered during sampling, and care was taken to ensure that the collected samples predominantly represent structural DW. Therefore, 3 truckloads of piles were taken from the different locations (approximately 30 different points) of the temporary storage site. Overall, 30 piles of mixed debris were collected for characterization.

Stage 3: Weight basis characterization of selected samples

This stage of the study involves two distinct characterization procedures for categorized as Stage 3.1 (Mixed-Debris) and Stage 3.2 (Debris). To clarify the terminology used in this study: Mixed Debris refers to the raw, unsorted DW. Debris refers specifically to the mineral-based fraction (concrete, brick, etc.) extracted from the mixed debris. In the characterization, the American Society for Testing and Materials Standard Test Method (ASTM) for Determination of the Composition of Unprocessed Municipal Solid Waste was applied to ensure that the waste was homogeneously mixed and characterized (ASTM D5231-92, 2024).

Stage 3.1: Mixed-debris characterization. This substage involves characterizing mixed debris. The selected three piles were characterized by hand sorting and heavy machinery use. Heavy machines were used for different purposes during characterization, such as spreading the waste on the ground and separating iron and bulky items from the piles. In total, 30 piles, approximately 490 tonnes of mixed debris, were characterized. The eight waste categories (textiles, paper/cardboard, plastic, wood, metals/electronics, bulky items, iron, and debris) were classified. After that, each component was weighed to determine its mass percentage in the pile (Supplemental Figure S7).

Stage 3.2: Debris characterization. In this stage, debris characterization was conducted to categorize the material fractions in

the separate piles. The heavy machine load of samples was taken from the homogeneously mixed debris by applying the quartering method of ASTM D5231-92 method. In total, 10 tonnes of debris were characterized. It was spread on the clean ground for the separation of larger concrete materials. After separating the larger materials, the leftover debris was sieved through a 1.5-cm sieve. The materials under the sieve were classified as 'sieved material', and the materials that could not pass through the sieve were separated by hand sorting. The eight waste categories (glass, wood, autoclaved aerated concrete (AAC), brick-tile, ceramic, stone, concrete, and sieved material (below 1.5-cm sieve)) were classified and weighed to determine the mass percentage in the sample (Supplemental Figure S8).

Results and discussion

This study investigated two main objectives: (i) to characterize DW generated from controlled demolitions carried out after the earthquake, and (ii) it examined how construction periods influence the composition of debris generated from buildings. The following sections present the findings from the field study in Malatya, providing insights into material fractions with potential for valorization within a framework.

Characterization of DW originated from post-earthquake controlled demolitions

The analysis of DW mass composition across different building periods (B1–B9) shows that the waste stream generally consists of two main components: debris and iron. Debris amounts showed consistently high mass percentage, ranging from approximately 94% to 97% across all construction periods. Iron represents a much smaller percentage of the total mass; it demonstrates the higher variability depending on the construction period, ranging between about 1.69% and 3.48%. A sharp increase was observed in the B7 building (2011–2018 period), where iron amount reaches approximately 4.23%. Therefore, it suggests differences in structural design practices, changes in the required amount of steel reinforcement, or the use of diverse structural steel systems across different construction periods. Wood, textiles, plastic, paper and cardboard, metals and electronic equipment, and bulky items appeared as secondary or minor fractions due to their low overall mass contribution, typically below 5% of the total mass. Wood was the most prevalent among these, occasionally reaching up to 0.8% in certain cases due to usage for flooring and roofing material in the buildings. The low percentages of these non-structural materials were caused by the removal of items before demolition, such as fixtures, furnishings, and other non-structural elements. The construction period and the mass fraction of these minor components have not been found to have any clear systematic correlation or temporal trend. Results showed that the newer buildings had higher iron composition (3.5%), whereas the older buildings had higher debris amounts. The TBEC on earthquake resistance in buildings affects the composition of buildings. These findings provide important insights for the valorization potential of DW within the built environment. The grouped mass fractions of DW, simplified into three categories: debris as inert rubble, iron, and other minor components, such as combining textiles, paper/cardboard, plastic, wood, metals/electronics, and bulky items and the average mass percentage for each construction period is given in Tables 1 and 2.

The two largest contributors, concrete and sieved material (below 1.5 cm), show opposite trends across periods. The mass fraction of concrete increased exponentially from 40.07% in pre-2000 buildings to 81.28% in the 2011–2018 period, clearly reflecting the widespread adoption of reinforced concrete structural systems and the rising quantity of concrete mass per unit area in modern buildings. In contrast, sieved material, consisting of fine aggregates, mortar, and small brick or tile fragments, dropped from 43.60% in older buildings to only 14.15% in between 2011 and 2018. It shows that debris composition has shifted from being fine-grained to being overwhelmingly dominated by coarse concrete. Traditional materials have also declined sharply: brick and tile represented 10.72% of debris in pre-2000 buildings, consistent with a decrease to 2.51% in newer construction periods, suggesting substitution by lighter or prefabricated alternatives. Other minor fractions, such as glass, AAC, ceramic, and stone, consistently remain negligible, never exceeding 5.70%. Data from the temporary storage site show an aggregate composition of 62.17% concrete and 27.80% sieved material, reflecting a mixture of older structures rich in wood and fine waste and newer ones dominated by concrete. Overall, the findings highlight that DW streams are now overwhelmingly concrete-centric, requiring focused waste management strategies on efficient crushing and processing of the concrete fraction to enable high-purity aggregate recovery.

Evaluation of building age and seismic codes influence on DW distribution

The building age is strongly related to construction materials and the number of buildings, which can impact the composition of earthquake waste. In addition, the buildings in Türkiye are mainly reinforced concrete. Xiao et al. (2023) reported DW composition of reinforced concrete and masonry structures. In reinforced concrete structures, concrete itself forms the largest component (34.8%), followed by bricks (21.9%). However, a variety of other materials are also present, including metals (2.3%), plastics (2.1%), timber (1.3%), glass (0.3%), roofing tiles (0.1%), and an uncategorized 'other' category (0.2%). Masonry structures show a distinct material profile (Xiao et al., 2023). Bricks are the dominant element (59.1%), with concrete still present as a significant component (34.8%). Similar to reinforced concrete structures, smaller percentages of plastics (1.9%), roofing tiles (5.2%), metal (0.3%), glass (0.3%), and 'other' materials (0.3%) are used in masonry structures. One key difference is the noticeably higher presence of timber

Table 1. Mixed debris composition across building periods and temporary storage site.

Waste categories/building year and number	Before 2000 (B1, B2, B3)		Between 2000 and 2011 (B4, B5, B6)		Between 2011 and 2018 (B7, B8, B9)		Temporary storage site		Overall
	Ave ± SD[a] (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave (%)
Textiles	6.7 ± 3.6	0.01	2.8 ± 0.2	0.005	0	0	3.8 ± 2.9	0.03	0.01
Paper and cardboard	0.7 ± 0.4	0.001	4.8 ± 2.1	0.01	0.2 ± 0.08	0.0003	0	0	0.004
Plastic	14.7 ± 4.5	0.03	39.3 ± 1.4	0.07	23.0 ± 4.4	0.05	15.8 ± 7.8	0.16	0.08
Wood	223.3 ± 22.7	0.45	322.9 ± 36.8	0.57	110.5 ± 26.7	0.23	44.9 ± 25.4	0.46	0.43
Metals and electronic equipments	4.4 ± 1.3	0.01	28.1 ± 9.7	0.05	3.9 ± 2.3	0.01	8.3 ± 5.2	0.09	0.04
Bulky items	0	0	83.3 ± 25.5	0.15	0	0	0	0	0.04
Iron	1100 ± 136.4	2.19	1300 ± 101.4	2.34	1633 ± 431	3.48	164.7 ± 102.5	1.69	2.43
Debris	48,883 ± 479	97.31	54,602 ± 1844	96.82	45,479 ± 1072	96.23	9480 ± 1610	97.57	96.98
Total	50,233 ± 426	100%[b]	56,383 ± 1835	100%[b]	47,250 ± 678	100%[b]	9717 ± 1501	100%[b]	100%[b]

[a]Average and standard deviation.
[b]Due to rounding of individual values, the sum of percentages may exceed 100%.

Table 2. Debris composition across building periods and temporary storage site.

Waste categories/building year and number	Before 2000 (B1, B2, B3)		Between 2000 and 2011 (B4, B5, B6)		Between 2011 and 2018 (B7, B8, B9)		Temporary storage site		Overall
	Ave ± SD[a] (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave (%)
Glass	0.27 ± 0.12	0.03	0.28 ± 0.1	0.04	0.15 ± 0.04	0.02	0.15 ± 0.04	0.03	0.03
Wood	8.9 ± 2.54	0.88	2.77 ± 0.7	0.41	2.2 ± 1.7	0.31	1.3 ± 0.8	0.18	0.45
AAC	0	0	0	0	0	0	4.1 ± 2.6	0.59	0.59
Brick and tile	110.2 ± 60.7	10.72	76.4 ± 26.9	10.19	18.6 ± 11.8	2.51	46.5 ± 17.9	7.06	7.62
Ceramic	48.3 ± 22.8	4.70	41.5 ± 13.3	5.70	12.9 ± 9.5	1.73	12.3 ± 0.9	1.98	3.53
Stone	0	0	0	0	0	0	4.6 ± 0.01	0.19	0.05
Concrete	396.7 ± 77.6	40.07	258.9 ± 39.2	35.86	576.7 ± 57.9	81.28	409.3 ± 143.9	62.17	54.84
Sieved material (below 1.5 cm)	438.0 ± 49.9	43.60	351.3 ± 68.8	47.80	99.0 ± 31.9	14.15	162.5 ± 43.8	27.80	33.34
Total	1002.4 ± 74.8	100%[b]	731.3 ± 153.3	100%[b]	709.6 ± 59.3	100%[b]	637.7 ± 128.7	100%[b]	100%[b]

AAC: autoclaved aerated concrete.
[a]Average and standard deviation.
[b]Due to rounding of individual values, the sum of percentages may exceed 100%.

(10.9%) in masonry structures compared to timber (1.3%) in reinforced concrete structures (Xiao et al., 2023).

The DW compositions of recyclables other than concrete varied across building periods (Tables 3 and 4). For instance, textiles were consistently negligible, ranging from 0% to 0.04%, and paper and cardboard accounted for a maximum of 0.02% in B6. Plastics showed low but variable contributions, reaching up to 0.08% in B6 and B8. Wood exhibited modest but notable presence, peaking at 0.74% in B5 and remaining below 0.61% in other buildings. Metals and electronic equipment fractions were minimal, with the highest share of 0.10% in B5. Bulky items were primarily detected in B5 and B6 (0.25% and 0.20%, respectively). Iron, the dominant minor material, ranged from 1.52% in B1 to 4.23% in B7, highlighting its relative importance compared to other minor fractions.

The regulations on the construction of earthquake-resistant buildings in Türkiye aimed to build stronger structures in the last three decades. Therefore, the construction year period (building age) impacted the concrete and iron amounts used in the buildings. The results of the study were consistent with the existing literature except concrete. Xiao et al. (2023) stated that reinforced concrete structures contain 93.8% debris, 2.3% metals, 2.1% plastics, 1.3% wood, and 0.5% other materials. It was observed that wood, plastic, and other materials proportions were lower. The reason was that the demolished buildings under control were emptied before the demolition period. Therefore, different waste contributors, such as households, were emptied from buildings. In this case, the authorities need to know different waste types and amounts that should be expected when removal of collapsed and demolished debris from buildings. The composition of waste from demolished buildings changes over time and location. For instance, Xiao et al. (2023) suggested that debris is the main component of earthquake DW. Therefore, the disposal of this material would be a focus of resource utilization, and the recycling strategies for waste wood, iron, plastics, and other solid waste should not be overlooked. Comparative literature survey with the mass-based composition of CDW across various European and global countries, with particular emphasis on comparing the findings from 'This Study (Türkiye)' is given in Table 5.

Previous studies have emphasized that the number of sampling units is a critical factor in ensuring representativeness. DW is inherently heterogeneous, and its characterization requires sampling strategies that account for large variability in material type, size, and origin. Depending on the target debris source and study objective, the number of waste loads required for representative characterization can be prohibitively large (Wasserman et al., 2022). Significantly larger sample masses are required to ensure representativeness for DW due to the large component size and mass of materials such as concrete blocks, beams, and masonry elements (Townsend and Anshassi, 2023). Several large-scale characterization studies reported in the literature support the use of high-mass sampling approaches for DW. Castro et al. (1997) characterized approximately 400 tonnes of mixed debris and subsequently reduced the material to a 5-tonne representative subsample for manual sorting. Similarly, urban-scale studies have reported that qualitative characterization samples may range from 100 to 400 tonnes, reflecting the practical challenges associated with the heterogeneity of DW streams (Rodrigo Eduardo Córdoba et al., 2019). Other studies based on punctual sampling at disposal areas reported total sample masses exceeding 300 kg, although these approaches were noted to have limitations in capturing bulky components such as large concrete blocks (Marques Neto, 2005; Pinto, 1989).

Comparing the findings of this study with the international data (Table 5), Türkiye's DW stream is notably more inert and concrete-rich than in many European and North American contexts, where mixed waste and wood fractions are higher. For instance, countries like Finland, Sweden, and the United States report wood fractions ranging from 14% to 27%, whereas mineral fractions typically range from 60% to 90% in most EU countries. The dominance of concrete in Türkiye (>58% of total DW) suggests a high potential for aggregate recovery and targeted recycling strategies, which can significantly contribute to a circular economy. Table 5 consistently show that mineral waste, including concrete, bricks, tiles, stone, and ceramics, dominates DW streams, often accounting for more than 90% of the total mass (European Commission, 2021; Damgaard et al., 2022). In addition, China has similar value as 87% (Zhang et al., 2024). In Türkiye, the cumulative mineral fraction is exceptionally high at approximately 96.95%, consisting largely of concrete (53.19%), followed by other minerals (32.95%) and brick and tile and ceramic (10.81%). This unusually high proportion underscores that Türkiye's DW stream is among the most inert, positioning it as a valuable resource for aggregate recovery.

On the other hand, in the presence of mixed waste, Italy stands out with the highest value (86.3%), whereas countries such as Denmark (21.1%), Norway (17.5%), Netherlands (14.2%), the Czech Republic (13.8%), France (13.3%), and Germany (5.1%) report considerable shares of mixed waste (Damgaard et al., 2022). The proportion of mixed waste observed in this study (Türkiye) is only 0.1%. Similarly, lightweight material such as wood (0.4%) is present in our study at far lower levels than in Finland (21.4%), Sweden (17.5%), Norway (14.5%), and the United States, where wood fractions range from 0.2% to 45.0% in the literature (Damgaard et al., 2022; European Commission, 2021; Townsend and Anshassi, 2023). These findings show that emptying the buildings before demolition excludes non-inert materials, or the building type differs significantly from that used in other countries.

Although mineral waste dominates, the distribution of structural materials in Türkiye reveals certain differences compared to higher-income European nations. The concrete fraction of 53.19% in Türkiye is higher than in most countries. This indicates that Türkiye's building stock generates a DW stream with a substantial concrete mass, pointing to high potential for valorization in terms of reuse and recycling on concrete aggregates. Türkiye's DW composition is defined by its high concrete

Table 3. DW compositions of buildings constructed before 2000 and between 2000 and 2011 (B1–B6).

Waste categories/ building year and number	Before 2000						Between 2000 and 2011					
	B1		B2		B3		B4			B5		B6
	Ave ± SD[a] (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)
Textiles	6.4 ± 5.5	0.04	0	0	0.27 ± 0.46	0.002	0.70 ± 0.9	0.004	1.2 ± 1.0	0.01	0.93 ± 1.6	0.01
Paper and cardboard	0.7 ± 1.21	0.004	0	0	0	0	0.47 ± 0.81	0.002	0.27 ± 0.46	0.001	4.03 ± 3.95	0.02
Plastic	8.8 ± 3.3	0.05	0	0	5.9 ± 1.5	0.04	11.6 ± 9.1	0.06	14.4 ± 17.1	0.07	13.3 ± 5.3	0.08
Wood	100 ± 0	0.61	56.7 ± 40.4	0.33	66.7 ± 28.9	0.40	89.6 ± 96.9	0.46	150 ± 86.6	0.74	83.3 ± 28.9	0.50
Metals and electronic equipments	1.9 ± 3.4	0.01	0	0	2.5 ± 2.3	0.01	4.6 ± 6.02	0.02	20.5 ± 26.2	0.10	3.03 ± 3.4	0.02
Bulky items	0	0	0	0	0	0	0	0	50 ± 86.6	0.25	33.3 ± 57.7	0.20
Iron	250 ± 50	1.52	333.3 ± 76.4	1.93	516.7 ± 76.4	3.12	316.7 ± 246.6	1.63	483.3 ± 292.9	2.39	500 ± 150	2.99
Debris	16,082 ± 3293	97.76	16,843 ± 1727	97.74	15,958 ± 4041	96.42	18,976 ± 4143	97.82	19,530 ± 3921	96.45	16,095 ± 2563	96.19
Total	16,450 ± 3294	100%[b]	17,233 ± 1629	100%[b]	16,550 ± 4048	100%[b]	19,400 ± 4025	100%[b]	20,250 ± 3666	100%[b]	16,733 ± 2457	100%[b]

DW: demolition waste.
[a]Average and standard deviation.
[b]Due to rounding of individual values, the sum of percentages may exceed 100%.

Table 4. DW compositions of buildings constructed between 2011 and 2018 (B7–B9) and temporary storage site.

Waste categories/building year and number	Between 2011 and 2018							
	B7		B8		B9		Temporary storage site	
	Ave ± SD[a] kg	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)	Ave ± SD (kg)	Ave (%)
Textiles	0	0	0	0	0	0	3.75 ± 2.85	0.03
Paper and cardboard	0	0	0	0	0.13 ± 0.23	0	0	0
Plastic	4.6 ± 1.6	0.03	12.7 ± 6.4	0.08	5.7 ± 4.0	0.03	15.8 ± 7.8	0.16
Wood	28.5 ± 4.6	0.19	15.3 ± 5.8	0.10	66.7 ± 28.9	0.40	44.9 ± 25.4	0.46
Metals and electronic equipments	3.9 ± 6.8	0.03	0	0	0	0	8.3 ± 5.2	0.09
Bulky items	0	0	0	0	0	0	0	0
Iron	1283.3 ± 275.4	4.23	983.3 ± 583.8	3.58	433.3 ± 125.8	2.62	164.7 ± 102.5	1.69
Debris	14,030 ± 1838	95.52	14,355 ± 7342	96.24	16,028 ± 2522	96.94	9480 ± 1610	97.57
Total	15,350 ± 1852	100%[b]	15,367 ± 6784	100%[b]	16,533 ± 2398	100%[b]	9717 ± 1501	100%[b]

DW: demolition waste.
[a]Average and standard deviation.
[b]Due to rounding of individual values, the sum of percentages may exceed 100%.

Table 5. Literature comparison of DW percentages across different countries.

Country/waste category	Mineral waste (%)	Concrete (%)	Bricks (%)	Tiles and ceramic (%)	Mixed/other mineral/inert waste (%)	Plastic (%)	Metal (%)	Glass (%)	Wood (%)	Gypsum (%)	Insulation (%)	Paper and cardboard (%)	Hazardous waste (%)	Mixed waste, generic (%)	Total (%)
Belgium[a,b]	93	—	—	—	—	0.112	1.5	0.2	2.5	—	—	—	2.7	—	100
Bulgaria[a,b]	93.9	—	—	—	—	—	5.6	0.1	0.4	—	—	—	—	—	100
China[c]	87	48	21	10	8	—	7	—	—	—	—	—	—	6	100
Czech Republic[a]	75.9	30.3	17.8	0.3	27.5	—	—	—	—	0.2	1.4	—	8.7	13.8	100
Denmark[a,d]	57.3	34.5	5.6	2.3	14.9	0.2	11.4	0.8	4	1.9	0.6	—	2.7	21.1	100
Finland[a,b]	61.4	—	—	—	—	—	9.1	—	21.4	—	—	—	8.1	—	100
France[a]	73.4	33.6	2.7	2.7	34.4	0.8	2.3	0.2	3.5	3.5	0.2	—	2.9	13.3	100
Germany[a]	71.4	31.4	7.8	1.7	30.5	0.2	11	0.5	4.1	0.8	0.1	—	6.8	5.1	100
India[e]	93	23	31	—	39	—	5	—	2	—	—	—	—	—	100
Ireland[a,b]	95.7	—	—	—	—	0.1	0.7	0.1	2.5	—	—	—	1	—	100
Italy[a]	—	—	—	—	—	0.1	11.3	0.2	0.4	—	—	—	1.8	86.3	100
Malaysia[f]	38	20	9	—	9	—	62	—	—	—	—	—	—	—	100
Nepal[g]	96	10.4	74.7	0.2	10.5	—	0.4		3.8	—	—	—	—	—	100
Netherlands[a,h]	63.733	6.7	1.4	0.033	55.6	0.8	12.9	0.3	5.1	0.3	0.1	0.2	2.4	14.2	100
Norway[a,i]	42.8	—	—	—	—	0.6	6	0.6	14.5	4.4	0	1.3	12.3	17.5	100
Portugal[a,b]	91.7	—	—	—	—	0.3	4.3	0.2	2.3	—	—	—	1.3	—	100
Spain[a,b]	97.8	—	—	—	—	0.2	0.5	0.1	1	—	—	—	0.5	—	100
Sweden[a,b]	73.9	—	—	—	—	—	2.2	0.2	17.5	—	—	—	6.2	—	100
United Kingdom[a,b]	95.1	—	—	—	—	0.1	3	0.1	0.9	—	—	—	0.7	—	100
USA[j,k]	87	56		24	7	—	—	—	<1	13	—	—	—	—	100
USA[k,l]	55	—	—	—	55	—	4	—	41	—	—	—	—	—	100
USA[k,m]	64	18	—	—	46	—	3	—	27	6	—	—	—	—	100
USA[k,m]	44	2	—	—	42	—	—	—	45	11	—	—	—	—	100
USA[k,n]	87.0	36.0	—	24.0	27.0	—	—	—	0.2	13.0	—	—	—	—	100
Türkiye (this study)	96.95	53.19	10.81		32.95	0.08	2.46	0.03	0.43	—	—	0.004	—	<0.1	100

Mineral waste refers to combination of concrete, bricks, tiles and ceramic and mixed/other mineral/inert waste. For the results of this study, percentages of brick and tile and ceramic combined in this table since these wastes characterized within different groups. For the values of Türkiye, overall average debris percentages from Table 1 were combined with the overall average of the data from Table 2 and divided into mineral fractions. Mixed waste refers to the uncategorized waste stream such as MSW. — represent no data. DW: demolition waste; USA: United States.

[a]Damgaard et al. (2022).
[b]European Commission (2021).
[c]Zheng et al. (2017).
[d]Danish EPA (2020).
[e]Faruqi et al. (2020).
[f]Mah et al. (2016).
[g]Poudel et al. (2019).
[h]Mulders (2013).
[i]Statistics Norway (2024).
[j]Tiwary (2016).
[k]Townsend and Anshassi (2023).
[l]Cunningham Environmental Consulting et al. (1997).
[m]Cascadia Consulting Group (2006).
[n]Cascadia Consulting Group (2008).

content, presenting an important source for mineral recycling globally. Consequently, waste management strategies in Türkiye should prioritize optimizing the recovery and processing of concrete aggregates.

The comparability of DW composition results across different studies should be interpreted with caution, as variations in sampling strategies, sample sizes, and demolition practices can significantly influence reported waste fractions. In particular, the proportion of mixed waste is highly sensitive to whether data are derived from controlled demolition activities conducted for scientific purposes or from routine, large-scale demolition operations. Controlled demolition is typically performed with greater care and supervision, often allowing partial material separation at source, which may result in lower reported mixed-waste fractions.

In contrast, DW generated under real post-disaster conditions or time-constrained demolition processes may exhibit higher levels of material mixing due to operational urgency and limited segregation. The literature referenced in this article highlights a broad range of sampling contexts, especially controlled demolition practices.

Limitations and future perspectives

This study provides a detailed analysis of DW composition from buildings of different ages in Malatya, Türkiye; however, several limitations should be noted. Firstly, focusing on a single city with controlled demolitions may limit the generalizability of the results to other regions with different building types or demolition practices. Secondly, pre-demolition removal of non-structural materials likely led to underestimation of minor fractions such as wood, plastics, textiles, and metals. Thirdly, the sampling of debris piles, while random and replicated, may not capture all variability across building types and demolition methods.

Future studies should expand, including both uncontrolled, controlled and selective demolitions, and assess material quality and recyclability. Evaluating mechanical properties of concrete aggregates, metal purity, and contamination in minor fractions would support targeted valorization. This study establishes a methodological framework for future research for DW fraction studies in different regions, combining systematic field sampling with mass-based characterization. Expanding the approach to include multiple provinces, uncontrolled demolitions, and detailed quality assessments of recovered materials would further enhance knowledge of DW valorization potential and support sustainable DW management globally. Integrating DW characterization with life cycle assessment and circular economy approaches could further enhance sustainable recycling strategies and inform policy globally.

Conclusion

A detailed analysis of DW from buildings of different construction periods, benchmarked against international data, reveals a clear evolution in its composition. The study demonstrates a shift away from traditional mixed-material construction towards structures increasingly dominated by concrete. Debris constitutes the vast majority of DW, approximately 94–97%, with other materials representing only minor fractions. Specifically, the concrete fraction has risen dramatically, from around 40% in buildings constructed before 2000 to over 80% in those built between 2011 and 2018, accompanied by a marked decline in traditional materials such as wood, brick, and tile. The iron fraction also shows a notable increase in the 2011–2018 period, indicating that building age can influence iron content and, consequently, the potential for targeted recovery. Understanding these variations is critical for designing waste management strategies that optimize the recovery of high-quality aggregates from the dominant concrete fraction while facilitating selective recovery of metals from newer buildings. Given that mixed waste is minimal, recovery processes can focus on advanced crushing and sorting techniques to produce cleaner recycled outputs. Information on the building age and material composition can increase the efficiency of DW management. Therefore, it is possible to enhance resource recovery, reduce environmental impacts, and support faster, more sustainable DW management. Furthermore, this study provides a methodological framework for future research investigating how construction practices, material choices, and demolition methods influence DW composition, offering insights relevant to both Türkiye and worldwide.

Acknowledgements

The authors gratefully acknowledge the financial support provided by Istanbul Technical University and The Scientific and Technological Research Council of Türkiye (TÜBİTAK). The authors also wish to express their sincere appreciation to the Ministry of Environment, Urbanization and Climate Change, the Malatya Governor's Office, the Malatya Metropolitan Municipality, the Yeşilyurt District Municipality, and the Battalgazi District Municipality for their valuable assistance and collaboration during the study. The authors are thankful to the supports of Prof. Alper Ilki, Dr. Pinar Inci, Ali Tamer Cetinkaya, Tolga Cinar, Yigit Berat Kaya before the study. During the preparation of this work, the authors used ChatGPT and Gemini in order to enhance clarity and fluency of selected passages. After using these tools, the authors reviewed and edited the content as needed for the article.

ORCID iDs

Kadir Özçelik https://orcid.org/0000-0001-6863-1261
Serra Selin Övez https://orcid.org/0009-0007-1256-323X
Kadriye Elif Maçin https://orcid.org/0000-0002-5989-7954
Osman Atilla Arıkan https://orcid.org/0000-0002-0716-1865

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Istanbul Technical University, Scientific Research Projects (Grant number: MÇAP-2023-44509). This work was also supported by the TÜBİTAK 1001 — The Scientific and Technological Research Projects Funding Programme (Grant number: 124Y212).

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability statement

The data are available from the corresponding author on reasonable request.

Supplemental material

Supplemental material for this article is available online.

References

Alkan SN, Yücetürk GD and Şengül Ö (2025) Life cycle assessment analysis of recycled concrete aggregate incorporating fly ash and hemp fiber. *Environmental Research and Technology* 8(3): 523–534. https://doi.org/10.35208/ert.1538648

ASTM D5231-92 (2024) *American Society for Testing and Materials Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste*. ASTM.

Bassani M, Riviera PP and Tefa L (2017) Short-term and long-term effects of cement kiln dust stabilization of construction and demolition waste. *Journal of Materials in Civil Engineering* 29(5): 04016286. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001797

Bayram B, Greiff K, Gerlich L, et al. (2025) Environmental and economic implications of selective demolition and advanced recycling of construction waste. *Sustainable Production and Consumption* 57: 61–79. https://doi.org/10.1016/j.spc.2025.05.007

Brandao R, Edwards DJ, Melo ACS, et al. (2023). Reverse supply chain practices for construction and demolition waste in the Brazilian Amazon: A multi-stakeholder view. *Journal of Material Cycles and Waste Management* 25(4): 2245–2261. https://doi.org/10.1007/s10163-023-01680-1

Buzkan C and Erman O (2020). Yapısal atıkların geri dönüşüm sorunu ve Türkiye'deki durumun mevzuat bakımından değerlendirilmesi (In Turkish). *Doğal Afetler Ve Çevre Dergisi* 6(1): 76–89. https://doi.org/10.21324/dacd.570141

Cascadia Consulting Group (2006) Targeted statewide waste characterization study: Detailed characterization of construction and demolition waste, June 2006. A Report Produced Under Contract by Cascadia Consulting Group for the California Environmental Protection Agency, Integrated Waste Management Board.

Cascadia Consulting Group (2008) Seattle Public Utilities: 2007 Construction & Demolition Waste Composition Study. Final report.

Castro MCAA, Schalch V, Fernandes Junior JL, et al. (1997). Caracterização física e granulométrica dos entulhos gerados na construção civil na cidade de São Paulo. In: *Anais do 19° Congresso Brasileiro de Engenharia Sanitária e Ambiental*. Associação Brasileira de Engenharia Sanitária e Ambiental (ABES), pp.1667–1673.

Cha GW, Choi SH, Hong WH, et al. (2023). Developing a prediction model of demolition-waste generation-rate via principal component analysis. *International Journal of Environmental Research and Public Health* 20(4): 3159. https://doi.org/10.3390/ijerph20043159

Cunningham Environmental Consulting, Cascadia Consulting Group, Sky Valley Associates and ElwayResearch (1997) Seattle public utilities construction, demolition and land clearing debris waste composition study: Final report. Seattle.gov.

Damgaard A, Lodato C, Butera S, et al. (2022). *Background Data Collection and Life Cycle Assessment for Construction and Demolition Waste (CDW) Management*. EUR 31323 EN, Publications Office of the European Union.

Danish EPA (2020). *Danish Waste Statistics 2019*. Danish EPA.

Earthquake Quick Fact Sheet (2019) Turkey: New building code for earthquake resilience. Available at: https://www.preventionweb.net/quick/26386 (accessed 31 October 2024).

Esa MR, Halog A and Rigamonti L (2017). Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *Journal of Material Cycles and Waste Management* 19(3): 1144–1154. https://doi.org/10.1007/s10163-016-0516-x

European Commission (2021) *Generation of Waste-by-Waste Category, Hazardousness and NACE Rev. 2 Activity*. Eurostat.

Eurostat (2024) *Waste Statistics – Construction and Demolition Waste*. European Commission.

Faruqi MHZ and Siddiqui FZ (2020) A mini review of construction and demolition waste management in India. *Waste Management & Research* 38(7): 708–716. https://doi.org/10.1177/0734242X20916.

Huang B, Wang X, Kua H, et al. (2018) Construction and demolition waste management in China through the 3R principle. *Resources, Conservation and Recycling* 129: 36–44. https://doi.org/10.1016/j.resconrec.2017.09.029

İlcan H (2025) Recycling-oriented characterization and valorization of concrete waste from the February 6th Kahramanmaraş earthquakes in sustainable built environment. *Journal of Material Cycles and Waste Management* 27(5): 1–18. https://doi.org/10.1007/s10163-025-02301-9

Karanafti A, Tsikaloudaki K and Theodosiou T (2022, December) Assessing the construction and demolition waste volume for a typical Mediterranean residential building. *IOP Conference Series: Earth and Environmental Science* 1123(1): 012024. https://doi.org/10.1088/1755-1315/1123/1/012024

Li J, Ji J, Zuo J, et al. (2023). Is policy the necessary or sufficient driving force of construction and demolition waste recycling industry development? Experience from China. *International Journal of Environmental Research and Public Health* 20(6): 4936. https://doi.org/10.3390/ijerph20064936

Ma W and Hao JL (2024) Enhancing a circular economy for construction and demolition waste management in China: A stakeholder engagement and key strategy approach. *Journal of Cleaner Production* 450: 141763. https://doi.org/10.1016/j.jclepro.2024.141763

Mah CM, Fujiwara T and Ho CS (2016) Construction and demolition waste generation rates for high-rise buildings in Malaysia. *Waste Management & Research* 34(12): 1224–1230. https://doi.org/10.1177/0734242X16666944

Marques Neto JC (2005) *Gestão dos resíduos de construção e demolição no Brasil*. Editora RiMa.

Ministry of Environment, Urbanization, and Climate Change of the Republic of Türkiye (MoEUCC) (2023) Damage Assessment Report for Buildings in 11 Provinces (in Turkish). Available at: https://csb.gov.tr/bakan-kurum-11-ilimizde-279-bin-binanin-acil-yikilacak-agir-hasarli-yikik-veya-orta-hasarli-oldugunun-tespitini-yaptik-bakanlik-faaliyetleri-38479 (accessed 16 March 2024).

Mulders L (2013). *High Quality Recycling of Construction and Demolition Waste in the Netherlands*. Utrecht University.

Oliveira MDPSL, de Oliveira EA and Fonseca AM (2021). Strategies to promote circular economy in the management of construction and demolition waste at the regional level: A case study in Manaus, Brazil. *Clean Technologies and Environmental Policy* 23(9): 2713–2725. https://doi.org/10.1007/s10098-021-02197-7

Pinto TP (1989) *Perda de materiais em processos construtivos tradicionais*. Departamento de Engenharia Civil, Universidade Federal de São Carlos.

Poudel R, Hirai Y, Asari M, et al. (2019). Field study of disaster waste management and disposal status of debris after Gorkha Earthquake in Kathmandu, Nepal. *Journal of Material Cycles and Waste Management* 21(4): 753–765. https://doi.org/10.1007/s10163-019-00835-3.

Reinhart DR and McCreanor PT (1999). Disaster Debris Management-Planning Tools. Final Report, US Environmental Protection Agency Region IV.

Rodrigo Eduardo Córdoba da J, Santiago CD, Pugliesi É, et al. (2019). Alternative construction and demolition (C&D) waste characterization method proposal. *Engenharia Sanitaria E Ambiental* 24(1): 199–212. https://doi.org/10.1590/s1413-41522019179720.

SBO (2023) Kahramanmaras and Hatay earthquakes report. Presidency of the Republic of Turkey Strategy and Budget Office. Available at: https://www.sbb.gov.tr/wp-content/uploads/2023/03/2023-Kahramanmaras-and-Hatay-Earthquakes-Report.pdf (accessed 10 January 2025).

SKD (2024). Kentsel dönüşüm, deprem ve olası diğer afetler sonucunda oluşan yıkıntı atıklarının yönetimi rehberi (In Turkish). *Debris Waste Management Guide Project*. Available at: https://www.skdturkiye.org/en/our-projects-bcsd/debris-waste-management-guide-project/ (accessed 10 January 2025).

Statistics Norway (2024) Waste from building and construction. Available at: https://www.ssb.no/en/natur-og-miljo/statistikker/avfbygganl (accessed 23 February 2024).

Temelli UE, Sezgin N, Cumali BO, et al. (2025) Analysis of construction and demolition waste prediction post-earthquake disasters. *Engineering Science and Technology, an International Journal* 67: 102078. https://doi.org/10.1016/j.jestch.2025.102078

Tissera WDA, Dahanayake R and Edirisinghe V (2022) The applicability of regulations for the disposal of construction and demolition waste in Sri Lanka. In: *Proceedings of 10th World Construction Symposium*, 24-26 June 2022, Sri Lanka, pp.821–832.

Tiwary AR (2016) Landfill volume gain from the diversion of construction and demolition waste. Master Thesis, Graduate School of the University of Texas at Arlington.

Townsend TG and Anshassi M (2023) Construction and Demolition Debris. Springer International Publishing.

Turkish Statistical Institution (2022) *Waste Statistics in Türkiye* (in Turkish). Available at: https://veriportali.tuik.gov.tr/tr/press/54134.

United Nations Environment Programme (2023) Millions of tons of earthquake rubble await removal in Türkiye. Available at: https://www.undp.org/press-releases/millions-tons-earthquake-rubble-await-removal-turkiye (accessed 12 February 2025).

USEPA (2020) *Advancing Sustainable Materials Management: 2020 Fact Sheet*. Environmental Protection Agency.

Wasserman M, Anshassi M and Townsend T (2022) Assessing sample number requirements for municipal solid waste composition studies. *Journal of Hazardous, Toxic and Radioactive Waste* 26(1): 0000652. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000652

Xiao J, Deng Q, Hou M, et al. (2023) Where are demolition wastes going: Reflection and analysis of the February 6, 2023 earthquake disaster in Turkey. *Low-carbon Materials and Green Construction* 1(1): 17. https://doi.org/10.1007/s44242-023-00017-3

Zhang H, Li X and Ding Z (2024) Optimal supply chain performance: Risk aversion to green innovation. *Management Decision* 62(12): 3996–4020. https://doi.org/10.1108/MD-07-2023-1281

Zhao Y, Goulias D, Tefa L, et al. (2021) Life cycle economic and environmental impacts of CDW recycled aggregates in roadway construction and rehabilitation. *Sustainability* 13(15): 8611. https://doi.org/10.3390/su13158611

Zheng L, Wu H, Zhang H, et al. (2017) Characterizing the generation and flows of construction and demolition waste in China. *Construction and Building Materials* 136: 405–413. https://doi.org/10.1016/j.conbuildmat.2017.01.055