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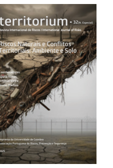

POST-EARTHQUAKE CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT: THE CASE OF THE 2023 TURKEY EARTHQUAKE*

GESTÃO DE RESÍDUOS DE CONSTRUÇÃO E DEMOLIÇÃO PÓS-TERRAMOTO: UM CASO EM 2023 DE UM TERRAMOTO NA TURQUIA

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ABSTRACT

A magnitude 7.8 earthquake impacted southern and central Turkey and northern and western Syria on 6 February 2023. The epicentre was 37 km west-northwest of Gaziantep. This was followed by a 7.7 magnitude earthquake. This quake was located 95 km north-northeast of the previous one. There was extensive destruction and tens of thousands of deaths. Construction and demolition waste (CDW) management is an essential part of disaster recovery, considering the rising frequency of natural disasters throughout the world. To mitigate risks and lighten the load on natural resources during the rebuilding phase, proper waste management is crucial. Social, economic, and environmental gains are all possible with well-planned disaster waste management. This analysis focuses on the waste created by the Turkey Earthquake of 2023 by assessing the CDW management method, analysing its shortcomings, and offering suggestions for better disaster recovery in the future.

Keywords: CDW, post-earthquake recovery, disaster waste management.

RESUMO

Um terramoto de magnitude 7,8 afetou o sul e centro da Turquia, assim como o norte e oeste da Síria a 6 de fevereiro de 2023. O epicentro foi a 37 km a oeste-noroeste de Gaziantep. Este foi seguido por um terramoto de magnitude 7,7 localizado a 95 km a norte-nordeste do anterior. Verificou-se uma destruição extensa e dezenas de milhares de mortes. A gestão de resíduos de construção e demolição (RCD) é uma parte essencial para a recuperação de desastres, considerando a frequência crescente de catástrofes naturais em todo o mundo. A mitigação dos riscos e o alívio da carga sobre os recursos naturais durante a fase de reconstrução, é crucial para a gestão adequada dos resíduos. Benefícios sociais, económicos e ambientais são todos possíveis com uma gestão bem planeada de resíduos provenientes de desastres. Esta análise centra-se nos resíduos gerados pelo terramoto de 2023 na Turquia, avaliando o método de gestão de RCD, suas deficiências e oferecendo sugestões para uma melhor recuperação de desastres no futuro.

Palavras-chave: RCD, recuperação pós-terramoto, gestão de resíduos de desastres.

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Introduction

During and after the post-disaster phase, disaster waste represents a significant concern. Depending on the nature of the waste generated after a disaster, existing waste facilities and personnel are frequently overwhelmed (Brown *et al.*, 2010). This circumstance may hinder emergency services and threaten the public and ecological well-being. Therefore, both short-term and long-term reintegration could be hindered by ineffective and improper post-disaster waste management (Domingo and Luo, 2017).

Various nations have implemented diverse strategies to effectively handle and control the disposal of debris resulting from disasters. Effective and enduring waste management practices can reduce waste generation and promote the reuse, recycling, and recovery of waste. It is worth to mention that managing CDW after a disaster is inherently more challenging than regular CDW management due to its intricate nature and contamination.

Several disaster waste management (DWM) documents adopted by the nations contain recycling guidance (EPA, 2019; New Zealand Ministry of Civil Defense and Emergency, 2018; Japan Ministry of the Environment, 2018; Government of South Australia, 2018; UNOCHA, 2013; UNEP, 2012; USEPA, 2008; FEMA, 2007; UNDP, 2006; SWANA, 2005; Solid Waste Authority, 2004; State of California, 1997).

Besides the governmental organizations, various authors have categorized the consequences of a disaster-induced CDW using different methodologies. The predominant body of published research has primarily concentrated on pre-disaster endeavors, encompassing safeguarding water supply systems and formulating efficient evacuation strategies. Conversely, there has been comparatively little emphasis on post-disaster response activities, such as the management of debris and the reconstruction of infrastructure.

For example, Karunasena *et al*. (2009) classified CDW based on the sorts of materials. Fetter and Rakes [12] identified two stages of disaster-debris cleanup procedures. The initial phase commences promptly following the disaster, with the objective of removing debris obstructing evacuation routes and other crucial approaches to guarantee unimpeded access to the afflicted area. The second phase is characterized by its extended duration and encompasses the coordination and supervision of debris collection, as well as activities focused on minimizing debris volume through sorting, recycling, and proper disposal. In their study, Brown and Milke (2016) found that several factors must be evaluated to determine the feasibility of disaster waste recycling programs. These factors include the volume of waste, the degree of waste mixing, the potential health hazards to humans and the environment, the extent of the waste area, the priorities of the community, the funding mechanisms, and the existing regulations as well as those specific to the disaster. The authors stated that an effective recycling program necessitates proficient administration, encompassing unambiguous and rigorously implemented policies (via sound contracts or regulations) and proactive pre-event preparation.

A number of researchers have devised decision-making models, guidelines, and waste management plans to efficiently and effectively handle post-earthquake disaster debris. Karunasena *et al*. (2009) highlighted five essential prerequisites that must be determined before developing efficient techniques for managing debris after a disaster. The key factors to consider include: identification of appropriate disposal sites and potential recyclable materials, accurate assessment of waste quantity, composition, and source, evaluation of local waste handling facilities' capacity, analysis of the extent of reconstruction work and potential utilization of recycled building waste, and comprehension of government and local authority structures responsible for waste management. The decision model proposed by Fetter and Rakes (2012) aims to determine the optimal locations for temporary disposal and storage reduction facilities to assist in disaster debris clean-up operations. A reverse logistic model presented by Hu and Sheu (2013) focused on minimizing economic, risk-induced and psychological costs during post-disaster debris disposal. Baycan (2004) presented details regarding the collection, segregation, recycling efforts, and disposal methods for disaster-related demolition waste in the aftermath of the Marmara earthquake.

Complex natural hazards such as earthquakes frequently involve secondary hazards such as landslides, tsunamis, and so on. Structures, facilities, and consumer durables are all turned into disaster waste because of the earthquakes' tremendous harm they inflict on people's lives and property. As stated by Domingo *et al*. (2017) and Karunasena *et al*. (2009), in the aftermath of an earthquake, CDW is 'not typical' due to its reduced recycling rates (more waste to landfill + CH_4 emissions) and higher hazard levels (human and environmental).

CDW makes up the bulk of waste left behind after an earthquake. Mineral waste (bricks, stones, concrete blocks, tiles, cement, concrete), steel bars, metal, wood, plastic, glass, paper and cardboard, electrical wires and cables, furnishings, whiteware and hazardous substances are the most common types of waste left behind after an earthquake. The widespread liquefaction also produces large amounts of potentially dangerous silt (Vásquez *et al.*, 2016). This CDW has a lot of recyclable components.

Articles have already been written about recycling CDW caused by earthquakes (Skinner, 1995; Reinhart and McCreanor, 1999; Kartam *et al.*, 2004; Blengini, 2009; Kofoworola and Gheewala, 2009). CDW is recyclable and may be utilized in extant markets, as well as in applications following a disaster. Common reuses include landfill cover, slope stabilization, and concrete aggregate (Channell *et al.*, 2009); geopolymer-based materials (Panizza *et al.*, 2020; Volpintesta *et al.*, 2023); and road base and subbase material (Zhang *et al.*, 2020).

The aim of this research is to present CDW management after the 2023 Turkey earthquake and the amount of CDW based on international disaster case studies and a broader literature view. Specifically, it aims to answer the following: (i) What is the calculated amount of total waste and CDW generated by the past earthquakes? (ii) What are the barriers for post-earthquake CDW management? (iii) What are the environmental, health and historical observations related to DWM?

Damage caused and disaster waste generated by the 2023 Turkey earthquake

The Pazarcik (Mw 7.7; focal depth: 8.6 km) and Elbistan (Mw 7.6; focal depth: 7 km) districts of Kahramanmaraş were the epicenters of two significant earthquakes that struck Turkey on February 6, 2023, at 04:17 and 13:24, respectively (AFAD, 2023 a; b). As a result of the earthquakes, more than 48 thousand people lost their lives, more than half a million buildings were damaged, communication and energy infrastructures were damaged and significant financial losses occurred. The total number of structures in the region was roughly 2,6 million. About ninety per cent of said building stock was residential, six per cent was commercial, and three per cent was public. As of 2022, the number of homes in the 11 earthquake-affected provinces was 5,6 million, and its proportion of the total housing stock in Turkey was 14.05 per cent (fig. 1). At least 301,000 buildings either collapsed or will need to be demolished as a result of the earthquakes (ITU, 2023).

In the zone damaged by the earthquake, 86.7% of buildings and 95.4% of apartments are constructed using reinforced concrete as presented in Table I. The load-bearing systems of the remaining buildings are as follows: 2.4% steel, 3.5% masonry, and 3.6% prefabricated. The other category comprises loadbearing systems made of wood, a combination of materials, or those that are not clearly defined.

Table I - Structural Systems of Buildings in the Earthquake-Affected Region.

Tabela I - *Sistemas Estruturais de Edifícios na Região Afetada pelo Terremoto.*

	Reinforced concrete	Steel	Masonry	Prefabricated	Others
Buildings	86.7	2.4	3.5	3.6	3.9
Apartments	95.4	0.4	1.3	0.6	2.3

Even though there are many factors that affect the destruction of collapsed buildings (reinforced concrete structures), the most obvious ones were the age of the

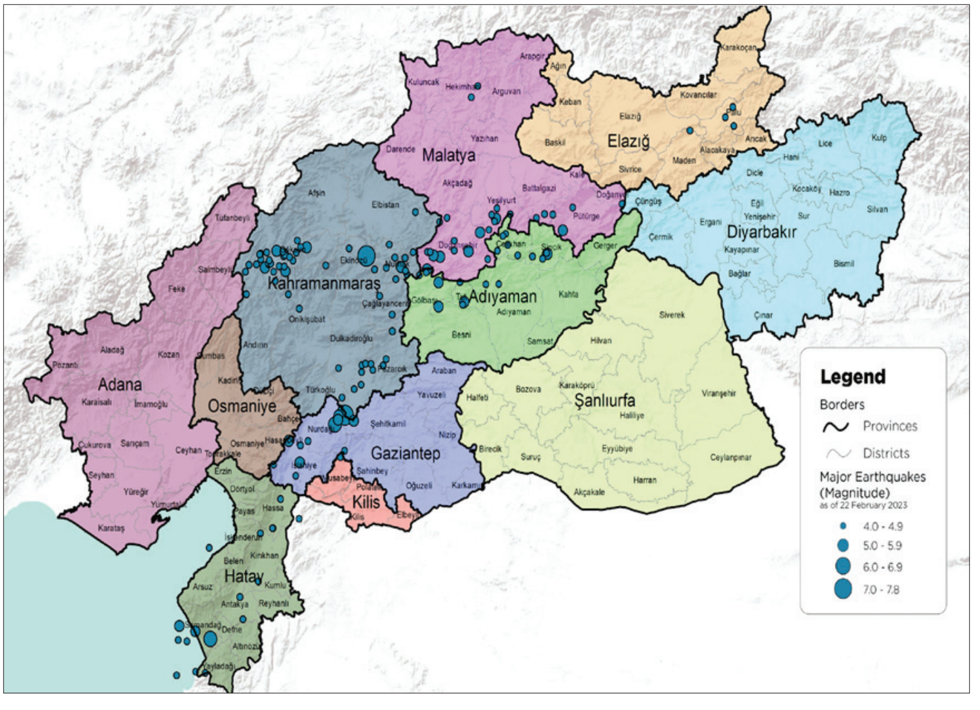

Fig. 1 - Provinces affected by the 2023 Turkey earthquake (Source: USGS, 2023).

Fig. 1 - *Províncias afetadas pelo terramoto de 2023 na Turquia (Fonte: USGS, 2023).*

buildings, the low bearing capacity of the ground on which the foundations are placed, the quality of the materials used in the construction, the cross-section dimensions of the columns and beams and the amount of reinforcement, and the lack of structural system elements in accordance with the regulations in force. In the provinces of Kahramanmaraş and Adıyaman, it has been seen many cases of "soft storey". In places like Hatay-Antakya and Adıyaman-Gölbaşı, it has also been seen that buildings collapsed in an angled position by sinking into the ground, or the whole building leans to one side or sinks into the partially liquefied ground (fig. 2) (ITU, 2023; TMMOB, 2023; Reliefweb, 2023).

Estimated waste quantities of some of the past earthquakes

According to a preliminary damage assessment analysis by the World Bank (2023), the two very significant earthquakes that struck Türkiye on February 6 inflicted an estimated $34.2 billion in direct physical damage, or about 4% of the country's GDP in 2021. The estimated waste volume is between 450-920 million metric tons (Xiao *et al.*, 2023). Hence, the volume of disaster waste produced by the 2023 Turkey Earthquake is greater than the volumes generated by other recent earthquakes (Table II).

Fig. 2 - Examples of damaged buildings: (a) Hatay, (b) Kahramanmaraş (Source: TMMOB, 2023).

Fig. 2 *- Exemplos de edifícios danificados: (a) Hatay, (b) Kahramanmars (Fonte: TMMOB, 2023).*

Table II - Estimated Waste Quantities Generated by Different Earthquakes.

Tabela II *- Quantidades Estimadas de Resíduos Gerados por Diferentes Terramotos.*

Year	Event	Estimated Waste Quantity (metric tons)	Source
1976	Friuli earthquake, Italy (6.5M_w)	0.3 million	(Faleschini *et al.*, 2017)
1994	Northridge earthquake, USA (6.4M_w)	2 million	(Lauritzen, 1998)
1995	Great Hanshin-Awaji earthquake, Japan (6.9M_w)	20 million	(Denot, 2016)
1999	Izmit earthquake, Turkey (7.6M_w)	13 million	(Baycan, 2004;)
1999	Chi-Chi earthquake, Taiwan (7.7M_w)	30 million	(Yang, 2009)
2004	Chūetsu earthquake, Japan (6.6M_w)	0.6 million	(Sakai *et al.*, 2019)
2008	Wenchuan earthquake, China (7.9M_w)	380 million	(Xiao *et al.*, 2012)
2009	L'Aquila earthquake, Italy (6.3M_w)	2 million	(Gabrielli *et al.*, 2018)
2010	Haiti earthquake (7.0M_w)	23–60 million	(Brown, 2012)
2010; 2011	Canterbury earthquakes, New Zealand (2010: 7.1M_w; 2011: 6.3M_w)	9 million	(Brown and Milke, 2012)
2011	Great East Japan Earthquake (9.0-9.1M_w)	28 million	(Sasao, 2016)
2012	Emilia earthquake, Italy	0.6 million	(Gabrielli *et al.*, 2018)
2015	Gorkha earthquake, Nepal (7.8M_w)	19 million	(Gyawali, 2022; Abhimanyu and Raj, 2019)
2016	Kumamoto earthquake, Japan (7.0M_w and a foreshock of 6.2M_w)	3.16 million	(Saffarzadeh *et al.*, 2017)
2017	Puebla earthquake, Mexico (7.1 M_w)	0.35 million	(Hernández-Padilla and Anglés, 2021)
2018	Sulawesi earthquake, Indonesia (7.5M_w)	0.2 million	(Parura and Rahardyan, 2020)
2020	Zagreb earthquake, Croatia (5.3 M_w)	0.1 million	(Grbeš *et al.*, 2021)
2023	Great South Turkey earthquake (7.8M_w and a foreshock of 7.5M_w)	450-920 million	(Xiao *et al.*, 2023)

DWM legislation in Turkey

There are two sources that explicitly describe the management of disaster-related waste in Turkey (Elvan and Turker, 2015). The 2004 Regulation on Control of Excavation, Construction, and Demolition Waste and the 2015 Waste Management Regulation are the two regulations. According to the first regulation, it is the responsibility of the relevant municipalities to take or ensure that the necessary measures are taken so as not to negatively impact the environment and human health during the selection, construction, or operation of the landfill site for the construction and demolition wastes generated by the disaster, as well as to manage the permit processes for recycling facilities and storage areas within the municipality's borders (Ünal and Yavuz, 2023).

The same regulation assigns the highest local authority the responsibility of establishing a Crisis Center to determine the disaster's waste management principles. In accordance with the 44th article of the regulation, the amount of waste that may be generated in the event of a natural disaster, as well as the tools, equipment, and suitable areas for waste storage, are determined in advance in accordance with the principles outlined in the Excavation Soil, Construction, and Demolition Waste Control Regulation. liable for making the required provisions. In other words, the municipality or the individuals and organizations to whom the municipality has delegated its authority are responsible for the transportation and storage of debris generated as a result of natural hazards (Ministry of Environment and Urbanization of Turkey, 2015).

According to the information on page 46 of the Turkey Disaster Response Plan published by AFAD in 2022, the Disaster Debris Removal Group is responsible for debris management. This group is comprised of solution partners such as the Ministry of Environment, Urbanization, and Climate Change, the Ministry of Energy and Natural Resources, the Investment Monitoring and Coordination Department, local governments, NGOs, and the private sector (Unlu *et al.*, 2010; AFAD, 2022).

With the "Presidential Decree on Settlement and Construction Under the State of Emergency" published on February 24, 2023, the task of storing debris was left to the governorships. Moreover, the production and use of asbestos was prohibited in all European Union member states as of January 1, 2005, and with the passage of a law in 2010, the production, use, and sale of white asbestos were also prohibited in Turkey (AFAD, 2022).

In accordance with the aforementioned legal framework, the initial emergency response was not well-defined. It appeared that no position had been created for strategic management and coordination of the entire waste management process. No organization appeared to have oversight of the entire waste management system, in terms of debris and waste management. Therefore, no entity was actively identifying constraints and capacity limitations, and protocols and strategies were determined ad hoc. During the initial phases of response and recovery, some planning work was performed, but it did not appear to be institutionalized.

Environmental, health and historical considerations and observations related to DWM

Heritage sites in the earthquake region are not only significant for Turkey, but for the entire globe. Arslantepe Mound, Nemrut Mountain, Diyarbakır Walls, and Hevsel Gardens in Malatya, Adıyaman, Diyarbakır, and Şanlıurfa, which are on the UNESCO World Heritage List, and Göbeklitepe keep the multicultural and multireligious region's history alive today. In addition to World Heritage sites and monuments, the historical cities in the region, such as Antakya, which contain significant examples of Turkish civil architecture, shed light on the region's cultural, social, and economic history.

Among its historical heritage, the earthquake zone hosts more than 60 protected areas (nature conservation area, national park, nature park, wildlife development area, natural site etc.) and 35 important natural areas that stand out with international criteria in terms of living species diversity. This diversity, which extends from large wetland ecosystems to cedar, larch and oak forests and mountain steppes, also provides information about the rare species diversity of the region (Doygun, 2009; Üzümcüoğlu, 2023).

Historical artifacts destroyed or damaged by the earthquakes are Habib-i Neccar Mosque, Antakya Ulu Mosque, Church of Saints Peter and Paul, Malatya Yeni Mosque, Gaziantep Castle, Karakuş Tumulus Pylon, Diyarbakır Walls, Diyarbakır St.George Church, Historical Antakya Houses, Darb ı Sak Castle, Hazrat Ukkaşe Tomb and Gaziantep İçkale Mosque (photo 1 and photo 2). There is no evidence or record that damaged or undamaged particles of these historical artefacts are kept in accordance with the regulations.

Some major observations related to environmental and health significance are listed below:

- The location where debris were dumped in Adyaman is a creek bed with a sign that reads "It is prohibited to dump debris" from the Adyaman Municipality. The water in the stream bed, where the debris was dumped, combines with the Karakaya Dam, where the drinking water for Gaziantep and Urfa is collected (TMA, 2023; TATD, 2023);
- It has been observed in Hatay Samandağı that rubble and wastes are deposited into the Mileyha Wetland, which is the migration route of birds and the breeding

ground of endemic plants, thereby endangering the diversity of living things, human health, and the existence of air and water;

- In Malatya, debris was dumped 18 kilometers from the city center in an agricultural and residential area. This region obtains its irrigation by excavating wells, and it is an agricultural region. Agricultural areas that were harmed by quarrying a few years ago now cause significant migration and/or health issues with asbestos (Korkmaz *et al.*, 2011);
- The majority of the structures devastated in the earthquake zone were constructed prior to 1999. According to the Map of Turkey Asbestos Deposits, the earthquake-affected region is among those in the country where environmental asbestos is concentrated. (TTS, 2023);
- The rubble of the earthquake-damaged structures, which may contain toxic waste, spread to settlements and areas close to temporary settlements, causing housing conditions to deteriorate and social reactions (TMA, 2023);
- As a result of the scarcity of landfills in the earthquake-stricken area, a number of environmental problems have arisen, as the debris frequently contains hazardous substances (TMA, 2023).

Landfills are the final stage in the process of DWM. In the case of the Turkey earthquake of 2023, the 'quick select and go' method was utilized, which made the processing of the remaining waste less cost-effective, and thus it was sent to landfills. The insufficiency of waste transfer stations in the region is one of the factors for this decision. To minimize the risk to public health posed by landfills, a surcharge was not imposed at the landfill for receiving asbestos at the existing waste transfer stations (WHO, 2023; SBB, 2023).

The majority of waste can be reused or recycled, making recycling of CDW routine in a disaster (Amato *et al.*, 2019). For example, the majority of CDW can be separated, pulverized, and recycled as aggregates for concrete or road filling (Tabata *et al.*, 2017; Zhu *et al.*, 2012), and as aggregated bricks and blocks (Endoh, 2016). The research findings demonstrate that the aforementioned hierarchy was not utilized in post-disaster CDW management following the 2023 Turkey earthquake. Non-hazardous materials such as stone, bricks, tiles, aggregates, reinforced concrete, asphalt, and glass were not disposed of via land reclamation.

Limitations for DWM

Prior to the occurrence of the crisis, the risk in this region has not been reduced to a level where it can be effectively managed. Uncertain roles and responsibilities caused confusion among organizations and professionals involved in the process. Despite the fact that a number

Photo 1 - Examples of damaged historical buildings: (a) Gaziantep İçkale Mosque, (b) Historical Antakya Houses, (c) Gaziantep Castle (Source: TMMOB, 2023).

***Fot. 1** - Exemplos de edifícios históricos danificados: (a) Mesquita Gaziantep İçkale, (b) Casas Históricas Antakya, (c) Castelo Gaziantep (Fonte: TMMOB, 2023).*

Photo 2 - Examples of damaged historical buildings: (a) Karakuş Tumulus Pylon, (b) Church of Saints Peter and Paul (c) (Source: TMMOB, 2023).

***Fot. 2** - Exemplos de edifícios históricos danificados: (a) Monumento Karakuş Tumulus, (b) Igreja de São Pedro e São Paulo (c) (Fonte: TMMOB, 2023).*

of organizations worked diligently on waste management, the absence of communication and coordination due to a lack of repeated exercises is a major flaw in this instance.

During the process, the capacity of waste management facilities, the management of hazardous materials, and the preservation of personal property posed significant obstacles. In addition, the region's limited disposal sites caused a number of environmental issues.

Lack of policies, regulations, and acts related to DWM plans; organizational limitations with lack of labour skills and training programmes; lack of DWM interest by the government; and reluctance to implement DWM by the authorities are some of the other limitations.

Conclusion

This paper evaluated DWM for the 2023 Turkey earthquake, considering both the environmental and the heritage-related aspects. Recent seismic feedback has highlighted the significance of DWM, highlighting the urgency with which it must be handled. Numerous strategies for dealing with disaster debris have been implemented in various nations.

Rapid waste management is essential for reopening roads and reviving the local economy, getting life back to normal as soon as possible, and minimizing any health and environmental hazards. Authorities in charge of organizing waste management in the aftermath of natural disasters need methodological and operational tools to reduce waste generation and plan for waste collection, transportation, and treatment in accordance with waste management policy objectives.

The study's findings indicate that there was no pre-existing plan for managing CDW before the earthquake occurred. As a consequence, several inefficiencies arose initially, causing a significant delay in the overall healing process. The study identified several challenges, such as inadequate waste processing capacity, conflicts in current legislation, absence of a pre-disaster waste management plan that includes the feasibility and design of recycling systems after a disaster, absence of clear power distribution among involved organizations and individuals, the bureaucratic nature of the decision-making process, lack of collaborative working practices and lack of earthquake safety procedures for heritage-related structures.

In summary, the findings suggest that the absence of a pre-existing disaster recovery plan and insufficient resources, such as waste processing facilities and legislation, hinder the efficiency of the process. These issues must be addressed in order to enhance the management of construction and demolition waste in future disasters.

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