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Çetin, Sultan; Kirchherr, Julian

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ORIGINAL PAPER

The Build Back Circular Framework: Circular Economy Strategies for Post-Disaster Reconstruction and Recovery

Sultan Çetin[1] · **Julian Kirchherr**[2,3,4]

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Abstract

Scholars have recently debated the potential of the circular economy (CE) as a crisis response strategy; however, concrete examples demonstrating its effectiveness in such applications remain limited. This study addresses this gap by investigating how CE principles—narrowing, slowing, closing, and regenerating resource loops— can be integrated into post-disaster reconstruction and recovery, with a focus on the 2023 Kahramanmaraş Earthquakes in Türkiye. Using an exploratory qualitative research design, including an integrative literature review, workshop with 24 participants and 21 expert interviews, this study develops the Build Back Circular (BBC) framework. The framework proposes ten action strategies: (1) Upcycle, reuse or recycle post-disaster waste, (2) Integrate circular design principles, (3) Introduce circular policies, (4) Leverage digital technologies, (5) Raise awareness and expand knowledge, (6) Drive the market with circular business opportunities, (7) Involve local communities, (8) Improve cooperation and collaborations, (9) Integrate CE principles into post-disaster urban development, and (10) Stimulate the use of healthy, local, and biobased materials. These strategies aim not only to enhance resource efficiency and resilience but also to address the social dimensions of CE, promoting an inclusive recovery. Successful implementation requires a collaborative ecosystem of government, municipalities, academia, the construction sector, and civil society. By bridging the fields of CE and disaster management, this research offers valuable insights for policymakers, researchers, and practitioners to integrate CE into post-disaster reconstruction and urban development processes. Beyond Türkiye's recovery, it aims to support global disaster risk frameworks (e.g., UN's Sendai Framework), enhancing crisis management through a CE lens.

Keywords Circular Economy · Circular construction · Sustainability · Recovery · Reconstruction · Disaster management · Urban development

Extended author information available on the last page of the article

Introduction

The world has faced numerous crises in the recent decades, including the COVID-19 pandemic, geopolitical conflicts, climate change-related events, and both natural and human-induced disasters. These disasters significantly impact the global economy [1], damaging infrastructure, supply chains, and essential systems that societies rely on [2]. In our interconnected world, global crises have both local and widespread effects, impacting all sectors. For example, the economic impact of the COVID-19 pandemic was particularly severe for emerging economies, leading to increased poverty and inequality at both local and global levels [3].

Natural disasters, such as earthquakes and floods, are among the most devastating disasters, causing extensive loss of life, property damage, and economic disruption. In 2023 alone, approximately 400 natural hazard-related disaster events were reported worldwide, affecting 93.1 million people, causing an estimated $202.7 billion in economic loss, and resulting in over 86,000 deaths [4]. The United Nations (UN) projects a 40% increase in the number of disaster events by 2030 due to climatic hazards such as droughts and extreme precipitation [2]. In response, countries must prioritize preparation and mitigation efforts to counter these adverse effects by building sustainable, resilient systems. A promising strategy is the adoption of the Circular Economy (CE), which can enhance resilience and sustainability by promoting resource efficiency, reducing dependency on raw materials, energy and water, and stimulate innovative solutions and business opportunities to manage and recover from crises [5].

The CE is widely regarded as a promising strategy to address the sustainability crisis [6]. Traditionally, scholars have limited the scope of CE to this specific area of concern. However, the recent paper by Hartley, et al. [7] challenges this narrow view suggesting that applying CE principles can enhance system resilience. This resilience has beneficial secondary effects on various interconnected crises related to sustainability, including mitigating supply chain challenges through circular value chains, increasing economic stability by reducing resource dependency, and fostering innovation-driven growth. Indeed, Wuyts, et al. [5] demonstrate how CE principles served as a constructive driver of change in the healthcare sector in Flanders in Belgium as a response to COVID-19 pandemic. For example, textile leftovers were used to produce masks, and baby monitors were donated to hospitals for patient surveillance [5]. These adaptive responses illustrate the potential of CE in addressing urgent supply shocks and building resilient sectors against future crises.

While some researchers examine the potential of the CE as a crisis response, current efforts largely focus on specific crises (e.g., [5, 8]), with limited attention to other significant disasters like earthquakes and tsunamis. These natural events have profound impacts on the economy, society, and the built environment [1], as reconstructing destroyed assets, managing post-disaster waste, and rehabilitating communities consume substantial resources [9]. Scholars suggest that post-disaster recovery can present a unique opportunity to restore communities to their pre-disaster condition while enhancing their resilience through sustainable practices [10–13]. A renowned example is the “Build Back Better” (BBB) framework [14], developed by the UN after the 2004 Indian Ocean Tsunami. This framework provides a holistic approach, integrating physical, social, environmental, and economic resilience to recovery [15, 16].

The BBB framework has played an influential role in shaping disaster recovery practices worldwide, with key elements such as risk reduction, economic recovery, and community participation to strengthen communities against future disasters [15]. Its principles have been incorporated into major international guidelines, including the Sendai Framework for Disaster Risk Reduction [14], which promotes sustainable development [17]. Building on the BBB Framework, the World Green Building Council developed a sustainable post-disaster reconstruction toolkit to support built environment stakeholders [18]. This toolkit aligns with key Sustainable Development Goals (SDGs), such as SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 3 (Good Health and Well-being) [18]. While these initiatives offer valuable resilience strategies, the connection between post-disaster urban development and sustainability remains limited [12], particularly from a CE perspective.

Integrating CE principles into post-disaster reconstruction may offer a pathway to sustainable urban development in affected cities. Evidence from circular city initiatives in Amsterdam, London and Paris reveal the importance of spatial planning, as circular systems depend on access to land, infrastructure, and resources in cities [19, 20] and necessitate a multidimensional, systems-thinking approach [20, 21]. At the municipal level, CE initiatives can cultivate conditions for community resource-sharing (e.g., secondary product exchange) and skill development (e.g., repair practices) [21]. In Malmö, for example, the city has allocated dedicated physical spaces to facilitate sharing and collaborative consumption among residents [21]. Nevertheless, disaster management literature frequently neglects these spatial and social dimensions, instead prioritizing narrow applications of CE, such as waste management (e.g., debris recycling) (see, e.g., [22–24]). This limited focus reveals a significant gap in the literature, particularly in understanding CE's broader potential to support sustainable and resilient reconstruction efforts in the built environment.

In this study, we address the underexplored role of CE principles in disaster reconstruction, focusing on Türkiye's post-crisis phase following the catastrophic earthquakes of early 2023. These earthquakes led to approximately 50,000 fatalities, destroyed or damaged hundreds of thousands of buildings, and severely impacted critical infrastructure [25]. Türkiye is currently in the recovery stage, focusing on constructing new homes for victims, repairing infrastructure, and managing post-disaster waste [22, 23]. This situation presents both a major challenge and an opportunity to rethink the rebuilding process, with CE principles potentially offering a sustainable and resilient path to enhance the recovery process.

Given the severity of the situation in Türkiye, where rapid reconstruction is essential, the primary objective of this paper is to develop an action-oriented framework that integrates CE principles into the post-disaster reconstruction processes in the affected cities. The urgency stems from the need to not only reconstruct quickly but also to seize this opportunity to incorporate sustainable practices through CE, which can enhance long-term resilience. Due to the pressing nature of the recovery, this framework is designed to be practical and actionable, with the potential to be applied in real-life reconstruction efforts as the recovery process will likely take several more years. This article answers the following two research questions:

- What circular strategies can potentially be applied in the post-disaster reconstruction and recovery in Türkiye?
- Who are the key actors that play a crucial role in implementing circular reconstruction and recovery strategies?

The remainder of this article is structured as follows: First, the literature background is presented, followed by an explanation of the research design, data collection, and analysis methods. Then, the findings are presented and discussed, and finally, the study is concluded.

The 2023 Kahramanmaraş Earthquakes

On February 6th, 2023, two significant earthquakes, with a magnitude of M_W 7.8 and M_W 7.6, struck Southeastern Türkiye (epicenters located in Kahramanmaraş), with a nine-hour interval between them [26, 27]. Subsequently, a separate earthquake, registering M_W 6.4, affected the province of Hatay on February 20th. The combined impact of these seismic events extended across a vast geographical area, encompassing 11 Turkish cities and the northern region of Syria. The collective population of affected cities exceeds 14 million [28]. The earthquakes resulted in a casualty toll of over 48,000 lives lost, substantial damage to nearly half a million buildings, and significant impairment of civil infrastructure [25, 27, 29]. Approximately 2.3 million individuals have currently an immediate housing requirement and the economic impact of the disaster to the Turkish economy is estimated to be about 103,6 billion USD, equivalent to 9% of the country's gross domestic product in 2023 [25].

The earthquakes generated a large volume of debris, with estimates ranging from 50 to 920 million tons [30–32], by far the largest generated worldwide after an earthquake in the past decades [33]. This debris includes a wide array of materials including household waste, toxic chemicals, white goods, and organic waste requiring careful management to mitigate health and environmental risks [34, 35]. However, a recent research revealed shortcomings in ongoing debris management practices in the affected cities, which lack proper waste management for efficient debris removal, treatment, and disposal [33]. Furthermore, the absence of preventive measures result in the release of hazardous substances into the air (e.g., asbestos) [36], leading to the formation of dust clouds in the region [33, 37]. In summary, the 2023 Kahramanmaraş earthquakes in Türkiye have caused extensive damage on the built environment, resulting in a housing crisis affecting millions, and generating a massive volume of debris, which require urgent actions to implement sustainable recovery.

Disaster Management Theory

Disaster management (DM) theory is an extensive field of research encompassing various definitions and frameworks. The UN Office for Disaster Risk Reduction defines disaster management as "*The organization, planning and application of measures preparing for, responding to and recovering from disasters.*"[38] From a temporal perspective, DM is typically divided into three phases: (1) *pre-crisis*, (2) *crisis*, and (3) *post-crisis* [39]. The disaster cycle of Alexander [40] puts forward four main processes that intersect with the crisis phases, namely, *mitigation, preparation, response,* and *recovery* (Fig. 1). The *pre-crisis* phase denotes the period preceding a disaster, during which activities related to disaster *mitigation* (to reduce risks and negative effects) and *preparedness* (to minimize the adverse effects) are undertaken [10]. *Crisis* phase includes immediate *response* actions taken before, during, or in the immediate aftermath of a disaster to save lives, ensure safety, and meet the basic needs of affected individuals. The post-crisis phase pertains to the period of *recovery*,

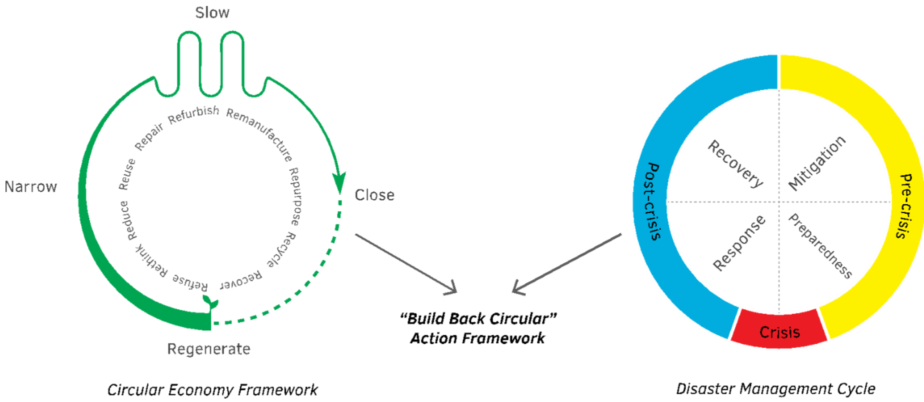

Fig. 1 Theoretical frameworks constituting the backbone of Build Back Circular Framework [39–42]

during which efforts and planning are directed towards restoring the affected area to its usual state [39, 40].

Recovery is a multifaceted process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environments. It is a comprehensive process, involving a range of governmental and non-governmental stakeholders as well as individuals and communities affected by the disaster [10, 12]. Typical actions during recovery processes include the clearance, removal, and disposal of debris, provision of temporary and permanent housing, preservation of cultural and historical sites, and provision of psychosocial support [10]. Scholars argue that post-disaster recovery presents a unique opportunity not only to rebuild communities but also to enhance their resilience and long-term sustainability [10–13]. For instance, in the aftermath of the 2004 Indian Ocean Tsunami, the "Build Back Better" (BBB) framework emerged as a holistic approach aimed at improving physical, social, environmental, and economic conditions [15]. The BBB framework seeks to bolster community resilience, reduce vulnerability to future disasters, and create safer environments [13]. For a successful BBB implementation, it is essential to integrate lessons-learned from post-disaster experiences, identify risk reduction solutions, and implement structural changes in regulations [16].

Circular Economy as a Window of Opportunity

Drawing inspiration from the BBB framework, a significant window of opportunity to integrate CE principles into ongoing recovery efforts in Türkiye emerges. Rebuilding homes, restoring infrastructure, and handling post-disaster debris pose significant challenges, requiring large amounts of resources and energy. This is anticipated to result in substantial costs reaching billions of dollars for Türkiye [23]. At this critical recovery stage, the CE can serve as a guiding framework to reduce dependency on natural resources and energy while offering new business opportunities, thereby assisting key stakeholders in tackling these major challenges. Moreover, CE can inform future disaster recovery planning and regulations and support governmental and non-governmental entities in identifying recovery actions [43].

The CE aims to create a regenerative economic system by replacing the linear take-make-waste model with a new set of core principles addressing environmental quality, economic development, and social equity [44, 45]. Within the built environment, there are four core CE principles that can be applied across the life cycle stages [41, 42, 46]: (1) *Narrowing the loops* aims to reduce resource use and waste through strategies such as designing buildings with low-carbon lightweight materials. (2) *Slowing the loops keeps* the buildings and products in use as long as possible by prolonging their lifetime through strategies through reuse, repair, and maintenance. (3) *Closing the loops* is directed towards the end-of-life, aiming to recover value through recycling. Finally, (4) *Regenerate* seeks to make positive impact on natural environmental and society by, e.g., designing systems that improve biodiversity and human-nature interaction. These core principles are inherently encompass what are known as "R strategies" (e.g., rethink, reduce, reuse, etc.) [47] (Fig. 1).

Although a distinct research field linking DM and the CE has not yet emerged, numerous connections between the two domains are evident, particularly, in disaster waste management. For instance, review papers by Brown, et al. [48] and Zhang, et al. [49] emphasize "recycling" as an environmentally friendly waste treatment option favored over alternatives such as landfilling and open burning. Recycling debris offers various benefits, including reducing landfill usage, minimizing raw material consumption in rebuilding, generating revenue from recycled materials, and creating new job opportunities [48, 50, 51]. Another area of alignment involves directly reusing debris, such as original stones, in the restoration of heritage buildings [52]. Recently, some scholars proposed to integrate circular design principles (e.g., design for disassembly) into the technical requirements of post-disaster temporary and permanent structures [43] and designed easy-to-assemble temporary shelters [53]. Overall, embracing circular approaches appears to present numerous opportunities to reduce the environmental impact of recovery while also aiding in reducing associated costs. This study will expand current knowledge by offering a holistic perspective on the potential of CE in DM, as we will demonstrate in the subsequent sections.

Research Design

The disaster recovery phase demands swift action from key actors, often necessitating rapid decision-making and potential modifications to existing regulations [12]. Given the urgent need for post-earthquake recovery solutions in Türkiye, our study aimed to identify practical steps for key actors to integrate CE principles into ongoing reconstruction efforts. As this research field is immature, our research adopts an exploratory qualitative design [54], structured around multiple data collection stages, as illustrated in Fig. 2, resulting in the development of an action-oriented framework. Given the interdisciplinary nature of the topic, we followed a multi-method approach [55], combining an integrative literature review with a workshop and semi-structured interviews. This approach enabled us to triangulate findings from various sources, enhancing the robustness of our analysis and increasing the validity of our conclusions.

In the initial phases of data collection, which involved a workshop and a literature review, we employed an inductive approach, allowing main patterns and themes to emerge. This process helped to refine research questions, delineate the scope of the study, and identify initial strategies for integrating CE principles into post-disaster reconstruction and recov-

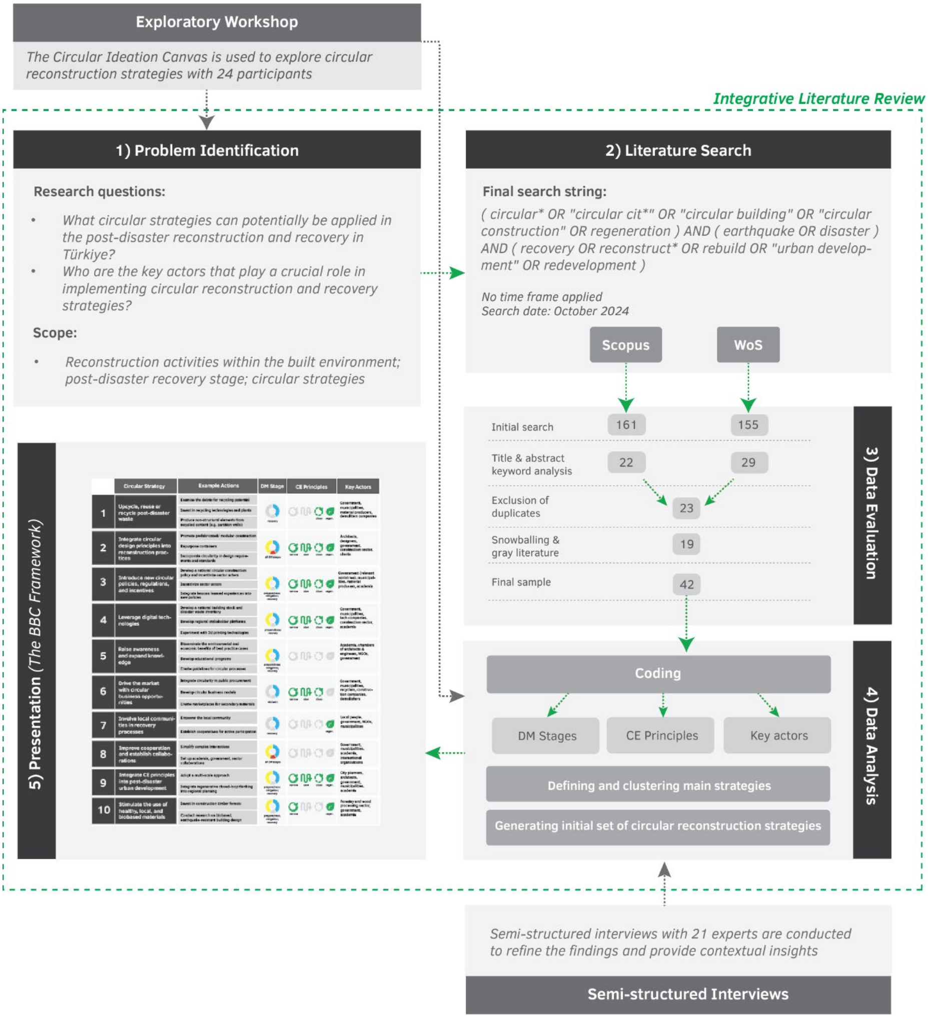

Fig. 2 Research design

ery. Next, we developed and applied a literature-based framework to guide an abductive analysis of the semi-structured interviews and literature findings, enabling us to iteratively reconcile emerging insights from experts with a set of CE strategies initially identified from the literature review.

Exploratory Workshop

To explore the potential entry areas for CE implementation in reconstruction, a workshop was held in Ankara in January 2024 with sector professionals. This workshop was a part of a full-day event aimed at raising CE awareness within the Turkish construction sector and exploring the potential of CE in rebuilding of earthquake-affected cities. The event was organized by the corresponding author in collaboration with the Dutch Embassy in Ankara, featuring presentations from experts in the Netherlands, as well as professionals from the Turkish construction sector and academia.

Out of more than 50 invitees, 24 participants joined the workshop, organized into four groups from different professional backgrounds (see Table 1). To facilitate discussion, we used an adapted version of the “Circular Collaboration Canvas” by Brown, et al. [56] to guide the participants in exploring possible circular scenarios and relevant actors (see Appendix A Fig. 5). The canvas consisted of five key steps: (1) Challenge, (2) Circular idea, (3) Resources and users, (4) Collaborative partners, and (5) Actions. Under the guidance of the principal author, participants worked on the canvas for approximately 90 min and presented their circular solutions at the end of the session. The outcomes of this workshop were instrumental in specifying the research questions and defining the scope of the study, as well as in triangulating the findings from the literature review and interviews.

Integrative Literature Review

According to Snyder [57], three main types of literature reviews exist: systematic, semi-systematic, and integrative (or also referred to as critical). Given the purpose of our study and the emerging nature of research at the intersection of CE and DM, we chose to conduct an integrative literature review. The integrative review is particularly suited for synthesizing diverse types of literature [58], providing a comprehensive understanding of complex fields [59], where both theoretical and empirical insights are still developing [57]. Unlike other forms of literature reviews, the integrative review aims to advance knowledge and theoretical frameworks, rather than merely summarizing or cataloging existing studies within a narrowly defined scope [58, 59].

One of the common critiques of this method is its potential lack of transparency, particularly in literature selection and analysis [57, 58]. To mitigate these concerns, we ensured that the entire review process was transparent and replicable by following five steps defined by Whittemore and Knafl [58]. As illustrated in Fig. 2, we systematically documented each step of the literature search, including the databases used, search terms, inclusion and exclusion criteria, and the rationale for selecting particular studies. Moreover, we addressed the inherent risk of bias in the analysis process by critically triangulating the literature with findings from our workshop and interview data. This triangulation strengthened the validity of our conclusions and contributed to the development of an actionable framework.

Problem Identification

The primary objective of our study is to identify actionable circular reconstruction strategies documented in literature or implemented in practice. Using insights from the workshop findings and existing literature, we refined the scope of our research and clarified our research questions. This study addresses the following questions:

- What circular strategies can potentially be applied in the post-disaster reconstruction and recovery in Türkiye?
- Who are the key actors that play a crucial role in implementing circular reconstruction and recovery strategies?

Table 1 Participant details from the exploratory workshop ($n=24$) and semi-structured interviews ($n=21$)

Research stage/no	Role	Affiliation	Expertise	Years of experience
Workshop-Group 1	Senior advisor	Government office	Economic affairs	35
	Architect	Architecture office	Conservation	35
	Associate professor	University & non-governmental organization	Construction & Demolition Waste; Sustainability	25
	Architect	Architecture office	Urban & architectural design	20
	Consultant	Non-governmental organization	Sustainability	10
Workshop-Group 2	Advisor	Government office	Innovation	13
	Architect	Project development office	Circular design	30
	General manager/ CTO	IT company	Smart cities and buildings	25
	Secretary general	Non-governmental organization	Construction materials	25
	Assistant professor	University	Architecture	9
Workshop-Group 3	Architectural design director	Construction company	Sustainable construction	20
	Advisor	Government office	Innovation, Tech & Science	15
	MSc student	University	Architectural design	n/a
	Architect	Architectural office	Urban & architectural design	36
	Head of projects	Modular construction company	Off-site circular construction	13
	Trainee	Government office	Healthcare	4
	Managing director	Prefab construction	Construction	35
Workshop-Group 4	Architect/ co-founder	Architectural design office	Building information modelling	7
	Associate professor	University & non-governmental organization	Planning & real estate development	20
	Structural engineer	Engineering company	Structural health monitoring	8
	Sustainability consultant & architect	Consultancy company	Life cycle assessment	10
	Project developer	University	Urban design	16
	Innovation engineer & PhD candidate	Construction materials company & university	Construction materials	3
	Architect & co-founder	Architectural design studio	Building information modelling	12
Interviewee 1	Architect	Architecture office	Urban & architectural design	20
Interviewee 2	Architect	Architecture office	Conservation	35
Interviewee 3	Architect	Architecture & consultancy office	Urban & architectural design	25
Interviewee 4	Associate Professor	University	Recycling technologies	30
Interviewee 5	Consultant	Non-governmental organization	Waste management & circular economy	16
Interviewee 6	General manager/ CTO	IT company	Smart cities and buildings	25

Table 1 (continued)

Research stage/no	Role	Affiliation	Expertise	Years of experience
Interviewee 7	Secretary general	Non-governmental organization	Construction materials	25
Interviewee 8	Professor	University	Earthquake resistant structures	34
Interviewee 9	Professor	University	Circular construction materials	25
Interviewee 10	Associate professor	University & non-governmental organization	Construction & Demolition Waste; Sustainability	25
Interviewee 11	Professor	University	Digitalization & circular built environment	25
Interviewee 12	Associate professor	University	Architectural technology	19
Interviewee 13	Consultant	Non-governmental organization	Software development	23
Interviewee 14	Architectural design director	Construction company	Sustainable construction	20
Interviewee 15	Consultant	Non-governmental organization	Sustainable development policy	20
Interviewee 16	Environmental engineer	Non-governmental organization	Water and wastewater management	36
Interviewee 17	Senior Commercial Officer	Government office	Circular economy	10
Interviewee 18	R&D Specialist	Construction materials company	Sustainable cement	14
Interviewee 19	Associate professor	University & non-governmental organization	Planning & real estate development	20
Interviewee 20	Construction specialist	Government office	Earthquake resistance design & energy efficiency	17
Interviewee 21	Head of department	Government office	Sustainability	20

Our scope is limited to reconstruction efforts within the built environment during the post-disaster phase. While we acknowledge that DM stages are interconnected, we focus specifically on the recovery process. Additionally, although DM encompasses a wide array of social, economic, and environmental factors, these broader dimensions are beyond the scope of our current research.

Literature Search

Building on the workshop outcomes and preliminary literature review, we identified an initial set of search terms. Using multiple academic databases—namely, Scopus and Web of Science—we identified several relevant academic articles. To broaden our scope, we supplemented this search with additional sources such as white papers, governmental reports through web searches. We also employed snowballing techniques to expand the pool of relevant literature further. After an initial round of literature review in April 2024 and feedback from peer reviewers, we expanded our search terms in October 2024, as follows:

(circular OR "circular cit*" OR "circular building" OR "circular construction" OR regeneration) AND (earthquake OR disaster) AND (recovery OR reconstruct* OR rebuild OR "urban development" OR redevelopment)*

The initial screening process involved reviewing the titles, abstracts, and keywords of articles retrieved from the databases. No specific time frame was applied. To maintain relevance, we limited our search to articles in English and Turkish and excluded subject areas unrelated to our study, such as medicine, astronomy, and nursing. This initial screening yielded 161 papers in Scopus and 155 papers in Web of Science.

Data Evaluation

We applied the following inclusion and exclusion criteria. Studies were included if they (1) addressed the impact of a disaster on the built environment and (2) incorporated circular strategies. Studies were excluded if they (3) focused on other aspects of DM, such as victims' mental health, or (4) were unavailable in full text. After applying these criteria, the number of eligible articles was reduced to 22 in Scopus and 29 in Web of Science. Following the exclusion of duplicates, a total of 23 papers formed the core dataset. Snowballing and gray literature searches contributed an additional 19 papers, resulting in a final sample of 42 papers (a full list of the final sample is provided in Appendix B Table 2).

Data Analysis

The final sample was analyzed using a literature-based framework. Initially, we identified a set of potential circular reconstruction strategies. Each paper was systematically coded according to the main stages of DM (i.e., mitigation, preparedness, response, and recovery) [40], core CE principles (i.e., narrow, slow, close, and regenerate) [41, 42, 46], and key actors involved. Similar strategies were then grouped into ten distinct clusters.

Presentation

Through an iterative process involving literature, workshop, and interview data (see next section), we developed a framework that serves as the foundation for our work, which will be presented in the Findings section. This framework organizes our findings into main themes, helping readers follow the key strategies and insights identified in our research.

Semi-Structured Interviews

Semi-structured interviews were conducted to enhance and refine the initial findings from the previous steps, and to provide contextual insights into Türkiye's post-disaster recovery efforts. Given that CE is a relatively new concept in the Turkish construction sector, recruiting professionals who met our selection criteria was challenging. The recruitment process evolved organically, beginning with desk research to identify potential interviewees, who were then contacted via email and social networks. The Dutch Embassy in Ankara and Consulate in Istanbul helped spread the word through their networks, and workshop participants were also invited to participate and encouraged to nominate additional relevant contacts.

A total of 21 professionals from diverse backgrounds were ultimately recruited as interview participants (see Table 1). Interviewees were selected based on three key criteria: (1) a minimum of 10 years of professional experience, (2) expertise in fields related to CE, and (3) knowledge of the Turkish construction sector, with familiarity or experience in post-disaster reconstruction viewed as an added qualification. Interviews were conducted online via Microsoft Teams, recorded, and transcribed verbatim. The duration of the interviews ranged from 30 to 100 min, allowing for in-depth exploration of actionable strategies, relevant actors and potential challenges. Transcripts were anonymized to protect participant confidentiality and were deposited in an open data repository for transparency. The interview questions and a selection of interviewee quotes can be found in Appendix C and D Tables 3 and 4 for reference.

Findings

The Build Back Circular Framework

The analysis of research data resulted in ten actionable strategies and key stakeholders to integrate CE principles into Türkiye's post-disaster reconstruction. Figure 3 presents the Build Back Circular (BBC) Framework summarizing these strategies which are detailed in the following subsections. References to workshop, literature, and interview data for each strategy can be found in Appendix E Table 5.

Strategy 1: Upcycle, Reuse or Recycle Post-Disaster Waste

One of the most frequently discussed circular strategies for Türkiye concerns the effective management of post-earthquake debris. The substantial volume of debris posed significant challenges to proper waste management. Currently, post-disaster waste is characterized by a mixture of materials, including concrete, bricks, metals, wood, furniture, and organic waste (Şahmaran and Özçelikci [35]; Interviewees 7 & 13). This heterogeneity complicates the process, increases the cost of recycling (Görgün, et al. [34]; Interviewee 9) and might pose health risks due to the presence of hazardous materials such as asbestos [31, 60]. While there are no official statistics available, field experiences suggest that a considerable portion of metal reinforcements is recovered from the debris and recycled (Görgün, et al. [34]; Interviewees 3, 7 & 18). There is a need for studies examining the debris from health and recycling potential perspectives (Interviewees 10 &14). In addition, advanced separation technologies such as optical and magnetic separators or sensor-based approaches can be employed to recover mixed-waste [35, 61].

Once properly separated, post-disaster waste presents significant opportunities for circular practices, particularly upcycling, reuse, and recycling [35]. Upcycling refers to transforming waste materials into new products of higher value [62]. In response to hurricanes Katrina and Rita in 2005, the Katrina Furniture Project employed a collaborative approach that engaged local communities in upcycling wood waste through six-week design workshops. This initiative led to the creation of various furniture designs, generating income and developing professional skills [62, 63]. Additionally, a review by Lamour and Cecchin [64] highlighted the potential of repurposing scrap tires into civil structures like load-bearing

	Circular Strategy	Example Actions	DM Stage	CE Principles	Key Actors
1	Upcycle, reuse or recycle post-disaster waste	Examine the debris for recycling potential Invest in recycling technologies and plants Produce non-structural elements from recycled content (e.g. partition walls)	recovery	close, regen.	Government, municipalities, material producers, demolition companies
2	Integrate circular design principles into reconstruction prac-tices	Promote prefabricated/ modular construction Repurpose containers Incorporate circularity in design require-ments and standards	all DM stages	narrow, slow, close, regen.	Architects, designers, government, construction sector, clients
3	Introduce new circular policies, regulations, and incentives	Develop a national circular construction policy and incentivize sector actors Incentivize sector actors Integrate lessons learned experiences into new policies	preparedness; mitigation; recovery	narrow, slow, close, regen.	Government (relevant ministries), municipal-ities, material producers, academia
4	Leverage digital technologies	Develop a national building stock and disaster waste inventory Develop regional stakeholder platforms Experiment with 3d printing technologies	preparedness; recovey	narrow, slow, close, regen.	Government, municipalities, tech companies, construction sector, academia
5	Raise awareness and expand knowledge	Disseminate the environmental and economic benefits of best practice cases Develop educational programs Create guidelines for circular processes	preparedness; mitigation; recovery		Academia, chambers of architects & engineers, NGOs, government
6	Drive the market with circular business opportunities	Integrate circularity in public procurement Develop circular business models Create marketplaces for secondary materials	recovery	narrow, slow, close	Government, municipalities, recyclers, construc-tion companies, demolishers
7	Involve local communities in recovery processes	Empower the local community Establish cooperatives for active participation	recovery	regen.	Local people, government, NGOs, municipalities
8	Improve cooperation and establish collaborations	Simplify complex interactions Set up academia, government, sector collaborations	all DM stages		Government, municipalities, academia, international organisations
9	Integrate CE principles into post-disaster urban development	Adopt a multi-scale approach Integrate regenerative closed-loop thinking into regional planning	preparedness; mitigation; recovery	narrow, slow, close, regen.	City planners, architects, government, municipalities, academia
10	Stimulate the use of healthy, local, and biobased materials	Invest in construction timber forests Conduct research on biobased, earthquake-resistant building design	preparedness; mitigation; recovery	narrow, regen.	Forestry and wood processing sector, government, academia

Fig. 3 The Build Back Circular Framework

elements and drainage systems. While recycling disaster waste into aggregate is a common practice, our analysis revealed alternative uses, such as producing non-structural construction elements like partition walls (Interviewees 1, 2, 10 & 11) and pavements [65].

The government and municipalities can play a pivotal role in organizing and incentivizing the sector to invest in the necessary machinery and establish mobile and fixed recycling facilities. For example, in collaboration with the Japanese government, the UNDP is establishing advanced debris recycling facilities in Hatay and Kahramanmaraş, which will remove hazardous waste and recycle debris for new uses in construction [66]. These efforts also involve transferring Japanese expertise in disaster waste management to Turkish construction sector [66]. However, remoteness and logistics might pose a challenge, especially in rural or hard-to-reach areas to establish such facilities. Additionally, to enhance the recycling rate, responsible ministries should facilitate, and support innovation as currently material producers encounter difficulties due to regulations that limit the permissible percentage of recycled content (Interviewee 7).

Strategy 2: Integrate Circular Design Principles into Reconstruction Practices

The recovery stage involves several key reconstruction activities, including the construction of temporary housing (short-term), repairing damaged buildings and infrastructure, and rebuilding permanent housing (long-term) [10, 67–69]. As noted by Coppola [10], this stage is the most costly among DM phases. Indeed, in Türkiye, the financial impact of reconstruction and recovery is estimated to exceed 103.6 billion USD [70]. With an urgent need to provide approximately half a million homes [25], integrating circular design into reconstruction practices presents promising avenues to meet this incredible target while simultaneously enhancing urban resilience against potential disasters.

The circular design strategies, such as design for disassembly, flexible space design, and adaptive reuse, aim to narrow, slow, close, and regenerate resource loops throughout the life cycle stages of buildings, from the design phase to end-of-use [46]. Our analysis showed that prefabrication and modular construction emerge as promising approaches to increase production speed, mitigate construction waste and meet increasing housing demands ([34, 43, 51, 68, 69], Interviewees 1, 8, 10, 11 &17). These methods support Türkiye's adoption of lightweight steel and timber construction techniques [71], particularly beneficial in rural areas facing logistical challenges with traditional concrete construction (Interviewees 9 &18). However, although prefabrication is advanced, modular construction for permanent buildings is a new method and might face several cultural challenges (e.g. resistance from users (Interviewee 19)).

Circular construction approaches can mitigate the unsustainable practices in temporary housing production [69], which often prioritize cost-efficiency over environmental and social sustainability, lacking circularity mindset [43, 67, 68]. Currently, temporary housing is typically provided from prefabricated containers in the earthquake region. According to Interviewees 20 and 21, around 200,000 containers, soon to be abandoned, could be repurposed into structures such as schools and dormitories. By adopting the sustainable design guidelines, such as the one developed by Montalbano and Santi [68], which was based on examples from Türkiye, the U.S., Italy, and Japan, new circular design methods can be developed for the Turkish context. An incremental approach focused on flexibility and adaptability, as proposed by Askar, et al. [67], can further enhance economic, social, and environmental sustainability during the transition from temporary to permanent housing.

To promote widespread adoption of these design concepts, educational programs targeting architects, engineers, and construction professionals should be developed (see, Strategy 5). Additionally, design requirements and standards for temporary and permanent buildings should prioritize disassembly and circular materials (Hill, et al. [51];[68] Interviewee 7). As we outline in Strategy 3 and 9, overarching CE policies and urban planning should be linked to circular building development at the micro scale.

Strategy 3: Introduce New Circular Policies, Regulations, and Incentives

The Turkish construction sector operates linearly and is typically resistant to new concepts and technologies (Interviewee 1). To introduce circularity into reconstruction processes, the sector should be encouraged through new policies, regulations, and incentives. The government, through relevant ministries and municipalities, can play a key role in introducing and enforcing new redevelopment policies [72] integrating CE (Interviewee 1) and therefore their capacity should be enhanced [70]. At the macro level, a national circular construction policy should be developed to increase the level of reuse and recycling rates, considering the country's 2023 zero carbon targets and the cross-sectoral connections explored in the DEEP Project (UNDP, 2023; Interviewee 11). This policy should be supported by national climate policies as well as disaster management and emergency action plans (Interviewee 16). As suggested by Kocabas, et al. [73], national climate change action plan can provide a basic policy framework for incentivizing local municipalities and initiatives. Lessons learned from the previous policy implementation failures should inform future policies [74].

Cleverly designed incentives and penalties (e.g., subsidies for R&D and taxes on landfilling) for the private sector can encourage companies to adopt circular practices (Hill, et al. [51]; Interviewee 1) and support the creation of new collaborative partnerships involving private companies, academia, government, and municipalities (Interviewees 13, 14, 15, 18). A disaster waste recycling regulation could enable material producers to innovate new construction materials from debris (Interviewees 2, 17). To ensure comprehensive outcomes, policy development should also prioritize social value creation alongside environmental and economic goals. This aligns with strategies 5, 7, and 8 in our framework, which emphasize social benefits of circular reconstruction such as community involvement, job creation, and long-term awareness.

Although Türkiye is proficient in creating urban policies, it faces challenges in their implementation and enforcement [75], which poses a significant obstacle (Interviewees 9, 11). This issue points to a broader challenge of institutional capacity [76] and the need and willingness for organizational learning [77]. Corbacioglu and Kapucu's analysis of previous earthquakes [78] highlighted that the failure to implement earthquake codes prior to the 1999 Marmara earthquake stemmed from gaps in these areas. The Marmara earthquake became a turning point, prompting organizational adaptations in disaster management, as seen in the Duzce earthquake that followed [77]. However, more than two decades later, our research indicates that significant gaps still remain in organizational and cultural learning, as well as in disaster planning efforts. Many of the interviewed experts emphasized the need for institutional change and advanced disaster management planning to overcome these barriers (Interviewees 3, 7, 8, 9, 10, 11, 14, 16). As we discuss in Strategy 8, collaboration and broad stakeholder involvement [76, 79] on policy making can be an alternative path to move forward.

Strategy 4: Leverage Digital Technologies

Digital technologies offer numerous possibilities to implement circular strategies in the built environment, from designing circular buildings and processes to managing resource data along the lifecycle stages [46, 80]. Our findings highlight the need for a national building stock and post-disaster waste inventory, where life cycle data on buildings, materials, and debris can be monitored and exchanged with relevant stakeholders (e.g., demolishers and architects) ([34, 81]; Interviewee 13, 16). This system can be developed using geographic information systems (GIS), artificial intelligence, building information modeling, and advanced scanning technologies ([82, 83]; Interviewee 6). It can further be accompanied by existing tools such as the YerelBilgi system and municipal IT systems [70], and connected to digital marketplaces for secondary materials to increase reuse and recycling rates in the region (Interviewee 13).

GIS can be leveraged to map, analyze, and visualize spatial data to establish circular reconstruction hubs, support urban mining activities [84], and enhance community participation in redevelopment decision-making processes [85, 86]. Additionally, a regional digital platform that maps local construction actors is believed to be beneficial for stimulating collaboration within the sector to implement circular building solutions like modular buildings (Interviewee 12). According to Tang and Xu [65], relevant international examples, such as Japan's "Building Material Exchange Center," demonstrate how a digital platform can effectively share detailed information about post-earthquake waste materials, including their source, type, quantity, and flow and help stakeholders collaborate.

Additive manufacturing (i.e., 3D printing) could serve as a sustainable alternative to traditional construction techniques, as it allows the use of local materials like earth-based materials (see, e.g., Chadha, et al. [87]) and wood waste [63], and is faster and cheaper ([35]; Interviewee 9). A research group from Hacettepe University in Tükiye is currently conducting research on the potential of using recycled debris in large scale 3d printing [35].

Furthermore, several other digital technologies such as remote sensing technologies (e.g., drones), scanning technologies and artificial intelligence applications can be used to identify and estimate the volume of post-disaster waste to gain insights into how to recover reusable and recyclable materials. For example, Saffarzadeh, et al. [88] demonstrated how drones can be used for aerial surveys for analyzing disaster debris in Nishihara Village in Japan. By utilizing photogrammetry and 3D laser point scanning, Yu and Fingrut [89] created a digital library of reclaimed timber based on the geometric and physical parameters to stimulate design with reuse (see also [90]). Similarly, scanning technologies can be used for the post-disaster restoration of the historical architectural heritage [91] and deep learning methods can be used to waste identification [92]. To increase the adoption of these innovations, small-scale experiments can be conducted to demonstrate their efficacy and potential benefits and pitfalls.

Strategy 5: Raise Awareness and Expand Knowledge

The analysis of research data underscores the critical need for structured approaches in raising awareness and expanding knowledge of the CE within and beyond the sector. As interviewees noted, raising public awareness through public figures, exemplary projects, and transparent communication of results is crucial (Interviewee 2, 9, 18). Best practice cases should be showcased to demonstrate their feasibility and benefits, both economically and environmentally ([35]; Interviewee 2, 7, 11, 13, 18). Furthermore, educational programs, such as certified training programs targeting sector professionals in critical areas like circular design and demolition should be developed by organizations such as chambers of architects and engineers ([34, 51]; Interviewee 2, 7, 10, 11, 12, 14). Public and private clients, contractors, architects and the deconstruction workforce should be targeted due to their pivotal role in circular construction ([34, 93]; Interviewee 7, 10, 14).

Academia plays a key role in creating and disseminating knowledge while educating the next generation of construction professionals, both of which are essential for a successful transition to circular building industry (Interviewee 2, 12). A comparative analysis of undergraduate architectural education in earthquake-prone countries—Japan, Italy, the U.S., and Türkiye—revealed that Turkish universities lack foundational courses on disaster mitigation and preparedness [94]. To address this gap, it is recommended to develop interdisciplinary curricula that integrate CE principles alongside DM education. An inspiring example is the master course "Circul-Ar, Shapes and Methodologies of the Circular Architecture" developed by the University of Camerino. The course integrates multi-disciplinary competencies with a focus on reconstruction in post-disaster areas by promoting the innovative use of renewable, natural, and reusable materials [90].

Finally, guidelines outlining practical steps to implement circular construction practices should be created in areas such as selective demolition, modular buildings, circular building design, and sustainable disaster waste management ([34, 60]; Interviewee 16). These efforts should be complemented by robust regulatory frameworks and incentives from governmental institutions to ensure long-term commitment and impact (Interviewee 8).

Strategy 6: Drive the Market with Circular Business Opportunities

Our analysis suggests two actions to drive the market forward. First, integrating circularity into public procurement policy is essential ([34], Hill, et al. [51]; Interviewees 1, 9, 10, 11, and 16). Since the government and municipalities are significant public clients (for both public buildings and reconstructing homes for victims), this integration can stimulate sector adoption and create economies of scale, ultimately influencing regional supply and demand for circular materials. Exemplifying circularity in public buildings such as schools could also help increase awareness (Interviewees 1 and 9). Second, ensuring coordination among government bodies, municipalities, civil society, and industry players, particularly in sectors like steel and cement, is crucial for building a coherent recycling market (Interviewee 16). However, the lack of financing models and proper coordination among stakeholders remains a significant barrier to broader adoption (Interviewee 3). Therefore, the construction market needs to innovate new business models. For example, establishing material marketplaces in the region, functioning as centers for storing, upgrading, and recycling materials, can generate social, economic, and environmental benefits [81, 93]. These secondary material hubs can be supported by digital marketplaces to increase demand and supply turnovers and provide new job opportunities for local workers.

Strategy 7: Involve Local Communities in Recovery Processes

The recovery period involves a diverse group of stakeholders and has a significant long-term impact on a community's social and economic well-being [95]. Empowering the local community to take ownership of recovery activities is crucial (Interviewee 2) [79]. Their active participation in circular reconstruction can prolong the life of buildings, reduce waste, and ensure that policies are feasible and community-oriented [51]. In Miharu Town, Japan, bottom-up approaches proved effective in enhancing cultural adequacy and environmental adaptation in temporary housing projects [96]. Similarly, in the aftermath of the Canterbury Earthquake Sequence in New Zealand, locals played an active role in several urban regeneration projects in response to significant delays in recovery execution plans [97]. These initiatives include repurposing shipping containers into a temporary shopping mall, transforming a vacant site into an activity hub, and building a mobile bike repair shop, which proved successful and remained, connecting with the city's bicycle infrastructure policy [97]. According to Interviewees 2 and 3, such policy initiatives can serve as an inspiration, encouraging local actors to lead redevelopment efforts. These efforts should be supported by the state's provision of adequate infrastructure and resources, ensuring that local participation is both effective and sustainable [75]. Local initiatives, such as cooperatives and secondary material marketplaces, can play a critical role in rebuilding efforts and expanding awareness of circularity (Interviewee 3). Additionally, fostering skills through community-based workshops can enhance preparedness, encourage locals to construct their homes, and provide economic opportunities such as new jobs (Interviewees 3, 6, and 9).

Strategy 8: Improve Cooperation and Establish Collaborations

Our analysis highlights the importance of improving cooperation and establishing collaborations among local, national, and international actors for circular reconstruction. Currently, there is a considerable lack of cooperation between ministries, municipalities, and civil society in the earthquake region, which hinders efficient post-disaster management (Interviewees 3, 7, and 18). Simplifying the complex interactions between municipalities, governmental authorities, ministries, and relevant organizations is essential for effective cooperation [34, 73, 98].

Academic institutions, in collaboration with governmental bodies, international universities, and the private sector, can pioneer socio-techno advancements for circular reconstruction (Interviewee 14). A good example is the Matra REGIMA project (Regeneration of Istanbul Metropolitan Area), developed by Istanbul Technical University and the Matra Social Transformation Fund of the Netherlands Ministry of Foreign Affairs, in collaboration with the local municipality [75]. Following the 1999 Marmara earthquakes, the project pioneered an innovative, community-centered collaboration model for post-disaster urban regeneration. The project demonstrated that successful regeneration efforts require well-trained professionals, active NGO (Non-Governmental Organization) involvement, and legislative support for participatory planning [75].

Collaborations with foreign development agencies can also finance energy-efficient and circular housing projects [34]. Encouraging sector actors to engage with the global community is critical for advancing CE knowledge and practices (Interviewees 15 and 17). Seeking technical assistance from European counterparts in circular practices can be beneficial at the municipal level for knowledge transfer (Interviewee 10). As noted by Lu and Xu [99], collaboration is often more difficult than initiating it, making clear and mutually agreed-upon guidelines essential for long-term success.

Strategy 9: Integrate CE Principles into Post-Disaster Urban Development

Urban design and planning play a crucial role in the redevelopment and reconstruction of devastated cities, shaping socio-economic connections across various spatial scales, from transportation networks to public spaces [100]. In post-disaster recovery, comprehensive spatial planning is essential for sustainable regeneration, addressing not only the physical environment but also the revitalization of communities and the economy [72, 79]. The interviews and analysis of literature reveal a consensus on the lack of initial planning and coordination in Türkiye's approach to disaster management and urban redevelopment [73, 75], which poses a critical challenge to integrating CE principles into recovery processes (Interviewees 3, 7, 9, 10, 11, 14, 16). Urban development must align with broader master plans to ensure CE is integrated into both macro and micro-scale planning, considering regional interdependencies in sectors such as agriculture, mobility, and energy (Interviewee 11) [101]. According to interviewees, a multi-scale planning approach that includes pre-disaster planning, robust infrastructure development, and a CE mindset could address issues more effectively than the current isolated, small-scale approaches (Interviewees 8, 11, and 12). Furthermore, a regenerative closed-loop regional planning approach, where one city's waste becomes other city's resource, could enhance sustainability, resource management as well as provide economic benefits ([34, 43]; Interviewees 9 & 11).

A significant challenge for developing circular strategies in urban planning lies in the absence of discussions around key regulatory elements such as building permits, and land values [86, 98]. These regulatory frameworks can either facilitate or hinder the adoption of circular practices and business models, and without addressing them, it will be difficult to successfully implement CE principles at the urban scale. An inspiring example from the Netherlands is the CircuLaw initiative [102], which serves as a knowledge platform designed to help policymakers, project leaders, and procurement officers better navigate and utilize existing laws and regulations to promote the CE. A similar approach can help overcome legal complexities around integrating CE principles into urban planning. In addition, to address the neglected social and institutional issues that arise after disasters, it is essential to develop legal strategic plans to support urban policies, ensuring that recovery processes are participatory and contribute to enhancing social capital [79].

Strategy 10: Stimulate the use of Healthy, Local, and Biobased Materials

Biobased materials such as timber and bamboo offer significant environmental benefits compared to traditional building materials like concrete and serve as renewable resources

[63, 103]. Considering the massive scale of housing need in the earthquake-affected regions, timber and locally sourced materials are believed to be sustainable alternatives (Interviewees 10, 11). There is currently a local material use policy in place that mandates construction companies to use locally produced construction materials driving the local market (Interviewee 14)). Although timber construction has traditional roots in Turkish architecture (Interviewee 11), current economic systems and contractor practices pose obstacles. The Turkish forestry sector should improve certification and planned timber cultivation, while the construction sector should adopt modular and lightweight construction systems to harness both traditional knowledge and contemporary techniques (Interviewees 10, 11). Investment in construction timber forestry is needed to lower material prices.

Besides timber, bio-based materials like hemp and corn-stalk composites present promising, sustainable alternatives for construction in Türkiye, offering benefits such as insulation, cost-effectiveness, and waste reduction [104, 105]. These materials make use of agricultural waste while reducing dependence on petroleum-based products [105]. Further research is needed to explore their scalability, seismic performance, and how supportive regulatory frameworks can help integrate them into Türkiye's construction sector. Additionally, developing earthquake-resistant biobased building components and architectural designs could alleviate concerns related to their safety and economic feasibility. The Turkish construction sector and academia can benefit from studying Japanese timber construction techniques (see, e.g., [106]) and Japanese architectural resilience (see, e.g., [107]), which have proven earthquake-resistant qualities, to inform the development of resilient biobased construction practices.

Overview of Key Actors

The BBC framework also presented key actors who can play crucial roles in integrating circularity into reconstruction processes, as summarized in Fig. 4. In Türkiye's post-disaster reconstruction and redevelopment, the government stands as the most influential and powerful player [108]. Through its regulatory authority, the government and ministries

Fig. 4 Simplified illustration of key actors and their roles in the BBC Framework

can establish a circular recovery framework for construction and waste management by introducing and enforcing regulations that mandate the use of recycled materials, promote modular construction methods, and ensure adherence to circular principles. As the largest client, particularly through organizations like the Housing Development Administration of Türkiye (TOKI) [72], the government can drive demand for circular products and services, thereby influencing market dynamics and facilitating innovation in the construction sector. Municipalities can complement this by regulating urban planning to integrate CE principles into reconstruction projects, supporting sustainable development at the local level [21].

Academia plays a crucial role in research and education by generating knowledge, raising awareness, and disseminating insights to inform industry practices and shape policies. The construction sector should collaborate with stakeholders to innovate and adopt circular construction methods to reduce waste and enhance construction efficiency. Civil society, represented by NGOs and community-based organizations, should advocate for sustainable practices and actively involve local communities in reconstruction efforts with municipalities. The public should demand policies that prioritize environmental sustainability, earthquake resilience and community well-being. In addition to identified key actors, other relevant players such as military and fire departments should be involved in pre-disaster planning processes, as these actors play a crucial role during emergency response stage and their actions can significantly impact economic, social and environmental aspects of disaster waste management [74].

Together, these actors should form a collaborative ecosystem to support the successful implementation of the BBC Framework. In this context, ecosystem thinking involves recognizing that the value creation and capture in circular reconstruction is not limited to individual actors but shared across a network of stakeholders [109], including government, construction companies, municipalities, and the public. This interconnected approach is essential for advancing CE principles in reconstruction, as each actor's actions influence the entire system. For example, construction companies may innovate with bio-based materials, while municipalities ensure regulatory support.

Such an ecosystem-driven approach requires close collaboration, where actors coordinate to co-create solutions, share resources, and adjust their roles dynamically to respond to changing circumstances [110]. As proposed by Konietzko, et al. [111], the integration of collaborative innovation, experimentation, and platformization could be a key to success. Through experimentation, actors can trial new materials, business models and processes, while platformization, as we also mentioned in Strategy 4, enables coordination and communication within the ecosystem. By stimulating collaboration among diverse actors, this ecosystem approach can ensure that circular strategies are not isolated but interconnected, driving systemic change in reconstruction and recovery.

Discussion

Currently, DM literature is somewhat isolated, focusing primarily on the end-of-life management of disaster waste while often lacking a holistic circular development perspective. Similarly, despite a growing body of literature on the circular built environment [112], there remains a significant gap in studies specifically addressing circular recovery and reconstruction in the built environment. This gap is especially important given that the principles of CE [41, 42, 46] are very relevant to post-disaster reconstruction. Reconstruction efforts require substantial resources [1, 10], often exceeding those needed for constructing new buildings. With the construction sector being the largest global consumer of raw materials and a significant generator of waste [113], it is surprising that there are only a few studies covering circular reconstruction concepts (see, e.g., Arnetoli and Bologna [43]). As natural disasters are expected to increase in frequency [2], expanding research into circular reconstruction strategies is crucial. Therefore, our study is among the very first to address this gap by linking CE principles with crisis recovery through a circular reconstruction perspective, supported by empirical data from Türkiye's construction sector.

In the BBC framework, we presented ten circular reconstruction and recovery strategies aimed at facilitating sustainable reconstruction and creating a resilient built environment. From a CE perspective, these strategies enable the principles of narrowing, slowing, closing, and regenerating resource loops across various spatial levels. They offer inspiration for circular urban development and contribute to the growing field of circular cities. As highlighted by Williams [19], spatial planning is pivotal in shaping circular cities, and our work lays the foundations by presenting potential policy interventions and identifying urban planning needs to embed circularity at multiple spatial scales. These strategies can also support efforts in greenfield city developments, brownfield site redevelopments, and broader urban renewal projects.

From a disaster waste management perspective, our analysis revealed that upcycling, reusing and recycling post-disaster can provide economic and social benefits as end-of-life strategies to close resource loops. This finding aligns with and expands on the work of DM scholars such as Brown et al. [48], Hill et al. [51], Tabata, et al. [24] and Zhang et al. [49], who emphasize the sustainability benefits of recycling debris over traditional methods like landfilling. In particular, reusing and upcycling debris appear to be highly impactful, as demonstrated in the Katrina Furniture Project [63], where local communities not only gained valuable skills but also received income through material repurposing efforts. While DM literature often focuses on using digital technology for debris identification (see, e.g., [88, 92]), our study reveals that digital innovations like GIS, AI, and sensing technologies can go further by creating detailed inventories of reusable elements and providing crucial support for designers (see, [89–91]). By leveraging these tools in both identification and design, it may become possible to establish circular hubs in cities [84], enabling circular business models for secondary materials.

In addition, providing rapid housing solutions is a pressing challenge following disaster waste management. Our study suggests that circular design principles can address unsustainable housing production in two ways. First, circular construction techniques such as modular construction reduce production time while providing flexibility and adaptability to changing needs. Second, soon-to-be-abandoned temporary housing containers can be repurposed into new, low-rise structures, such as community centers and schools, extending their lifecycle and reducing waste. However, realizing this potential may require incentives and policy support from central and local governments to encourage market uptake. Initiating with demonstration projects could help overcome mental barriers among potential users by showcasing the benefits of circular solutions.

The BBC framework extends beyond these crucial aspects of recovery, which address more visible challenges (i.e., great volume of debris and the immediate housing requirement), encompassing a broad range of opportunities for circular reconstruction for various key stakeholders. For example, we present potential use cases of digital technologies to manage life cycle data of building stock and post-disaster debris and discuss the role of urban planning in creating regenerative loops at the regional scale. Other strategies we explore include involving local communities in recovery processes, circular public procurement, educational programs, and innovating new business models to drive the market. In this sense, our framework provides a holistic approach to circular reconstruction.

To implement these strategies, the government and responsible ministries are central decision-makers alongside municipalities, acting as lawmakers and the largest public client for most reconstruction works in the region. However, as also suggested by Brown et al. [56] and Konietzko et al. [42], an ecosystem perspective is crucial for implementing circular strategies, where stakeholders should collaborate and cooperate. Our work identifies several key actors within five groups (Fig. 4) and suggests potential actions for each to realize the BBC Framework. Since circular construction is a relatively new concept in Türkiye, countries currently implementing circular reconstruction may soon emerge as frontrunners, facilitating valuable knowledge transfer to other nations facing disasters with significant impacts on their housing stock. Overall, we encourage the international community to engage with countries struggling with disaster recovery to share expertise and support sustainable practices.

Additionally, from a DM perspective, it is essential that future policies and innovations are developed based on the lessons learned from the past disasters [15]. Our work examines the Kahramanmaraş earthquakes as a case and blends data from different sources, covering all DM stages, although the primary focus is on the recovery stage. Therefore, the insights gained from this study can provide valuable directions for policymakers in integrating CE principles into national or local DM, urban transformation and sustainability policies in Türkiye and beyond.

Future research building on the BBC framework should explore the policy interventions required to facilitate a circular construction ecosystem, while also analyzing the power dynamics that influence the distribution of benefits and losses during this transition. Empirical studies have shown that since the 2000s, powerful actors, including government institutions and partnering developers, have heavily influenced urban regeneration projects in Türkiye, often achieving their goals. However, vulnerable groups, such as low-income populations and tenants, have frequently been marginalized and left behind in these processes [108] (see also another example from New Zealand [86]). To ensure a just transition, it is essential to examine which actors may benefit or be sidelined in the shift to a circular reconstruction economy. Furthermore, understanding the ethical implications of these shifts will be critical to creating a circular model that is both resilient and equitable for all stakeholders.

Limitations

Although this study adopts a holistic approach, it has certain limitations. First, the research scope was limited to reconstruction activities within the built environment. While building upon the UN's BBB framework, this study did not detail how CE principles could contribute to the social and economic aspects of recovery, which are central in the BBB framework [95]. Future studies should explore these areas, such as the role of communities in circular reconstruction and the economic and environmental impacts of implementing circular reconstruction strategies. Quantifying such impacts would be especially valuable, providing a more comprehensive understanding of the potential benefits of circular reconstruction.

Second, while we, the authors of this work, are experts in CE, we acknowledge that we have only recently engaged with DM literature for the purposes of this study. Although we conducted an extensive search to familiarize ourselves with DM literature—using broad keywords such as "circular*," "disaster," and "recovery"—the exclusion of more specific terms like "resilience," “recycling,” and “waste management” may have limited the scope of the literature reviewed. Future research could benefit from collaboration between DM and CE experts, and should consider expanding the range of keywords to ensure a more comprehensive literature review, potentially exploring additional strategies for sustainable post-disaster recovery.

Third, the focus was on Türkiye's recovery process, which has a unique cultural, social, economic, and political context. Given the increasing number of natural disasters globally, including floods, hurricanes, and wildfires, future research should investigate how CE principles can be adapted and implemented across various settings. For instance, different geographic areas may have varying community structures, resource availability, and historical experiences with disaster recovery, all of which can influence the applicability of CE strategies. Future studies can build upon our framework by conducting comparative analyses of recovery efforts in regions affected by different disasters. Our proposed framework may change significantly if applied to different contexts.

Finally, empirical studies are recommended to examine the barriers and enablers of implementing the strategies listed in the BBC framework. For example, the use of biobased materials such as timber offers promising environmental benefits however cultural barriers like resistance of people should be investigated alongside its economic feasibility.

Conclusion

The world has been mired in fundamental crises over the past decade, including the COVID-19 pandemic, escalating geopolitical tensions and wars—such as those in the Middle East and Eastern Europe—and an increase in climate-related disasters. These challenges have imposed severe hardships on people and have significantly impacted global economies and infrastructure. Recently, adopting Circular Economy (CE) principles has been proposed as a viable strategy to address these multifaceted crises [7]. CE offers a promising alternative for crisis recovery by enhancing resilience and sustainability through resource efficiency, reducing dependency on raw materials, and fostering innovative solutions. Building on this proposal, our study focuses on the post-disaster recovery phase of Türkiye following the Kahramanmaraş earthquakes of 2023. Through three phases of data collection— a workshop with 24 construction professionals, an integrative literature review, and semi-structured interviews with 21 experts— the Build Back Circular (BBC) Framework was developed to integrate CE principles into the post-disaster reconstruction of the affected region.

The BBC Framework, inspired by the UN's BBB initiative, identifies ten action strategies for key stakeholders: (1) Upcycle, reuse or recycle post-disaster waste, (2) Integrate circular design principles into reconstruction practices, (3) Introduce circular policies, regulations, and incentives, (4) Leverage digital technologies, (5) Raise awareness and expand knowledge, (6) Drive the market with circular business opportunities, (7) Involve local communities in recovery processes, (8) Improve cooperation and establish collaborations, (9) Integrate CE principles into post-disaster urban development, and (10) Stimulate the use of healthy, local, and biobased materials. Implementing these strategies, as with every CE strategy, requires a collaborative ecosystem approach, where governments, municipalities, academia, the construction sector, and civil society organizations work together.

This study is among the very first to link crisis recovery and CE from a circular reconstruction perspective, thus addressing an important gap in the academic literature. Our wok indicates that adopting CE principles offers the dual benefits of enhancing resilience against natural disasters and providing sustainability advantages. The BBC framework can support policymakers by providing a clear set of actionable strategies that can be translated into supportive regulations and incentives to encourage circular recovery practices. For academia, the framework offers a foundation for further research to explore the long-term impacts of CE-based reconstruction and to develop innovative methodologies that can be applied in different geographical contexts. Relevant international organizations such as the UN may integrate our findings into their disaster risk reduction frameworks, enhancing global efforts in managing and mitigating the impacts of future crises. Admittedly, CE is often considered a panacea. This study demonstrates that, indeed, CE may be a panacea at least in post-crisis recovery. Overlooking the benefits of CE in this context would be a considerable missed opportunity.

Appendix A

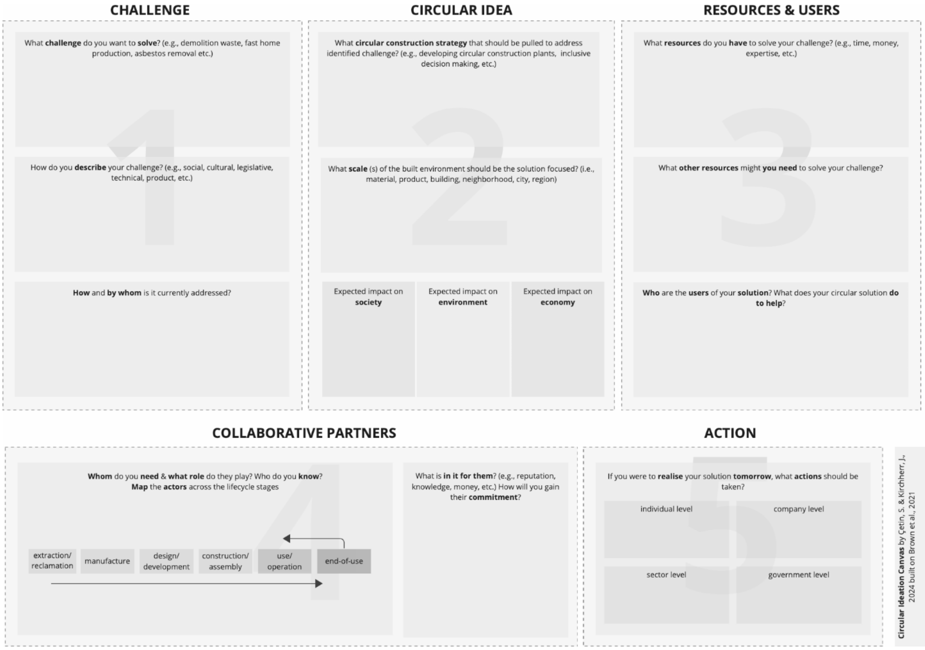

Fig. 5 Circular Ideation Canvas built on the work of Brown, et al. [56]

Appendix B

Table 2 The list of selected documents for the integrative literature review

Review stage	Authors	Title
	Angelucci, et al. [81]	A repository of recovered materials from post-earthquake reconstruction areas
	Askar, et al. [67]	From Temporary to Permanent; A Circular Approach for Post-disaster Housing Reconstruction
	Banwell and Kingham [98]	(Un)successful Urban Regeneration and Wellbeing Inter-Sector Collaboration in a Regenerating Post-Disaster City
	Bedini and Bronzini [101]	The post-earthquake experience in Italy. Difficulties and the possibility of planning the resurgence of the territories affected by earthquakes
	Cocco and Ruggiero [114]	From rubbles to digital material bank. A digital methodology for construction and demolition waste management in post-disaster areas
	Dionisio, et al. [86]	The potential of geospatial tools for enhancing community engagement in the post-disaster reconstruction of Christchurch, New Zealand
	Galluccio, et al. [63]	Design for Resilient Post-Disaster Wood Waste Upcycling: The Katrina Furniture Project Experience and Its "Legacy" in a Digital Perspective
	Genadt [107]	Three Lessons from Japan on Architectural Resilience
	Hobbs, et al. [97]	A city profile of ¯Otautahi Christchurch
	Karimi, et al. [53]	Architectural Design Criteria Considering the Circular Economy and Buildability for Smart Disaster Relief Shelter Prototyping
	Kocabas, et al. [73]	Climate Change Mitigation: From Carbon-Intensive Sprawl Toward Low Carbon Urbanization: Progress and Prospects for Istanbul
	Lu and Xu [99]	NGO collaboration in community postdisaster reconstruction: field research following the 2008 Wenchuan earthquake in China
	Di Ludovico, et al. [100]	Post-earthquake reconstruction as an opportunity for a sustainable reorganisation of transport and urban structure
	Mocerino, et al. [91]	Innovation and Resilience in the Redevelopment, Restoration and Digitalisation Strategies of Architectural Heritage
	Montalbano and Santi [96]	Sustainability of Temporary Housing in Post-Disaster Scenarios: A Requirement-Based Design Strategy
	Ozcevik, et al. [79]	Flagship regeneration project as a tool for post-disaster recovery planning: the Zeytinburnu case
	Ozcevik, et al. [75]	Building Capacity through Collaborative Local Action: Case of Matra REGIMA within Zeytinburnu Regeneration Scheme
	Özdoğan and Güney [94]	The importance of architecture education for disaster mitigation
	Pradhananga and ElZomor [93]	Revamping Sustainability Efforts Post-Disaster by Adopting Circular Economy Resilience Practices
	Tang and Xu [65]	Construction and Utilization of Post-earthquake Waste Building Materials
	Ulisse, et al. [85]	Territorial Regeneration in the Crater Municipalities After the Earthquake of L'Aquila: Social Challenges and Innovative Approaches
	Waite [72]	Policy Recommendations for the Planning of Multi-Level Redevelopment and Social Housing Practices
	Waite [108]	Power Differentials in Istanbul Redevelopment Practices: Toward a More Collaborative Decision-Making Process

Table 2 (continued)

Review stage	Authors	Title
Snowballing and gray literature	Arnetoli and Bologna [43]	Design Scenarios for a Circular Vision of Post-disaster Temporary Settlements
	Bolger and Doyon [21]	Circular cities: exploring local government strategies to facilitate a circular economy
	Bonifazi, et al. [61]	Hyperspectral imaging approach for the identification of construction and demolition waste from earthquake sites
	Doğdu and Alkan [60]	Deprem Sonrası Oluşan İnşaat ve Yıkıntı Atıklarının Değerlendirilmesi: 6 Şubat 2023 Kahramanmaraş Depremleri
	Görgün, et al. [34]	Kentsel Dönüsüm, Deprem ve Olası Diger Afetler Sonucunda Olusan Yıkıntı Atıklarının Yönetimi Rehberi
	Hill, et al. [51]	Sustainable Management of the Built Environment from the Life Cycle Perspective
	Khaled [115]	The Japanese Experience: The role of circular economy in natural disaster response
	Lamour and Cecchin [64]	Repurposed materials in construction: A review of low-processed scrap tires in civil engineering applications for disaster risk reduction
	Nakaya [116]	Circular economy and post-disaster recovery: Evolving story of Minami Sanriku
	Okumuş, et al. [71]	*Reconstruction in Türkiye After the 6 february earthquakes: Assessment of Water and Sanitation, Modular Buildings, Circular Economy Sectors*
	Perrucci and Baroud [69]	A Review of Temporary Housing Management Modeling: Trends in Design Strategies, Optimization Models, and Decision-Making Methods
	Rayhan and Bhuiyan [83]	Review of construction and demolition waste management tools and frameworks with the classification, causes, and impacts of the waste
	Reconstruction Agency [117]	The Minamisanriku BIO facility (Case Studies of Business Recovery in Iwate, Miyagi and Fukushima)
	Ruggiero, et al. [90]	From Debris to the Data Set (DEDA) a Digital Application for the Upcycling of Waste Wood Material in Post Disaster Areas
	Şahmaran and Özçelikci [35]	Best Environmental Practices In Earthquake Waste Management From Türkiye
	Temelli, et al. [31]	Afet Zamanlarında İnşaat Yıkıntı Atıklarının Belirlenmesi ve Atıkların Değerlendirilmesi: Kahramanmaraş Depremi Örneği
	Tsui, et al. [84]	Geographic Information Systems for Circular Cities and Regions
	UNDP [70]	Recovery and Reconstruction after the 2023 Earthquakes in Türkiye UNDP offer and proposed projects
	Zhang, et al. [92]	Assessment of deep learning-based image analysis for disaster waste identification

Appendix C

Table 3 Semi-structured interview questions

No	Interview question
1	How would you rate the level of circular economy awareness at the national, sectoral and personal levels? (From very low to very high)
2	How would you prioritize the challenges that should be addressed in earthquake-affected cities, in order of importance?
3	What are the main strategies or approaches you currently observe in the reconstruction process in earthquake-affected regions?
4	Do you notice any sustainability or circularity considerations incorporated into these reconstruction strategies or approaches?
5	In your opinion, are there any achievable opportunities or low-hanging fruit for integrating circularity in the reconstruction process?
6	Who are the actors that play a key role in integrating these circular strategies into the reconstruction process?
7	What changes would be necessary (for example, in policy, business, and sector) to push circularity in the reconstruction process?
8	Which current policies promote the circular economy in Türkiye?
9	What are the main challenges for circular reconstruction?

Appendix D

Table 4 Selection of interviewee quotes for each of the circular strategies mentioned in the BBC Framework

BBC Strategy	Quote
(1) Reuse or recycle post-disaster waste	*"The most important one I think at the moment is the utilization of the debris, the construction waste. I think that's a huge amount of stuff that needs to be taken care of, and it also has a quite a lot of potential. So, I think there needs to be an intelligent response to that... For example, there is such a study to make the filling material an option against very expensive alternatives like fired clay materials, bricks, or gas concrete. This can be recommended very quickly and can achieve economies of scale in this area. So, there is a need for eco-friendly, high-insulation-value materials for the partition walls, exterior walls, and cladding materials of those buildings."* *– Interviewee 1*
(2) Design temporary and permanent buildings with circular design principles	*"Yes, indeed, Turkey is prone to earthquakes, and the damages caused are significant each year. In any case, in every year we need more and more temporary houses. So therefore, in that case, these modular buildings can be transferred from one earthquake area to another earthquake area easily..."* *-Interviewee 8*
(3) Introduce new policies, regulations, and incentives for circular construction	"*.. and finally, policies and regulations should be established regarding this matter.... Policymaking can include incentives and positive sanctions. In other words, it can also involve rewards. Those who implement strategies using circular materials or circular construction techniques that genuinely protect the environment can be rewarded... However, it's crucial that these policies are discussed comprehensively, both top-down and bottom-up, to ensure effective implementation and enforcement..."* *-Interviewee 18*
(4) Develop and utilize digital technologies	"*Information sharing, data sharing, and similar activities are important, but they are not the major issues... We need to have data on new buildings so that we can benefit from it throughout the life cycle of those constructions. For example, when it comes time for demolition, we should be able to perform selective demolition, knowing what materials are in the building and where they are located. In this context, these strategies have potential. Can I take some materials from there and use them elsewhere or recycle them? Having an inventory or a digital reflection—not exactly a digital twin, as that's a different concept—of all these processes is crucial."* *-Interviewee 13*
(5) Raise awareness and expand knowledge in circularity	*"For example, we can prepare guides... We should also do something for urban transformation. I mean, an enormous amount of waste is mentioned in urban transformation... we can prepare a selective demolition guide, for example, by creating something like a master plan for different parts of the country, especially the Marmara and earthquake regions. We can organize trainings quickly. Who will deal with these demolition wastes?... both public institutions and maybe NGOs, these search and rescue associations... or the people who will operate these facilities. I'm talking about the construction and operation of those facilities, new recovery facilities, recycling facilities. These can be done. A database can be created. Preparations for this can be started quickly..."–* *-Interviewee 16*
(6) Raise awareness and expand knowledge in circularity	*"Green public procurement is perceived as more expensive construction in Türkiye. Unfortunately, all examples are like this; there is not much feasibility. Therefore, we need to somehow make these economically feasible... So, I think, as I said, even if the public sector incurs some losses, they should increase the examples of these and not neglect any public projects... I mean, in schools, state buildings, it should always start with green procurement, and as the numbers increase..."* *-Interviewee 9*

Table 4 (continued)

BBC Strategy	Quote
(7) Involve local stakeholders in recovery processes	*"... Perhaps cooperatives formed by municipalities or initiated by the municipality could be effective. There is a culture of forming cooperatives in Antakya... There are opportunities for both housing production and producing with local construction materials and transforming them. Locally, a second-hand construction material market has already developed."* *-Interviewee 3*
(8) Improve cooperation and establish collaborations	*"It is necessary to open up the actors in the sector to the outside world, that is, those working in the field, the day-to-day business-as-usual workers need to be exposed to the outside world."——Interviewee 15*
(9) Integrate CE principles into urban planning	*"Yes, so they're moving towards more micro-scale planning rather than regional planning, macro-scale planning. However, if you consider this within the framework of the circular economy, you'd think of planning at varying scales... so national planning, regional planning, urban planning, then neighborhood planning, housing design, and so on. Of course, I understand the urgency of addressing housing needs. Solving the housing problem is important, but directly focusing on housing without addressing the others... I think a different strategy could be pursued... A lot of things come into play in the circular built environment... That's where I find the process lacking...* *-Interviewee 11*
(10) Stimulate the use of healthy, local, and biobased materials	*"Ah, well, Türkiye was a timber country. It is so sad that we still don't have a FSC certification in Türkiye... And, [city] and surroundings, they already have a lot of locally sourced material like timber. And, designing for disassembly should be talked more than ever now because we don't know ten years from now, there's going to be another earthquake and how these houses will stand because they are not spending any money to infrastructure again..."* *-Interviewee 10*

Appendix E

Table 5 Literature, interview and workshop references in the Build Back Circular Framework

No	BBC Strategy	References
1	Upcycle, reuse or recycle post-disaster waste	Bonifazi et al., 2021; Dogdu et al., 2023; Galluccio et al., 2024; Görgün et al., 2024; Hill et al., 2023; Khaled, 2023; Lamour and Cecchin, 2021; Okumuş et al., 2024; Pradhananga and ElZomor, 2023; Rayhan and Bhuiyan, 2023; Reconstruction Agency, 2020; Şahmaran and Özçelikci, 2023; Tang and Xu, 2013; Temelli et al., 2023; Tsui et al., 2024; UNDP, 2023; Interviewees 1, 2, 5, 7, 9, 10, 11, 13, 14, 16, 17, 20, 21; Workshop 3 and 4
2	Integrate circular design principles into reconstruction practices	Arnetoli and Bologna, 2023; Askar et al., 2019; Genadt, 2019; Görgün et al., 2024; Karimi et al., 2023; Khaled, 2023; Montalbano and Santi, 2023; Okumuş et al., 2024; Perrucci and Baroud, 2020; Pradhananga and ElZomor, 2023; Rayhan and Bhuiyan, 2023; Şahmaran and Özçelikci, 2023; Interviewees 7, 8, 9, 10, 11, 17, 18, 20, 21; Workshop 1, 3, 4
3	Introduce new circular policies, regulations, and incentives	Görgün et al., 2024; Hill et al., 2023; Kocabas et al., 2014; Ozcevik et al., 2009; UNDP, 2023; Waite, 2019; Interviewees 1, 2, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 20, 21; Workshop 1
4	Leverage digital technologies	Angelucci et al., 2018; Arnetoli and Bologna, 2023; Bonifazi et al., 2021; Cocco and Ruggiero, 2023; Dionisio et al., 2015; Galluccio et al., 2024; Görgün et al., 2024; Karimi et al., 2023; Mocerino et al., 2024; Montalbano and Santi, 2023; Nakaya, 2024; Okumuş et al., 2024; Rayhan and Bhuiyan, 2023; Ruggiero et al., 2024; Şahmaran and Özçelikci, 2023; Tang and Xu, 2013; Tsui et al., 2024; Ulisse et al., 2024; UNDP, 2023; Zhang et al., 2023; Interviewees 6, 12, 13, 16, 18; Workshop 4
5	Raise awareness and expand knowledge	Dogdu et al., 2023; Görgün et al., 2024; Hill et al., 2023; Okumuş et al., 2024; Pradhananga and ElZomor, 2023; Ruggiero et al., 2024; Şahmaran and Özçelikci, 2023; UNDP, 2023; Özdoğan and Guney, 2016; Interviewees 1, 2, 7, 8, 9, 10, 11, 12, 16, 18; Workshops 1, 2
6	Drive the market with circular business opportunities	Angelucci et al., 2018; Görgün et al., 2024; Hill et al., 2023; Okumuş et al., 2024; Pradhananga and ElZomor, 2023; Reconstruction Agency, 2020; Interviewees 1, 3, 8, 9, 10, 11, 16, 18; Workshops 2, 3
7	Involve local communities in recovery processes	Askar et al., 2019; Bolger and Doyon, 2019; Dionisio et al., 2015; Hill et al., 2023; Hobbs et al., 2022; Montalbano and Santi, 2023; Nakaya, 2024; Okumuş et al., 2024; Ozcevik et al., 2009; Ozcevik et al., 2010; Perrucci and Baroud, 2020; Reconstruction Agency, 2020; Ulisse et al., 2024; UNDP, 2023; Waite, 2019; Waite, 2023; Interviewees 3, 6, 9, 18; Workshops 2, 4
8	Improve cooperation and establish collaborations	Görgün et al., 2024; Hill et al., 2023; Hobbs et al., 2022; Lu and Xu, 2014; Okumuş et al., 2024; Ozcevik et al., 2010; UNDP, 2023; Interviewees 10, 14, 15, 16, 17; Workshop 1
9	Integrate CE principles into post-disaster urban development	Arnetoli and Bologna, 2023; Banwell and Kingham, 2023; Bedini and Bronzini, 2018; Bolger and Doyon, 2019; Hill et al., 2023; Khaled, 2023; Kocabas et al., 2014; Ludovico et al., 2020; Ozcevik et al., 2009; Ozcevik et al., 2010; Interviewees 4, 8, 9, 11, 12, 14
10	Stimulate the use of healthy, local, and biobased materials	Galluccio et al., 2024; Genadt, 2019; Montalbano and Santi, 2023; Reconstruction Agency, 2020; Interviewees 7, 10, 11, 14; Workshop 1

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Data Availability The data presented in this study are openly available in 4TU. Research Data at https://doi.org/10.4121/7cd30541-f7d6-4a6f-be1c-90062f1a3ae6.

Declarations

Competing Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors and Affiliations

Sultan Çetin[1] · **Julian Kirchherr**[2,3,4]

✉ Sultan Çetin
s.cetin@tudelft.nl

1 Department of Management in the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, the Netherlands

2 Department of Social Sciences and Business, Roskilde University, Roskilde, Denmark

3 Innovation Studies Group, Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands

4 Cambridge Center for Environment, Energy and Natural Resource Governance, University of Cambridge, Cambridge, UK