Circular Economy and Sustainability
https://doi.org/10.1007/s43615-023-00321-x

REVIEW PAPER

Circular Economy in Construction Sector—a Guideline for Policy Makers from Global Perspective

Hammadhu HaitherAli[1] · **G Anjali**[1]

Received: 13 January 2023 / Accepted: 24 October 2023

Abstract
Construction and demolition waste (CDW) comprises the major portion of solid waste and it is becoming a global concern due to rapid urbanisation. Construction and demolition waste management (CDWM) and circular economy (CE) are interconnected as both focus on waste prevention and resource conservation. However, without having an efficient CDWM system, CE establishment is not possible. Policies are the leverage for any national or local level action. Although there are policies and regulations on CDW, inadequate enforcement and challenges faced during implementation have made the policies dormant or unsuccessful. Hence, there is a dire need to understand various aspects and challenges involved in CDWM to develop effective polices. This study explains political, market, environmental, economic, social, local, and technical aspects of CDWM and how different regions are striving to implement CE. Best practices, pioneers in CE, major challenges faced during CE establishment, and how policies could be used to overcome the issues are discussed. A continuous improvement framework to establish CE in construction sector and a robust action plan to implement the framework at the regional level have been proposed in this study. This study will guide policy maker to develop policies that are inclusive, flexible, and dynamic to enable gradual circular transition.

Keywords Construction and Demolition Waste · CE · Action Plan · Policy · Framework

Introduction

Rapid urbanisation and economic development have led to rise in resource consumption and waste generation per capita. According to the OECD, 2019, construction sector is one of the largest consumer of natural resources and the largest generator of solid waste [1]. Over ten billion tons of construction and demolition waste (CDW) per year has been produced globally which is 25% of the total waste occupying 35% of landfill [2–4]. Although over 90% of CDW has reuse, recycling potential only 20–30% is recovered [5]. In developing countries, more than 90% of waste is either dumped illegally or burned. Moreover, unauthorised disposal of CDW is creating social, economic, and environmental issues [6,

✉ G Anjali
anjaligopakumar@vit.ac.in

[1] School of Civil Engineering, Vellore Institute of Technology, Chennai, India

Published online: 17 November 2023

7]. Construction and demolition waste management (CDWM) is a complex and challenging task all over the world because of its nature, composition, volume, and complexity [4]. However, few western countries such as Netherlands started embracing circular economy (CE) and achieving more than 90% resource recovery and recycling. It is possible for them with the help combination of policies, suitable technologies, and effective CDWM [8, 9]. CE encourages the opportunity to reduce virgin material consumption and associated environmental impact by encouraging reduce, reuse, and recycling of CDW. Adopting CE harnesses multiple benefits including economic benefits such as GDP growth and social benefits such as job opportunities [5, 10, 11]. Since policies act as a stimulator leveraging CE, it is imperative for the policy makers to have knowledge about entire dynamics of the system [12]. Hence, it is important to understand the market, political, social, environmental, economic, and technical aspects of CDWM. Learnings from best practices who are pioneers in CE, challenges faced by other regions, and how policies could be an effective tool to overcome those challenges are essential to develop successful policies and hence discussed in this study.

Existing research articles on CE are very generic, focusing towards specific region and discussing mostly on the overall importance, barriers, and benefits of achieving it. This study gives a clear guideline for policy makers from the global perspective. It highlights on the various aspects to be considered before framing policies and the importance of policies in achieving CE. This study strives to answer the below questions:

- What are the various aspects to be considered while framing policies for CE in construction sector?
- What are the lessons to be learnt from other regions with respect to CDWM and CE implementation?
- How policy and interventions could be used to overcome the major issues and challenges in CDWM and CE?

Finally, a framework for framing policy and an action plan for effective implementation of policy are recommended.

Understanding Construction and Demolition Waste

Definition and Composition of CDW

The European Catalogue of Waste (Directive 75/442/CEE and 94/904/CE) classifies CDW into eight groups as indicated in Fig. 1, where the hazardous wastes are highlighted in red and other wastes are non-hazardous [2, 13]. Composition of CDW varies greatly depending on the location, size, source, and type of the building or structure.

Linear Economy and Its Consequences

Construction sector consumes about 50% of the total raw material and 36% of energy in European Union [14]. Non-metallic mineral consumption such as sand, gravel, and limestone is expected to double from 79 GT in 2011 to 167 GT in 2060. It comprises about half of the total material consumption around the world [15, 16]. Seventy percent of the building waste is from high-rise construction projects and has high recycling

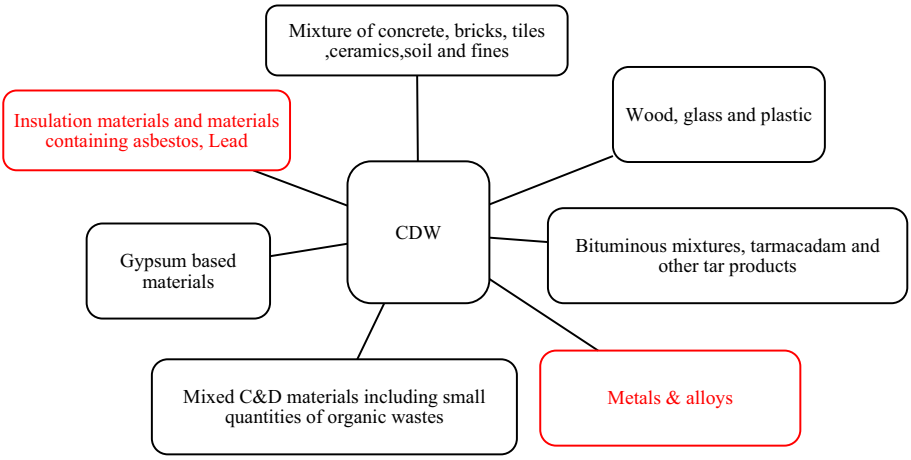

Fig. 1 Types of materials in CDW

potential [17]. Despite having high reuse and recycling potential, vast proportion of CDW is being open dumped or disposed of at landfills especially in developing countries [18–20]. Figure 2 shows the percentage of waste going to landfill among different regions in the world. Landfilling leads to severe wastage of natural resources [16]. Moreover, there is a huge environmental cost associated with landfilling. The impacts can range from contaminated groundwater to greenhouse gas emissions. However, landfilling is still being the most popular method of waste disposal [18, 19, 21]. This clearly shows that construction sector is following linear principles where the resources are majorly ending in landfill.

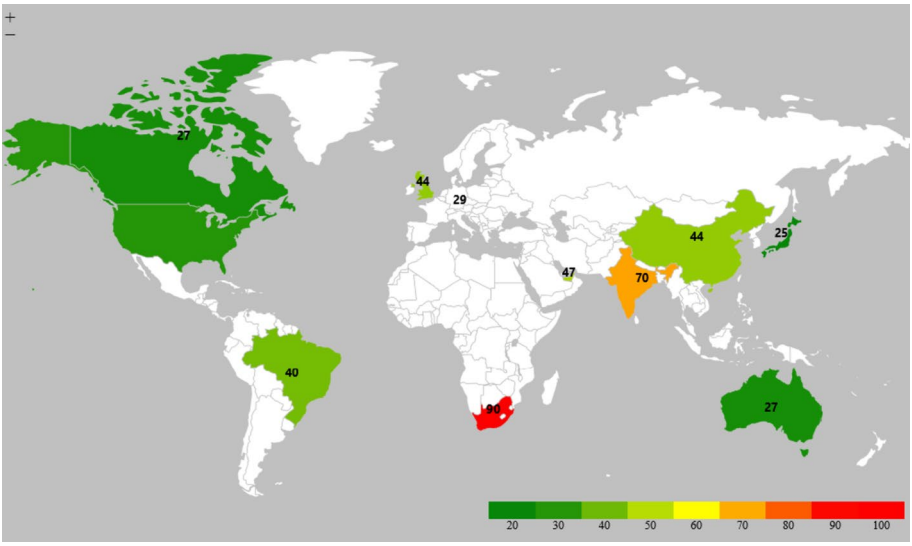

Fig. 2 CDW landfilling percentage

CDWM and Transition Towards CE

Generally, CDW is managed according to the waste hierarchy starting from prevention to disposal at landfill with prevention being the most desirable. The best way to manage CDW before and after generation is detailed below.

Prevention

During the design and planning phase of a construction and demolition project, CDW generation shall be prevented by (i) refusing waste generation by considering alternative processes, methods, and materials and (ii) following sustainable design such as designing for deconstruction/dismantling [22–24].

Reduce

Waste minimisation is most desirable in CDWM [25], which can be achieved by giving more attention during the planning and design stage [26]. Waste reduction shall also be achieved through procurement of sustainable materials, adopting lean construction practices, effective resource management, and onsite CDWM practices. During the use phase, strive to reuse, repair, and refurbish the structure and its components as long as possible to increase the life cycle [21, 27–29].

Recycle

Recycling and reusing the materials will reduce land use conflicts, carbon footprint, pollution, and energy and water consumption [7, 30, 31]. However, profound knowledge on characteristics of materials and their environmental impacts is required for better handling and to increase the possibilities of recovery and recycling [32–34].

Recycling is proved to have economic and environmental benefits. Hence, after being generated, recycling is the best way to handle CDW. The best way to handle CDW has been proposed in Fig. 3.

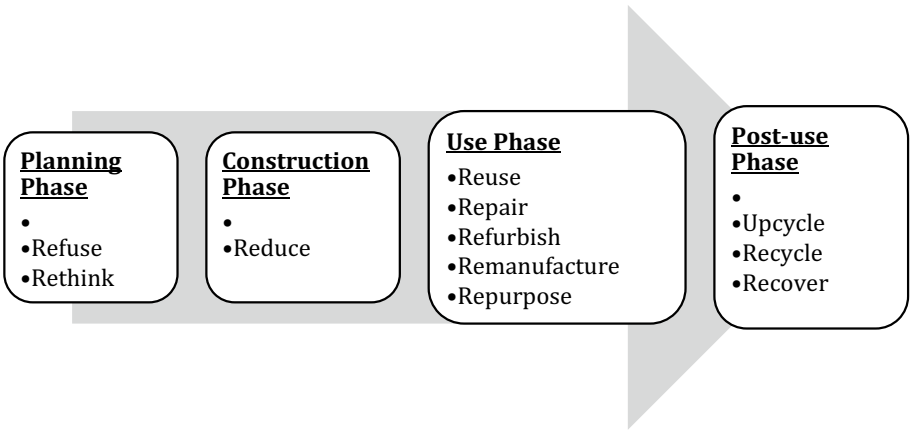

Fig. 3 The best way to handle CDW

Minimising the processing cost and transportation distance to the treatment facility and having CDW preliminary storage site under proximity are essential to control illegal dumping. Developing strategies for local level implementation involving local authorities and organisations improve the effectiveness of CDWM [35].

CE and waste hierarchy pave a new way by rethinking, redesigning, and repurposing building and their elements to reduce the impact throughout the lifecycle. CE prevents resource wastage by closing the loop and encourages transition from take-make-dispose culture [10]. CE thinking has led to the idea of up cycling rather than simple reutilization of materials without considering quality of utilisation [36]. Principles of CE have started influencing national strategic vision. Several CE initiatives have been taken and regulations have been launched around the world [37]. CE policies have been adopted by China at first in 2008, Denmark in 2013, and Colombia in 2014; Netherlands, Korea, and Finland in 2016; and France, Slovenia, and Greece in 2018. However, CE implementation is complex and unsatisfactory in these countries as construction sector is characterised by multiple stakeholder involvement and huge investments with several interconnected attributes [38]. It will not be possible to properly implement CE without the support of smaller-scale organisations, including municipalities and micro and small construction enterprises [35]. System wide transformation from linear to CE will be achievable only with incremental change. Achieving nationwide transformation needs change in fundamental economic activity having CE at the highest level of political decision-making. Setting up a waste management hierarchy and focusing towards prevention would be helpful in initiating the transition [38, 39]. Both CDWM and CE are interconnected where CE is not achievable in construction sector without having a robust CDWM system in place.

Aspects of CDWM

In order to frame holistic CE policies for construction sector, it is important to understand the following aspects.

Magnitude of Waste Generation and Global Market Status

CDW has a global market size of USD 212.8 billion in 2021 and it is expected to reach USD 287.4 billion by the year of 2027. Growth of residential projects is creating a huge drive to the market and emerging economies such as Asia Pacific, Africa, and South America are found to be the major market area. Notably, India is found to be the fastest-growing market for CDW in South East Asia [40].

Figure 4a shows the top ten generators of CDW around the globe in million tons per year. According to the World Bank report, 2.01 billion tons of waste is generated by global cities accounting for 0.74 kg/person/day. It is expected to increase by 70% reaching 3.40 billion tons by 2050. China is the largest generator of CDW while Iceland is the least generator. This assures that the rate of generation varies with the population and economic activities [41]. In case of a natural disaster, the amount of debris generated varies from 5 to 15 times the annual waste generation rates of the community based on the nature, severity, and location of the disaster [42]. Figure 4b shows the proportion of CDW among the total solid waste generated among the world countries.

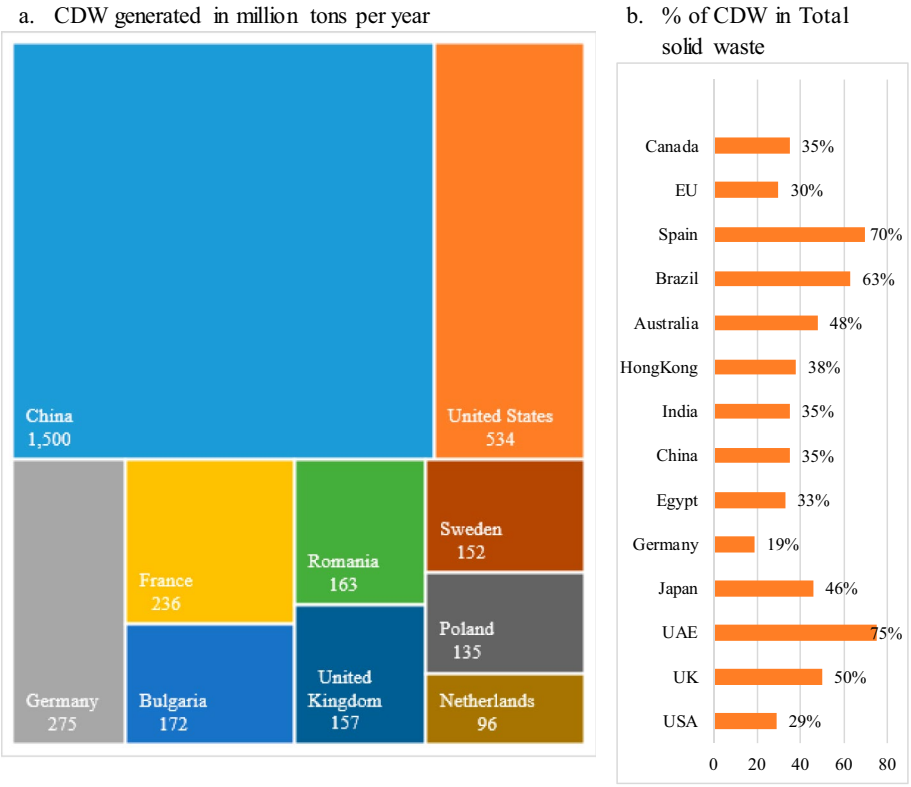

Fig. 4 **a** CDW generated (in million tons) among the top generators. **b** Proportion of CDW among total solid waste (in %). Major sources: [3, 21, 41]

Environmental Aspect

To understand the environmental aspect, life cycle assessment (LCA) would be the appropriate tool as it accounts for the entire life cycle of the material and associated environmental impact [43, 44]. Hence, results from few LCA studies have been discussed below to understand the importance of environmental consideration of CDW.

Leachate, emission of H_2S gas, and heavy metals such as lead in paints, copper, chromium, and arsenic in treated wood create major environmental impacts and need to be considered while handling CDW. This heavy metal leakage could contaminate soil, surface, and groundwater [21, 44]. For instance, difficulty in sorting and lack of demand lead to disposal of drywall in landfill leading to increased hydrogen sulphide (H_2S) production under anaerobic conditions [45]. The LCA study performed on residential house revealed that building material manufacturing process has the highest share of environmental impact, and transportation of building materials contributes up to 20% of the impact. Hence, local material sourcing and prefabrication are recommended to reduce impact [46]. A streamlined LCA analysis stresses on waste minimization and indicates that improper disposal methods would lead to negative environmental impact [47]. Prevention could contribute to 60% waste reduction and 62% lesser impact compared to without prevention scenario [43]. Improper disposal of CDW leads to destruction of urban centres by creating a nuisance on

public roads, clogging sewers, and degrading water resources which gets aggravated during economic expansion. Since, transportation is found to create a major impact from the recycling process preference shall be given to on-site recycling wherever feasible. Ninety percent of energy consumption and GHG emission could be prevented by on-site recycling process [48, 49]. It is recommended to limit the transportation distance to 40 km otherwise the benefit of recycling waste would be eliminated by increased carbon emission [50, 51]. Landfilling leads to the highest impact while recycling after selective demolition has the least impact on the environment [30]. From LCA, it is understood that impact reduction is possible through judicious and wise selection of materials and methods. As a whole, prevention is the best way before generation, and recycling is found to be an effective way after generation to reduce carbon emission and other environmental impact.

Technical Aspects of Management

The unavailability of advanced technology decreases the chances of recovering the materials without getting damaged, and conventional building methods prevent deconstruction of structure [29, 52]. Several studies highlighted that the lack of technology is one of the major barrier in establishing CE in construction sector [5, 53, 54]. Traditional method of CDWM is no longer providing a promising solution in the current scenario where the waste is increasing in quantity and complexity. Hence, there is a dire need for predictive management methods with higher efficiency [55]. Tools and technologies such as Building Information Modelling (BIM), Big Data, Geographic Information Systems (GIS), Internet of Things, Radio-Frequency Identification, Block chain, and Simulation & Modelling are very helpful in CDWM and CE transition [56]. Information and Communication Technologies (ICT) are highly useful in CDWM assisting in real-time monitoring, risk management, and decision-making [56, 57].

Although recycling is found to be an effective CDWM approach, transportation and logistics affect the total environmental and economic benefits of recycling. Hence, it is vital to adopt innovative technology to maximise the benefit and minimise the impact of recycling. Then only, stakeholder engagement in recycling could be achieved, resulting in improved recycling and diversion of CDW from landfill [12]. Cost-effective and innovative recycling technologies can increase the quality, reduce the cost, and thereby increase recycled material consumption [56]. Developed economies have the advantage of innovative advanced technologies which helps them to achieve higher CDW recovery with good quality in comparison to developing countries [12].

Economic Aspect

Since, cost benefit is a primary consideration for any stakeholder to participate in CDWM and commitment towards CE**,** it is important to consider the economic aspect of CE. Cost involved in government supervision, penalty for illegal dumping, cost associated with removing illegal dump, processing cost of legal dumping, tipping fee, capital cost for treatment facility, and incentive for participation by public and private companies should be considered while working towards CE implementation in construction sector [58, 59]. Economic instruments such as tax, incentives, penalties, and subsidies are identified to be most effective and influencing strategy for CDWM enabling circular transition [60–64]. As availability of virgin material at low cost is a major challenge, taxing the virgin materials enhances the support for secondary materials. From the UK, Denmark, and Sweden, it is

understood that imposing tax on virgin material would directly boost secondary material market [65]. Similarly, landfill change is identified as the most successful strategy to control landfilling [37].

Since waste treatment facility and CDWM infrastructure incur huge capital investment with longer period of return, there is lack of interest from public and private parties. In such scenario, public–private partnership (PPP) is found to be helpful where public and private party have partnership in establishment and running of processing facility. Public sector offers land and private sector would be given responsibility to finance, build, and operate infrastructure projects until the projects are transferred back to the public sector [66, 67]. Transferring the transportation and recycling process of CDWM to a private body helps to remove the entry barrier into recycling business [68].

Long-term operation is difficult for recycling plant without subsidies [69]. In order to increase the subside efficiency, government has to adopt general dynamic subsidy mechanism which varies according to the consumer quality perception. If government is willing to pay high subsidies, then it can give subsidies for both production and consumption of recycled materials; if it is not able to subsidies both, then it can prioritise supporting production. This would help to achieve immediate results and stability in market [70]. Although government subsidy is found to increase the profit of recycler, the learning of recycler makes the subsidy more efficient through process optimisation resulting in maximum profit and minimum impact [71]. Already, stationary plants are running successfully in many regions with positive net present value and internal rate of return. Mobile recycling plants shall also be supported by the municipality by providing concrete waste for free and getting the recycled aggregates at discounted price [65]. However, recycling CDW is economically feasible only when the recycled product is better in terms of cost and quality compared to the conventional product [3, 65]. Insisting sustainable procurement strategy, setting clear specification with consistent valuation procedure for secondary materials/products, procurement of secondary materials for public projects, developing a material catalogue, collaborating with manufacturers, and establishing independent audit for secondary materials would help to boost the recycling market [72].

Social Aspect

Lack of stakeholder engagement, coordination, and commitment is one of the major barrier in CE establishment and stakeholders' behaviour greatly impacts the level of implementation [73–75]. Majority of construction companies are micro and small companies which follow inappropriate waste management practices [76]. Support from construction stakeholders is important to reduce landfilling [77]. Landfill charge and recycling fee are found to impact the contractors' recycling preferences [68]. Stakeholder's perception and willingness to pay [78] should be considered while planning for secondary market establishment [77]. Hence, awareness among the stakeholders especially among the authorities and contractors is essential to achieve effective policy implementation and establish CE. Coordination and collaboration can be achieved through knowledge transfer and networking [79]. Stakeholder's commitment shall be improved by providing incentives for good practices [3], penalising non-compliance, and through strict supervision [80]. For transformation towards CE, both horizontal coordination across government departments and with other stakeholders from goal setting to action and vertical coordination across authority levels are required [81]. Involving stakeholders in policy-making, collaboration among the secondary material producer and consumer, inclusive and participatory planning by including

local waste management practitioners in decision-making, having regular meeting with interested parties and improving the CDWM system based on feedback, and developing an industry-wide agreement on procurement of recycled aggregates and its quality assurance would help to boost secondary materials market and drive CE through stakeholder participation [60, 82].

Local/Regional Aspect

Since policy enforcement, monitoring, and control lie entirely in the hands of local authority, participation and commitment of local authorities are highly essential [35]. Local authorities are responsible for integrated waste management [83]. Due to lack of awareness, training, adequate supervision, infrastructure, and resources, municipalities are spending additional cost in removing illegal dump [84]. Investment in local municipalities for logistic optimisation, stakeholder engagement, improving secondary material market, and local economy is very important to achieve CE. Consideration should be given on awareness, training, and knowledge sharing to improve onsite and offsite CDWM [76, 85]. Supervising illegal disposal shall be shared with other stakeholders such as NGO and public [58].

Political Aspect

Although policy is the leverage for CE, policy inadequacy has been reported in Thailand [86], Chile [12], Dutch [56], Kuwait [75], Australia [87], Italy [88, 89], China [90], India [73, 91], Vietnam [67], USA [90], and Portugal [92]. National vision is important to stimulate infrastructure, funding, and legal enforcement where policymakers are the facilitators of CE [93]. The whole value chain must be considered to deal with dynamic complexity and the stakeholders in construction has to realise that adopting CE aid in economic, social, and environmental value addition [21, 94].

Construction Material Recycling Law enacted by Japan in the year 2000, enforced mandatory recycling of iron, wood, concrete, and asphalt. This resulted in a 33% increase in the CDW recycling within the period 1996 to 2008 [95]. Landfill tax in New Zealand, tax for extracting natural aggregates in Europe, and waste disposal charging scheme for construction projects in Hong Kong are few examples indicating the importance of policies in CE transition [96] (Yu et al., 2021). Finland has many good policies and regulations that facilitate its leading role in CE such as 'Natural Resource Strategy for Finland: using natural resources intelligently'—2009; Resolution on Strategic Programme for the CE, 2021 [81]; and 'Leading the cycle: Finnish Road Map to a CE'—2016 [38].

It is vital to be cautious, since certain policies such as imposing higher waste disposal fee might worsen illegal dumping as the public tend to bifurcate the fee [97]. Consumption of recycled materials is legalised in many regions such as USA, Italy, Japan, and France [65]. It is also important to consider the cross-regional impact of policies. After China's National Sword Policy banned the waste import, Australia realises the inadequacy in waste treatment facilities and urgency in need for innovative and advance strategies for CDWM [72]. Hence, a clear and structured policy with long-term credibility is required [88]. Hence, it is understood that policy has a huge impact on local and global CE practices.

Policies should be bi-directional to achieve a CE and the entire system should not be 'waste centric' instead it should shift towards 'designing-out-of-waste'. Through the bi-directional approach, feedback from stakeholders on the ground should be considered at the micro level, evaluation of the supply chain should be made at the meso level to adjust

the regional level policy, and final policy adjustment should be made at the macro or national level. This kind of approach would help in effective and successful policymaking [98]. Diverse policy instruments should be used in synergy, aligned with the dynamics of the secondary materials supply chain [99]. Policies can be categorised into control and command policy and information-based and market-based policy [100]. A combination and wise use of policy instruments are required for successful, socially acceptable, and feasible CE policy [101].

Learning from Other Countries

Table 1 shows the good practices in CDWM and CE establishment in construction industry among various regions along with suggestions and recommendation to improve.

Pioneers in CE

Austria and Netherlands which are pioneers in CDWM rely on local waste regulation framework and waste management plan rather than national regulation. Countries having dense infrastructure for CDWM recycling such as the UK and Germany show high recovery rate [107].

Anti-waste Law, 2020, launched in France, aims in system-wide circular transition encouraging business, municipalities, and citizens to adopt circular practices and eliminate waste. The law strives to initiate societal transformation and establishes new measures such as reparability index and ban on destructing unsold goods. This law is a supportive tool for the countries' climate policy and French Climate Plan. It broadly utilises EPR schemes to prevent waste generation. The principle goals of France CE are as follows: (1) stimulating design for CE; (2) preserving value through resource management; (3) making the economics work for CE; (4) investing in innovation, skills, and infrastructure; and (5) collaborating for the system change [114].

Amsterdam Circular Strategy 2020–2025 aims in achieving sustainable cites by reducing raw material consumption. It is working towards the ambition of halving the virgin material consumption by 2030 and becoming fully circular by 2050. It aims in designing climate-adaptive cities using sustainable materials for roads, playgrounds, and bridges. Special attention is intended to be paid in closing the building material loop by including circular criteria in tendering of infrastructural and public projects, encouraging disassembly and segregation of components for higher level application, and stimulating circular renovation of public and private housing.

A global project on circular construction called CIRCuIT (Circular Construction in Regenerative Cities) is funded by the EU Horizon 2020 programme. Project areas include Helsinki region/ Vantaa, Copenhagen, London, and Hamburg. The project is working under three themes to achieve circular construction which are given below:

a) Extending building lifecycle through repurposing or refurbishment
b) Development of flexible construction which is versatile and modifiable and allows dismantling
c) Enabling reuse of building components and recycling of materials after dismantling of buildings [125]

Table 1 Region-wise analysis of good practices, suggestion, and recommendations for CE

Region	Good practices	Suggestions and recommendations
Africa	Have secondary market for bricks, wood, metal scrap, and plastics [102]	Stringent policies, effective monitoring, strict enforcement, inclusive system, and engagement at the local level are highly required to establish a good CDWM system in Africa [103]
Australia	• 76% of the debris is recycled • Has Landfill charge	• Technology intervention in waste minimisation and industry-academia collaboration is required [87] • Need for cross-regional waste management mechanisms • Establish a dynamic penalty system according to the landfill and treatment capacity and stakeholder compliance • Collaborative landfill charge prevents illegal dumping and minimize waste generation in cross-region [104] • Raise awareness and fostering networks via different channels, develop sustainable business models, standardise business approach across the supply chain • Establish central marketplace (physical/online) • Advertise secondary market • Tax break/incentive to use recycled materials • Coalition with private companies and research • Supply chain consideration, sustainable procurement, knowledge sharing on best practices [72, 105, 106]
Austria	• Rely on local waste management plan • Landfill Ban • Landfill Tax [107]	Best in CE [8]
Brazil	• Well established policy [83] • Mandated use of recycled aggregates in pavements [108]	Need quality control on recycled materials for large-scale applications [83]

Table 1 (continued)

Region	Good practices	Suggestions and recommendations
China	• China follows PPP for recycling and transportation of CDW • Mandated use of recycled aggregates in public and private projects • 20% must be used in government funded project—Shenzhen, Shanghai • Concrete below C25 should consist of 15% recycled aggregates—Suzhou • In Hangzhou, Xi'an, Chengdu, and Zhoukou, recycled building materials are the first consideration in government-funded projects [68] • Regulation permits the use of recycled materials in foundation and subgrade of pavements [108] • Encouraged green building technology adoption and green subsidy policies to encourage sustainable building practice [109] • Actively working on improving the effectiveness of CDW management by using economic instruments such as incentives and subsidiaries, establishing an integrated network called urbanisation resource environment (URE) system and adopting cleaner production policies [97, 110] Hongkong—permits the use of recycled materials in foundation and subgrade of pavements [108] Waste landfill charge [111]	Need more investment in CDWM Use subsidy and environmental tax to boost recycling Need to understand the casual relationship between the stakeholders and their influence in CDWM [97] Lack of guidelines on CDW sorting and collection, lack of knowledge and standard for reuse and recycling of CDW, and immature market preventing CE transition. Need to improve the existing CE model through 3R approach [62, 97]

Table 1 (continued)

Region	Good practices	Suggestions and recommendations
Europe	EU Waste Framework Directive (2008/98/EC), which sets a target for the recycling of non-hazardous CDW at a minimum of 70% of its weight by 2020 B2B schemes in Europe are successful such as deposit refund scheme for construction packaging, drums, etc. [60] Recovery rate of over 90% is recorded in some of the highly developed nations such as Italy, Netherlands, Ireland, and Luxembourg since 2010. Iceland, France, and Sweden also show an excellent recovery rate and it is 100% for Netherlands. At the same time, Montenegro in Europe recorded 0% recovery rate in 2018 [9] Spain Traceability of CDW with local licensing Deposit based on estimated waste from site waste management plan later it gets refunded by submitting waste management certificates [60] Landfill Tax [112]	• Transform the recovery target from weight-based target into material specific target in order to achieve true circularity • Circular design, digitisation, and material passport improve effectiveness [113]
Finland	CE has been achieved in Finland though innovations, digital solutions, responsible investors, business, consumers, and smart regulations [81]	Best in CE [8]
France	Extended Producer Responsibility has been launched in 2022 Landfill Ban Landfill Tax [112]	Need to achieve societal transformation [114]
Germany	Waste generators are responsible for segregation, recycling, and reuse of CDW [108] Landfill Ban [112]	Need for more facility equally distributed in all regions [8]

Table 1 (continued)

Region	Good practices	Suggestions and recommendations
Greece	Promoted CE through 3R concept Developed multi-stakeholder partnership in CE implementation Support circular entrepreneurship Having dedicated indicators to monitor CE [38]	• Develop Stakeholder engagement • Support entrepreneurship • Develop dedicated indicators for progress monitoring • Set up separate ministry for overseeing CE implementation and progress [38]
India	CDWM is heterogeneous among the cities while Delhi is pioneering Established recycling plants are successfully running under PPP [73, 115]	Need for stakeholder engagement Need for stringent policy enforcement [73, 116, 117]
Japan	Mandated recycling of certain demolished materials [108] Landfilling fee, tax breaks, and soft loans for recycling companies; low-interest loan for consuming secondary materials [100]	Good in CE [38]
Korea	Increasing trend in number of recycling plants producing quality aggregates as well as the number of quality certifications [118] South Korea has an innovative Framework Act on Resource Circulation (FARC) (Act No. 14229, May 29, 2016) and several regulatory measures in place Mandated recycling ratio [38]	Although the quality of recycled aggregates is increasing in par with natural aggregate, negative public perception is still impacting the market of secondary products [118]
Netherlands	Landfill Ban Landfill Tax Effective local waste management plan Effective implementation [112] Pioneer in CE	Best in CE [8, 38]
Portugal	Landfill Tax [112]	Need for higher-end large-scale CDW processing plant Need focus on reducing transportation and processing of non-treatable materials to increase optimisation and profit [119]

Table 1 (continued)

Region	Good practices	Suggestions and recommendations
Singapore	Constructed an industrial park for recycling and rented out recycling plants to private enterprises for low rent 99% of CDW is reused and recycled [120] Collection and transportation are managed by private sector Informal sector is authorised and play wider role in recovering valuables [121–123]	Singapore has one of the best and most comprehensive systems for waste management. It is capable of achieving 99% of CDW excluding soil and sludge. The incoming CDW is sorted, valuable materials are recovered, and finally, the remaining content is incinerated in waste-to-energy plants. The National Environment Agency of Singapore (NEA) is maintaining a well-updated website containing a database of the organisations involved in waste management; the online directory contains information about traders, waste collectors, and recycling facilities. It has established a licensing system for waste collectors involved in the collection and handling of CDW [28, 102]
UK	Waste and Resources Action Programme (WRAP) in 2012 aid conserve natural resources and prevent wastage Mandatory onsite waste reduction [108] Standardised systems and single-large market for secondary materials Landfill tax, aggregate levy allowing UK to achieve the highest rate of resource recovery in EU. Fiscal policies and legislation have proved to be the key drivers of waste minimisation in UK construction industry [77]	Lack of government support for market. Government support, public tender including recycled material, training, and qualification of secondary materials is required. Cost reimbursement for purchasing recycled material has positive effective whereas labelling creates negative effect [124]
USA	Rewarding zero CDW emitter, developing techniques such as 'design for deconstruction', placing accountability on individuals such as developers and allocating large fund for collection and management of CDW Has developed CDWM system and levy waste landfill charge [90]	Need to focus on establishing system that focuses on waste prevention and CE and sustainability [90]

A report from Ellen Macarthur Foundation 'Towards The CE' sheds light on the transition path from linear to CE. It clearly indicates that CE is the only answer for our present and future resource challenges and has huge economic opportunities. The report indicated that skills in designing and manufacturing of circular products, new business models where products become services, skills in reverse logistics and treatment, and improving intersector and intercycle performance are the building blocks for CE [126].

Issues in Establishing CE and How Policy-Based Solution Could Overcome the Issue

CDW management system is informal at the local level and the entire system lies in the hands of informal sector in developing countries [18]. There is a huge disparity and inaccuracy in the estimation of amount of CDWs generated [127]. Although the quality of recycled aggregates produced from recycling plant is increasing on par with natural aggregate, negative public perception is still impacting the market of secondary products [102, 118]. There is a lack of database and policy monitoring system which provide reliable and accurate information on material flow and waste generated [128]. Proper database management system on CDW would help in better monitoring, estimation of future rate of generation, and planning of treatment facilities and landfills [28]. Since decision makers are often changing, there is no ambition for long-term CE strategies. Decision on waste and resources management and its strategies are often fragmented among departments and municipalities [59]. Similarly, CE and CDWM involve multiple barriers and challenges. From a thorough literature survey [5, 17, 19, 25, 26, 35, 62, 65, 72, 78, 85, 87, 93, 107, 108, 111, 112, 117, 129–137], the most repeated and highlighted challenges and barriers faced by countries around the world in CDW management and CE establishment has been extracted and summarised in Table 2 along with policy-oriented solution.

Framework to Achieve CE in CDW Management

Policy process is cyclic and iterative involving five stages such as setting agenda, formulating policy, decision-making, implementing, and evaluating [36]. Initially, a policy guideline has to be set up which acts a s a basic policy upon which frameworks, subsequent policies, and regulations for CE shall be built based on feasibility and requirement. One-size-fits-all approach should be avoided and policy should be flexible and established in phases allowing modifications according to feedback from the previous phase [31]. Attention should be given to promotion of policies and information exchange. Identify and structure the data necessary for monitoring CE at macro and microlevel. Include the perspectives from national, regional, and municipality level stakeholders and get feedback on policy from policymakers at each level [31]. Encourage collaboration of academia, policy makers, and other stakeholders to establish a clear structure of CE. Develop clear indicators to monitor and track the progress and performance of CE [89, 138].

Framework to CE in CDWM has been proposed below (Fig. 5) based on the findings made from various aspects. A cyclic process has been proposed since the improvement is iterative and continuous based on feedback and technological advancement.

Table 2 Issues/challenges and policy-based solution to achieve CE in construction sector

Category	Issues/challenges	Policy-based solution
Policy and intervention	Lack of policy/regulation and unclear responsibilities	Developing holistic policy and continuous improvement based on feedback Policy focused on value creation with long-term vision [138] Making clear roles and responsibilities Setting exclusive ministry for framing CE policies, encourage coordination, and overseeing establishment [38] Regulatory and financial support for industrial transformation [67]
Market	Availability of virgin material at low cost Low-quality recycled materials/products Lack of market for secondary products/materials Lack of standardisation for secondary materials and their applications	Increasing virgin material price Taxing virgin materials [65] Penalty for illegal disposal and Incentives for pricing green materials [83, 108, 108] VAT refund policy [139] Stimulate research on improving quality and identifying advanced technology Market development is urgent need with advertising [85] Establish online/physical market [140] Legalise secondary material consumption [65] Establish material bank [141] Embrace service-oriented business leasing, pay-peruse, buy-back policies [141] Certify of recycled products [142]
Data	Lack of data on CDW generation, characteristics, material flow across the life cycle, cost involved in management, landfill, etc	Develop transparent, safe, and reliable platform for data and information sharing [138]
Infrastructure	Lack of infrastructure Longer transportation distance to treatment facility Lack of Reverse logistics and circular business models	Establish infrastructure with PPP [66] Support entrepreneurs in circular business Partnering with small and medium business for handling parts of CDW process [119] Mandating EPR Setting up infrastructure for reverse logistics [143, 144]

Table 2 (continued)

Category	Issues/challenges	Policy-based solution
Technology	Lack of technology adoption for tracing material flow, data collection, and in the CDWM process	Support and encourage technology adoption through fiscal instruments and appreciating best practices Adopt BIM and material passport [53, 113, 145, 146] It is fundamental to have digital collaboration to encourage new business models and material circularity [141]
Enforcement, monitoring and control	Lack of enforcement and poor implementation Poor supervision and control	Allocate resources and performance evaluation for local authorities to enforce polices implementation Clear definition of roles and responsibilities Conduct premonition audit [147] Initiate changes in design and construction process [141] Interdepartmental coordination among authorities [143] Stakeholders compliance [82, 111] Supervision [148, 149] Fiscal policies for waste minimisation [3]
Stakeholder engagement	Lack of coordination among government departments Lack of commitment from local authority/municipality Lack of stakeholder/contractors' support Lack of communication and collaboration	Allocate resources and performance evaluation for local authorities to enforce polices implementation Clear definition of roles and responsibilities Mandate use of secondary materials/products Government should act as a model in procuring secondary materials for public projects Incentives and subsides for procuring secondary materials Support business adopting material circularity Encourage collaboration of academia, policy makers, and other stakeholders to establish clear structure of CE indicators [89, 138]. Digital collaboration. [141] Promote economic viability and profit for contractors [58, 84] Local networking opportunity to improve commitment and business [147, 150]

Table 2 (continued)

Category	Issues/challenges	Policy-based solution
Knowledge	Lack of knowledge on materials, treatment methods, and applications	Establishing dedicated institute or collaborate with academia for developing uniform national guidelines and standards for reuse and recycling materials Create awareness about secondary materials/products among consumers Educate and train waste practitioners [140] Encourage design for circularity [141] Interdisciplinary research [151]

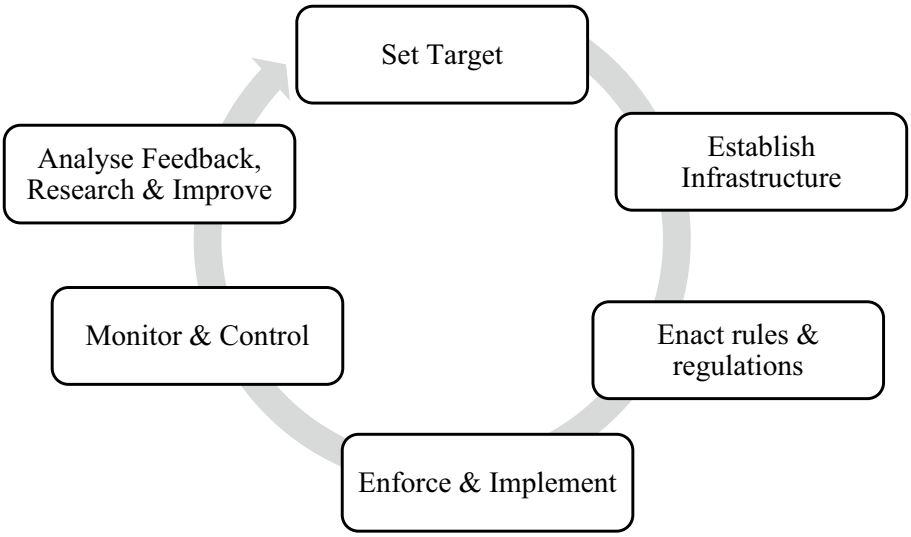

Fig. 5 Framework to achieve CE in CDW management

Action Plan to Implement the Framework

An action plan has been proposed to establish a robust waste management system across the state/county considering the state/county in three levels (Table 3). The entire central authority will be at macro level who are capable of creating policies and regulations for the whole region; the lower-level authorities or local bodies would be at micro level who have direct responsibility for implementing the regulations at ground level; and medium-level bodies will be the controlling group of micro level bodies and act as an intermediary between macro and minor level authorities. Medium-level authorities will be involved in the enforcement, facilitating, and monitoring of regulations.

Conclusion

This study involves analysing various aspects of CDW, challenges involved, and situation of global region with respect to CDWM. Finally, a framework for policy development and action plan for the implementation of CE in construction sector with focus on CDWM are given as a guide to policymakers. By analysing the various aspects and global scenarios, the following conclusion has been made.

- It is observed that based on economic activity, population, and national approach towards material conservation, the amount of CDW generated, recovery rate, recycling rate, and landfilling rate varies.
- Effectiveness of CDWM depends on the local legislation, enforcement, infrastructure availability, and construction and demolition practices.
- CDW has a higher opportunity for the application of the CE principle by promoting the reduction, reuse, and recycling of materials. However, the effectiveness of imple-

Table 3 Action plan to achieve zero landfill

Level	Action plan
Macro	• Set up an exclusive governing body for CDW with clear roles and responsibilities • Set a 'Net zero' target with a timeline with quantifiable and achievable milestones • Allocate fund and resources • Create infrastructure • Create a transparent platform to gather data, trace material flow, get overall statistics, and decision-making • Create rules and regulations • Make amendments based on feedback from micro and medium level • Continuous monitoring and control • Use a combination of financial tools such as penalties, subsidies, and tax waivers to achieve targets • Establish collaboration with academia to encourage research on technology and materials towards 'Net zero' • Enact regulations to control air pollution from the construction sector • Support and evaluate local authority
Medium	• Enforce rules and regulation • Establish infrastructure—C&D recycling plant, collection, and transportation facilities • Robust monitoring and control • Harness technology such as GIS, GPS, and RFID • Focus on efficient IEC • Capacity building • Conduct stakeholder meetings with builders, architects, and contractors and educate them through regional technical schools/centres on technologies such as 3D printing and deconstruction and tools such as BIM in order to become 'zero waste' producer • Develop SOP for CDW management • Mandate on-site segregation • Enforce mandatory dust control measures • Acknowledge best practices with rewards and awards
Micro	• Implement rules and regulations on CDW at local level • Create a warehouse for storing pre-used and unused materials • Setup laboratory to check the quality of materials • Set material-wise targets for proper management of CDW • Encourage entrepreneurs working on whole or a part of CDW management, such as logistics, recycling, and manufacturing secondary products from CDW • Create an online platform for trading surplus, pre-used, and secondary building materials • Strive to achieve behavioural change through continuous enforcement and education • Integrate and acknowledge scrap dealers into the system and design the system in such a way that no material can flow into the illegal market • Create an entry and exit permit system for construction and demolition projects • Deploy technology such as block chain, Internet of Things, and GPS to trace material flow and automate the permit system • Monitor dust control implementation practices

menting CE models highly relies on national policies but the policymakers shows less engagement in circular economic concepts.

- The policy should have holistic high level vision on waste prevention rather than addressing end of pipeline issue or focusing on single issue such as landfilling.
- Collaboration with academia and supporting research is important to improve quality of secondary material and technology. Industry wide collaboration is required for supporting secondary materials market
- CE and policy enforcement are not possible without local level engagement and action.

- Need for legalisation, standardisation, and acknowledgement of secondary material utilisation and online or physical market to sell.

Policy and interventions are mandatory for driving CE transformation. Fiscal instruments are very effective. Lack of coordination among government departments could be overcome by clearly defining roles and responsibilities with an exclusive ministry for CE at the top. There is a need for transparent, unified database platform for sharing information and decision-making. Illegal dumping is a global issue and recycling market has great opportunity. Integration of informal sector into the waste management system would help in achieving higher recycling and recovery rate with existing infrastructure. By following the proposed action plan at three different levels would help in achieving CE gradually through continuous improvement. Authority at the macro level should understand the dynamics of the medium and micro levels and continuously improve the system according to the feedback and impact. Integrating technology would help in getting real-time data and in effective decision-making. Stakeholder engagement is essential and shall be achieved through networking and combination of policies. As a whole, a flexible iterative policy with local level action would facilitate successful nationwide CE transition.

Author Contribution HRKH: conceptualisation, methodology, data collection, writing—original draft, visualisation. AG: supervising, review and editing.

Data Availability Data will be made available on request to corresponding author.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

References

1. OECD (2019) Global material resources outlook to 2060: economic drivers and environmental consequences. OECD
2. Alsheyab MAT (2022) Recycling of construction and demolition waste and its impact on climate change and sustainable development. Int J Environ Sci Technol 19:2129–2138. https://doi.org/10.1007/s13762-021-03217-1
3. Ghaffar SH, Burman M, Braimah N (2020) Pathways to circular construction: an integrated management of construction and demolition waste for resource recovery. J Clean Prod 244. https://doi.org/10.1016/j.jclepro.2019.118710
4. Wu H, Zuo J, Zillante G, et al (2019) Status quo and future directions of construction and demolition waste research: a critical review. J Clean Prod 240. https://doi.org/10.1016/j.jclepro.2019.118163
5. Munaro MR, Tavares SF (2023) A review on barriers, drivers, and stakeholders towards the circular economy: the construction sector perspective. Clean Responsible Consum 8:100107. https://doi.org/10.1016/j.clrc.2023.100107
6. Ferronato N, Guisbert Lizarazu GE, Gorritty Portillo MA et al (2022) Environmental assessment of construction and demolition waste recycling in Bolivia: focus on transportation distances and selective collection rates. Waste Manag Res 40:793–805. https://doi.org/10.1177/0734242X211029170

7. Ram VG, Kishore KC, Kalidindi SN (2020) Environmental benefits of construction and demolition debris recycling: evidence from an Indian case study using life cycle assessment. J Clean Prod 255:120258. https://doi.org/10.1016/J.JCLEPRO.2020.120258
8. Villoria Sáez P, del Río MM, Atanes Sánchez E et al (2019) Viability of gypsum composites with addition of glass waste for applications in construction. J Mater Civ Eng 31:04018403. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002604
9. Statistics/Eurostat. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/cei_wm040/default/table?lang=en. Accessed 5 Nov 2022
10. Nodehi M, Taghvaee VM (2022) Applying circular economy to construction industry through use of waste materials: a review of supplementary cementitious materials, plastics, and ceramics. Circ Econ Sust 2(3):987–1020. https://doi.org/10.1007/s43615-022-00149-x
11. Nodehi M, Taghvaee VM (2022) Alkali-activated materials and geopolymer: a review of common precursors and activators addressing circular economy. Circ Econ Sust 2(1):165–196. https://doi.org/10.1007/s43615-021-00029-w
12. Véliz KD, Ramírez-Rodríguez G, Ossio F (2022) Willingness to pay for construction and demolition waste from buildings in Chile. Waste Manag 137:222–230. https://doi.org/10.1016/j.wasman.2021.11.008
13. Del Río MM, Gracia PI, Azevedo ISW (2010) Sustainable construction: construction and demolition waste reconsidered. Waste Manag Res 28:118–129. https://doi.org/10.1177/0734242X09103841
14. Shape S (2018) WorldGBC Europe Network urges the European Commission for the EU2050 long term strategy. SBC GREECE
15. Global material resources outlook to 2060 (2019) Glob Mater Resour Outlook to 2060. https://doi.org/10.1787/9789264307452-EN
16. UN calls for urgent rethink as resource use skyrockets (2019) UN Environ. http://www.unep.org/news-and-stories/press-release/un-calls-urgent-rethink-resource-useskyrockets. Accessed 4 May 2022
17. Umar UA, Shafiq N, Ahmad FA (2021) A case study on the effective implementation of the reuse and recycling of construction & demolition waste management practices in Malaysia. Ain Shams Eng J 12:283–291. https://doi.org/10.1016/j.asej.2020.07.005
18. Ferronato N, Torretta V (2019) Waste mismanagement in developing countries: a review of global issues. Int J Environ Res Public Health 16:1060. https://doi.org/10.3390/ijerph16061060
19. Mama CN, Nnaji CC, Nnam JP, Opata OC (2021) Environmental burden of unprocessed solid waste handling in Enugu State, Nigeria. Environ Sci Pollut Res 28:19439–19457. https://doi.org/10.1007/s11356-020-12265-y
20. Osmani M (2011) Chapter 15 - construction waste. In: Letcher TM, Vallero DA (eds) Waste. Academic Press, Boston, pp 207–218
21. Chen Q, Feng H, Garcia de Soto B (2022) Revamping construction supply chain processes with circular economy strategies: a systematic literature review. J Clean Prod 335:130240. https://doi.org/10.1016/J.JCLEPRO.2021.130240
22. Joensuu T, Edelman H, Saari A (2020) Circular economy practices in the built environment. J Clean Prod 27. https://doi.org/10.1016/j.jclepro.2020.124215
23. Buyle M, Galle W, Debacker W, Audenaert A (2019) Sustainability assessment of circular building alternatives: consequential LCA and LCC for internal wall assemblies as a case study in a Belgian context. J Clean Prod 218:141–156. https://doi.org/10.1016/J.JCLEPRO.2019.01.306
24. Won J, Cheng JCP, Lee G (2016) Quantification of construction waste prevented by BIM-based design validation: case studies in South Korea. Waste Manag 49:170–180. https://doi.org/10.1016/j.wasman.2015.12.026
25. Yuan H (2017) Barriers and countermeasures for managing construction and demolition waste: a case of Shenzhen in China. J Clean Prod 157:84–93. https://doi.org/10.1016/j.jclepro.2017.04.137
26. Kabirifar K, Mojtahedi M, Changxin Wang C, Vivian W.Y. T (2020) A conceptual foundation for effective construction and demolition waste management. Clean Eng Technol 1. https://doi.org/10.1016/j.clet.2020.100019
27. Charef R, Lu W, Hall D (2022) The transition to the circular economy of the construction industry: insights into sustainable approaches to improve the understanding. J Clean Prod 364:132421. https://doi.org/10.1016/J.JCLEPRO.2022.132421
28. Hoang NH, Ishigaki T, Kubota R et al (2020) A review of construction and demolition waste management in Southeast Asia. J Mater Cycles Waste Manag 22:315–325. https://doi.org/10.1007/S10163-019-00914-5/FIGURES/4

29. Akinade O, Oyedele L, Oyedele A et al (2020) Design for deconstruction using a circular economy approach: barriers and strategies for improvement. Prod Plan Control 31:829–840. https://doi.org/10.1080/09537287.2019.1695006
30. Ferronato N, Moresco L, Guisbert Lizarazu GE, et al (2021) Comparison of environmental impacts related to municipal solid waste and construction and demolition waste management and recycling in a Latin American developing city. Environ Sci Pollut Res 1–15. https://doi.org/10.1007/s11356-021-16968-8
31. Wang H, Pan X, Zhang S, Zhang P (2021) Simulation analysis of implementation effects of construction and demolition waste disposal policies. Waste Manag 126:684–693. https://doi.org/10.1016/j.wasman.2021.03.056
32. Kirchherr J, Reike D, Hekkert M (2017) Conceptualizing the circular economy: an analysis of 114 definitions. Resour Conserv Recycl 127:221–232. https://doi.org/10.1016/J.RESCONREC.2017.09.005
33. Yeheyis M, Hewage K, Alam MS et al (2013) An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability. Clean Technol Environ Policy 15:81–91. https://doi.org/10.1007/s10098-012-0481-6
34. Lu W, Peng Y, Xue F et al (2018) 3.21 - The fusion of GIS and building information modeling for big data analytics in managing development sites. In: Huang B (ed) Comprehensive Geographic information systems. Elsevier, Oxford, pp 345–359
35. Ramos M, Martinho G, Pina J (2023) Strategies to promote construction and demolition waste management in the context of local dynamics. Waste Manag 162:102–112. https://doi.org/10.1016/J.WASMAN.2023.02.028
36. Nylén E-JA, Salminen JM (2019) How does the circular economy discourse affect policy-making? The case of streamlining waste utilisation in Finnish earthworks. Resour Conserv Recycl 149:532–540. https://doi.org/10.1016/j.resconrec.2019.06.029
37. López Ruiz LA, Roca Ramón X, Gassó Domingo S (2020) The circular economy in the construction and demolition waste sector – a review and an integrative model approach. J Clean Prod 248. https://doi.org/10.1016/J.JCLEPRO.2019.119238
38. Fitch-Roy O, Benson D, Monciardini D (2021) All around the world: assessing optimality in comparative circular economy policy packages. J Clean Prod 286:125493. https://doi.org/10.1016/j.jclepro.2020.125493
39. Zhang C, Hu M, Di Maio F et al (2022) An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. Sci Total Environ 803:149892. https://doi.org/10.1016/J.SCITOTENV.2021.149892
40. Construction & demolition waste market global forecast to 2026 Markets and Markets. https://www.marketsandmarkets.com/MarketReports/construction-demolition-waste-market-225127553.html. Accessed 13 May 2022
41. Kaza S, Yao LC, Bhada-Tata P, Van Woerden F (2018) What a waste 2.0. What a Waste 20 A Glob Snapshot Solid Waste Manag to 2050. https://doi.org/10.1596/978-1-4648-1329-0
42. Reinhart D, McCreanor P (1999) Disaster debris management - planning tools. Report submitted to the United States Environmental Protection Agency. https://www.researchgate.net/publication/237778695_Disaster_Debris_Management_-_Planning_Tools
43. Bizcocho N, Llatas C (2019) Inclusion of prevention scenarios in LCA of construction waste management. Int J Life Cycle Assess 24:468–484. https://doi.org/10.1007/s11367-018-1462-8
44. Yun S, Ryu D, Khim J (2020) Evaluation of the recyclability of construction and demolition waste fines as a garden substrate and soil amendment agent: a case study from the Republic of Korea. J Mater Cycles Waste Manag 22:479–487. https://doi.org/10.1007/s10163-019-00941-2
45. Lee S, Xu Q, Booth M et al (2006) Reduced sulfur compounds in gas from construction and demolition debris landfills. Waste Manag 26:526–533. https://doi.org/10.1016/j.wasman.2005.10.010
46. Achenbach H, Wenker JL, Rüter S (2018) Life cycle assessment of product- and construction stage of prefabricated timber houses: a sector representative approach for Germany according to EN 15804, EN 15978 and EN 16485. Eur J Wood Wood Prod 76:711–729. https://doi.org/10.1007/s00107-017-1236-1
47. Wu H, Duan H, Zheng L et al (2016) Demolition waste generation and recycling potentials in a rapidly developing flagship megacity of South China: prospective scenarios and implications. Constr Build Mater 113:1007–1016. https://doi.org/10.1016/j.conbuildmat.2016.03.130
48. Chong WK, Hermreck C (2010) Understanding transportation energy and technical metabolism of construction waste recycling. Resour Conserv Recycl 54:579–590. https://doi.org/10.1016/j.resconrec.2009.10.015
49. Sormunen P, Kärki T (2019) Recycled construction and demolition waste as a possible source of materials for composite manufacturing. J Build Eng 24. https://doi.org/10.1016/j.jobe.2019.100742

50. Attia T, Elshaboury N, Hesham A, Elhadary M (2021) Quantifying construction and demolition waste using SLAM-Based mobile mapping system: a case study from Kafr El Sheikh, Egypt. In: 2021 International Conference on Data Analytics for Business and Industry (ICDABI). IEEE, Sakheer, Bahrain, pp 459–463. https://doi.org/10.1109/ICDABI53623.2021.9655946
51. Mhatre P, Gedam VV, Unnikrishnan S (2021) Material circularity potential for construction materials – the case of transportation infrastructure in India. Resour Policy 74:102446. https://doi.org/10.1016/j.resourpol.2021.102446
52. Akanbi LA, Oyedele LO, Omoteso K et al (2019) Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. J Clean Prod 223:386–396. https://doi.org/10.1016/j.jclepro.2019.03.172
53. Demestichas K, Daskalakis E (2020) Information and communication technology solutions for the circular economy. Sustainability 12:7272. https://doi.org/10.3390/su12187272
54. Devaki H, Shanmugapriya S (2023) Investigating barriers to sustainable management of construction and demolition waste: the case of India. J Mater Cycles Waste Manag. https://doi.org/10.1007/s10163-023-01631-w
55. Nabavi-Pelesaraei A, Bayat R, Hosseinzadeh-Bandbafha H et al (2017) Modeling of energy consumption and environmental life cycle assessment for incineration and landfill systems of municipal solid waste management - a case study in Tehran Metropolis of Iran. J Clean Prod 148:427–440. https://doi.org/10.1016/j.jclepro.2017.01.172
56. Zhang C, Hu M, Yang X et al (2020) Upgrading construction and demolition waste management from downcycling to recycling in the Netherlands. J Clean Prod 266:121718. https://doi.org/10.1016/j.jclepro.2020.121718
57. Yu Y, Yazan D, Junjan V, Iacob M (2022) Circular economy in the construction industry: a review of decision support tools based on Information & Communication Technologies. J Clean Prod null:null. https://doi.org/10.1016/j.jclepro.2022.131335
58. Du L, Feng Y, Lu W, et al (2020) Evolutionary game analysis of stakeholders' decision-making behaviours in construction and demolition waste management. Environ Impact Assess Rev 84. https://doi.org/10.1016/j.eiar.2020.106408
59. Paiho S, Mäki E, Wessberg N et al (2020) Towards circular cities—conceptualizing core aspects. Sustain Cities Soc 59:102143. https://doi.org/10.1016/J.SCS.2020.102143
60. Gálvez-Martos J-L, Styles D, Schoenberger H, Zeschmar-Lahl B (2018) Construction and demolition waste best management practice in Europe. Resour Conserv Recycl 136:166–178. https://doi.org/10.1016/j.resconrec.2018.04.016
61. Ghisellini P, Ji X, Liu G, Ulgiati S (2018) Evaluating the transition towards cleaner production in the construction and demolition sector of China: a review. J Clean Prod 195:418–434. https://doi.org/10.1016/j.jclepro.2018.05.084
62. Huang B, Wang X, Kua H et al (2018) Construction and demolition waste management in China through the 3R principle. Resour Conserv Recycl 129:36–44. https://doi.org/10.1016/j.resconrec.2017.09.029
63. Meyer DE, Li M, Ingwersen WW (2020) Analyzing economy-scale solid waste generation using the United States environmentally-extended input-output model. Resour Conserv Recycl 157. https://doi.org/10.1016/j.resconrec.2020.104795
64. Zheng L, Wu H, Zhang H et al (2017) Characterizing the generation and flows of construction and demolition waste in China. Constr Build Mater 136:405–413. https://doi.org/10.1016/j.conbuildmat.2017.01.055
65. Hoang NH, Ishigaki T, Kubota R et al (2021) Financial and economic evaluation of construction and demolition waste recycling in Hanoi, Vietnam. Waste Manag 131:294–304. https://doi.org/10.1016/j.wasman.2021.06.014
66. Bao Z, Lu W, Chi B et al (2019) Procurement innovation for a circular economy of construction and demolition waste: lessons learnt from Suzhou, China. Waste Manag 99:12–21. https://doi.org/10.1016/j.wasman.2019.08.031
67. Lockrey S, Nguyen H, Crossin E, Verghese K (2016) Recycling the construction and demolition waste in Vietnam: opportunities and challenges in practice. J Clean Prod 133:757–766. https://doi.org/10.1016/j.jclepro.2016.05.175
68. Su Y, Chen J, Si H et al (2021) Decision-making interaction among stakeholders regarding construction and demolition waste recycling under different power structures. Waste Manag 131:491–502. https://doi.org/10.1016/j.wasman.2021.06.025
69. Bao Z, Lu W (2020) Developing efficient circularity for construction and demolition waste management in fast emerging economies: lessons learned from Shenzhen, China. Sci Total Environ 724. https://doi.org/10.1016/J.SCITOTENV.2020.138264

70. Guo F, Wang J, Song Y (2022) How to promote sustainable development of construction and demolition waste recycling systems: production subsidies or consumption subsidies? Sustain Prod Consum 32:407–423. https://doi.org/10.1016/j.spc.2022.05.002
71. Hu Q, Su P, Xiong F (2021) Dynamic game strategies for construction and demolition waste recycling with learning and reference effects. Environ Impact Assess Rev 89:106592. https://doi.org/10.1016/j.eiar.2021.106592
72. Shooshtarian S, Caldera S, Maqsood T et al (2022) Analysis of factors influencing the creation and stimulation of the Australian market for recycled construction and demolition waste products. Sustain Prod Consum 34:163–176. https://doi.org/10.1016/j.spc.2022.09.005
73. Jain S, Singhal S, Jain NK, Bhaskar K (2020) Construction and demolition waste recycling: investigating the role of theory of planned behavior, institutional pressures and environmental consciousness. J Clean Prod 263. https://doi.org/10.1016/J.JCLEPRO.2020.121405
74. Kolaventi SS, Tezeswi TP, Siva Kumar MVN (2019) An assessment of construction waste management in India: a statistical approach. Waste Manag Res. https://doi.org/10.1177/0734242X19867754
75. Al-Raqeb H, Ghaffar SH, Al-Kheetan MJ, Chougan M (2023) Understanding the challenges of construction demolition waste management towards circular construction: Kuwait Stakeholder's perspective. Clean Waste Syst 4:100075. https://doi.org/10.1016/j.clwas.2023.100075
76. Ramos M, Martinho G, Vasconcelos L, Ferreira F (2023) Local scale dynamics to promote the sustainable management of construction and demolition waste. Resour Conserv Recycl Adv 17:200135. https://doi.org/10.1016/j.rcradv.2023.200135
77. Ajayi SO, Oyedele LO (2017) Policy imperatives for diverting construction waste from landfill: experts' recommendations for UK policy expansion. J Clean Prod 147:57–65. https://doi.org/10.1016/J.JCLEPRO.2017.01.075
78. Li J, Zuo J, Wang G et al (2020) Stakeholders' willingness to pay for the new construction and demolition waste landfill charge scheme in Shenzhen: a contingent valuation approach. Sustain Cities Soc 52:101663. https://doi.org/10.1016/j.scs.2019.101663
79. Kliem D, Scheidegger A, Kopainsky B (2021) Closing the mineral construction material cycle – an endogenous perspective on barriers in transition. Resour Conserv Recycl 175:105859. https://doi.org/10.1016/j.resconrec.2021.105859
80. Ma M, Tam VWY, Le KN, Li W (2020) Challenges in current construction and demolition waste recycling: a China study. Waste Manag 118:610–625. https://doi.org/10.1016/j.wasman.2020.09.030
81. Lazarevic D, Salo H, Kautto P (2022) Circular economy policies and their transformative outcomes: the transformative intent of Finland's strategic policy programme. J Clean Prod 379:134892. https://doi.org/10.1016/j.jclepro.2022.134892
82. Rincón-Moreno J, Ormazábal M, Jaca C (2022) Stakeholder perspectives in transitioning to a local circular economy: a case study in Spain. Circ Econ Sust 2(2):693–711. https://doi.org/10.1007/s43615-021-00098-x
83. Thives LP, Ghisi E, ThivesJúnior JJ (2022) An outlook on the management of construction and demolition waste in Brazil. Clean Mater 6:100153. https://doi.org/10.1016/j.clema.2022.100153
84. Wu Z, Yu ATW, Shen L (2017) Investigating the determinants of contractor's construction and demolition waste management behavior in Mainland China. Waste Manag 60:290–300. https://doi.org/10.1016/j.wasman.2016.09.001
85. Liu J, Wu P, Jiang Y, Wang X (2021) Explore potential barriers of applying circular economy in construction and demolition waste recycling. J Clean Prod 326. https://doi.org/10.1016/J.JCLEPRO.2021.129400
86. Tangtinthai N, Heidrich O, Manning DAC (2019) Role of policy in managing mined resources for construction in Europe and emerging economies. J Environ Manage 236:613–621. https://doi.org/10.1016/j.jenvman.2018.11.141
87. Shooshtarian S, Maqsood T, Caldera S, Ryley T (2022) Transformation towards a circular economy in the Australian construction and demolition waste management system. Sustain Prod Consum 30:89–106. https://doi.org/10.1016/j.spc.2021.11.032
88. Agovino M, Casaccia M, Crociata A (2016) The impact of European Regional Development Fund on separate waste collection: evidence from Italian regions. Environ Sci Policy 61:97–107. https://doi.org/10.1016/j.envsci.2016.04.001
89. Cristiano S, Ghisellini P, D'Ambrosio G, et al (2021) Construction and demolition waste in the Metropolitan City of Naples, Italy: state of the art, circular design, and sustainable planning opportunities. J Clean Prod 293. https://doi.org/10.1016/j.jclepro.2021.125856
90. Aslam MS, Huang B, Cui L (2020) Review of construction and demolition waste management in China and USA. J Environ Manage 264. https://doi.org/10.1016/J.JENVMAN.2020.110445

91. Khandare MJ, Khandare SM (2016) Waste materials & management in civil, mechanical & electronics engineering. In: International Conference & Workshop on Electronics & Telecommunication Engineering (ICWET 2016). IET, Mumbai. https://doi.org/10.1049/cp.2016.1151
92. De Melo AB, Gonçalves AF, Martins IM (2011) Construction and demolition waste generation and management in Lisbon (Portugal). Resour Conserv Recycl 55:1252–1264. https://doi.org/10.1016/j.resconrec.2011.06.010
93. Negash YT, Hassan AM, Tseng ML, et al (2021) Sustainable construction and demolition waste management in Somaliland: regulatory barriers lead to technical and environmental barriers. J Clean Prod 297. https://doi.org/10.1016/j.jclepro.2021.126717
94. Dewagoda KG, Ng ST, Chen J (2022) Driving systematic circular economy implementation in the construction industry: a construction value chain perspective. J Clean Prod 381:135197. https://doi.org/10.1016/j.jclepro.2022.135197
95. Akhtar A, Sarmah AK (2018) Construction and demolition waste generation and properties of recycled aggregate concrete: a global perspective. J Clean Prod 186:262–281. https://doi.org/10.1016/j.jclepro.2018.03.085
96. Yu ATW, Wong I, Wu Z, Poon C-S (2021) Strategies for effective waste reduction and management of building construction projects in highly urbanized cities—a case study of Hong Kong. Buildings 11:214. https://doi.org/10.3390/buildings11050214
97. Hua C, Liu C, Chen J et al (2022) Promoting construction and demolition waste recycling by using incentive policies in China. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-19536-w
98. Smol M (2023) Inventory and comparison of performance indicators in circular economy roadmaps of the European countries. Circ Econ Sust 3(1):557–584. https://doi.org/10.1007/s43615-021-00127-9
99. Esa MR, Halog A, Rigamonti L (2017) Strategies for minimizing construction and demolition wastes in Malaysia. Resour Conserv Recycl 120:219–229. https://doi.org/10.1016/j.resconrec.2016.12.014
100. Li J, Yao Y, Zuo J, Li J (2020) Key policies to the development of construction and demolition waste recycling industry in China. Waste Manag 108:137–143. https://doi.org/10.1016/j.wasman.2020.04.016
101. Boonman H, Verstraten P, van der Weijde AH (2023) Macroeconomic and environmental impacts of circular economy innovation policy. Sustain Prod Consum 35:216–228. https://doi.org/10.1016/j.spc.2022.10.025
102. Aboginije A, Aigbavboa C, Thwala W, Samuel S (2020) Determining the impact of construction and demolition waste reduction practices on green building projects in Gauteng Province, South Africa. In: Proceedings of the International Conference on Industrial Engineering and Operations Management. UAE, Dubai, pp 10–12
103. AfricA waste management summary for decision-makers. https://wedocs.unep.org/20.500.11822/25515. Accessed 22 Feb 2022
104. He L, Yuan H, Wu H (2022) Collaborative mechanism for promoting the cross-regional management of construction and demolition waste. J Clean Prod 372:133706. https://doi.org/10.1016/j.jclepro.2022.133706
105. Shooshtarian S, Maqsood T, Wong PSP, et al (2020) Australian construction and demolition waste management system in Australia: investigation of challenges and opportunities. https://doi.org/10.20944/preprints202007.0118.v1
106. Wu H, Zuo J, Yuan H, et al (2020) Cross-regional mobility of construction and demolition waste in Australia: an exploratory study. Resour Conserv Recycl 156. https://doi.org/10.1016/J.RESCONREC.2020.104710
107. Villoria Sáez P, Osmani M (2019) A diagnosis of construction and demolition waste generation and recovery practice in the European Union. J Clean Prod 241:118400. https://doi.org/10.1016/j.jclepro.2019.118400
108. Menegaki M, Damigos D (2018) A review on current situation and challenges of construction and demolition waste management. Curr Opin Green Sustain Chem 13:8–15. https://doi.org/10.1016/J.COGSC.2018.02.010
109. Yang Z, Chen H, Mi L et al (2021) Green building technologies adoption process in China: how environmental policies are reshaping the decision-making among alliance-based construction enterprises? Sustain Cities Soc 73:103122. https://doi.org/10.1016/j.scs.2021.103122
110. Wang H, Chen D, Duan H et al (2019) Characterizing urban building metabolism with a 4D-GIS model: a case study in China. J Clean Prod 228:1446–1454. https://doi.org/10.1016/j.jclepro.2019.04.341
111. Yuan H, Chini AR, Lu Y, Shen L (2012) A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste. Waste Manag 32:521–531. https://doi.org/10.1016/J.WASMAN.2011.11.006
112. Ramos M, Martinho G (2023) An assessment of the illegal dumping of construction and demolition waste. Clean Waste Syst 4:100073. https://doi.org/10.1016/j.clwas.2022.100073

113. Hild P (2023) The circular economy and circular building practices in Luxembourg. Circ Econ Sust. https://doi.org/10.1007/s43615-023-00256-3
114. France's anti-waste and circular economy law. https://www.ellenmacarthurfoundation.org/circular-examples/frances-anti-waste-and-circular-economy-law. Accessed 13 May 2022
115. Arora R, Paterok K, Banerjee A, Saluja MS (2017) Potential and relevance of urban mining in the context of sustainable cities. IIMB Manag Rev 29:210–224. https://doi.org/10.1016/j.iimb.2017.06.001
116. Jain S, Singhal S, Jain NK (2019) Construction and demolition waste generation in cities in India: an integrated approach. Int J Sustain Eng 12:333–340. https://doi.org/10.1080/19397038.2019.1612967
117. Kolaventi SS, Momand H, Tezeswi TP, Kumar MVNS (2021) Implementing site waste-management plans, recycling in India: barriers, benefits, measures 175:30–51. https://doi.org/10.1680/jensu2100032
118. Papastamoulis V, London K, Feng Y, Zhang P, Crocker R, Patias P (2021) Conceptualising the circular economy potential of construction and demolition waste: an integrative literature review. Recycling 6(3):61. https://doi.org/10.3390/recycling6030061
119. Coelho A, de Brito J (2013) Economic viability analysis of a construction and demolition waste recycling plant in Portugal – part I: location, materials, technology and economic analysis. J Clean Prod 39:338–352. https://doi.org/10.1016/j.jclepro.2012.08.024
120. Waste statistics and overall recycling. https://www.nea.gov.sg/our-services/waste-management/waste-statistics-and-overall-recycling. Accessed 22 May 2022
121. Borongan G, Okumura S (2010) Municipal waste management report: status-quo and issues in Southeast and East Asian Countries. United Nations Environment Programme Regional Resource Center for Asia and the Pacific (AIT-UNEP RRC.AP), Klong Luang, Thailand
122. Nguyen T (2018) Current status of construction and demolition waste management in Vietnam: challenges and opportunities. Int J Geomate 15:23–29. https://doi.org/10.21660/2018.52.7194
123. Yukalang N, Clarke B, Ross K (2017) Barriers to effective municipal solid waste management in a rapidly urbanizing area in Thailand. Int J Environ Res Public Health 14:1013. https://doi.org/10.3390/ijerph14091013
124. Katerusha D (2021) Barriers to the use of recycled concrete from the perspective of executing companies and possible solution approaches - case study Germany and Switzerland. Resour Policy 73:102212. https://doi.org/10.1016/j.resourpol.2021.102212
125. Policy: circular economy - City of Amsterdam. https://www.amsterdam.nl/en/policy/sustainability/circular-economy/. Accessed 4 May 2023
126. Reimagining our buildings and spaces for a circular economy. https://ellenmacarthurfoundation.org/topics/built-environment/overview. Accessed 4 May 2023
127. Qiao L, Liu D, Yuan X, et al Generation and prediction of construction and demolition waste using exponential smoothing method: a case study of Shandong Province, China. https://doi.org/10.3390/su12125094
128. Arora M, Raspall F, Cheah L, Silva A (2020) Buildings and the circular economy: estimating urban mining, recovery and reuse potential of building components. Resour Conserv Recycl 154:104581. https://doi.org/10.1016/j.resconrec.2019.104581
129. Al-Otaibi A, Bowan PA, Abdel Daiem MM, et al (2022) Identifying the barriers to sustainable management of construction and demolition waste in developed and developing countries. Sustain 14. https://doi.org/10.3390/SU14137532
130. Campbell-Johnston K, ten Cate J, Elfering-Petrovic M, Gupta J (2019) City level circular transitions: barriers and limits in Amsterdam, Utrecht and The Hague. J Clean Prod 235:1232–1239. https://doi.org/10.1016/j.jclepro.2019.06.106
131. Ding Z, Gong W, Li S, Wu Z (2018) System dynamics versus agent-based modeling: a review of complexity simulation in construction waste management. Sustainability 10:2484. https://doi.org/10.3390/su10072484
132. Hossain MU, Ng ST, Antwi-Afari P, Amor B (2020) Circular economy and the construction industry: existing trends, challenges and prospective framework for sustainable construction. Renew Sustain Energy Rev 130. https://doi.org/10.1016/J.RSER.2020.109948
133. Iacovidou E, Purnell P (2016) Mining the physical infrastructure: opportunities, barriers and interventions in promoting structural components reuse. Sci Total Environ 557–558:791–807. https://doi.org/10.1016/j.scitotenv.2016.03.098
134. Jin R, Li B, Zhou T et al (2017) An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. Resour Conserv Recycl 126:86–98. https://doi.org/10.1016/j.resconrec.2017.07.034
135. Kanters J (2020) Circular building design: an analysis of barriers and drivers for a circular building sector. Buildings 10. https://doi.org/10.3390/BUILDINGS10040077

136. Mahpour A (2018) Prioritizing barriers to adopt circular economy in construction and demolition waste management. Resour Conserv Recycl 134:216–227. https://doi.org/10.1016/j.resconrec.2018.01.026
137. Ratnasabapathy S, Alashwal A, Perera S (2021) Exploring the barriers for implementing waste trading practices in the construction industry in Australia. Built Environ Proj Asset Manag 11:559–576. https://doi.org/10.1108/BEPAM-04-2020-0077
138. Reich RH, Vermeyen V, Alaerts L, Van Acker K (2023) How to measure a circular economy: a holistic method compiling policy monitors. Resour Conserv Recycl 188:106707. https://doi.org/10.1016/j.resconrec.2022.106707
139. Lingling H, Hongping Y (2022) Impacts of tax refund on enterprise's decisions on recycled materials production: a cross-regional perspective. Comput Ind Eng 167:108035. https://doi.org/10.1016/j.cie.2022.108035
140. Kabirifar K, Mojtahedi M, Wang C, Tam VWY (2020) Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: a review. J Clean Prod 263. https://doi.org/10.1016/j.jclepro.2020.121265
141. Giorgi S, Lavagna M, Wang K et al (2022) Drivers and barriers towards circular economy in the building sector: stakeholder interviews and analysis of five European countries policies and practices. J Clean Prod 336:130395. https://doi.org/10.1016/j.jclepro.2022.130395
142. Shooshtarian S, Caldera S, Maqsood T et al (2021) An investigation into challenges and opportunities in the Australian construction and demolition waste management system. Eng Constr Archit Manag. https://doi.org/10.1108/ECAM-05-2021-0439
143. Borbon-Galvez Y, Curi S, Dallari F, Ghiringhelli G (2021) International industrial symbiosis: cross-border management of aggregates and construction and demolition waste between Italy and Switzerland. Sustain Prod Consum 25:312–324. https://doi.org/10.1016/j.spc.2020.09.004
144. Paschoalin Filho JA, da Bezerra CM, S, Guerner Dias AJ, (2020) Environmental indicators proposal for construction solid waste management plans assessment. Manag Environ Qual An Int J 31:1623–1645. https://doi.org/10.1108/MEQ-07-2019-0153
145. Charef R, Alaka H, Ganjian E (2019) A BIM-based theoretical framework for the integration of the asset End-of-Life phase. IOP Conf Ser Earth Environ Sci 225:12067. https://doi.org/10.1088/1755-1315/225/1/012067
146. Zbašnik-Senegačnik M, Koprivec L (2020) Construction waste as a resource in a sustainable built environment. Igra Ustvarjalnosti 28–36. https://doi.org/10.15292/IU-CG.2020.08.028-036
147. Christensen TB, Johansen MR, Buchard MV, Glarborg CN (2022) Closing the material loops for construction and demolition waste: the circular economy on the island Bornholm, Denmark. Resour Conserv Recycl Adv 15:200104. https://doi.org/10.1016/j.rcradv.2022.200104
148. Chen J, Hua C, Liu C (2019) Considerations for better construction and demolition waste management: identifying the decision behaviors of contractors and government departments through a game theory decision-making model. J Clean Prod 212:190–199. https://doi.org/10.1016/j.jclepro.2018.11.262
149. Su Y, Si H, Chen J, Wu G (2020) Promoting the sustainable development of the recycling market of construction and demolition waste: a stakeholder game perspective. J Clean Prod 277. https://doi.org/10.1016/j.jclepro.2020.122281
150. Yuan H, Du W, Ma X et al (2023) Critical factors to influence the illegal dumping behavior of construction and demolition waste: an ISM-DEMATEL analysis. Dev Built Environ 14:100159. https://doi.org/10.1016/j.dibe.2023.100159
151. Yu Y, Junjan V, Yazan DM, Iacob ME (2022) A systematic literature review on Circular Economy implementation in the construction industry: a policy-making perspective. Resour Conserv Recycl 183. https://doi.org/10.1016/j.resconrec.2022.106359

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH ("Springer Nature").

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users ("Users"), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use ("Terms"). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval , sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com