

Sustainable Management of the Built Environment from the Life Cycle Perspective

Will Hill, S.M.ASCE¹; Hiba Jalloul, S.M.ASCE²; Mohammad Movahedi, S.M.ASCE³; and Juyeong Choi, Ph.D., A.M.ASCE⁴

Abstract: Decisions made at every stage of the built environment life cycle impact how materials in that environment are eventually managed at the end of their life, whether in a linear or cyclical manner. Linear fates often terminate in landfills, whereas more sustainable cyclical fates are continuously extended through reduction, reuse, repair, recycling, and recovery (5Rs) practices. Despite a notable increase in the literature on sustainable construction and demolition waste (CDW) management, there is still a lack of studies comprehensively addressing the full life cycle of the built environment. A gap also exists in the understanding of the root causes underlying unsustainable CDW management practices. To address these gaps and shortcomings, this study synthesizes the literature on CDW management to identify the causal factors contributing to the current unsustainable management practices, their root causes across the life cycle of the built environment, and sustainable strategies with proven efficacy in mitigating the detected root causes. Considering the implications of these strategies on the management of CDW, as well as their applicability across different stages of the built environment life cycle, this study characterizes them using the 5Rs waste hierarchy and using a five-stage built environment life cycle framework: interim, planning, construction, use, and end of life. All such information is integrated into a single ranking framework that proposes prioritized sustainable strategic pathways to address the most relevant root causes of unsustainable CDW management across the entire built environment life cycle. The actual implementation of the proposed framework for the sustainable management of the built environment is demonstrated through an analysis of Louisiana, in which peacetime construction/demolition and disaster debris generation and reconstruction/demolition have resulted in large amounts of CDW that often ended in landfills. Future decision makers can avoid similar fates by mitigating their own root causes of unsustainable waste management by better utilizing relevant mitigation strategies. DOI: [10.1061/JMENEAM.ENG-4759](https://doi.org/10.1061/JMENEAM.ENG-4759). © 2023 American Society of Civil Engineers.

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Introduction

In the built environment, every structure has a life cycle, originating from natural resource extraction and processing, continuing with construction, operation, and maintenance, and ending in final disposition (Koroneos et al. 2013; Singh et al. 2011). The majority of the waste generated at the final stage of the built environment life cycle (i.e., structure's peacetime demolition or destruction by disaster events) often ends up in landfills without appropriate segregation and treatment (Bovea and Powell 2016). With the high

volume of construction and demolition waste (CDW) being generated and subsequently dumped (Ding et al. 2018; Jalloul et al. 2022c), limited landfill space is being depleted (Akanbi et al. 2018), particularly in the US where the maximum holding capacities of most landfills are soon to be reached (Anuranjita et al. 2017). Environmental impacts associated with low recovery rates of CDW also include high energy consumptions and depletion of valuable resources during the production of building materials, for both new construction and postdisaster rebuilding, rather than using existing waste materials (Jalloul et al. 2022a; Ruiz et al. 2020).

Acknowledging the need for more sustainable management practices within our built environment, several studies tackled the issue of CDW management. The application of circular economy (CE) principles (i.e., reducing, reusing, and recycling) to the management of CDW has been a particularly prevalent focus of recent literature. For instance, Ruiz et al. (2020) developed a theoretical framework comprising 14 strategies to enable the adoption of CE in CDW management. Ghisellini et al. (2018) aimed to investigate the feasibility of adopting a CE approach when managing CDW, in the first place, by exploring the environmental and economic costs and benefits of doing so. Çimen (2021), Ginga et al. (2020), and Joensuu et al. (2020) presented reviews of the available literature on the application of CE practices in the built environment, particularly for the management of CDW. These reviews tried to identify the general research trends in the studied literature, as well as highlight existing knowledge gaps such as the impact on the life cycle stages, roles of different stakeholders, and the limited effectivity of current CDW recycling and reuse practices (Çimen 2021; Ginga et al. 2020).

¹Master's Student, Dept. of Civil and Environmental Engineering, Florida A&M Univ.-Florida State Univ. (FAMU-FSU) College of Engineering, Tallahassee, FL 32310. ORCID: <https://orcid.org/0000-0002-5774-5551>. Email: whill@eng.famu.fsu.edu

²Ph.D. Candidate, Dept. of Civil and Environmental Engineering, Florida A&M Univ.-Florida State Univ. (FAMU-FSU) College of Engineering, Tallahassee, FL 32310. ORCID: <https://orcid.org/0000-0001-7814-7406>. Email: hj20bf@fsu.edu

³Ph.D. Student, Dept. of Civil and Environmental Engineering, Florida A&M Univ.-Florida State Univ. (FAMU-FSU) College of Engineering, Tallahassee, FL 32310. ORCID: <https://orcid.org/0000-0002-5811-5180>. Email: mm21cu@fsu.edu

⁴Assistant Professor, Dept. of Civil and Environmental Engineering, Florida A&M Univ.-Florida State Univ. (FAMU-FSU) College of Engineering, Tallahassee, FL 32310 (corresponding author). ORCID: <https://orcid.org/0000-0002-7136-0500>. Email: jchoi@eng.famu.fsu.edu

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Aside from CE-related studies, some previous research works also investigated the sustainable management of CDW, either with a focus on a specific aspect or a certain region. Wang et al. (2017), for example, discussed the challenges faced during every stage of CDW management, with a particular focus on the role of governments and enacted policies. Yuan et al. (2018) focused on the role of project managers in reducing CDW generation during the project execution stage. Cruz Rios et al. (2021), on the other hand, focused on the design stage, investigating the enablers and barriers to building design that facilitate the recycling and reuse of the generated CDW. As for region-specific research on the management of CDW, examples include studies on CDW management practices in China (Huang et al. 2018; Jin et al. 2017; Liu et al. 2020; Yuan 2017), India (Kar and Jha 2021), the UK (Ajayi and Oyedele 2017), Italy (Balletto et al. 2021), Ireland (Duran et al. 2006), Australia (Park and Tucker 2017), and Canada (Yeheyis et al. 2013).

As demonstrated, the sustainable management of the built environment has been of interest to many researchers. Each of the previous studies in the area of CDW management touched upon some of the reasons behind the current dearth in the implementation of sustainable management practices and/or some of the recommended mitigation strategies. However, an integrative research endeavor that delineates all such reasons and strategies in a comprehensive manner has been hitherto lacking. Within this regard, having a holistic view of the focused insights from prior work would provide a deeper understanding of the problem and the potential solutions. As such, in this study, a systematic review of the literature is conducted to comprehensively identify all causal factors, along with their corresponding root causes, contributing to the unsustainable management of what remains following the last stage of the life cycle of our built environment (i.e., CDW).

In addition to detecting the source of the problem, this study identifies the recommended mitigation strategies corresponding to each of the detected root causes. Because the application of different mitigation strategies depends on the stage of the life cycle of the built environment at the time of implementation, the mitigation strategies are characterized based on a five-stage built environment life cycle framework: interim, planning, construction, use, and end of life. Further, because these mitigation strategies have different implications on the management of CDW, this study characterizes them using the 5Rs waste hierarchy: reduce, reuse, repair, recycle, and recover. Lastly, because resources available for mitigation are often limited, mitigation strategies need to be prioritized. As such, this study ranks identified mitigation strategies using an integrated prioritization scoring system.

The knowledge synthesized in this study presents a basis for a practical holistic framework that can be utilized by stakeholders at every stage of the built environment life cycle to better identify and prioritize sustainable CDW management strategies within the context of fundamental causes. To investigate how this framework can be applied in practice, the management of CDW in Louisiana throughout peacetime and disaster is taken as a case study. Relevant root causes of unsustainable CDW management practices were identified, and accordingly, their corresponding mitigation strategies were prioritized.

The remainder of the paper is structured as follows. First, this paper presents a background on the built environment life cycle and the waste management hierarchy, followed by the description of the employed methodology. The, this paper presents the results of the literature review in terms of the identified causal factors and root causes of the unsustainable management of CDW. The mitigation strategies corresponding to each of the identified root causes are presented and characterized. These mitigation strategies are subsequently ranked and prioritized. The application of the proposed

framework for the sustainable management of the built environment is demonstrated thereafter through a case study of Louisiana, investigating the management practices of the CDW generated in recent decades from disasters and urban expansion. Finally, the conclusions of this study are presented.

Background

Built Environment Life Cycle

The life cycle stages of the built environment are most commonly defined in the literature by the standards set by the International Organization for Standardization [ISO 21931-1:2010 (ISO 2010)] and the British Standards Institution and European Committee for Standardization (BS EN) [BS EN 15978 (BSI 2011)]. The ISO 21931-1 standard provides a broad baseline for building sustainability, and the life cycle stages it has defined are often used when assessing the environmental performance of the built environment (Wu et al. 2017). Those include production, construction, in-use, and end of life (ISO 2010). BS EN 15978, on the other hand, is a European standard that outlines procedures for conducting life cycle assessments (LCA) of buildings (Thibodeau et al. 2019). Similar to the ones defined by ISO, the stages of the building life cycle defined in the BS EN 15978:2011 standard are product, construction process, use, and end of life.

Despite the widespread adoption of the four stages of the built environment life cycle presented in ISO and BS EN standards, some researchers critiqued their spatiotemporal limitations and recommended considering broader system boundaries, including methodological and functional dimensions (Broto et al. 2012; Pan et al. 2018). One of the suggested approaches to study the built environment life cycle is using the concept of urban metabolism. This approach fundamentally looks at the exchange processes that create urban environments in the same way that metabolic exchange processes create and maintain cells (Broto et al. 2012). As opposed to isolated and linear processes, as presented in the ISO and BS EN standards, urban metabolism considers elements of the built environment as part of a larger ecosystem with material and energy flows. Dijst et al. (2018) acknowledged that the traditionally described stocks and flows of materials, as tracked through material flow analysis under the urban metabolism approach, are interrelated with drivers, needs, facilitators/constraints, and activities in urban environments. All of this is subject to a spatial and temporal flexibility in the built environment and implies that the CDW stocks and flows will be unevenly distributed throughout the built environment over its life cycle with some geographic regions having periods of zero input/output.

However, despite the lack of material flow, the aforementioned drivers, needs, facilitators/constraints, and activities in urban environments may still influence future flows. As such, this idea of a broader ecosystem is important when discussing a sustainable built environment because there are dynamics involved in structure sustainability existing long before and after construction is finished.

Waste Management Hierarchy

The concept of waste management hierarchy has been commonly adopted in the literature (Bovea and Powell 2016; Esa et al. 2017; Ghafalkar et al. 2015; Zhang et al. 2022). Despite that, there is no consensus on the number of levels, commonly known as the R-imperatives, that make up the hierarchy, or on what these R-imperatives represent (Tserng et al. 2021). The 3Rs waste hierarchy, which promotes reduction, reuse, and then recycling

before disposal in a landfill, is the most commonly mentioned when discussing concepts of circular economy (Liu et al. 2020; Ruiz et al. 2020). However, specifically in regard to waste management, the 5Rs topology is predominant (Reike et al. 2018) because it provides a more defined and clear hierarchy. Based on the type of the waste stream, variations of the 5Rs hierarchy exist, accounting for the impact of the waste stream properties on the sustainability and feasibility of its management imperatives (Bovea and Powell 2016). With regards to CDW management, the five R-imperatives that are most relevant are reduce, reuse, repair, recycle, and recover, and they can be defined as follows:

- **Reduce:** Strategies that aim to reduce CDW waste at the source by using nonmaterial alternatives to products and minimizing resource usage (Tserng et al. 2021).
- **Reuse:** Reuse strategies are focused on utilizing salvaged construction materials again in building and construction applications (Huang et al. 2018).
- **Repair:** Repairing involves restoring and maintaining materials harvested from the CDW stream to serve their original purpose (Morseletto 2020).
- **Recycle:** The application of recycling consists of processing CDW waste to be used in the manufacturing of construction materials instead of relying on virgin materials (Ruiz et al. 2020).
- **Recover:** Recovery strategies within the context of CDW mainly refer to the production and recovery of energy from components of the CDW stream with high energy content, such as wood and plastics (Chau et al. 2017).

Research Methodology

In this study, the authors adopted a three-step research methodology, as illustrated in Fig. 1. The following subsections provide further explanation of the details of each of the three adopted steps.

Step 1: Identification of Causal Factors, Root Causes, and Mitigation Strategies for Unsustainable Management of CDW

The identification of the causal factors and root causes behind the unsustainable management practices of CDW, along with the recommended strategies needed to address them, was carried out by means of a systematic literature review. This enabled synthesizing the current body of knowledge and answering the research question in a reproducible and clear manner (Cook et al. 1997). Specifically, the guidelines proposed by Kitchenham and Brereton (2013) were followed to systematically review the literature, which necessitate thoroughly explaining the adopted search strategy and providing the inclusion and exclusion criteria adopted during the screening and selection process. These guidelines have been widely used to systematically review the existing literature in various contexts, including the management of CDW (Çimen 2021; Ghisellini et al. 2018; Ruiz et al. 2020).

To find all relevant literature, two major databases were queried: Google Scholar and Web of Science. Relevant technical reports published by governmental agencies and international organizations, including the USEPA, FEMA, and USACE, were also collected. Using these resources, the search and review process was conducted in a three-phase manner.

Phase (a): Identification of Causal Factors

The first phase of the search and review process aimed to identify all causal factors contributing to the unsustainable management of CDW. A structured keyword search was used to identify the relevant literature. Specifically, combinations of keywords pertaining to (1) the built environment waste, and (2) the causal factors for its unsustainable management were used as outlined in Table 1.

Phase (b): Discovery of Root Causes

Following the identification of the main causal factors behind the unsustainable management practices of CDW, the second phase of the search and review process was conducted to detect their root

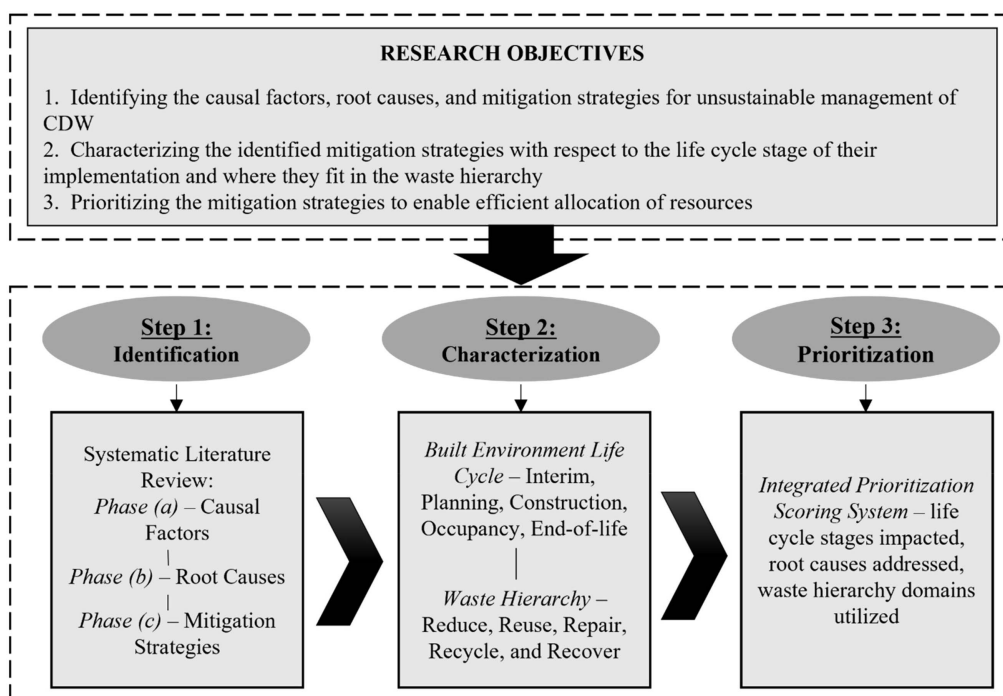


Fig. 1. Research framework.

Table 1. Keywords used in Phase (a) of the search and review process

Aspect	Keywords
Built environment waste	Built environment, construction and demolition waste, C&D waste, CDW, construction waste, demolition waste, disaster debris, disaster waste
Causal factors for unsustainable management	Sustainable waste management, sustainable construction management, circular economy, life cycle analysis, life cycle costing, recycling, reusing, reducing, 3Rs, deconstruction, building information modeling

causes, or what is known as root cause analysis (RCA). In this phase, the causal factors identified in Phase (a) were utilized as keywords to find the relevant literature. Resulting root causes determined during this phase, along with the previously identified main causal factors, were organized in a fishbone diagram, serving as a structured approach to understanding the problem and the causes contributing to it (Ilie and Ciocoiu 2010). To guide the organization of the main causes and their root causes in the fishbone diagram, the 5W1H method was followed, during which the questions of who, what, when, where, why, and how were asked.

Phase (c): Identification of Strategies

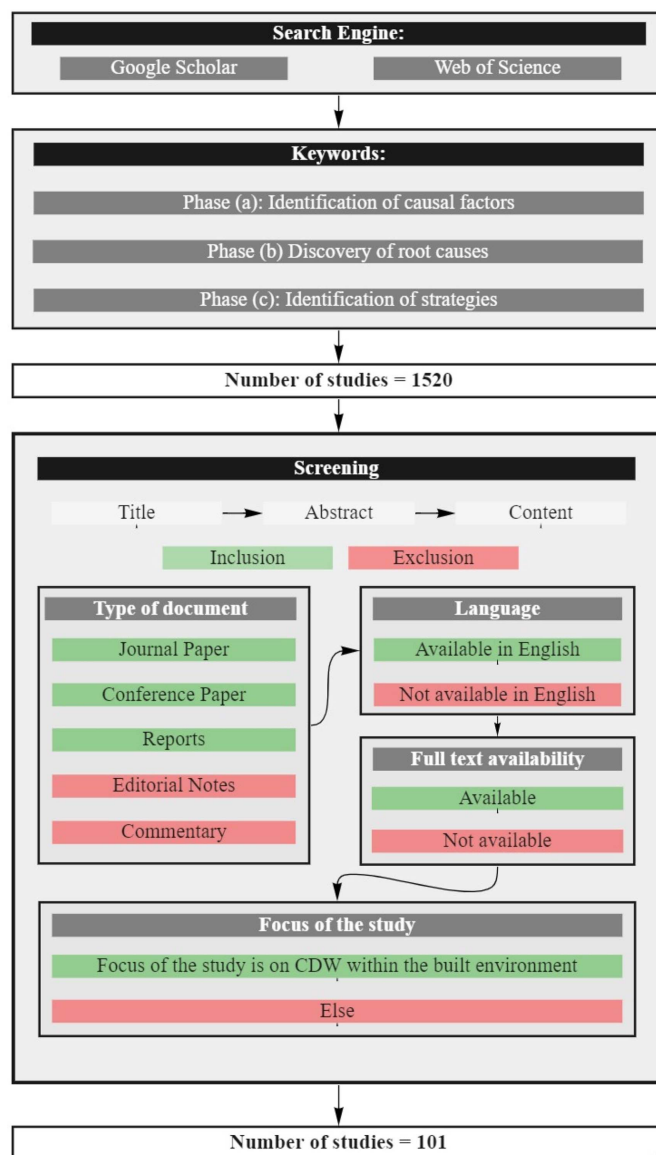
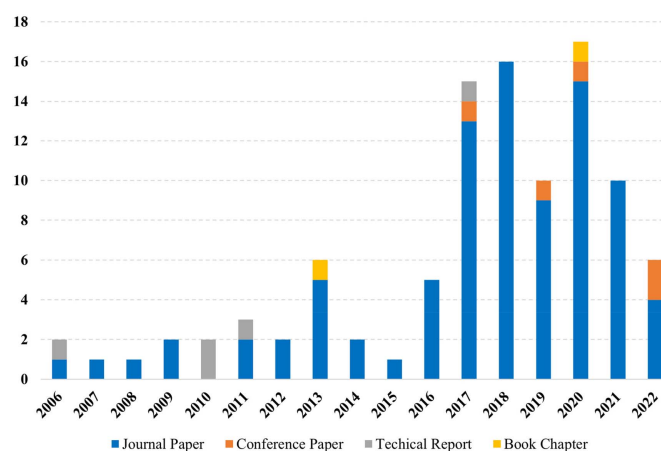
The third and final phase of the search and review process aimed to identify the appropriate solutions or mitigation strategies to address the previously detected root causes of unsustainable management of CDW over the life cycle of the built environment. During this phase, keywords such as CDW “policy,” “management,” “economics,” and “logistics” were used to refine the search.

Fig. 2 depicts details of the conducted search and review process. The results of the keyword search used during each of the aforementioned three phases of the search and review process were either selected for further analysis or discarded based on a set of inclusion and exclusion criteria covering the document type, language, full text availability, and focus (Fig. 2). More specifically, the retrieved studies and reports were screened by first examining their titles, then reviewing their abstracts, and finally assessing their full text based on the adopted inclusion and exclusion criteria.

The search and review process ended in the selection of 101 documents that were carefully reviewed to extract the causal factors and root causes behind the unsustainable management practices of CDW, along with their recommended mitigation strategies. The selected documents spanned across various disciplines including waste management, construction management, materials science and engineering, disaster recovery, urban planning, public policy, and economics. They comprised 89 peer-reviewed journal papers, five conference papers, five technical reports, and two book sections, spanning the time period 2006–2022. The distribution of the documents based on their type and publication year is presented in Fig. 3. Most of the reviewed documents were published during 2017–2021. This reflects an increase in academic attention and interest of researchers toward sustainable management practices, particularly relating to the waste generated across the life cycle of the built environment.

Step 2: Characterization of Mitigation Strategies

To provide insights about the implications of the identified mitigation strategies for unsustainable CDW management, they were characterized based on where they fit in the waste management hierarchy. For such characterization, the previously defined five

**Fig. 2.** Search and review process methodology.**Fig. 3.** Distribution of the reviewed documents based on their type and publication year.

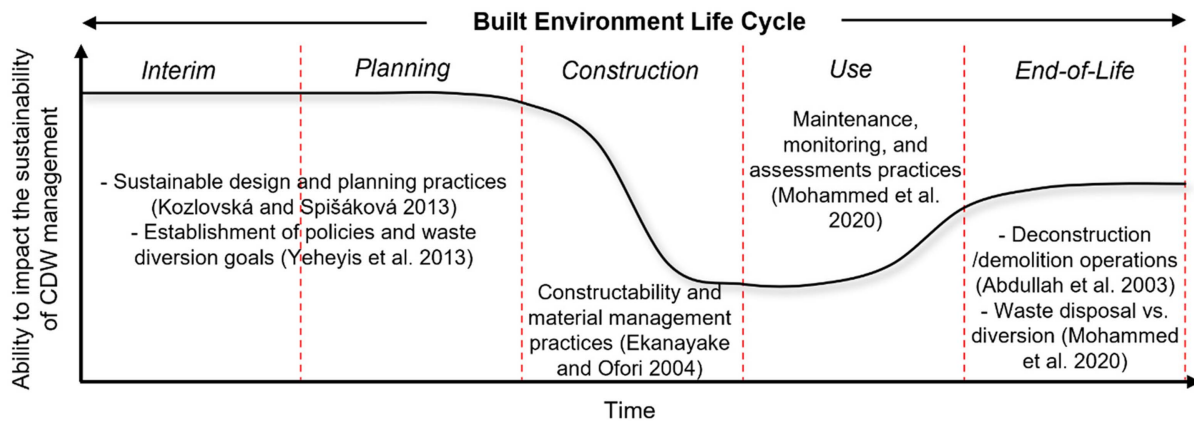


Fig. 4. Ability to impact the sustainability of CDW management during different stages of the built environment life cycle.

R-imperatives that are most relevant to CDW management (i.e., reduce, reuse, repair, recycle, and recover) were used.

Further, to guide their implementation, the identified mitigation strategies were characterized based on when they can be implemented during the life cycle of the built environment. In this regard, this study used a modified version of the ISO/BS EN standards for the built environment life cycle to address their previously discussed shortcomings. Specifically, to incorporate a broader ecosystem or system boundaries, an interim stage was defined to represent the period of time, for any given piece of land, preceding the planning for any structure in the built environment to be constructed in that land. Accordingly, the mitigation strategies identified in this study were characterized using a five-stage framework to the built environment life cycle: interim, planning, construction, use, and end of life. It is important to note that these life cycle stages are not explicitly linear, nor must they occur in isolation. A structure in the use stage, for example, could also be considered in the planning or construction stage if major refurbishments or repairs are underway. As such, some mitigation strategies were characterized to be applicable to more than one stage of the built environment life cycle.

Step 3: Prioritization of Mitigation Strategies

Identified and characterized mitigation strategies were ranked using an integrated prioritization scoring system. The system considers the merit of a mitigation strategy across the life cycle of the built environment and with respect to the end-of-life material management to be dependent on three scoring criteria: (1) applicability, (2) effectiveness, and (3) environmental preference, each having a normalized subscore of up to 10 points for a total perfect score of 30 for a given mitigation strategy. Strategies can then be prioritized based on their merit in each criterion (e.g., which strategy is most applicable), or according to their holistic priority indicated by their total score (i.e., which strategy is the most applicable, effective, and environmentally preferred). The following sections describe each of these criteria and how its subscore was computed for each mitigation strategy.

Applicability

The applicability of a mitigation strategy is assessed based on the life cycle stages of the built environment during which this strategy can be applied. Within this regard, it was assumed that the level of impact a mitigation strategy has on the sustainable management of the built environment varies based on when it is applied during the built environment life cycle. A similar concept has been used in the

area of construction project management when describing the level of influence changes have on the cost of a construction project during different stages of its life cycle. Within this regard, a typical cost/influence curve for a construction project would show a decreasing trend of influence along the project's life cycle, highlighting that the ability to influence costs is highest during the earliest stages (Messner 2019). In this study, such a cost/influence curve was adapted to the context of sustainability of the built environment (Fig. 4).

The earliest stages of the built environment life cycle, i.e., interim and planning, would still be the most impactful when promoting sustainable CDW management practices due to their downstream effects. More specifically, significant potential reductions in the generation of CDW can be attained through sustainable design and planning practices (Kozlovská and Spišáková 2013), and more effective implementation of sustainable CDW management practices can be realized when policies and waste diversion goals are established early on in the built environment life cycle (Yeheyis et al. 2013). Similar to the construction project management cost/influence curve, the impact of mitigation on the sustainability of CDW management decreases during subsequent life cycle stages. During the construction stage for example, with plans being already finalized and designs being often completed, reducing the amount of CDW to be generated is limited to mitigation strategies that target constructability and material management practices (Ekanayake and Ofori 2004). The impact of mitigation on the sustainability of CDW management further decreases during the use stage, during which only maintenance, monitoring, and assessments practices can be amended (Mohammed et al. 2020).

This impact, however, increases during the end-of-life stage, during which deconstruction/demolition operations occur that largely impact the reusability and recyclability of the waste generated (Abdullah et al. 2003). These end-of-life actions also influence decisions on how this waste will be managed, i.e., disposed versus diverted (Mohammed et al. 2020). The applicability subscore for each mitigation strategy was computed by summing the score of each life cycle stage during which this strategy can be applied. The scores of different life cycle stages ranged from 1 to 3, as presented in Table 2, to reflect the level of impact each stage has on the sustainable management of the built environment which was illustrated in Fig. 4. The prioritization of strategies that impact multiple life cycle stages is intended to support more integrated and holistic approaches to sustainable management of the built environment as supported in the life cycle thinking literature (Petit-Boix et al. 2017).

Table 2. Applicability criteria scoring

Stages of the built environment life cycle impacted	Score
Interim	3
Planning	3
Construction	2
Occupancy	1
End of life	2

Table 3. Effectiveness criteria scoring

Proportion of root causes of unsustainable management of CDW addressed	Score
≤20% of the identified root causes	2
21%–40% of the identified root causes	4
41%–60% of the identified root causes	6
61%–80% of the identified root causes	8
≥81% of the identified root causes	10

Effectiveness

The effectiveness of a solution usually refers to how well it can solve a problem. As such, in this study, the effectiveness of a mitigation strategy was assessed based on its ability to address the root causes of unsustainable management of CDW. More specifically, the effectiveness subscore for each mitigation strategy was assigned based on the percentage of the identified root causes it addresses, as described in Table 3. The scoring guidelines are given in terms of percentages and not discrete counts to make the proposed scoring system applicable in any scenario.

In practice and depending on the scenario studied, some and not all of the identified root causes might exist. As such, the effectiveness subscore of a mitigation strategy would be determined depending on the number of root causes addressed out of the total number of root causes identified in the scenario under study.

Environmental Preference

The environmental preference of a mitigation strategy was assessed based on the waste hierarchy domains utilized by the mitigation strategy within the 5Rs waste hierarchy. Although all 5Rs serve as basis for sustainable waste management within the built environment, they have been ranked by scholars and practitioners from the most to the least environmentally preferred as reduce, reuse, repair, recycle, and then recover (Zhang et al. 2022). As such, the environmental preference subscore for each mitigation strategy is computed by summing the score of each R that a strategy supports, as outlined in Table 4.

This study adopted the 5Rs waste hierarchy as a widely applicable hierarchy, but any hierarchical system that ranks waste management methods with regards to their environmental impacts can be used. Waste management hierarchies may change depending on material properties/conditions and preference, and locally relevant hierarchies may serve best. If that is the case, the final prioritization score will still indicate the strategy that is most preferred for the environment in question.

Identification of Causal Factors and Root Causes of Unsustainable Management of CDW

Information obtained from the systematic literature review indicated that the sustainability of waste management, specifically that of CDW, is largely impacted by materials' conditions, applicable

Table 4. Environmental preference criteria scoring

Domains of the waste hierarchy utilized	Score
Reduce	5
Reuse	4
Repair	3
Recycle	2
Recover	1

policies and regulations, governing economic factors, the support of stakeholders, available logistics and infrastructure capabilities, and the level of coordination and planning. For the aforementioned six causal factors, the conducted root cause analysis (Fig. 5) led to the identification of the corresponding 18 root causes behind the unsustainable management of CDW in the built environment.

Challenging Material Conditions

Challenging material conditions are a fundamental causal factor of unsustainable management of CDW that can be minimized and managed but never eliminated. With respect to the 5Rs waste hierarchy, the most effective means of addressing the root causes is reduction (Ginga et al. 2020; Yeheyis et al. 2013). Simply put, fewer components in a building or infrastructure result in less waste to manage during the end-of-life stage. It is often the high volumes of CDW, whether the whole or a fraction of it, that make it so hard to manage sustainably due to limitations in the resources and infrastructure needed (Brown and Milke 2016; Duran et al. 2006; Gálvez-Martos et al. 2018; Kim et al. 2018).

Yet even at lower volumes, or in systems that can handle a high throughput of CDW, the challenges of contamination (Brown and Milke 2016; Duran et al. 2006; Gálvez-Martos et al. 2018) and complex heterogeneous mixtures (Aboutalebi Esfahani 2020; Akinade et al. 2018; Dahlbo et al. 2015; Duran et al. 2006; Lahtela et al. 2019; Luther 2006; Sormunen and Kärki 2019) complicate sustainable management options by increasing the complexity and worker power needs of processing or, as is sometimes the case with contamination, making materials too dangerous to process. Addressing each of these root causes leads to sustainable management by making the 5R waste hierarchy easier to implement. Lower volumes of CDW already account for reduction but also make the necessary steps for reuse, repair, recycling, and recovery more manageable because required limited resources can be effectively allocated to the processes. Similarly, when contamination and high heterogeneity are less of a problem, existing CDW management infrastructure has a better capacity to meet the demand.

These root causes of high waste volume, contamination, and complex heterogeneous mixtures strongly dictate the causal factor of challenging material conditions in affecting sustainable CDW management. Even if all of the other causal factors are perfectly addressed, this causal factor would still dictate the sustainability of the waste management process overall. This is because the sustainability of CDW management is fundamentally a question of the quality and quantity of materials used. In other words, a near-perfect CDW management system that cannot manage these root causes will falter in attaining sustainability.

Ineffective Policies and Regulations

Insufficient implementation of policies and regulations at any level of government directly results in unsustainable CDW management (Liu et al. 2020). This is because policies and regulations impact every stage of the built environment life cycle and are scalable to be

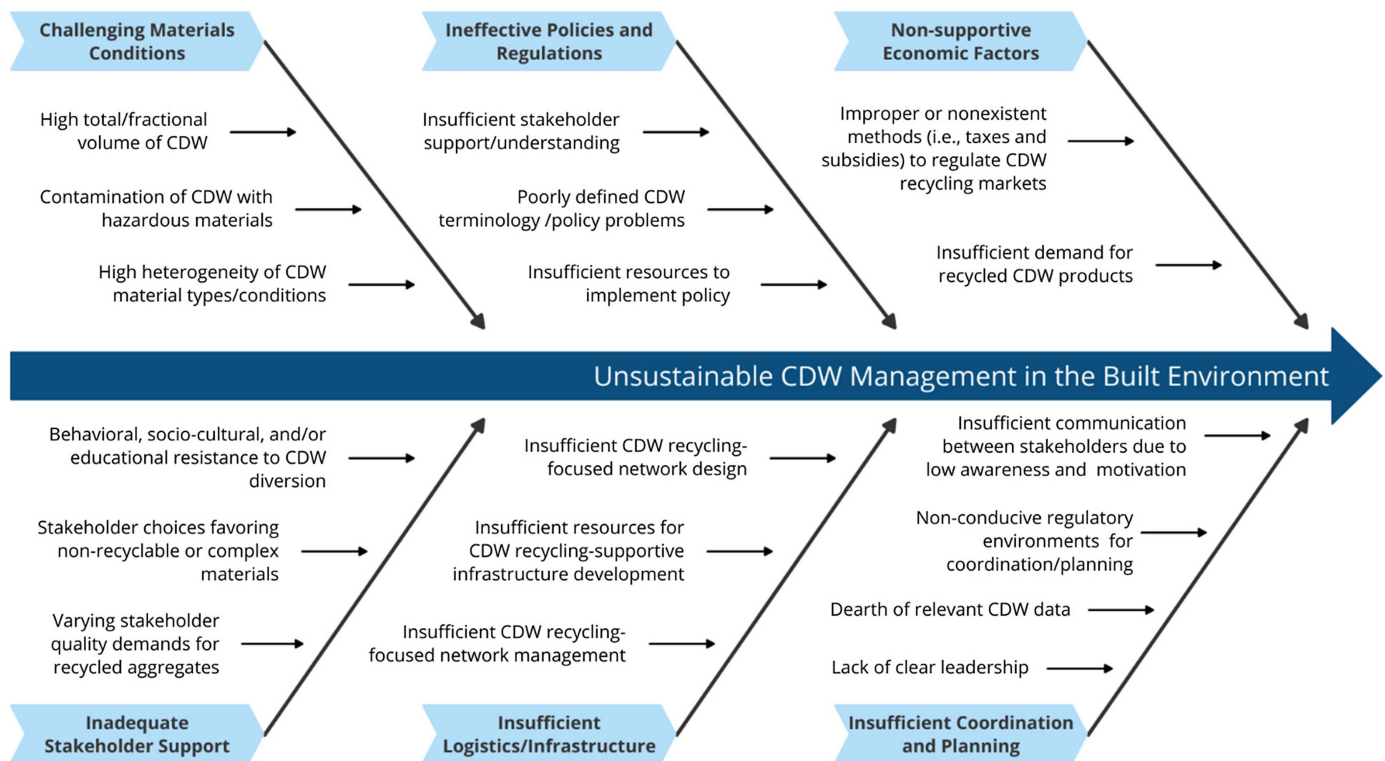


Fig. 5. Ishikawa diagram for the causal factors and root causes of unsustainable management of CDW.

effective at the local, regional, state, national, and international levels. One example of this can be seen in the building codes that dictate planning, construction, repair during use, and more. This can be analyzed at the level of a single home, but cumulative effects of structural code can be seen in the broader built environment as well. Effective policies and regulations can mitigate or eliminate issues that arise through challenging material conditions, economic factors, logistics/infrastructure, and coordination/planning by guiding stakeholder choice.

The prevalence of illegal dumping is a good example of stakeholder support and economic factors not supporting policies and regulations (Blaisi 2019). In a sustainable CDW market, weak support of policies and regulations, or a lack of understanding, from stakeholders at any level can result in unsustainability (Menegaki and Damigos 2018). With illegal dumping, it is often a lack of financial incentive combined with low buy in from stakeholders that make dumping of CDW in prohibited places a viable option. If the key actors and decision makers do not follow the relevant policy or regulation in a CDW management system, then the policy/regulation must be modified to include more appropriate checks and balances. This lack of checks and balances can be caused by another root cause relating to the insufficiency of resources to implement the policies and regulations (Giorgi et al. 2018; Huang et al. 2018; Di Maria et al. 2018; Menegaki and Damigos 2018). This insufficiency can leave legislation futile by not enabling ground-level stakeholders to affect change.

Even when stakeholder support and resources for implementation align with the governing policies and regulations, a weak definition of what CDW is, or what the policy problem is, can still lead to unsustainable CDW management (Aboutaleb Esfahani 2020; Dahlbo et al. 2015; Duran et al. 2006; Hoang et al. 2020a, b; Mália et al. 2013; Mihai 2019). Due to regional variations in material availability and construction practices, what qualifies as CDW can change. Similarly, the context of problems corresponding

to the CDW to be managed will change. Policies and regulations must explicitly state what counts as CDW, what does not, and why. The legislation must also clearly define any challenges being addressed within a local/regional context. If either CDW definition or policy problem definition are left too general, this can exacerbate the other root causes of insufficient stakeholder support/understanding and insufficient resources due to lack of specificity in what is needed to address the problem.

Nonsupportive Economic Factors

CDW practices in the built environment are part of broader social and economic dynamics. The literature on circular economies has highlighted this fact by considering how CDW by-products from the built environment serve as a source for downstream products such as recycled aggregates (Galán et al. 2019; Jiménez-Rivero and García-Navarro 2017; Lahtela et al. 2019). Markets that dictate the flow and availability of these CDW materials often require explicit economic intervention (e.g., landfill taxes and recycling subsidies) to balance supply and demand (Duran et al. 2006). Otherwise, in unregulated environments, illegal dumping and/or cost-prohibitive recycling might dominate (Marzouk and Azab 2014).

Unsustainable CDW markets are often characterized by two root causes: improper or nonexistent methods to regulate waste markets, such as taxes and subsidies (Agamuthu 2008; Hoang et al. 2020a; Huang et al. 2018; Di Maria et al. 2018), and an insufficient demand for recycled products (e.g., aggregates) relative to natural products (e.g., newly mined stone or freshly cut timber) (Dahlbo et al. 2015; Duran et al. 2006; Hoang et al. 2020a; Luther 2010; Mihai 2019). If economic instruments can be utilized alongside systems to bolster demand for recycled products (i.e., quality control), it becomes possible to create a supportive economic environment for sustainable CDW management.

Inadequate Stakeholder Support

The key stakeholders influencing sustainable management of the built environment are the government, designers, CDW producers, community members, and CDW recyclers (Jiménez-Rivero and García-Navarro 2017; Shan et al. 2017). Government stakeholders range from the local to international levels and influence every level of the built environment life cycle. Designer groups are the stakeholders who have a strong influence in the planning stage of a structure, such as architects, engineers, and owners. CDW producers include construction companies as well as the manufacturers making the component parts of a structure. The community exists as a broad stakeholder designation accounting for the occupants and regional neighbors to a structure who might influence its use stage. Finally, CDW recyclers are private and/or public entities engaged in all end-of-life material processing that do not include landfilling.

The described distinct groups of stakeholders often have different objectives that play out across varying spatiotemporal dimensions (Pan et al. 2020). This leads to variations in stakeholder support regarding sustainable management of the built environment. These variations can arise from one of the root causes of this causal factor, which is behavioral, sociocultural, and/or educational resistance to CDW diversion (Menegaki and Damigos 2018; Zhang et al. 2019). Whether by psychology, culture, or educational background, stakeholders can be predisposed to resist certain paths of CDW management.

Interrelated with this is the second root cause, which is the occurrence of stakeholders actively favoring non-recyclable or complex materials. This often reduces the likelihood of sustainable management (Liu et al. 2020). In CDW markets, another root cause of insufficient stakeholder support is varying quality demands for recycled aggregates (He and Yuan 2020; Silva et al. 2017). The ultimate result of stakeholder choice in a CDW market heavily influences the sustainability of that market.

Among the stakeholder groups, some people have more influence than others. The most influential actors on sustainability in the built environment are the designers and the government (Hollberg et al. 2020; Jin et al. 2017). Their respective choices have far-reaching implications that not only influence downstream life cycle stages from the point of action but also influence life cycle outcomes for other structures. For example, a designer's choice to use design for deconstruction principles in the planning stage (Ding et al. 2016) increases the likelihood of a future structure being more sustainably built from reused components. However, government policy during the interim stage, before the structure was designed, might impose ill-informed code restrictions on the more sustainable design for deconstruction principles.

Insufficient Logistics/Infrastructure

A well-designed (reduced, repairable, and reusable), sustainably sourced (reusable, recyclable, and recoverable), well-maintained (reusable and recyclable), and selectively demolished structure (reusable, recyclable, and recoverable) can still meet a linear fate in a dump. From the perspective of the 5Rs waste hierarchy, sustainable waste logistics and infrastructure must support reduction, reuse, repair, recycling, and energy recovery. The last two, in particular, rely heavily on well-regulated waste logistics and infrastructure (Aydin 2020; Gálvez-Martos et al. 2018). Not only must the appropriate facilities and equipment exist, but they must also be situated in accessible locations and managed in coordination to ensure long-term survivability. Broadly speaking, sustainable strategies implemented prior to a structure's end of life should reduce it and also make it more repairable, reusable, recyclable, and recoverable. It is the sufficiency of logistics and infrastructure that helps

realize these goals by actually facilitating repair, reuse, recycling, and energy recovery.

For waste logistics and infrastructure to be a causal factor in the overall sustainability of CDW management, it is important to address the root cause insufficiencies in recycling-focused network design (Pan et al. 2020), resources to expand infrastructure (Lockrey et al. 2016; Mihai 2019), and recycling-focused network management (Hoang et al. 2020b; Huang et al. 2018). It is effectively the sufficient design, management, and availability of resources for CDW management logistics and infrastructure that determine their success. Physical facilities must be available and function well to take a sustainable structure and process its materials whether by reuse, recycling, or recovery. Logistic choices must also be made and supported so that sustainable buildings can be repaired during their lives.

Insufficient Coordination and Planning

Insufficient coordination and planning are a common cause among the other causal factors for unsustainable CDW management. Insufficiencies in logistics and infrastructure, stakeholder support, economic factors, policies and regulations, and even material conditions can all be explained, in part, as products of insufficient coordination and planning (Huang et al. 2018; Pan et al. 2020). This reflects the fact that each causal factor can be found in the others, and, as such, all of the root causes addressed here should not be considered as isolated causes but instead as existing at various points upstream to more proximal manifestations of unsustainable decision-making.

In a broad sense, coordination and planning is undermined by four root causes. These include (1) insufficiencies in communication between stakeholders due to low motivation, low awareness, and/or poor infrastructure (Huang et al. 2018; Lockrey et al. 2016); (2) nonconducive regulatory environments for coordination/planning (Menegaki and Damigos 2018; Yuan 2017); (3) insufficient clear leadership (Yuan 2017); and (4) insufficient relevant CDW data (Giorgi et al. 2018; Hoang et al. 2020b; Jalloul et al. 2022b; Menegaki and Damigos 2018; Yuan 2017). Good communication, supportive regulatory environments, strong leadership, and actionable data are essential for coordination and planning. The significance of relevant CDW data bears special attention as it facilitates communication, regulation, and leadership.

Identification and Characterization of Mitigation Strategies for Unsustainable Management of CDW

Each of the root causes of unsustainable management of CDW presents an opportunity for intervention. The literature review facilitated the identification of these intervention opportunities in the form of 26 mitigation strategies that can be implemented across different life cycle stages and in support of different levels of the 5Rs waste hierarchy (Table 5). For each mitigation strategy, the key decision-making stakeholders involved, the resulting action, the impacted life cycle stages, and the domains of the 5Rs waste hierarchy utilized are presented in Table 6.

Table 5. Abbreviations for the life cycle stages and waste hierarchy

Life cycle stages	Waste hierarchy
Interim (I)	1. Reduce
Planning (P)	2. Reuse
Construction (C)	3. Repair
Use (U)	4. Recycle
End of life (E)	5. Recover

Table 6. Identified and characterized mitigation strategies for unsustainable management of CDW

Code	Mitigation strategies	References	Who makes the decision	Result of the action	Life cycle stage involved	Waste hierarchy level supported
S1	Control and separate the CDW stream as early as possible	Aboutalebi Esfahani (2020), Brandon et al. (2011), Galán et al. (2019), Huang et al. (2018), Lahtela et al. (2019), Mália et al. (2013), Menegaki and Damigos (2018), and Ruiz et al. (2020)	CDW producer, CDW recycler	This creates homogenized CDW streams that are easier to manage and results in higher quality CDW products.	C, U, E	2, 4, 5
S2	Add standard materials to the CDW stream to meet end-product technical/normative standards	Aboutalebi Esfahani (2020), Akhtar and Sarmah (2018), and Tam et al. (2009)	CDW recycler	Conforming to materials' standards makes end-products more appealing to consumers.	E	4
S3	Improve building and material design standards	Huang et al. (2018), Lahtela et al. (2019), and Ruiz et al. (2020)	Government, designers	Improving design standards with sustainability in mind makes all other life cycle stages easier to manage and improves end-of-life recyclability.	I, P, C, U, E	1, 2, 3, 4, 5
S4	Use prefabrication and modular construction, ideally using CDW sourced materials	Amaral et al. (2020), Çimen (2021), Mignacca and Locatelli (2021), Poon (2007), and Whittaker et al. (2021)	Designers, CDW producer	Prefabrication and modular construction make end-of-life material harvesting easier. Using CDW sourced materials supports a robust CDW product market.	I, P, C, U, E	1, 2, 3, 4, 5
S5	Create certifications/normative standards for recycled aggregates (RAs)	Aboutalebi Esfahani (2020), Duran et al. (2006), and Liu et al. (2020)	Government	These certifications and standards ensure aggregate quality and help maintain demand for CDW products.	I, E	4
S6	Develop policies that explicitly support sustainable (5Rs) CDW hierarchy and the development of the needed local CDW infrastructure	Fetter and Rakes (2012), Gálvez-Martos et al. (2018), Huovila et al. (2019), Di Maria et al. (2018), and Yuan (2017)	Government, CDW recycler	The EU has successfully done this, and a broader international effort to do the same will make it easier to create international CDW standards and markets. Also, the 5Rs waste hierarchy developed in concert with appropriate infrastructure is proven to increase sustainable end-of-life decisions for building materials.	I, P, C, U, E	1, 2, 3, 4, 5
S7	Create policies that define CDW using a definition that works in accordance with regional, national, and international efforts	Galán et al. (2019), Gálvez-Martos et al. (2018), and Hoang et al. (2020b)	Government	A consistent CDW definition opens up other opportunities for broader policy action, data collection, consistent research, and more.	I, C, E	1, 2, 4
S8	Ban backfilling as a CDW management strategy	Galán et al. (2019), Giorgi et al. (2018), and Jiménez-Rivero and García-Navarro (2017)	Government	Backfilling prevents any potential valorization of CDW.	E	2, 4
S9	Support green building/public procurement	Hoang et al. (2020a, b), Jiménez-Rivero and García-Navarro (2017), and Menegaki and Damigos (2018)	Government	An established green building procurement policy institutionalizes the act of using sustainable materials and practices.	I, P, C, U, E	1, 2, 3, 4
S10	Support public–private partnerships (PPPs)	Hoang et al. (2020b), and Huang et al. (2018)	Government, CDW recycler	PPPs blend the funding and resources of the public sector with the innovation of the private sector. They diffuse risk and improve efficiency.	I, P, C, U, E	1, 2, 3, 4, 5
S11	Develop local policies (in concert with economic instruments) to address specific material types and guide their management	Jiménez-Rivero and García-Navarro (2017), and Tam et al. (2009)	Government	Policies addressing specific materials, as opposed to broad sweeping CDW policies, ensure that the unique management needs of each material type are met in the most optimal way possible.	I, P, C, U, E	1, 2, 4, 5

Table 6. (Continued.)

Code	Mitigation strategies	References	Who makes the decision	Result of the action	Life cycle stage involved	Waste hierarchy level supported
S12	Before creating and implementing a policy for CDW management, check that all factors related to the policy environment and policy implementation are supportive	Li et al. (2020)	Government	Although policy creation may be one of the most powerful tools for CDW management, it must be done in line with available resources, local markets, and sociocultural concerns.	I, P, C, U, E	1, 2, 4
S13	Economic instruments (e.g., taxes on natural aggregates, taxes on landfilling, and subsidies) must be used to support sustainable CDW management choices.	Duran et al. (2006), Fetter and Rakes (2012), Gálvez-Martos et al. (2018), Huang et al. (2018), Mália et al. (2013), Di Maria et al. (2018), and Tam et al. (2009)	Government	Profit is a strong motivator for CDW producers and other CDW stakeholders. Economic instruments are a necessary tool to ensure a strong CDW market as well as a well incentivized CDW management structure.	I, P, C, U, E	1, 2, 4, 5
S14	Community members should play a role in the repair, refurbishment, and remanufacture of built environment elements, which prolongs structure life and delays CDW creation	Ruiz et al. (2020)	Community	Community members (i.e., families and business owners) play a critical role in maintaining properties and delaying the end-of-life stage of structures (i.e., reducing the CDW load).	U, E	2, 3, 4
S15	Community members should help dictate policy direction	Li et al. (2020)	Community	When community members help dictate CDW related policy, it helps to ensure that the policy can actually be enacted in the community it is meant to impact.	I, P, C, U, E	1, 2, 3, 4, 5
S16	Design recycling networks to optimize cost, psychosocial, and environmental health considerations (multiobjective reverse logistics network design is effective)	Brown and Milke (2016), Correia et al. (2021), Di Maria et al. (2018), and Pan et al. (2020)	CDW recycler	This is necessary to incentivize CDW recycling over landfilling and increase its feasibility.	E	4, 5
S17	Develop recycling facilities in accordance with the concept of economies of scale (i.e., build in locations with high volume demand)	Duran et al. (2006), and Di Maria et al. (2018)	Government, CDW recycler	Increasing the economic feasibility of CDW recycling would increase its implementation.	E	4, 5
S18	Provide training for CDW workers on sustainable management practices and follow up with enforcement	Bakshan et al. (2017), Begum et al. (2009), Hoang et al. (2020a), and Liu et al. (2020)	Government, CDW producer	Proper CDW management, implemented considering end-of-life material recyclability, is critical for recapturing materials from structures for use as secondary products.	P, C, U, E	1, 2, 3, 4
S19	Develop a robust cyber infrastructure for CDW data collection and database management	Gálvez-Martos et al. (2018), Giorgi et al. (2018), Hoang et al. (2020b), Jalloul et al. (2022b), Kleemann et al. (2017), Li et al. (2022), Mália et al. (2013), Menegaki and Damigos (2018), and Mihai (2019)	Government, CDW recycler, CDW producer	CDW data are essential for more advanced research and policy development. Information about the quantity and composition of CDW is critical for making sustainable management decisions.	I, P, C, U, E	1, 2, 4
S20	Establish a centralized CDW management framework that relies on a systematic and quantitative approach	Gálvez-Martos et al. (2018), Karunasena et al. (2012), and Kim et al. (2018)	Government, CDW recycler	Centralized, systemized, and quantified CDW management allows for more strategic control of the supply chain and enables new policy to take effect more easily and be better informed and more effective.	I, P, C, U, E	1, 2, 4

Table 6. (Continued.)

Code	Mitigation strategies	References	Who makes the decision	Result of the action	Life cycle stage involved	Waste hierarchy level supported
S21	Use building information modeling (BIM)-based CDW management in coordination with other stakeholders	Akanbi et al. (2018), Akinade et al. (2018), Amaral et al. (2020), Ozorhon and Karahan (2017), and Won et al. (2016)	Government, designer, CDW recycler, CDW producer	Greater coordination among stakeholders regarding management of building materials and improved decision making facilitates sustainability.	I, P, C, U, E	1, 2, 4
S22	Tailor CDW management contracts to match local needs (i.e., lump-sum contracts when disposal costs are high)	Brown and Milke (2016)	Government, CDW producer	Management contracts are another important tool to incentive CDW recycling over landfilling.	E	2, 4, 5
S23	Create coordinated CDW management plans at national, regional, and local levels	Gálvez-Martos et al. (2018), and Iacoboaia et al. (2019)	Government, CDW recycler	When CDW management is coordinated across multiple scales, it becomes easier to pool resources, enact policy, and maintain a robust market for CDW products, among other benefits.	I, P, C, U, E	1, 2, 4, 5
S24	Focus on collaborative relationships with cooperative enterprises for a new supply chain management	Brandão et al. (2020), Liu et al. (2020), and Long et al. (2020)	CDW recycler	Much like PPPs, these business-to-business collaborations can lead to innovation, risk sharing, and a more evolved supply chain for CDW management.	I, P, C, U, E	1, 2, 4, 5
S25	Use selective deconstruction	Correia et al. (2021), Galán et al. (2019), Giorgi et al. (2018), Kamrath (2013), and Ruiz et al. (2020)	CDW producer	Selective deconstruction makes it easier to sort CDW, determine its quantity and composition, and manage it properly.	E	1, 2, 4, 5
S26	Conduct preconstruction and predemolition audits	Giorgi et al. (2018), Menegaki and Damigos (2018), and Ruiz et al. (2020)	CDW producer	Preconstruction and predemolition audits clarify the nature of the materials present and allow for strategic management during occupancy and postdemolition.	P, C, U, E	1, 2, 3, 4, 5

To develop a sustainable CDW management within the built environment, it is necessary to implement mitigation strategies that impact multiple root causes across the life cycle of structures. Supported by the literature, Fig. 6 correlates causal factors, root causes, and mitigation strategies to better understand where each strategy is most applicable.

Prioritization of the Mitigation Strategies

Addressing unsustainable CDW management in the built environment is an effort that competes against other objectives and must be completed with limited resources. Using the integrated scoring system presented in this study, all 26 strategies were scored and prioritized based on their (1) applicability, (2) effectiveness, and (3) environmental preference. The effectiveness subscores of the mitigation strategies were computed in the case when all listed root causes of unsustainable CDW management are present (i.e., 18 root causes). Fig. 6 was used to find the number of root causes addressed by each strategy to subsequently calculate the effectiveness subscores. For example, according to Fig. 6, S5 addresses 6 out of the 18 root causes (i.e., 33%), resulting in an effectiveness subscore of 4 as per the scoring guidelines provided in Table 3. Fig. 7 presents the resulting total and subscores of all 26 mitigation strategies in a descending order, from the highest ranked strategy (S6) to the lowest ranked strategy (S2).

The top strategies for sustainable management of the built environment from the life cycle perspective are, in order, S6 (score of 28); S10, S11, and S23 (tied with a score of 26); and S9 and S12 (tied with a score of 25.33).

S6: Develop Policies that Explicitly Support a Sustainable (5Rs) CDW Hierarchy and the Development of the Needed Local CDW Infrastructure

Policymakers at all levels of government are responsible for developing legislation that explicitly enforces the 5Rs waste hierarchy. However, this enforcement must be paired with mechanisms established in statutes that develop structural and operational infrastructure aligning with the 5Rs. In practice, this might look like a reduction policy that requires more stringent design standards paired with the provision of building information modeling (BIM) software (Huang et al. 2018) or improved urban planning with subsidized continuing education and mandated best-practice documents.

This strategy primarily depends on government and CDW recyclers to be effective but is supported by the political action of community occupants, as well as the policy adherence of CDW producers and designers. Government stakeholders (i.e., policy makers) shape the 5Rs mandate for a region through legislation, and CDW recyclers actualize this mandate by fulfilling the benefits of recycling and recovery. CDW producers and designers also help implement the mandate by supporting actions related to reduction, reuse, and repair and maintaining requirements for increased

Causal Factors	Root Causes	Mitigation Strategies																									
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Challenging Materials Conditions	High total/fractional volume of CDW																										
	Contamination of CDW with hazardous materials																										
	High heterogeneity of CDW material types/conditions																										
Ineffective Policy and Regulations	Insufficient stakeholder support/understanding																										
	Poorly defined CDW terminology and policy problems																										
	Insufficient resources to implement policy																										
Unsupportive Economic Factors	Improper or nonexistent methods to regulate CDW recycling markets																										
	Insufficient demand for recycled CDW products																										
Inadequate Stakeholder Support	Behavioral, socio-cultural, and/or educational resistance to CDW diversion																										
	Stakeholder choices favoring non-recyclable or complex materials																										
	Varying stakeholder quality demands for recycled aggregates																										
Insufficient Logistics/Infrastructure	Insufficient CDW recycling-focused network design																										
	Insufficient resources for CDW recycling-infrastructure development																										
	Insufficient CDW recycling-focused network management																										
Insufficient Coordination and Planning	Insufficient stakeholder communication due to low awareness and motivation																										
	Non-conductive regulatory environments for coordination/planning																										
	Lack of clear leadership																										
	Dearth of relevant CDW Data																										

Fig. 6. Mapping between the identified mitigation strategies and the root causes they address.

recyclability and recovery. Community occupants, as the voting populace who determine which policy makers are in power, ultimately influence policy formation indirectly and play a critical role in the success of this strategy.

S6 can be seen in action with the European Waste Framework Directive (WFD). Published in 2008 by the European Union (EU), the WFD set standards for waste management, including recycling goals, and required member states to create national waste prevention programs and incorporate the WFD into their national policies. Although issues of CDW regulation, data quality, underdeveloped logistics, and market readiness still plague some member states, the EU managed to reduce landfilled CDW from 22% in 2010 to 12% in 2014 (Sáez and Osmani 2019). Specifically, among the four member states (France, Portugal, Slovenia, and Spain) that developed specific CDW regulations related to the WFD, three (Portugal, Slovenia, and Spain) were among the member states with the lowest CDW generation in the EU. The relative success of the WFD shows that a well-coordinated alignment of enforceable policy/regulation with a prioritized sustainability framework can be effective, and it supports the use of this strategy.

S10: Support Public–Private Partnerships

As described by Hoang et al. (2020b), public–private partnerships (PPPs) combine the benefits of the public sector and private sector to support commercial feasibility in the private sector and realize goals of the public sector. Within the context of sustainable CDW management, PPPs enable public entities to partner with the private sector in establishing CDW recycling infrastructure, thereby providing potential for upfront capital and increased coordination with

other CDW stakeholders in the CDW management process. In such partnerships, the motives of the private sector CDW producers and collectors are profit-related, whereas the public sector is accountable to a broader constituency with overlapping economic, environmental, and societal goals (Hoang et al. 2020b). Bringing these motives into alignment is a potential benefit of formalized PPPs and a necessity for sustainable CDW management across the life cycle of the built environment.

S11: Develop Local Policies (in Concert with Economic Instruments) to Address Specific Material Types and Guide Their Management

S11 parallels the lessons of S6 in that policy is a powerful mechanism for ensuring the sustainability of the built environment, but it must be implemented strategically and in alignment with other elements of the process in question. Specifically, S11 recommends that policy makers develop CDW management legislation that simultaneously considers the critical components of economic incentive and material variability. The importance of considering these together comes from the fact that the different material types present in CDW require varying tools, processes, and skills to sustainably manage them.

For example, some timber elements may be selectively deconstructed and reused in another structure (Ramage et al. 2017), and concrete may be hauled to a crusher and used to produce recycled aggregates (Silva et al. 2017). The variation in time and effort required for each material type means that CDW management policy must consider economic incentives and disincentives for each material flow.

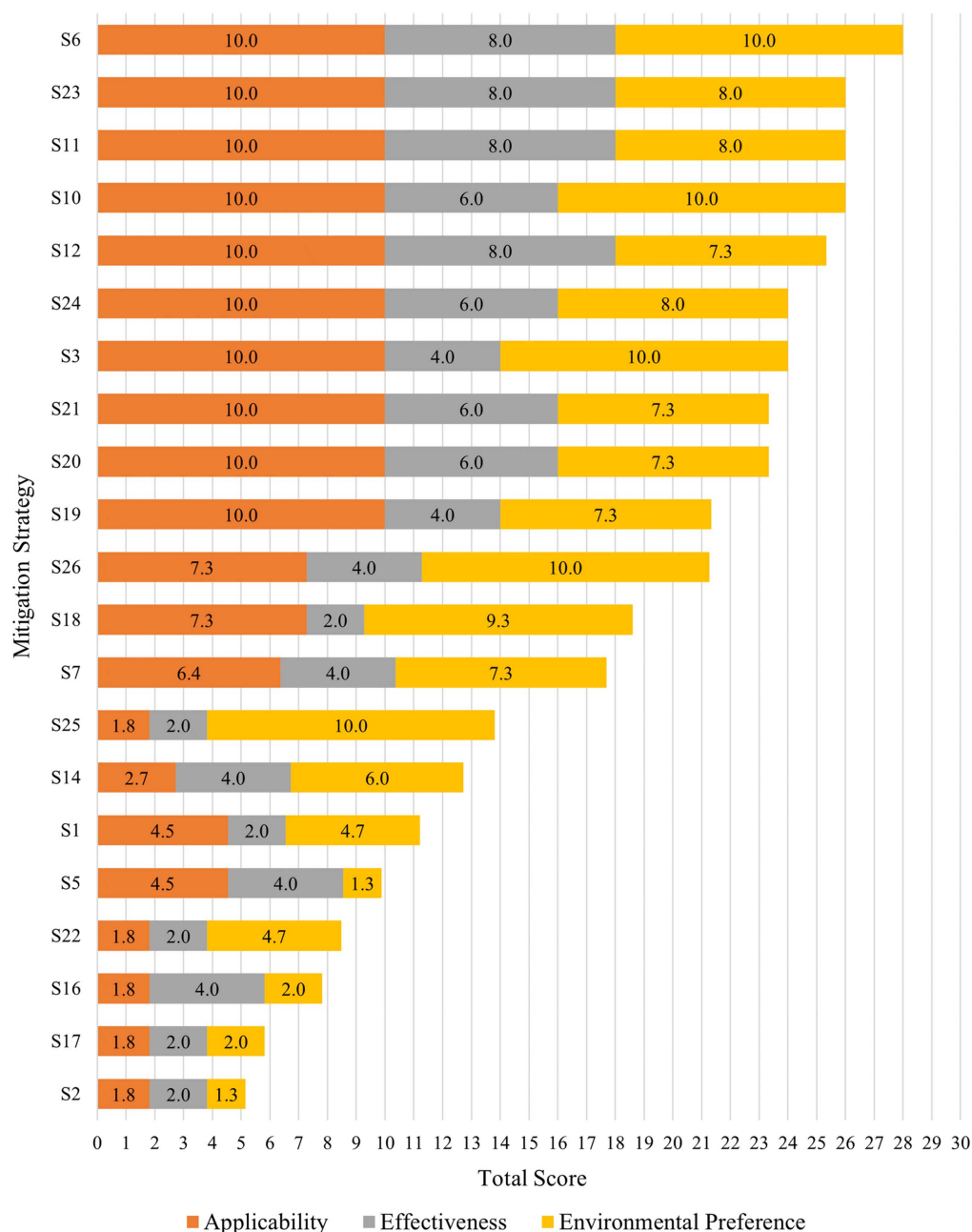


Fig. 7. Rankings of the mitigation strategies.

S23: Create Coordinated CDW Management Plans at National, Regional, and Local Levels

Strategies S6, S10, S11, and S12 all included elements of increased coordination, which emphasizes the critical need for coordination to facilitate sustainable management. However, because these strategies primarily focus on policy and partnership, they do not adequately address other important aspects of coordination, namely planning and scope. Strategy S23 specifically calls for coordinated CDW management planning at varying geographical scopes. Although CDW management planning is important under any circumstances, it is critical that it is done at the local, regional, and national levels in a coordinated manner so that one plan is supported by the others (Sáez and Osmani 2019).

Variations in regional resources, as well as in the nature of critical CDW producing events (e.g., disasters) in the life cycle of the built environment, imply that there will be regional differences in

CDW production and management (Mália et al. 2013). A simple example of this might exist if a high-CDW-producing county without CDW recycling infrastructure is located near a low-CDW-producing county with robust CDW recycling infrastructure. From the perspectives of these counties, both local and national CDW plans might help improve sustainable management of CDW material flows prior to the end-of-life stage. However, at the end-of-life stage, a regional plan that is coordinated with the local and national plans would help ensure that the high-CDW-producing county can access the other county's CDW recycling infrastructure.

S9: Support Green Building/Public Procurement

Green building/public procurement (GPP) is often government-led and requires the procurement of goods and services, having fewer environmental impacts when compared with others over the life cycle of the built environment (Cheng et al. 2018). At its simplest,

GPP supports a built environment constructed out of environmentally conscious materials with environmentally conscious methods. Research has indicated that GPP can stimulate the private sector's adoption of sustainable construction standards even in regions without their own GPP policy and, more broadly, has the ability to influence regional channels of supply and demand that are essential for broader sustainability markets (Simcoe and Toffel 2014). Simcoe and Toffel (2014) noted that government procurement policies have the power to stimulate local demand for green buildings, lower prices for green building components by attracting new suppliers, leverage economies of scale, instigate learning effects, and solve market coordination issues for green buildings.

The improvements from GPP in structural material sustainability and overall sustainability market dynamics lower the barriers to entry for reduction, reuse, repair, recycling, and recovery, thus enabling the 5Rs waste hierarchy. Effectively, a mandate to use more environmentally positive materials in building construction benefits upstream and downstream life cycle stages and makes sustainable CDW management easier.

S12: Before Creating and Implementing a Policy for CDW Management, Check that All Factors Related to the Policy Environment and Policy Implementation Are Supportive

S12 can qualify as a metastrategy for the implementation of other strategies that involve policy at any level (e.g., national, local, and regional) because it guides the strategic development and deployment of policy. Although many critical factors influence sustainable CDW management, studies have shown that policy instruments are often the most influential (Jiménez-Rivero and García-Navarro 2017; Liu et al. 2020). However, because a policy is created and implemented in highly complex and changing environments, its efficacy is variable and dependent on several factors (Li et al. 2020).

Li et al. (2020) extensively explored policy instrument choice for CDW management and found that command-and-control, market-based, and information-based methods were the most common. These policy instruments appeared as the most common throughout the literature as well. From their analysis of policy instrument choice, Li et al. (2020) identified resource availability, policy problem/goal clarity, legitimacy, acceptance of targeted groups, and environmental concern of the public as the most crucial factors influencing that choice. Policymakers are encouraged to apply S12 by investigating these crucial factors before developing and implementing policy for sustainable CDW management in the built environment. Other stakeholders should consider relevant implications of this strategy at their respective levels as well.

Case Study: Sustainable Management of Louisiana's Built Environment

The knowledge synthesized in this study presents a guide for a holistic three-step framework for the sustainable management of the built environment. The first step entails the identification of the causal factors and root causes of unsustainable CDW management that are present in the area under study from those outlined in Fig. 5. Following the identification of the causes of the problem, stakeholders in the second step should identify mitigation strategies applicable to the root causes present in their community, guided by the information presented in Fig. 6 and Table 6. During the third step, identified relevant strategies should be ranked using the developed integrated scoring system to prioritize their implementation amid typical limitations on available resources for actionable planning and mitigation.

The state of Louisiana was taken as a case study to demonstrate how the framework proposed in this study can be applied to a geographic region that has experienced large outputs of CDW. In the last 2 decades, the state has experienced major changes in the built environment that have instigated construction and demolition activities generating significant CDW. These can be categorized into two groups: (1) construction/demolition due to the development of new buildings and infrastructure with the expansion of the urban areas; and (2) reconstruction/demolition due to redevelopment activities after major disasters. Outside of construction, reconstruction, and demolition, recurrent disasters have been a major source of CDW in and of themselves due to their destructive nature.

Louisiana is a coastal state on the Gulf of Mexico, which makes this state prone to disasters such as hurricanes, floods, and tropical storms. Over the life cycle of the built environment, the frequent occurrence of disasters punctuates periods of relative peace and drives CDW production. For example, Fig. 8 illustrates the number of privately owned house permits issued in Louisiana from 2000 to 2021, revealing how disasters can affect the construction industry (US Census Bureau 2022).

Each of the illustrated disasters generated massive amounts of CDW. For instance, as a result of Hurricane Katrina, about 64.3 million cu yd (49.16 million m³) of CDW were generated (Luther 2006). In the years since Hurricane Katrina, the state has also witnessed an internal population flux with northern and rural parishes losing population as people move to urban and suburban centers (US Census Bureau 2020). Specifically, the New Orleans region, Baton Rouge, and parts of Calcasieu Parish experienced significant increases in population. Concurrently, investments in petrochemical plants and energy infrastructure (Wendland 2020), along with several other upcoming infrastructure projects (Wood 2022), contributed to nondisaster mediated CDW streams.

Step 1: Identification of Causal Factors and Root Causes

The first step toward implementing the proposed framework is to identify the causal factors and root causes that could contribute to unsustainable CDW management in the built environment of Louisiana. Upon reviewing the literature, along with Louisiana's legislation and regulations, 11 root causes, relevant to 6 causal factors, were identified (Table 7).

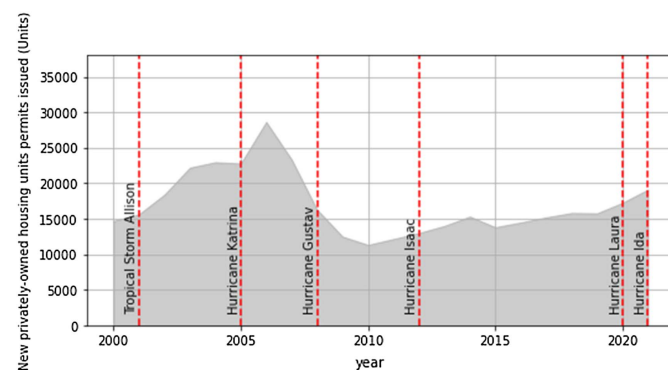


Fig. 8. Number of new privately owned housing permits issued between 2000 and 2021 alongside major natural disasters that occurred during this period. (Data from US Census Bureau 2022.)

Table 7. Identified causal factors and root causes contributing to the unsustainable CDW management in Louisiana

Causal factor	Root causes
Challenging materials conditions	High total/fractional volume of CDW Contamination of CDW with hazardous materials High heterogeneity of CDW material types/conditions
Ineffective policies and regulations	Poorly defined CDW terminology and policy problems Insufficient resources for policy implementation
Nonsupportive economic factors	Improper or nonexistent methods to regulate CDW recycling markets
Inadequate stakeholder support	Stakeholder choices favoring nonrecyclable or complex materials Varying stakeholder quality demands for recycled aggregates
Insufficient logistics/infrastructure	Insufficient CDW recycling-focused network design Insufficient CDW recycling-focused network management
Insufficient coordination and planning	Dearth of relevant CDW data

Challenging Materials Conditions

With large-scale development and redevelopment in Louisiana, CDW management systems have been challenged by complex CDW conditions, often resulting in unsustainable CDW linear fates. Hurricane Katrina alone generated about 64.3 million cu yd of debris in 8 days in Louisiana (Luther 2010). According to the Louisiana Department of Environmental Quality (LDEQ) (LDEQ 2020c), such a high rate of CDW generation challenged the CDW management strategies in place in the affected areas in Louisiana.

In addition to the high CDW generation rate, the contamination of CDW with hazardous materials is another factor contributing to unsustainable CDW management in Louisiana. An example of such hazardous material is asbestos. According to a survey conducted by LDEQ, there were traces of asbestos in at least 21 CDW landfills up to 2019 (LDEQ 2020b), indicating the contamination of the disposed CDW, which might have impeded its sustainable management.

CDW also contains various materials with a wide range of conditions which could pose a challenge to effectively implementing a sustainable management plan. The extreme cases of this challenge can be found in postdisaster circumstances, where other wastes streams (e.g., white goods, vegetative debris, and vehicle parts) mix with CDW, as was the case during many disasters in Louisiana (LDEQ 2020b; Luther 2010).

Ineffective Policies and Regulations

There are various laws and regulations, both at the federal and state level, in place regarding the management and handling of CDW in Louisiana (LDEQ 2020c; Louisiana Division of Administration 2021). For example, LAC 33: VII discusses the standard of handling CDW in detail. This code acts as the backbone of the CDW management system in Louisiana, and supplementary codes and regulations are dedicated to answering specific challenges like the management of CDW contaminated with asbestos in the aftermath of a disaster (Louisiana Division of Administration 2021).

To be specific, the state's comprehensive plan for disaster clean-up and debris management enforces restrictions on handling CDW and in which conditions they can be sent to landfills in times

of emergency. This plan was introduced in response to Hurricane Katrina in 2005 and revised several times afterward. The state's comprehensive disaster clean-up and debris management plan, however, does allow the contractor to landfill the majority of the CDW generated during disasters (LDEQ 2020c).

Nonsupportive Economic Factors

Contractors that recycle solid waste can benefit from tax credits under LAC 33: VII (Louisiana Division of Administration 2021). Corporate recycling tax credits are also available for tax-paying entities who purchase qualified new recycling manufacturing or processing equipment per LDEQ. Other options such as the Restoration Tax Abatement Program in Baton Rouge are available to some communities to encourage "the reuse, expansion, improvement and renovation of existing buildings" (City of Baton Rouge 2022). However, beyond tax programs like these, there is very limited information available on the current state of economic incentives and disincentives available for landfilling versus the 5R-imperatives in the state of Louisiana.

Inadequate Stakeholder Support

Although governmental agencies in the state of Louisiana do broadly support recycling efforts (i.e., LDEQ), there is little to be found on explicit support for sustainable CDW management. Similarly, with almost no major CDW recycling infrastructure, the CDW recycler stakeholder group is minimal in the state. Continuing this trend, querying the Louisiana Engineering Society (2022) website using keywords such as CDW and sustainable did not return any results, reflecting a broader limitation in finding designer stakeholders advocating sustainable CDW management in the state.

Insufficient Logistics/Infrastructure

According to USEPA's Incident Waste Decision Support Tool (I-WASTE DST), the state of Louisiana has only one registered CDW recycler, which is located just outside Lake Charles in Calcasieu Parish (USEPA 2022). Although this may not be a completely accurate representation of the condition of CDW recycling infrastructure in the state, there is limited information to indicate otherwise. This limited availability of information also indicates insufficiencies in logistics and infrastructure. By contrast, I-WASTE DST did identify 49 inert or construction and demolition landfills in the state.

Insufficient Coordination and Planning

Louisiana drafted multiple plans to forge effective communication among stakeholders and to coordinate the efforts of the entities involved in the built environment. These plans engaged all stakeholders in the environment and outline a clear leadership role (LDEQ 2020a, c; Louisiana Division of Administration 2021). Furthermore, Louisiana requires all entities to keep detailed records of all activities and materials that fall into the category of solid wastes, including CDW, even after a disaster (Louisiana Division of Administration 2021). However, more extensive data on the quantity and quality of the CDW in the state are not reported in state legislation or the literature. Although the LDEQ does offer information and educational materials for stakeholders in the state and broadly supports recycling, CDW sustainable management practices and waste hierarchies are not specifically addressed.

Step 2: Identification of Relevant Mitigation Strategies

Based on the identified causal factors and root causes, the relevant strategies that help in supporting sustainable CDW management are presented in Table 8.

Table 8. Root causes identified in Louisiana and their relevant mitigation strategies

Root cause	Relevant mitigation strategies
High total/fractional volume of CDW	S3, S4, S6, S9, S11, S14, S17, S21, S24, S26
Contamination of CDW with hazardous materials	S1, S3, S4, S6, S9, S11, S14, S18, S21, S24, S25, S26
High heterogeneity of CDW material types/conditions	S1, S2, S3, S4, S6, S9, S11, S14, S21, S23, S24, S25, S26
Poorly defined CDW terminology and policy problems	S5, S6, S7, S9, S11, S12, S15, S19, S21, S23
Insufficient resources for policy implementation	S6, S10, S12, S13, S16, S17, S20, S23
Improper or nonexistent methods to regulate CDW recycling markets	S6, S10, S12, S13, S22
Stakeholder choices favoring nonrecyclable or complex materials	S3, S4, S5, S6, S9, S11, S13, S16, S21, S24, S26
Varying stakeholder quality demands for recycled aggregates	S2, S5, S10, S11
Insufficient CDW recycling-focused network design	S6, S10, S12, S16, S17, S19, S20, S23
Insufficient CDW recycling-focused network management	S5, S8, S10, S11, S12, S16, S19, S20, S21, S22, S23, S24
Dearth of relevant CDW data	S1, S7, S19, S20, S21, S23

Table 9. Rankings of mitigation strategies in the Louisiana case study (11 root causes present) compared with the general framework prioritization (all 18 root causes present)

Setting	Priority of the mitigation strategies
Louisiana case study	S6, S10, S11, S9, S21, S3, S4, S23, S24, S12, S26, S13, S15, S19, S20, S18, S7, S25, S1, S14, S5, S22, S8, S16, S17, S2
General framework	S6, S23, S11, S10, S12, S9, S24, S15, S3, S21, S20, S13, S19, S26, S4, S18, S7, S25, S14, S1, S5, S22, S16, S8, S17, S2

Step 3: Prioritization of Mitigation Strategies

Following the identification of the relevant mitigation strategies, they were prioritized using the integrated prioritization scoring system presented in this study. In application, the scoring system necessitates accounting for the total number of present root causes of unsustainable CDW management when calculating the effectiveness subscores. This because the effectiveness subscore of each strategy is based on the proportion of root causes it addresses.

Taking S1 as an example, a total of 11 root causes were identified in this case study, and S1 impacts three of them. This results in S1 having an effectiveness subscore of 4 because it addresses 3/11 (i.e., 27.3%) of the root causes present in this case study. Meanwhile, when generally considering all of the identified 18 root causes of unsustainable management of CDW, S1 impacts 3/18 (i.e., 16.6%) of them, for an effectiveness subscore of 2. This means that S1 is more effective in the context of this case study compared with the general context. The updated prioritization order of the mitigation strategies in the Louisiana case study can be compared with the general framework prioritization order in Table 9.

Discussion

One of the benefits of a retrospective analysis with the framework proposed in this study is the ability to compare recommended strategy implementation with actual implementation to identify gaps in practice that, if filled, could significantly improve the sustainability of CDW management in a region. In this case study, 11 root causes of unsustainable CDW management were identified as persistent issues for the state of Louisiana during both peacetime and disaster. These root causes were then correlated with their suggested mitigation strategies, and those strategies were prioritized with respect to the root causes present. This discussion aimed to highlight the highest ranked strategies and explore gaps, if any, that exist in their implementation in Louisiana over the last decades.

Applying the prioritization framework revealed that S6 is the highest-ranking strategy for Louisiana's root causes of unsustainable CDW management, just as it is the highest ranking for the general review. This was followed by S10 and S11 tied for second place and S9 and S21 tied for third. When compared with the

general review prioritization, the differences indicate some key takeaways:

- S6 is still the highest priority strategy. Policy based on the 5Rs hierarchy that aligns with CDW infrastructure development is still the most impactful.
- S10 and S11 remained in thesecond place. PPPs (i.e., S10) and local policy developed in concert with economic instruments to address certain material streams (i.e., S11) still remain top strategic approaches.
- S23 fell to a tied fourth place ranking alongside S3 and S24, which remained static, and S4 which increased in priority. S23 advocates coordinated CDW management plans at national, regional, and local levels, and this may be less of a priority for Louisiana due to increased policy cohesion post-Katrina. The increased priority of S4, using prefabrication and modular construction, may be due to the low influence of the causal factor of insufficient coordination and planning in which S4 has no impact.
- S9 remained at third place priority, whereas S21 rose to third place from a fifth place position in the general review. Green public procurement (i.e., S9) remained just as important, but the use of BIM-based CDW management practices in coordination with other stakeholders (i.e., S21) gained priority based on the needs of Louisiana.

When these top priority strategies are taken into consideration alongside the identified root causes, it is notable that S6, S9, S10, S11, and S21 collectively address all 11 root causes. However, some root causes are more comprehensively addressed than others. For example, all root causes related to challenging material conditions are addressed by all the strategies except for S10. By contrast, other root causes are variably addressed by the strategies. The dearth of relevant CDW data, for example, is addressed only by one mitigation strategy (S21).

Further investigation of these high priority strategies in the context of Louisiana's built environment revealed that little to no information is publicly available that indicates the state is actively pursuing any of them. The LAC33: VII and the I-WASTE DST identification of one CDW recycler in the state falls short of fulfilling S6. With regards to S10, there is legislation through the state Department of Transportation supporting PPPs, but otherwise no

significant evidence of this being broadly done in the practice of CDW management (Louisiana State Legislature 2022). For S11, there is a lack of conclusive policy documents highlighting specific CDW management by waste stream, and it has already been established that there are insufficient economic mechanisms to regulate CDW management in the state. Similarly, for S9, there is not sufficient evidence of green public procurement in the state nor widespread BIM-based CDW management in coordination with stakeholders, as suggested by S21.

If the state of Louisiana were to adopt any one of the aforementioned priority strategies, let alone all of them, it is expected that there would be measurable drops in CDW landfilling and increases in the reduction, reuse, repair, recycling, and recovery of structures, ultimately benefiting the built, natural, and social systems of the state.

Conclusions

When investigating the life cycle of the built environment from a cradle-to-grave perspective, current CDW disposal practices were found to only result in the cradle (i.e., natural resources) becoming depleted and the grave (i.e., landfills) becoming full. Ensuring the sustainability of our built environment, however, will not be possible with the status quo; it rather requires reframing how the built environment is managed, particularly with respect to what is normally considered as the end of life for materials (i.e., landfilling or incineration of CDW).

Through a systematic literature review, root cause analysis, and other methodologies, the causal factors and root causes of unsustainable CDW management in the built environment were identified in this study. This was accompanied by the identification of strategies to mitigate the unsustainable impacts of those root causes. When combined with a prioritization scoring system, this created the paper's proposed framework for identifying the most effective mitigation strategies for the unsustainable management of CDW. To demonstrate its implementation, this framework was then applied to the state of Louisiana due to its high levels of CDW generation from construction, reconstruction, and demolition due to disaster recovery and peacetime urban expansion. It was found that 11 root causes were present, and a selection of prioritized strategies were suggested that are not currently widely implemented in the state.

Although the overall identification of root causes and mitigation strategies within this study was intended to be generalized enough for a global audience, it is important to recognize that national, regional, and local variations in the built environment are significant enough to require root causes, strategies, and prioritization systems sensitive to those needs. There may not be a one-size-fits-all solution, and the concepts in this paper should be considered as a loose guide by which communities can develop their own causes, strategies, and priorities. It is also important that communities acknowledge the importance of integrated and holistic sustainable CDW management methods. Although it is tempting to allocate resources to certain critical life cycle stages, sustainably managed structures can still end up in landfills, and completely mismanaged structures can still be recycled.

Delving into causal factors and root causes of unsustainable CDW management over the life cycle of the built environment provides the necessary perspective to develop effective mitigation strategies that can be implemented with priority. This same approach can be applied to other waste streams (i.e., not just CDW) for a more holistic understanding of sustainability in the built environment. There is also a need to expand the framework to

include natural and social systems (e.g., human factors) to develop a more integrated and comprehensive understanding of sustainable material management. Ultimately, identified and prioritized targeted mitigation strategies may move the built environment away from linear fates like landfilling and make truly circular communities a reality.

Data Availability Statement

No data, models, or code were generated or used during this study.

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References

- Abdullah, A., C. J. Anumba, U. Kingdom, and E. Durmisevic. 2003. "Decision tools for demolition techniques selection." In *Proc., 11th Rinker Int. Conf. Deconstruction and Materials Reuse*, 55–72. Rotterdam, Netherlands: CIB Publications.
- Aboutalebi Esfahani, M. 2020. "Evaluating the feasibility, usability, and strength of recycled construction and demolition waste in base and sub-base courses." *Road Mater. Pavement Des.* 21 (1): 156–178. <https://doi.org/10.1080/14680629.2018.1483259>.
- Agamuthu, P. 2008. "Challenges in sustainable management of construction and demolition waste." *Waste Manage. Res.* 26 (6): 491–492. <https://doi.org/10.1177/0734242X08100096>.
- Ajayi, S. O., and L. O. Oyedele. 2017. "Policy imperatives for diverting construction waste from landfill: Experts' recommendations for UK policy expansion." *J. Cleaner Prod.* 147 (Feb): 57–65. <https://doi.org/10.1016/j.jclepro.2017.01.075>.
- Akanbi, L. A., L. O. Oyedele, O. O. Akinade, A. O. Ajayi, M. Davila Delgado, M. Bilal, and S. A. Bello. 2018. "Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator." *Resour. Conserv. Recycl.* 129 (Feb): 175–186. <https://doi.org/10.1016/j.resconrec.2017.10.026>.
- Akhtar, A., and A. K. Sarmah. 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>.
- Akinade, O. O., L. O. Oyedele, S. O. Ajayi, M. Bilal, H. A. Alaka, H. A. Owolabi, and O. O. Arawomo. 2018. "Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment." *J. Cleaner Prod.* 180 (Apr): 375–385. <https://doi.org/10.1016/j.jclepro.2018.01.022>.
- Amaral, R. E. C., J. Brito, M. Buckman, E. Drake, E. Ilatova, P. Rice, C. Sabbagh, S. Voronkin, and Y. S. Abraham. 2020. "Waste management and operational energy for sustainable buildings: A review." *Sustainability* 12 (13): 5337. <https://doi.org/10.3390/su12135337>.
- Anuranjita, A., G. Berghorn, D. Bates, and M. M. Syal. 2017. *Life cycle assessment framework for demolition and deconstruction of buildings*. East Lansing, MI: Michigan State Univ.
- Aydin, N. 2020. "Designing reverse logistics network of end-of-life-buildings as preparedness to disasters under uncertainty." *J. Cleaner Prod.* 256 (May): 120341. <https://doi.org/10.1016/j.jclepro.2020.120341>.
- Bakshan, A., I. Srour, G. Chehab, M. Elfadel, and J. Karaziwan. 2017. "Behavioral determinants towards enhancing construction waste management: A Bayesian network analysis." *Resour. Conserv. Recycl.* 117 (Feb): 274–284. <https://doi.org/10.1016/j.resconrec.2016.10.006>.

- Balletto, G., G. Borruso, G. Mei, and A. Milesi. 2021. "Strategic circular economy in construction: Case study in Sardinia, Italy." *J. Urban Plann. Dev.* 147 (4): 05021034. [https://doi.org/10.1061/\(ASCE\)UP.1943-5444.0000715](https://doi.org/10.1061/(ASCE)UP.1943-5444.0000715).
- Begum, R. A., C. Siwar, J. J. Pereira, and A. H. Jaafar. 2009. "Attitude and behavioral factors in waste management in the construction industry of Malaysia." *Resour. Conserv. Recycl.* 53 (6): 321–328. <https://doi.org/10.1016/j.resconrec.2009.01.005>.
- Blaisi, N. I. 2019. "Construction and demolition waste management in Saudi Arabia: Current practice and roadmap for sustainable management." *J. Cleaner Prod.* 221 (Jun): 167–175. <https://doi.org/10.1016/j.jclepro.2019.02.264>.
- Bovea, M. D., and J. C. Powell. 2016. "Developments in life cycle assessment applied to evaluate the environmental performance of construction and demolition wastes." *Waste Manage.* 50 (Apr): 151–172. <https://doi.org/10.1016/j.wasman.2016.01.036>.
- Brandão, R., S. Ang, and A. E. Braga Jr. 2020. "Partnership oriented reverse supply chain toward construction and demolition waste recycling." In *Partnerships for the goals*, edited by W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, and T. Wall. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-71067-9_130-1.
- Brandon, D. L., V. F. Medina, and A. B. Morrow. 2011. "A case history study of the recycling efforts from the United States army corps of engineers hurricane katrina debris removal mission in Mississippi." *Adv. Civ. Eng.* 2011 (3). <https://doi.org/10.1155/2011/526256>.
- Broto, V. C., A. Allen, and E. Rapoport. 2012. "Interdisciplinary perspectives on urban metabolism." *J. Ind. Ecol.* 16 (6): 851–861. <https://doi.org/10.1111/j.1530-9290.2012.00556.x>.
- Brown, C., and M. Milke. 2016. "Recycling disaster waste: Feasibility, method and effectiveness." *Resour. Conserv. Recycl.* 106 (Jan): 21–32. <https://doi.org/10.1016/j.resconrec.2015.10.021>.
- BSI (British Standards Institution). 2011. *Sustainability of construction works—Assessment of environmental performance of buildings*. BS EN 15978:2011. London: BSI.
- Chau, C. K., J. M. Xu, T. M. Leung, and W. Y. Ng. 2017. "Evaluation of the impacts of end-of-life management strategies for deconstruction of a high-rise concrete framed office building." *Appl. Energy* 185 (Jan): 1595–1603. <https://doi.org/10.1016/j.apenergy.2016.01.019>.
- Cheng, W., A. Appolloni, A. D'Amato, and Q. Zhu. 2018. "Green Public Procurement, missing concepts and future trends—A critical review." *J. Cleaner Prod.* 176 (Mar): 770–784. <https://doi.org/10.1016/j.jclepro.2017.12.027>.
- Çimen, Ö. 2021. "Construction and built environment in circular economy: A comprehensive literature review." *J. Cleaner Prod.* 305 (Jul): 127180. <https://doi.org/10.1016/j.jclepro.2021.127180>.
- City of Baton Rouge. 2022. *Restoration tax abatement program*. Baton Rouge, LA: City of Baton Rouge.
- Cook, D. J., C. D. Mulrow, and R. B. Haynes. 1997. "Systematic reviews: Synthesis of best evidence for clinical decisions." *Ann. Internal Med.* 126 (5): 376–380. <https://doi.org/10.7326/0003-4819-126-5-199703010-00006>.
- Correia, J. M. F., G. C. de Oliveira Neto, R. R. Leite, and D. da Silva. 2021. "Plan to overcome barriers to reverse logistics in construction and demolition waste: Survey of the construction industry." *J. Constr. Eng. Manage.*, 147 (2): 04020172. [https://doi.org/10.1061/\(asce\)co.1943-7862.0001966](https://doi.org/10.1061/(asce)co.1943-7862.0001966).
- Cruz Rios, F., D. Grau, and M. Bilec. 2021. "Barriers and enablers to circular building design in the US: An empirical study." *J. Constr. Eng. Manage.* 147 (1): 04021117. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0002109](https://doi.org/10.1061/(ASCE)CO.1943-7862.0002109).
- Dahlbo, H., J. Bachér, K. Lähinen, T. Jouttijärvi, P. Suoheimo, T. Mattila, S. Sironen, T. Myllymaa, and K. Saramäki. 2015. "Construction and demolition waste management—A holistic evaluation of environmental performance." *J. Cleaner Prod.* 107 (Jan): 333–341. <https://doi.org/10.1016/j.jclepro.2015.02.073>.
- Dijst, M., et al. 2018. "Exploring urban metabolism—Towards an interdisciplinary perspective." *Resour. Conserv. Recycl.* 132 (May): 190–203. <https://doi.org/10.1016/j.resconrec.2017.09.014>.
- Di Maria, A., J. Eyckmans, and K. Van Acker. 2018. "Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making." *Waste Manage.* 75 (May): 3–21. <https://doi.org/10.1016/j.wasman.2018.01.028>.
- Ding, Z., W. Gong, S. Li, and Z. Wu. 2018. "System dynamics versus agent-based modeling: A review of complexity simulation in construction waste management." *Sustainability* 10 (7): 2484. <https://doi.org/10.3390/su10072484>.
- Ding, Z., Y. Wang, and P. X. W. Zou. 2016. "An agent based environmental impact assessment of building demolition waste management: Conventional versus green management." *J. Cleaner Prod.* 133 (Aug): 1136–1153. <https://doi.org/10.1016/j.jclepro.2016.06.054>.
- Duran, X., H. Lenihan, and B. O'Regan. 2006. "A model for assessing the economic viability of construction and demolition waste recycling—The case of Ireland." *Resour. Conserv. Recycl.* 46 (3): 302–320. <https://doi.org/10.1016/j.resconrec.2005.08.003>.
- Ekanayake, L. L., and G. Ofori. 2004. "Building waste assessment score: Design-based tool." *Build. Environ.* 39 (7): 851–861. <https://doi.org/10.1016/j.buildenv.2004.01.007>.
- Esa, M. R., A. Halog, and L. Rigamonti. 2017. "Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy." *J. Mater. Cycles Waste Manage.* 19 (3): 1144–1154. <https://doi.org/10.1007/s10163-016-0516-x>.
- Fetter, G., and T. Rakes. 2012. "Incorporating recycling into post-disaster debris disposal." *Socioecon. Plann. Sci.* 46 (1): 14–22. <https://doi.org/10.1016/j.seps.2011.10.001>.
- Galán, B., J. R. Viguri, E. Cifrian, E. Dosal, and A. Andres. 2019. "Influence of input streams on the construction and demolition waste (CDW) recycling performance of basic and advanced treatment plants." *J. Cleaner Prod.* 236 (Nov): 117523. <https://doi.org/10.1016/j.jclepro.2019.06.354>.
- Gálvez-Martos, J. L., D. Styles, H. Schoenberger, and B. Zeschmar-Lahl. 2018. "Construction and demolition waste best management practice in Europe." *Resour. Conserv. Recycl.* 136 (Sep): 166–178. <https://doi.org/10.1016/j.resconrec.2018.04.016>.
- Gharfalkar, M., R. Court, C. Campbell, Z. Ali, and G. Hillier. 2015. "Analysis of waste hierarchy in the European waste directive 2008/98/EC." *Waste Manage.* 39 (May): 305–313. <https://doi.org/10.1016/j.wasman.2015.02.007>.
- Ghisellini, P., M. Ripa, and S. Ulgiati. 2018. "Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review." *J. Cleaner Prod.* 178 (Mar): 618–643. <https://doi.org/10.1016/j.jclepro.2017.11.207>.
- Ginga, C. P., J. M. C. Ongpeng, and M. K. M. Daly. 2020. "Circular economy on construction and demolition waste: A literature review on material recovery and production." *Materials (Basel)* 13 (13): 2970. <https://doi.org/10.3390/ma13132970>.
- Giorgi, S., M. Lavagna, and A. Campioli. 2018. "Guidelines for effective and sustainable recycling of construction and demolition waste." In *Designing sustainable technologies, products and policies*, 211–221. New York: Springer International.
- He, L., and H. Yuan. 2020. "Investigation of construction waste recycling decisions by considering consumers' quality perceptions." *J. Cleaner Prod.* 259 (Jun): 120928. <https://doi.org/10.1016/j.jclepro.2020.120928>.
- Hoang, N. H., T. Ishigaki, R. Kubota, T. K. Tong, T. T. Nguyen, H. G. Nguyen, M. Yamada, and K. Kawamoto. 2020a. "Waste generation, composition, and handling in building-related construction and demolition in Hanoi, Vietnam." *Waste Manage.* 117 (Nov): 32–41. <https://doi.org/10.1016/j.wasman.2020.08.006>.
- Hoang, N. H., T. Ishigaki, R. Kubota, M. Yamada, and K. Kawamoto. 2020b. "A review of construction and demolition waste management in Southeast Asia." *J. Mater. Cycles Waste Manage.* 22 (2): 315–325. <https://doi.org/10.1007/s10163-019-00914-5>.
- Hollberg, A., G. Genova, and G. Habert. 2020. "Evaluation of BIM-based LCA results for building design." *Autom. Constr.* 109 (Jan): 102972. <https://doi.org/10.1016/j.autcon.2019.102972>.
- Huang, B., X. Wang, H. Kua, Y. Geng, R. Bleischwitz, and J. Ren. 2018. "Construction and demolition waste management in China through the 3R principle." *Resour. Conserv. Recycl.* 129 (Jul): 36–44. <https://doi.org/10.1016/j.resconrec.2017.09.029>.
- Huovila, P., U. Iyer-Raniga, and S. Maity. 2019. "Circular economy in the built environment: Supporting emerging concepts." *IOP Conf. Ser.*

- Earth Environ. Sci. 012003. <https://doi.org/10.1088/1755-1315/297/1/012003>.
- Iacoboaia, C., M. Aldea, and F. Petrescu. 2019. "Construction and demolition waste challenge for the European union?" *Theor. Empirical Res. Urban Manage.* 14 (1): 30–52.
- Ilie, G., and C. N. Ciocoiu. 2010. "Application of fishbone diagram to determine the risk of an event with multiple causes." *Manage. Res. Pract.* 2 (1): 1–20.
- ISO. 2010. *Sustainability in building construction—Framework for methods of assessment of the environmental performance of construction works—Part 1: Buildings*. ISO 21931-1:2010. Geneva: ISO.
- Jalloul, H., J. Choi, S. Derrible, and N. Yesiller. 2022a. "Towards sustainable management of disaster debris: Three-phase post-disaster data collection planning." In *Proc., Construction Research Congress 2022*. Reston, VA: ASCE.
- Jalloul, H., J. Choi, N. Yesiller, D. Manheim, and S. Derrible. 2022b. "A systematic approach to identify, characterize, and prioritize the data needs for quantitative sustainable disaster debris management." *Resour. Conserv. Recycl.* 180 (May): 106174. <https://doi.org/10.1016/j.resconrec.2022.106174>.
- Jalloul, H., A. Pinto, and J. Choi. 2022c. "A pre-demolition planning framework to balance sustainability and productivity." In *Proc., Construction Research Congress 2022*, 892–901. Reston, VA: ASCE.
- Jiménez-Rivero, A., and J. García-Navarro. 2017. "Exploring factors influencing post-consumer gypsum recycling and landfilling in the European Union." *Resour. Conserv. Recycl.* 116 (Jan): 116–123. <https://doi.org/10.1016/j.resconrec.2016.09.014>.
- Jin, R., B. Li, T. Zhou, D. Wanatowski, and P. Piroozfar. 2017. "An empirical study of perceptions towards construction and demolition waste recycling and reuse in China." *Resour. Conserv. Recycl.* 126 (Nov): 86–98. <https://doi.org/10.1016/j.resconrec.2017.07.034>.
- Joensuu, T., H. Edelman, and A. Saari. 2020. "Circular economy practices in the built environment." *J. Cleaner Prod.* 276 (Dec): 124215. <https://doi.org/10.1016/j.jclepro.2020.124215>.
- Kamrath, P. 2013. "Demolition techniques and production of construction and demolition waste (CDW) for recycling." In *Handb. Recycl. Concr. demolition waste*, 186–209. Sawston, UK: Woodhead Publishing.
- Kar, S., and K. N. Jha. 2021. "Exploring the critical barriers to and enablers of sustainable material management practices in the construction industry." *J. Constr. Eng. Manage.* 147 (9): 04021102. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0002125](https://doi.org/10.1061/(ASCE)CO.1943-7862.0002125).
- Karunasena, G., D. Amaratunga, and R. Haigh. 2012. "Postdisaster construction & demolition debris management: A Sri Lanka case study." *J. Civ. Eng. Manage.* 18 (4): 457–468. <https://doi.org/10.3846/13923730.2012.699913>.
- Kim, J., A. Deshmukh, and M. Hastak. 2018. "A framework for assessing the resilience of a disaster debris management system." *Int. J. Disaster Risk Reduct.* 28 (Jan): 674–687. <https://doi.org/10.1016/j.ijdr.2018.01.028>.
- Kitchenham, B., and P. Brereton. 2013. "A systematic review of systematic review process research in software engineering." *Inf. Software Technol.* 55 (12): 2049–2075. <https://doi.org/10.1016/j.infsof.2013.07.010>.
- Kleemann, F., H. Lehner, A. Szczypińska, J. Lederer, and J. Fellner. 2017. "Using change detection data to assess amount and composition of demolition waste from buildings in Vienna." *Resour. Conserv. Recycl.* 123 (Aug): 37–46. <https://doi.org/10.1016/j.resconrec.2016.06.010>.
- Koroneos, C. J., C. Achillas, N. Moussiopoulos, and E. A. Nanaki. 2013. "Life cycle thinking in the use of natural resources." *Open Environ. Sci.* 7 (1): 1–6. <https://doi.org/10.2174/1876325101307010001>.
- Kozlovská, M., and M. Spišáková. 2013. "Construction waste generation across construction project life-cycle." *Organ. Technol. Manage. Constr. Int. J.* 5 (1): 687–695. <https://doi.org/10.5592/otmcj.2013.1.5>.
- Lahtela, V., M. Hyvärinen, and T. Kärki. 2019. "Composition of plastic fractions in waste streams: Toward more efficient recycling and utilization." *Polymers (Basel)* 11 (1): 69. <https://doi.org/10.3390/polym11010069>.
- LDEQ (Louisiana Department of Environmental Quality). 2020a. "Disaster debris management." Accessed March 29, 2022. <https://deq.louisiana.gov/page/disaster-debris-management>.
- LDEQ (Louisiana Department of Environmental Quality). 2020b. *Solid waste landfill report*. Baton Rouge, LA: LDEQ.
- LDEQ (Louisiana Department of Environmental Quality). 2020c. *State of Louisiana department of environmental quality comprehensive plan for disaster clean-up and debris management*. Baton Rouge, LA: LDEQ.
- Li, J., J. Zuo, W. Jiang, X. Zhong, J. Li, and Y. Pan. 2020. "Policy instrument choice for construction and demolition waste management: The case study of Shenzhen, China." *Eng. Constr. Archit. Manage.* 27 (6): 1283–1297. <https://doi.org/10.1108/ECAM-11-2019-0632>.
- Li, Y., H. Sun, D. Li, J. Song, and R. Ding. 2022. "Effects of digital technology adoption on sustainability performance in construction projects: The mediating role of stakeholder collaboration." *J. Manage. Eng.* 38 (3): 04022016. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0001040](https://doi.org/10.1061/(ASCE)ME.1943-5479.0001040).
- Liu, H., H. Long, and X. Li. 2020. "Identification of critical factors in construction and demolition waste recycling by the grey-DEMATEL approach: A Chinese perspective." *Environ. Sci. Pollut. Res.* 27 (8): 8507–8525. <https://doi.org/10.1007/s11356-019-07498-5>.
- Lockrey, S., H. Nguyen, E. Crossin, and K. Verghese. 2016. "Recycling the construction and demolition waste in Vietnam: Opportunities and challenges in practice." *J. Cleaner Prod.* 133 (Jun): 757–766. <https://doi.org/10.1016/j.jclepro.2016.05.175>.
- Long, H., H. Liu, X. Li, and L. Chen. 2020. "An evolutionary game theory study for construction and demolition waste recycling considering green development performance under the Chinese government's reward–penalty mechanism." *Int. J. Environ. Res. Public Health* 17 (17): 1–21. <https://doi.org/10.3390/ijerph17176303>.
- Louisiana Division of Administration. 2021. *Louisiana administrative code title 33 environmental quality*. Baton Rouge, LA: Louisiana Division of Administration.
- Louisiana Engineering Society. 2022. "Search results for." Accessed March 10, 2022. <https://www.les-state.org/>.
- Louisiana State Legislature. 2022. "Part VII-A. Louisiana 'no bidding of architectural and engineering professional services' policy." Accessed March 28, 2022. <https://www.legis.la.gov/Legis/Law.aspx?d=410629>.
- Luther, L. 2006. *Disaster debris removal after Hurricane Katrina: Status and associated issues*. Washington, DC: Congressional Research Service, the Library of Congress.
- Luther, L. 2010. *Managing disaster debris: Overview of regulatory requirements, agency roles, and selected challenges*. Washington, DC: Congressional Research Service, the Library of Congress.
- Mália, M., J. De Brito, M. D. Pinheiro, and M. Bravo. 2013. "Construction and demolition waste indicators." *Waste Manage. Res.* 31 (3): 241–255. <https://doi.org/10.1177/0734242X12471707>.
- Marzouk, M., and S. Azab. 2014. "Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics." *Resour. Conserv. Recycl.* 82 (Jan): 41–49. <https://doi.org/10.1016/j.resconrec.2013.10.015>.
- Menegaki, M., and D. Damigos. 2018. "A review on current situation and challenges of construction and demolition waste management." *Curr. Opin. Green Sustainable Chem.* 13 (Oct): 8–15. <https://doi.org/10.1016/j.cogsc.2018.02.010>.
- Messner, J. 2019. "The lifecycle of a building project." Chap. 2 in *Introduction to the building industry*. State College, PA: Pennsylvania State Univ.
- Mignacca, B., and G. Locatelli. 2021. "Modular circular economy in energy infrastructure projects: Enabling factors and barriers." *J. Manag. Eng.* 9 (5): 1–13. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000949](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000949).
- Mihai, F. C. 2019. "Construction and demolition waste in Romania: The route from illegal dumping to building materials." *Sustainability* 11 (11): 3179. <https://doi.org/10.3390/su11113179>.
- Mohammed, M., N. Shafiq, N. A. W. Abdallah, M. Ayoub, and A. Haruna. 2020. "A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach." *IOP Conf. Ser. Earth Environ. Sci.* 476 (1): 012010. <https://doi.org/10.1088/1755-1315/476/1/012010>.
- Morseletto, P. 2020. "Targets for a circular economy." *Resour. Conserv. Recycl.* 153 (Feb): 104553. <https://doi.org/10.1016/j.resconrec.2019.104553>.

- Ozorhon, B., and U. Karahan. 2017. "Critical success factors of building information modeling implementation." *J. Manage. Eng.* 33 (3): 04016054. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000505](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000505).
- Pan, W., K. Li, and Y. Teng. 2018. "Rethinking system boundaries of the life cycle carbon emissions of buildings." *Renewable Sustainable Energy Rev.* 90 (Jul): 379–390. <https://doi.org/10.1016/j.rser.2018.03.057>.
- Pan, X., Q. Xie, and Y. Feng. 2020. "Designing recycling networks for construction and demolition waste based on reserve logistics research field." *J. Cleaner Prod.* 260 (Jul): 120841. <https://doi.org/10.1016/j.jclepro.2020.120841>.
- Park, J., and R. Tucker. 2017. "Overcoming barriers to the reuse of construction waste material in Australia: A review of the literature." *Int. J. Constr. Manage.* 17 (3): 228–237. <https://doi.org/10.1080/15623599.2016.1192248>.
- Petit-Boix, A., P. Llorach-Massana, D. Sanjuan-Delmás, J. Sierra-Pérez, E. Vinyes, X. Gabarrell, J. Rieradevall, and E. Sanyé-Mengual. 2017. "Application of life cycle thinking towards sustainable cities: A review." *J. Cleaner Prod.* 166 (Nov): 939–951. <https://doi.org/10.1016/j.jclepro.2017.08.030>.
- Poon, C. S. 2007. "Reducing construction waste." *Waste Manage.* 27 (12): 1715–1716. <https://doi.org/10.1016/j.wasman.2007.08.013>.
- Ramage, M. H., et al. 2017. "The wood from the trees: The use of timber in construction." *Renewable Sustainable Energy Rev.* 68 (Feb): 333–359. <https://doi.org/10.1016/j.rser.2016.09.107>.
- Reike, D., W. J. V. Vermeulen, and S. Witjes. 2018. "The circular economy: New or refurbished as CE 3.0?—Exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options." *Resour. Conserv. Recycl.* 135 (Aug): 246–264. <https://doi.org/10.1016/j.resconrec.2017.08.027>.
- Ruiz, L. A. L., X. R. Ramon, and S. G. Domingo. 2020. "The circular economy in the construction and demolition waste sector—A review and an integrative model approach." *J. Cleaner Prod.* 248 (Mar): 119238. <https://doi.org/10.1016/j.jclepro.2019.119238>.
- Sáez, P. V., and M. Osmani. 2019. "A diagnosis of construction and demolition waste generation and recovery practice in the European Union." *J. Cleaner Prod.* 241 (Dec): 118400. <https://doi.org/10.1016/j.jclepro.2019.118400>.
- Shan, M., B. G. Hwang, and L. Zhu. 2017. "A global review of sustainable construction project financing: Policies, practices, and research efforts." *Sustainability* 9 (12): 2347. <https://doi.org/10.3390/su9122347>.
- Silva, R. V., J. de Brito, and R. K. Dhir. 2017. "Availability and processing of recycled aggregates within the construction and demolition supply chain: A review." *J. Cleaner Prod.* 143 (Feb): 598–614. <https://doi.org/10.1016/j.jclepro.2016.12.070>.
- Simcoe, T., and M. W. Toffel. 2014. "Government green procurement spillovers: Evidence from municipal building policies in California." *J. Environ. Econ. Manage.* 68 (3): 411–434. <https://doi.org/10.1016/j.jeem.2014.09.001>.
- Singh, A., G. Berghom, S. Joshi, and M. Syal. 2011. "Review of life-cycle assessment applications in building construction." *J. Archit. Eng.* 17 (1): 15–23. [https://doi.org/10.1061/\(ASCE\)AE.1943-5568.0000026](https://doi.org/10.1061/(ASCE)AE.1943-5568.0000026).
- Sormunen, P., and T. Kärki. 2019. "Recycled construction and demolition waste as a possible source of materials for composite manufacturing." *J. Build. Eng.* 24 (Jul): 100742. <https://doi.org/10.1016/j.job.2019.100742>.
- Tam, V. W., D. Kotrayothar, and Y.-C. Loo. 2009. "On the prevailing construction waste recycling practices: A South East Queensland study." *Waste Manage. Res.* 17 (2): 167–174. <https://doi.org/10.1177/0734242X08091864>.
- Thibodeau, C., A. Bataille, and M. Sié. 2019. "Building rehabilitation life cycle assessment methodology—State of the art." *Renewable Sustainable Energy Rev.* 103 (Apr): 408–422. <https://doi.org/10.1016/j.rser.2018.12.037>.
- Tserng, H., C. Chou, and Y. Chang. 2021. "The key strategies to implement circular economy in building projects—A case study of Taiwan." *Sustainability* 13 (2): 754. <https://doi.org/10.3390/su13020754>.
- US Census Bureau. 2020. *American community survey data releases*. Suitland-Silver Hill, MD: US Census Bureau.
- US Census Bureau. 2022. *Building permits survey: Historical data*. Suitland-Silver Hill, MD: US Census Bureau.
- USEPA. 2022. "Incident waste decision support tool (I-WASTE DST)." Accessed April 1, 2022. <http://www2.epa.gov/bdrtool/login.asp>.
- Wang, Y., Y. Tang, and W. Yao. 2017. "Research on the whole process management of construction waste." In *ICCREM 2016: BIM application and off-site construction*, 398–405. Reston, VA: ASCE.
- Wendland, T. 2020. "Louisiana's chemical corridor is expanding. So are efforts to stop it." Accessed March 25, 2022. <https://www.npr.org/2020/03/20/814882296/louisianas-chemical-corridor-is-expanding-so-are-efforts-to-stop-it>.
- Whittaker, M. J., et al. 2021. "Novel construction and demolition waste (CDW) treatment and uses to maximize reuse and recycling." *Adv. Build. Energy Res.* 15 (2): 253–269. <https://doi.org/10.1080/17512549.2019.1702586>.
- Won, J., J. C. P. Cheng, and G. Lee. 2016. "Quantification of construction waste prevented by BIM based design validation: Case studies in South Korea." *Waste Manage.* 49 (Mar): 170–180. <https://doi.org/10.1016/j.wasman.2015.12.026>.
- Wood, L. 2022. "United States construction industry report Q1 2022: Large construction activities in Louisiana to support the industry." Accessed March 20, 2022. <https://www.businesswire.com/news/home/20220217005535/en/United-States-Construction-Industry-Report-Q1-2022-Large-Construction-Activities-in-Louisiana-to-Support-the-Industry-ResearchAndMarkets.com>.
- Wu, S. R., X. Li, D. Apul, V. Breeze, Y. Tang, Y. Fan, and J. Chen. 2017. "Agent-based modeling of temporal and spatial dynamics in life cycle sustainability assessment." *J. Ind. Ecol.* 21 (6): 1507–1521. <https://doi.org/10.1111/jiec.12666>.
- Yeheyis, M., K. Hewage, M. S. Alam, C. Eskicioglu, and R. Sadiq. 2013. "An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability." *Clean Technol. Environ. Policy* 15 (1): 81–91. <https://doi.org/10.1007/s10098-012-0481-6>.
- Yuan, H. 2017. "Barriers and countermeasures for managing construction and demolition waste: A case of Shenzhen in China." *J. Cleaner Prod.* 157 (Jul): 84–93. <https://doi.org/10.1016/j.jclepro.2017.04.137>.
- Yuan, H., H. Wu, and J. Zuo. 2018. "Understanding factors influencing project managers' behavioral intentions to reduce waste in construction projects." *J. Manage. Eng.* 34 (6): 1–12. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000642](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000642).
- Zhang, C., M. Hu, F. Di Maio, B. Sprecher, X. Yang, and A. Tukker. 2022. "An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe." *Sci. Total Environ.* 803 (Jan): 149892. <https://doi.org/10.1016/j.scitotenv.2021.149892>.
- Zhang, F., C. Cao, C. Li, Y. Liu, and D. Huisingh. 2019. "A systematic review of recent developments in disaster waste management." *J. Cleaner Prod.* 235 (Oct): 822–840. <https://doi.org/10.1016/j.jclepro.2019.06.229>.