energies

Review

A Comprehensive Review on Construction and Demolition Waste Management Practices and Assessment of This Waste Flow for Future Valorization via Energy Recovery and Industrial Symbiosis

Natalija Cudecka-Purina [1,2,*], Jekaterina Kuzmina [3], Janis Butkevics [4], Arsirii Olena [5], Oleksii Ivanov [5] and Dzintra Atstaja [4,6,*]

1 Department of Management, BA School of Business and Finance, LV-1013 Riga, Latvia
2 EKA University of Applied Science, LV-1009 Riga, Latvia
3 Department of Economics and Finance, BA School of Business and Finance, LV-1013 Riga, Latvia; jekaterina.kuzmina@ba.lv
4 BA School of Business and Finance, LV-1013 Riga, Latvia; janis.butkevics@ba.lv
5 Department of Information System, Odesa Polytechnic National University, 65044 Odesa, Ukraine; arsiriy@op.edu.ua (A.O.); o.v.ivanov@op.edu.ua (O.I.)
6 Faculty of Social Sciences, Rīga Stradiņš University, LV-1007 Riga, Latvia
* Correspondence: natalija.cudecka-purina@ba.lv (N.C.-P.); dzintra.atstaja@ba.lv or dzintra.atstaja@rsu.lv (D.A.)

Abstract: Construction and demolition waste (CDW) is one of the largest contributors to global waste streams, simultaneously posing significant environmental and resource management challenges. The management of CDW, particularly its potential for energy recovery and industrial symbiosis, has garnered increasing attention as part of a circular economy approach. This comprehensive review explores global practices in CDW management, analysing theoretical developments, technological advancements, and emerging resource recovery and reuse trends. Background: CDW accounts for more than a third of all waste generated in the EU. A wide variety of materials, such as concrete, bricks, wood, glass, metals, and plastics, make it a very un-homogenous waste stream with high potential for material recovery through different approaches. Methods: This review draws on an extensive analysis of scientific literature, case studies, and industry reports to assess current practices in the CDW stream and assessment of the feasibility of energy recovery, industrial symbiosis, and object reconstruction. Results: The originality of the current research is based on a Latvian case study on CDW management that provides valuable insights into household-level practices and progress towards relevant UN SDGs. Conclusions: Various CDW streams have an undeniable potential for valorization through various approaches. Currently, the most common approach is recovery and recycling, although CDW has the potential to broaden its application within the circular economy framework. For instance, industrial symbiosis is a solution that can not only boost the valorization of CDW but also significantly increase material circularity.

Keywords: circular economy; construction and demolition waste (CDW); energy recovery; industrial symbiosis; sustainable development

check for updates

Citation: Cudecka-Purina, N.; Kuzmina, J.; Butkevics, J.; Olena, A.; Ivanov, O.; Atstaja, D. A Comprehensive Review on Construction and Demolition Waste Management Practices and Assessment of This Waste Flow for Future Valorization via Energy Recovery and Industrial Symbiosis. *Energies* **2024**, *17*, 5506. https://doi.org/10.3390/en17215506

Received: 27 September 2024
Revised: 23 October 2024
Accepted: 26 October 2024
Published: 4 November 2024

1. Introduction

The proper management and utilization of CDW arising from the construction, demolition, and maintenance of buildings, infrastructure, and roads play a crucial role in sustainable urban development. This process is essential for several reasons. It significantly reduces the use of landfills and their associated environmental impacts, thereby contributing to environmental protection. Conserving natural resources, such as concrete, bricks, wood, glass, metals, and plastics, aids in conserving natural resources. From an economic perspective, effective waste management can lower disposal costs and potentially generate revenue from recycled materials. Furthermore, it demonstrates a commitment to sustainability and environmental responsibility, improving the public image of construction projects and the entities involved.

Construction and demolition waste quantities in the European Union vary from 310 to almost 700 million tons, accounting for a range from 0.63 to 1.42 tons per capita annually [1]. Although technologies for separating and recovering CDW are well established, easily accessible, and generally affordable, recycling rates and material recovery across the EU vary significantly, ranging from less than 10% to over 95% [2], with an 89% recovery rate among the EU-28 [3]. EU country case studies demonstrate that a dedicated plan for CDW utilization not only provides strategic direction for the long-term development of CDW recycling but also facilitates the creation of a comprehensive resource use and treatment system. For example, Denmark has issued a national waste resource management plan every few years since 1992, which helped increase the CDW recycling rate to 86% by 2012. The Netherlands improved its use rate from 83% in 2006 to 85% in 2015, largely due to the implementation of its waste management plan [4]. Countries not having enhanced regulatory frameworks and improved data collection practices in place to effectively monitor CDW management tend to fall behind, with recovery rates below the EU average.

Municipalities have a significant role in CDW management since they are typically responsible for enforcing waste management regulative provisions, delivering the necessary infrastructure for waste collection and processing, and promoting recycling efforts. Efficient CDW management is critical not only for environmental protection but also for public health and sustainable urban development [5]. This includes setting up the necessary infrastructure, such as facilities for waste sorting, recycling, and processing. Municipalities also play a crucial role in education and awareness, providing training and information to contractors, developers, and the public about the importance and methods of proper CDW management in their administrative territories.

Municipalities also play a key role in promoting waste-to-energy (WtE) initiatives, which are increasingly seen as a sustainable approach to managing waste flows [6]. Such an approach applies to the management of CDW where municipalities' involvement encompasses regulatory frameworks, infrastructure development, public engagement, and collaboration with various stakeholders to optimize the utilization of CDW for energy recovery (According to the definition of the European Environment Agency, energy recovery is a form of resource recovery in which the organic fraction of waste is converted to some form of usable energy. Recovery may be achieved through the combustion of processed or raw refuse to produce steam, through the pyrolysis of refuse to produce oil or gas, and through the anaerobic digestion of organic wastes to produce methane gas [7]). The large volume of generated CDW highlights the potential for incorporating it into WtE facilities, as many CDW components, such as wood, plastics, and other combustible materials, can be transformed into energy; therefore, the policies and activities of the municipalities shall, inter alia, focus on the diversion of CDW potentially used for energy recovery from landfills.

On the other hand, for the implementation of effective management of the construction of municipal infrastructure facilities, as well as the reduction and mapping of environmental risks from the disposal of CDW, solutions are known that require the creation of an automated conceptual system for the inventory of construction projects using geographic information systems (GIS) [8,9]. At the same time, GIS contain attribute data about the digital model of the construction site, the status of its inventory, data on the construction stage, the results of the inventory of potentially necessary materials and materials that can be reused at one site or another site, etc.

2. Literature Analysis

2.1. Analysis of Previous Studies

Upon conducting a comprehensive exploration of the Scopus database with respect to the subject of CDW, a notable yield of 5245 scholarly articles published in the English language emerges. The genesis of academic interest in CDW dates back to the year 1966, when it was first mentioned within scholarly circles. Nevertheless, it was not until the 1990s that this research theme truly garnered traction within the academic circles. A significant increase in interest is observable, culminating in the year 2022, during which an impressive corpus of 740 articles on the subject were disseminated (Figure 1).

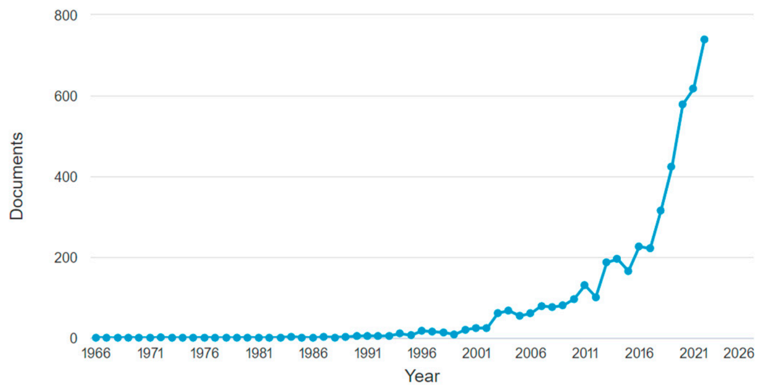

Figure 1. Quantity of articles on CDW published on Scopus 1966–2022 [10].

An analysis of the geographical distribution of contributions to this domain reveals that the People's Republic of China stands as a formidable thought leader, having produced more than 650 scholarly articles (Figure 2). India's scholarly output comes second, with a count nearing 450 articles. Furthermore, both Spain and the United States demonstrate almost parallel contributions, each circulating approximately 420 articles on the topic.

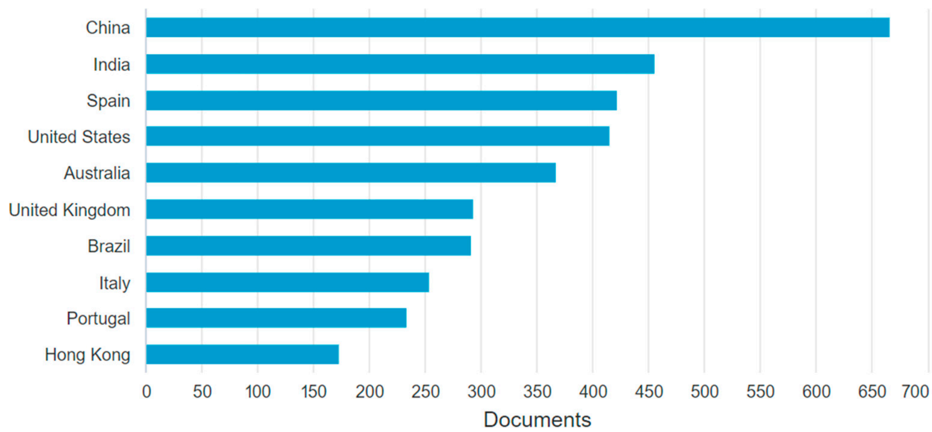

Figure 2. Leading countries in CDW research on Scopus [10].

However, an intriguing contraction in the data emerges when narrowing down the search parameters to focus on household-generated CDW. The results from such a refined query present a single article ("Physical, chemical and biological characteristics of stored greywater from unsewered") [11]. Based on Scopus research, the authors have narrowed the research period for Web of Science, starting from the time when the number of publications increased (Figure 3).

A parallel investigation conducted on the Web of Science (WOS) database corroborates this observation. The overarching search for CDW on WOS reveals a total of 4561 scholarly papers (Figure 4).

Notably, China remains the dominant contributor, whereas countries such as Spain, Australia, India, and the USA exhibit significantly reduced publication counts, with Spain, Australia, India, and the USA having just over half the output of China. A further refinement of the WOS search to include the aspect of household production precipitates a sharp decline in results, showcasing a limited set of only nine papers.

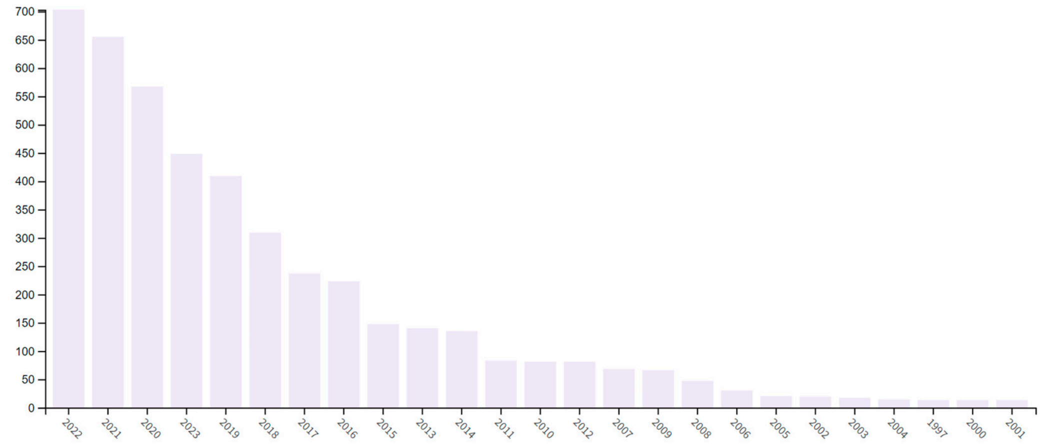

Figure 3. Number of articles on CDW published on WOS 2001–2022 [12].

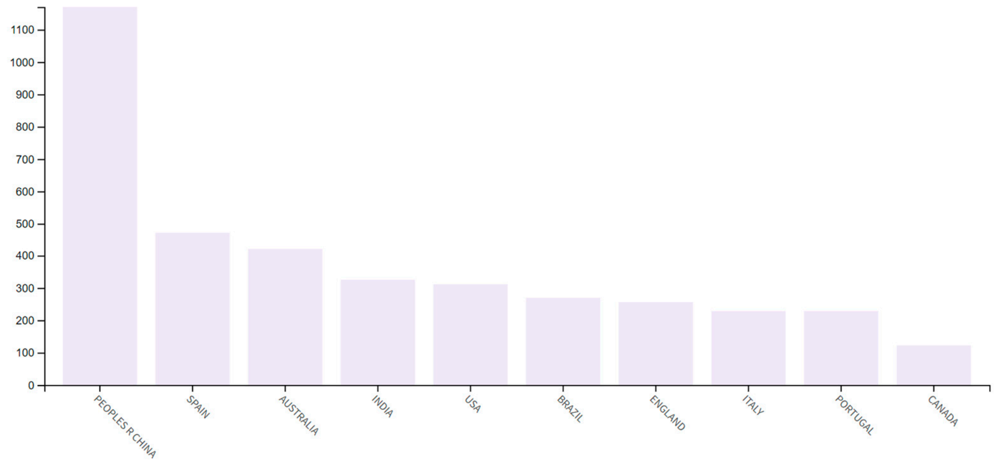

Figure 4. Leading countries in CDW research on WOS [12].

The authors analysed nine papers that contained both "CDW" and "house-generated" using R-Studio. In the R Software framework, examinations were carried out using the BiblioShiny function. This function serves as a gateway to the Bibliometrix online platform, as elaborated by Aria and Cuccurullo [13]. The outcomes from this process provided the foundational data for the analyses delineated in this paper, as detailed in Figure 5.

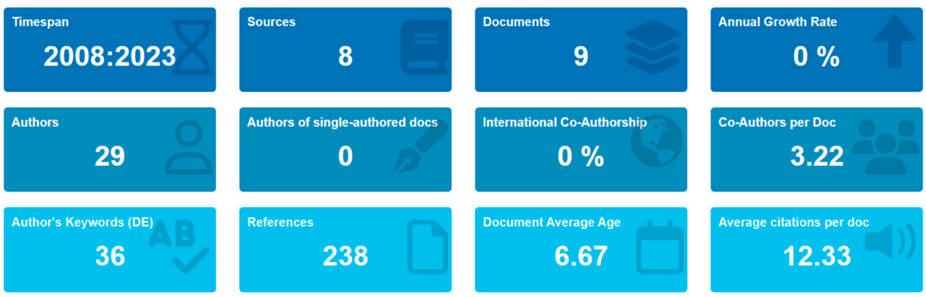

Figure 5. Key information about data and document types (developed by the authors via BiblioShiny).

At first, authors created a Sankey diagram in Bibliometrix to examine how the various authors' keywords interrelate throughout the papers; this diagram is displayed in Figure 6.

Within the Sankey diagram, the dimensions of the boxes correlate with the prevalence of each theme's appearance. The interconnecting flows between these boxes depict the progression patterns of the respective themes. Notably, a more robust connecting line indicates a stronger linkage between the paired themes.

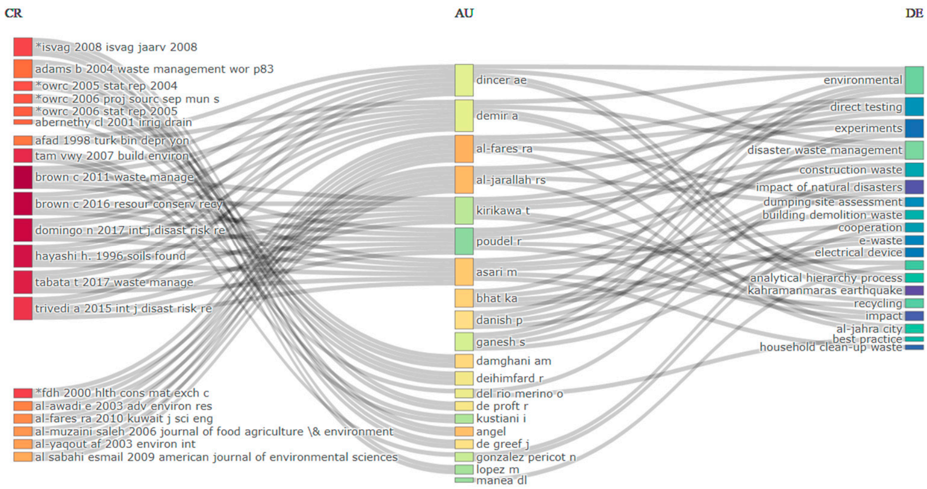

Figure 6. Three-field plot in BiblioShiny: authors (AU), cited references (CR), and keywords (DE) (developed by the authors via BiblioShiny, by *cases where the data period has a limit are noted).

At the beginning of this data analysis, five keywords related to sustainability and resource management were chosen: "Circular economy", "Construction and demolition waste", "Energy recovery", "Industrial symbiosis", and "Sustainable development". These particular keywords were used to search for relevant research papers in the SCOPUS database, a large collection of academic publication. The materials were selected from the period 2017–2024 in Europe. The search results were filtered in order to identify the key relevant studies. The selected papers were analysed to gather information about when and where the research was conducted. The data were exported into a CSV file and then visualized using a software called VOSViewer 1.6.20 to create visual representations of the research trends. By visualizing these data, researchers can gain a more comprehensive understanding of the current state of research and identify potential gaps or areas for future study. Figure 7 demonstrates trend topics occurring in the selected papers. Here, some of the most used keywords are "circular economy", "construction and demolition waste", and "sustainable development". By selecting materials in SCOPUS, 91 documents were chosen. An analysis of these selected materials showed that the majority were published in 2023 in Italy, Spain, and Portugal.

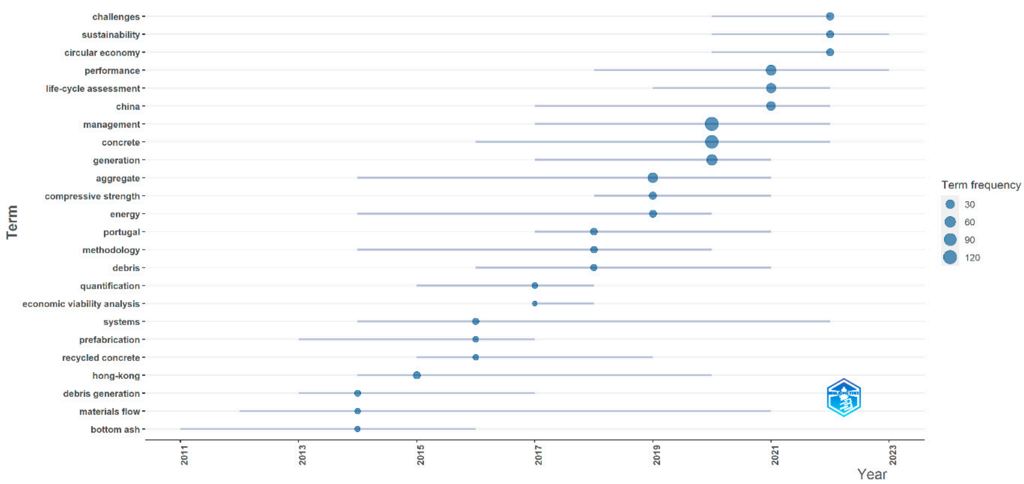

Figure 7. Topic trends in the assessed papers (developed by the authors via Biblioshiny).

Within the VOSviewer tool, settings have been adjusted so that keywords were categorized into different clusters based on their co-occurrence associations (Figure 8). Eventually, the clusters represented on the network maps across different periods were juxtaposed and assessed in connection to one another, which shows the relevance of the research and the possible further directions of the research.

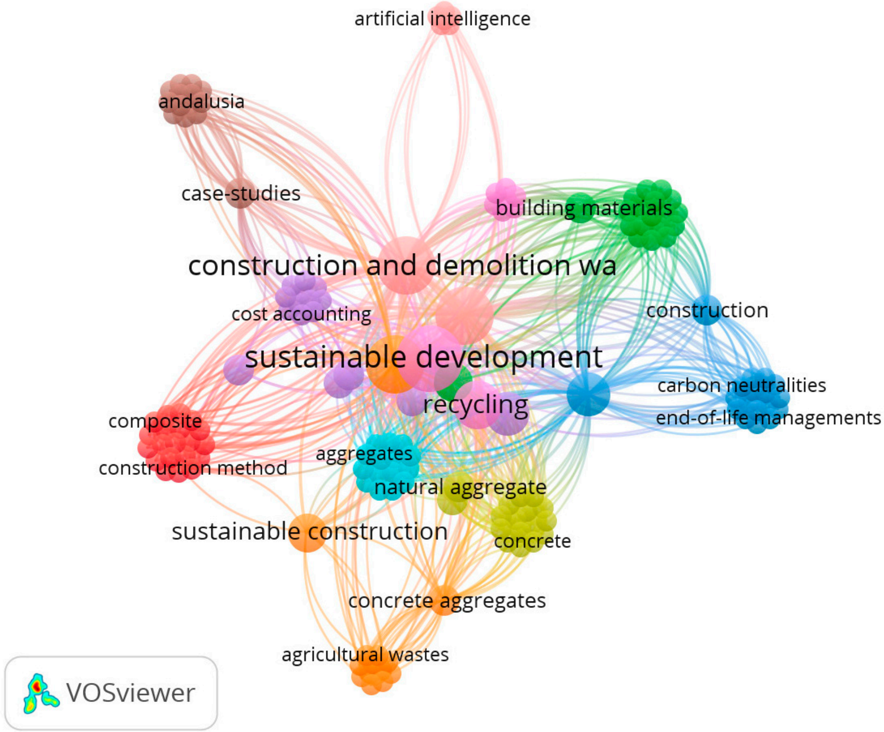

Figure 8. Keyword co-occurrence in the assessed papers (developed by the authors via VosViewer).

Figure 9 showcases a map that elucidates the connections between two articles when they are both referenced within a singular document (specifically, those references discovered pertaining to the authors). This connectivity is determined based on the most recurrently cited authors within the group, which are subsequently delineated into clusters and differentiated using varied colour hues. With the help of data visualizations, researchers can quickly and efficiently perceive large amounts of data and discover meaningful structures, patterns, and trends hidden in them. In this process, it is convenient to select scientific literature for further research. Research has confirmed that the use of successful visualizations significantly eases the user's memory and problem solving, in addition to speeding up visual attention and search processes.

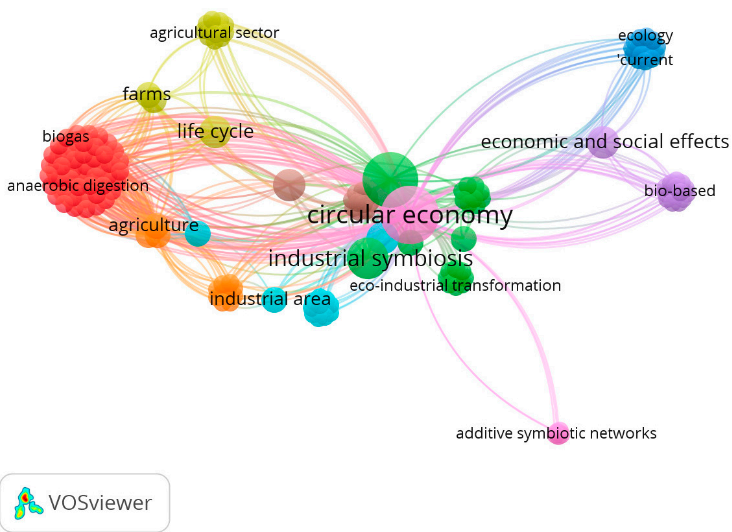

Figure 9. Co-citations by reference map (developed by the authors via VosViewer).

2.2. Circularity Challenges in CDW Management

With growing global interest in the transition to circular economy, as evidenced by increasing attention from researchers, policymakers, governments, and industries [14–16], there is a pressing need to reassess current construction practices. This reassessment should prioritize the integration of new and innovative methods and services that mitigate environmental impacts. Central to this approach is the repurposing of building components and materials, which can help minimize waste generation and reduce costs [17,18]. The construction sector holds particular importance in this transition due to its economic significance—representing an extensive share of global GDP and employment—and its environmental impact, with the potential to significantly lower energy demand and contribute to climate change mitigation [2,4]. Accordingly, the construction and building sectors are pivotal to the advancement of the circular economy, offering opportunities for enhanced resource efficiency, optimized energy use across building lifecycles, improved sustainable material quality, increased recycling rates, and more effective design solutions [19].

The literature on CDW management in European countries underscores the importance of obtaining dependable, clear, and comprehensive data that accurately represent the technical and economic performance of waste collection, sorting, treatment, and disposal processes [20]. Such data are essential for evaluating the efficiency of current waste management practices and for guiding future improvements in recycling and resource recovery efforts across the region. (The European Environment Agency defines recycling as a resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or a similar product. The EU waste strategy distinguishes between reuse meant as material reuse without any structural changes in the materials; recycling meant as a material recycling, only, and with a reference to structural changes in the products; and recovery meant as energy recovery only [7]). Moreover, the absence of standardized data reporting frameworks across countries complicates comparisons and the development of best practices for CDW management. Although the recovery rates for mineral and non-hazardous CDW are reported to be high, often exceeding 90% in some countries, these figures can be misleading [21]. A significant issue arises from the lack of clarity, assuming whether these recovered materials are repurposed in high-grade applications, such as in new construction projects, or in low-grade uses like backfilling. This ambiguity stems from differing interpretations of the terms "recycling" and "backfilling" across EU member states, with backfilled CDW frequently being reported as recycled, despite its limited potential for further value-added applications.

The EU member states with the highest rates of CDW recovery have typically implemented stringent regulations, such as landfill bans (e.g., Belgium and the Netherlands) or imposed significant landfill taxes (e.g., the UK), which incentivize recycling and recovery efforts. These policy measures have proven effective in diverting CDW from landfills and promoting sustainable waste management practices (Resource Efficient Use of Mixed Wastes, 2017). These measures have increased the recycling process, mainly through downcycling. An example of the Netherlands—the recycling rate for CDW has consistently been high, reaching 95% as early as 2001, largely driven by the waste landfill ban. By 2010, the recycling rate had nearly reached 100%. However, the utilization of CDW has predominantly been focused on low-grade applications, with 78% by weight being used in road foundations by 2015. Only a small fraction, approximately 3% by weight, was incorporated into concrete production, while the remaining 19% was used for site elevation in road and building construction [22,23]. In the context of the circular economy, it is crucial to prioritize the activation of upcycling and reuse processes. However, several barriers still hinder the implementation of these more efficient circular practices. These obstacles include technological limitations, economic feasibility, regulatory challenges, and market acceptance, all of which must be addressed to enhance circular strategies' effectiveness [24,25]. Gherman et al. (2023) highlights that while tools such as building information modelling (BIM) and life cycle assessment are widely utilized, research on the integration of emerging technologies, including artificial intelligence and blockchain, to improve CDW circularity remains limited [26]. Scholars have also highlighted the need to address social dimensions, such as organizational culture, employee well-being, and motivation, when considering circularity tools at the micro level. A significant identified gap is the absence of a comprehensive theoretical framework that adequately addresses these social components [27,28]. Luciano et al., 2022, emphasized that economic and legal barriers prevent full implementation of CDW recycling in the EU. such as inadequate design standards, the low cost of disposal compared to recycling, inadequate urban planning, an underdeveloped market for recycled materials, and limited CDW processing facilities, and the lack of policies and regulations in many countries [29].

The sorting of CDW has been identified as a pivotal focus within the field of waste management research, with substantial potential to optimize resource recovery and minimize landfill usage. Sorting construction waste before disposal/being dumped in a landfill is viewed as good [30]. Additionally, on-site sorting can enhance reuse and recycling rates, reduce waste transportation and disposal costs, and extend landfill lifespan. [31]. Despite the importance of sorting, recent studies underscore several gaps that hinder progress in this area. One particularly significant gap lies in the limited adoption and integration of advanced sorting technologies, including AI-powered robotics, automated sensor systems, and machine learning algorithms, which could dramatically enhance both the efficiency and accuracy of CDW sorting processes. Furthermore, there is a need for deeper investigation into the adaptability of these technologies to different types of CDW, as well as their cost-effectiveness, scalability, and alignment with existing regulatory standards across various regions [32,33]. Figure 10 provides an overview of CDW sorting processes, defining origin of CDW, types of waste under each category, corresponding solutions for management of CDW and practical activities undertaken by inhabitants, when dealing with CDW management.

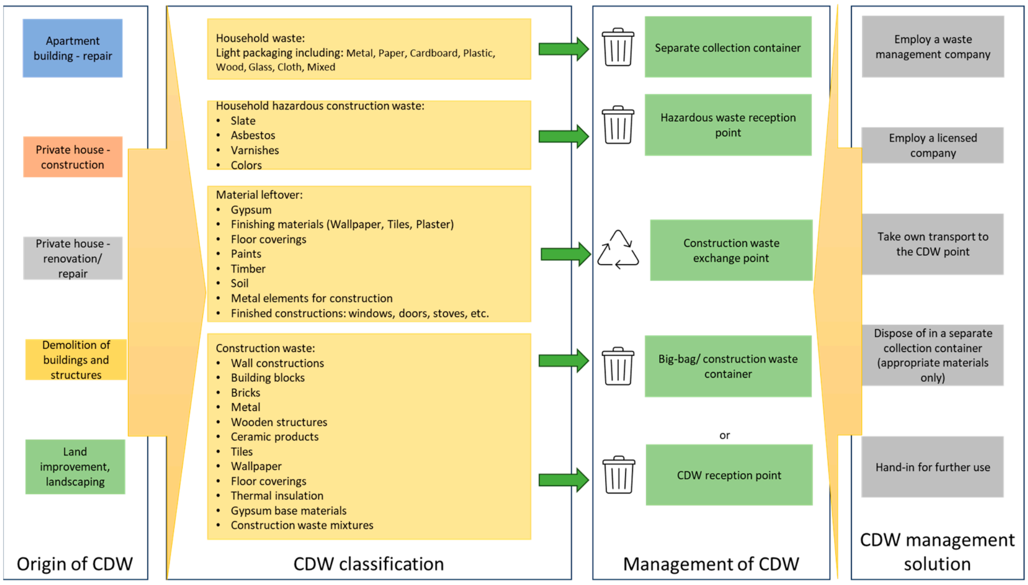

Figure 10. Diagram of CDW sorting processes (developed by authors, based on [34]).

Yeheyis at al. (2012) proposed the integrated CDW management framework and divided it into three stages in the lifecycle of a construction project: the pre-construction phase (including planning and design), the construction and renovation phase, and the demolition phase (Figure 11). At each stage of the construction project lifecycle, the framework applies the 3R approach (reduce, reuse, and recycle) to maximize reuse, recycling, and industrial symbiosis, thereby minimizing CDW disposal. [35] The figure depicts also source of information for assessment of CDW LCA-based sustainability index (depicted with dashed lines).

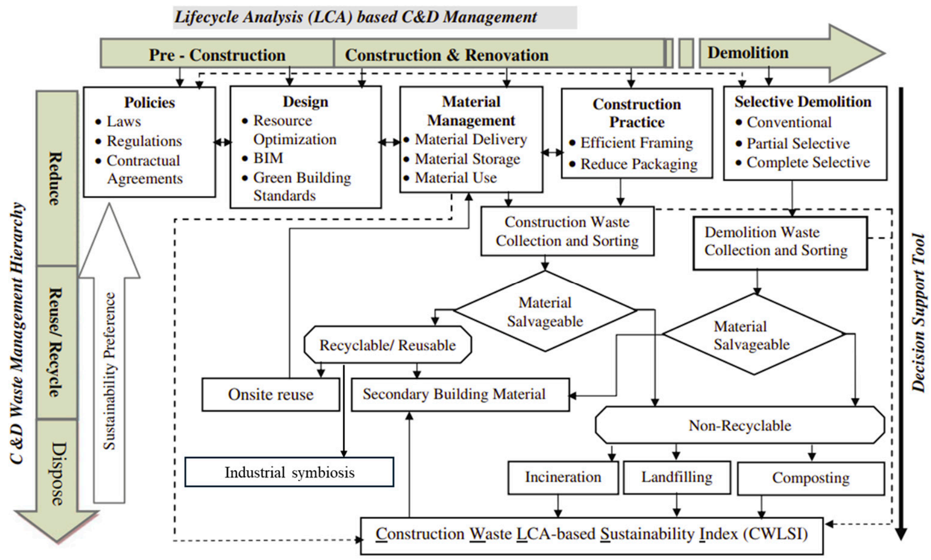

Figure 11. Theoretical framework for lifecycle-based integrated CDW management system (adopted by authors, based on [35]).

Ruiz et al. (2020) proposed a conceptual framework approach for adopting the CE in the CDW sector. This framework considers influential CE strategies and their interaction through the five primary lifecycle stages of the industry: pre-construction, construction and renovation activities, collection, end of life, material recovery and recycling [36]. The suggested framework in this research is focused on adopting CE as a solution to reduce waste generation and maximize the recycling and recovery of CDW and its use as secondary materials in the construction sector. Building CDW recycling or recovery facilities is one effective way to improve waste recycling rates and reduce landfilling [37] and is an important node of the supply chain for CDW recycling. The economic viability of waste recycling facilities should be taken into consideration. If no recycling facilities are nearby, transportation costs may be higher than landfill fees, which is not economically viable for contractors [38]. This can lead to a situation when contractors directly send waste to landfill sites. A mature CDW recycling market enables the recycling of CDW and contributes to a higher recycling rate. Governments play a crucial role in promoting the waste recycling market [38–40] through financial incentives and legislation. Supplies of waste to recycling companies, the price and quality of recycled products, and demand are also important. If contractors have on-site or off-site recycling facilities far from construction sites, they send their waste to off-site recycling facilities. In addition, the lack of specifications, technical, or quality standards for recycled final products tends to result in concerns regarding the quality of these products and make them unattractive both for construction companies and for the clients [41,42]. This further leads to resistance from using recycled products and decreasing demand [43,44]. In addition, designers were found to be reluctant to specify recycled products in their designs due to lack of information about the market availability and quality, cost pressure, and negative perceptions of clients [45,46]. Recycled products tend to undergo more treatment processes, leading in increasing cost and reducing price competitiveness [46,47]. The latest data indicates that recycled products have no price advantages over those made from original materials in China because of the high cost associated with recycling process. Thus, waste recycling companies require government subsidies, and the recycling market needs financial incentives to develop further [48,49]. Although the government subsidy is a valuable policy tool, the government should ensure it is practicable and feasible and also certain precautions measures have to be taken info consideration.

2.3. Energy Recovery Potential from Construction and Demolition Waste

The heterogeneous nature of CDW is a function of multiple variables, including the specific construction activity, material selection, and regional construction methodologies.

The waste stream composition exhibits significant variability across different project types. Demolition activities, for instance, yield more inert materials like concrete, masonry, and ferrous metals [50]. Conversely, new construction projects tend to generate a greater volume of lightweight materials, including packaging waste, polymeric substances, timber, and material offcuts [51]. Renovation and refurbishment endeavours present a distinct waste profile, often characterized by an increased presence of gypsum-based products, insulation materials, and potentially hazardous substances such as asbestos-containing materials or lead-based paint residues [52]. This variability in CDW composition underscores the complexity of waste management strategies in the construction sector and highlights the need for tailored approaches to waste characterization, segregation, and valorisation.

Previous research analysing municipal solid waste use shows that from an energy recovery viewpoint, it is best to recycle paper, wood, and plastics; to anaerobically digest food and yard wastes; and to incinerate textile waste. Comparing the use of municipal solid waste for energy recovery with demolition wastes, Kim et al. concluded that it is difficult to technically and economically operate energy conversion or recovery, because the ratio of combustibles in demolition waste is lower than that in household waste, even in the same waste type (paper, wood, fiber), and it needs to go through a mechanical sorting process due to different sizes and the characteristics of the incombustibles existing in demolition waste [53].

Wood is one of the most significant components of CDW that can be utilized for energy recovery. It can be processed into wood chips or pellets and used as biomass fuel in combustion systems or gasification processes. In Spain, recovered wood is predominantly processed into chips, which serve dual purposes: as a feedstock for energy generation and as a raw material in the manufacture of particleboards [54].

In Latvia in 2019, 70% of collected construction waste was a mixture of construction waste and inert materials, while 20% consisted of only inert materials [52]. The large proportion (70%) of mixed construction waste and inert materials in Latvia's waste stream could potentially be utilized in energy production where combustible materials such as wood, plastics, and textiles have high calorific values, contributing to the overall energy output of WtE processes. Modern WtE plants are capable of handling heterogeneous waste streams, making them suitable for processing this mixed fraction [55]. The composition of Latvia's construction waste stream presents significant opportunities for energy recovery. While challenges exist, this approach could play a crucial role in sustainable waste management, contributing to both waste reduction and energy generation goals.

3. Case Study: Latvian Municipalities

This section offers a case study from Latvian municipalities, which was carried out with an emphasis on the analysis of the real situation in the household sector, which, according to the municipalities (based on a survey of the municipalities carried out at the end of 2022), constitutes the main source of littering in the context of CDW (70% of surveyed municipalities). While developing CDW management flowcharts, the researchers were able to identify both positive practices in CDW management and actions that are not allowed according to the current regulatory framework. In the previous research, practical recommendations were developed for the improvement of regulatory acts, and in addition, proposals have been drawn for improving the management system of CDW, which are aimed at promoting cooperation between participating parties. The authors see that the results of the previous and current research can be used as a "roadmap" for municipalities, promoting environmentally friendly and resource-efficient management of CDW [49].

3.1. Background of the Research: Progress Towards UN SDGs

According to scientific research, the UN Sustainable Development Goals (UN SDGs) most affected by construction and demolition waste are 11, Sustainable Cities and Communities; 12, Responsible Consumption and Production; and 13, Climate Action. The following section will provide some evidence for each of the goals mentioned above, highlighting the role of CDW management in the process.

The latest UN report on the progress towards the SDGs highlights that EU countries have already achieved some progress, with higher results for SDG 11 and average results for SDG 12 and SDG 13. Table 1 below provides descriptive statistics based on the UN report [56].

Table 1. Descriptive statistics.

	SDG 11 Score	SDG 12 Score	SDG 13 Score
Mean	94.828	55.162	73.591
Std. Deviation	3.663	13.913	12.472
Minimum	83.883	27.707	39.472
Maximum	98.785	84.555	90.540
75th percentile	97.393	64.777	82.900
25th percentile	93.707	42.900	69.215

Figure 12 demonstrates three-dimensional clustering of EU countries in terms of their progress towards UN SDG 11, UN SDG 12, and UN SDG 13. The explained variance ratio (k) is 91.71%, so one statistical piece of one statistical evidence is given. Six clusters are built, demonstrating the degree of progress among different countries: the yellow one consists of Belgium, Denmark, Estonia, Cyprus, and Austria; the green one consists of Bulgaria, Spain, Croatia, Italy, Hungary, Poland, Portugal, and Romania—the most significant cluster, consisting of eight countries; the purple one consists of the Czech Republic, Germany, Lithuania, Slovenia, and Finland; the grey one consists of Ireland, Luxembourg, and the Netherlands; the red one consists of Greece, France, Latvia, and Sweden; the blue one consists of Malta. The following observations could be made: There is a general trend of high performance in UN SDG 11 across all countries, suggesting that European nations are doing well in sustainable urban development. The performance of SDG 12 and 13 is more varied, indicating areas where many countries could improve. Some countries perform excellently in one area but poorly in others. For example, Luxembourg scores high in UN SDG 11 but low in UN SDGs 12 and 13. The clustering does not directly correlate with performance in any UN SDG, suggesting it is based on a more complex set of factors. Moreover, Eastern European countries like Romania and Hungary perform surprisingly well in UN SDGs 12 and 13, outperforming many Western European nations.

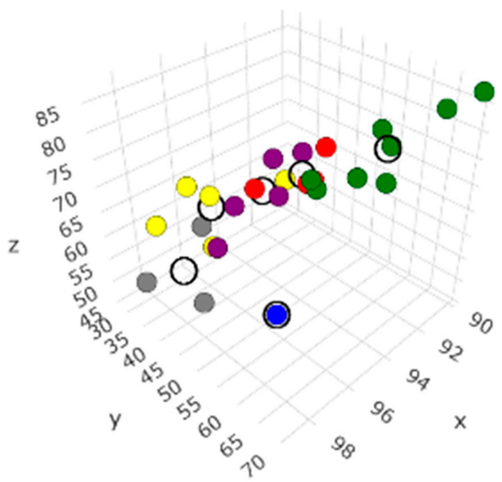

Figure 12. Progress towards UN SDGs—cluster analysis (developed by the authors based on [56]), where white dots are the centre of each cluster & collared dots represent six clusters as described above.

It is evident that CDW, with its significant impact on urban sustainability, is a problem of urgent and immense scale. Several studies have shown that it accounts for above

30% of total solid waste generation in many countries, posing serious challenges for waste management in cities and affecting the overall sustainability of urban environments. More evidence is provided in research papers by [22,57]. One can conclude that CDW management crucially influences a country's performance in achieving UN SDG 11, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable.

The effective management of CDW plays a significant role in urban development and directly impacts several targets within UN SDG 11. One of the key roles of CDW management is in reducing the environmental impact of cities. When CDW is poorly managed, it can lead to increased pollution in terms of air quality and water contamination. However, by implementing proper waste management practices, one can significantly reduce these negative impacts. Furthermore, efficient CDW management practices not only contribute to the sustainable use of resources but also bring about a brighter future. By shifting to the recycling and reuse of materials from construction and demolition activities, countries can reduce the demand for virgin resources, minimize waste sent to landfills, and decrease their carbon footprint associated with new material production. The management of CDW also has implications for urban planning and land use. Effective waste management can reduce the need for landfill space, allowing cities to utilize land more efficiently for productive purposes. Moreover, how a country handles its CDW impacts its ability to provide adequate, safe, and affordable housing. Efficient waste management can contribute to more cost-effective construction processes by reducing disposal costs and providing recycled materials for new construction projects. Lastly, a country's approach to CDW management reflects its commitment to sustainable urbanization and capacity for urban planning and management. Countries implementing comprehensive waste management policies and practices demonstrate a higher level of urban governance and a more substantial commitment to sustainable development principles, offering hope for a more sustainable and resilient future. According to the latest statistics [56], the Baltic States are demonstrating good results above the EU average level (EST: 98.8; LV: 94.9; LT: 95.3). These figures surpass the EU average levels, indicating that the Baltic region is making substantial headway in creating sustainable urban environments. Estonia stands out with its score, placing it among the top performers in the EU for this goal. However, it is noteworthy that while Latvia and Lithuania have achieved scores above 94, they still fall below the 75th percentile. This suggests that there is considerable potential for further improvement in these countries to reach the highest echelons of SDG 11 performance within the EU. By focusing on enhancing CDW management, these countries can not only advance their standing in SDG 11 metrics but also contribute significantly to overall urban sustainability. The implementation of comprehensive CDW management strategies offers a multifaceted approach to addressing various targets within SDG 11, positioning the Baltic States as potential leaders in sustainable urban development within the European Union.

The authors see that the construction industry, as a significant consumer of raw materials and producer of waste, has the potential to improve the management of CDW significantly. This is crucial for achieving responsible consumption and production patterns. More evidence is provided in research papers by [19,57–59]. It is obvious that CDW management significantly impacts a country's performance in UN SDG 12, which focuses on sustainable consumption and production pattern implementation. The construction industry is one of the largest consumers of raw materials and generators of waste, and therefore, it plays a crucial role in achieving this SDG. As a result, the management of CDW directly contributes to several targets within SDG 12, in particular to those related to the efficient use of primary resources, waste reduction, and sustainable practices. Countries implementing robust CDW management systems are committed to responsible consumption and production. When CDW is not adequately managed, it leads to the loss of valuable materials that could be reused or recycled. Furthermore, the proper management of CDW contributes to reducing waste generation, another key target of SDG 12. Countries prioritizing waste prevention, minimization, and recycling in construction tend to perform better. The management of CDW also influences a country's progress towards sustainable public procurement practices.

Governments that incorporate waste management criteria into their procurement policies for construction projects demonstrate a commitment to sustainable consumption. Moreover, effective CDW management contributes to developing sustainable business practices within the construction sector. Companies that adopt circular economy principles in their operations, such as designing for recyclability and implementing take-back systems for construction materials, align their practices with the goals of UN SDG 12. Lastly, countries that prioritize CDW management often see improvements in their overall waste management systems and infrastructure. This can lead to waste tracking, reporting, and monitoring advancements, which are essential for measuring progress towards UN SDG 12 targets.

According to the latest statistics [56]—i.e., the following results: EST, 41.2; LV, 56.6; LT, 48.3—these figures reveal a notable disparity among the three countries, with Latvia significantly outperforming its Baltic neighbours and surpassing the average performance level. Despite Latvia's relatively strong showing, it is crucial to note that all three Baltic countries have achieved scores below the 75th percentile for UN SDG 12 within the European Union. This positioning indicates that there is substantial room for enhancement in their pursuit of responsible consumption and production practices. Moreover, effective CDW management aligns closely with the core principles of UN SDG 12, offering a practical pathway for the Baltic States to boost their performance in this area.

Research demonstrates that CDW contributes to greenhouse gas emissions through transportation and disposal processes. Additionally, the "embodied carbon", which refers to the carbon dioxide emitted during the production and transportation of materials, in wasted materials represents a significant environmental impact. More evidence is provided in research papers by [22,56,59]. One can note that CDW management significantly influences a country's performance in UN SDG 13, which focuses on urgent action to combat climate change and its impacts. The relationship between CDW management and climate action is multifaceted, affecting greenhouse gas emissions, resource consumption, and overall environmental sustainability. Undoubtedly, the construction industry is a significant contributor to global carbon emissions through its operational activities and the embodied carbon in building materials. So, when CDW is not managed correctly, it exacerbates these emissions in several ways, such as the disposal of waste in landfills leading to the release of methane and the transportation of CDW to disposal sites contributing to carbon emissions using fossil fuels.

Moreover, effective waste management in the construction sector can lead to innovations in low-carbon building techniques and materials. These innovations can have far-reaching effects, potentially transforming the construction industry's impact on climate change and improving the country's overall performance in SDG 13. The management of CDW also plays a role in urban resilience and adaptation to climate change. Proper waste management can contribute to more sustainable urban development, reducing the heat island effect in cities and improving overall environmental quality. Additionally, how a country manages its CDW can influence its overall waste management policies and infrastructure, affecting its climate action performance. Advanced waste management systems often incorporate energy recovery technologies, such as waste-to-energy facilities, which can provide alternative energy sources. Lastly, how a country approaches CDW management can indicate its overall commitment to environmental sustainability and climate action. This commitment often extends to other sectors and can positively influence the country's overall performance in achieving the targets set out in SDG 13.

The latest statistics [56] present the following results: EST, 69.2; LV, 76.4; LT, 76.1. These data reveal a notable distinction among the three countries: Latvia and Lithuania are performing above the EU average in SDG 13. Estonia, however, remains below the EU average in this goal. These results suggest that while the Baltic States, particularly Latvia and Lithuania, have made commendable progress in climate action, there is still significant potential for all three countries to enhance their efforts. Reaching the 75th percentile and beyond would require focused strategies and potentially increased investment in climate mitigation and adaptation measures, while CDW management could positively affect progress.

3.2. Methodology of the Research

This review draws on an extensive analysis of scientific literature, case studies, and industry reports to assess current practices in the CDW stream and assessment of the feasibility of energy recovery, industrial symbiosis and object reconstruction. This research also covered a survey of the households with respect to the common practices of CDW management. As part of the research, from 31 October to 10 November 2022, a survey of Latvian residents (18–75 years old) was conducted on construction waste management in Latvia. During this period, 2005 respondents were interviewed using the CAWI (Computer Aided Web Interviewing) method, 67% of whom were directly involved in the construction, repair, improvement, and/or demolition of their own or their family's real estate. Initially, it was foreseen to assess 2000 respondents, 50% of whom were directly involved in the construction, repair, improvement, and/or demolition of their own or their family's real estate. In addition to the survey, a municipality representative focus group was assessed to identify best practices of CDW on the municipality level.

3.3. Results of the Research

To ensure a more thorough evaluation of the current situation in the aspects of the creation and management of CDW, it is important to highlight some of the results of the survey developed by the authors in 2022:

- 47% of respondents have carried out repairs or construction work in an apartment in the last five years;
- 36% of respondents have undertaken repairs and/or construction work in a private house, and 6% have done so in a summer house or garden house.

The most commonly performed type of repairs or construction work is cosmetic repair, for example, painting, changing tiles or plumbing, etc. (78% of respondents). Other jobs or activities are mentioned relatively less often. Regarding the scope of repairs and related regulatory actions, the following can be concluded:

- Most respondents (73%) from those, who have undertaken repairs or construction work in their household during the last five years, resulting in the generation of CDW, did not perform work that required coordination with the building authority.
- 17% of respondents had obtained an approval from the building authority for those works that did not require it, and 3% of respondents indicate that the works were aligned with the building authority only partially—not all works for which approval was necessary were aligned.
- Finally, 7% of the respondents indicated that they did not know whether the work undertaken required coordination with the building authority.

Figure 13 shows the results of the population survey in the context of the CDW morphological composition.

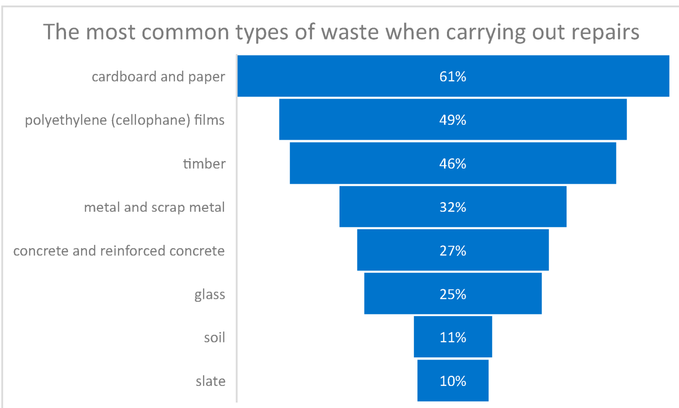

Figure 13. The results of the survey on most common types of CDW occurring in households during repair work (developed by the authors).

It can be concluded from the figure above that the most frequent type of waste when carrying out household repairs is cardboard and paper. However, along with the frequency of the type of materials generated, their composition, admixtures, level of contamination, origin, and danger must also be considered. Evaluating the volumes of CDW occurrence, Figure 14 visually shows the most common volumes generated by household CDW. This indicator is particularly important when evaluating optimal CDW management methods that would be more suitable for households. It follows from Figure 14 that 57% of the respondents noted that during household repairs, they generate less than 1 m^3 of CDW. On the other hand, 29% of the respondents noted that they generate more than 1 m^3 CDW when carrying out household repairs, of which 20% noted that they generate up to 4 m^3 CDW and only 9% noted that they generate more than 4 m^3 CDW when carrying out household repair works.

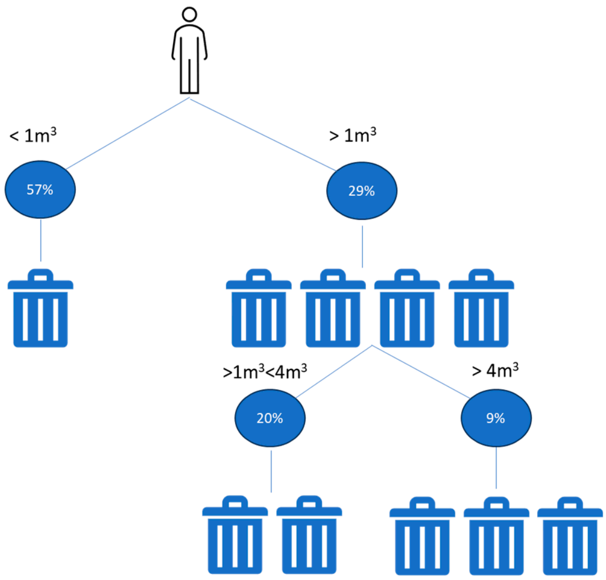

Figure 14. The results of the survey on volumes of CDW occurring in households during repair work (developed by the authors).

Based on the results of the conducted survey, Figure 15 schematically represents the choices of the population when getting rid of CDW.

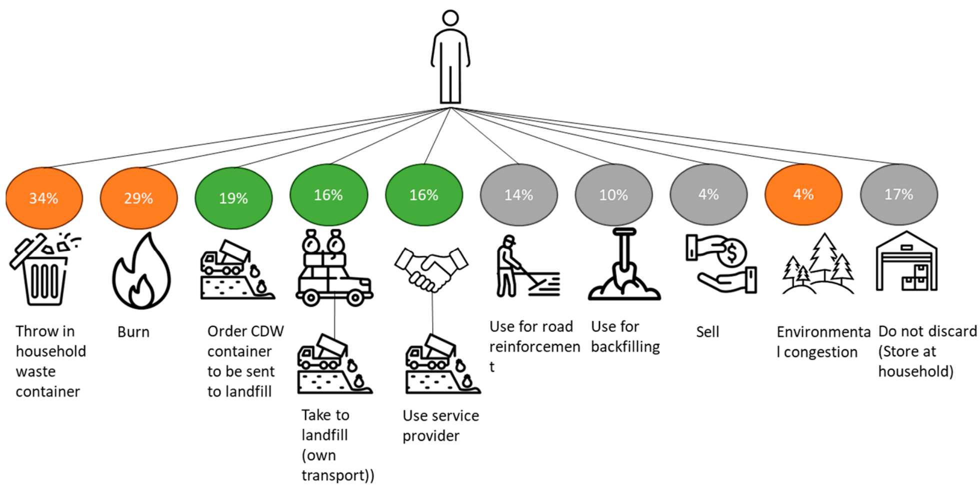

Figure 15. The results of the survey on the types of behaviour of residents with CDW created in the household (developed by the authors).

From Figure 15, it can be concluded that the actions of residents regarding CDW management can be divided into three categories:

- Orange—activities not permitted by regulatory acts of the Republic of Latvia;
- Green—activities that are in accordance with regulatory acts of the Republic of Latvia;
- Grey—activities that are permissible according to regulatory acts, but the compliance of which should be verified. The "sale" activity also appears in the grey category, because if the material is not yet classified as waste and it is possible to sell it on the market, then this activity is permissible, and it also contributes to popularizing circular economy in society.

According to the survey questions, it was concluded that inhabitants would be interested in sorting CDW so that others could use CDW as resources, mentioning the creation of a digital platform for information exchange as one of the possibilities.

The results of another survey—a survey of the responsible persons of the municipalities (focus group discussions were held at the end of 2022 by the authors)—and the analysis of the regulatory framework made it possible to carry out the current assessment of the CDW system, identifying those aspects that cause the most problems and where some improvements are needed. The biggest identified problem, which is also confirmed by the results of the inhabitant survey, is the low level of knowledge of the inhabitants about the proper, regulatory, legal, and environmentally friendly management of CDW, as more than a third of respondents mentioned placing CDW in household waste containers as one of the actions. In addition, this behaviour can be explained by the fact that most of the surveyed residents (57%) generate an insignificant amount of CDW (less than 1 m^3), so they probably do not think about the fact that it should be managed differently from household waste. This behaviour can be explained by the fact that the general level of awareness and education of the population about the environmentally friendly management of CDW is relatively low. However, the population survey shows that CDW management is an important problem in the opinion of the inhabitants, which requires a systemic solution, with the same requirements and conditions for the inhabitants, regardless of their location and municipality.

An Example of Good Practice in CDW Management in the Context of Households

The opening of the first exchange point for CDW, building materials, and repair items (exchange point) on October 2023 in Latvia can be mentioned as one of the proofs of the inhabitants' interest and desire to get involved in the management of CDW. The main activity of the exchange point is to ensure the transfer of various construction materials for processing or exchange for already sorted construction waste, in addition to the repeated use of construction materials and repair items, i.e., returning them for secondary use. An exchange point has been established in the construction waste sorting and recycling centre "Nomales", where construction waste (rubble, soil, concrete constructions, etc.) is already sorted and processed into reusable materials.

At the exchange point, you can bring, pick up, or exchange reusable items free of charge, such as the following:

- Building materials;
- Repair tools;
- Interior items;
- Working electrical engineering.

The building material and repair tool exchange point is equipped with 16 waste containers and rooms for the safe storage and exchange of building materials and electrical goods. Samples for the use of recycled CDW are displayed in the sorting area—for example, a gabion wall filled with recycled CDW materials has been installed. Also, at the exchange point, construction waste of a certain quality can be exchanged for soil or rubble obtained in secondary waste processing. It is important to note that many of the things handed over at the exchange point are classified as hazardous waste, such as paints, oils, varnishes, electric and electronic equipment, etc., which must not be thrown into unsorted household waste containers. By bringing these items over to the exchange point, residents not only clean their homes from hazardous waste but will also be provided an opportunity to return various materials and goods to the economic cycle to foster re-use. However, it should be noted that the exchange point does not accept following types of waste:

- Undetectable substances, liquids, and chemicals;
- Substances dangerous to health and life;
- Empty paint, varnish, and oil containers;
- Gypsum;
- Furniture;
- Asbestos and asbestos-containing materials;
- Bulky plumbing, etc.

Although the exchange point has been operating relatively recently, evaluating the available statistical data, it can be concluded that for three months (October–December 2023), residents handed over 638 CDW units, with a total weight of 2.5 tons. During the reporting period, residents considered 379 CDW units to be valuable and took them, with a total weight of two tons, and as of 31 December 2023, there were 259 units untaken at the exchange point, with a total weight of 0.5 tons. It can be concluded that the largest share of CDW, which was brought over at the exchange point, consists of shingles, various types of mortar, tiles, tile glue, etc. This example is a positive confirmation of the fact that inhabitants are happy to use the opportunity to extend the life cycle of resources that they do not need, thus saving waste management costs for themselves and giving the opportunity for those who need it to obtain necessary resources free of charge.

4. Discussion

At the commercial level, generation, transport, and recycling of CDW have been studied already for almost 25 years and have received a lot of attention worldwide, especially in European countries. However, at the household level, these issues are dealt with differently among the countries, lacking appropriate attention and uniform approach [2,19,60,61]. Even though significant progress has already been achieved in the last decade, Latvia is still in the early stages of implementing a functioning CDW management system. The current CDW management system in the field of recycling in Latvia is still in the formative stage, but its creation is fragmentary, and there is no unified process management system. Therefore, it does not meet the requirements of modern economic development and market development.

As a result of the study, a block diagram (Figure 16) has been developed, determining that CDW includes all the materials generated during the dismantling of a household object and which cannot be further used in the given object without appropriate processing (dust sweeping, crushing, sieving, and other operations). Under this scheme, a compliance/framework for the proper management of CDW will be established. In each of the CDW generation sources, any waste can occur from those divided by their types in the CDW classification block. Additionally, when evaluating existing practices in households regarding types of CDW management, it can be concluded that households can choose one or more CDW management solutions at the same time.

Figure 16 also reflects the life cycle of CDW for the promotion of AE, which includes two development directions: at the level of waste management companies and households. It is important to emphasize that waste management companies also play an essential role in the management of CDW, because in the case of a resident, there are three basic activities that he can perform to ensure the circulation of CDW: storing surpluses, selling surpluses, and delivering surpluses to building material exchange points (these activities are the ones that directly foster re-use, thus highlighted with green dashed box). On the other hand, waste management companies can ensure that the flow of CDW, which initially ends up in separate waste collection areas or is disposed of in a CDW-compliant way, is prepared for recycling, after which physical material processing takes place and, further, it is possible to offer these resources on the secondary resource market, thus replacing the primary necessary material purchase with secondary materials.

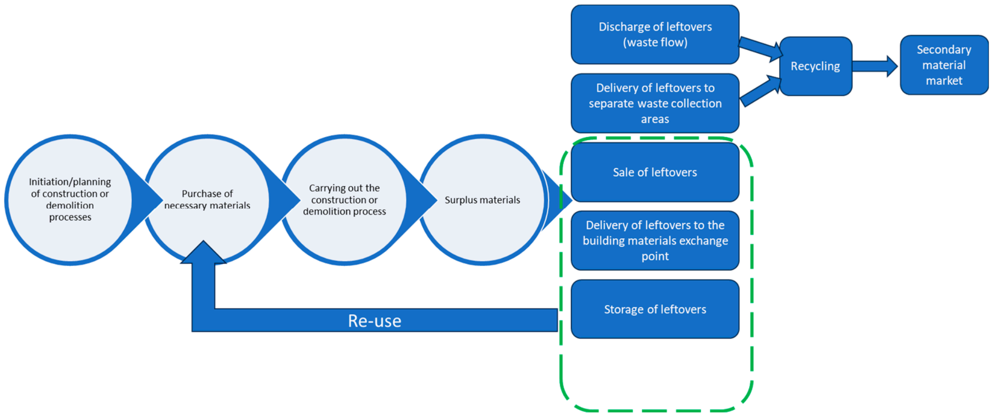

Figure 16. Block diagram determining CDW flow (developed by the authors).

While this study provides a preliminary overview of the potential for energy recovery from construction and demolition waste (CDW) in Latvia, focusing on CDW management challenges in households, there remain significant gaps that warrant further research. One critical area of investigation is the quantification of the energy yield from CDW based on its specific composition in Latvia. Given the heterogeneous nature of CDW, which includes materials such as wood, plastics, metals, and concrete, the proportion of combustible materials is a key factor influencing the energy recovery potential. To accurately estimate the energy output, detailed studies should be conducted on the physico-chemical properties of various CDW components, including their calorific value, moisture content, and chemical stability. This would help to identify which materials within the mixed waste fraction are most suitable for energy recovery and how their combustion behaviour influences overall energy efficiency.

Additionally, seasonal variations in CDW generation must be considered. Construction activities often fluctuate based on climate conditions, which could result in variations in both the volume and composition of waste generated throughout the year. These fluctuations could impact the consistency of feedstock for energy recovery processes, potentially affecting the operational stability and economic viability of waste-to-energy (WtE) facilities. A thorough analysis of seasonal CDW flows would enable a more robust planning of energy recovery strategies and align them with the operational needs of existing and future WtE infrastructure in Latvia.

Furthermore, the integration of CDW into Latvia's energy recovery systems must be evaluated within the broader context of the country's waste-to-energy technologies and capacities. Current and planned WtE facilities [49,62], their technological capabilities, and their throughput capacities will play a crucial role in determining the feasibility of large-scale CDW energy recovery. Research must therefore assess the compatibility of CDW with the existing WtE infrastructure, considering factors such as pre-treatment requirements, emission standards, and potential retrofitting needs. As Latvia continues to invest in WtE technologies, understanding how these facilities can efficiently process CDW without compromising their environmental and operational performance will be vital for optimizing energy recovery from this waste stream.

WtE technologies also interact in a significant manner with industrial symbiosis aspects. In the built environment, it is also important to consider aspects of financial viability when assessing the CDW stream to understand what approach can lead to higher resource valorization and contribute to material circularity. From the perspective of the latter, industrial symbiosis is an aspect that can significantly contribute to circularity, which is currently in a significant decline—the latest report on the circularity gap reveals that the circularity ration in 2022 dropped to 7.2% compared to 9.1% in 2018, which is a decrease of over 20%. Simultaneously, material consumption continues to rise at an unprecedent speed. In just the past six years alone, global consumption reached over half a trillion tonnes of materials—nearly as much as the entirety of the 20th century [63].

According to Eurostat data, the generation of secondary raw material use in Latvia is much lower than the EU average (respectively 5.4% and 11.5% of the total flow of raw materials in 2022). In this regard, little progress can be observed in Latvia, since in 2010 the use of secondary raw materials in Latvia reached only 1.2% of the total flow of raw materials, compared to the EU average of 10.7%. However, many and comprehensive activities must be carried out to ensure an increase in this indicator in the near future. And this is why the researchers see a potential in different advanced information technology solutions for effective assessment. CDW can either be used for WtE, industrial symbiosis, or building; containing this potential CDW can be reconstructed in an economically efficient manner. Industrial symbiosis is seen as a strong facilitator for the implementation of Green Deal concepts by significantly cutting the use of primary resource consumption, strengthening intersectoral cooperation, retrieving vast amounts of valuable resources before they become waste, and boosting resource efficiency. When using waste or by-products as input materials, companies enhance production efficiency, reduce waste disposal and input acquisition costs, and decrease dependency on primary resources [64].

Future Research Directions

For the effective implementation of the circular economy business model for the use of secondary resources and CDW in the built environment, it is proposed to create an automated conceptual inventory system of facilities in need of reconstruction using a geographic information system (GIS). The GIS contains a digital model of the object, the current status of its inventory, data on the level of destruction, the results of the inventory of potentially necessary materials and materials that can be reused, etc.

The implementation of the project will increase the efficiency of resource use in the reconstruction of infrastructure facilities by limiting the use of primary resources, reducing investment and transport costs for the processing and production of primary resources, increasing local employment, attracting citizens to green workplaces, and potentially reducing CO_2 emissions in the process of reconstruction. In addition, such a digital model would allow assessing the economic component of potential project, i.e., identifying the approach that gives higher valorization and is economically efficient from the circular economy framework perspective. To build a specialized geoinformation system for the management and utilization of CDW, the following developments are planned:

1. A geodata model of construction objects, which contains attributive (thematic and temporal) and spatial components of geodata, which will allow creating a geodatabase in a specialized GIS. The thematic component contains a digital model of the object and the current status of its inventory, as well as data on the stage of construction. The time component contains the scenario of the inventory method, as well as the results of the inventory of potentially required materials and materials that can be reused, etc.
2. A method of classifying construction objects based on the proposed geodata model will allow building a knowledge base of construction objects, integrating it into a specialized GIS, and thereby reducing the time of conducting a conceptual inventory of objects according to a specified scenario and increasing the efficiency of their construction.

Figure 17 shows an example visualization of the implementation of models and the method of analysing risk zones of potentially dangerous objects in geoinformation systems. The developed GIS is based on the model of technogenic risk zones from a shock wave, oil spill fire, and “fireball” considering the developed gas station geodata model, which allows creating a geodatabase and a method for determining technogenic risk zones based on it.

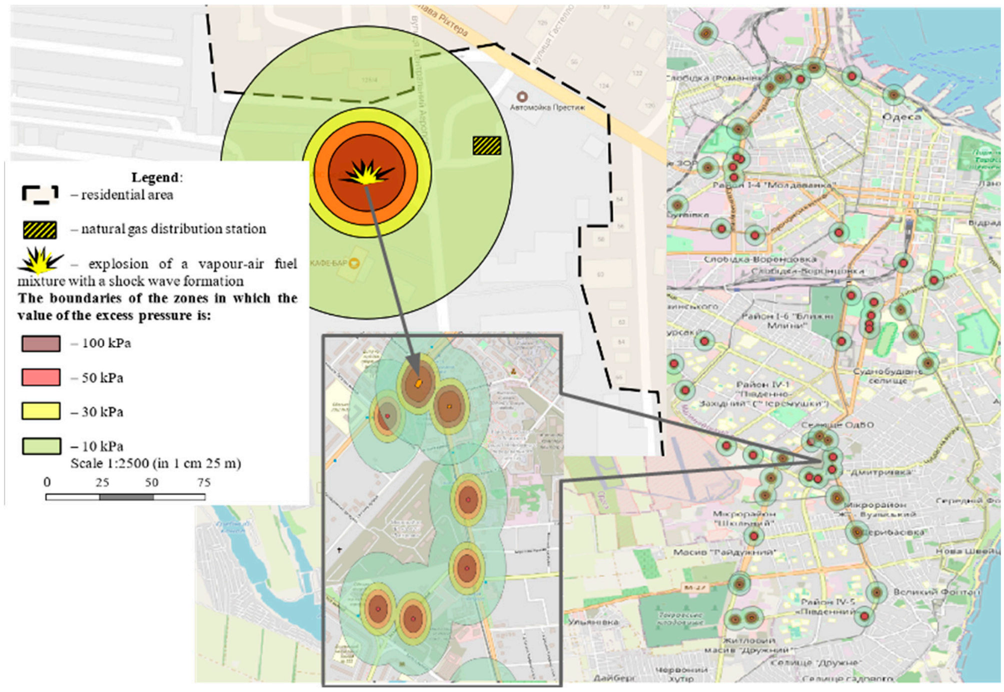

Figure 17. The results of the risk zones visualization from the gas stations according to the specified accident scenario and scale for the city of Odessa in the subsystem QGIS (developed by the authors).

Based on the built map analysis, it is possible to note the following for gas stations:

- Some gas stations do not comply with the norms of fire-fighting distance to so-called "care" objects (enterprises, organizations, residential areas, etc.).
- Some gas stations are located not only in residential areas but also near highways with a significant flow of cars, which, especially in the rush hour, increases the negative consequences of an accident.
- Some gas stations are located close to one another, for example, petroleum and gas stations, which in case of an accident can cause the development of the scenario by a "domino" cascade effect (risk zones on the map are overlapped) [65,66].

5. Conclusions

To achieve the research goal, the current paper is based on an extensive literature analysis on CDW management that reveals significant research growth since the 1990s, with China leading in contributions. Moreover, it allowed us to determine that key challenges include the need for standardized data reporting frameworks and the ambiguity in defining recycling terms, which hinder the accurate assessment and comparison of CDW management practices across countries. Despite high reported recovery rates in some EU countries, much of this is downcycling rather than high-value recycling or reuse. Barriers to implementing more efficient circular practices encompass technological issues such as the lack of advanced sorting and recycling technologies, economic issues such as the high cost of recycling and the low market value of recycled materials, regulatory issues such as the absence of strict recycling laws, and market acceptance issues such as the low demand for recycled materials.

The authors claim that future research directions should prioritize the development of standardized methodologies for CDW sorting and recycling to ensure cross-regional consistency and efficiency. The exploration of innovative technologies, including artificial intelligence-driven sorting systems and blockchain for material flow tracking, presents potential avenues for enhancing the economic viability and environmental performance of CDW management. Furthermore, attention should be directed towards the formulation of comprehensive policy frameworks that not only mandate CDW sorting and recycling but also provide financial incentives and regulatory support to foster industry-wide adoption. Addressing these challenges is crucial for advancing towards a more circular and sustainable approach in the construction sector, necessitating collaboration between policymakers, industry stakeholders, and researchers.

The originality of the current research is based on a Latvian case study on CDW management that provides valuable insights into household-level practices and progress towards relevant UN SDGs. The authors were able to demonstrate that Latvia shows above-average performance in SDG 11 and SDG 13, but it falls below the 75th percentile, indicating room for improvement. As for SDG 12, Latvia outperforms its Baltic neighbours but still has significant potential for enhancement. Moreover, the authors presented the results of a household survey that revealed that 67% of respondents were involved in construction or renovation activities, with 47% conducting apartment repairs in the last five years. Most repairs (73%) did not require building authority approval, suggesting a prevalence of small-scale renovations. The most common CDW types were cardboard and paper, with 57% of respondents generating less than 1 m^3 of waste.

Notably, this study uncovered concerning waste disposal practices, with over a third of respondents improperly disposing of CDW in household waste containers. This highlights a critical need for improved public education on proper CDW management. Both needs are urgent to improve the progress towards the UN SDGs.

The authors highlight that an innovative solution emerged with the establishment of Latvia's first CDW exchange point in October 2023. This initiative promotes the circular economy by facilitating the reuse and exchange of construction materials and tools. Early data show promising results, with 638 CDW units (2.5 tons) brought in and 379 units (2 tons) taken for reuse within three months. These findings underscore the importance of targeted education programs, improved regulatory frameworks, and innovative solutions like exchange points to enhance CDW management at the household level.

Another asset of the current paper is its discussion regarding the CDW management system, particularly its role in the recycling of CDW. Despite efforts in recent years, the system remains fragmented, lacking a unified process, and needs to meet modern economic and environmental demands. In conclusion, the current study emphasizes the need for improved management systems for CDW and CDW at the household and commercial levels. It also stresses the importance of GIS-based solutions for better waste management and risk mitigation, particularly in construction and urban planning.

The authors conclude that the CDW stream has an undeniable potential for valorization in various approaches. One of the most common ones is recycling, although the literature analysis also suggests that 20–30 per cent of the total CDW flow can be used for energy recovery. The analysis also suggests that 20–30 per cent of the total CDW flow can be used for energy recovery. Further research is needed to accurately quantify the potential for energy recovery from CDW and to identify effective waste management practices to harness this potential. In addition to this, industrial symbiosis is another solution that can not only boost the valorization of CDW but also significantly increase national and consequently global circularity.

The GIS-based solution that the authors foresee developing in the nearest future could become a useful tool for decision-makers to choose between different CDW valorization options.

Future research directions will be linked with the assessment of real estate objects that require reconstruction (for example, war-destroyed buildings or abandoned buildings) or objects that need to be demolished. With the help of the GIS tool, it would be possible to assess the best available solutions for either the reconstruction or demolition of the object, based on a range of input data, including life cycle assessment, costs for particular activities, material costs, the potential of material reuse, environmental impact, and circular economy trends.

Author Contributions: Conceptualization, N.C.-P., D.A. and J.K.; methodology, J.K.; software J.K., N.C.-P. and A.O.; validation, J.B. and O.I.; formal analysis, N.C.-P., J.B. and O.I.; investigation, J.B., A.O. and O.I.; resources, D.A.; data curation, N.C.-P. and A.O.; writing—original draft preparation, N.C.-P., J.K., J.B. and O.I.; writing—review and editing, N.C.-P.; visualization, J.K. and J.B.; supervision, N.C.-P. and D.A.; project administration, N.C.-P.; funding acquisition, D.A. and N.C.-P. All authors have read and agreed to the published version of the manuscript.

Funding: The research is financed by the Recovery and Resilience Facility project "Internal and External Consolidation of the University of Latvia" (No.5.2.1.1.i.0/2/24/I/CFLA/007), LU-BA-ZG_2024/1-0008.

Data Availability Statement: The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding authors.

Acknowledgments: Grant No. LU-BA-ZG-2024/1-0020, grant No. 5.2.1.1.i.0/2/24/I/CFLA/007, LIFE20 IPE/LV/000014, LIFE Waste to Resources IP; COST Action CA21103 Implementation of Circular Economy in the Built Environment (CircularB); COST Action CA22110—Cooperation, development and cross-border transfer of Industrial Symbiosis among industry and stakeholders (LIAISE).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Teixeira, A.B.; Barkat, H.; Sampaio, C.H.; Moncunill, J.O. Recovery of demolished house rocks from construction and demolition waste with water jigs. *Minerals* **2023**, *14*, 39. [CrossRef]
2. Sáez, P.V.; Osmani, M. A diagnosis of construction and demolition waste generation and recovery practice in the European Union. *J. Clean. Prod.* **2019**, *241*, 118400. [CrossRef]
3. Banias, G.F.; Karkanias, C.; Batsioula, M.; Melas, L.D.; Malamakis, A.E.; Geroliolios, D.; Skoutida, S.; Spiliotis, X. Environmental Assessment of Alternative Strategies for the Management of Construction and Demolition Waste: A Life Cycle Approach. *Sustainability* **2022**, *14*, 9674. [CrossRef]
4. Wang, Q.; Jiang, T.; Liu, L.; Zhang, S.; Kildunne, A.; Miao, Z. Building a whole process policy framework promoting construction and demolition waste utilization in China. *Waste Manag. Res.* **2022**, *41*, 914–923. [CrossRef]
5. Baki, O.G.; Ergun, O.N.; Nogay, A. Recycling of municipal solid waste in Sinop, Turkey: Practices, problems and challenges. *J. Inst. Sci. Technol.* **2020**, *10*, 45–52. [CrossRef]
6. Mabalane, P.N.; Oboirien, B.; Sadiku, E.R.; Masukume, M. A techno-economic analysis of anaerobic digestion and gasification hybrid system: Energy recovery from municipal solid waste in South Africa. *Waste Biomass Valorization* **2020**, *12*, 1167–1184. [CrossRef]
7. European Environment Agency. Glossary. 2024. Available online: https://www.eea.europa.eu/help/glossary/eea-glossary/ (accessed on 10 August 2024).
8. Vasiutynska, K.; Arsirii, O.; Ivanov, O. Development of the method for assessing the action zones of hazards in an emergency at a city filling station using geoinformation technology. *Technol. Audit. Prod. Reserves* **2017**, *6*, 29–38. [CrossRef]
9. Zhao, M.; Liu, X. Regional risk assessment for urban major hazards based on GIS geoprocessing to improve public safety. *Saf. Sci.* **2016**, *87*, 18–24. [CrossRef]
10. Scopus 2024. Available online: https://www.scopus.com/ (accessed on 20 September 2024).
11. Sall, O.; Takahashi, Y. Physical, chemical and biological characteristics of stored greywater from unsewered suburban Dakar in Senegal. *Urban Water J.* **2006**, *3*, 153–164. [CrossRef]
12. Web of Science Platform. Available online: https://clarivate.com/products/scientific-and-academic-research/research-discovery-and-workflow-solutions/webofscience-platform/ (accessed on 10 September 2024).
13. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
14. De Mattos, C.A.; Albuquerque, T.L. Enabling Factors and Strategies for the Transition toward a Circular Economy (ce). *Sustainability* **2018**, *10*, 4628. [CrossRef]
15. Antón, J.M.R.; Andrada, L.R.; Celemín-Pedroche, M.S.; Peñalver, S.M.R. From the Circular Economy to the Sustainable Development Goals in the European Union: An Empirical Comparison. *Int. Environ. Agreem. Politics Law Econ.* **2021**, *22*, 67–95. [CrossRef] [PubMed]
16. Özçatalbaş, O. An Evaluation of the Transition from Linear Economy to Circular Economy. In *Sustainable Rural Development Perspective and Global Challenges*; IntechOpen: London, UK, 2023. [CrossRef]
17. Rakhshan, K.; Morel, J.; Alaka, H.; Charef, R. Components reuse in the building sector–a systematic review. *Waste Manag. Res. J. Sustain. Circ. Econ.* **2020**, *38*, 347–370. [CrossRef]
18. Forghani, R.; Sher, W.; Kanjanabootra, S.; Totoev, Y.Z. The Attitudes of Demolition Contractors to Reusing Building Components: A Study in New South Wales, Australia. *Eur. J. Sustain. Dev.* **2018**, *7*, 364–370. [CrossRef]

19. Mavlutova, I.; Atstaja, D.; Gusta, S.; Hermanis, J. Management of Household-Generated Construction and Demolition Waste: Circularity Principles and the Attitude of Latvian Residents. *Energies* **2024**, *17*, 205. [CrossRef]
20. Taboada, G.L.; Seruca, I.; Sousa, C.; Pereira, Á. Exploratory data analysis and data envelopment analysis of construction and demolition waste management in the European Economic Area. *Sustainability* **2020**, *12*, 4995. [CrossRef]
21. Nadazdi, A.; Naunovic, Z.; Ivanisevic, N. Circular Economy in Construction and Demolition Waste Management in the Western Balkans: A Sustainability Assessment Framework. *Sustainability* **2022**, *14*, 871. [CrossRef]
22. Zhang, K.; Qing, Y.; Umer, Q.; Asmi, F. How construction and demolition waste management has addressed Sustainable Development Goals: Exploring academic and industrial trends. *J. Environ. Manag.* **2023**, *345*, 118823. [CrossRef]
23. Zhang, C.; Hu, M.; Yang, X.; Miranda-Xicotencatl, B.; Sprecher, B.; Di Maio, F.; Zhong, X.; Tukker, A. Upgrading construction and demolition waste management from downcycling to recycling in the Netherlands. *J. Clean. Prod.* **2020**, *266*, 121718. [CrossRef]
24. Tambovceva, T.; Bajāre, D.; Shvetsova, I.V.; Tereshina, M.; Titko, J. Awareness and attitude of Latvian construction companies towards sustainability and waste recycling. *J. Sib. Fed. Univ. Humanit. Soc. Sci.* **2021**, *14*, 942–955. [CrossRef]
25. Nunes, K.R.A.; Mahler, C.F. Comparison of construction and demolition waste management between Brazil, European Union and USA. *Waste Manag. Res. J. Sustain. Circ. Econ.* **2020**, *38*, 415–422. [CrossRef]
26. Gherman, I.-E.; Lakatos, E.-S.; Clinci, S.D.; Lungu, F.; Constandoiu, V.V.; Cioca, L.I.; Rada, E.C. Circularity Outlines in the Construction and Demolition Waste Management: A Literature Review. *Recycling* **2023**, *8*, 69. [CrossRef]
27. Birgovan, A.L.; Lakatos, E.S.; Nita, V.; Sim, A. A Review of Circularity Indicators and Psychological Factors: A Comprehensive Analysis of Circularity Practices in Organizations. *Econ. Ecol. Socium* **2024**, *8*, 16–26. [CrossRef]
28. Gorgon, M.I.; Bercea, O.B.; Păcurariu, R.L.; Boscoianu, M. Social Economy and the Transition towards Circular Economy: A Survey Based Approach. *Econ. Ecol. Socium* **2024**, *8*, 98–110. [CrossRef]
29. Luciano, A.; Cutaia, L.; Altamura, P.; Penalvo, E. Critical issues hindering a widespread construction and demolition waste (CDW) recycling practice in EU countries and actions to undertake: The stakeholder's perspective. *Sustain. Chem. Pharm.* **2022**, *29*, 100745. [CrossRef]
30. Lu, W.; Yuan, H. A framework for understanding waste management studies in construction. *Waste Manag.* **2011**, *31*, 1252–1260. [CrossRef] [PubMed]
31. Wang, J.; Yuan, H.; Kang, X.; Lu, W. Critical success factors for on-site sorting of construction waste: A China study. *Resour. Conserv. Recycl.* **2010**, *54*, 931–936. [CrossRef]
32. Klewe, T.; Völker, T.; Landmann, M.; Kruschwitz, S. Libs-consort: Development of a sensor-based sorting method for construction and demolition waste. In Proceedings of the 21st Ibausil International Conference on Building Materials, Weimar, Germany, 13 September 2023; Volume 6, pp. 973–976. [CrossRef]
33. Shimizu, H.; Fukuda, T.; Yabuki, N. Deep-learning point cloud classification for estimating the weight of single-material construction and demolition waste of unknown shape. In Proceedings of the 41st Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2023), Graz, Austria, 20–22 September 2023. [CrossRef]
34. Overstreet, K. What Does It Cost to Recycle Building Materials? *Archdaily*, 28 May 2023.
35. Yeheyis, M.B.; Hewage, K.; Alam, M.; Eskicioglu, C.; Sadiq, R. An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. *Clean Technol. Environ. Policy* **2012**, *15*, 81–91. [CrossRef]
36. Ruiz, L.A.; Ramón, X.R.; Domingo, S.G. The circular economy in the construction and demolition waste sector- A review and an integrative model approach. *J. Clean. Prod.* **2020**, *248*, 119238. [CrossRef]
37. Yuan, H. Barriers and countermeasures for managing construction and demolition waste: A case of Shenzhen in China. *J. Clean. Prod.* **2017**, *157*, 84–93. [CrossRef]
38. Nikmehr, B.; Reza Hosseini, M.; Rameezdeen, R.; Chileshe, N.; Ghoddousi, P.; Arashpour, M. An integrated model for factors affecting construction and demolition waste management in Iran. *Eng. Constr. Archit. Manag.* **2017**, *24*, 1246–1268. [CrossRef]
39. Hu, Q.; Peng, Y.; Guo, C.; Cai, D.; Su, P. Dynamic incentive mechanism design for recycling construction and Demolition waste under dual information asymmetry. *Sustainability* **2019**, *11*, 2943. [CrossRef]
40. Mavlutova, I.; Fomins, A.; Spilbergs, A.; Atstaja, D.; Brizga, J. Opportunities to Increase Financial Well-Being by Investing in Environmental, Social and Governance with Respect to Improving Financial Literacy under COVID-19: The Case of Latvia. *Sustainability* **2022**, *14*, 339. [CrossRef]
41. Ghaffar, S.H.; Burman, M.; Braimah, N. Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *J. Clean. Prod.* **2020**, *244*, 118710. [CrossRef]
42. Calvo, N.; Varela-Candamio, L.; Novo-Corti, I. A dynamic model for construction and demolition (C&D) waste management in Spain: Driving policies based on economic incentives and tax penalties. *Sustainability* **2014**, *6*, 416–435. [CrossRef]
43. Udawatta, N.; Zuo, J.; Chiveralls, K.; Yuan, H.; George, Z.; Elmualim, A. Major factors impeding the implementation of waste management in Australian construction projects. *J. Green Build.* **2018**, *13*, 101–121. [CrossRef]
44. Hoang, N.H.; Ishigaki, T.; Kubota, R.; Tong, T.K.; Nguyen, T.T.; Nguyen, H.G.; Yamada, M.; Kawamoto, K. Waste generation, composition, and handling in building-related construction and demolition in Hanoi, Vietnam. *Waste Manag.* **2020**, *117*, 32–41. [CrossRef]
45. Shooshtarian, S.; Caldera, S.; Maqsood, T.; Ryley, T. Using Recycled Construction and Demolition Waste Products: A Review of Stakeholders' Perceptions, Decisions, and Motivations. *Recycling* **2020**, *5*, 31. [CrossRef]

46. Oyedele, L.O.; Ajayi, S.O.; Kadiri, K.O. Use of recycled products in UK construction industry: An empirical investigation into critical impediments and strategies for improvement. *Resour. Conserv. Recycl.* **2014**, *93*, 23–31. [CrossRef]
47. Huang, B.; Wang, X.; Kua, H.; Geng, Y.; Bleischwitz, R.; Ren, J. Construction and demolition waste management in China through the 3R principle. *Resour. Conserv. Recycl.* **2018**, *129*, 36–44. [CrossRef]
48. Su, Y.; Si, H.; Chen, J.; Wu, G. Promoting the sustainable development of the recycling market of construction and demolition waste: A stakeholder game perspective. *J. Clean. Prod.* **2020**, *277*, 122281. [CrossRef]
49. Atstaja, D.; Cudecka-Purina, N.; Koval, V.; Kuzmina, J.; Butkevics, J.; Hrinchenko, H. Waste-to-Energy in the Circular Economy Transition and Development of Resource-Efficient Business Models. *Energies* **2024**, *17*, 4188. [CrossRef]
50. Shyshkin, E.; Chernonosova, T.; Haiko, Y.; Ivasenko, V.; Krasnokutska, I. Recycling of construction waste as an innovative direction of the program of post-war reconstruction of destroyed cities. *Ce/Papers* **2023**, *6*, 1039–1047. [CrossRef]
51. Kupusamy, K.; Nagapan, S.; Abdullah, A.H.; Kaliannan, S.; Sohu, S.; Subramaniam, S.; Maniam, H. Construction waste estimation analysis in residential projects of Malaysia. *Eng. Technol. Appl. Sci. Res.* **2019**, *9*, 4842–4845. [CrossRef]
52. Zhang, L.; Wu, H.; Wang, X.; Wu, F.; Ding, Z.; Song, L.; Zhong, P. Investigation of rates of demolition waste generated in decoration and renovation projects: An empirical study. *Buildings* **2024**, *14*, 908. [CrossRef]
53. Gallardo, A.; Carlos, M.; Bovea, M.D.; Ortega-Colomer, F.J.; Albarrán, F. Analysis of refuse-derived fuel from the municipal solid waste reject fraction and its compliance with quality standards. *J. Clean. Prod.* **2014**, *83*, 118–125. [CrossRef]
54. Llana, D.F.; González-Alegre, V.; Portela, M.; García-Navarro, J.; Íñiguez-González, G. Engineered wood products manufactured from reclaimed hardwood timber. In Proceedings of the World Conference on Timber Engineering (WCTE 2023), Oslo, Norway, 19–22 June 2023. [CrossRef]
55. Firtina-Ertis, İ.; Ayvaz-Cavdaroglu, N.; Çoban, A. An optimization-based analysis of waste to energy options for different income level countries. *Int. J. Energy Res.* **2021**, *45*, 10794–10807. [CrossRef]
56. United Nations. Sustainable Development Report 2024. *The SDGs and the UN Summit of the Future.* Available online: https://dashboards.sdgindex.org/ (accessed on 26 August 2024).
57. Viswalekshmi, B.R.; Bendi, D.; Opoku, A.; Kugblenu, G. Impact of construction and demolition waste on the realisation of the sustainable development goals. In *The Elgar Companion to the Built Environment and the Sustainable Development Goals*; Edward Elgar Publishing: Cheltenham, UK, 2024; pp. 265–279. [CrossRef]
58. Papamichael, I.; Voukkali, I.; Loizia, P.; Zorpas, A.A. Construction and demolition waste framework of circular economy: A mini review. *Waste Manag. Res.* **2023**, *41*, 1728–1740. [CrossRef]
59. HaitherAli, H.; Anjali, G. Sustainable urban development: Evaluating the potential of mineral-based construction and demolition waste recycling in emerging economies. *Sustain. Futures* **2024**, *7*, 100179. [CrossRef]
60. Kim, D.; Pak, D.; Chun, S. The influence of energy recovery from waste on landfill gas: A case study from Korea. *Pol. J. Environ. Stud.* **2018**, *27*, 2613–2622. [CrossRef]
61. Moschen-Schimek, J.; Kasper, T.; Huber-Humer, M. Critical review of the recovery rates of construction and demolition waste in the European Union–An analysis of influencing factors in selected EU countries. *Waste Manag.* **2023**, *167*, 150–164. [CrossRef] [PubMed]
62. Gálvez-Martos, J.-L.; Styles, D.; Schoenberger, H.; Zeschmar-Lahl, B. Construction and demolition waste best management practice in Europe. *Resour. Conserv. Recycl.* **2018**, *136*, 166–178. [CrossRef]
63. Fraser, M.; Conde, Á.; Haigh, L. The Circularity Gap Report 2024. Circle Economy. 2024. Available online: https://www.circularity-gap.world/2024#download (accessed on 26 August 2024).
64. Fraccascia, L.; Yazan, D.M. The role of online information-sharing platforms on the performance of Industrial Symbiosis networks. *Resour. Conserv. Recycl.* **2018**, *136*, 473–485. [CrossRef]
65. Arsirii, O.O.; Ivanov, O.V.; Smyk, S.Y. Risk Zones from the Filling Stations Modelling with Application of Geoinformation Technology. *Her. Adv. Inf. Technol.* **2021**, *4*, 84–95. [CrossRef]
66. Labib, A.; Jones, D.; Ivanov, O.; Arsirii, O.; Smyk, S. Analysis of Petrol Station Vulnerability Factors Regarding Accidents Using Analytic Hierarchy Process and Ranking. In Proceedings of the 11th International Scientific and Practical Conference "Information Control Systems & Technologies" (ICST-2023), Odesa, Ukraine, 21–23 September 2023; Volume 3513, pp. 330–341. Available online: https://ceur-ws.org/Vol-3513/paper27.pdf (accessed on 2 September 2024).