Sustainability in Energy and Buildings: Research Advances ISSN 2054-3743
Vol. 10. Sustainability in Energy and Buildings (SEB-22) Short Papers pp.1-14 : seb22s-001

APPLICATION OF THE BUSINESS MODEL OF CIRCULAR ECONOMY IN THE FIELD OF CONSTRUCTION AND DEMOLITION WASTE: A LITERATURE REVIEW

Argiro Dimoudi, Professor of Department of Environmental Engineering of Democritus University of Thrace, Head of Ecological Building Materials' Laboratory

Penelope Marmaridou, Ph.D. Candidate of the Department of Environmental Engineering, Democritus University of Thrace

Abstract

In this paper, there is an attempt to map the existing literature about Construction and Demolition Waste (CDW) and the implementation of Circular Economy (CE). After researching on the Web, specifically on renowned scientific platforms, known for the credibility of their sources and the austere acceptance criteria, the results were organized in tables and charts. Through observation of the findings, it is clear that Sustainable Development and Management of the CDW on the basis of CE is a promising scientific field, with plenty of room for advancement.

Key-words/phrases: construction and demolition waste, circular economy, CDW management, sustainability

1. Introduction

Construction and demolition waste (CDW [1]) is a peculiar environmental issue that has been addressed to the public community only quite recently. It's about the materials that occur after the construction of a building, its renovation or its demolition, due to no longer being proper for use. Road construction and land mining are considered special categories of activities that produce CDW, but are not often taken into consideration (Dahlbo et al. 2015). The plethora of the detrimentous environmental consequences they cause is to be taken into serious consideration.

CDW can originate from housing buildings, commercial buildings, and industrial buildings as well as bridges and road networks (Ghisellini et al. 2017). According to reports of the

[1] ***Abbreviations:*** *CDW (Construction and Demolition Waste), EPA (Environmental Protection Agency), CE (Circular Economy), GWP (Global Warming Potential), AP (Acidification Potential), EP (Eutrophication Potential), GRI (Groundwater Replenishment Potential)*

Presented at KES-SEB-2022 14-16 September 2022

Environmental Protection Agency (EPA) of the USA in 2018, the main materials found in the CDW stream are concrete, steel, wood, gypsum and plaster and bricks and ceramic tiles (Bao et al. 2019).

The Environmental Protection Agency (EPA) of the USA recognized CDW as a potential source of pollution in 2001 which immediately led to a massive system of coordination, whose goal was defining the quantities of CDW produced per annum and the ways of treatment implemented, so decisions could be made for their secure and sustainable management. In 2016, construction and building materials' industry accounted for 6.2% of Gross Domestic Product (GDP) of global economy, 6.3% of the European economy and 5.7% of the economy of Latin America (Ruiz et al. 2019).

The country that produces the largest quantities of CDW is China, with the USA following and the European Union comes third. In 2017, the CDW stream in China accounted for 40% of the total municipal solid waste production. Approximately 75% of the cities of China are surrounded by large volumes of CDW (Huang et al. 2018), 80% of which could be treated and redistributed in the market as secondary building materials (Ma et al. 2020).

CDW can be sorted into two distinct categories, based on their ability to react with chemical substances and biological entities, as inert and non-inert. Moreover, there is another way of categorization of CDW, based on the nature of the waste itself. Therefore, there is a physical form of CDW, which is the material stream itself, and the non-physical form, that is mostly about time delays and unexpected terms of expenditure.

The current paper is an attempt to examine the current literature on the management of CDW. More specifically, the search is focused on the variety of applications of the Circular Economy (CE) in the field of construction and demolition waste, as presented in the researches published through the years. Subsequently, each approach on the matter shall be compared with one another and, hopefully, conclusions shall be extracted about the implementation of such a business model and the challenges that are to be answered.

2. Circular Economy

2.1 Definition of Circular Economy

In the previous section, there was a brief description of CDW, but to fully grasp the essence of this project, the definition of Circular Economy must also be presented and analyzed. According to Ginga et al. 2020, Circular Economy or CE is the financial system based on business models that replace the end of life of a product- a part that every product that does not receive continuous support either because

the exit processes have been terminated or due to reaching the end of its useful era- with the process of recycling or alternatively the option of reuse and the retrieval of materials during production, distribution and consumption procedures. The definition of Hellen McArthur Foundation refers to CE as the process that aims to preserve products, materials and their components at the highest level concerning their economic value, the time duration and the usefulness, with the greater purpose of eradicating leftovers and waste.

CE can be achieved with a number of alternatives:

- ***Reduce****: the consumer chooses to purchase and use a product in a lower frequency, due to the knowledge of its consequences of the environment.*
- ***Reuse****: the discarded product can used as it is in a new application, in the existing state. This highly depends on the nature of the product and the degree of alternation it has been through since its first use.*
- ***Transmutation****: the discarded product goes through slight processing and gets used for the same or different purposes.*
- ***Recycling****: the discarded product goes through extended processing and new materials occur for the manufacturing of new products.*
- ***Refusal****: the choice of the consumer not to buy the product, if they are aware of the hazardous consequences of its manufacturing process or of the product itself.*
- ***Energy retrieval****: the discarded product is used as a fuel, thereby releasing its energy content as heat.*
- ***Incineration****: The discarded product is burned and ash occurs that, if treated properly, can be used for multiple purposes, like in a land filling site or soil conditioner. It does not fall into the previous category because the retrieval of energy is not the primary purpose.*

According to the Lansik Scale, which was first presented in 1979 and continues to be valid with a few alterations, the solid waste management methods mentioned above are sorted to show the preferable one, as it seems in the table below:

Table 1: Lansik Scale, 1979. Source: Zhang et al. 2020

Lansik Scale, 1979 (origin of the hierarchy of waste management methods)	
Most desirable	Reduce
	Reuse
	Recycle
	Energy Retrieval
	Incineration
Less desirable	Landfill

2.2 CE in the field of CDW

The construction sector is responsible for about 40% of the carbon dioxide emissions on a global level. More than 50% of the overall amount of waste that is generated in the said sector come from the activities that bring the useful phase of the products to an end, such as demolition. However, only 30% of these materials are recycled or reused (MacArthur 2013, Ruiz et al. 2019, Osobajo et al. 2020).

The factors that affect the retrieval of materials are presented below:

- **Time**: Selective demolition requires more time in comparison with the traditional way, therefore higher costs are expected. Optimal solutions that are relative to the likelihood of recycling and reuse should be severely taken into consideration.
- **Financial feasibility and market acceptance**: The cost of removal of an element (e.g. a ceramic tile) should be balanced by its market price, while simultaneously a recycled product should be competitive and accepted by future users. For some materials, like metals, the market prices depict seasonal variations.
- **Space**: When there are space limitations on the construction site, the sorting of the collected materials must take place in a waste sorting unit. The space distribution requires especially good planning.
- **Location**: The number of recycling units near the construction site or the local waste management services can limit the efficiency of retrieval of materials that come from demolition activities.
- **Weather conditions**: Some techniques are highly dependent on some very specific weather conditions that may not

conform to the time schedule of activities of a construction project (Liu et al. 2021).

2.3 Benefits of the application of CE

The environmental benefits from the application of the Circular Economy business model in the field of CDW are measurable. The consequences that are avoided from the replacement of the virgin raw materials with recycled ones are ten times more than those of the use of newly manufactured materials in terms of CO_2 emissions and eight times more in terms of primary energy consumption (Coelho et al. 2013).

Recycling can save 54% of the initial energy used for the manufacturing of a product, while reuse saves 6.22% and incineration only 0.44%. The option of fixing is also of interest, as it depicts especially low environmental impact in comparison with demolition and reconstruction. Briefly, the GWP (Global Warming Potential) indicators are lowered by 13%, AP (Acidification Potential) indicator is lowered by 34%, EP (Eutrophication Potential) indicator is lowered by 266% and GRI (Groundwater Replenishment Indicator) is lowered by 91% (Ghisellini et al. 2017). When it comes to global warming potential, the most environmentally friendly method of CDW management is recycling, followed by incineration and land filling (Huang et al. 2018).

In a survey conducted in processing sites in Lisbon of Portugal, which are operating for more than sixty years, it was found that the embodied environmental impact which occurs from the equipment installation and its replacement after a period of time is negligible in comparison with the overall impact (embodied impact, operational impact and transportation impact). This kind of CDW recycling sites depict higher rates of primary energy saving and CO_2eq emissions saving relatively with other waste management facilities per processed mass unit. The overall equilibrium of CO_2eq can be ten times bigger, from the saving aspect, than the equivalent percentage of recycled final product from a municipal solid waste processing facility and five times bigger in terms of consumed primary energy saving aspect (Coelho et al. 2013).

3. The existing literature on the implementation of CE in the CDW sector

3.1 Goal and scope of the survey

The information presented above comes from reading papers and articles related to the matter and, generally, searching the Web and all existing sources about the issue.

As it was mentioned in the introduction, the goal of the current paper is to examine the existing sources providing information on the implementation of the CE business model in the field of CDW. This means tracking as many research papers, review articles about methods and scientific models and books referring to the topic as possible and examining the relevance of their content with the correlation of the two terms mentioned beforehand.

3.2 Methodology of the research

The research will be conducted on the websites of Science Direct, Elsevier, Scopus and Emerald Insight. These websites are platforms that are renowned for the plethora of content they provide to the public in a vast variety of scientific fields, such as Medicine, Engineering, Biology, and Physics and so on. The acceptance criteria for a paper are rather strict, which ensure the reliability of the content, its relativity to certain matters and terms and the usefulness to the reader.

The terms that will be searched are “construction and demolition waste management”, “CDW management methods”, “CDW treatment”, “CDW treatment methods”, “CDW and circular economy” and “CE in the field of CDW”. Consequently, the sources will be divided by their form, the subject area and the year they were published. There might be some variations in the findings depending on the structure of each platform.

The next step is about organizing the findings of the research. This means that the information will be presented in the form of tables that will show the number of sources found in each platform, their nature and the year of publication, if such information is provided. Charts shall provide a more definite picture of the current situation. Last but not least, the findings will lead to conclusions about the existing literature, its relativity to the issue and the prevailing form of the publication.

3.3 Results

In this section, the results of the application of the methodology mentioned in the previous chapter are being organized in calculation sheets and shown in the form of tables and figures.

Table 2: Number of annual publications for the period 2018-2022 on several scientific fields

	Year					Subject			
	2018	***2019***	***2020***	***2021***	***2022***	***Env. Science***	***Energy***	***Engineering***	***Materials Science***
CDW management methods	1283	1617	2315	3164	873	6165	2866	7993	3327
CDW treatment	997	1267	1860	2642	764	5334	2898	8772	4579
CDW treatment methods	668	898	1176	1748	551	3376	1379	3593	3058
CDW and Circular Economy	575	780	1005	1560	481	2976	1836	5670	4306
CE in the field of CDW	206	323	570	1025	354	2727	2361	7159	4841
Total	**3729**	**4885**	**6926**	**10139**	**3023**	**20578**	**11340**	**33187**	**20111**

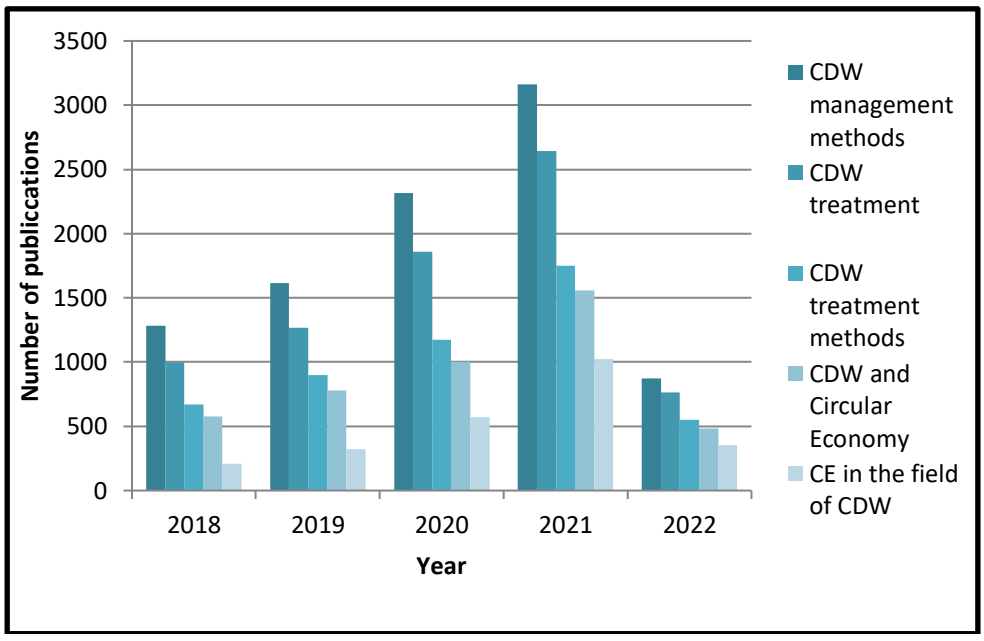

Figure 1: Number of annual publications for each term for the period 2018-2022

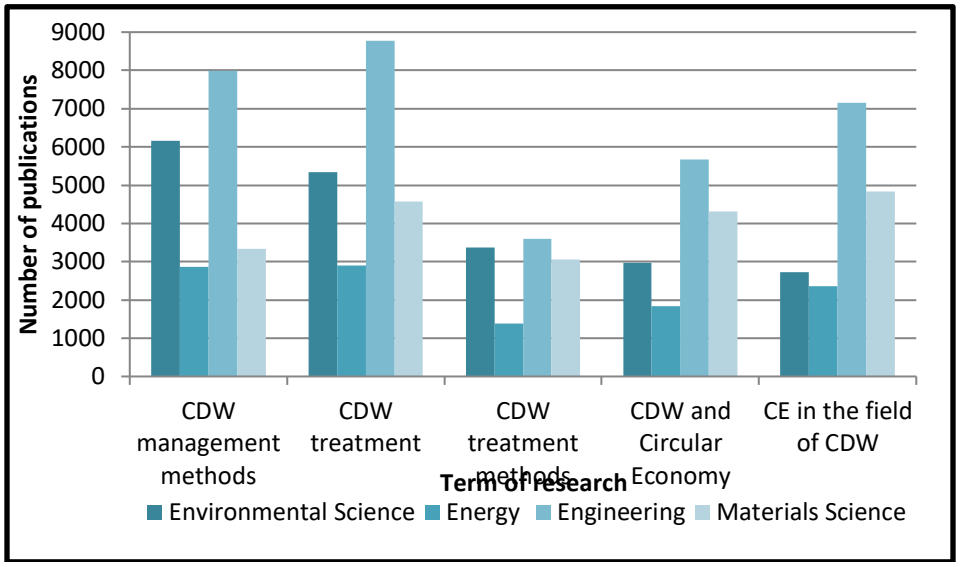

Figure 2: Number of publications for each term of research on every related scientific field for the period 2018-2022

Table 3: Number of publications on Science Direct and Elsevier during the period 2018-2022

	Platform					
	Science Direct				Elsevier	
	Research article	*Review Article*	*Book chapters*	*Encyclopedia*	*Books*	*Journals*
CDW management methods	1081	154	120	21	2190	184
CDW treatment	1019	142	109	19	7366	351
CDW treatment methods	2683	380	236	36	2084	72
CDW and Circular Economy	2383	349	206	33	6854	276
CE in the field of CDW	228	58	36	7	12737	723
Total	**7394**	**1083**	**707**	**116**	**31231**	**1606**

Table 4: Number of publications on Scopus and Emerald Insight during the period 2018-2022

Platform							
	Scopus				Emerald Insight		
	Articles	*Reviews*	*Book chapters*	*Books*	*Article*	*Book parts*	*Case study*
CDW management methods	9263	1108	426	155	738	85	6
CDW treatment	7158	935	252	124	674	63	2
CDW treatment methods	3971	581	164	86	256	43	2
CDW and Circular Economy	3214	524	111	76	232	33	2
CE in the field of CDW	1585	313	76	50	105	29	2
Total	25191	3461	1029	491	2005	253	14

A) Science Direct

As it occurs, research articles are the majority of the publications concerning all related topics, from the general approach of management of CDW to the treatment methods that are utilized. Review articles are the next ones following in numbers. They are a valuable source of information as they evaluate the reliability of a method and its repeatability. Book chapters and encyclopedia are rare compared to the other two categories, as this scientific topic is relatively new, therefore it is constantly evolving and it is difficult to simultaneously organize the already found information and keep up with the new found.

When it comes to the subject area of the publications related to CDW and their management/treatment, Environmental Science is the prevailing domain. It is a quite general scientific field concerning environmental preservation, but, as mentioned before, the sustainable management of CDW is a quite recent concept, thus speculations and theoretical approaches are mostly made. The second scientific field in line is Materials Science, which is a natural consequence, as the main goal is to develop new materials with enhanced properties that come from treated construction and demolition waste.

Concerning the year of publication, it is easily seen that there is a rising interest in CDW through the years. For the year 2022, the number is significantly lower, but this is due to being still in the third month of the year. It is expected to rise and reach the level of the previous year (2021) and, even, surpass it.

B) Elsevier

The structure of the Elsevier platform is somewhat different than that of Science Direct. However, the same logic path is being followed.

According to Table 3, books are the predominant form of publication for CDW management/treatment methods. However, there is a significant issue related to the relevancy of all these publications to the actual scientific topic. Many of the titles are being incuded only because one of the words in the search bar is in the title of the publication, but the content is far from studying the circularity of CDW. Therefore these numbers are not and cannot be deemed representative of the current situation in Research and Development in the field of Circular Economy and Construction and Demolition Waste Management.

It is obvious that Engineering is the predominant field of study of CDW management and treatment. This is due to the interest of the scientific community about the mechanical properties of the recycled building materials. Energy is the following field, which is reasonable, as the amount of energy that is demanded to execute the necessary processes to recycle CDW is a crucial factor about defining if its profile can be characterized environmentally friendly, as well as defining the financial feasibility of the methods.

C) Scopus

It is prominent that the organization of the tables and the charts about Scopus is similar to that of Science Direct. This also provides a better chance for comparison between the two platforms. Once again, research articles are the predominant form of publication, followed by review articles. This could mean that there is a high degree of development and research in the field of CDW with interesting findings that need to be evaluated by peer scientist, so the information is verified.

From Table 1, as well as Figure 2, it is seen that engineering is the main aspect from which CDW is being studied. As it was mentioned before, this is significant, as the mechanical properties of the recycled building materials play a significant role to the final results, which are steady and safe buildings and constructions in general.

Both the chart and the table show that as time passes, the interest about the circularity of construction and demolition waste is growing. Once again, the number of publications in 2022 is lower only because at the point the research about this paper was made, it

was only the third month of the year. The number is expected to reach the levels of 2021 and, even, surpass it.

D) Emerald Insight

The organization of the Emerald Insight platform is somehow simpler than that of Science Direct and Scopus and quite similar to that of Elsevier.

It occurs that articles are once again the prevailing form of publication, without defining the percentages of research articles and peer reviews. Books parts, which are mostly chapters from encyclopedia, are rarer and case studies are the new, but quite interesting, entry with prospects of advancing in the foreseeable future. Though the numbers are quite lower in comparison with other platforms, the same tendency can still be observed, explained in the same manner with the previous data found about the year of publications.

Comparing all the platforms, it is important to mention that there is a significant degree of overlap, as many of the sources appear on more than one platform. Moreover, not all the numbers can be characterized representative. This is because of the algorithm is mixing various scientific fields and quite often shows more results than demanded. Based on a single word on the search bar, it can mingle sources irrelevant to the topic of interest, therefore increasing the number of appearing researches.

4. Conclusions and Challenges

In the current review paper, there was an attempt to map the existing sources concerning the management of construction and demolition waste and the application of the Circular Economy business model. For this purpose, several scientific platforms, known for the austerity of their acceptance criteria and their scientific integrity, were used the results of the research on the Web were organized in calculation sheets. Consequently, tables and figures were made, that were able to provide a more defined picture and lead to some of the conclusions that are demonstrated below:

i. The field of Construction and Demolition waste management is relatively new; therefore there is plenty of room for research on the said scientific topic. New ways to treat and discard the remnants of CDW will be studied, with extra care about utilizing their full potential before they are land filled or incinerated, which are the least wanted options.
ii. Although there is a growing interest for sustainable management of CDW, there is a long way to achieve a high

rate of circularity of this waste stream, as the mechanical properties of the recycled building materials are an issue of vital essence for the structural integrity for future construction projects that integrate such elements. Hence, review articles are expected to grow in numbers and affect significantly the process of scientific research.

iii. The publications tend to increase as time passes, which is the aftermath of natural resources depletion. This leads to the scientific community to attempt utilizing the full potential of the existing resources and achieving circularity in the highest rate possible. Thus, the number of publications will increase in the following years.

iv. Energy is a vital field of study, among Engineering and Materials' Science. Though the physical and mechanical properties of recycled building materials are crucial quality factors, sustainability cannot be achieved if the treatment processes are extremely energy-demanding.

Future challenges will have to deal with the quality standards of the building materials occurring from the recycling process of CDW, the establishment of legal frameworks that ensure the sustainable management of the said waste stream, the compliance and cooperation of the public sector and the governmental authorities, the financial feasibility of this business sector and the competitiveness of these products against the "virgin" ones, and ensuring that every aspect of this issue is approached with regard to the environment and its well-being, in terms of energy and natural resources consumption (Liu et al. 2021).

5. Sources

1. Bao Z., Lu W., Chi B., Yuan H., Hao J., "Procurement innovation for a circular economy of construction and demolition waste: Lessons learnt from Suzhou, China", Waste Management 99, p. 12-21, 19th August 2019, https://doi.org/10.1016/j.wasman.2019.08.031
2. Coelho A., De Brito J., "Environmental analysis of a construction and demolition waste recycling plant in Portugal – Part I: Energy consumption and CO_2 emissions", Waste Management 33, p. 1258-1267, 16th February 2013, http://dx.doi.org/10.1016/j.wasman.2013.01.025
3. Dahlbo H., Bachér J., Lähtinen K., "Construction and demolition waste management: holistic evaluation of environmental performance", Journal of Cleaner Production 107, p. 333-341, 6th March 2015, http://dx.doi.org/10.1016/j.jclepro.2015.02.073
4. Ginga C.P., Ongpeng J. M., Daly M.K., "Circular Economy on Construction and Demolition Waste: A Literature Review on Material Recovery and Production", Materials 13, p. 2970-2988, 3rd July 2020, doi: 10.3390/ma13132970
5. Huang B., Wang X., Kua H., Geng Y., Bleischwitz R., Ren J., "Construction and demolition waste management in China through the 3R principle", Resources, Conservation & Recycling 129, p. 36-44, 17th October 2017, http://dx.doi.org/10.1016/j.resconrec.2017.09.029
6. Liu J., Wu P., Jiang Y., Wang X., "Explore potential barriers of applying circular economy in construction and demolition waste recycling", Journal of Cleaner Production 326, p. 129400, 16th October 2021, https://doi.org/10.1016/j.jclepro.2021.129400
7. Luis Alberto López Ruiz, Xavier Roca Ramón, Santiago Gassó Domingo, The circular economy in the construction and demolition waste sector – a review and an integrative model approach, Journal of Cleaner Production (2019), https://doi.org/10.1016/j.jclepro.2019.119238
8. Ma M., Tam V., N. Le K., Li W., "Challenges in current construction and demolition waste recycling: A China study", Waste Management 118, p. 610-625, 1st October 2020, https://doi.org/10.1016/j.wasman.2020.09.030
9. Osobajo O., Oke A., Omotayo T., Obi L.I., "A systematic review of circular economy research in the construction industry", Systematic review of circular economy research, p. 2046-6099, Accepted 22nd June 2020, DOI 10.1108/SASBE-04-2020-0034
10. Patrizia Ghisellini, Maddalena Ripa, Sergio Ulgiati, Exploring environmental and economic costs and benefits of a circular

economy approach to the construction and demolition sector. A literature review, Journal of Cleaner Production (2017), https://doi: 10.1016/j. jclepro.2017.11.207

11. Zhang C., Hu M., Di Maio F., Sprecher B., Yang X., Tukker A., "An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe", Science of Total Environment 803, p. 149892, 1st September 2021, https://doi.org/10.1016/j.scitotenv.2021.149892