

Article

Zero Waste Systems: Barriers and Measures to Recycling of Construction and Demolition Waste

Lilliana Abarca-Guerrero ^{1,*} , Susi Lobo-Ugalde ², Nicole Méndez-Carpio ³, Rosibel Rodríguez-Leandro ³ and Victoria Rudin-Vega ²

¹ Chemistry School, Environmental Protection Research Center, Instituto Tecnológico de Costa Rica, Cartago 30104, Costa Rica

² Asociación Centroamericana para la Economía, la Salud y el Ambiente, San Jose 40602, Costa Rica

³ Chemistry School, Instituto Tecnológico de Costa Rica, Cartago 30104, Costa Rica

* Correspondence: labarca@itcr.ac.cr; Tel.: +506-88325488

Abstract: Urbanization, population growth, increased consumption, infrastructure, and housing needs are some of the factors that result in increased waste. Recycling has been a crucial way to reduce the amount of materials that end up in disposal sites and is how citizens, more aware of the impacts on the environment, participate in some of the schemes to reduce waste. Zero waste is an approach developed to preserve the finite resources available, but major barriers are hindering its efficient and effective implementation. This study intended to unveil those barriers in the Costa Rican construction sector and to propose measures to increase the recycling rates. In order to achieve the objective, construction companies, cement producers, waste managers, personnel of refuse material facilities, waste transformers, construction material distributors, and a director of the Ministry of Health were interviewed to determine the challenges in the valorization of concrete, wood, metal, and packaging waste materials. This article reports the findings, which include, among others, the fact that most construction companies dispose the waste without any separation, except for metals. The cement producer companies do not participate in any form of collection system in spite of the available technology and equipment and the absence of innovative technologies for the transformation of materials.

Keywords: zero waste barriers; construction industry; recycling; measures for valorization of construction waste



Citation: Abarca-Guerrero, L.; Lobo-Ugalde, S.; Méndez-Carpio, N.; Rodríguez-Leandro, R.; Rudin-Vega, V. Zero Waste Systems: Barriers and Measures to Recycling of Construction and Demolition Waste. *Sustainability* **2022**, *14*, 15265. <https://doi.org/10.3390/su142215265>

Academic Editor: Miklas Scholz

Received: 21 September 2022

Accepted: 8 November 2022

Published: 17 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Cities around the world are expanding rapidly due to population growth, with the consequence of an increasing consumption of resources and the production of residues. Municipalities, mostly responsible for waste management, face a burden on the municipal budget caused by the high costs associated with its management [1,2].

Different approaches and tools have been proposed in order to reduce waste. In 1979, Dr. Ad Lansink, introduced the Waste Hierarchy as a simple ranking system used for the different waste management options, according to which is the best for the environment. Its objective is to maximize efficiency in the use of natural resources by means of reducing waste at the source, reusing materials, recycling, energy recovery, and landfilling. In spite of criticism, it has been incorporated in the regulations in different parts of the world [3].

Another concept shaped after a conference in Geneva in 2002 is Zero Waste. This is a set of principles proposing the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health [4].

Both approaches, as well as others proposed, include recycling as one of the means to reduce the loss of materials in the environment. Nevertheless, achieving Zero Waste in

urban centers remains a utopian quest, unless there is a good understanding of the inputs and outputs of materials [5].

Although recycling is a challenge for all the countries, some European countries report high recycling rates: Germany 56.1%, Austria 53.8%, and Switzerland 49.7% and in Asia: South Korea 53.7% and Singapore 34.0% [6]. On the other hand, low values are reported in Latin America, where the Inter-American Development Bank estimated that only 2.2% of all municipal solid waste is recycled under any sort of formal arrangement [7]; the value reported for Costa Rica is around 3% [8].

1.1. Household Waste Recycling in Costa Rica

Two different studies report the barriers for the low recycling rate of household waste in Costa Rica. They are grouped according to financial, institutional/regulations, technical, and socio-cultural aspects and presented in Table 1.

Table 1. Barriers for household waste recycling [9,10].

Financial	Low (international) prices of recycled materials, operation, and investments costs are not covered
	Limited market, few companies determine the price and buy materials
	High direct costs: taxes, social charges, electricity price, high transportation costs
	Recycling sector has difficulties accessing credit due to guarantees needed, equipment is not allowed as collateral, high interest rates
	Lack of measures to consider the base recyclers (waste pickers) when the landfills are closed
	High costs and complicated processes to formalize recycling related businesses
Institutional/normative	Infrastructure and equipment are expensive
	Lack of financial incentives for the activity
	Excessive requirements (permits), complex and slow registration processes
	Government not supporting procurement of products with recycled material
	Lack of support to the recycling sector from decision makers
	Unfair competition by non-formalized companies, which operate with lower costs
Socio-cultural	Formal companies can no longer buy material from waste pickers
	Most municipalities do not collect waste separately, as a result much material goes to final disposal sites
	Poor separation by households of recyclable materials, especially plastic
	Little recognition of grassroots recyclers (waste pickers) and their work by the municipalities and citizens
Technological	Different stakeholders in the recycling value chain do not understand the needs of each other
	Lack of recognition of the good initiatives and investments made in the solid waste sector
	No technical support from knowledge organizations for the transformation of materials. The recyclers learn by doing
	Companies lack knowledge on modern machinery and technologies to improve and increase production processes
	Workers at recycling related businesses with low skills
	There are no detailed statistics on available materials, real savings, or ecological footprint due to recycling
	Materials cannot be transformed in the country

1.2. Construction Sector and the Environment

As cities grow, more investments in infrastructure are needed, as well as housing projects to provide shelter and services to the increasing population. This situation has imposed pressure upon the construction sector [11–14].

This industry is well known as contributing to a significant percentage of the Gross Domestic Product (GDP) in low- and middle-income countries, providing employment

to a substantial portion of the working population. Nevertheless, at the same time it is perceived as a major contributor to environmental degradation, due to its high consumption of natural resources, such as water and energy among others, and the generation of, inter alia, greenhouse gases, waste, waste waters, and dust [15–17].

Construction and demolition waste (C&DW) is considered the largest waste flow worldwide and has reached to 30–40% of total waste according to Akhtar and Sarmah [18], while some other scholars have reported higher proportions of C&DW disposed in landfills, as presented in Table 2.

Table 2. Percentage of C&DW at different landfill sites.

Country	C&D Waste (% by Weight)	Reference
Netherlands	26	[19]
Hong Kong	44	[20]
England and Wales	42.2	[21]
Kuwait	15–30	[22]
USA	20–29	[19,23,24]
Australia	20–30	[25]
Germany	19	[25]
Finland	13–15	[26]
Japan/Tokyo	57	[27]
Worldwide	13–35	[19,28]

C&DW has been extensively studied in developed countries, but few reports are from low- and middle-income countries, such as Costa Rica. Therefore, a study was performed in the country with the participation of fifty-two (52) companies: 30 small, 15 medium, and 7 large firms. They were asked, among others, the types of non-hazardous and hazardous waste produced during the development of their projects. Figures 1 and 2 show the percentage of companies that reported the generation of the specific non-hazardous and hazardous waste streams. The most common non-hazardous materials include cement bags (2-layers kraft paper + polypropylene), pieces of polyvinyl chloride (PVC), electric wires, clean wood, and plastic (high and low density) packaging materials [29]. At the time of the study, the insulation materials were considered as non-hazardous, as mentioned by del Río Merino et al. [30]. On the other hand, polyvinyl chloride (PVC) was at the center of a controversial debate, in which a number of diverging scientific, technical, and economic opinions have expressed that it affects human health and the environment.

The most important hazardous materials consist of metallic and plastic paint containers and paint residues in mixing vessels, textiles impregnated with solvents used to clean surfaces before painting, paintbrushes, and gypsum-based materials, all of which are disposed generally in inadequate disposal sites making it a toxic waste. Asbestos was reportedly not present.

Various studies have analyzed the composition (in percentage) of C&DW, which is presented in Table 3. Concrete and related materials, wood, metal, gypsum, and plaster, as well as packaging materials, are the most abundant ones found in those countries.

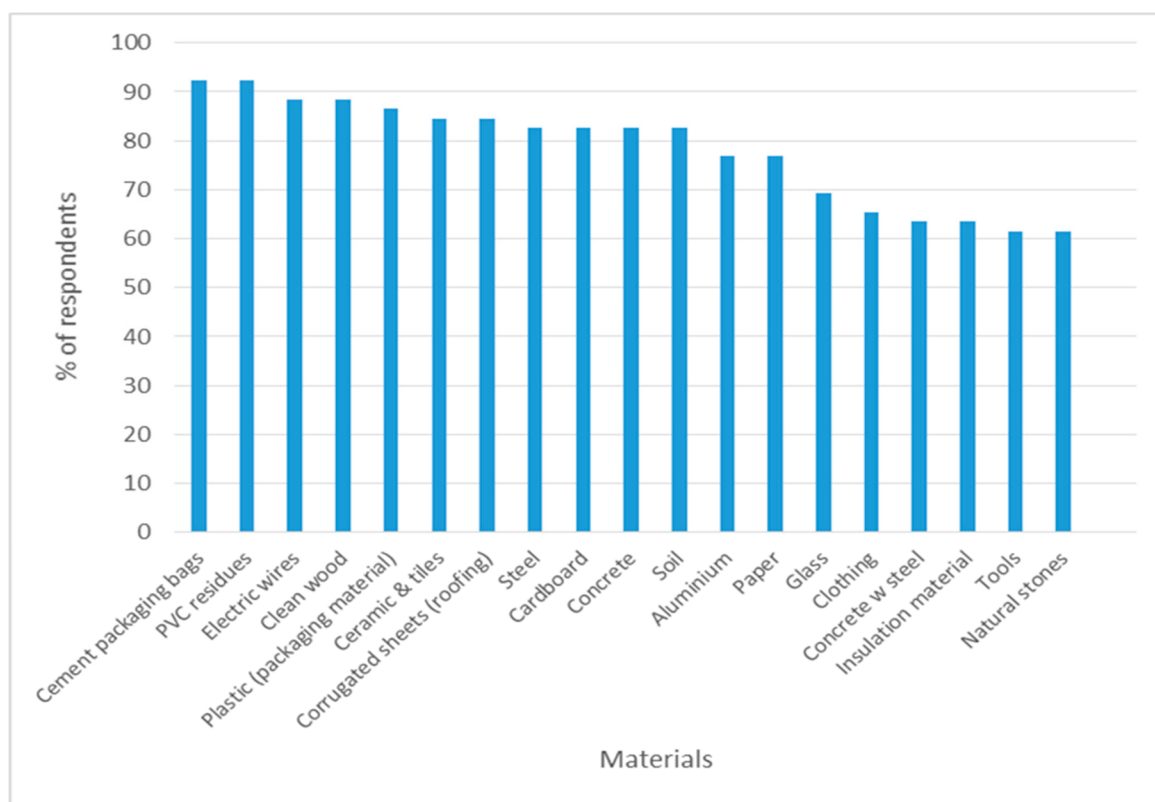


Figure 1. Percentage of companies reporting non-hazardous waste streams.

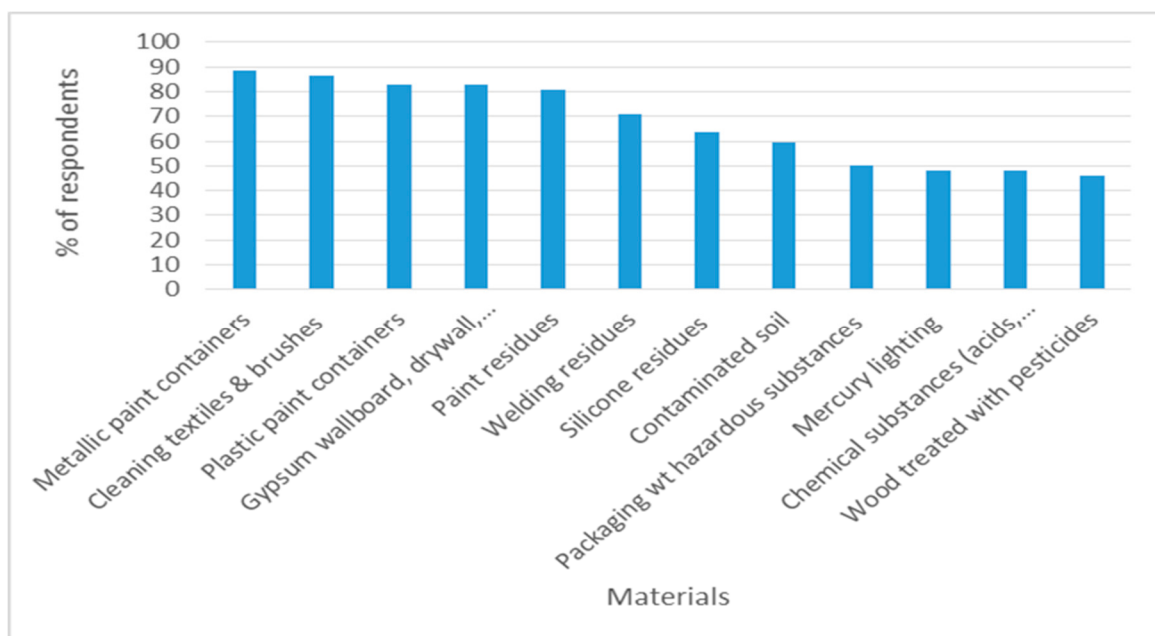


Figure 2. Percentage of companies reporting hazardous waste streams.

Table 3. Composition (in percentage) of C&DW in different countries.

Type of Construction	Place	Composition (%)								Reference
		Concrete	Masonry (Concrete Blocks, Bricks, and Concrete Residues)	Wood	Gypsum and Plaster	Metals	Roofing Materials	Plastic	Paper/ Cardboard	
Residential and non-residential	Lebanon	23.00	17.44	11.50	-	3.30	-	-	-	[31]
	Norway	45.80		13.67	6.25	1.32	-	4.50		[32]
	Thailand	46.00		14.00	6.00	1.00	2.00	5.00		[33]
	Spain	29.30	-	5.40	3.60	8.80	-	3.80	3.40	[34]
	USA	40.00–50.00	1.00–5.00	20.00–30.00	5.00–15.00	1.00–5.00	1.00–10.00	1.00–5.00	-	[35]
	Chongqing, China	14.00	23.00–29.00	15.00	-	2.50	-	-	4.00	[36]
Non-residential (general)	Florida, USA									[37]
Non-residential (Institutional)	Malaysia	65.80	1.60	5.00	-	1.00	0.20	0.05		[38]
	Portland, Oregon, USA	-	-	20,50	-	-	-	-	19.30	[39]
Total intervals		14.00–65.80	1.00–46.00	5.00–30.00	3.60–15.00	1.00–8.80	0.20–10.00	0.05–5.00	0.05–19.30	
Unknown	Texas, USA	48.50		40.70	-	2.10	-	0.30	1.20	[40]

1.3. Construction and Demolition Waste Recycling

The amount of C&DW generated in Costa Rica by the industry is also increasing at a rapid rate and the proper management of it is a challenge, particularly in developing countries. Recycling is one of the options to obtain a Zero Waste Activity, but the construction industry is far from reaching sustainability. Therefore, a study was done in order to determine the obstacles faced by the Costa Rican construction sector in order to increase recycling rates for concrete, wood, metal, and packaging materials. The barriers studied are presented in Tables 4–8, which are grouped around technical, financial, social, environmental, and legal aspects.

Table 4. Barriers to recycling of C&DW according to technical aspects.

Material	Location	Barrier	Source
Concrete	European Union (EU)	Research deficiencies about alternatives for concrete recycling except for road works	[41]
Concrete	EU	Separation at source inadequate, reducing the quality of the waste material for recycling	[41]
Concrete	EU	Design of buildings do not consider the end of life of the building	[41]
Concrete	EU	Green building systems of some European countries (e.g., German Sustainable Building Certificate, HQE-Haute Qualité Environnementale in France, BREEAM-BRE Environmental Assessment Method in the UK), do not integrate in their rating charts the re-use of concrete elements and the use of structural concrete made of recycled aggregates	[41]
Concrete	Canada	Residual contaminants reduce aggregate compressive strength by about 25%	[42]
Concrete	Canada	Source separation of materials is difficult	[42]
Concrete	Canada	It is not cost effective to deconstruct and reuse concrete	[42]
Wood	Canada	Inadequate management of on-site grading, particularly in the case of preserved wood products	[42]
Wood	Canada	Lack of knowledge on treatments options enabling the reuse and recycling of preserved wood	[42]
Wood	Canada	Absence of infrastructure for the collection, transport, storage, and preparation of preserved or untreated wood	[42]
Steel	Canada	Complications of reusing building components in “as is” condition	[42]
Wood	Norway	The barrier is related to form, strength, and contaminations	[42]
Concrete	Norway	Removal of paint in concrete is costly therefore it is sent to special disposal sites	[42]
Concrete	Norway	Construction companies might not have the equipment to separate concrete from the reinforcing bars	[42]
Concrete	Norway	New road projects consider recycled concrete to be of low quality, despite evidence showing the contrary	[42]
Kraft paper packaging	N.I.	Bags impregnated with cement causes conventional paper recycling to be impossible	[43]

N.I. not indicated.

Table 5. Barriers to recycling of C&DW according to financial aspects.

Material	Location	Barrier	Source
Concrete	European Union	Funding problems for research on alternatives to optimize existing options for recycling	[41]
Concrete	Canada	Recycled aggregates are considered of low quality, therefore it should have a lower price	[41]
General	N.I.	Lack of funding to implement circular economy in C&DW management	[41]
General	N.I.	Construction costs do not reflect environmental costs	[42]
General	N.I.	Lack of time for C&DW separation	[42]
General	N.I.	Absence of contractual requirements for the reuse and recycling of materials	[42]
General	N.I.	Reluctance to segregate for recycling and re-using materials with a low economic value or difficult to reuse	[42]
General	N.I.	Perspective that C&DW management are not cost-effective	[42]
Wood	Canada	Infrastructure for timber recycling is considered costly	[42]
Concrete	Japan	It is more costly and energy-intensive to produce aggregates from recycled concrete than from virgin raw materials	[42]
Concrete	Norway	The cost of virgin gravel can be cheaper than recycled aggregate when the transportation and storage costs are added	[42]
Concrete	USA	Recycling plants are not always available near demolition sites and sometimes charge a fee to process the demolition waste; it is cheaper to transport waste to the landfills	[42]
General	N.I.	Priority is given to economic benefits and not to environmental aspects	[42]
General	N.I.	Lack of financial incentives for reduction or recycling of C&DW	[42]

N.I. not indicated.

Table 6. Barriers to recycling of C&DW according to social aspects.

Material	Location	Barrier	Source
General	N.I.	Attitude of constructors toward C&DW	[44–46]
General	N.I.	User preference for new over reused or recycled materials	[45,47]
General	N.I.	Construction industry culture	[44]
General	N.I.	Lack of a well-developed C&DW recycling market	[42,48]
General	N.I.	Low customer demand for sustainable buildings	[49]
General	N.I.	Difficulty to modify labor practices	[48]
General	N.I.	Belief that efforts will not be sufficient to eliminate C&DW completely	[12]

N.I. not indicated.

Table 7. Barriers to recycling of C&DW according to environmental aspects.

Material	Location	Barrier	Source
Concrete	European Union	Deficiencies in the planning, design, renovation, and deconstruction processes hinder the “zero discharge” target	[41]
General	N.I.	Inefficient processes of dismantling, classification, transport, and recovery of C&DW	[42,44,50]
General	N.I.	C&DW reduction does not receive sufficient attention in construction planning and design	[49,50]
General	N.I.	Limited use of recyclable materials in construction	[50]
General	N.I.	Unfriendly methods in the construction and demolition processes	[46,47,51,52]
General	N.I.	Landfilling is preferred due to the lack of incentives for other treatments	[47,53,54]
General	N.I.	Lack of Extended Producer Responsibility for construction materials	[55,56]
General	N.I.	Complexity for the transformation of the sector into a circular economy model of production and consumption	[45,46,56]
General	N.I.	Lack of knowledge and awareness related to the management of C&DW	[44,47,56]
General	N.I.	No benefits for sorting packaging materials	[44]
General	N.I.	Lack of integration of sustainable C&DW management	[56]
General	N.I.	Uncertainty in moving toward circular economy in C&DW management	[45,56]
General	N.I.	Lack of certainty on the status of the C&DW	[42,44]

N.I. not indicated.

Table 8. Barriers to recycling of C&DW according to legal aspects.

Material	Location	Barrier	Source
Concrete	European Union	Insufficient regulation support prohibiting the disposal of C&DW in dumps or landfills, so there is less encouragement to recycle it	[41]
Concrete	European Union	Deficiencies in certifications demonstrating that recycled concrete complies with standards and can meet the same properties as virgin materials	[41]
General	N.I.	Inadequate regulations and enforcement for C&DW	[47,48,55,57,58]
General	N.I.	Lack of clear C&DW national goals, objectives, and vision	[46,54,59]
General	N.I.	Lack of standardized reporting and accessible data on C&DW reduction	[12,46]
General	N.I.	Contractors lacking economic penalizing methods for C&DW management	[48]
General	N.I.	Lack of coordination among stakeholders of construction sector	[49]
General	N.I.	Inconsistencies between different governmental institutions	[49]
General	N.I.	Absence of industry standards or performance standards for C&WM	[60]
General	N.I.	Individual responsibilities in terms of waste management are poorly defined	[60]
General	N.I.	Lack of enforcement of construction and waste management policies and plans	[48]
Wood	Japan	The recycling policy is not complied with, as the preference is to use wood as an energy resource rather than to recycle	[42]

N.I. not indicated.

This article reports the findings and provides some ideas on how to overcome these barriers.

2. Materials and Methods

This study had the aim to determine the barriers different stakeholders from the construction sector face in order to reduce C&DW by means of recycling. It also intended to provide some actions that would increase recycling rates. In order to obtain information,

the literature provided an overview of the reported barriers affecting household waste recycling as well as C&DW. A questionnaire for different stakeholders of the construction sector was prepared based on the information gathered and sent to thirty contractors (30) of small, middle, and big size construction companies. Another one was planned for the only two (2) cement producers, which are part of multi-national companies from Mexico and Switzerland as well as another one adapted for twenty-five (25) waste managers along with two (2) refuse material facilities, all registered at the Ministry of Health with a permit to manage specific types of waste. Additionally, a survey was prepared to be applied to nine (9) waste transformers utilizing construction waste for recycling purposes, three (3) cement, wood, and metal distributors to determine environmental practices within the company toward recycling and one (1) director of the Ministry of Health to determine the vision and support toward C&DW recycling.

The questionnaire contained questions that covered a number of topics: general information about their business, questions related to the recovery of construction and demolition waste, the technical, financial, social, environmental, and legal barriers faced by their organizations, and ideas on how to overcome them, according to their point of view. Prior to the data collection, the survey instrument was pre-tested for ease of understanding and content validity. Suggestions to improve the tool were included as recommended.

Efforts were made to ensure high response rates from respondents, especially due to the fact that, the research was performed during the COVID-19 pandemic. These included telephone follow-ups, e-mails with reminders, interviews, and site visits (when possible). The responses were obtained from a total of ten (10) construction companies, eleven (11) waste managers (5 related to wood, 3 to metals, and 3 to concrete), two (2) cement-producing companies, six (6) waste transformers, and one (1) material refuse center.

An interview was prepared for the director of the Ministry of Health in which the main topics presented were related to the Costa Rican legislation in regard to waste in general and C&DW, barriers for recycling from the normative point of view, and the support the Ministry provides to enable the environment to increase C&DW recycling rates.

3. Results and Discussion

The number of responses received does not necessarily allow for generalizations but permits the determination of the challenges different stakeholders face in relation to C&DW recycling toward a Zero Waste System. However, an individual perspective is provided on each of the actors involved.

3.1. Construction Companies

Ten construction companies provided information in which most of them dispose wastes without any separation, except for metals, due to their value in the market, especially steel, iron, and aluminum. Four respondents mentioned the separation of concrete waste to be used within the project and half of them reuse wood in the same or other projects as formwork. Packaging materials sometimes are utilized to fill up hollow concrete blocks as a way to reduce the waste sent to the disposal sites.

3.2. Cement Producing Companies

Two companies produce cement in Costa Rica. Both stated being aware of the waste produced from their products and having a collection system for their packaging materials; however, the latter functions mainly under contracts between the cement companies and big construction firms. This practice is the result of the obligation, for the contractors, to have a proper waste management system in order to participate in public tenders. The waste collected becomes alternative fuel in the cement kilns. Small and medium companies and hardware shops do not participate in any form of collection system in spite of the available technology and equipment.

3.3. Waste Management Companies

3.3.1. Concrete Managers

Three concrete managers responded to the questionnaire. One of the respondents expressed they collected the waste and disposed it in a landfill. Another one indicated they classified the waste into two categories: clean or contaminated. In case of clean material, it was used as covering material in landfills, while the contaminated one was disposed in a fixed place of the landfills. The third company informed the concrete waste was not properly separated because that required more labor, thus increasing construction costs; therefore, they preferred to send it to a landfill.

3.3.2. Wood Managers

Four wood managers provided answers to the questionnaires. Each company, respectively, pointed out the lack of innovative solutions for this type of waste. Efforts have been made to reduce it but the cost to remove nails, concrete, and other materials increases the expenses of the treatment. In some cases, wood is used as fuel for kilns in the cement companies; in others, it is chipped and used as soil amendment or pelleted for fuel.

3.3.3. Metal Managers

Three metal managers reported the collection and separation of copper, bronze, steel, aluminum, and other metal scrap to be exported mainly to Asia and other countries in Europe and America.

3.3.4. Packaging Materials

No organization was found to manage packaging materials from the construction and demolition sector.

3.3.5. Material Transformation Facilities

Material transformation organizations are mainly micro and small enterprises facing many financial, institutional, technical, and socio-cultural challenges. They mentioned the burdens faced in order to transform materials from the construction and demolition sector. Access to credits and modern transformation technology among others are critical barriers to be more effective in recycling those wastes.

3.3.6. Distributors of Construction Materials

Only one company responded to the information requested and indicated that there is no extended responsibility for the materials they bring into the market. As a result, their participation in the management of the associated wastes is null.

3.3.7. Governmental Office

The congress of Costa Rica passed the National Waste Management Law in 2010, but it still lacks specific regulations for C&DW. Therefore, there is no incentive for the companies to implement the efficient use of materials and good treatment practices.

3.4. Materials Reused and/or Recycled in Costa Rica

During the study it was found that the only materials reused are clean and painted wood to be used as formwork or scaffoldings. The removed soil is used for gardening if it is not polluted.

Most of the metals are exported to Europe, Asia, North America, and some are recycled in the country. A diversity of plastic materials from packaging are transformed as recycled resins. They are mostly High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), and Polypropylene (PP). In less quantities, they are Polyvinyl Chloride (PVC or Vinyl), Polyvinyl Chloride (PVC), and Polystyrene (PS or Styrofoam) on an experimental recycling development stage. Polyethylene Terephthalate (PET or PETE) is mostly exported.

3.5. Barriers Found for C&DW Recycling in Costa Rican

3.5.1. Technical Barriers

It was found that the starting point of the low rate of recycling of C&DW is the fact that the designs of buildings do not consider the end of life. Once the waste is produced, the separation at the source is difficult, costly, and inadequate. There are deficiencies in the research in order to treat and recycle the concrete, wood, and packaging material. Metals are an exception due to the price in the international markets. Additionally, there is an absence of infrastructure and equipment for the separation at the source.

3.5.2. Financial Barriers

The construction companies have the perception that C&DW management is not cost-effective and that priority is given to economic benefits not to environmental aspects. The construction costs do not reflect environmental costs; it is cheaper to transport waste to the landfills. Additionally, funding research on the implementation of circular economy and alternatives to optimize existing options for recycling is difficult. In the country, it is more costly and energy-intensive to produce aggregates from recycled concrete than from virgin raw materials, the cost of virgin gravel can be cheaper than recycled aggregate when the transportation and storage costs are added. The market for recycled materials is not well developed.

3.5.3. Environmental Barriers

The country has promoted the principle of Extended Producer Responsibility for materials declared of special management but not yet to any construction material. The directors of construction companies lack knowledge and awareness related to the management of C&DW. Sustainable construction is still at an initial stage.

3.5.4. Social

Clients do not demand sustainable buildings. The construction industry as a whole has a culture in which they believe that efforts will not be sufficient to eliminate C&DW completely. The workers at the construction sites resist modifying their construction practices.

3.5.5. Legal

There is a national law related to waste in general but there are inadequate regulations and enforcement for C&DW. It is easier to dispose C&DW in dumps or landfills than find opportunities for reuse or recycle. Contractors lack penalizing methods for C&DW management. The country is lacking clear C&DW national goals, objectives, and vision.

3.6. Measures Proposed for the Valorization of C&DW

The questionnaire included items in relation to measures the organizations would propose to valorize the waste produced. These are summarized below as technical, financial, environmental, social, and legal measures.

3.6.1. Technical

- Conduct further research to demonstrate that recycled aggregates can be used for other purposes than structural or road projects.
- Train engineers and architects on alternatives for the use of concrete waste.
- Raise awareness among construction companies and managers so that they do not discard painted concrete, since cement producers can recycle it.
- Encourage partnerships between construction companies, managers, and processors of C&DW.
- Promote access to information or participation in international fairs to gain new insights in technology, innovation, and equipment for the transformation of C&DW.

3.6.2. Financial

- Create a market for recycled materials within the construction sector.
- Promote the environmental and economic benefits of using recycled materials in construction companies.
- Develop incentives, exemptions, or environmental certificates, for those companies with proper management of C&DW.
- Train managing SMEs on circularity and its important role in the market.
- Request the banking sector (public and private) open more accessible green credits for proper C/DW management.
- Promote the transformation and national commercialization of C&DW, through financial facilities for the acquisition of required equipment and infrastructure.
- Ensure cement producing companies are aware of the environmental impact of their packaging and their extended responsibility as producers.

3.6.3. Environmental

- Create alliances with other companies in order to exchange waste materials that can be reused.
- Incentivize research on the transformation of C&DW into new products.
- Create a seal and/or product certification for recycled construction materials.
- Raise awareness, through talks or training, to cement producers and distributors, regarding Extended Producer Responsibility toward their packaging materials.
- Comply with legislation regarding the management of wood and cement packaging materials.

3.6.4. Social

- Create a permanent dialogue platform among actors in the value chain, which facilitates coordination, training, technical assistance, and exchange of experiences.
- Create awareness on clients, designers, and constructors on the uses of recycled materials in projects, where quality can be guaranteed.
- Incorporate topics associated to sustainable construction, where the integration of recycled materials is considered, into university curricula.
- Encourage universities and research centers to investigate the technical characteristics of recycled C&DW.
- Ensure construction companies are aware of the importance of separating their waste for its recovery and recycling.
- Promote, through construction unions (e.g., Construction Chambers, Federation of Engineers, and alike), the use of recycled materials that meet the quality criteria established by such entities.
- Develop a strategy involving all the actors from the sector in searching for solutions to C&DW.

3.6.5. Legal

- Develop specific regulations for the proper management of C&DW.
- Enforce existing regulations in relation to C&DW current practices.
- Ensure information is available from regulatory entities regarding the procedures that construction companies must follow in relation to C&DW.
- Update the legal requirements to be more flexible for the collection and processing of waste materials.
- Propose the inclusion of the informal collection sector into the simplified Tax Regime and eliminate the obligation to pay taxes when the transaction is lower than a threshold.

4. Conclusions

Zero Waste proposes the conservation of all resources by different means, one of them being the recycling of wasted products. Nevertheless, there are limiting factors and barriers

that hinder performance regarding C&DW management. Understanding the barriers that limit the recycling of C&DW can promote the development of solutions that are technically safe, economically viable, environmentally sound, and socially and legally accepted.

The barriers found in Costa Rica have as well been reported by other authors and presented on Tables 4–8. They have been presented to the ministries of Economic Affairs, Health, Finances, Environment, and the construction sector with the objective to determine paths to reduce or eliminate them with the objective to promote circular economy for the sector.

Efforts are being made in the country to start the use of C&DW as base for roads, as well as to increase the recycling rate of materials that can be transformed in the country.

In Costa Rica, the challenges for an efficient and effective C&DW management require the participation of different stakeholders. The construction sector must adopt responsibility for the environmental impact of their processes and materials chosen for their products. The government must provide an enabling environment by promoting legislation and removing the barriers that would cause the activity to have less impact on the environment. The customers must be aware of their responsibility for their choices of materials, construction processes, and the end of life of the waste produced.

Universities and research centers can promote innovation incorporating new ideas for recycled products and processes, which can generate changes. Nevertheless, those products and processes should be developed according to the respective legislation in the country.

Contractors, manufacturers, distributors, and vendors of construction materials and products are not obliged in Costa Rica to adopt any responsibility for the end of life of their products. Extended Producer Responsibility (EPR) could be a policy to encourage the construction sector to reduce the environmental burden of C&DW. At this moment, the country has 14 types of waste under EPR voluntarily agreements, but none correspond to C&DW.

Author Contributions: Conceptualization, L.A.-G., S.L.-U. and V.R.-V.; data collection, L.A.-G., S.L.-U., N.M.-C., R.R.-L. and V.R.-V.; formal analysis and investigation, L.A.-G., S.L.-U., N.M.-C., R.R.-L. and V.R.-V.; methodology, L.A.-G., S.L.-U. and V.R.-V.; project administration, L.A.-G. writing—original draft preparation and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received partial funding from Instituto Tecnológico de Costa Rica, project Transforma Residuos en Recursos sponsored by the Federal Ministry of Environment from Germany (BMU), Fundación CRUSA, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and was supported by the Ministry of Environment and Energy and Dirección Cambio Climático from Costa Rica.

Institutional Review Board Statement: During the analysis of proposals, it was determined that the study did not need an Ethics Committee evaluation since the information requested did not involve sensitive data. The questionnaires stated in the introduction of the tools the following: “Your . . . (organization, municipality, institution, company) play an extremely important role in the recycling chain in our country, but at the same time it faces great financial, institutional and technical challenges. These can be seen as barriers to increasing the collection of waste materials. The purpose of the following survey, is to determine the factors or barriers that affect the work your” (organization, municipality, institution, company) do.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We would like to thank all anonymous reviewers for their inspiring and constructive comments on the paper.

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

References

1. Tseng, M.L.; Chiu, A.S.F.; Liu, G.; Jantaralolica, J. Circular Economy enables sustainable consumption and production in multilevel supply chain system. *Resour. Conserv. Recycl.* **2020**, *154*, 104601. [CrossRef]
2. Abarca-Guerrero, L.; Maas, G.; Hogland, W. Solid waste management challenges for cities in developing countries. *Waste Manag. J.* **2013**, *33*, 220–232. [CrossRef]
3. Lansink, A. *Challenging Changes: Connecting Waste Hierarchy and Circular Economy*; LEA: Hague, The Netherlands, 2017; pp. 23–26.
4. Zero Waste International Alliance (ZWIA). 2018. Available online: <https://zwia.org/zero-waste-definition/> (accessed on 2 August 2022).
5. Awasthi, A.K.; Cheela, V.R.S.; D’Adamo, I.; Iacovidou, E.; Islam, M.R.; Johnson, M.; Miller, T.R.; Parajuly, K.; Parchomenko, A.; Radhakrishnan, L.; et al. Zero waste approach towards a sustainable waste management. *Resour. Environ. Sustain.* **2021**, *3*, 100014. [CrossRef]
6. European Environmental Bureau (EEB); Eunomia. Recycling—Who Really Leads the World? Identifying the World’s Best Municipal Waste Recyclers. Available online: https://eeb.org/wp-content/uploads/2019/06/Recycling_who-really-leads-the-world-REPORT.pdf (accessed on 11 August 2022).
7. Inter-America Development Bank (IADB). Solid Waste Management in Latin America and the Caribbean. August 2015. Available online: <https://publications.iadb.org/en/solid-waste-management-latin-america-and-caribbean> (accessed on 11 August 2022).
8. Ministerio de Salud; Ministerio de Ambiente y Energía. Línea Base del Plan Nacional de Residuos Marinos 2021–2030. 2021. Available online: <https://minae.go.cr/noticias-minae/documentos/259-plan-nacional-de-residuos-marinos-2021-2030> (accessed on 11 August 2022).
9. Rodríguez Leandro, R. Retos y Oportunidades para la Valorización de Residuos Sólidos en Costa Rica. Licentiate Thesis, Instituto Tecnológico de Costa Rica, Cartago, Costa Rica, 2020. Available online: https://repositoriotec.tec.ac.cr/bitstream/handle/2238/11464/TFG_Rosibel_Rodr%C3%a9uez_Leandro.pdf?sequence=1&isAllowed=y (accessed on 4 August 2022).
10. Abarca-Guerrero, L.; Lobo-Ugalde, S. *Análisis de Mercado de los Residuos Sólidos Ordinarios, sus Subproductos y Evaluación del Costo-Beneficio de las Tecnologías Disponibles en Residuos Valorizables que Pueden Dar una Oportunidad de Negocio*; Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH: Bonn, Germany, 2020; Available online: <https://girs.arksoftqa.com/GEI/Tecnologias%20y%20subproductos/2.%20Impactos%20y%20An%C3%A1lisis%20Costo%20Beneficio%20de%20tecnologias.pdf> (accessed on 11 August 2022).
11. Reid, J.M.; El-Gamil-Hassan, K.; Al-Kuwari, M.S. Improving the management of construction waste in Qatar. *Waste Resour. Manag.* **2016**, *169*, 21–29. [CrossRef]
12. Abarca-Guerrero, L.; Maas, G.; van Twillert, H. Barriers and Motivations for Construction Waste Reduction Practices in Costa Rica. *Resources* **2017**, *6*, 69. [CrossRef]
13. Negash, Y.T.; Hassan, A.M.; Tseng, M.-L.; Wu, K.-J.; Ali, M.H. Sustainable construction and demolition waste management in Somaliland: Regulatory barriers lead to technical and environmental barriers. *J. Clean. Prod.* **2021**, *297*, 126717. [CrossRef]
14. Karji, A.; Namian, M.; Tafazzoli, M. Identifying the key barriers to promote sustainable construction in the United States: A principal component analysis. *Sustainability* **2020**, *12*, 5088. [CrossRef]
15. Ngowi, A. Challenges facing construction industries in developing countries. *Build. Res. Inf.* **2002**, *30*, 149–151.
16. Gangoellis, M.; Casals, M.; Forcada, N.; Macarulla, M. Analysis of the implementation of effective waste management practices in construction projects and sites. *Resour. Conserv. Recycl.* **2014**, *93*, 99–111. [CrossRef]
17. Al-Otaibi, A.; Bowan, P.A.; Abdel daïem, M.M.; Said, N.; Ebohon, J.O.; Alabdullatif, A.; Al-Enazi, E.; Watts, G. Identifying the Barriers to Sustainable Management of Construction and Demolition Waste in Developed and Developing Countries. *Sustainability* **2022**, *14*, 7532. [CrossRef]
18. Akhtar, A.; Sarmah, A.K. Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective. *J. Clean. Prod.* **2018**, *186*, 262–281. [CrossRef]
19. Bossink, B.A.G.; Brouwers, H.J.H. Construction waste: Quantification and source evaluation. *J. Constr. Eng. Manag.* **1996**, *122*, 55–60. [CrossRef]
20. Hong Kong Environmental Protection Department. Statistics Data. Available online: <https://www.epd.gov.hk/epd/english/top.html> (accessed on 18 September 2019).
21. Lawson, N.; Douglas, I. Recycling construction and demolition waste—A UK perspective. *Environ. Manag. Health* **2001**, *12*, 146–157. [CrossRef]
22. Kartam, N.; Al-Mutairi, N.; Al-Ghusain, I.; Al-Humoud, J. Environmental management of construction and demolition waste in Kuwait. *Waste Manag.* **2004**, *24*, 1049–1059. [CrossRef]
23. Apotheker, S. Construction and demolition debris—The invisible waste stream. *Resour. Recycl.* **1990**, *9*, 66–74.
24. Peng, C.L.; Grosskopf, K.R.; Kibert, C.J. Construction waste management and recycling strategies in the United States. In Proceedings of the First Conference of CIB TG 16 on Sustainable Construction, Tampa, FL, USA, 6–9 November 1994; pp. 689–696.
25. Brooks, K.A.; Adams, C.; Demsetz, L.A. Germany’s Construction and Demolition Debris Recycling Infrastructure: What Lessons Does It Have for the US? In Proceedings of the First Conference of CIB TG 16 on Sustainable Construction, Tampa, FL, USA, 6–9 November 1994; pp. 647–656.
26. Heino, E. Recycling of Construction Waste. In Proceedings of the First Conference of CIB TG 16 on Sustainable Construction, Tampa, FL, USA, 6–9 November 1994; pp. 565–572.

27. Kennedy, C.; Cuddihy, J.; Engel-Yan, J. The changing metabolism of cities. *J. Ind. Ecol.* **2007**, *11*, 43–59. [\[CrossRef\]](#)
28. Llatas, C. A model for quantifying construction waste in projects according to the European waste list. *Waste Manag.* **2011**, *31*, 1261–1276. [\[CrossRef\]](#)
29. Rosales-Calvo, S.; Abarca-Guerrero, L.; Leandro-Hernandez, A.G.; Angulo-Varela, J.P. Construction waste and potential environmental impacts. *Tecnol. Marcha* **2022**, *35*, 95–103.
30. Del Río Merino, M.; Izquierdo, P.; Weis, I. Sustainable construction: Construction and demolition waste reconsidered. *Waste Manag. Res.* **2010**, *28*, 118–129. [\[CrossRef\]](#)
31. Bakshan, A.; Srouf, I.; Chehab, G.; El-Fadel, M. A field based methodology for estimating waste generation rates at various stages of construction projects. *Resour. Conserv. Recycl.* **2015**, *100*, 70–80. [\[CrossRef\]](#)
32. Bergsdal, H.; Bohne, R.E.; Brattebø, H. Projection of construction and demolition waste in Norway. *J. Ind. Ecol.* **2007**, *11*, 3. [\[CrossRef\]](#)
33. Kofoworola, O.F.; Gheewala, S.H. Estimation of construction waste generation and management in Thailand. *Waste Manag.* **2009**, *29*, 731–738. [\[CrossRef\]](#)
34. MartínezLage, I.; Martínez, F.; Herrero, C.V.; Ordóñez, J.L.P. Estimation of the annual production and composition of C&D Debris in Galicia (Spain). *Waste Manag.* **2010**, *30*, 636–645.
35. Sandler, K. Analyzing what's recyclable in C&D debris. *Biocycle* **2003**, *44*, 51–54.
36. Zhao, W.; Leeftink, R.B.; Rotter, V.S. Evaluation of the economic feasibility for the recycling of construction and demolition waste in China-the case of Chongqing. *Resour. Conserv. Recycl.* **2010**, *54*, 377–389. [\[CrossRef\]](#)
37. Cochran, K.; Townsend, T.; Reinhart, D.; Heck, H. Estimation of regional building-related C&D debris generation and composition: Case study for Florida, US. *Waste Manag.* **2007**, *27*, 921–931.
38. Begum, R.A.; Siwar, C.; Pereira, J.J.; Jaafar, A.H. A benefit-cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia. *Resour. Conserv. Recycl.* **2006**, *48*, 86–98. [\[CrossRef\]](#)
39. United States Environmental Protection Agency. *Characterization of Building-Related Construction and Demolition Debris in the United States*; Report No. EPA530-R-98-010; United States Environmental Protection Agency: Washington, DC, USA, 1998. Available online: https://www.epa.gov/sites/production/files/2016-03/documents/charact_bulding_related_cd.pdf (accessed on 15 August 2022).
40. Bakchan, A.; Faust, K.M. Construction waste generation estimates of institutional building projects: Leveraging waste hauling tickets. *Waste Manag.* **2019**, *87*, 301–312. [\[CrossRef\]](#)
41. European Commission. Service Contract on Management of Construction and Demolition Waste-SR1, Final Report Task 2. 2011. Available online: https://environment.ec.europa.eu/system/files/2020-12/2011_CDW_Report_0.pdf (accessed on 1 August 2022).
42. Nakajima, S.; Russell, M. *Barriers for Deconstruction and Reuse/Recycling of Construction Materials*; International Council for Research and Innovation in Building and Construction: Ottawa, ON, Canada, 2014; Available online: https://www.researchgate.net/publication/264671518_Barriers_for_Deconstruction_and_ReuseRecycling_of_Construction_Materials_in_Norway (accessed on 1 August 2022).
43. Laredo dos Reis, J.; Cardoso, J.; Ferreira, P. Mechanical Properties of Recycled Kraft Paper Residue Polyester Composites. *Mater. Res.* **2014**, *17*, 888–892. [\[CrossRef\]](#)
44. Crawford, R.H.; Mathur, D.; Gerritsen, R. Barriers to improving the environmental performance of construction waste management in remote communities. *Procedia Eng.* **2017**, *196*, 830–837. [\[CrossRef\]](#)
45. Mittal, V.K.; Sangwan, K.S. Prioritizing barriers to green manufacturing: Environmental, social and economic perspectives, variety management in manufacturing. *Procedia CIRP* **2014**, *17*, 559–564. [\[CrossRef\]](#)
46. Veleva, V.; Bodking, G.; Todorova, S. The need for better measurement and employee engagement to advance a circular economy: Lessons from Biogen's "ZeroWaste". *J. Clean. Prod.* **2017**, *154*, 517–529. [\[CrossRef\]](#)
47. Ranta, V.; Aarikka-Stenroos, L.; Ritala, P.; Mäkinen, S.J. Exploring institutional drivers and barriers of the circular economy: A cross-regional comparison of China, the US, and Europe. *Resour. Conserv. Recycl.* **2018**, *135*, 70–82. [\[CrossRef\]](#)
48. Yuan, H.; Shen, L.; Wang, J. Major obstacles to improving the performance of waste management in China's construction industry. *Facilities* **2011**, *29*, 224–242. [\[CrossRef\]](#)
49. Kuijsters, A. Environmental Response of the Chilean Building Sector. Master's Thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, 2004.
50. Dumlaio-Tan, M.L.; Halog, A. Chapter 2. Moving Toward a Circular Economy in SolidWaste Management. In *Advances in Solid and Hazardous Waste Management: Concepts and Practices*, 1st ed.; Goel, S., Ed.; Springer International Publishing: New York, NY, USA, 2017; pp. 29–48.
51. Singh, J.; Ordóñez, I. Resource recovery from post-consumer waste: Important lessons for the upcoming circular economy. *J. Clean. Prod.* **2016**, *134*, 342–353. [\[CrossRef\]](#)
52. Lee, J.; Pedersen, A.B.; Thomsen, M. Are the resource strategies for sustainable development sustainable? Downside of a zero waste society with circular resource flows. *Environ. Technol. Innov.* **2014**, *1*, 46–54. [\[CrossRef\]](#)
53. Hossain, M.U.; Wu, Z.; Poon, C.S. Comparative environmental evaluation of construction waste management through different waste sorting systems in Hong Kong. *Waste Manag.* **2017**, *69*, 325–335. [\[CrossRef\]](#)
54. Esa, M.R.; Halog, A.; Rigamonti, L. Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *J. Mater. Cycles Waste Manag.* **2016**, *19*, 1144–1154. [\[CrossRef\]](#)

55. Li, J.; Yu, K. A study on legislative and policy tools for promoting the circular economic model for waste management in China. *J. Mater. Cycles Waste Manag.* **2011**, *13*, 103–112. [[CrossRef](#)]
56. Ritzén, S.; Sandström, G.Ö. Barriers to the circular economy—Integration of perspectives and domains. *Procedia CIRP* **2017**, *64*, 7–12. [[CrossRef](#)]
57. Abba, A.H.; Noor, Z.Z.; Yusuf, R.O.; Din, M.F.M.D.; Hassan, M.A.A. Assessing environmental impacts of municipal solid waste of Johor by analytical hierarchy process. *Resour. Conserv. Recycl.* **2014**, *73*, 188–196. [[CrossRef](#)]
58. Osmani, M.; Villoria-Sáez, P. Current and emerging construction waste management status, trends and approaches. In *Waste*, 2nd ed.; Letcher, T.M., Vallero, D.A., Eds.; Elsevier Inc.: Amsterdam, The Netherlands, 2019; pp. 365–380.
59. Yong, D. Plant location selection based on fuzzy TOPSIS. *Int. J. Adv. Manuf. Technol.* **2006**, *28*, 839–844. [[CrossRef](#)]
60. Teo, M.M.M.; Loosemore, M. A theory of waste behavior in the construction industry. *Constr. Manag. Econ.* **2001**, *19*, 741–751. [[CrossRef](#)]