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A Framework to Develop and Improve Construction and Demolition Waste Management Through the Collaborative Action of Organizations, Governments, and Academia

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Abstract: It is estimated that by 2050, global construction and demolition waste will almost double by 2025, and its total amount will grow to 3.4 billion tons. Effective construction and demolition waste management can bring environmental benefits and socio-economic advantages to relevant stakeholders and construction projects. This study proposes a framework for developing and improving CDWM in the Triple Helix sectors: governments, organizations, and academia. The framework is based on the published research methods-Triple Helix core framework research technique for promoting WM. The perspectives and challenges of CDWM, the technical-scientific scenario, the framework, and the writers' thoughts were all taken into account. 22 action plans to triple Helix sectors are proposed in this study, which uses the approach of literature review and content analysis to examine articles in the Scopus database and patents in the Orbit database. China, the US, and Australia are the nations under study. The main objective of this project is to add experience elements from both public and private organizations to the CDWM literature in order to develop a new knowledge block with realistic qualities. This study's main practical contribution is a set of principles for Triple Helix departments to follow as they develop and improve CDWM products and technologies for both private and public usage.

Keywords: Construction and Demolition Waste, Management, Triple Helix, Framework, Opportunity, Challenge

1. Introduction

For a long time, the construction industry has been praised for its significant contribution to creating a building environment, creating employment, and maintaining economic growth [1]. In the past few years, global urbanization has developed at an alarming rate. In 2016, the overall expansion of global urbanization reached 54.3% [2, 3], and today, the global urbanization rate has reached 55% [4]. Urbanization has brought considerable pressure on the construction industry, and more buildings need to be built to meet the expectations of current and future generations [5]. Every year, a large amount of construction and demolition waste (C&DW) will be generated during the construction, transformation, and demolition of buildings and infrastructure. The world produces more than 10 billion tons of C&DW every year, including about 700 million tons in the United States and more than 800 million tons in the European Union [6], 35 - 65% of global landfill sites [7-9]. In addition, Australia generates more than 27 million tons of CDW every year [10], accounting for 44% of the total waste generated [11], while the recovery rate is less than 60% [12]. According to the report, the amount of construction waste generated in the world every year will nearly double, reaching 2.2, and will reach 1 billion by 2025. According to 5 tons of building demolition and recycling, it is estimated that by 2050, global C&DW will almost double 2025 [13], and its total amount will grow to 3.4 billion tons [14].

Additionally, the idea that trash is pollution is progressively giving way to the idea that garbage is a resource that may be recycled, reused, and even converted into energy [15]. WM aims to safeguard people and the environment, increase product longevity, and consume less energy and space. These steps assist in lessening the damaging effects of human activity on the environment [16–18]. Effective construction and demolition waste management (ECDWM) can bring environmental benefits and socio-economic advantages to relevant stakeholders and construction projects [19].

This paper applied the relevant research methods of general waste management carried out by Anuardo et al. [20] to construction waste management, and proposed a framework to develop and improve CDWM of the triple Helix sectors; government, organizations, and academia. The framework was created by the authors' suggestions, the technical-scientific scenario, and the opportunities and challenges of CDWM (Figure 1).

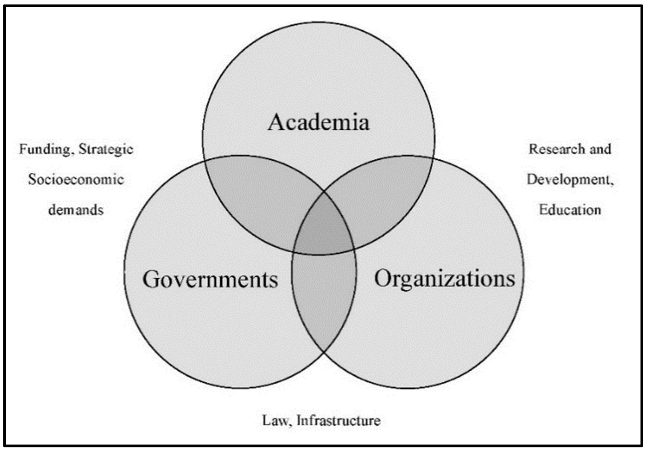

Figure 1. *The three strands of the triple helix are academia, government, and organizations.*

The organization is the production place of goods and services; in the interaction and exchange between the other two departments, the government is the source of legal protection, and academia is the environment for creating modern technology and knowledge [21]. In this case, organizations, governments, and academia can take some actions to apply and improve CDWM. This paper's sole goal is to suggest a framework for organizations, governments, and academics to build and improve CDWM based on a technical-scientific scenario. The idea behind this framework aids in constructing the framework to support the implementation of strategic CDWM as well as decision-making processes that incorporate expert and stakeholder viewpoints of CDWM. And scientifically add the experience elements of public and private institutions to CDWM literature to form a new knowledge block with realistic characteristics. In addition, it can provide actions for various departments of Triple Helix to help develop solutions and technologies to improve CDWM, so that these departments can work independently and jointly.

2. Method and Steps of Research

The combined research methodologies of a literature review and content analysis were used to carry out this study. In order to better understand the topic and identify any gaps in the literature, the literature review was utilized to gather and assess the available literature on CDWM. Based on a methodical assessment of the data, content analysis was utilized to discover trends in CDWM publications [22]. Thus, by combining these two approaches, it is possible to propose policies and initiatives through the qualitative way of reviewing publications, leading to the creation of pertinent insights that advance the field [23, 24]. This examination of the literature and content analysis of the articles help to analyze and comprehend WM and to design a framework for its growth [25]. The patents for developing the technical-scientific scenario were searched on the Orbit database. The platform is trusted by more than 100,000 users and can access the largest accurate patent database and scientific literature database. Its technology helps top management, intellectual property experts and legal professionals transform data into actionable insights to solve their strategic problems [26]. The keyword "construction and demolition waste management" was used to filter the patents by appearing in the titles and objects of the invention of groups of patents released between 2016 and 2021.

There are five steps to the research: I– Definition of the research objectives; II– Definition of search criteria, data collection, and data analysis; III– Research development; IV– Results and discussions; V–Conclusion. These steps are shown in the method flow in Figure 2.

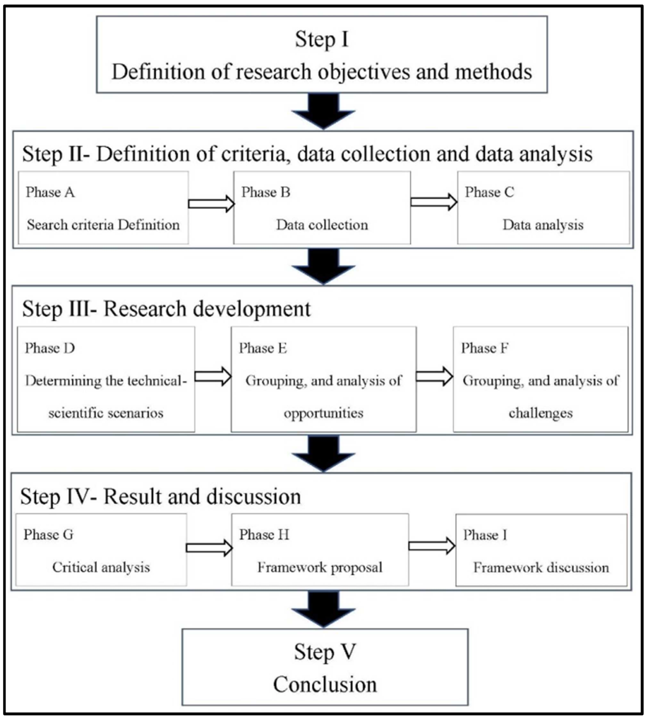

Figure 2. *There are five steps in the research method flow.*

In Step I, the research objectives and methods were defined (Section 1).

In Step II, phase A, the search criteria for data collection are defined. Scopus provides indicators for reference analysis and contains most of the data that can be used in other databases [27-29]. Therefore, the Scopus database chooses articles for the compilation of the technical-scientific scenario and the grouping of the difficulties and research possibilities. As the search criteria, the keyword is "construction and demolition waste management", the publication year is from 2016 to 2021 (Figure 3), and the reporting language is English. On the Orbit database, patents for creating the technical-scientific situation were looked for. This platform is trusted by more than 100,000 users and can access the largest accurate patent database and scientific literature database. The keyword "construction and demolition waste management" was used to filter the patents by appearing in the titles and objects of the invention of groups of patents released between 2016 and 2021.

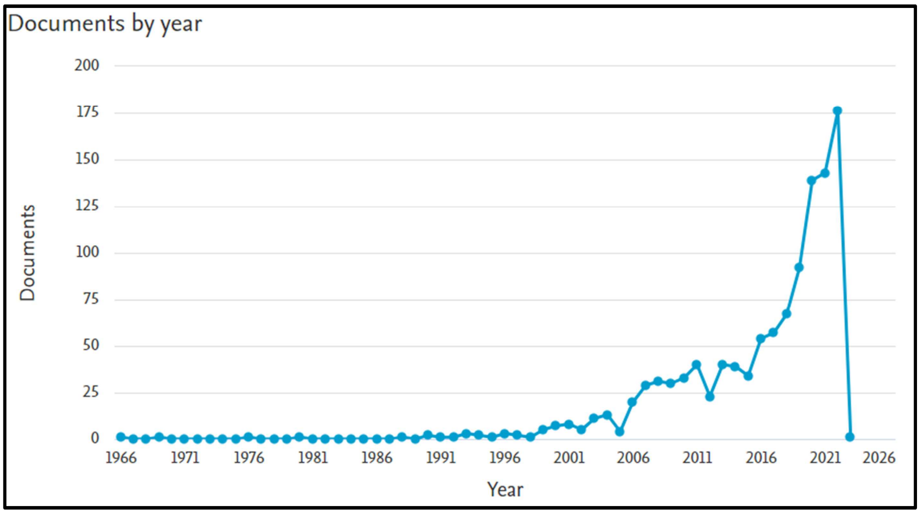

Figure 3. *Articles on CDWM topics increased linearly between 2016 and 2021. Of the 1122 cases, 552, accounted for 49.2%. (source: https://www.scopus.com/term/analyzer.uri?sid=71306bc80f70e26996ba7cb1ea61e886&origin=resultslist&src=s&s=TITLE-ABS-KEY%28construction+demolition+waste+management%29&sort=cp-f&sdt=cl&sot=b&sl=55&count=1122&analyzeResults=Analyze+results&cluster=scosubtype%2c%22ar%22%2ct%2bscolang%2c%22English%22%2ct&txGid=c19e1a1b420771ed6b2cc818371aa924).*

Phase B involved gathering data from 622 patents on the Orbit platform and 552 publications in the Scopus database that matched the search parameters of Phase A. Phase C involved the analysis of the data gathered in Phase B to rank the major nations according to the number of patents published and the h-index. First, the ten nations with the greatest h-index and the most published patents were ranked (Patent Position and H-Index Position, respectively). Then, the index (Final Position Index), which was created by averaging the positions of the countries' H-Index Position and Patent Position variables in both columns, was applied (Figure 4). This logic has already been validated and successfully used in Nunhes et al. [22, 30]. According to the Final Position Index in Figure 4, this index shows that the country is better positioned the lower the average value between the variables. The top three nations were found to have the greatest h-index and to have published 84.7% of all patents. China, the United States, and Australia were the chosen nations based on these criteria.

Patent Position			H-Index			Final Position Index				
No	Countries	Patents	No	Countries	H-Index	Final Position	Main countries	Patents	H-Index	Publications
1	China	360	1	China	38	1	China	360	38	129
2	United States	131	2	Australia	25	5	United States	131	20	34
3	European Patent Office(EP)	117	3	Spain	17	5.5	Australia	36	25	66
4	India	92	4	Italy	17	6.5	India	92	9	32
5	Korea	80	5	Hong Kong	22	8	Japan	65	13	23
6	Japan	65	6	United Kingdom	20	8.5	Brazil	28	15	37
7	World Intellectual Property Organization(WO)	65	7	Brazil	15					
8	Canada	46	8	United States	17					
9	Australia	36	9	India	9					
10	Brazil	28	10	Japan	13					

$$Final\ Position = \frac{Patent\ Position + H - Index\ Position}{2}$$

Figure 4. *Using a country ranking that takes into account the average number of patent registrations and the H index of scientific publications, three pertinent nations are chosen. China, the United States, and Australia are the chosen nations by this measure.*

In Step III, research is developed in three stages: D, which involves identifying technical-scientific scenarios; E, which involves grouping and analyzing possibilities; and F, which involves grouping and analyzing problems. The significant organizational, governmental, and academic endeavors of a few chosen nations were compiled through content analysis in phase D to create the technical-scientific scenario of CDWM based on the triple helix model. The 30 papers with the highest number of citations and the scientific gaps they picked for phase B were used to identify and categorize the CDWM development possibilities and challenges in phases E and F (Table 1).

Table 1. *30 most cited articles on the fields of CDWM.*

Title	Authors	Source	Cited by	Scientific Gaps
Construction and demolition waste management in China through the 3R principle	Huang, B., et. al	Resources, Conservation and Recycling	372	Analyze existing CDWM management strategies and status
Construction and demolition waste best management practice in Europe	Gálvez-Martos, J.-L., et. al	Resources, Conservation and Recycling	314	Development of management methods to improve resource efficiency and reduce the impact on the environment
Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA	Hossain, M. U., et. al	Resources, Conservation and Recycling	219	Development of environmental impact assessment technology for C&DW recycling
Investigating the determinants of contractor's construction and demolition waste management behavior in Mainland China	Wu, Z., et. al	Waste Management	212	Development of a theoretical model for studying the decisive factors of DWM behavior of construction enterprises
Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review	Ghisellini, P., et. al	Journal of Cleaner Production	211	Development of a circular economy framework to achieve an environmentally and economically sustainable CDWM
Characterizing the generation and flows of construction and demolition waste in China	Zheng, L., et. al	Construction and Building Materials	211	Development of an analysis method for DW generation and flow based on a weight-per-construction-area method
An empirical study of perceptions towards construction and demolition waste recycling and reuse in China	Jin, R., et. al	Resources, Conservation and Recycling	199	Investigating management status to promote C&DW recycling and reuse
Recycling phosphogypsum and construction demolition waste for cemented paste backfill and its environmental impact	Chen, Q., et. al	Journal of Cleaner Production	191	Development of a technology to recycle different kinds of C&DW
Use of recycled aggregates from construction and demolition waste in geotechnical applications: A literature review	Cardoso, R., et. al	Waste Management	174	Development of a technology for C&DW recycling
Prioritizing barriers to adopt circular economy in construction and demolition waste management	Mahpour, A.	Resources, Conservation and Recycling	171	Development of a framework to facilitate C&D waste management toward the circular economy.
Improving construction and demolition waste collection service in an urban area using a simheuristic approach: A case study in Sydney, Australia	Yazdani, M., et. al	Journal of Cleaner Production	138	Development of a new simulation method for optimizing C&DW collection path planning
Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery	Ghaffar, S.H., et. al	Journal of Cleaner Production	137	CDWM method to improve the circulation of building environment and achieve sustainable development
Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making	Di Maria, A., et. al	Waste Management	131	Combining two life cycle theories to realize the sustainable development of CDWM
An environmental assessment model of construction and demolition waste based on system dynamics: a case study in Guangzhou	Liu, J., et. al	Environmental Science and Pollution Research	121	Environmental, economical, and social impact assessment of C&DW treatment technology
An empirical study of construction and demolition waste generation and implication of recycling	Islam, R., et.al	Waste Management	111	Estimation of C&DW generation and economic benefit analysis of C&DW recovery
Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment	Akinade, O. O., et. al	Journal of Cleaner Production	108	Management tools for meeting the needs of C&DW administrators
Status quo and future directions of construction and demolition waste research: A critical review	Wu, H., et. al	Journal of Cleaner Production	105	Future-oriented CDWM research direction
Evaluating the transition towards cleaner production in the construction and demolition sector of China: A review	Ghisellini, P., et. al	Journal of Cleaner Production	102	Strategy for transition to Clean Production to achieve sustainable CDWM
Sustainable multi-period reverse logistics network design and planning under uncertainty utilizing conditional value at risk	Rahimi, M., et. al	Journal of Cleaner Production	101	Modeling theory for C&DW recycle

Title	Authors	Source	Cited by	Scientific Gaps
(CVaR) for recycling construction and demolition waste				
Urban construction and demolition waste and landfill failure in Shenzhen, China	Yang, H., et. al	Waste Management	99	Research on strategies for proper management and monitoring of C&DW
Developing efficient circularity for construction and demolition waste management in fast emerging economies: Lessons learned from Shenzhen, China	Bao, Z., et. al	Science of the Total Environment	98	Suggestions on developing C&DW circular economy
Procurement innovation for a circular economy of construction and demolition waste: Lessons learnt from Suzhou, China	Bao, Z., et. al	Waste Management	98	CDWM improvement plan for developing the circular economy
Barriers and countermeasures for managing construction and demolition waste: A case of Shenzhen in China	Yuan, H.	Journal of Cleaner Production	98	Challenges and countermeasures of CDWM in economically developed areas
Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization	Won, J., et. al	Automation in Construction	97	Development of processes and technologies to effectively manage and minimize C&DW
Quantification of construction waste prevented by BIM-based design validation: Case studies in South Korea	Won, J., et. al	Waste Management	96	Development of a technique for estimating C&DW generation in the design verification stage
Estimating and calibrating the amount of building-related construction and demolition waste in urban China	Lu, W., et. al	International Journal of Construction Management	87	Statistical method for estimating the generation of C&DW
Geospatial characterization of building material stocks for the life cycle assessment of end-of-life scenarios at the urban scale	Mastrucci, A., et. al	Resources, Conservation and Recycling	87	The framework of CDWM management strategy to support decision-making
Strategies for minimizing construction and demolition wastes in Malaysia	Esa, M.R., et. al	Resources, Conservation and Recycling	87	Management plan to reduce the generation of C&DW
Demolition waste generation and recycling potentials in a rapidly developing flagship megacity of South China: Prospective scenarios and implications	Wu, H., et. al	Construction and Building Materials	86	Advanced methods for investigating the incidence of demolition waste and quantifying that.
Life cycle assessment of the end-of-life phase of a residential building	Vitale, P., et. al	Waste Management	83	DWM and environmental impact analysis for each stage of the residential building life cycle

Step IV is carried out in three stages. The primary issues, opportunities, and challenges for establishing CDWM were chosen in Phase H. The actions outlined in the framework were discussed in Phase I.

Step V details the accomplishment of the goals outlined in this work, as well as the key contributions, restrictions, and recommendations for further research.

3. Research Development

This section analyzes the dadas searched in phase B and introduces the development of the technical-scientific scenario and the opportunities and challenges of CDWM. That is, it is equivalent to the Step III phases D, E, and F. This knowledge influences the actions which will be proposed in the Framework for the Development and Improvement of Construction and Demolition Waste Management (Section 4. Result and Discussion).

3.1. Technical-Scientific Scenario

The CDWM technical-scientific scenario shows the research results of the most prominent countries (Phase B - China, the United States, and Australia) in the development of research on this topic from 2016 to 2021. The text is organized following the organization, government, and academic sectors of the Triple Helix, which help to elaborate the framework suggested in this work.

3.1.1. China

China is the country with the most articles published on the CDWM topic with the highest h-index between 2016 and 2021. (Figure 4).

The top three organizations in producing patents on CDWM are EASTMAN CHEMICAL, DSM IP ASSETS and SHENZHEN UNIVERSITY [31]. EASTMAN CHEMICAL is actively seeking solutions to address global challenges and develop stable and sustainable materials [32]. This company has developed systems and technologies for recycling new building materials without landfilling or burning plastics by using molecular recycling and so on [33-35]. DSM IP ASSETS has developed a technology to decompose lignocellulose and combine it with an organic acid to produce alcohol [36]. Using this technology, waste wood in construction waste can be recycled. Shenzhen University, using network technology, artificial intelligence technology, 3D laser scanning technology, etc., has formed a system to predict the amount of waste generated from building demolition, thus, developing some technologies that can improve the intelligence of construction waste disposal [37-40].

Regarding government initiatives in China, the initial purpose of CDWM was to save the environment. To address and stop the production and contamination of C&DW, the Environmental Protection Law was enacted in 1989. The first Urban Construction Waste and Construction Waste Related to CDWM Regulation in China was implemented in 2003. C&DW and other similar activities are defined by this statute. The first law, created for CDWM, was released by the Ministry of Housing and Urban-Rural Development (MOHUD) in 2005. Its official name is People's Republic of China's Urban Construction Waste Management Regulation and Solid Waste Pollution Prevention Law. It entails the gathering, moving, utilizing, and finally dumping of C&DW. The Construction Waste Processing Technical Specifications for CD waste treatment were published in 2010 by the Ministry of Housing and Urban Development [41] and the "The Earthquake-stricken Construction Waste Technical Guidelines". However, these provisions have been implemented, but the conditions for CDWM are still unsatisfactory. Therefore, there are serious environmental impacts [42]. However, the 3Rs treatment is particularly effective for CDWM, reducing energy consumption and environmental impact [43]. The maintenance and improvement of recycled building materials can also be accomplished through carbonization [44]. According to the 3Rs principle, CDWM policies in several Chinese cities have been reported in terms of monetary subsidies, incentives, obstacles, and C&DW disposal and treatment methods [1]. Different policies and recommendations on the development of ecological civilization, the economy, environmental protection, management of solid waste, and municipal garbage disposal have been developed by the National Development and Reform Commission (NDRC). There are various laws and regulations, but they must be managed carefully and put into practice [41]. In the Mainland of China, national and provincial regulations are being formulated to encourage the use of recycled building materials [12]. Hong Kong and Taiwan also have the same laws, where construction sites are monitored for the existence of legal CDWM practices [45, 46]. Legal enforcement and financial subsidies are the basic drivers [1, 12].

In academia, research and education institutions that succeed in CDWM, as well as authors' publications, were examined. The most well-known authors in China are Wang, J., Wu, and Duan, H. Wang, J. et. al [19, 47] put forward methods and suggestions for C&DWM policymakers to reduce carbon dioxide generated by C&DW and its treatment costs in China. If there is no appropriate management policy for persistent organic pollutants, their pollution of the environment will increase, therefore, the treatment of harmful elements such as brominated flame retardants and heavy metals in C&DW has also been studied [48]. Wu, H. et. al [49] taking Shenzhen City, China as an example, to obtain the fundamental information of the whole process from construction waste generation to disposal, developed an advanced method to estimate and extrapolate the generation, flows, and utilization options of construction waste through in-depth investigation of construction and demolition sites, recyclers and government departments.

Attaching institutions for study and instruction that emphasize CDWM are Shenzhen University, Tongji University, Chongqing University and the Chinese Academy of Sciences. These universities have established research institutions in the fields of architectural environment optimization design and environmental planning and management, conducted research on urban construction environmental sustainability and development model, low carbon economic development theory, environmental ecology, etc., and trained many talents in this field, occupying the important position in environmental science research and education departments [50-52]. The Chinese Academy of Sciences has set up an ecological and environmental science research center, including treatment of solid waste and recovery laboratory, to develop new recovery technologies and theories. It investigates municipal solid waste, polymer waste, biological waste, and trash from construction projects [53]. The Chinese government has set up a basic scientific research fund for the Central University to improve the efficiency of the scientific research investment system and enable it to innovate and improve its best talents [54]. The other research fund focused on is the National Natural Science Foundation of China, which has carried out the project "Impact of human activities on the environment and disasters". The characteristics, interactions, and safe disposal of industrial and urban solid waste are the key concerns examined [55].

3.1.2. United States

The United States is the second-largest country in terms of the number of WM patents published between 2016 and 2021 as well as the eighth-largest country in terms of the number of academic publications published on the topic.

The top three companies for CDWM patent production are EASTMAN CHEMICAL, DSM IP ASSETS and NOVOZYMES [31]. In the United States, EASTMAN CHEMICAL combined one or more pyrolysis units such as a catalytic cracking unit to form a method and system for the decomposing waste resin to prepare hydrocarbons [56]. DSM IP ASSETS has registered the same patent in the United States as in China. Through cooperation with biological problem solvers, NOVOZYMES is researching and developing enzyme and microbial technology and has developed highly active enzymes in the field of construction waste treatment to decompose them [57, 58].

The Resource Conservation and Recovery Act, which the U.S. government passed, specifies rules for the appropriate treatment of hazardous and non-hazardous solid waste. RCRA sections 40 CFR 257 and 258.2, cover harmless waste generated from CD debris, including construction, demolition, reduction, landfill, environmental, and safety-related issues. It enables governments to determine their primary responsibilities and encourages them to create and execute their waste management-based rules [59–61]. The primary legislation regarding C&DW generation and disposal is known as CERCLA, or the Comprehensive

Environmental Response Compensation and Liability Act. Contractors are in charge of working on and managing their C&DW activities, per CERCLA [62]. The bill classifies states into three categories based on solid waste management (SWM), including CDWM practices and law enforcement [59]. According to their performance and CDWM plans, the majority of US states have promoted their regulations and oversight organizations to deal with CD waste.

In academia, the authors most articles published on CDWM from 2016 to 2021 were, Timothy Glyndon Townsend, Kasey M. Faust and Amal Bakchan. T. G. Townsend, proposed a method to quantify construction waste management, reduce waste and improve the recycling rate by estimating the end-of-life path of various construction materials managed in the CD stream [63]. K. M. Faust and A. Bakchan et al. proposed a multi-dimensional CDWM framework, including estimation of C&DW generation, treatment plan, treatment cost, on-site recycling, and disposal site allocation. This framework can improve the synergy between CDWM and construction management, which not only ensures the strategic consistency between the construction objectives and CDWM but also helps to promote and encourage the sustainable development of the construction industry [64, 65].

University of Florida, Yale University, and The University of Texas at Austin are among the educational and research institutions in CDWM. The College of Design, Construction & Planning (DCP) of University of Florida is only one of six colleges in the U.S. that combines all of the design and construction disciplines. The DCP's objective is to enhance the quality of the built and natural environments by providing outstanding educational and professional programs and research efforts that deal with built and natural environment planning, design, construction, and preservation. The college has set up architectural design, construction management, sustainable construction environment, landscape design, and other related disciplines, and achievements have been made in education and research in those areas [66]. Yale University has an environmental affairs department responsible for managing hazardous waste disposal on campus. The person who generated them is responsible for correctly collecting, processing, labeling, and storing them in their work area [67]. Regarding the implementation of management plans in the university environment, some universities have different levels of budget and staffing. It is difficult to successfully implement waste collection and treatment without a well-structured institution. However, the setting and identification of trash cans is a low investment and the basis for any effective WM plan in a university environment [68]. The Sustainable Development Center of the University of Texas at Austin was established in 2001. Its mission is to lead sustainable development research and practice in Texas, the United States, and the world through complementary projects of research, education, and community outreach. The unique feature of CSD is that it integrates various interests and develops creative, balanced, and achievable solutions for the physical and social challenges faced by the planning, construction, and protection of buildings, communities, and regions [69].

Based on the best available scientific information, the United States Environmental Protection Agency ensures the fair and effective management and implementation of federal laws to reduce national environmental risks and protect human health and the environment. It also collects sufficient and accurate information through all sectors of society - communities, individuals, enterprises, state, local and tribal governments - to effectively participate in the management of human health and environmental risks [70].

3.1.3. Australia

Australia is the nation with the ninth-highest number of waste management patents published between 2016 and 2021. It is also the nation with the second-highest h-index of scholarly articles published on the subject.

In organizations, OVOZYMES is the leading producer of CDWM patents. [31]. NOVOZYMES has registered the same patents in the as in China and United States. This has been discussed in 3.1.1 and 3.1.2.

In response to the emerging socio-environmental issues caused by the improper management of C&D waste materials, Australian federal and state governments have started to prioritize these resources in their environmental planning [71]. The waste strategy document is an important part of waste management and governance in Australia. Although there are no statutory powers, they guide the efforts of different organizations and industries involved in waste management. On the one hand, they need to be formulated according to the relevant jurisdictional law. On the other hand, they also have a significant impact on the jurisdictional legislative framework through the proposed implementation goals, targets, and reforms. In Australia, waste strategy papers similar to legislation are prepared at the state and regional levels. These strategic documents are usually developed and updated by the competent Environmental Protection Agency (EPA), which has primary responsibility for the waste stream. In South Australia and Western Australia, this document was prepared by the Green Industry SA and the Waste Management Authority, respectively. For example, in Western Australia (WA), Part 1 – Waste Strategy (Part 4 – Management Document) of the Waste Avoidance and Resource Recovery Act 2007 entrusted the Waste Management Agency with the preparation of a draft waste strategy that includes a long-term strategy for continuous improvement of waste services, waste avoidance, and resource recovery. The main framework of Australia's waste strategy is the waste hierarchy. The framework covers a range of waste disposal options, in order of priority. Waste classification is a nationally and internationally recognized concept used to prioritize and guide waste management. Alternatives include prevention, reduction, reuse, recycling, energy recovery, (treatment), and disposal [72].

In academia, the most well-known authors who wrote on

CDWM between 2016 and 2021 are Zuo, J., Tam, V. W. Y., and Chileshe, N. Zuo, J. et. al have drawn the flow chart of national C&DW (Australia), meanwhile, gaining awareness of the effects that C&D waste's geographical movement has on the environment, provides the index and essential information for the LCA methodology's development in evaluating the effectiveness of C&D waste management [73, 74]. Tam, V. W. Y. et. al through partial least squares based structural equation modeling using SmartPLS, have analyzed the data which are 108 large construction companies that were approached via an online questionnaire, proved that CDW stakeholders' attitudes (CDWSA) were the most effective factor to CDWM [75]. Chileshe, N. et. al analyzed information that includes the external and internal stakeholders' influence strategies on reverse logistics supply chain's (RLSC's) quality assurance in the construction waste management and revealed the root causes affecting RLSC, thereby the research result that can decide appropriate measures to overcome the macro uncertainty of RLSC was obtained [76]. Also, the driving factors of reverse logistics are divided into economic, environmental, and social forces, and using the structured equation model analyzed the questionnaire survey results of construction experts, thereby, have proposed a roadmap for improving RL outcomes [7]. Education institutes that excel in CDWM are the Western Sydney University, the University of Adelaide and RMIT University.

The University of Western Sydney has colleges and research institutions, which are responsible for education and research related to environmental and human health protection and modern construction environmental design [77]. Adelaide University has established the Institute for Sustainability, Energy and Resources, and the Environmental Institute, which are studying environmental protection and sustainability [78]. RMIT University has the School of Property, Construction, and Project Management specializing in construction and project management, and is conducting research and training to develop a sustainable construction industry [79].

3.2. Scientific Opportunities and Challenges for CDWM

This topic will introduce the opportunities and challenges of CDWM research, which will help to build a development framework.

3.2.1. Opportunities for CDWM Development

Based on the scientific gaps in Table 1, CDWM development opportunities are grouped according to similarity. Table 2 displays the authors and their clusters.

Table 2. *The authors and their clusters of CDWM development opportunities.*

Clusters	Authors
Development of tools, systems, and methods for CDWM	[1, 49, 80-89]
Development of modern techniques for C&DW treatment	[90, 91]
Development of technologies for generation estimating, collection, and reuse of C&DW	[12, 92-96]
Advance of CDWM towards the circular economy	[97-100]
New approach to sustainable development of CDWM	[101-106]

The cluster "Development of tools, systems, and methods for CDWM" includes the opportunities to improve CDWM, by different countries, regions, and construction enterprises considering environmental and economic factors. According to Yuan, H. et. al [89], the dispersion of CDWM departments of national and regional governments, and the lack of CDWM basic information and attention to that, may provide new research opportunities. The development of new CDWM systems and tools will help to improve this situation and make the whole management process more sustainable. The cluster "Development of modern techniques for C&DW treatment" includes research opportunities for the final processing stage in CDWM. The fact that the disposal of waste from construction or demolition sites in landfills is still common [90] practice can propose opportunities for the development of these treatment techniques. The fact that there is no national-level statistical data on the generation [93], and collection routings are uncertain [95], provides research opportunities for technology development of generation estimation, collection, and reuse of C&DW. The cluster "Development of technologies for generation estimation, collection, and reuse of C&DW" includes the research opportunities of technology solutions which through questionnaires, and case studies, by researching the changing trend of C&DW generation and characteristics can improve CDWM. Proper management of C&DW is a key challenge amid global advocacy of the circular economy [97]. Therefore, the cluster "Advance of CDWM towards the circular economy" provides research opportunities to overcome the challenges in transitioning to the circular economy of CDWM and for accelerating the development of the C&DW circular economy. The cluster "New approach to sustainable development of CDWM" provides research opportunities for creating a sustainable and clean construction environment by taking several measures, such as reducing the burden of C&DW on the environment such as land and air pollution, and improving the recycling of building materials, and so on.

3.2.2. Challenges of Waste Management

The challenges were discovered in the 30 articles on CDWM that received the highest citations (Table 1), and they were then clustered into groups based on commonalities. Table 3 displays these clusters along with their authors.

Table 3. *Clusters of construction and demolition waste management challenges.*

Clusters	Authors
Lack of reliable information on CDWM	[49, 92, 93]
Inadequate understanding, thinking mode, and management awareness of stakeholders	[12, 80, 81, 86, 87, 94, 102]
Lack of plans, policies, regulations, and ability of CDWM	[1, 89, 92, 97, 106]
Negative environmental and economic impacts	[80-85, 88, 90, 91, 95, 96, 98-105]

The Cluster "Lack of relevant information on CDWM" through the articles that compose it, shows that there are many problems in its management due to the lack of national statistical data on the generation and recovery of C&DW. These statistics are very important in the management of C&DW, one of the negative effects of rapid urbanization [93]. More accurate statistics can make the CDWM more effective, such as the generation, collection, transportation, utilization, and landfill plan of C&DW. The challenge presented in the cluster "Inappropriate understanding, thinking mode, and management awareness of stockholders" is that, although regulations on construction waste disposal have been formulated and mature technologies have been developed, the practice of CDWM is considered impossible in field projects. Since CDWM requires the team to recruit participants from different disciplines, whether multiple parties involved in C&D waste transfer agree on this topic may affect the effectiveness of communication [12]. That must change the thinking mode of all stakeholders in the construction industry and overcome the technical problems to reach a consensus on the CDWM strategy. The challenge “Lack of plans, policies, regulations, and ability of CDWM” contemplates the lack of effective legislation that considers the several types of waste and how they should be treated in the recycling process. If properly managed, these C&DW can become valuable resources of the country [92]. Therefore, the government, according to the actual situation of its own country, should standardize and disseminate the definition of main C&DW types and formulate policies on disposal sites, procedures, methods, etc., avoiding illegal dumping. Additionally, it must aid in the creation of strategies to lower C&DW output. The challenge "Negative environmental and economic impacts" considers the environmental and economic burden caused by improper CDWM. If the C&DW is classified, screened, and reused, not only economic benefits can be obtained, but also the negative impact on the environment will be greatly reduced. For example, Cardoso, R. et. al [90] have proposed alternative solutions that can create new market opportunities and are conducive to the environment, by developing the technology of using concrete, one of the building materials, as the recycled aggregate.

4. Results and Discussions

The framework for CDWM development and improvement is introduced in this section. It is founded on the author's experience, the development of the technical-scientific scenario, and the identification of research opportunities and challenges. Based on the Triple Helix, it includes CDWM action suggestions (Table 4).

Table 4. *Framework for CDWM development and improvement.*

Sector	Domain	Action Proposals	Triple-Helix Connection
Governments	Policies, Legislation	According to the specific conditions of regions and cities, corresponding legal mechanisms should be established to support the national law enforcement of CDWM	Organizations and Academia
		Formulate laws for the management of specific C&DW, such as waste resin	Academia
		Include the informal recyclers in the process of management and treatment of C&DW, conciliating their interests with other stakeholders	Organizations and Academia
		Establish legal and institutional mechanisms to encourage C&DW recycling and recycling enterprises	Organizations and Academia
		Formulate policies for CDWM transfer to the circular economy	Organizations and Academia
	Public Operation	Improve the environmental awareness of stakeholders through various publicity and education activities on CDWM	Organizations and Academia
		Establish partnerships with startups or technology companies to develop systems for C&DW quantification	Organizations and Academia
Organizations	Technology	Develop new applications for the tracking system and optimize the processing path of C&DW, including generation, recycling, and reuse	Governments and Academia
		Develop the best management system for design and construction to reduce the generation of C&DW	Academia
		Invest in research and development to obtain new C&DW treatment patents	Governments and Academia
		Generate and mine reliable data on waste management to improve more accurate diagnosis and management decisions	Governments and Academia
		Create applications that promote the commercialization of C&DW recycled materials	Governments and Academia
	Services	Provide consulting services to help employees of construction companies identify waste separation and improve training	Academia
		Establish the governance process that is conducive to the formulation of corporate strategies that are compatible with national CDWM strategies	Governments
		Establish partnerships with universities and research centers, develop technologies and processes to establish the sustainable CDM strategies	Academia
		Create and publish sustainability reports on the development of C&DW recycled materials	Governments

Sector	Domain	Action Proposals	Triple-Helix Connection
Academia	Research, Development, Services	Develop education and publicity projects to raise social concern about CDWM	Governments and Academia
		Cooperate with relevant government departments and construction companies to carry out C&DW technology solutions and management research	Governments and Organizations
		Scientifically support the work of government departments responsible for the management of C&DW	Governments
		Develop reuse technology for various C&DW	Organizations
		Develop the techniques for CDWM transfer to the circular economy	Governments and Organizations
		Develop training and publicity processes to improve the awareness and thinking mode of stakeholders on CDWM, and their environmental awareness	Governments and Organizations

The "Organizations" sector was structured in the domains "Policies, Legislation" and "Public Operation". In "Policies, Legislation", actions opinioned that institutional mechanisms should be established to guarantee the national and regional law enforcement of CDWM. It is also suggested that informal recycling enterprises should actively participate in the management and treatment process of C&DW, and actively encourage the activities of these enterprises. Another action is to Formulate laws for the management of specific C&DW, such as waste resin, and establish legal and institutional mechanisms to encourage C&DW recycling and recycling enterprises. The actions in "Public Operation" advocated to improve the environmental awareness of stakeholders through publicity and education activities on CDWM, and cooperation with enterprises to carry out systematic development of C&DW quantification.

In the "Organizations" sector, the propositions are around the domains "Technology" and "Services". The action of "Technology" aims to automate the management and treatment of C&DW and improve its effectiveness. These actions include the development of the management system to reduce the generation of C&DW, and the development of the technologies to ensure more accurate management decisions by optimizing the prediction of the generation and treatment path of C&DW. In addition, application development actions to promote the commercialization of C&DW recycling materials are also proposed.

In "Services", the actions aim to improve the training and social attention of construction company employees. That also includes building partnerships to develop sustainable corporate strategies through the active development of recyclable materials.

In the "Academia" section, the action area is proposed to be research, development, and service. Research actions may include cooperating with relevant government departments and construction companies to carry out C&DW technology solutions and management research, scientifically supporting the work of government departments responsible for the management of C&DW, etc. Actively developing various C&DW reuse technologies or technologies transferred to the circular economy will help reduce the environmental and economic burden of C&DW. Under cooperation with government agencies or enterprises, it is also necessary to formulate the awareness and thinking mode of relevant people on CDWM, and the education and publicity procedures to improve environmental awareness.

The effect of these elements of the Triple Helix can be further strengthened through their synergy. "Academia" can improve the construction of waste disposal laboratories and research projects through the financial support of "Governments" and the "Organizations". "Governments" and "Organizations" can cooperate with the academic community to solve the technical problems of construction waste management. The "Organizations" and "Academia" communities can collect information about construction waste and support the construction waste management plan formulated by the government. "Governments" can encourage "Organizations" to pursue sustainable development in policy or finance. This kind of support will be more effective when receiving academic support from educational and research institutions.

5. Conclusion

This work provides a framework for improving CDWM. The framework is based on the initiatives taken by organizations, governments, and academia, as well as the opportunities and challenges noted in the literature and the authors' suggestions. The main purpose of this work is to add the experience elements of public and private institutions to the CDWM literature to form a new knowledge block with realistic characteristics. The main application contribution of this work is to provide measures for Triple Helix departments to help them develop and improve CDWM solutions and technologies for personal and collaborative purposes. The search criteria and databases employed in this study are responsible for some of its limitations. If change that, you can modify the list of articles, institutions, organizations, and patents to be analyzed for other countries. In addition, if new countries are added, new ideas can be added to the framework proposed by the project. We advise you to change these search criteria and utilize different databases in future studies in order to include fresh scenarios and activities in this framework.

Conflict of Interest Statement

All the authors do not have any possible conflicts of interest.

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