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The Evolution of Research on C&D Waste and Sustainable Development of Resources: A Bibliometric Study

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Abstract: Construction and demolition (C&D) waste is steadily increasing as both urbanization and the construction industry advance. Therefore, numerous studies on C&D waste have been conducted. In this paper, the literature published in the field of C&D waste and sustainable development from 2002 to 2022 was utilized to examine the current state of research and potential future research hotspots via the bibliometric method. Herein, 3550 studies found in the literature were analyzed using Citespace and VOSviewer, two efficient visual analysis programs, for the annual quantitative distribution, contribution and cooperation of authors, influential and productive countries/regions and institutions, keyword co-occurrence analysis, literature co-citation analysis and identification of research frontiers. The findings show an exponential rise in publications on construction waste and sustainable resource development, while the research focus has clearly shifted from recycling and reduction of C&D waste to harmless and resourceful treatment in the last five years. The keywords "optimization", "implementation" and "strategy" also indicate that more emphasis is being placed on the research of management method realization mechanisms, technological optimization schemes and policy strategies. The research results of this paper will help participants in the construction industry to grasp the current research hotspots and development trend in the field of C&D waste and the sustainable development of resources. It also plays a positive role in formulating relevant regulations and policies, reducing resource waste and construction project costs.

Keywords: construction and demolition waste; sustainable development; bibliometric study; visualization

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1. Introduction

The reduction and recycling of construction and demolition (C&D) waste is crucial to human society and has a significant impact on sustainable development. Although C&D waste and sustainable development of the ecological environment were initially only the concern of local governments, they will eventually pose a threat to regional and global development [1]. With the rapid urbanization of the world, in order to resolve the serious conflict between increasing C&D waste and environmental protection, it is necessary to explore economically attractive sustainable solutions for the reduction and recycling of C&D waste [2]. The world is currently undergoing profound changes that have not occurred in a century; it is urgent to solve the problem of the large amount of waste produced by human construction activities and to develop research on the sustainability of resources.

C&D waste usually refers to construction waste, decoration waste and demolition waste generated during the construction, renovation and demolition phases of a project [3]. It is mainly composed of large amounts of inert materials (bricks, concrete, etc.), timber, asphalt, metals and plastic [4]. Economic, social, health and technical factors jointly affect the development direction of C&D waste research, and its key areas mainly include recycling [5–8], reduction [9,10], environmental impact [11–13], and reduction of the environmental footprint of C&D waste [14,15].

Existing research results have shown that the process of recycling construction waste will be accelerated in some developing countries, while the trend of recycling construction waste in developed countries will gradually change [16]. Recently, the investigation of greenhouse emissions [17–19], carbon footprint [20,21], human factors [22,23] and waste treatment policies [24–26] in the research on recycling construction waste have developed rapidly. It is worth noting that human factors are more likely to appear in research related to construction waste, indicating that it is one of the important factors for the effective management of C&D waste. Li et al. further quantitatively studied the impact of construction waste reduction behavior based on the theory of planned behavior [27]. According to Udawtt, there were both technical and man-made obstacles to waste management in Australian construction projects, but the latter were more dominant [28]. Studies have shown that the development and progress of construction waste management is driven by social motivation and policies [25]. Therefore, the updating of laws and regulations on the treatment of construction waste can also reflect the change in research works on construction waste. Reducing construction waste has always been a hot topic in academia. Some scholars have explored effective methods from the perspectives of construction technology [29] and management methods [30]. With the increase in environmental damage, more and more research has been conducted on the environmental benefits of reduction management [31]. Recently, some scholars have studied the dynamic trend of construction waste by using visual analysis software [32]. The results show that extensive research has been conducted on construction waste reduction, system dynamics analysis and life cycle assessment over the past decade, while the circular economy, big data, building information modeling (BIM), environmental impact (carbon footprint), prefabricated buildings, human factors and logistics planning of construction waste transportation have been vigorously developed from 2019 to 2021. It can be seen that the effective management of C&D waste is related to the sustainability of resources, and then affects the ecological environment and economic development of the whole society [33,34]. Treatment methods are gradually developing towards the direction of resource sustainability, which mainly refers to developing the means of recycling and the reduction of construction waste to monitor and reduce harmful impacts on resources, including the comprehensive application of BIM technology [35–37], 3D printing technology [38,39] and other information technologies, as well as the circular economy and other management methods at various stages of the construction waste life cycle [40].

Since C&D waste has increased steeply and attracted the attention of the industry, many scholars have conducted hot spots and trends research on C&D waste or the sustainable development of resources. However, resource sustainability is closely linked to the development and progress of C&D waste management. Unfortunately, there is a gap in the discussion of the overall hotspots and trends in C&D waste and the sustainable development of resources. Therefore, this paper adopts a more reliable bibliometric analysis method to analyze 3550 publications collected from the Web of Science core collection, including annual quantitative distribution, author cooperation, influential and productive countries/regions and institutions, keyword co-occurrence analysis, literature co-citation analysis and identification of research frontiers, so as to further discover emerging technologies and theories for efficient resource utilization, improve the quality of engineering projects and reduce costs, and promote a virtuous cycle of resources in the construction industry. In the second section, the determination process of the research methods and data collection are expounded. The third section presents the analysis results, and accordingly, the results are further discussed in the fourth section. The research conclusions on C&D waste and the sustainable development of resources are shown in the fifth section.

2. Methods

2.1. Research Method

Knowing the hotspots, frontiers and status of a field can guide further research, and bibliometrics can achieve this [41]. Manual literature analysis [42] and scientometric analysis [43] are two methods commonly used in bibliometrics. In order to make the research results more accurate, scientometric analysis, which can visually present the quantitative analysis results, is adopted in this paper [44]. Citespace software developed by Professor Chen Chaomei [45], and VOSviewer, a scientific knowledge mapping software developed by professors Van Eck and Waltman [46] of Leiden University in the Netherlands, are both effective tools for visualization analysis. Many researchers have used Citespace and VOSviewer to research related fields. For example, Zheng et al. summarized the intellectual structure and evolution model of partnership research in the construction industry using Citespace [47]. Chellappa et al. analyzed the status of research on the safety of Indian construction workers through VOSviewer [48]. Therefore, Citespace and VOSviewer are selected in this paper to conduct author cooperation analysis, analysis of countries/territories and institutions, keyword co-occurrence and cluster analysis on the selected literature, in order to study the research status in the field of C&D waste and sustainable development.

2.2. Data Collection and Collation

Web of Science (WoS) and Scopus are the preferred databases for researchers conducting bibliometric analysis. Since the WoS database contains extensive literature in engineering, social science, medicine, management, philosophy and other disciplines, it is chosen as the database to select research data. The search terms in this study are "sustainability OR sustainable development" and "construction waste* OR C&D OR construction waste management OR demolition waste* OR decoration and renovation waste management", and the literature language in the data was restricted to English at the same time. By comparing the search results of all databases and core collections of WoS, it is found that although the former published articles earlier (since 1994), the eight articles published between 1994 and 2001 are mainly early explorations on the sustainable development of construction waste and resources, with little impact on the identification of current hot spots and trends. Meanwhile, the literature in the core collection of WoS is groundbreaking and of high quality in terms of construction waste [49,50]; therefore, the original data of 3550 publications selected in this study are all from it, including research articles, review articles, proceedings papers, data papers and early access, and excluding editorial materials, letters and book reviews.

3. Results

3.1. Analysis of Publications

Quantitative distribution data for articles published on C&D waste and the sustainable development of resources are analyzed by Citespace, as shown in Figure 1. Among them, the countries with the highest number of publications are specially shown in stacked columns. The broken line in the figure represents the cumulative number of publications in the field, which reflects the development status of research results in this field from 2002 to 2022. It can be found by analyzing the broken line that the first article was published in 2002, and the number of published articles was less than 25 for six consecutive years, with slow growth. In 2016, the number of annual publications exceeded 100 for the first time, and academia became more and more interested in this field. In 2022, more than 700 articles were published, making the research more diversified. Thus, according to the above research results, the research progress since 2002 can be roughly divided into three parts: the exploration phase (2002–2007), the initial growth phase (2008–2015) and the rapid development phase (2016–2022).

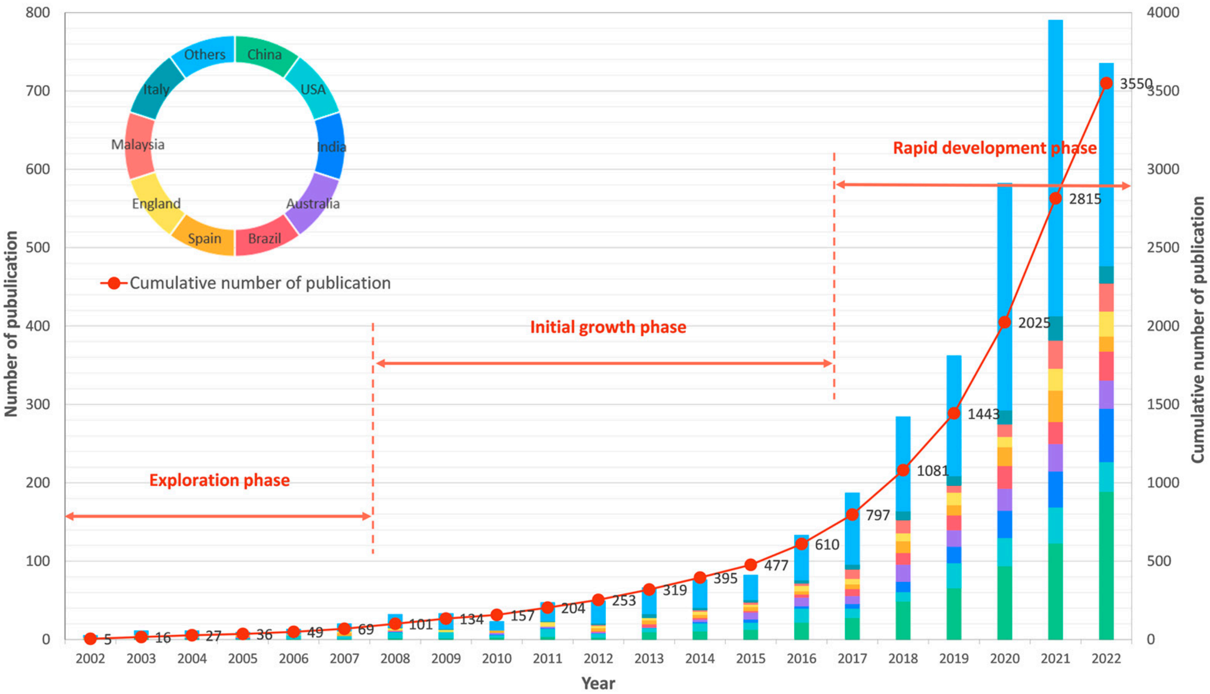


Figure 1. Statistical chart of literature publication.

At the same time, the stacked columns also presented the research status in the field of C&D waste and the sustainable development of resources among countries. It can be seen that China's development in this field shows an exponential growth trend, while India and Brazil grew very slowly in the early stage, until they became active in 2018. Related research in the United States and Australia has developed steadily, while studies in Malaysia, Italy and other countries have shown fluctuating growth.

Table 1 lists the 10 most productive journals. The number of publications of *Journal of Cleaner Production* (11.414%) ranks first, which shows its high influential status, followed by *Sustainability* (8.012%), *Construction and Building Materials* (7.787%), *Materials* (2.952%) and *Resources Conservation and Recycling* (2.839%). Obviously, preservation of the environment, building materials, and sustainable development are the core themes of the top 10 most productive publications. This shows that researchers' journal selection is relatively simple, and we can pay more attention to these journals to track the research frontiers and hot articles in the field of C&D waste and the sustainable development of resources.

Table 1. The proportion of published journals.

NO.	Publication	Count	Proportion
1	*Journal of Cleaner Production*	406	11.414%
2	*Sustainability*	285	8.012%
3	*Construction and Building Materials*	277	7.787%
4	*Materials*	105	2.952%
5	*Resources Conservation and Recycling*	101	2.839%
6	*Journal of Building Engineering*	67	1.884%
7	*Environmental Science and Pollution Research*	61	1.715%
8	*Buildings*	44	1.237%
9	*Waste Management*	44	1.237%
10	*Journal of Materials in Civil Engineering*	42	1.181%

3.2. Co-Author Analysis

Co-author analysis can identify authors who have made significant contributions to this field, and their changes in research interests also reflect research trends to some extent. At the same time, the regional or global development of this field can be grasped in a timely manner by revealing the close relationship between them.

3.2.1. Co-Authorship Analysis

In this bibliometric study, 11,795 authors were included in the research on C&D waste and the sustainable development of resources. As shown in Figure 2, the network view and density view of 149 authors with more than 5 articles were drawn by VOSviewer. In the network view, a node represents an author, and its size is proportional to the number of articles by each author. The links between nodes intuitively demonstrate the cooperative relationship between authors. The thicker the line, the closer the connection between them. The distance between nodes indicates the affinity between them, and different colors represent different clusters of author collaboration. Accordingly, in the density view, the more nodes around a node, the brighter the color and the closer the cooperation.

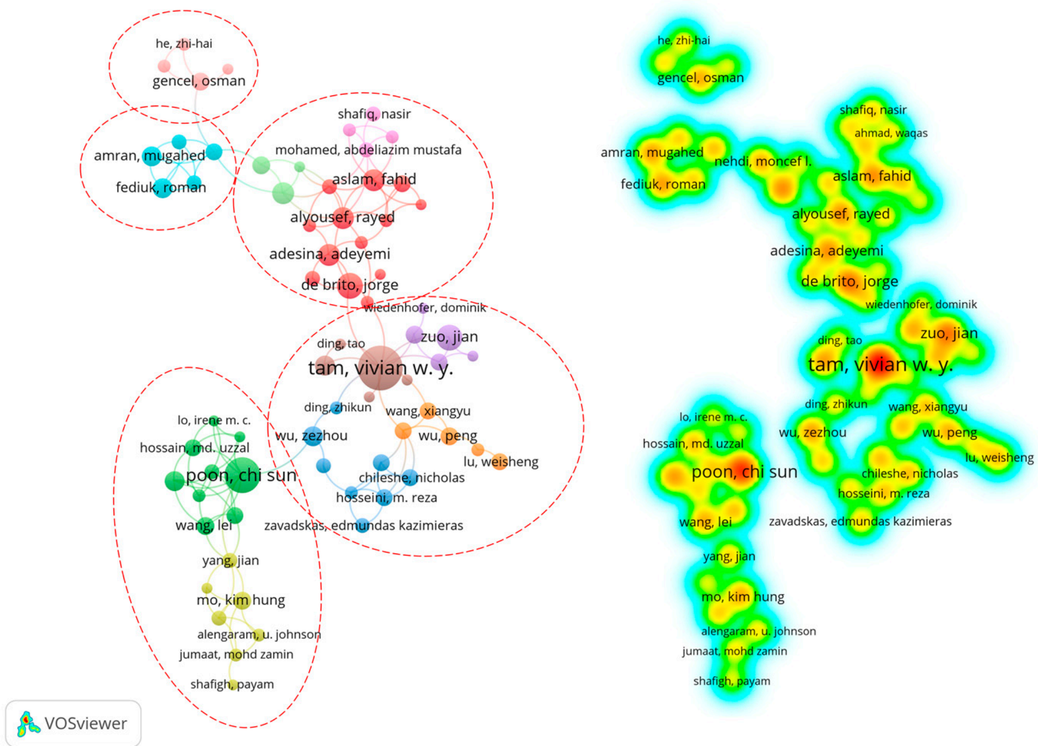


Figure 2. Co-author network.

As can be seen from Figure 2, 149 authors were labeled as 11 research clusters according to their degree of cooperation, and they can be roughly divided into five research communities. With Vivian W.Y. Tam, an author from the University of Western Sydney, as the central author, the most connected research community is formed with Jian Zuo from the University of South Australia and Xiangyu Wang from Curtin University, Australia, etc. They focused primarily on recycled aggregate concrete and sustainable performance assessment, while recent research has focused mainly on quality improvement of recycled concrete and lean construction management. Another closely connected research community consists of Chi Sun Poon, Lei Wang and Md Uzzal Hossain et al. They mainly worked on the environmental friendliness and sustainable management of recycled concrete products.

3.2.2. Co-Institution Analysis

To discover the important research organizations in the field of C&D waste and the sustainable development of resources, the collaborative network of institutions with more than 10 published articles is shown in Figure 3. In this part, 115 nodes represent 115 institutions, most of which are universities. The size of the node depends on the number of publications, and the degree of collaboration between the two institutions is indicated by the thickness of the lines. Colors of institutions represent the clusters to which they belong. As can be seen from Figure 3, Hong Kong Polytechnic University is the largest node, which is most closely related to the purple cluster and the blue cluster, such as Tongji University, Hong Kong University and City University of Hong Kong in the purple cluster, while in the blue cluster, the China Academy of Science and Shanghai Jiao Tong University are the main partners, indicating that there are close cooperations between top scientific research institutions and top universities in China. There are also orange clusters and red clusters with frequent cooperation. Malaysia Petroleum University is the central institution that maintains close cooperation with Chongqing University, Melbourne Institute of Technology, Milan Institute of Technology, Curtin University and Delft University of Technology, etc. It also shows that global institutions attach greater importance to the areas of C&D waste and the sustainable development of resources, and are actively expanding cooperation and exchange of research experiences.

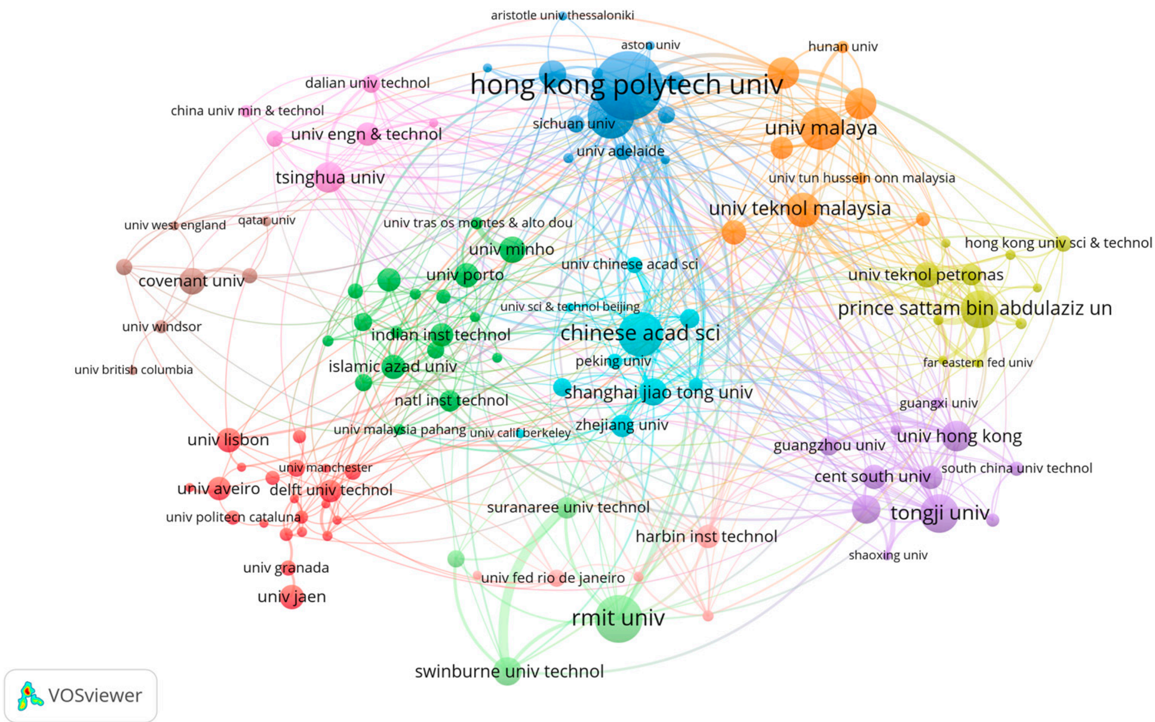


Figure 3. Co-institution network.

3.2.3. Co-Country Analysis

The research situation of countries/territories was analyzed using VOSviewer. A total of 117 countries/territories have contributed to this field, but only 69 countries/territories with more than or equal to 10 papers are presented in Figure 4. Similarly, the larger the node, the more articles the country or region has published, and the thicker the line, the more frequently the two countries/territories communicate. China is the most productive country (n = 828, 23.32%), followed by India (n = 339, 9.55%), Australia (n = 299, 8.42%), the United States (n = 285, 8.03%) and England (n = 258, 7.27%).

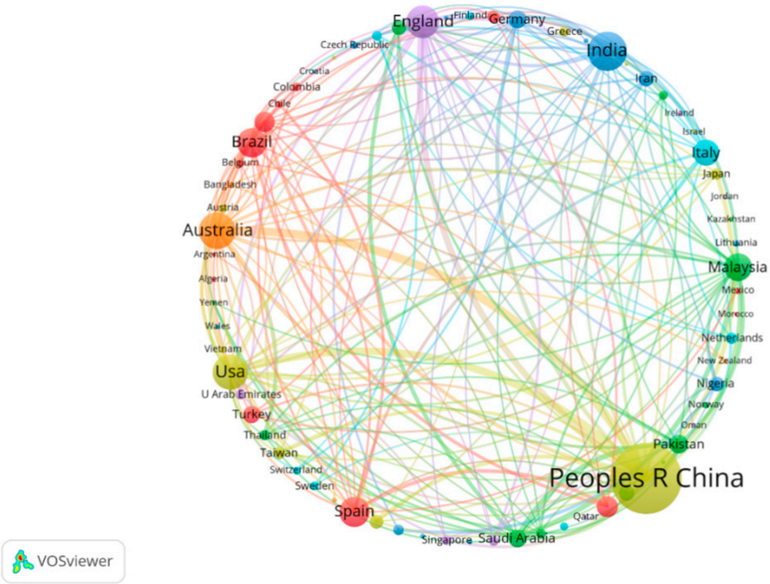
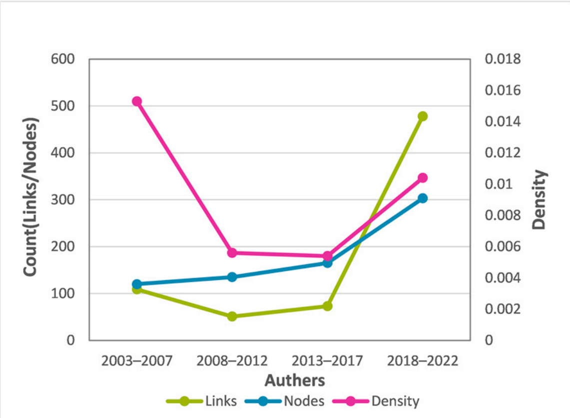


Figure 4. Co-country network.

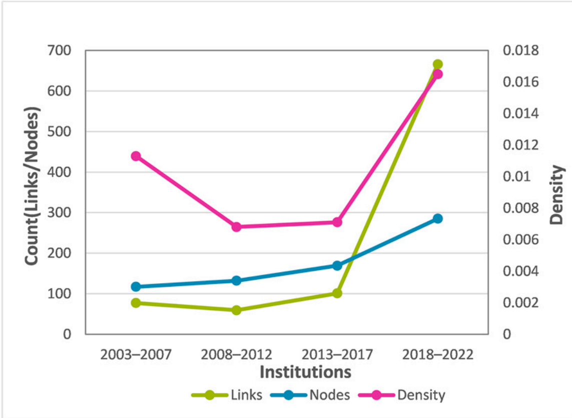
With the development of the construction industry, countries pay more attention to construction waste. It can be observed that China, which publishes the most articles, has very frequent cooperation with Australia, the United States and England. These countries have many partners and have made rapid progress in C&D waste and the sustainable development of resources through global communication, cooperation and information sharing. As can be seen from Figure 1, despite India publishing research articles later than expected, the number of articles on construction waste has increased rapidly in recent years, indicating that India has gradually realized the importance of the sustainable development of construction resources.

Analyzing the research cooperation network among individuals, institutions and countries from the perspective of temporal evolution can better reveal the overall development trend of this field in recent years [51]. Starting from the year (2003) when the number of papers was more than 10, longitudinal change charts of nodes, links, and density are illustrated using Citespace. Among them, the time interval is set to 5 years, nodes represent authors, links represent cooperation among authors, and the density is the actual number of relationships in the network divided by the theoretical maximum coefficient. Figure 5 shows the results. Three line charts show changes in relevant parameters for individuals, institutions and countries, respectively. The horizontal axis represents time, the left side of the vertical axis represents the counts of nodes and links, while the right side represents density value.

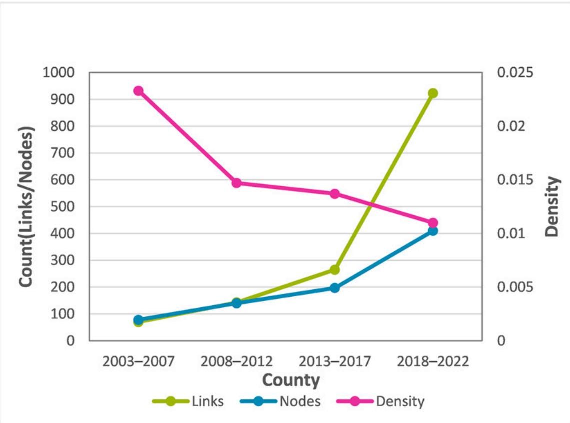
It can be seen from Figure 5 that the blue line representing the number of authors continues to grow, indicating that new researchers (individuals, institutions, and nations) have joined and contributed to the field of C&D waste and sustainable development as a result of the current environmental deterioration, and the increase has gradually accelerated since 2018. Another set of green lines indicates a change in the number of links among researchers, which is also on the rise in general. Although the number of collaborations between individuals and institutions decreased slightly from 2003 to 2007, they all resumed their enthusiasm for cooperation in 2008 and continued to increase later, while cooperation between countries kept increasing throughout the period. The strength of the nodes' collaboration is shown by the purple line. According to Figure 5, research on C&D waste and sustainable development was still in its infancy between 2003 and 2017. Many new researchers were still in the exploratory phase and had not started active external communication, which led to a downward trend in the overall density line. With the continuous deepening of research, this field has achieved great results. Therefore, researchers have engaged in active experience sharing and academic cooperation to seek new breakthroughs in the field, making the density curve rise again.



(**a**)



(**b**)



(**c**)

Figure 5. (**a**) Longitudinal analysis of co-author networks. (**b**) Longitudinal analysis of co-institution networks. (**c**) Longitudinal analysis of co-country networks.

3.3. Keywords Analysis

Keywords are concise summaries of the research content covered. We can identify the main hotspots and central trends in the field of C&D waste and the sustainable development of resources through bibliometric analysis.

3.3.1. Keywords Co-Occurrence Analysis

As shown in Figure 6, the co-occurrence network with 528 keywords that have a frequency of more than 10 was presented by VOSviewer. Each node represents a keyword, and the frequency of keywords is expressed by the size of the nodes. The thickness of the connection lines between nodes intuitively reflects the intensity of the connection between keywords. These keywords are mainly distributed in the first three clusters, respectively by three colors (red, green and blue).

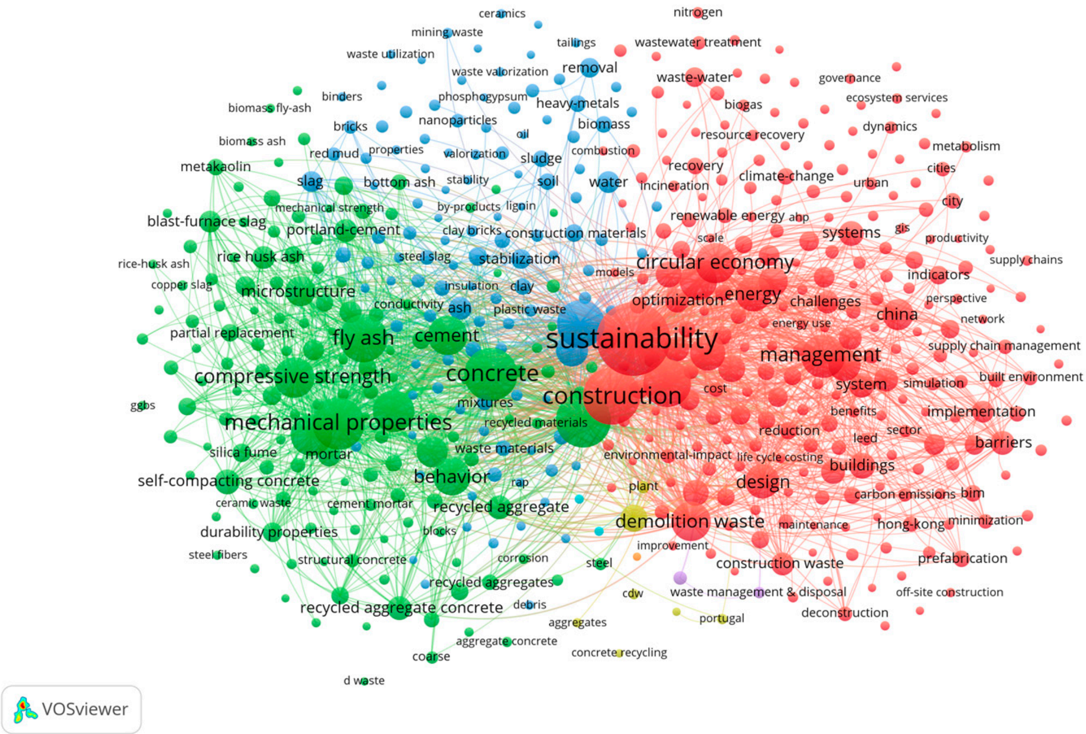


Figure 6. Keywords co-occurrence network.

As can be seen from Figure 6, except for the keywords "sustainability", "construction" and "waste" searched in this research, "performance" (n = 566), "concrete" (n = 516) and "mechanical properties" (n = 492) are the top 3 keywords frequently used. It demonstrates that the study of materials' mechanical properties is especially crucial in the field of C&D waste and the sustainable development of resources in order to expand the market for recycled products, enhance participants' confidence in the use of recycled products in construction projects (especially recycled concrete products), and ensure their bearing capacity and durability within the design period. How to improve the quality of recycled products has gradually become a hot point in this field. Some scholars have analyzed the physical properties of concrete containing recycled aggregate [52]. Other scholars have studied the mechanical, permeable and physical properties of recycled aggregate by summarizing previous publications, and finally put forward the basic performance classification mainly used for concrete, which provides a practical method for measuring the quality of recycled aggregate [53]. As self-compacting concrete has become extremely popular in recent decades, Aslani et al. evaluated the optimal mix design of recycled concrete and crumb rubber aggregates in self-compacting concrete to optimize performance [54]. These are followed by "fly ash" (n = 408), "life cycle assessment" (n = 401) and "management" (n = 339), indicating that in addition to concentrating on waste treatment technology and treatment goals, it is equally necessary to explore and innovate new waste management methods to alleviate the tremendous burden of natural resource consumption and environmental degradation. Advanced management tools and methods play an important role in promoting the economic and environmental benefits of the construction industry. The introduction of the life cycle assessment (LCA) management method reflects that current research on construction waste is not just limited to waste reduction and recycling in the construction stage; BIM, big data, and other technical tools can be used for detailed planning, error correction, and waste management during the planning and design period to reduce C&D waste. At the purchasing phase, more green and recycled materials can be ordered to reduce the environmental impact of construction waste. Hossain et al. compared the environmental impact of producing recycled aggregate from C&D waste with that of producing natural aggregate from raw materials using a life cycle assessment approach [55].

Lu et al. established performance benchmarks for the management of construction waste in different project categories using big data technology to promote better management of construction waste [56]. Figure 6 also shows newer high-frequency keywords, such as "circular economy" (n = 285) and "microstructure" (n = 151). Studies have shown that about three quarters of the solid waste generated by the construction industry has residual value [57]. As awareness of sustainable development and resource management improved, many nations started exploring new models, and researchers gradually paid more attention to waste reduction, so as to minimize the negative impact of construction waste on the environment and further realize the sustainable development of resources. This also makes the circular economy model continue to attract the attention of researchers [58,59].

3.3.2. Keyword Evolution Analysis

In order to more intuitively understand the research work of C&D waste and sustainable development, the evolution of keywords in this field was analyzed using Citespace, as shown in Figures 7 and 8. The time axis in Figure 7 indicates the time point when the keyword first appeared. The red section in Figure 8 represents a sudden increase in interest in keywords during this period.

As can be seen, "emission" and "sustainable development" appeared the earliest, demonstrating that harmful gases produced by the construction industry, particularly CO_2, are responsible for the deterioration of the ecological environment. It is the gradual exposure of ecological and social issues that promote the sustainable development trend of the construction industry. Although the issue of emissions was brought up in 2002, little research has been carried out on it, and it has only recently become active. Some researchers have started to reduce CO_2 emissions by studying environmentally-friendly and cost-competitive geopolymer concrete to gradually replace ordinary Portland concrete (OPC) that is energy-dependent and environmentally damaging [60]. There are also scholars who calculated the carbon emissions of geopolymer recycled aggregate concrete and studied its physical properties, such as slump and compressive strength, in order to prove its feasibility to replace OPC-based concretes [61]. From Figure 7, it is also clear that many keywords related to materials, such as "energy", "concrete", "cement", and "aggregate", occurred between 2004 and 2006. Among them, "energy" has the highest centrality (centrality = 0.13) and functions as a bridge. The energy consumption and pollution of the construction industry is enormous, so scholars have begun to pay attention to the environmental performance of the construction industry and its materials [62]. The keywords "environmental impact" and "design" appeared in 2006 and also reflect that researchers have gradually shifted their focus to other links besides the construction phase, in order to optimize the final disposal process of waste materials [63]. In the following years, most efforts were devoted to the development and performance optimization of various recycled materials. Since 2018, the emergence of "green concrete" and "circular economy" indicates that the construction industry has been guided by new theories, such as green building and the circular economy [64,65]. It is necessary to explore new and effective management models to promote resource utilization of construction waste and the sustainable development of construction resources.

With the development of C&D waste and the sustainable development of resources, although the introduction of new topics has slowed down after 2018, there are still many new opportunities and challenges. Combined with Figure 8, it can be seen that the keywords "optimization", "implementation" and "strategy" have again received great attention from academia in the recent period (2019–2022). Their respective citation bursts also rank among the top three. Therefore, these keywords can be identified as recent hot topics in this field. Identifying and implementing standards for green building materials (GBM) and assessing their sustainability, breaking down barriers to promoting a circular economy (CE), integrating life cycle sustainability assessment (LCSA) into the design phase to optimize building performance, and designing waste minimization strategies are expected to be future research directions.

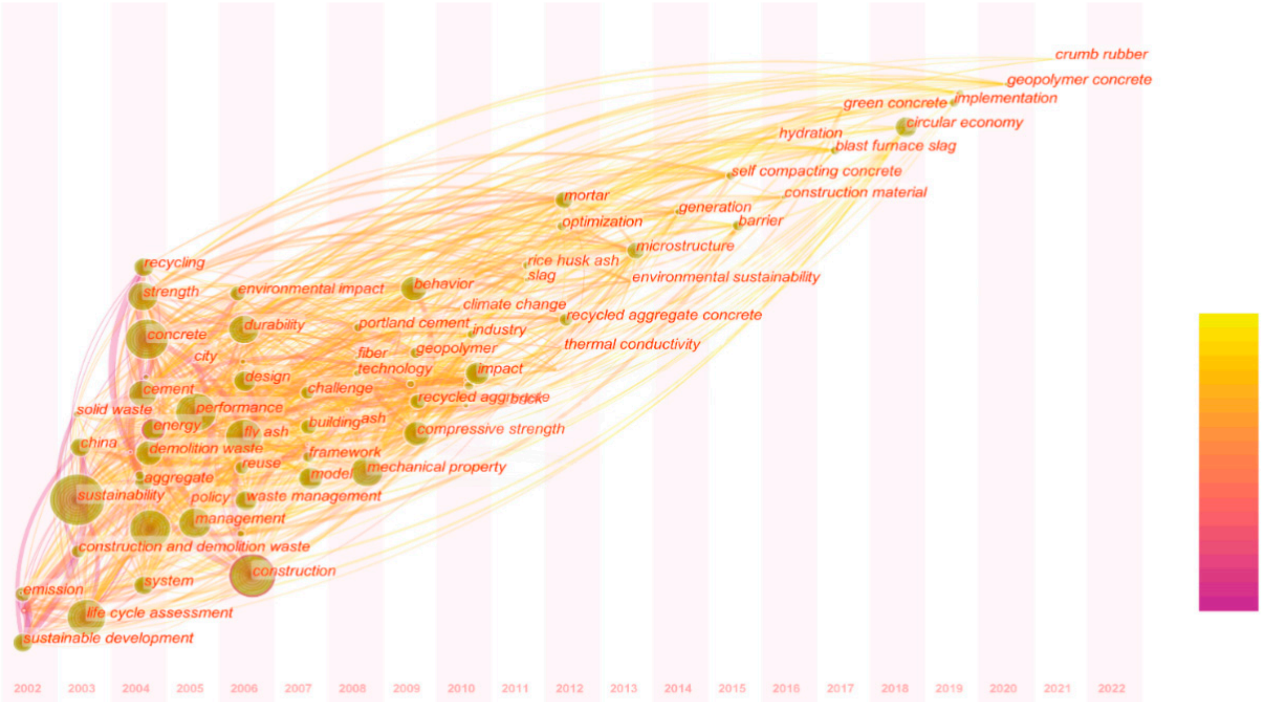
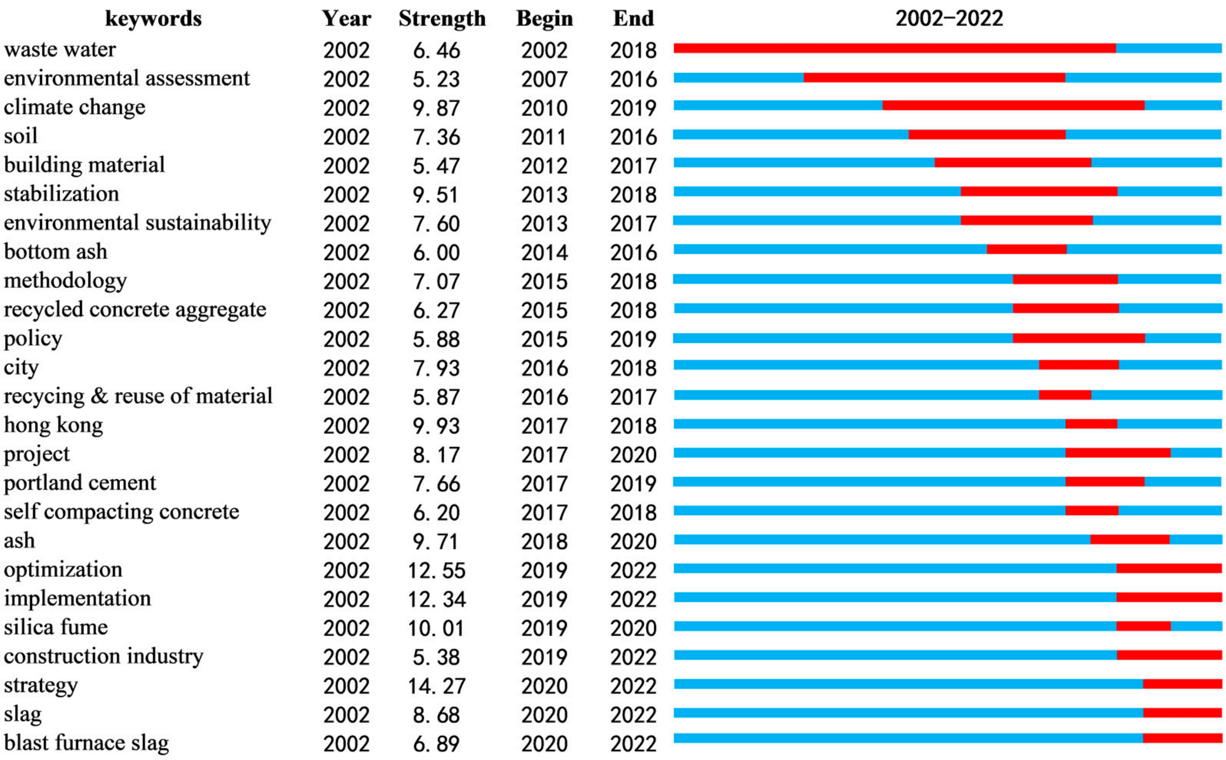


Figure 7. Keywords timezone view.



keywords	Year	Strength	Begin	End	2002–2022
waste water	2002	6. 46	2002	2018	
environmental assessment	2002	5. 23	2007	2016	
climate change	2002	9. 87	2010	2019	
soil	2002	7. 36	2011	2016	
building material	2002	5. 47	2012	2017	
stabilization	2002	9. 51	2013	2018	
environmental sustainability	2002	7. 60	2013	2017	
bottom ash	2002	6. 00	2014	2016	
methodology	2002	7. 07	2015	2018	
recycled concrete aggregate	2002	6. 27	2015	2018	
policy	2002	5. 88	2015	2019	
city	2002	7. 93	2016	2018	
recycing & reuse of material	2002	5. 87	2016	2017	
hong kong	2002	9. 93	2017	2018	
project	2002	8. 17	2017	2020	
portland cement	2002	7. 66	2017	2019	
self compacting concrete	2002	6. 20	2017	2018	
ash	2002	9. 71	2018	2020	
optimization	2002	12. 55	2019	2022	
implementation	2002	12. 34	2019	2022	
silica fume	2002	10. 01	2019	2020	
construction industry	2002	5. 38	2019	2022	
strategy	2002	14. 27	2020	2022	
slag	2002	8. 68	2020	2022	
blast furnace slag	2002	6. 89	2020	2022	

Figure 8. Top 25 keywords with the strongest citation bursts.

3.4. Documents Co-Citation Analysis

In this paper, a cluster analysis of references, which reflect the knowledge bases and research frontiers, was carried out using the g-index operation in Citespace (the scale factor k = 25), and each cluster was labeled by keyword terms. Finally, 13 main clusters were generated (Cluster 0 was the search keyword, cluster 8 and 21 had little relationship with the research topic, and cluster 9 was repeated, so 4 clusters were manually deleted [66]). Modularity and silhouette values are 0.7877 and 0.8974, indicating the high reliability of the clustering structure. The result is shown in Figure 9 and Table 2.

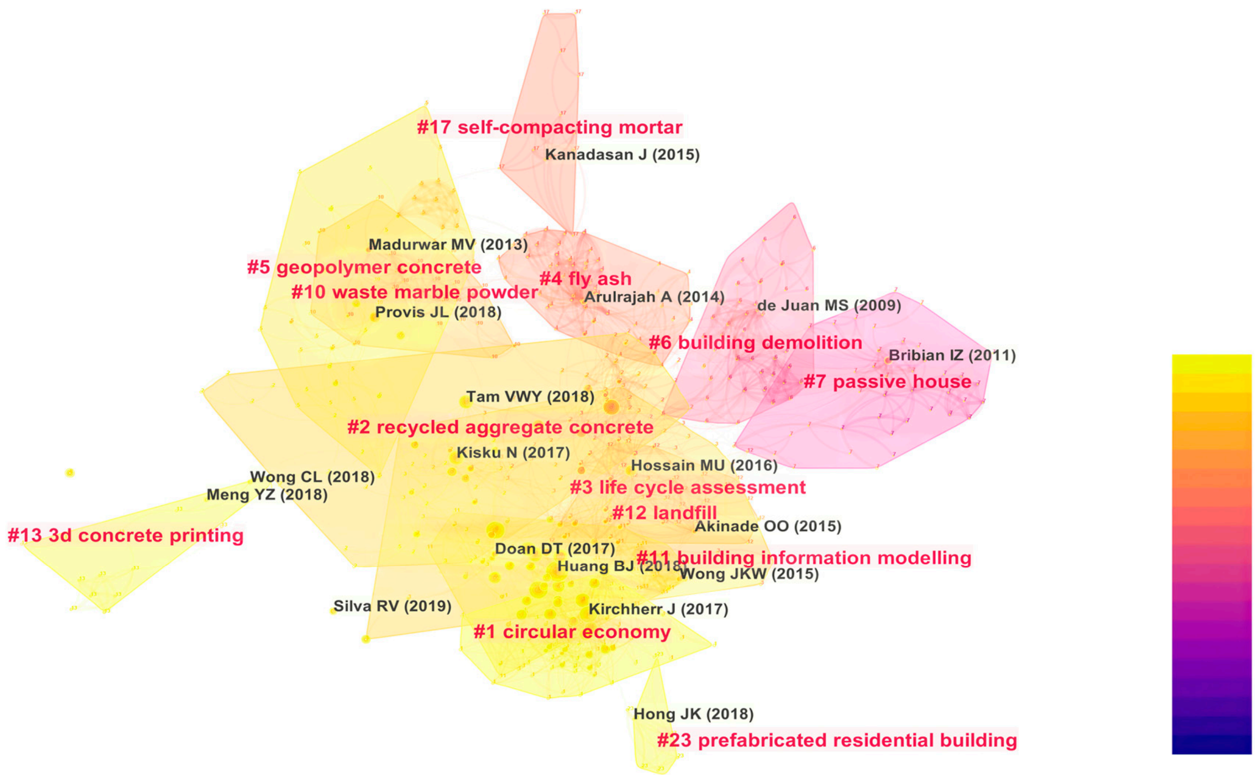


Figure 9. Cluster analysis of documents co-citation.

Table 2. Cluster information.

Cluster ID	Cluster Label	Size	Mean Year
1	Circular economy	84	2018
2	Recycled aggregate concrete	74	2015
3	Life cycle assessment	65	2015
4	Fly ash	54	2012
5	Geopolymer concrete	45	2017
6	Building demolition	44	2009
7	Passive house	42	2009
10	Waste marble powder	31	2014
11	Building information modelling	30	2017
12	Landfill	29	2013
13	3D concrete printing	14	2018
17	Self-compacting mortar	13	2012
23	Prefabricated residential building	7	2018

In Table 2, the cluster size represents the number of co-cited references in the cluster. The larger the value, the more popular it is in a certain field. The average year can reflect the development trend of cluster. It can be seen from the results that there were many studies on the definition, classification and treatment of C&D waste in the early stages, and then the research direction turned to life cycle assessment and performance research of recycled aggregate concrete. In recent years, most scholars have begun to discuss the sustainable development of C&D waste based on some emerging theories, materials and technologies, such as the circular economy, geopolymer concrete, 3D printing technology and prefabricated buildings, in order to further explore the sustainable development mode of C&D waste resources.

To further understand the recent development status of this research area, the three clusters with the highest average years are listed in Table 3. Meanwhile, the three most active cited articles and the three most active citing articles related to the cluster are listed in order to identify the intellectual bases and research frontiers in this field [67]. Details are discussed below.

Table 3. The three most active citing and cited papers in the latest three clusters.

Cluster ID	Cited Publications		Citing Publications	
	Author	Year	Author	Year
1	Kirchherr, Julian et al. [68]	2017	Norouzi, Masoud et al. [59]	2021
	Geissdoerfer, Martin et al. [69]	2017	Yu, Yifei et al. [71]	2022
	Mahpour, Amirreza [70]	2018	Rahla, Kamel Mohamed et al. [72]	2021
13	Wong, Chee Lum et al. [73]	2018	Ahmed, Ghafur H et al. [76]	2022
	Meng, Yazi et al. [74]	2018	Sahin, Hatice Gizem et al. [77]	2022
	Habert, G. et al. [75]	2018	Qian, Hao et al. [78]	2022
23	Hong, Jingke et al. [79]	2018	Lopez-Guerrero, Rafael E et al. [82]	2022
	Teng, Yue et al. [80]	2018	Yuan, Mengqi et al. [83]	2022
	Hao, Jianli et al. [81]	2020	Zhang, Riqi et al. [84]	2022

Cluster 1 is labeled "circular economy", which has been a hot topic in the last five years. The three most active cited papers mainly focus on defining the circular economy and identifying obstacles to its implementation. Kirchherr et al. [68] summarized 114 definitions of CE and finally outlined the definition, which refers to an economic system that replaces the "end-of-life" of waste with reducing, reusing and recycling materials and recycling in the production/distribution and consumption process. Geissdoerfer et al. [69] provide conceptual clarity by illustrating similarities and differences between the terms "circular economy" and "sustainability" to improve the efficiency of the use of these approaches in research and practice. Mahpour [70], on the other hand, provided direction for further research by identifying barriers to the transition to CE in C&D waste management. Therefore, on the basis of intellectual bases, the three papers most actively cited are related to the promotion of CE. Norouzi et al. [59] further clarified the development process of CE through bibliometric analysis, and put forward future research topics, such as exploring the relationship between the smart city and CE, developing the business model of CE, etc. Yu et al. [71] found the lack of a decision-making framework in CE mainly from the perspective of policy formulation, and proposed a bi-directional policy-making mechanism based on two policy models. Rahla et al. [72] proposed strategies to promote the circular economy in three respects: resource management, architectural design methods, and digitalization of the construction industry.

Cluster 13, labeled "3D concrete printing", reflects that researchers have recently paid particular attention to the combination of waste disposal with 3D printing technology. In the intellectual bases, Wong et al. [73] found that brick powder is the most practical form of recycled brick, but it can only be used sparingly as concrete aggregate because it cannot significantly improve concrete performance. Meng et al. [74] reviewed the published literature on the use of various wastes in the production of concrete blocks, demonstrating the good potential of incorporating C&D waste into concrete blocks as aggregates. Habert et al. [75] provided medium-term and long-term solutions to environmental problems in concrete production. In the most active citing papers, Ahmed et al. [76] reviewed the existing 3D concrete printing technology and studied the different application technologies for structural reinforcement. Sahin et al. [77] showed that the use of geopolymers, recycled aggregates and waste in the mix design of 3D printed concrete (3DPC) can contribute to the sustainability of 3DPC. Qian et al. [78] also suggested that using recycled products as 3D concrete printing materials can reduce carbon emissions and technology costs, which have high economic and environmental benefits. In general, 3D concrete printing technology is worth promoting in the field of C&D waste and the sustainable development of resources.

Cluster 23 is labeled "Prefabricated Residential Building" (PRB), so the top three cited papers all focus on the topic of prefabricated buildings. Hong et al. [79] established a framework for cost performance analysis to investigate the basic cost composition of prefabricated buildings, and assess the impact of adopting prefabricated technologies on the total cost of actual construction projects. Teng et al. [80] systematically examined evidence of reducing building life cycle carbon through prefabricated technologies. It showed that prefabrication resulted in a 15.6% reduction in embodied carbon and a 3.2% reduction in operational carbon. Hao et al. [81] developed a BIM-based approach to evaluating carbon emission reduction of a prefabricated building project, which showed that prefabrication has less negative environmental impact compared to traditional building technology. In the three citing papers, Lopez-Guerrero et al. [82] considered that the sustainability of industrial building systems (IBS) had previously only been examined in terms of environmental aspects and through qualitative indicators. To fill the gap, IBS sustainability was assessed using quantitative and qualitative indicators based on economic, social and environmental aspects. Based on evolutionary game theory, Yuan et al. [83] discussed the evolutionary decision-making behavior and stabilization strategy of the government, real estate developers and homebuyers in the PRB industry. They also proposed a promotion mechanism to help China's construction industry achieve orderly and sustainable development of the PRB. Zhang et al. [84] assessed the environmental impact of prefabricated building policies in Hong Kong SAR and Singapore by comparing these policies. This shows that researchers are beginning to notice the impact of prefabricated buildings on environmental benefits and sustainable development.

In general, Cluster 1 discusses the resourceful and sustainable treatment of construction waste from the perspective of circular economy management methods. Cluster 13 focuses on 3DCP technology for the reuse of construction waste. Cluster 23, on the other hand, focuses more on prefabricated building policies and regulations, and takes them as a new engine for reducing waste and carbon footprint and promoting resourceful utilization of construction waste.

4. Discussion

The research hotspots in the field of C&D waste and sustainable development of resource can be concluded based on the findings of keyword co-occurrence and cluster analysis. According to Figure 6, "performance", "concrete", "mechanical-properties", "fly-ash", "management", "life-cycle assessment", "circular economy" and "microstructure" have high frequency. At present, concrete is the material most often considered among recycled products. Geopolymer concrete, steel fiber recycled aggregate concrete, and other new types of recycled concrete are being developed. Research on the compressive strength, flexural strength, slump, durability and other mechanical properties of recycled concrete are also enduring topics in this field. In recent years, construction waste management methods have been developed and some achievements have been made. Academia has given the life cycle assessment (LCA) approach a lot of attention, showing that relevant research on reducing the environmental footprint is a hot topic in this area, as shown in Table 2. The application of LCA in the resource management of C&D waste places an emphasis on preventing the overall environmental impact of waste throughout the entire process. It changes the previous idea of focusing only on economic benefits or technological development, optimizes the specific steps of some promising technologies, and provides a new direction for the management of construction waste. There are also proposals to incorporate Life Cycle Sustainability Assessment (LCSA) into building design. In addition, the related research on CE and reduction has also become the focus in this field, so as to further improve the level of resourceful and harmless utilization of construction waste.

Combined with Figure 8 and Table 3, research frontiers in C&D waste and resource sustainability can be identified. Although the circular economy has been extensively promoted in recent years, many countries still face difficulties in implementing it due to a variety of problems. The development of 3D concrete printing technology conforms to the current trend of construction informatization. It can realize the recycling of resources when choosing construction waste as printing materials. Prefabricated buildings can make full use of their labor-saving and energy-saving advantages in the selection of prefabricated materials, production process and construction process, but the technical bottleneck of using construction waste in prefabricated buildings has always existed. Therefore, breaking the restriction of CE promotion and effective implementation, optimizing the performance of recycled products to meet the material selection standards of emerging technologies, such as 3D printing technology and prefabricated technology, using evolutionary game theory and other methods to study the behavior factors of various stakeholders and making policy suggestions to the government to encourage the use of the above management methods and technologies can be regarded as the current research frontiers.

Trends in C&D waste and sustainable development are summarized in Figures 7 and 8 and Table 2. The construction industry has contributed significantly to energy consumption and environmental damage while advancing economic development, such as resource shortages, greenhouse gas emissions, land loss, and other issues. The contradiction between them is becoming increasingly acute. As a result, many countries are gradually realizing that if construction waste continues to rise in line with the current situation, it will lead to huge losses. Therefore, the concept of resource sustainability is gradually integrated into construction waste considering the high residual value of construction waste. First, scholars started to develop and study recycled products to value construction waste and expand the market, such as recycled aggregate, recycled blocks and recycled bricks. After that, scholars began to emphasize the reduction in construction waste, and pay attention to the economic and environmental benefits of resource recovery to prove its sustainability, such as life cycle assessment, performance optimization of recycled products, the establishment of an environmental benefit assessment model, cost compensation model research, etc. BIM, GIS and big data technology are also constantly evolving. The circular economy and green building materials have been the focus of C&D waste and sustainable development in recent years, as the aim is to explore a new management model and fully integrate the idea of resource sustainability. In general, the evolution process can be summarized as recycling–reduction–sustainability. It is worth emphasizing that the stages in the evolution process is not completely separate from each other. For example, in the past five years, in addition to focusing on sustainability, reduction technologies such as 3D printing technology and prefabricated construction are constantly advancing.

Through the discussion of the above research hotspots, research frontiers and development trends, future research directions are also proposed:

1. Promoting innovation in recycling technology. Recycling construction waste is a key strategy for the sustainable development of resources in the future. More attention should continue to be paid to the pre-treatment and reproductive phases of construction waste. First, it can more effectively reduce waste generation at the source and lower the cost of construction projects, such as material costs, labor costs and management fees. Second, it may increase the secondary or multiple utilization potential of different types of construction waste and prolong their life, so as to improve the utilization rate of construction waste resources, which plays a role in saving resources, improving the environment and promoting the sustainable development of society.
2. Developing information technology for the reduction in construction waste. The development of construction waste reduction is the focus of scientific research. It is not only a scientific problem, but also a common concern of politics, economics and society. At present, some information technologies, such as BIM, GIS and big data, have made good achievements in predicting waste generation and reducing waste output. However, some newly developed technologies, such as 3D concrete printing

and prefabricated construction, are still only used in projects with simple structure and small scale. How to combine existing mature information technologies or find new ones to solve the limitations of emerging technologies deserves further consideration.

3. More research on top-level design. The direction of development in the field of C&D waste and sustainability is also influenced by policy. Combined with research frontiers and hotspots, it is clear that current research focuses primarily on environmental benefits, such as carbon emissions and environmental footprints. Therefore, further improvement of relevant policies and regulations can enhance the environmental awareness of participants and provide impetus for the effective operation of the recycling industry chain. First, it is necessary to establish a comprehensive supervision system. BIM, GIM and other technologies can be fully used to supervise the whole process of the recycled products industry. Second, it is necessary to formulate effective incentive policies to promote the development of the construction waste industry. Financial support can be provided to recycling companies in the research and development of new materials and technologies.
4. More investigation of different project stakeholders. As things stand, it is inefficient to promote the recycling of C&D waste only through government procurement and subsidies. The participation of contractors in the reduction in construction waste and the willingness of recycling companies to engage in the development of production materials and technology research is not strong. Therefore, establishing a behavior model to find the motivation to stimulate all stakeholders to actively participate in the resourceful disposal of construction waste can be taken as the future development direction in order to guide the market stakeholders' selection behavior of resourceful treatment and achieve higher economic, social and environmental benefits.

5. Conclusions

In this paper, 3550 publications related to C&D waste and the sustainable development of resources are visually analyzed using Citespace and VOSviewer, in order to identify research hotspots, research fronts, and development trends in this field. The conclusions are summarized as follows:

1. Research progress on C&D waste and the sustainable development of resources can be roughly divided into exploration phase (2002–2007), initial growth phase (2008–2015) and rapid development phase (2016–2022). China is the most active country in this field, while the United States, India, Australia, Brazil, Spain, the United Kingdom, Malaysia and Italy contribute a large number of publications. The *Journal of Cleaner Production*, *Sustainability*, *Construction and Building Materials*, *Materials*, and *Resource Conservation and Recycling* are the most productive journals, which is closely related to the impact of journals in the field of C&D waste and sustainable development.
2. Based on the author's contributions and collaboration, it seems that more and more scholars have begun to devote themselves to research in this field. However, most of them only communicate with members of small research groups. Among the most active institutions, they are also more inclined to cooperate with domestic universities and research institutes. At present, there is still relatively little global cooperation.
3. The results of keyword co-occurrence and cluster analysis indicate that research and development of recycled products, methods for reducing construction waste, and sustainable management modes have been current research hotspots. Among them, the circular economy, life cycle sustainability assessment, and the environmental benefits of recycled products have attracted much attention.
4. The identification of research trends shows that the evolution process in this field is summarized as recycling–reduction–sustainability, and future research directions are also proposed. On the one hand, strengthening the research and development of new technologies for waste recycling and reduction can optimize the process of C&D waste management, reduce the waste of resources and construction project costs. On the other hand, more discussion of top-level design and stakeholder behavior factors is

conducive to breaking the restriction on the circular economy and other management modes, changing the inherent thinking of stakeholders, so as to promote the green development of the construction industry and improve social benefits.

In addition, some constraints on bibliometrics methods have been found. (1) The data used in bibliometric analysis vary due to the different screening criteria of researchers. (2) Two types of visualization software may present different results. Therefore, this paper tries to use one kind of software to analyze a similar set of data. (3) The correlation between cited papers and citing papers may not be obvious in some clusters, and new technical methods should be adopted to minimize the occurrence of such problems.

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