sustainability

MDPI

Review

Cutting Waste Minimization of Rebar for Sustainable Structural Work: A Systematic Literature Review

Keehoon Kwon, Doyeong Kim and Sunkuk Kim *

Department of Architectural Engineering, Kyung Hee University, Yongin-si 17104, Korea; charade0820@naver.com (K.K.); dream1968@khu.ac.kr (D.K.)
* Correspondence: kimskuk@khu.ac.kr; Tel.: +82-31-201-2922

Abstract: Rebar, the core resource of reinforced concrete structures, generates more carbon dioxide per unit weight than any other construction resource. Therefore, reducing rebar cutting wastes greatly contributes to the reduction of greenhouse gas (GHG). Over the past decades, many studies have been conducted to minimize cutting wastes, and various optimization algorithms have been proposed. However, the reality is that about 3 to 5% of cutting wastes are still generated. In this paper, the trends in the research on cutting waste minimization (CWM) of rebar for sustainable work are reviewed in a systematic method with meta-analysis. So far, the literature related to cutting waste minimization or optimization of rebar published has been identified, screened, and selected for eligibility by Preferred Reporting Items for Systematic Reviews and Meta-Analyses, and the final 52 records have been included in quantitative and qualitative syntheses. Review by meta-analysis was conducted on selected literatures, and the results were discussed. The findings identified after reviewing the literature are: (1) many studies have performed optimization for the market length, making it difficult to realize near-zero cutting wastes; (2) to achieve near-zero cutting wastes, rebars must be matched to a specific length by partially adjusting the lap splice position (LSP); (3) CWM is not a one-dimensional problem but an n-dimensional cutting stock problem when considering several rebar combination conditions; and (4) CWM should be dealt with in terms of sustainable value chain management in terms of GHG contributions.

Keywords: rebar cutting waste; minimization; optimization; structural work; systematic literature review

Citation: Kwon, K.; Kim, D.; Kim, S. Cutting Waste Minimization of Rebar for Sustainable Structural Work: A Systematic Literature Review. *Sustainability* **2021**, *13*, 5929. https://doi.org/10.3390/su13115929

Academic Editor: Nicholas Chileshe

Received: 14 April 2021
Accepted: 21 May 2021
Published: 24 May 2021

1. Introduction

Reinforced concrete (RC) structures, such as buildings and infrastructure, use enormous amounts of concrete and rebar during the construction phase. In 2012, global concrete and concrete constituent consumption reached about 10 billion m^3 [1], and the amount is rapidly increasing every year due to increased demand for RC structures along with global economic development. Rebar, the core resource of RC structures, generates more CO_2 per unit weight than any other construction resource. For example, C25/30 concrete generates embodied CO_2 (ECO_2) of 95 kg-ECO_2/t, but reinforcement bar (rebar) generates ECO_2 of 872 kg-ECO_2/t, which is equivalent to about 9.2 times of the concrete [2]. Therefore, reducing the cutting waste of rebars greatly contributes to the reduction of GHG [3]. Over the past few decades, numerous studies have been conducted on minimizing cutting wastes, and various optimization algorithms have been proposed. However, in reality, cutting wastes are still generated in the process of cutting and bending of rebars, which are at least 3% to 5% [3–7], and as much as 5% [4,6–11] to 8% [12], compared to the volume shown in the structural drawings.

Estimating how much rebar cutting wastes contribute to global GHG is a very difficult task, but to confirm the need for sustainable structural work, the authors follow a three-step estimation process after surveying literature and actual data: (1) analyzing the concrete and rebar ratio after surveying actual project data for concrete and rebar in Korea; (2) estimating the global annual use of concrete and rebar, and CO_2 emissions by rebar using global concrete consumption in 2012, world GDP growth rate [13], and analyzed concrete and rebar ratio; and (3) estimating the global annual rebar cutting wastes and the resulting CO_2 emissions, applying the relatively conservative waste rates of 3 to 5% rates identified in the literature mentioned above.

Although the construction environment varies from country to country, in case of high-rise residential buildings in Korea, the analysis of 30 projects, as shown in Table 1, showed that the rebar quantity compared to concrete was found to be about 0.070 ton/m^3, and commercial buildings have long-span heavily loaded attributes compared to residential buildings. The analysis of 12 projects showed a result of about 0.119 ton/m^3. The average of these amounts is calculated at about 0.077 ton/m^3. If this average value is applied to 10.058 billion m^3 [1], as of 2012 as shown in Table 2, about 778.9 million ton of rebar usage is calculated. Applying the world GDP growth rate as shown in Table 2, rebar usage increases every year, which is estimated to be about 947 million tons in 2019.

Table 1. Estimation of rebar quantity compared to concrete in reinforced concrete structures.

Description	No. of Projects	Concrete (m^3)	Rebar (Ton)	Rebar/Concrete (Ton/m^3)
Residential buildings	30	4,680,573	327,489	0.070
Commercial buildings	12	835,514	99,698	0.119
Sum	42	5,516,087	427,187	0.077

Source: authors' research results.

Table 2. Estimated global annual use of concrete and rebar, and CO_2 emissions of rebar.

Year	World GDP Growth Rate (%)	Concrete (Billion m^3)	Rebar (Ton)	CO_2 Emission (Ton·CO_2)
2012	2.52	10.058	778,930,801	266,082,762
2013	2.66	10.326	799,650,360	273,160,563
2014	2.85	10.620	822,440,395	280,945,639
2015	2.88	10.926	846,126,679	289,036,873
2016	2.59	11.209	868,041,360	296,522,929
2017	3.26	11.574	896,339,508	306,189,576
2018	3.10	11.933	924,126,033	315,681,453
2019	2.48	12.229	947,044,359	323,510,353

Source: authors' research results.

For reference, it is impossible to investigate all RC structures around the world to estimate global rebar usage by year. Therefore, despite some errors, it is meaningful to have applied some data of high-rise residential and commercial buildings in Korea. Later, when the data of investigation into various RC structures are added, the range of error will gradually decrease. The application of the world GDP growth in 2012 was also estimated in the same context, as shown in Table 2, because data on global concrete and concrete constituent consumption by year could not be obtained.

Using an estimated global annual use of rebar, if about 0.3416 ton·CO_2/ton [14], which is the unit value of rebar CO_2 in Korea, is applied, the generation of about 323.5 million tons of CO_2 in 2019 is estimated, starting with 266.1 million ton·CO_2 in 2012. For reference, the unit value of CO_2 is different according to industrial structure by country, so it is not possible to obtain a unified value. Therefore, in this study, the calculation was performed based on data analyzed in Korea.

If a rebar cutting waste rate of about 3 to 5% is applied based on this value, about 23.368 to 38.947 million tons of wastes are generated as of 2012, as shown in Table 3, and the amount keeps increasing every year to reach about 28.411 to 47.352 million tons in 2019. When calculating the corresponding CO_2 emission, the amount increases annually from about 7.982 to 13.304 million ton·CO_2 in 2012 to reach about 9.705 to 16.176 million ton·CO_2 in 2019, as shown in Table 3. If the near-zero cutting waste of rebars is realized, the effect of

CO_2 emission reduction of up to 16.176 million tons can be achieved, and the corresponding GHG is reduced. For reference, since the rebars placed into structures vary in length, diameter, and number, it is impossible to combine them without cutting wastes, called zero cutting wastes, by the length of rebars supplied by the steel mill. However, by combining rebars with special lengths supplied by the steel mill, cutting wastes can be reduced to close to zero, which is called near-zero cutting wastes.

Table 3. Estimation of global annual rebar cutting wastes and CO_2 emissions.

Year	Rebar (Ton)	Cutting Wastes of Rebar (Ton)		CO2 Emissions from Cutting Wastes (Ton·CO_2)	
		3%	5%	3%	5%
2012	778,930,801	23,367,924	38,946,540	7,982,483	13,304,138
2013	799,650,360	23,989,511	39,982,518	8,194,817	13,658,028
2014	822,440,395	24,673,212	41,122,020	8,428,369	14,047,282
2015	846,126,679	25,383,800	42,306,334	8,671,106	14,451,844
2016	868,041,360	26,041,241	43,402,068	8,895,688	14,826,146
2017	896,339,508	26,890,185	44,816,975	9,185,687	15,309,479
2018	924,126,033	27,723,781	46,206,302	9,470,444	15,784,073
2019	947,044,359	28,411,331	47,352,218	9,705,311	16,175,518

Source: authors' research results.

As shown in Table 2, demand for buildings and infrastructure increases in line with global economy growth and corresponding demand for RC structures increases every year. The increase in RC structures leads to demand chains that increase demand for concrete and rebars, as shown in Table 2, resulting in an annual increase in rebars cutting waste and CO_2 emissions such as Table 3. In particular, it is expected in the future to be more concentrated in developing countries where the population is concentrated [15,16]. The increase in global cutting waste of rebars not only causes unnecessary cost losses but also problems of generating large amounts of CO_2 in the production, transportation, and processing phases. Therefore, research to realize near-zero cutting waste is critical to implement sustainable rebar work.

So far, many studies have been conducted to optimize the use of rebars or to reduce the cutting waste. However, the near-zero cutting waste has not yet been realized. However, the near-zero cutting waste has not yet been implemented. The study on cutting stock problem (CSP), which is considered to be the beginning of cutting waste minimization (CWM), was first mentioned by Kantorovich in 1939 and was first published in Management Science in 1960 [17]. Therefore, CSP-related literature has been searched for since 1960 in this study. The literature on the optimization of rebar cutting waste was basically targeted from 1990 to 2020, because the CSP-related research in rebar work started in earnest from 1991. In this paper, we performed a search and review of studies related to optimization or cutting waste minimization of rebars that have been conducted so far and identified the status and problems of existing studies. We then proposed the direction of future research to implement near-zero cutting waste and identify its potential.

2. Data Sources and Methodology

2.1. Data Sources

There are literature databases of various fields around the world, but for the search of articles related to minimal cutting waste of rebars, Scopus, Science Direct, Web of Sciences (WoS), Taylor and Francis Online, Springer Link, American Society of Civil Engineers (ASCE) Library, and Willey Online Library were used. Some dissertations or literature published in internationally uncertified journals were searched for using Google or Google Scholar databases.

2.2. Systematic Literature Review

SLR is an exact and reproducible method for identification, evaluation, and interpretation of predefined fields of study [18]. Kitchenham and Charters defined "a systematic literature review is a means of identifying, evaluating, and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Individual studies contributing to a systematic review are called primary studies; a systematic review is a form of secondary study" [19]. Since similar SLR methodologies have been proposed by several scholars [20,21], MDPI publisher based in Basel, Switzerland recommends that the authors follow Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [22], checklist, and flow diagram for reporting systematic reviews and meta-analyses.

In construction field, numerous literature review articles have been published, not based on SRL [23–28], before 2010. The reason for this is that the perception of SLR in the construction field was not high. Since 2010, with the exception of some articles [29–34], most review articles have been written based on SLR [18,35–49]. After 2018, many review articles have been written according to PRISMA [18,46–49], and this study also follows the PRISMA statement for systematic reviews and meta-analysis.

2.3. Methodology

The previously mentioned literature database was sequentially searched using Boolean operator "AND" by keywords, such as rebar, rebar work, rebar optimization, and rebar cutting waste. As a result, Google Scholar found about 79,100 search results for literature related to rebar work, about 16,000 cases of rebar optimization, about 14,000 cases of rebar cutting waste, and about 4410 cases of rebar cutting waste optimization, as shown in Table 4. Google Scholar has confirmed that it includes various reports such as books, content, and dissertations along with academic papers in most databases, as shown in Table 4. In addition to construction, literature of almost all fields, such as medicine and chemistry, is searched by keywords. Additionally, it is confirmed that the search works even if there is a rebar or work in the name. Therefore, searching and reviewing all relevant literature in Google Scholar is an inefficient approach. Since the minimum cutting waste of rebars to be dealt with in this review article is a very specific topic, most of literature is searched in databases such as ScienceDirect, WoS, and ASCE Library. However, Google Scholar was used to search for books, magazines, and documents such as dissertations, which are not well searched for in databases such as WoS and ASCE, and when original text could be downloaded from these databases.

Table 4. Search by keyword in literature database (as of 1 December 2020).

Literature Database	Literature Keywords			
	Rebar Work	**Rebar Optimization**	**Rebar Cutting Waste**	**Rebar Cutting Waste Optimization**
Google Scholar	79,100	16,000	14,000	4410
ScienceDirect	9041	3191	409	211
Springer Link	4292	672	384	88
ASCE Library	3896	962	233	73
Willey Online Library	2796	776	265	116
Taylor and Francis Online	2002	628	176	60
Scopus	892	163	13	9
Web of Science	572	89	10	6

As shown in Table 4, a search for literature was performed on Google Scholar, ScienceDirect, Springer Link, and ASCE Library. It has been confirmed through the literature search process that the number of literatures searched for varies depending on the characteristics of each database. For example, topics such as rebar cutting waste correspond to construction engineering; therefore, literature is frequently searched for in databases of engineering fields. In particular, the ASCE Library is a database dedicated to the construction field; hence, many literatures related to this review paper have been searched for. When searching the literature with a keyword of rebar work, which includes all rebar-related work, many articles are retrieved as shown in Table 4. However, many literatures include corrosion of rebar, rebar tying tool, rebar cutting and bending machine, and rebar work schedule, and are not related to CWM. When search range is narrowed to rebar optimization and rebar cutting waste, the number of records is reduced dramatically. For reference, rebar optimization is the general word of rebar minimization, and rebar cutting waste literally means the waste remaining after cutting the rebar. Finally, in most databases, searching with rebar cutting waste optimization that has the same definition as CWM results in fewer records. In the case of Scopus and WoS, it is reduced to 9 and 6 records, respectively, but all records are valid. In other databases, many records are identified as RC design optimization.

Based on literature searched for on 1 December 2020, 1811 records were finally identified, as shown in Figure 1, excluding duplicated literature or literature not related to the subject of this study. Among them, duplicated 384 records were screened and 638 and 386 records that were not relevant to the rebar cutting work and rebar cutting optimization were excluded, respectively, to finally select 403 full-text articles. Then, 351 literatures related to design optimization of the RC components or frames were excluded. The reason is that design optimization of RC corresponds to pre-processing research of rebars optimization, while CWM of rebars covered in this study corresponds to post-processing research. As a result of reviewing some of the literature [50–81] related to design optimizations of rebars, it was confirmed that they are related to design optimization of RC components such as slab [50–57], beam [58–61], column [62–65], foundation [64], and wall [66–68], and design optimization of RC frames such as bridges [69–71] and building [72]. In addition, many studies related to design optimization have been well-organized in the review article [37].

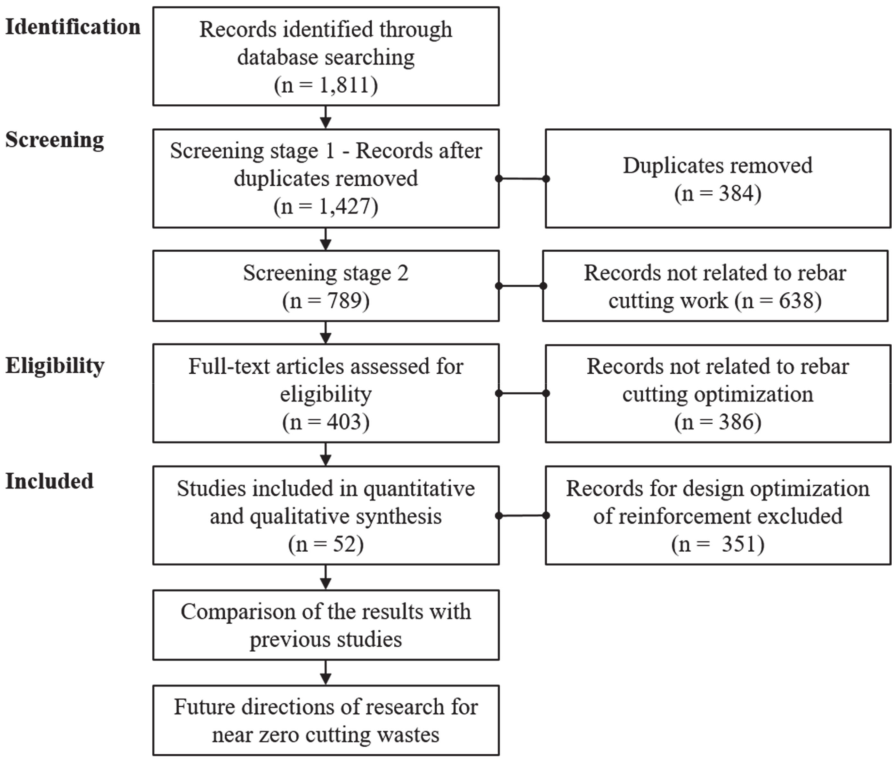

Figure 1. Flow diagram of the literature review and the analysis process. Source: authors' research results.

2.4. Descriptive Analysis

Studies in the field of construction project management vary widely, including time, cost, quality, and safety. In the Project Management Body of Knowledge, there are 13 knowledge areas [82], and there is countless management research connected with engineering technology, and post-processing research such as minimum cutting wastes of rebars is a very narrow and special topic. Therefore, it is confirmed that there are not many articles directly dealing with this topic. As shown in Table 5, 37 articles were published in the journal [3,4,6,8–12,63,83–110] and 11 articles were published in peer reviewed conference publication [7,55,62,71,111–117]. The rest have three dissertations [5,118,119] and one book chapter [120].

Table 5. Number of literatures by publication type.

Publication Type	Number of Literatures	Percent
Journal	37	71.2%
Proceedings	11	21.1%
Dissertation	3	5.8%
Book chapter	1	1.9%
Total	52	100.0%

Source: authors' research results.

When examining papers published in internationally certified SCI or SCIE journals, as shown in Table 6, the biggest number of papers, seven, were published in *Journal of Construction Engineering and Management* (*JCEM*) [6,84,87,95,97,101,102]. As of 2019, *Journal Impact Factor* (*JIF*) of *JCEM* is not as high as 2.347, but it is one of the most popular ASCE journals. In addition, two papers were published in *Automation in Construction* [63,94,105], and *Journal of Computing in Civil Engineering* [86,103], and one was published each in the remaining journals. It is notable that each paper was also published in high *JIF* journals, such as the *International Journal of Engineering Science* [85], *Computer-Aided Civil and Infrastructure Engineering* [110], and the *Journal of Advanced Research* [100]. It is assumed as such because the problem of minimizing the rebar cutting waste is important and difficult. *Construction Management and Economics* is not an SCI journal classified by JCR but was included in the list because it is internationally popular [99].

Table 6. List of the most popular journals.

Journal Title	Papers	Published Year	JIF 2019
Journal of Construction Engineering and Management	7	1993, 1994, 1996, 2000 (2 papers), 2007, and 2012	2.347
Automation in Construction	3	1995, 2019, and 2021	5.669
Journal of Computing in Civil Engineering	2	1995, 2013	2.979
International Journal of Engineering Science	1	2016	9.219
Computer-Aided Civil and Infrastructure Engineering	1	2014	8.552
Journal of Advanced Research	1	2016	6.992
Construction and Building Materials	1	2018	4.419
International Journal of Computer-Integrated Manufacturing	1	1998	2.861
Sustainability	1	2020	2.576
KSCE Journal of Civil Engineering	1	2014	1.515
Canadian Journal of Civil Engineering	1	2004	0.985
Construction Management and Economics	1	2014	-
Others	16	-	-
Sum	37		

Source: authors' research results.

Table 7 shows 37 articles that are classified by countries based on lead authors. According to Table 7, Korea has the largest number of publications, which is 16 articles, followed by Canada with 5, Israel with 4, and Turkey with 3; 5 countries, including Bangladesh, published 2 papers each. Eight countries, including Albania, published 1 paper each. In Korea, the number of rebars per unit area of RC structure has more than doubled due to the strengthening of seismic design standards in 1988 [121], the strengthening of noise standards between floors in 2000 [122], and the rapid increase in the number of high-rise buildings over 20 stories. Therefore, by continuously conducting studies on rebars design optimization and CWM of RC structures since 1999, the reduction in the use amount of rebar was confirmed.

Table 7. Number of literatures by country.

Country	Number of Articles	Remarks
Korea	16	
USA	6	
Canada	5	
Israel	4	
Turkey	3	
Bangladesh, India, UK, Taiwan, and Thailand	2	Five countries presented 2 papers each
Albania, Australia, Ethiopia, Germany, Iraq, Malaysia, Spain, and Ukraine	1	Eight countries presented 1 paper each
Total	37	

Source: authors' research results.

Figure 2 shows the number of articles published by year. One or two articles were published every year until 2004, but after 2012, the number of articles increased until 2016 with the development of various techniques, including computer-aided design (CAD) and building information models (BIM). It is confirmed that the number of articles dropped sharply to one in 2017 and increased again. In the past, cutting wastes were approached from an economic perspective; however, recently, research has been conducted from a sustainable construction perspective.

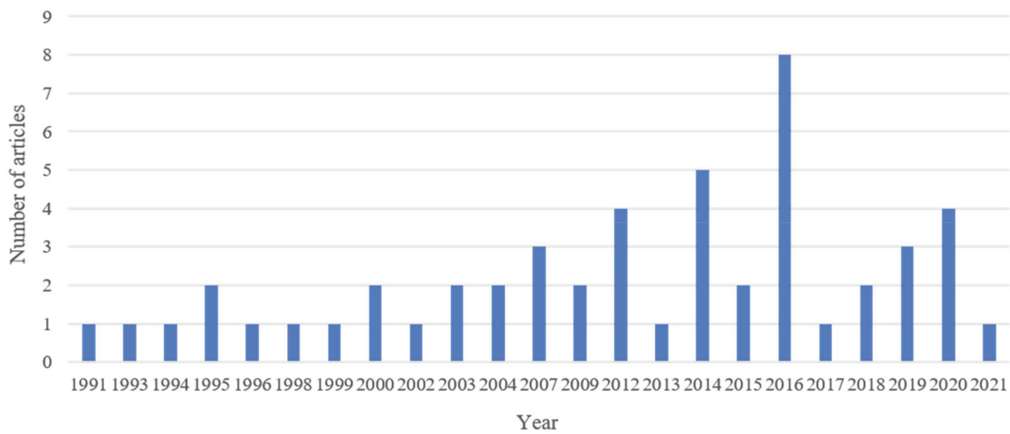

Figure 2. Number of published articles by year (Source: research results).

3. Review Results and Discussion

3.1. Selection of the Papers

As shown in Figure 1, the number of literatures corresponding to rebar cutting optimization through the identification, screening, and eligibility process was a total of 403, and 52 literatures related to RC design optimization were selected, excluding 351 literatures that fall under the category of pre-processing research of rebar optimization. They address the problems of rebars cutting waste, corresponding to post-processing research of rebars optimization after RC design. These literatures will be reviewed by factors such as application of optimization techniques and graphic solutions for CWM, range of rebar work process, consideration of lap space position, reflection of length in a special order, consideration of bending margin, and consideration of schedule. The review of selected literature will not only measure characteristics and trends of the research for CWM of rebars but also present a direction of future research. In addition to the selected literature, there is rebar modeling [123], using BIM solutions for optimized rebar work, and software that creates rebar details using the information generated after the structural design [124]. However, these were excluded in this paper as they are articles written for the promotion of commercial software and are not described mainly on CWM.

3.2. Identification of Cutting Waste Minimization-Related Factors

One-dimensional CSP has been studied not only in rebars but also in all areas of cutting linear stock material such as pipe and timber. Since the publication of Kantorovich's article [17], many articles have been published in various fields related to CSP [8,125–148]. In the case of rebar, research has been vigorously conducted after 1991 with the development of computer science, since it was first introduced as an example of CSP by Kantorovich [3]. This is mainly because the need for CSP in the construction field to build a single building on site was not highlighted much, unlike general manufacturing, which mass-produces large quantities of the same or similar products in factories. Moreover, it was not easy to develop algorithms to deal with varying variables, such as length, diameter, number of required, and point of use of rebar, which are subject to CSP, and algorithms to consider variables, such as bending margin, various market length, and special length.

In this study, factors that influence the analysis of attributes of the literature should be identified for quantitative and quantitative analysis of the final selected literature. The following is a summary of the variables identified during screening and eligibility assessment of full-text articles related to rebar optimization along with the authors' research experience.

- Applied optimization techniques: integer programming (IP), linear programming (LP), genetic algorithm (GA), simulated annealing (SA), binary search algorithm (BSA), heuristic algorithm (HA), and harmony search (HS) algorithm.
- Rebar work process: preparation of a drawing, quantity take-off, rebar production such as cutting and bending, and in-site rebar placement.

In addition, literature can be reviewed by lap splice position (LSP), use of special length (SpL) or stock length (StL) rebars, and schedule.

3.3. Results of Quantitative and Qualitative Review

3.3.1. Description by Optimization Techniques

Table 8 summarizes the optimization techniques adopted by the literature selected for rebar's CWM. Afzal et al. [37] introduces the definitions, advantages, disadvantages, and application cases of various algorithms in the study of RC structural design optimization. However, the problem of rebar cutting waste is relatively limited in the scope of study compared to RC design, so the literature is summarized by seven optimization techniques, as shown in Table 8. The advantages and disadvantages associated with rebar CWM are described by optimization techniques, and the classification of literature that adopted these techniques is presented in Table 8.

Table 8. Summary of the adopted optimization techniques.

Optimization Techniques	Advantage	Disadvantage	References
Linear programming (LP)	Flexibility to be paired up with other approximation to improve convergence	Slower in finding special-length-priority or waste-rate-priority solutions under multiple search conditions	[3–5,7,9,12,63,86,93,96,109,114]
Integer programming (IP)	Rapid generation of solutions under limited search conditions	Difficulty in search of solutions under complex conditions or in search of float number solutions	[7,12,63,100,101,104–106]
Genetic algorithm (GA)	Simplicity in programming, proof in finding the global optimum, applicable to diverse problem domains, computing performance, and diversity of solutions	Time consuming for formulating a CSP problem under complex combination conditions	[8,11,71,83,101,113,118]
Binary search algorithm (BSA)	Quick search for rebars of a specific length to be used in combination	Long CPU run-time for global search as the increase of rebar combination conditions	[10,116]
Simulated annealing (SA)	Use for combinatorial optimization problems in a discrete search space and simplicity in implementation	Large computing time and cost if boundary conditions are not provided	[6]
Heuristic algorithm (HA)	Low computing cost to obtain near-zero cutting waste solution	Large computing time and cost to obtain an optimized solution for all conditions	[62]
Harmony search (HS)	Easy to build and fast convergence for the optimal solution in a reasonable amount of computational time	Randomness, instability, and uncertainty of search direction	[117]

Source: authors' research results.

In the case of LP, it has an advantage in terms of flexibility to be paired up with other approximations to improve convergence, but there is a disadvantage in terms of being slower in finding special-length-priority or waste-rate-priority solutions under multiple search conditions. In studies of rebar's CWM, 12 articles were selected as optimization techniques [3–5,7,9,12,63,86,93,96,109,114]. The reason for this is that CSP or CWM problems have been adopted most often in modeling and have become more common.

Integral programming (IP) has the advantage of quickly generating solutions under limited search conditions, while many search conditions or requiring a float number solution are challenging. In rebar's CWM study, the second largest number of research articles is adopted in eight research articles [7,12,63,100,101,104–106], despite the fact that it takes considerable time to formulate the problem [101]. IP is one of the long-standing optimization techniques used as one-dimensional cutting stock problems like LP and is said to be the most common in modeling CWM problems.

GA has advantages such as simplicity in programming, proof in finding the global optimum, applicability to diverse problem domains, computational performance, and diversity of solutions, but it also has disadvantages such as being time consuming for formulating a CSP problem under complex combination conditions. As a result of reviewing the literature, seven articles have started to adopt GA since 2004 [8,11,71,83,101,113,118], and most of them have adopted LPs and IPs before. Salem, Shahin, and Khalifa [101] conducted a study comparing CWM using GA and IP models and then verified that GA further reduces the cutting waste of the rebar through a case study. Computational time of GA models is practical for everyday use and, in some cases, the GA model was able to lump the wastes in bigger lengths, thus achieving more savings.

Binary search algorithm (BSA) has an advantage in terms of providing quick-iterated local search for rebars of a specific length to be used in combination but has a disadvantage of long CPU run-time for global search as the increase of rebar combination conditions. BSA has the advantage of quickly performing iterated local search, so the CWM problem should be divided according to the supply schedule of rebars. In this case, there is a problem that the CWM effect is not greater than global search. BSA has been confirmed to have been adopted by two articles, as shown in Table 8 [10,116].

SA has advantages such as use for combinatorial optimization problems in a discrete search space and simplicity in implementation, while it has disadvantages of large computing time and cost if not providing boundary conditions. Porwal and Hewage asked "which conditions are more suitable?" when LP, IP, GA, BSA, sequential heuristic procedure, and SA are applied to a combination of rebar cutting patterns [6], and Porwal and Hewage proposed integration with BIM and combination with special-ordered length, available market lengths, and SpL of rebars by SA. In addition, the case study suggested that SA models are successful in complex combinatorial optimization programs through controlled randomization.

Heuristic algorithms are algorithms that solve problems in a more efficient way than conventional methods at the expense of optimality, completeness, and accuracy to obtain rapid solutions. Heuristic algorithms are expensive for accurate calculations and are frequently used if approximate solutions are sufficient. Bekdas and Nigdeli [62] optimized RC columns using a metaheuristic algorithm, called a bat algorithm.

HS is a metaheuristic search algorithm that tries to mimic the improvisation process of musicians in finding a pleasing harmony [149,150]. Although HS algorithm has better global optimization capability, its disadvantages are randomness and instability. Nonetheless, search direction of the algorithm is uncertain [150], and HS requires higher number of iterations [37]. HS was applied to optimize costs of materials, including concrete and rebars, by implementing design variables such as width and height of RC column, including diameters and number of reinforcements, and loading condition variables are implemented as harmony vectors [117].

HA is divided into local search-based metaheuristic algorithms, such as SA, and global search-based metaheuristic algorithms, such as GA and HS, to find better solutions. Therefore, HA or SA is more efficient if the target of rebar CWM is a local-search-based problem, and GA or HS is more effective if the target is a global-search-based problem.

Reference numbers written in Table 8 indicate that the corresponding optimization techniques are used in combination, for example, references [7,12,63], used a combination of IP and LP, and reference [101], performed rebar CWM using IP and GA.

3.3.2. Description by Rebar Work Process

Rebar work process consists of structural design, drawing work, quantity take-off (QTO), rebar production, and rebar placement. The literature related to structural design optimization of the RC component or frame has been sufficiently reviewed in other articles, and this paper reviews the literature that performed post-processing CWM from drawing creation to rebar placement. Table 9 shows literature review by rebar work process. Strategies to reduce rebar cutting waste are effective only when implemented from the drawing work stage. Accordingly, the top 20 literature, as shown in Table 9 references, suggested reducing cutting wastes in conjunction with drawings, and some literature included a mathematical algorithm that automatically writes rebar drawings using CWM algorithm [6,84,91,105,108,111].

Table 9. Summary by rebar work process.

Work Stage	Contents	References
Drawing work	Using the information provided in the drawing, rebar CWM-related tasks are performed. Alternatively, a rebar drawing is created by applying CWM algorithm.	[3,6,55,84,86–89,91,95,97,98,103,105,108,110,111,114,119,120]
Quantity take-off	Rebar CWM algorithm is connected to the QTO task and progress.	[3,5,6,85–87,90,91,98,103,107,108,111,113,115,116]
Rebar production	After completing the bar bending schedule, the work is performed to combine cutting patterns using CWM algorithm.	[6,8,87,88,91,92,94–96,99,107,111,112,116]
Rebar placement	For CWM, the cutting wastes are reduced by adjusting the lap splice position or length of the rebars in the range of satisfying the structural code.	[84,85,89,97,98,102,103,105,110,112,118,120]

Unlike ordinary materials, quite many variables should be considered in the case of the exact QTO work of rebars. It is a complex task that should reflect the size of stock material, concrete cover, and lap splice length, as well as variables not shown in the drawing, such as bending margin. Thus, studies have been conducted to develop algorithms to automate QTO in several studies [3,6,90,91,107,108,115], where variables such as the length and number of rebars applied could be directly utilized for rebar CWM algorithm. Thus, the second largest number of articles, as shown in Table 8, for reducing rebar cutting waste at the QTO stage is 16.

CWM algorithm has been widely applied to rebar production stages, including cutting and bending [6,8,87,88,91,92,94–96,99,107,111,112,116]. This is because the bar-bending schedule is prepared first before supplying rebars to the site, the cutting list is prepared, and the bar combination is performed by cutting patterns using the list. Several studies have indicated that the cutting wastes of rebars start from the purchase order stage [6,90,91,104]. This is because ordering by market length without analysis of optimal cutting patterns is a major factor in increasing cutting waste.

As for the study on reducing cutting waste in rebar replacement, 12 articles were published, as shown in Table 9 references. In the rebar placement stage, studies are divided into two—one is to prevent loss or waste caused by a mismatch in field installation after cutting, bending, and fabrication of rebars [84,89,97,105,112,118], and the other is to perform a detailing design and installation planning as an optimization method considering the productivity of the rebar placement [2,10].

The reference numbers written multiple times in Table 9 indicate that the corresponding article was performed on several stages of rebar works. For example, references [98] and [103] were performed for drawing work, QTO, and rebars placement stages, and references [84,89,97,105,110,120] were performed for drawing work and rebars placement stages.

3.3.3. Description by Other Factors

Because the location, size, and structural performance of RC components such as column, beam, foundation, slab, and wall are different, the length of the rebar generated after structural design is very diverse. Since rebar has the characteristic of being repeatedly installed, if the rebar is determined to have a certain length after structural design, the cutting patterns appear simple and the effect of CWM is also significant. LSP should be partially adjusted to satisfy the structural design codes to arrange the length of rebar in RC components constant. Several studies, as shown in Table 10, have revealed that the effect of CWM is significant when LSP was adjusted [6,7,12,86,105,108,112,119].

Table 10. Summary by other factors.

Factor	Contents	References
LSP	Adjusting lap splice position to satisfy structural code to make the length of rebars used for cutting patterns constant	[6,7,12,86,105,108,112,119]
StL	Performing CWM on rebar in stock or market length	[3,4,6,9–11,86,90,104,105]
SpL	Performing CWM on rebars with special ordered length	[3,4,6,10,90]

As shown in Table 10, 10 rebar CWM-related articles are described for rebars of stock length (StL) or market length. This is because the CSP study on the optimization of the material of one-dimensional stock length stored in the factory is the beginning of rebar CWM. In particular, in the case of factory production, materials sold at a fixed length in the market are stored, and the combination of cutting pattern optimization is performed for mass production. However, in the case of a construction project, various lengths and number of rebars must be combined, so it is difficult to reduce cutting wastes using stock length. Therefore, rebar combination is needed by SpL [3,4,6,10,90].

The use of SpL can further reduce cutting wastes, in contrast to the use of StL [3,6,10]. However, the minimum quantity and pre-order time must be satisfied to order rebars with SpL. The length of rebars should be adjusted so that it is combined with SpL. Eventually, additional algorithms should be developed to adjust LSPs easily and quickly. The references in Table 10 are written several times, because the corresponding articles considered multiple factors for CWM. For example, Porwal and Hewage [6] incorporated StL and SpL as well as LSP into the study for CWM.

3.4. Discussion

If near-zero cutting waste of rebar, one of the most ECO_2 generating resources in construction materials, is realized, environment-friendly sustainable construction is implemented and the waste of high-cost resources is prevented. The results of SLR analysis on studies that attempted to reduce rebar cutting wastes showed that there were relatively many design optimizations of RC literature corresponding to pre-processing research, while the rebar CWM-related literature corresponding to post-processing research was 52 articles. The results of systematic critical review on CWM of rebar are summarized as follows:

- Applied optimization techniques: LP, IP, and GA were the most frequently adopted 27 articles, 84.4% of the total, and the remaining BSA, SA, HA, and HS were selected in 5 articles. Initially, optimization algorithms were adopted based on LP and IP, but recently, the adoption of HS and GA has been confirmed to increase. This is because HS and GA, which are operated based on expertise, can perform the task of realigning reinforcing bars with special lengths more easily and faster than mathematical algorithms. HS and GA can realign rebars that are repeatedly installed with special lengths more efficiently than IP, LP, and BSA, while satisfying structural requirements.
- Rebar work process: CWM studies have been conducted in many literatures linking four stages of work processes such as drawing work, QTO, rebar production, and rebar placement. The reason is that rebar CWM is linked to all four stages from drawing work to rebar placement. In addition, since the importance of information is determined according to the order of the rebar work process, it was confirmed that 20 papers, 16 papers, 14 papers, and 12 papers were associated with each work stage. In consideration of the characteristics that the initial information affects the information generated later, it was confirmed that performing CWM in the drawing work stage is most effective. If CWM is performed in the drawing work stage, the results are sequentially reflected in the QTO, rebar production, and rebar placement stages to minimize cutting wastes.
- Other factors: partially adjusted LSPs, while satisfying structural design codes, expect the related research to increase [12], due to the large effectiveness of CWM.

Although there have been many CWM studies on StL so far, it has been confirmed that the research focusing on SpL will be expanded in the future.

In general, rebars are sold as linear rods in the market. Therefore, most studies on minimum cutting waste have focused on algorithms to solve one-dimensional cutting stock problems because contractors purchase, cut, and bend them. With the development of software and hardware solutions for engineering programs, techniques such as GA, BIM, AR, VR, and integrated project delivery have been added. It is assumed that there is a fundamental problem that the cutting waste rate is not yet reduced to near-zero despite those studies.

In this study, we have confirmed that cutting wastes can be significantly reduced in the following two cases. First, the use of coiled rebars can reduce cutting wastes to near-zero. The coiled rebar, which has been used since the 1990s, automatically performs rebar cutting and bending by machine. Initially, coiled rebars with a diameter of 10 mm to 16 mm were processed, but recently, coiled rebars with a diameter of 50 mm are automatically cut and bent by machine [151]. Global near-zero cutting waste can be achieved if machines are available that automatically perform straightening, cutting, and bending after coiled rebars are produced and supplied in all countries. However, not many countries have an industrial structure that satisfies such a supply chain. Except for some countries in Europe and North America, most countries do not yet supply coiled rebars. Therefore, CWM research should be continued until the rebar supply chain is globally established.

Second, if mechanical rebar couplers are used, steel quantities are reduced compared to lap spaces and ECO_2 is also reduced proportionally. This study summarizes the comparisons between lap splices and mechanical couplers, as shown in Table 11. Lapping length and weight are different from high-tensile deformed bars 10 mm (D10) to 32 mm (D32) in diameter. The weight of couplers of each diameter is different, but the overall effect of reducing ECO_2 is significant when couplers are used. In the small case of D10, a weight of 0.166 kg/EA and an ECO_2 difference of 0.145 kg-ECO_2/EA are generated. In the large case of D32, a weight of 14.237 kg/EA and an ECO_2 difference of 12.415 kg-ECO_2/EA are generated, respectively. In particular, with mechanical rebar couplers, ECO_2 reduction effect can be achieved from at least 84.7% to up to 96.4% compared to splice lap.

Table 11. ECO_2 comparison between splice lap and coupler.

Size	Building Element	Unit Weight (KG/M)	Splice Length (M/EA)	Splice Weight (KG/EA)	Coupler Weight (KG/EA)	Weight Difference (KG/EA)	ECO_2 Difference (kg-ECO_2/EA)	Reduction Rate (%)
D10	Wall	0.560	0.350	0.196	0.030	0.166	0.145	84.7
D13	Wall	0.995	0.450	0.448	0.042	0.406	0.354	90.6
D16	Wall	1.560	0.660	1.030	0.060	0.970	0.845	94.2
D19	Wall	2.250	0.730	1.643	0.109	1.534	1.337	93.4
D22	Column	3.040	1.450	4.408	0.160	4.248	3.704	96.4
D25	Column	3.980	1.650	6.567	0.260	6.307	5.500	96.0
D29	Column	5.040	2.150	10.836	0.390	10.446	9.109	96.4
D32	Column	6.230	2.370	14.765	0.528	14.237	12.415	96.4

Source: authors' research results.

However, when comparing the cost of rebar splice and mechanical couplers, couplers cost is higher up to D25, as shown in Table 12, but couplers are cheaper in rebars of above D29. For reference, splice cost is calculated by multiplying rebar cost per ton and splice weight, and rebar cost includes material, shop drawing work, cutting and bending, and installation cost. RC structures use various diameters of rebars. As shown in Table 11, mechanical couplers for all sizes of rebar are more advantageous for ECO_2 reduction than splice laps. However, as shown in Table 12, the cost of rebar couplers from D10 to D25 is more expensive than lap splice. However, the analysis results in Tables 11 and 12 may be different in each country because the types of mechanical couplers are diverse in shape and the rebar work cost is different. In Korea, the use of a mechanical coupler for rebars with D25 mm or larger in diameter has little cost reduction effect, but it has been confirmed that the ECO_2 reduction effect is remarkable. In the U.S., despite the fact that mechanical butt splices provide a variety of benefits, it is realized that the cost is still higher than lap splices [152]. If carbon tax is applied, the cost benefit is generated as much as the ECO_2 reduction in Table 11, and related research should be added.

Table 12. Cost comparison between splice lap and coupler.

Size	Rebar Cost (USD/Ton)	Splice Cost (USD/EA)	Coupler Cost (USD/EA)	Difference (USD/EA)
D10	930.36	0.18	4.46	−4.28
D13	921.43	0.41	4.91	−4.50
D16	934.82	0.96	5.36	−4.39
D19	934.82	1.54	5.80	−4.27
D22	934.82	4.12	6.25	−2.13
D25	934.82	6.14	6.70	−0.56
D29	934.82	10.13	7.14	2.99
D32	934.82	13.80	7.59	6.21

Exchange rate: 1120 Won/USD as of 25 February 2021, Bank of Korea. (Source: authors' research results).

4. Conclusions

During this review research, several facts have been identified in addition to findings identified from meta-analysis, as described in the Section 3. Various CWM algorithms have been developed and have contributed to reducing cutting wastes. However, it was confirmed that many algorithms have two principal problems to be applied in the field. First, although some algorithms can theoretically implement CWM, it is difficult to apply in practice when various site conditions are reflected. Second, some algorithms can reduce cutting wastes of some or major RC components, such as columns, beams, and slabs, but cannot reduce the cutting wastes of the entire structure of a project to near-zero. A description of identified findings after literature review is as follows:

1. Although cutting wastes can be reduced using SpLs of rebars rather than market lengths, many studies conducted optimization on market lengths to minimize cutting wastes of some rebars, but near-zero cutting waste of the entire construction project was difficult to realize. This phenomenon has been clearly identified on rebars with a diameter of above D19.
2. To achieve near-zero cutting waste by SpL, research should be conducted (a) by determining an SpL that meets the minimum order quantity conditions during RC structure design, or (b) by finding a SpL that meets the minimum order quantity conditions after structural design. In both cases, partial adjustment of LSPs requires a specific length of rebars, and it has been confirmed to be more efficient to apply it during RC structure design.
3. Considering the conditions such as different use schedules of combined rebar, combinations by special length, and minimum quantity for special order, CWM is not a one-dimensional problem but an n-dimensional CSP. Therefore, it is difficult to realize near-zero cutting waste with algorithms for existing one-dimensional cutting stock problems.
4. It should be dealt with from a sustainable value chain management perspective beyond supply chain management. In particular, if research has been developed to (1) optimization by cutting or combination pattern, (2) optimization of rebar information generated after structural design results are drawn, and (3) optimization of the amount of rebars in the structural design stage, in the future, structural design and construction-integrated management should be developed. Structural design should be used to combine special lengths rather than market lengths or stock lengths. This requires GA-based near-zero cutting waste algorithms for developing and integrating them into the RC design process.

Author Contributions: Conceptualization, K.K. and S.K.; methodology, S.K.; validation, K.K., D.K., and S.K.; formal analysis, K.K. and S.K.; investigation, K.K. and D.K.; resources, K.K. and D.K.; data curation, K.K. and D.K.; writing—original draft preparation, K.K. and S.K.; writing—review and editing, K.K. and S.K.; supervision, S.K.; project administration, S.K.; funding acquisition, S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MOE) (No. 2017R1D1A1B04033761).

Institutional Review Board Statement: Not applicable.

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

Data Availability Statement: Data sharing is not applicable to this article.

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

Abbreviations

AR	Augmented Reality
ASCE	American Society of Civil Engineers
BIM	Building Information Model
BSA	Binary Search Algorithm
C25/30	Compressive Strength of Concrete in N/mm2 when Tested with Cylinder/Cube
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacture
CSP	Cutting Stock Problem
CWM	Cutting Waste Minimization
D10, D32	High-Tensile Deformed Bar in Diameter. D10: 10 mm, D32: 32 mm
EA	Each
ECO_2	Embodied Carbon Dioxide
GA	Genetic Algorithm
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HA	Heuristic Algorithm
HS	Harmony Search
IFC	Industry Foundation Classes
IP	Integer Programming
JCEM	Journal of Construction Engineering and Management
JCR	Journal Citation Reports
LP	Linear Programming
LSP	Lap Splice Position
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QTO	Quantity Take-Off
RC	Reinforced Concrete
SA	Simulated Annealing
SCI/SCIE	Science Citation Index/Science Citation Index Expanded
SLR	Systematic Literature Review
SpL	Special Length
StL	Stock Length
VR	Virtual Reality
WoS	Web of Sciences

References

1. Miller, S.A.; Horvath, A.; Monteiro, P.J.M. Readily implementable techniques can cut annual CO2 emissions from the production of concrete by over 20%. *Environ. Res. Lett.* **2016**, *11*, 074029. Available online: https://iopscience.iop.org/article/10.1088/1748-9326/11/7/074029/meta (accessed on 8 December 2020).
2. Lee, I.J.; Yu, H.; Chan, S.L. Carbon Footprint of Steel-Composite and Reinforced Concrete Buildings, Standing Committee on Concrete Technology Annual Concrete Seminar 2016, Hong Kong, 2016, Construction Industry Council. Available online: https://www.devb.gov.hk/filemanager/en/content_971/7_Carbon_Footprint_for_Steel_Composite_and_Reinforced_Concrete_Buildings.pdf (accessed on 26 December 2020).
3. Lee, D.; Son, S.; Kim, D.; Kim, S. Special-Length-Priority Algorithm to Minimize Reinforcing Bar-Cutting Waste for Sustainable Construction. *Sustainability* **2020**, *12*, 5950. [CrossRef]
4. Kim, S.K.; Kim, M.H. A Study on the development of the optimization algorithm to minimize the loss of reinforcement bars. *J. Archit. Inst. Korea* **1991**, *7*, 385–390. Available online: http://www.dbpia.co.kr/journal/articleDetail?nodeId=NODE00358879 (accessed on 26 December 2020).
5. Kim, G.H. A Study on Program of Minimizing the Loss of Re-Bar. Master's Thesis, Korea University,, Seoul, Korea, 2002; pp. 8–58.
6. Porwal, A.; Hewage, K.N. Building information modeling-based analysis to minimize waste rate of structural reinforcement. *J. Constr. Eng. Manag.* **2012**, *138*, 943–954. [CrossRef]
7. Nadoushani, Z.; Hammad, A.; Akbar Nezhad, A. A Framework for Optimizing Lap Splice Positions within Concrete Elements to Minimize Cutting Waste of Steel Bars. In Proceedings of the 33th International Symposium on Automation and Robotics in Construction (ISARC 2016), Auburn, AL, USA, 18–21 July 2016. [CrossRef]
8. Shahin, A.A.; Salem, O.M. Using genetic algorithms in solving the one-dimensional cutting stock problem in the construction industry. *Can. J. Civ. Eng.* **2004**, *31*, 321–332. [CrossRef]
9. Zubaidy, S.S.; Dawood, S.Q.; Khalaf, I.D. Optimal utilization of rebar stock for cutting processes in housing project. *Int. J. Adv. Res. Sci. Eng. Technol.* **2016**, *3*, 189–193. [CrossRef]
10. Kim, S.K.; Hong, W.K.; Joo, J.K. Algorithms for reducing the waste rate of reinforcement bars. *J. Asian Arch. Build.* **2004**, *3*, 17–23. [CrossRef]
11. Benjaoran, V.; Bhokha, S. Trim loss minimization for construction reinforcement steel with oversupply constraints. *J. Adv. Manag. Sci.* **2013**, *1*, 313–316. Available online: http://www.joams.com/uploadfile/2013/1024/20131024100240137.pdf (accessed on 26 December 2020). [CrossRef]
12. Nadoushani, Z.S.M.; Hammad, A.W.A.; Xiao, J.; Akbarnezhad, A. Minimizing cutting wastes of reinforcing steel bars through optimizing lap splicing within reinforced concrete elements. *Constr. Build. Mater.* **2018**, *185*, 600–608. [CrossRef]
13. Macrotrends LLC. World GDP Growth Rate 1961–2020. Available online: https://www.macrotrends.net/countries/WLD/world/gdp-growth-rate (accessed on 27 December 2020).
14. Choi, J.; Lee, D.; Kwon, G.; Kim, S. A Study on energy consumption and CO2 emission of rebar. *KIEAE J. Constr. Ind. Counc.* **2010**, *10*, 101–109. Available online: http://www.auric.or.kr/User/Rdoc/DocRdoc.aspx?returnVal=RD_R&dn=242412#.X_UgKtgzaUk (accessed on 6 January 2021). (In Korean)
15. Trading Economics. GDP Annual Growth Rate—Forecast 2020–2022. Available online: https://tradingeconomics.com/forecast/gdp-annual-growth-rate (accessed on 9 January 2021).
16. Schneeweiss, Z. The Data Show a Bleak Outlook for Global Economic Growth—Developing Countries Show Signs of Emerging from the Pandemic More Quickly Than Advanced Economies. *Market Magazine, Bloomberg*. Available online: https://www.bloomberg.com/news/articles/2020-10-09/global-economic-data-paint-a-bleak-picture-for-the-future (accessed on 9 January 2021).
17. Kantorovich, L.V. Mathematical methods of organizing and planning production. *Manag. Sci.* **1960**, *6*, 366–422. [CrossRef]
18. Wawak, S.; Ljevo, Ž.; Vukomanović, M. Understanding the Key Quality Factors in Construction Projects—A Systematic Literature Review. *Sustainability* **2020**, *12*, 10376. [CrossRef]
19. Kitchenham, B.; Charters, S. *Guidelines for Performing Systematic Literature Reviews in Software Engineering*; Version 2.3; EBSE Technical Report EBSE-2007-01; School of Computer Science and Mathematics, Keele University: Keele, UK; University of Durham: Durham, UK, 2007.
20. Denyer, D.; Tranfield, D. Producing a Systematic Review. In *The Sage Handbook of Organizational Research Methods*; Sage Publications: Thousand Oaks, CA, USA, 2009; pp. 671–689.
21. Petersen, K.; Feldt, R.; Mujtaba, S.; Mattsson, M. Systematic mapping studies in software engineering. In Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering (EASE), Bari, Italy, 26–27 June 2008; Volume 8, pp. 68–77.
22. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement, The PRISMA Group. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef]
23. Carnwell, R.; Daly, W. Strategies for the Construction of a Critical Review of the Literature. *Nurse Educ. Pract.* **2001**, *1*, 57–63. [CrossRef]
24. Isilay, T.; Attila, D. Competitiveness in Construction—A literature Review of Research in Construction Management Journals. In Proceedings of the 24th Annual ARCOM of the Conference, Cardiff, UK, 1–3 September 2008; Association of Researchers in Construction Management: Cardiff, UK, 2009; pp. 799–812.

25. Ortiz, O.; Castells, F.; Sonnemann, G. Sustainability in the Construction Industry: A Review of Recent Developments Based on LCA. *Constr. Build. Mater.* **2009**, *23*, 28–39. [CrossRef]
26. Yang, H.; Yeung, J.F.; Chan, A.P.; Chiang, Y.H.; Chan, D.W. A Critical Review of Performance Measurement in Construction. *J. Facilities Manag.* **2010**, *8*, 269–284. [CrossRef]
27. De Muynck, W.; De Belie, N.; Verstraete, W. Microbial Carbonate Precipitation in Construction Materials: A review. *Ecol. Eng.* **2010**, *36*, 118–136. [CrossRef]
28. Bygballe, L.E.; Jahre, M.; Swärd, A. Partnering Relationships in Construction: A literature Review. *J. Purch. Supply Manag.* **2010**, *16*, 239–253. [CrossRef]
29. Zhou, W.; Whyte, J.; Sacks, R. Construction Safety and Digital Design: A Review. *Autom. Constr.* **2012**, *22*, 102–111. [CrossRef]
30. Zuo, J.; Zillante, G.; Wilson, L.; Davidson, K.; Pullen, S. Sustainability Policy of Construction Contractors: A Review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3910–3916. [CrossRef]
31. Evins, R. A Review of Computational Optimisation Methods Applied to Sustainable Building Design. *Renew. Sustain. Energy Rev.* **2013**, *22*, 230–245. [CrossRef]
32. Wang, Z.; Lim, B.T.; Kamardeen, I. Change Management Research in Construction: A Critical Review. In Proceedings of the 19th CIB World Building Congress, Brisbane, Australia, 5–9 May 2013; Queensland University of Technology: Brisbane, Australia, 2013; pp. 1–14.
33. Buyle, M.; Braet, J.; Audenaert, A. Life Cycle Assessment in the Construction Sector: A review. *Renew. Sustain. Energy Rev.* **2013**, *26*, 379–388. [CrossRef]
34. Taroun, A. Towards a Better Modelling and Assessment of Construction Risk: Insights from A literature Review. *Int. J. Proj. Manag.* **2014**, *32*, 101–115. [CrossRef]
35. Tay, Y.W.D.; Panda, B.; Paul, S.C.; Noor Mohamed, N.A.; Tan, M.J.; Leong, K.F. 3D Printing Trends in Building and Construction Industry: A Review. *Virtual Phys. Prototyp.* **2017**, *12*, 261–276. [CrossRef]
36. Hanafi, A.G.; Nawi, M.N.M. Critical Success Factors for Competitiveness of Construction Companies: A Critical Review. *AIP Conf. Proc.* **2016**, *1761*, 020042. [CrossRef]
37. Afzal, M.; Liu, Y.; Cheng, J.C.; Gan, V.J. Reinforced Concrete Structural Design Optimization: A Critical Review. *J. Clean. Prod.* **2020**, *260*, 120623. [CrossRef]
38. Wuni, I.Y.; Shen, G.Q. Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *J. Clean. Prod.* **2020**, *249*, 119347. [CrossRef]
39. Abdirad, H.; Dossick, C.S. BIM curriculum design in architecture, engineering, and construction education: A systematic review. *J. Inf. Technol. Constr.* **2016**, *21*, 250–271.
40. Abd Jamil, A.H.; Fathi, M.S. Contractual challenges for BIM-based construction projects: A systematic review. *Built Environ. Proj. Asset Manag.* **2018**, *8*, 372. [CrossRef]
41. Marcher, C.; Giusti, A.; Matt, D.T. Decision Support in Building Construction: A Systematic Review of Methods and Application Areas. *Buildings* **2020**, *10*, 170. [CrossRef]
42. Babalola, O.; Ibem, E.O.; Ezema, I.C. Implementation of lean practices in the construction industry: A systematic review. *Build. Environ.* **2019**, *148*, 34–43. [CrossRef]
43. Saieg, P.; Sotelino, E.D.; Nascimento, D.; Caiado, R.G.G. Interactions of building information modeling, lean and sustainability on the architectural, engineering and construction industry: A systematic review. *J. Clean. Prod.* **2018**, *174*, 788–806. [CrossRef]
44. Alencar, L.; Alencar, M.; Lima, L.; Trindade, E.; Silva, L. Sustainability in the Construction Industry: A Systematic Review of the Literature. *J. Clean. Prod.* **2020**, *29*, 125730. [CrossRef]
45. Schwartz, Y.; Raslan, R.; Mumovic, D. The life cycle carbon footprint of refurbished and new buildings—A systematic review of case studies. *Renew. Sustain. Energy Rev.* **2018**, *81*, 231–241. [CrossRef]
46. Charef, R.; Alaka, H.; Emmitt, S. Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *Renew. Sustain. Energy Rev.* **2018**, *19*, 242–257. [CrossRef]
47. Martínez-Aires, M.D.; Lopez-Alonso, M.; Martinez-Rojas, M. Building information modeling and safety management: A systematic review. *Saf. Sci.* **2018**, *101*, 11–18. [CrossRef]
48. Gharbia, M.; Chang-Richards, A.; Lu, Y.; Zhong, R.Y.; Li, H. Robotic technologies for on-site building construction: A systematic review. *J. Build. Eng.* **2020**, *32*, 101584. [CrossRef]
49. Araújo, A.G.; Carneiro, A.M.P.; Palha, R.P. Sustainable construction management: A systematic review of the literature with meta-analysis. *J. Clean. Prod.* **2020**, *256*, 120350. [CrossRef]
50. Fiala, C.; Hájek, P. Environmentally based optimisation of RC slabs with lightening fillers. In Proceedings of the International Conference "Advanced Engineering Design (AED) 2006", Prague, Czech Republic, 11–14 June 2006; p. 6.
51. Borkowski, A. Optimization of slab reinforcement by linear programming. *Comput. Methods Appl. Mech. Eng.* **1977**, *12*, 1–17. [CrossRef]
52. Ahmadkhanlou, F.; Adeli, H. Optimum cost design of reinforced concrete slabs using neural dynamics model. *Eng. Appl. Artif. Intell.* **2005**, *18*, 65–72. [CrossRef]
53. Ahmed, M.; Datta, T. Minimum volume of curtailed reinforcement in rectangular slabs. *Civ. Eng. Syst.* **1984**, *1*, 151–159. [CrossRef]
54. Sahab, M.G.; Ashour, A.F.; Toporov, V.V. Cost optimisation of reinforced concrete flat slab buildings. *Eng. Struct.* **2005**, *27*, 313–322. [CrossRef]

55. Bavafa, M.; Kiviniemi, A. Optimised strategy by utilising BIM and set-based design: Reinforced concrete slabs. In Proceedings of the CIB W78 2012: 29th International Conference, Beirut, Lebanon, 17–19 October 2012; Corpus ID: 56437315. Available online: https://livrepository.liverpool.ac.uk/2007737/ (accessed on 12 February 2021).
56. Hájek, P. Integrated environmental design and optimization of concrete floor structures for buildings. In Proceedings of the 2005 World Sustainable Building Conference, Tokyo, Japan, 27–29 September 2005.
57. Eleftheriadis, S.; Duffour, P.; Stephenson, B.; Mumovic, D. Automated specification of steel reinforcement to support the optimisation of RC floors. *Autom. Construct.* **2018**, *96*, 366–377. [CrossRef]
58. Coello Coello, C.A.; Christiansen, A.D.; Hernandez, F.S. A simple genetic algorithm for the design of reinforced concrete beams. *Eng. Comput.* **1997**, *13*, 185–196. [CrossRef]
59. Leps, M.; Sejnoha, M. New approach to optimization of reinforced concrete beams. *Comput. Struct.* **2003**, *81*, 1957–1966. [CrossRef]
60. Govindaraj, V.; Ramasamy, J.V. Optimum detailed design of reinforced concrete continuous beams using genetic algorithms. *Comput. Struct.* **2005**, *84*, 34–48. [CrossRef]
61. Ferreira, C.; Barros, M.; Barros, A. Optimal design of reinforced concrete T-sections in bending. *Eng. Struct.* **2003**, *25*, 951–964. [CrossRef]
62. Bekdas, G.; Nigdeli, S.M. Bat algorithm for optimization of reinforced concrete columns. *Proc. Appl. Math. Mech.* **2016**, *16*, 681–682. [CrossRef]
63. Khondoker, M.T.H. Automated reinforcement trim waste optimization in RC frame structures using building information modeling and mixed-integer linear programming. *Autom. Constr.* **2021**, *124*, 103599. [CrossRef]
64. Bouassida, M.; Carter, J.P. Optimization of design of column-reinforced foundations. *Int. J. Geomech.* **2014**, *14*, 04014031. [CrossRef]
65. Rafiq, M.Y.; Southcombe, C. Genetic algorithms in optimal design and detailing of reinforced concrete columns supported by a declarative approach for capacity checking. *Comput. Struct.* **1998**, *69*, 443–457. [CrossRef]
66. Al-Mosawi, S.; Saka, M. Optimum design of single core shear walls. *Comput. Struct.* **1999**, *71*, 143–162. [CrossRef]
67. Camp, C.V.; Akin, A. Design of retaining walls using big bang-big crunch optimization. *J. Struct. Eng.* **2012**, *138*, 438–448. [CrossRef]
68. Yepes, V.; Alcalá, J.; Perea, C.; Gonzalez-Vidosa, F. A parametric study of optimum earth retaining walls by simulated annealing. *Eng. Struct.* **2008**, *30*, 821–830. [CrossRef]
69. Cohn, M.Z.; Lounis, Z. Optimal design of structural concrete bridge systems. *J. Struct. Eng.* **1994**, *120*, 2653–2674. [CrossRef]
70. Perea, C.; Alcala, J.; Yepes, V.; Gonzalez-Vidosa, F.; Hospitaler, A. Design of reinforced concrete bridge frames by heuristic optimization. *Adv. Eng. Softw.* **2008**, *39*, 676–688. [CrossRef]
71. Perea, C.; Baitsch, M.; Gonzalez-Vidosa, F.; Hartmann, D. Optimization of reinforced concrete frame bridges by parallel genetic and memetic algorithms. In Proceedings of the Third International Conference on Structural Engineering, Mechanics and Computation, Cape Town, South Africa, 10–12 September 2007; pp. 1790–1795.
72. Paya, I.; Yepes, V.; Gonzalez-Vidosa, F.; Hospitaler, A. Multiobjective optimization of concrete building frames by simulated annealing. *Comput. Aided Civ. Infrastruct. Eng.* **2008**, *23*, 596–610. [CrossRef]
73. Akin, A.; Saka, M.P. Harmony search algorithm based optimum detailed design of reinforced concrete plane frames subject to ACI 318-05 provisions. *Comput. Struct.* **2015**, *147*, 79–95. [CrossRef]
74. Amir, O. A topology optimization procedure for reinforced concrete structures. *Comput. Struct.* **2013**, *114*, 46–58. [CrossRef]
75. Balling, R.J.; Yao, X. Optimization of reinforced concrete frames. *J. Struct. Eng.* **1997**, *123*, 193–202. [CrossRef]
76. Bekdas, G.; Nigdeli, S.M. Modified harmony search for optimization of reinforced concrete frames. In *International Conference on Harmony Search Algorithm*; Springer: Singapore, 2017; pp. 213–221. [CrossRef]
77. Bond, D. The optimum design of concrete structures. *Eng. Optim.* **1974**, *1*, 17–28. [CrossRef]
78. Leite, J.P.B.; Topping, B.H.V. Improved genetic operators for structural optimization. *Adv. Eng. Softw.* **1998**, *29*, 529–562. [CrossRef]
79. Rajeev, S.; Krisnamoorthy, C.S. Genetic algorithm-based methodology for design optimization of reinforced concrete frames. *Comput. Aided Civ. Infrastruct. Eng.* **1998**, *13*, 63–74. [CrossRef]
80. Lee, C.; Ahn, J. Flexural design reinforced concrete frames by genetic algorithm. *J. Struct. Eng* **2003**, *129*, 762–774. [CrossRef]
81. Koumousis, V.K.; Arsenis, S.J. Genetic algorithms in optimal design of reinforced concrete members. *Comput. Aided Civ. Infrastruct. Eng.* **1998**, *13*, 43–52. [CrossRef]
82. PMI. *Construction Extension to the PMBOK_ Guide*, 3rd ed.; Project Management Institute, Inc.: Newtown Square, PA, USA, 2016.
83. Benjaoran, V.; Bhokha, S. Three-step solutions for cutting stock problem of construction steel bars. *KSCE J. Civ. Eng.* **2014**, *18*, 1239–1247. [CrossRef]
84. Bernold, L.E.; Salim, M. Placement-oriented design and delivery of concrete reinforcement. *J. Constr. Eng. Manag.* **1993**, *119*, 323–335. [CrossRef]
85. Chandrasekar, M.K.; Nigussie, T. Rebar Wastage in Building Construction Projects of Hawassa, Ethiopia. *Int. J. Sci. Eng. Res.* **2018**, *9*, 282–287. Available online: https://www.ijser.org/researchpaper/Rebar-wastage-in-building-construction-projects-of-Hawassa-Ethiopia.pdf (accessed on 30 December 2020).
86. Chen, Y.; Yang, T. Lapping pattern, stock length, and shop drawing of beam reinforcements of an RC building. *J. Comput. Civ. Eng.* **2013**, *29*, 04014028. [CrossRef]
87. Dunston, P.S.; Bernold, L.E. Adaptive control for safe and quality rebar fabrication. *J. Constr. Eng. Manag.* **2000**, *126*, 122–129. [CrossRef]

88. Ham, C.S.; Park, J.P.; Park, J.K.; Chung, J.Y.; Kim, I.H. A Study on the Development of Shop Drawings and Bar-bending Schedule Automation System for Apartment Housing. *J. Archit. Inst. Korea* **1999**, *15*, 111–119.
89. Jung, H.O.; Cho, H.H.; Park, U.Y. A Study on the Improvement of Erection Bar Detailing in Domestic Building Construction. *J. Korea Inst. Build. Constr.* **2009**, *9*, 39–46. [CrossRef]
90. Kim, D.; Lim, C.; Liu, Y.; Kim, S. Automatic Estimation System of Building Frames with Integrated Structural Design Information (AutoES). *Iran. J. Sci. Tech. Trans. Civ. Eng.* **2020**, *44*, 1145–1157. [CrossRef]
91. Kim, S.K.; Kim, C.K. Integrated automation of structural design and rebar work in RC structures. *J. Archit. Inst. Korea* **1994**, *10*, 113–121. Available online: http://www.dbpia.co.kr/journal/articleDetail?nodeId=NODE00359422 (accessed on 26 December 2020). (In Korean)
92. Mishra, S.P.; Parbat, D.K.; Modak, J.P. Field data-based mathematical simulation of manual rebar cutting. *J. Constr. Dev. Ctries.* **2014**, *19*, 111. Available online: http://web.usm.my/jcdc/vol19_1_2014/JCDC%2019 (accessed on 28 December 2020).
93. Nanagiri, Y.V.; Singh, R.K. Reduction of wastage of rebar by using BIM and linear programming. *Int. J. Tech.* **2015**, *5*, 329–334. [CrossRef]
94. Navon, R.; Rubinovitz, Y.; Coffler, M. Development of a fully automated rebar-manufacturing machine. *Autom. Constr.* **1995**, *4*, 239–253. [CrossRef]
95. Navon, R.; Rubinovitz, Y.; Coffler, M. Fully automated rebar CAD/CAM system: Economic evaluation and field implementation. *J. Constr. Eng. Manag.* **1996**, *122*, 101–108. [CrossRef]
96. Navon, R.; Rubinovitz, Y.A.; Coffler, M. Reinforcement-bar manufacture: From design to optimized production. *Int. J. Comput. Integr. Manuf.* **1998**, *11*, 326–333. [CrossRef]
97. Navon, R.; Shapira, A.; Shechori, Y. Automated rebar constructability diagnosis. *J. Constr. Eng. Manag.* **2000**, *126*, 389–397. [CrossRef]
98. Park, U.Y. BIM-Based Simulator for Rebar Placement. *J. Korea Inst. Build. Constr.* **2012**, *12*, 98–107. [CrossRef]
99. Polat, G.; Arditi, D.; Ballard, G.; Mungen, U. Economics of on-site vs. off-site fabrication of rebar. *Constr. Manag. Econ.* **2006**, *24*, 1185–1198. [CrossRef]
100. Poonkodi, N. Development of software for minimization of wastes in rebar in RCC structures by using linear programming. *Int. J. Adv. Res. Trends Eng. Technol.* **2016**, *3*, 1262–1267. Available online: https://www.researchgate.net/publication/316031463_Development_of_software_for_minimization_of_wastes_in_rebar_in_rcc_structures_by_using_linear_programming (accessed on 30 December 2020).
101. Salem, O.; Shahin, A.; Khalifa, Y. Minimizing cutting wastes of reinforcement steel bars using genetic algorithms and integer programming models. *J. Constr. Eng. Manag.* **2007**, *133*, 982–992. [CrossRef]
102. Salim, M.; Bernold, L.E. Effects of design-integrated process planning on productivity in rebar placement. *J. Constr. Eng. Manag.* **1994**, *120*, 720–738. [CrossRef]
103. Salim, M.; Bernold, L.E. Design-integrated process planner for rebar placement. *J. Eng.* **1995**, *9*, 157–167. [CrossRef]
104. Stainton, R.S. The Cutting Stock Problem for the Stockholder of Steel Reinforcement Bars. *Oper. Res. Q.* **1977**, *28*, 139–149. [CrossRef]
105. Zheng, C.; Yi, C.; Lu, M. Integrated optimization of rebar detailing design and installation planning for waste reduction and productivity improvement. *Autom. Constr.* **2019**, *101*, 32–47. [CrossRef]
106. Zheng, C.; Lu, M. Optimized reinforcement detailing design for sustainable construction: Slab case study. *Procedia Eng.* **2016**, *145*, 1478–1485. [CrossRef]
107. Kim, T.H.; Hong, C.G.; Kim, S. Quantity take-off algorithm for the reinforced concrete frame. *Korea J. Constr. Eng. Manag.* **2003**, *4*, 114–121. Available online: https://www.kicem.or.kr/html/sub08_01.jsp?tbnm=r&organCode2=kicem01&yearmonth=200303 (accessed on 30 December 2020).
108. Lee, S.; Kim, S.; Lee, G.; Kim, S.; Joo, J. Automatic Algorithms of Rebar Quantity Take-Off of Green Frame by Composite Precast Concrete Members. *Korea J. Constr. Eng. Manag.* **2012**, *13*, 118–128. (In Korean) [CrossRef]
109. Choi, H.; Lee, S.E.; Kim, C.K. Parametric Design Process for Structural Quantity Optimization of Spatial Building Structures. *J. Comput. Struct. Eng. Inst. Korea* **2017**, *30*, 103–110. [CrossRef]
110. Cho, Y.S.; Lee, S.I.; Bae, J.S. Reinforcement placement in a concrete slab object using structural building information modeling. *Comput. Aided Civ. Infrastruct. Eng.* **2014**, *29*, 47–59. [CrossRef]
111. Park, H.Y.; Lee, S.H.; Kang, T.K.; Lee, Y.S. Developing an Automatic System for Quantity Taking-off Cut and Bent Rebar and Making a Placing Drawing. In Proceeding of Conference in Architectural Institute of Korea, Cheongju, Korea, 26–27 October 2007; pp. 358–363. (In Korean)
112. Bendaj, B. Investigating the accuracy of fabricated rebar and rebar's placement in beams, and their impact in weight and cost of a building. In Proceedings of the 3rd International Balkans Conference on Challenges of Civil Engineering, 3-BCCCE, Tirana, Albania, 19–21 May 2016; Available online: https://core.ac.uk/reader/152490180 (accessed on 28 December 2020).
113. Chang, S.; Shiu, R.S.; Wu, I.C. Applying an A-Star Search Algorithm for Generating the Minimized Material Scheme for the Rebar Quantity Takeoff. In Proceedings of the 36th International Symposium on Automation and Robotics in Construction (ISARC 2019), Banff, AB, Canada, 21–24 May; 2019; 36, pp. 812–817. [CrossRef]

114. Hwang, J.W.; Park, C.J.; Wang, S.K.; Choi, C.H.; Lee, J.H.; Park, H.W. A Case Study on the Cost Reduction of the Rebar Work through the Bar Loss Minimization. In Proceedings of the KIBIM Annual Conference 2012, Seoul, Korea, 19 May 2012; Volume 2, pp. 67–68. (In Korean)
115. Hong, C.G.; Kim, T.H.; Kim, S.; Han, C.H. A study on the quantity estimation algorithm of reinforced concrete frame. In Proceedings of the 3rd Conference on Construction Engineering and Management, Korea Institute of Construction Engineering and Management, Seoul, Korea, 26 October 2002; p. 358. (In Korean). Available online: http://www.auric.or.kr/User/Rdoc/DocRdoc.aspx?returnVal=RD_R&dn=157040#.X-wJstgzaUk (accessed on 30 December 2020). (In Korean)
116. Matviyishyn, Y.; Janiak, T. Minimization of steel waste during manufacture of reinforced concrete. In *AIP Conference Proceedings*; AIP Publishing LLC: Melville, NY, USA, 2019; Volume 2077, p. 020040. [CrossRef]
117. Bekdas, G.; Nigdeli, S.M. The Optimization of Slender Reinforced Concrete Columns. *Proc. Appl. Math. Mech.* **2014**, *14*, 183–184. [CrossRef]
118. Zheng, C. Multi-Objective Optimization for Reinforcement Detailing Design and Work Planning on a Reinforced Concrete Slab Case. Master's Thesis, Alberta University, Edmonton, AB, Canada, 2018. [CrossRef]
119. Hasan, G.N.; Das, C.; Sumon, S.M.F.H. Splice Length of Reinforcing Bars Calculated in Different Design Codes. Bachelor's Thesis, Ahsanullah University of Science and Technology, Dhaka, Bangladesh, December 2015.
120. Mellenthin Filardo, M.; Walther, T.; Maddineni, S.; Bargstädt, H.J. Installing Reinforcement Rebars Using Virtual Reality and 4D Visualization. In *Proceedings of the 18th International Conference on Computing in Civil and Building Engineering*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 1200–1216. [CrossRef]
121. Lee, D.G. Establishment direction of seismic structure design standards. *Rev. Archit. Build. Sci.* **1988**, *32*, 26–29. Available online: http://www.auric.or.kr/dordocs/cart_rdoc2_.asp?db=CMAG&dn=59623 (accessed on 26 February 2021). (In Korean)
122. Jo, S.J.; Kim, T.H.; Haan, C.H. Investigation of the Standards for Dispute Resolution of the Floor Noises of Apartments. In Proceedings of the Architectural Institute of Korea-RA, Jeju, Korea, 2–3 December 2010; pp. 488–493. Available online: http://www.auric.or.kr/dordocs/cart_rdoc2_.asp?db=RD_R&dn=245401 (accessed on 26 February 2021). (In Korean)
123. Kochummen, J.; Colcombe, J. Revit and RebarCAD 3D: The BIM Solution for Rebar Modeling to Production Drawing. *Autodesk University*. Available online: https://www.autodesk.com/autodesk-university/class/Revit-and-RebarCAD-3D-BIM-Solution-Rebar-Modeling-Production-Drawing-2018#downloads (accessed on 13 January 2021).
124. Tekla. Making Rebar Detailing an Ingredient of your Construction Project Overall Success. Available online: https://www.tekla.com/resources/blogs/making-rebar-detailing-an-ingredient-of-your-construction-project-overall-success (accessed on 13 January 2021).
125. Arbib, C.; Marinelli, F.; Ventura, P. One-dimensional cutting stock with a limited number of open stacks: Bounds and solutions from a new integer linear programming model. *Int. Trans. Oper. Res.* **2016**, *23*, 47–63. [CrossRef]
126. Ben Amor, H.; Valério de Carvalho, J. Cutting stock problems. In *Column Generation*; Springier: Boston, MA, USA, 2005; pp. 131–161. [CrossRef]
127. Belov, G.; Scheithauer, G. Setup and open-stacks minimization in one-dimensional stock cutting. *Inf. J. Comput.* **2007**, *19*, 27–35. [CrossRef]
128. Berberler, M.; Nuriyev, U.; Yildırım, A. A Software for the one-dimensional cutting stock problem. *J. King Saud Univ. Sci.* **2011**, *23*, 69–76. [CrossRef]
129. Chen, C.; Hart, S.; Tham, W. A simulated annealing heuristic for the one-dimensional cutting stock problem. *Eur. J. Oper. Res.* **1996**, *93*, 522–535. [CrossRef]
130. Cherri, A.C.; Arenales, M.N.; Yanasse, H.H. The one-dimensional cutting stock problem with usable leftover—A heuristic approach. *Eur. J. Oper. Res.* **2009**, *196*, 897–908. [CrossRef]
131. Cui, Y.; Zhao, X.; Yang, Y.; Yu, P. A heuristic for the one-dimensional cutting stock problem with pattern reduction. *Proc. Inst. Mech. Eng. Part. B J. Eng. Manuf.* **2008**, *222*, 677–685. [CrossRef]
132. Dyckhoff, H. A new linear programming approach to the cutting stock problem. *Oper. Res.* **1981**, *29*, 1092–1104. [CrossRef]
133. Gradišar, M.; Kljajić, M.; Resinovič, G.; Jesenko, J. A sequential heuristic procedure for one-dimensional cutting. *Eur. J. Oper. Res.* **1999**, *114*, 557–568. [CrossRef]
134. Feifei, G.; Lin, L.; Jun, P.; Xiazi, Z. Study of One-Dimensional Cutting Stock Problem with Dual-Objective Optimization. In Proceedings of the International Conference on Computer Science and Information Processing (CSIP), Xi'an, China, 24–26 August 2012. [CrossRef]
135. Fernandez, L.; Fernandez, L.A.; Pola, C. Integer Solutions to Cutting Stock Problems. In Proceedings of the 2nd International Conference on Engineering Optimization, Lisbon, Portugal, 6–9 September 2010; Available online: https://scholar.google.com/scholar?q=related:Mk60IvrPB0kJ:scholar.google.com/&scioq=&hl=ko&as_sdt=0,5 (accessed on 30 December 2020).
136. Gilmore, P.C.; Gomory, R.E. A linear programming approach to the cutting-stock problem. *Oper. Res.* **1961**, *9*, 849–859. [CrossRef]
137. Gilmore, P.C.; Gomory, R.E. A linear programming approach to the cutting-stock problem-part II. *Oper. Res.* **1963**, *11*, 863–888. [CrossRef]
138. Goulimis, C. Optimal solutions for the cutting stock problem. *Eur. J. Oper. Res.* **1990**, *44*, 197–208. [CrossRef]
139. Haessler, R.W.; Sweeney, P.E. Cutting stock problems and solution procedures. *Eur. J. Oper. Res.* **1991**, *54*, 141–150. [CrossRef]
140. Haessler, R.W. Controlling cutting pattern changes in one-dimensional trim problems. *Oper. Res.* **1975**, *23*, 483–493. [CrossRef]

141. Jahromi, M.H.; Tavakkoli, R.; Makui, A.; Shamsi, A. Solving an one-dimensional cutting stock problem by simulated annealing and tabu search. *J. Ind. Eng. Int.* **2012**, *8*, 24. [CrossRef]
142. Khalifa, Y.; Salem, O.; Shahin, A. Cutting Stock Waste Reduction using Genetic Algorithms. In Proceedings of the 8th Annual Conference on Genetic and Evolutionary Computation, Seattle, WA, USA, 8–12 July 2006; pp. 1675–1680. [CrossRef]
143. Lin, P. Optimal Solution of One Dimension Cutting Stock Problem. Master's Thesis, Lehigh University, Bethlehem, PA, USA, 1994. Available online: https://preserve.lehigh.edu/cgi/viewcontent.cgi?referer=1&article=1286&context=etd (accessed on 30 December 2020).
144. Poldi, K.C.; Arenales, M.N. Heuristics for the one-dimensional cutting stock problem with limited multiple stock lengths. *Comput. Oper. Res.* **2009**, *36*, 2074–2081. [CrossRef]
145. Roodman, G.M. Near-optimal solutions to one-dimensional cutting stock problems. *Comput. Oper. Res.* **1986**, *13*, 713–719. [CrossRef]
146. Suliman, S. Pattern generating procedure for the cutting stock problem. *Int. J. Prod. Econ.* **2001**, *74*, 293–301. [CrossRef]
147. Vahrenkamp, R. Random search in the one-dimensional cutting stock problem. *Eur. J. Oper. Res.* **1996**, *95*, 191–200. [CrossRef]
148. Reinertsen, H.; Vossen, T.W.M. The one-dimensional cutting stock problem with due dates. *Eur. J. Oper. Res.* **2010**, *201*, 701–711. [CrossRef]
149. Askarzadeh, A.; Rashedi, E. Harmony Search Algorithm: Basic Concepts and Engineering Applications. In *Intelligent Systems: Concepts, Methodologies, Tools, and Applications*; Khosrow-Pour, M., Ed.; IGI Global: Hershey, PA, USA, 2018; pp. 1–30. [CrossRef]
150. Tian, Z.; Chao Zhang, C. An Improved Harmony Search Algorithm and Its Application in Function Optimization. *J. Inf. Process. Syst.* **2018**, *14*, 1237–1253. [CrossRef]
151. BFT International. New Generation of Rotor Straightening Machines with Hyperbolic Profiled Rollers Processing Diameters up to 36 mm Rebar and 50 mm Wire. Available online: https://www.bft-international.com/en/artikel/bft_New_generation_of_rotor_straightening_machines_with_hyperbolic_profiled_2551059.html (accessed on 27 December 2020).
152. Hurd, M.K. Mechanical vs. Lap Splicing. *Concrete Construction Magazine*. Available online: https://www.concreteconstruction.net/how-to/construction/mechanical-vs-lap-splicing_o (accessed on 14 January 2021).