Journal of Construction Engineering, Management & Innovation
2023 6(4):285-296
DOI 10.31462/jcemi.2023.04285296

RESEARCH ARTICLE

A novel special length rebar order approach based on AI optimization techniques for reduction of rebar cutting waste

Şahin Tolga Güvel, İbrahim Karataş

Osmaniye Korkut Ata University, Department of Civil Engineering, 80010 Osmaniye, Türkiye

Article History

Received 09 November 2023
Accepted 11 December 2023

Keywords

Rebar cutting waste
Optimization
Genetic algorithm
Fuzzy logic
Construction management
Sustainability

Abstract

Reducing the amount of waste material in the construction industry is a crucial goal for sustainability worldwide. Cutting rebars to fit the lengths needed for a building generates significant rebar waste. This study aims to reduce rebar-cutting waste in construction projects. In addition to planning the cut lengths of the standard 12-meter rebar using optimization methods, the study intends to reduce rebar-cutting waste by producing rebars in different lengths based on order frequency. A combination of genetic algorithm, fuzzy logic system, and a new algorithm method optimizes the cutting process, resulting in a significant reduction of rebar waste. Unlike prior studies, this research proposes a unique cutting length order for the rebar list created after optimization, aiming to reduce rebar cutting waste below the optimized level. The results show that the reduction in the amount of rebar waste is satisfactory.

1. Introduction

The construction sector is crucial for sustainable global development. Therefore, enhancing the sustainability of the construction industry, particularly in developing countries, is essential and crucial [1]. Sustainable development has been acknowledged as a crucial value since the early 1980s. Solid waste produced by the construction industry has gained significant attention worldwide. As a result, numerous studies have been published in various scientific journals to investigate waste management issues [2]. Minimizing material waste generated during construction is a crucial objective of sustainable construction. Material waste reduction has significant environmental and economic benefits. By reducing waste, material costs, as well as waste management costs, can be reduced, which leads to significant economic benefits [3]. The construction, development, and urbanization of a town generate a significant amount of material waste, which has a serious impact on the environment and human life. In China, for example, construction waste accounts for a substantial percentage of the total municipal waste [4]. Waste management has become an important aspect of project management due to the increasing awareness of the need to manage waste. Results from a questionnaire survey and structured interviews indicate that the implementation of waste management procedures has led to significant benefits such as proposing methods for on-site reuse of materials and proposing methods for reducing waste. These benefits have proven to be effective in overcoming the challenges associated with waste management [5].

Correspondence İbrahim Karataş ibrahimkaratas@osmaniye.edu.tr

Rebar used in construction sites is typically manufactured in standardized sizes, which results in a significant amount of waste during the cutting process to obtain the required lengths for construction. This is a critical issue in reinforced concrete construction, as rebar waste is a major form of construction waste [3, 6, 7]. Rebar waste is a significant source of construction waste, accounting for 21.1% [5] of overall waste generated. It is crucial to properly eliminate or minimize this waste [7].

Nadoushani et al. [6], conducted a study on lap splices of reinforcements in reinforced concrete elements to minimize shear waste caused by reinforcements in structural elements. The proposed approach focuses on determining lap joint patterns for rebar used in reinforced concrete structural members. A case study was conducted to implement the proposed approach for constructing 6-story building columns and shear walls. The study compared the estimated waste generated by the proposed method with the waste generated by conventional cutting waste minimization methods and optimized cutting patterns based on fixed lengths without flexibility. To address the problem of rebar-cutting waste during the design phase, researchers aimed to integrate building information modeling (BIM) with optimization techniques. By optimizing the lap splicing patterns through this framework, a reduction of 50.7% and 55.7% in rebar waste generated, and a decrease of 7.7% and 11.8% in rebar consumption for columns and shear walls, respectively, was observed [6]. The current method for minimizing cutting waste involves manual comparison of patterns by engineers, which is tedious and time-consuming. Combining the methodology with the BIM platform enhances the effectiveness of the design-construction integrated analysis and visualization process. This integration optimizes the use of rebars during the design phase and minimizes cutting waste. Automating the entire optimization methodology and seamlessly connecting it with simulation analysis at different stages is vital for end-users' benefit. The proposed optimization technique prevents possible material and time wastage [6, 8, 9]. In construction projects, an optimization method is employed to reduce rebar waste during cutting. The amount of waste generated from cutting can be significantly influenced by the pattern adopted. Selecting an optimized pattern can minimize the amount of waste produced [3, 10]. Previous studies have proposed various optimization techniques to minimize rebar trim loss, such as linear programming (LP), integer programming (IP), sequential heuristic procedure (SHP), and genetic algorithm (GA). These techniques have led to a decrease in the total amount of material used and generated waste. It is worth noting that the fuzzy logic method has proven to be highly effective in various engineering applications [11, 12]. The use of fuzzy logic methods for rebar reduction has not been very common. This study aims to investigate the effectiveness of this method in reducing rebar waste. The results obtained from this study highlight the potential for significant reduction in rebar waste through the implementation of these methods [3, 11]. Cutting patterns in construction are created by combining different rebar lengths. Any alteration in the required rebar lengths directly impacts the cutting patterns and the final amount of rebar waste. One of the material waste streams in constructing reinforced concrete structures is associated with rebar waste, accounting for up to 5% and 8% of the total waste in public and private residential construction, respectively. This rebar waste is generated by cutting rebars from standard to required lengths [3, 6, 13], the optimization method used a combination of genetic algorithm and fuzzy logic system to determine the most efficient rebar quantities for three different construction projects of varying scales. The study also analyzed the optimal rebar waste rates based on alternative production lengths and the standard 12-meter length. The findings showed a significant reduction in waste rates due to the analysis [13]. The results indicate that a considerable reduction in rebar waste is achievable by optimizing the cutting patterns.

The aim of this study is to apply a two-stage optimization different from the literature. In the first stage, optimization is made according to the rebar cutting lengths. In contrast, in the second stage, optimization is made according to the use of rebar with special lengths considering the waste rate, and the aim is to minimize the waste caused by rebar cutting. This approach differs from previous studies, as it considers both optimization and the use of special length rebar together.

2. Material and Method

2.1. Genetic algorithm (GA)

GA is an optimization algorithm based on the principles of genetics, natural selection, and the mechanics of natural solutions [14-16]. GA work by generating multiple solutions, creating a pool to apply fitness search [17]. In GA, a population of potential solutions is called chromosomes. Each chromosome represents a point in the search space, and its parameters define a specific location. These chromosomes exchange information with each other to find a better solution based on the fit function [18]. The chromosomes, which are the variables optimized and processed into the GA as chromosomes, form the initial population of the algorithm, with a predetermined fitness value [19]. As a result of genetic processes such as duplication, crossover, and mutation, a new population with higher fitness values is created by selecting the chromosome with the highest fitness value [20]. This process is continued until a determined stopping criterion is met, and in the end, the best individual is accepted as the solution.

2.2. Fuzzy logic system

The concept of Fuzzy Logic allows programmers to use everyday terms such as hot, warm, fast, and minor in algorithms and computer systems [18, 21]. In other words, Fuzzy Logic transforms real-world data into a fuzzy input [18]. In Fuzzy Logic based on fuzzy set theory, membership value takes different values ranging from 0 to 1. In fuzzy set logic, if an element's membership value is close to 1, it belongs to that cluster more, and if it is close to 0, it belongs to that cluster less. Input parameters, which are converted to fuzzy values with the membership function, are converted into a single fuzzy output value by fuzzy rules. The output value of the system is produced by converting this fuzzy output value to the real value. Such systems are called "Fuzzy rule-based systems" [22]. Fuzzy rule-based systems are used as a knowledge base which comprises If-Then rules and databases. The expert uses this knowledge base to convert real values into fuzzy logical values for efficient control. The system also includes an inference mechanism that allows the expert to apply appropriate rules and infer the results. The fuzzification interface is responsible for the fuzzification of input variables to activate the inference mechanism, while the defuzzification interface transforms the results of the inference mechanism into real inputs for the process [23, 25].

2.3. Hybrid genetic algorithm and fuzzy logic system model

The GA solutions in small and medium sizes have been largely calculated correctly. However, GA solutions were found to be less accurate at larger sizes. Therefore, Laribi et al. [23] presented a hybrid approach by suggesting the combination of genetic algorithm and fuzzy logic systems in their study. With this approach, fuzzy logic systems are suggested to be used by optimizing the limit values of the system's initial conditions created by the genetic algorithm. This process is requested to give better results for the subsequent optimization by taking advantage of how each variable evolves [18, 23]. To clarify, the initial values are randomly determined in the classical genetic algorithm process. However, when the genetic algorithm is combined with the fuzzy system, the variable development is monitored, and the most suitable limits of these initial values are adjusted. The calculated limit values are then used to start the second optimization process, and the algorithm continues to work in this loop until it identifies the best possible result [23].

2.4. The proposed framework

After reviewing the literature studies, it has been found that optimization algorithms can help determine the best cutting method to reduce rebar waste in construction projects. However, researchers have also looked into the possibility of using special cutting techniques to eliminate the most commonly generated waste and then minimizing the remaining waste with optimization techniques. To illustrate this process, a flow chart has been presented in Fig. 1. To begin with, the amount of reinforcement required for a building was calculated from its static project drawing. Then, a list of required cuts was prepared based on the standard 12m length for the reinforcement bars. This list was then used to determine the wastage for each bar length. The ones with the highest wastage were identified, and a special cutting order was given to minimize wastage for those bars. For the remaining bars, the total project wastage was calculated and compared between the optimized 12m standard length and the normal cutting list.

This method involves extracting the rebar cutting list and listing the required lengths of rebar, along with the number of each length needed. Additionally, the program data includes the amount of 12-meter-long rebar that is currently in stock. Once the optimization process is complete, a cutting pattern is formed, and the waste rate from the cutting process is calculated (as shown in Fig. 2). The proposed method involves sorting the rebars in the cutting list according to their total length after the cut. Special cut lengths for the rebar are ordered with the longest total length first, which reduces the cutting loss to zero for the length with the greatest overall length. To optimize the length and quantity of rebar needed for a project, it's important to avoid using special cut lengths that can be divided into 12 meters as an integer, such as 6, 4, 3, and 2 meters.

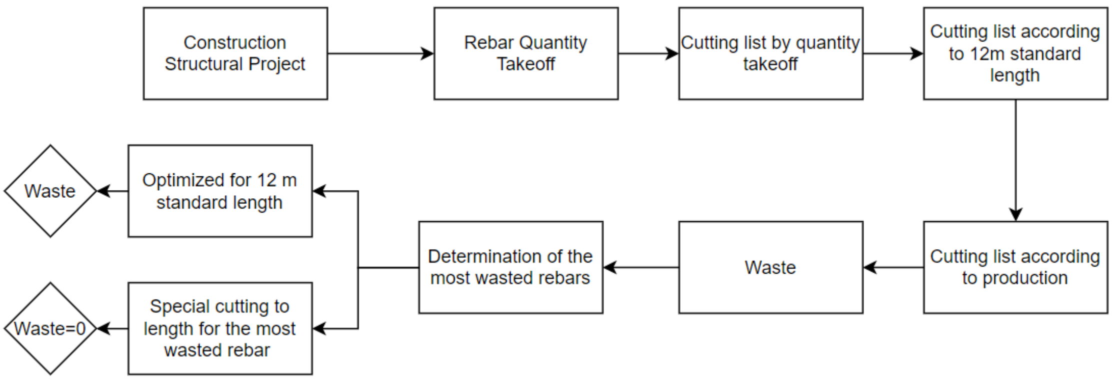

Fig. 1. Methodology flowchart

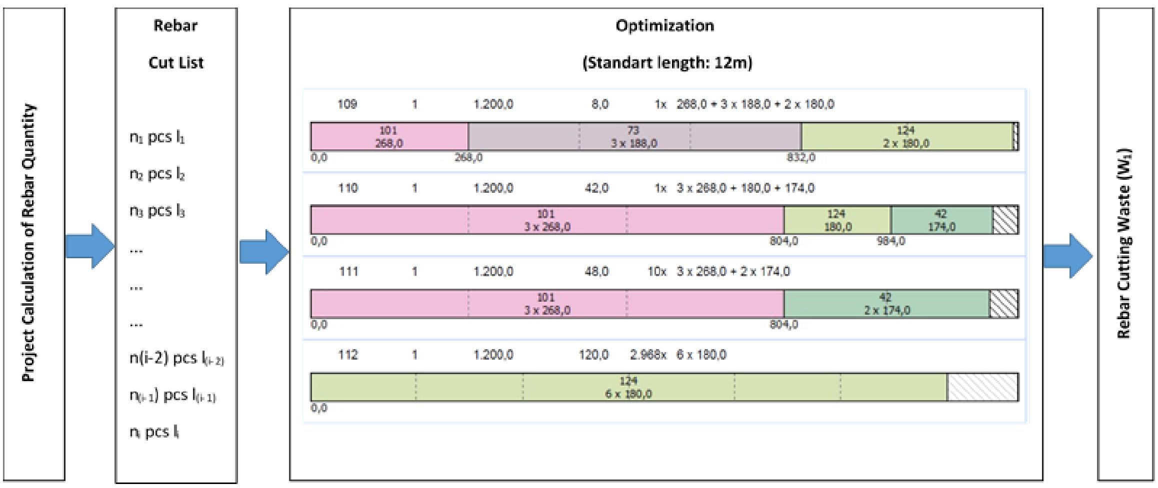

Fig. 2. Optimization method flowchart

These lengths are already obtained without wastage when cutting 12 meters of rebar. Other parts' cutting list should be entered with their respective length and quantity, and optimization should be performed accordingly. After optimization, the cutting waste rate for the project is calculated (refer to Fig. 3). This helps to determine how much rebar waste can be reduced by implementing necessary measures before optimization.

3. Results and Discussions

In this study, 5 public buildings were selected. Since the rebar wastage rate may vary depending on the type, characteristics and size of the building, care was taken to ensure that the projects were of similar sizes. These buildings are of similar sizes used rebars in different diameters ranging from 8 mm to 22 mm. The objective of the study is to reduce waste caused by cutting losses of rebar in construction projects. Table 1 lists the 5 projects used in the study and the calculated rebar quantities. The amount of rebar used in the projects varied between 147,022 kg and 310,929 kg, with a total rebar amount of about 1,195,148 kg for all 5 projects combined. In this study, CutLogic1D software [24], which is based on the combination of genetic algorithm and fuzzy logic system, was used to reduce the rebar waste ratio. With this software, the rebar dimensions calculated in the static project of a construction project and the rebar lengths and quantities are entered into the software, so that the rebar cutting plans are determined and the cutting loss is reduced.

For this purpose, the static projects of 5 (five) different structures with similar size are examined, and waste amounts are calculated for each diameter of rebar in the case of using the standard production 12m length. The cutting waste (W1) determined according to the optimization results are given in Table 2. According to the Table 2, it is determined that the total amount of the rebar cutting waste is about 34,312 kg and the rebar cutting waste ratio is about 2.87%. This rate is at a satisfactory level compared to the wastage rate between 5% and 8% stated in previous studies.

In the proposed method, the cutting lengths of the rebar with the maximum length in the total are determined for each diameter of rebar used in the projects. The rebar is then ordered based on the specified cutting lengths, and the special cutting length is made as close as possible to multiples of 12 m while ensuring the total length is shorter than 12 m.

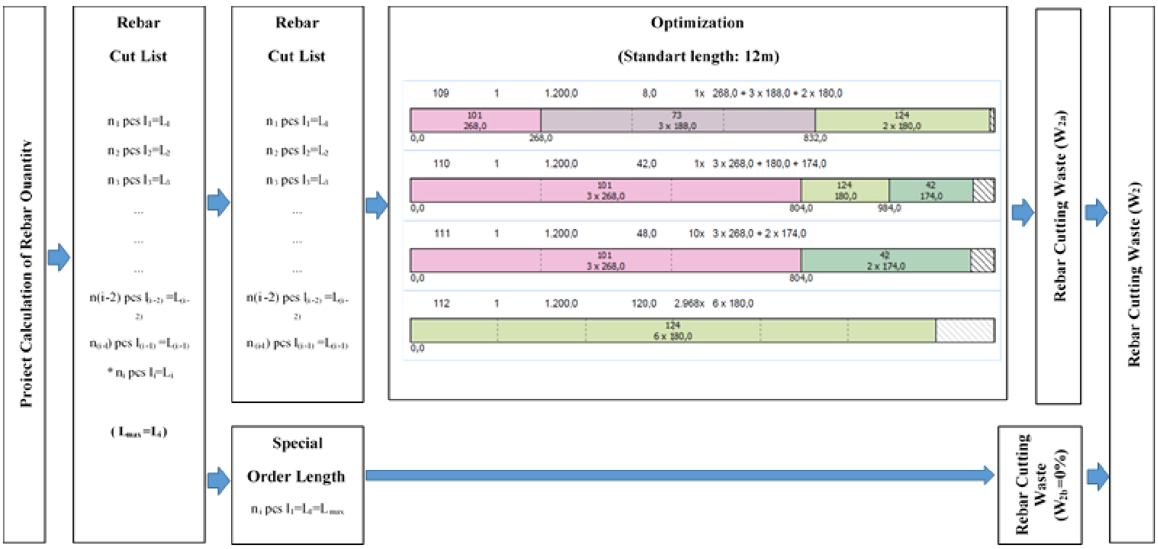

Fig. 3. Proposed method flowchart

Table 1. Rebar amount

Project	Rebar Amount (kg)								
	8 mm	10 mm	12 mm	14 mm	16mm	18 mm	20 mm	22 mm	Total
A	-	108,673	43,263	32,750	60,653	25,145	9,763	-	280,247
B	16,341	12,539	57,363	25,164	38,623	111,746	-	-	261,776
C	53,849	17,053	16,689	29,919	58,905	-	-	134,514	310,929
D	-	78,578	23,913	31,808	60,875	-	-	-	195,174
E	32,410	25,499	11,797	14,944	16,997	-	-	45,375	147,022
Total	102,600	242,342	153,025	134,585	236,053	136,891	9,763	179,889	1,195,148

Table 2. Rebar cutting waste optimization

Project	Cutting Waste	Rebar Cutting Wastes Optimization (W1)								
		8 mm	10 mm	12 mm	14 mm	16mm	18 mm	20 mm	22 mm	Total
A	Total kg	-	108,673	43,263	32,750	60,653	25,145	9,763	-	280,247
	Waste kg	-	3,054	1,134	488	795	4,866	2,847	-	13,184
	Waste %	-	2.81	2.62	1.49	1.31	19.35	29.16	-	4.70
B	Total kg	16,341	12,539	57,363	25,164	38,623	111,746	-	-	261,776
	Waste kg	11	285	2,289	1,029	850	648	-	-	5,112
	Waste %	0.07	2.27	3.99	4.09	2.20	0.58	-	-	1.95
C	Total kg	53,849	17,053	16,689	29,919	58,905	-	-	134,514	310,929
	Waste kg	38	51	414	589	2,179	-	-	3,834	7,105
	Waste %	0.07	0.30	2.48	1.97	3.70	-	-	2.85	2.29
D	Total kg	-	78,578	23,913	31,808	60,875	-	-	-	195,174
	Waste kg	-	479	540	1,314	1,899	-	-	-	4,232
	Waste %	-	0.61	2.26	4.13	3.12	-	-	-	2.17
E	Total kg	32,410	25,499	11,797	14,944	16,997	-	-	45,375	147,022
	Waste kg	1,339	235	625	435	253	-	-	1,792	4,679
	Waste %	4.13	0.92	5.30	2.91	1.49	-	-	3.95	3.18
Total	Total kg	102,600	242,342	153,025	134,585	236,053	136,891	9,763	179,889	1,195,148
	Waste kg	1,388	4,104	5,002	3,855	5,976	5,514	2,847	5,626	34,312
	Waste %	1.35	1.69	3.27	2.86	2.53	4.03	29.16	3.13	2.87

The special cutting length calculation for 12mm diameter rebar in project-A is shown in Fig. 4 according to the proposed method. Thanks to the 8.86 m long supply of rebar, there is no loss of 3.14 m long rebar, which would have resulted from cutting the rebar to 12 m (12 m - 8.86 m = 3.14 m). Therefore, cutting waste (W2a = 0%) does not occur in rebars ordered according to a special cutting length.

After determining the required lengths of the rebars for the five projects, they were cut to the appropriate sizes.

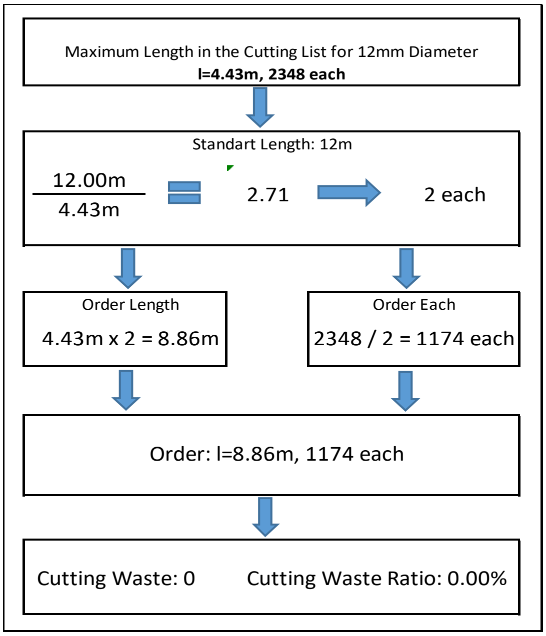

Fig. 4. Proposed method for 12 mm diameter

The total amount of rebar ordered with special lengths for these projects is 214,593 kg. Table 3 shows the cutting waste amount (W2a) of rebar ordered with special lengths, which is zero as no waste was generated while cutting them. The optimization process was then carried out for cutting lengths other than those ordered in special lengths. The cutting waste (W2b) calculated from the optimization results is given in Table 4. After analyzing Table 4, it was found that the total amount of cutting waste is 17,668 kg, corresponding to a cutting waste ratio of approximately 1.80%.

The proposed method for the total project calculates the cutting waste (W2) by evaluating the waste generated from both special length orders (W2a) and other lengths according to optimization (W2b). Table 5 shows the amount and ratio of rebar-cutting waste calculated using this method. The table reveals that the total amount of rebar-cutting waste is 17,668 kg, and the rebar-cutting waste ratio is 1.48%. These values are lower than those obtained through optimization. Additionally, the obtained rebar-cutting waste ratios are more satisfactory when compared to those determined in previous studies.

The waste generated from cutting rebar was compared between the optimization method and the proposed method. Results are presented in Table 6. For Project B and C, there was no reduction in rebar cutting waste for 8mm diameter, and for Project A, there was no reduction for 10mm diameter. However, there were significant reductions in rebar-cutting waste for other diameters. The reduction ratios for rebar cutting waste in 8mm, 10mm, 12mm, 14mm, 16mm, 18mm, 20mm, and 22mm diameter rebars were calculated to be 15.63%, 8.75%, 72.31%, 76.65%, 26.27%, 91.04%, 16.05%, and 43.57%, respectively. The reduction ratios of rebar cutting waste for Projects A, B, C, D, and E were calculated to be 48.98%, 68.43%, 32.81%, 50.69%, and 47.28%, respectively. The results of this analysis indicate that the proposed method yields better results when compared to the optimization method, with an improvement of 47.51%.

Based on previous studies, Nadoushani et al. [6] found that they could reduce the reinforcement of column and beam elements by 52-55%.

Table 3. Other than special order raber cutting wastes (W2a) optimization

Project	Cutting Waste	Other Than Special Order Raber Cutting Wastes (W2a) Optimization								
		8 mm	10 mm	12 mm	14 mm	16mm	18 mm	20 mm	22 mm	Total
A	Total kg	-	102,386	34,026	17,322	58,272	3,562	8,219	-	223,787
	Waste kg	-	3,054	367	102	751	62	2,390	-	6,726
	Waste %	-	2.98	1.08	0.59	1.29	1.73	29.08	-	3.01
B	Total kg	14,070	11,356	27,760	16,980	27,827	105,371	-	-	203,364
	Waste kg	11	262	253	166	490	432	-	-	1,614
	Waste %	0.08	2.31	0.91	0.98	1.76	0.41	-	-	0.79
C	Total kg	50,711	14,398	14,761	27,452	52,105	-	-	125,477	284,904
	Waste kg	38	42	279	335	1,683	-	-	2,397	4,774
	Waste %	0.07	0.29	1.89	1.22	3.23	-	-	1.91	1.68
D	Total kg	-	72,619	19,087	11,346	53,030	-	-	-	156,082
	Waste kg	-	334	302	194	1,257	-	-	-	2,087
	Waste %	-	0.46	1.58	1.71	2.37	-	-	-	1.34
E	Total kg	29,601	21,071	8,828	11,003	15,717	-	-	26,198	112,418
	Waste kg	1,122	53	184	105	225	-	-	778	2,467
	Waste %	3.79	0.25	2.08	0.95	1.43	-	-	2.97	2.19
Total	Total kg	94,382	221,830	104,462	84,103	206,951	108,933	8,219	151,675	980,555
	Waste kg	1,171	3,745	1,385	902	4,406	494	2,390	3,175	17,668
	Waste %	1.24	1.69	1.33	1.07	2.13	0.45	29.08	2.09	1.80

Table 4. Rebar Cutting Wastes of Special Orders (W2b)

Project	Cutting Waste	Rebar Cutting Wastes of Special Orders (W2b)								
		8 mm	10 mm	12 mm	14 mm	16mm	18 mm	20 mm	22 mm	Total
A	Total kg	-	6,287	9,237	15,428	2,381	21,583	1,544	-	56,460
	Waste kg	-	0	0	0	0	0	0	-	0
	Waste %	-	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00
B	Total kg	2,271	1,183	29,603	8,184	10,796	6,375	-	-	58,412
	Waste kg	0	0	0	0	0	0	-	-	0
	Waste %	0.00	0.00	0.00	0.00	0.00	0.00	-	-	0.00
C	Total kg	3,138	2,655	1,928	2,467	6,800	-	-	9,037	26,025
	Waste kg	0	0	0	0	0	-	-	0	0
	Waste %	0.00	0.00	0.00	0.00	0.00	-	-	0.00	0.00
D	Total kg	-	5,959	4,826	20,462	7,845	-	-	-	39,092
	Waste kg	-	0	0	0	0	-	-	-	0
	Waste %	-	0.00	0.00	0.00	0.00	-	-	-	0.00
E	Total kg	2,809	4,428	2,969	3,941	1,280	-	-	19,177	34,604
	Waste kg	0	0	0	0	0	-	-	0	0
	Waste %	0.00	0.00	0.00	0.00	0.00	-	-	0.00	0.00
Total	Total kg	8,218	20,512	48,563	50,482	29,102	27,958	1,544	28,214	214,593
	Waste kg	0	0	0	0	0	0	0	0	0
	Waste %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Rebar Cutting Waste for the Proposed Method (W2=W2a+W2b)

Project	Cutting Waste	Rebar Cutting Wastes for the Proposed Method (W2 = W2a + W2b)								
		8 mm	10 mm	12 mm	14 mm	16mm	18 mm	20 mm	22 mm	Total
A	Total kg	-	108,673	43,263	32,750	60,653	25,145	9,763	-	280,247
	Waste kg	-	3,054	367	102	751	62	2,390	-	6,726
	Waste %	-	2.81	0.85	0.31	1.24	0.25	24.48	-	2.40
B	Total kg	16,341	12,539	57,363	25,164	38,623	111,746	-	-	261,776
	Waste kg	11	262	253	166	490	432	-	-	1,614
	Waste %	0.07	2.09	0.44	0.66	1.27	0.39	-	-	0.62
C	Total kg	53,849	17,053	16,689	29,919	58,905	-	-	134,514	310,929
	Waste kg	38	42	279	335	1,683	-	-	2,397	4,774
	Waste %	0.07	0.25	1.67	1.12	2.86	-	-	1.78	1.54
D	Total kg	-	78,578	23,913	31,808	60,875	-	-	-	195,174
	Waste kg	-	334	302	194	1,257	-	-	-	2,087
	Waste %	-	0.43	1.26	0.61	2.06	-	-	-	1.07
E	Total kg	32,410	25,499	11,797	14,944	16,997	-	-	45,375	147,022
	Waste kg	1,122	53	184	105	225	-	-	778	2,467
	Waste %	3.46	0.21	1.56	0.70	1.32	-	-	1.71	1.68
Total	Total kg	102,600	242,342	153,025	134,585	236,053	136,891	9,763	179,889	1,195,148
	Waste kg	1,171	3,745	1,385	902	4,406	494	2,390	3,175	17,668
	Waste %	1.14	1.55	0.91	0.67	1.87	0.36	24.48	1.76	1.48

Table 6. Rebar Cutting Waste Amounts and Reduction Ratios ([1-W2/W1]%)

Project	Cutting Waste	Rebar Cutting Waste Amounts and Reduction Ratios ([1-W2/W1]%)								
		8 mm	10 mm	12 mm	14 mm	16mm	18 mm	20 mm	22 mm	Total
A	W1 (kg)	-	3,054	1,134	488	795	4,866	2,847	-	13,184
	W2 (kg)	-	3,054	367	102	751	62	2,390	-	6,726
	Reduction %	-	0.00	67.64	79.10	5.53	98.73	16.05	-	48.98
B	W1 (kg)	11	285	2,289	1,029	850	648	-	-	5,112
	W2 (kg)	11	262	253	166	490	432	-	-	1,614
	Reduction %	0.00	8.07	88.95	83.87	42.35	33.33	-	-	68.43
C	W1 (kg)	38	51	414	589	2,179	-	-	3,834	7,105
	W2 (kg)	38	42	279	335	1,683	-	-	2,397	4,774
	Reduction %	0.00	17.65	32.61	43.12	22.76	-	-	37.48	32.81
D	W1 (kg)	-	479	540	1,314	1,899	-	-	-	4,232
	W2 (kg)	-	334	302	194	1,257	-	-	-	2,087
	Reduction %	-	30.27	44.07	85.24	33.81	-	-	-	50.69
E	W1 (kg)	1,339	235	625	435	253	-	-	1,792	4,679
	W2 (kg)	1,122	53	184	105	225	-	-	778	2,467
	Reduction %	16.21	77.45	70.56	75.86	11.07	-	-	56.58	47.28
Total	W1 (kg)	1,388	4,104	5,002	3,855	5,976	5,514	2,847	5,626	34,312
	W2 (kg)	1,171	3,745	1,385	902	4,406	494	2,390	3,175	17,668
	Reduction %	15.63	8.75	72.31	76.65	26.27	91.04	16.05	43.57	48.51

Meanwhile, the method proposed in this study resulted in an average savings of 48% in reinforcement across all projects, not just limited to column and beam elements. Another study by Guvel and Karatas [13] investigated the reinforcement savings that could be obtained by using different length production alternatives, in addition to the standard 12m reinforcements. It has been found that by using different alternatives in construction projects, the waste of rebar can be significantly reduced. In a study conducted by Nadoushani et al. [3], the most commonly used rebar was reduced to zero by special ordering, and the amount of waste was minimized by optimizing other donated rebar. The aim was to minimize waste by optimizing trim loss in a project, and a 49.6% reduction was achieved throughout the project. Residential buildings emit 108.3 tons of carbon, educational buildings 490.62 tons, and commercial buildings 137.02 tons [26]. This study will also significantly reduce these carbon emissions in the construction sector. The proposed method was tested in five construction projects, and it was found that rebar waste was significantly reduced.

4. Conclusions

Reducing the amount of waste material in the construction industry is a crucial goal for sustainability globally. When rebars are cut to fit the required lengths in a building, a considerable amount of rebar waste is produced. The purpose of this study is to minimize the amount of rebar waste generated during construction projects. The study aims to achieve this by optimizing the cut lengths of the 12 m standard rebar and producing rebar in varying lengths based on the order, considering cutting lengths with high usage intensity. The goal is to reduce rebar cutting waste and improve efficiency in construction projects. During construction, the amount of waste generated from cutting rebars was estimated to be around 5% to 8% with traditional methods. However, with the implementation of computer software that utilizes genetic algorithms, fuzzy logic systems, and newly developed algorithms that combine both, the waste ratio has been significantly reduced to approximately 2.87%. The proposed method aims to minimize the amount of waste generated during rebar cutting by optimizing the process and ordering special cutting lengths. According to the results obtained, the total rebar waste ratio is 1.48%, which is significantly reduced. The proposed method has resulted in a satisfactory level of reduction in rebar waste. Compared to the optimization, the proposed method has reduced the rebar-cutting waste amount by 48.51%.

The proposed method was only tested on five reinforced concrete construction projects with similar sizes. The standard length of 12 meters is used globally in most countries, including Turkey. Although some countries have different standard lengths available, this study considers the 12-meter length to be valid worldwide. This is because the first optimization was performed using the standard length, and the second optimization was done with a special size order that is not produced in the standard length. In future studies, this method can be applied to construction projects of different sizes and types. Moreover, the method was applied to the most commonly used type of rebar due to its high cost for special ordering. In future studies, the costs of special-order rebar can be determined, and a waste optimization study can be conducted along with the cost analysis.

Although rebar-cutting waste did not decrease for some diameters, a reduction of more than 90% was observed in other diameters. The proposed method can be applied to any diameter of rebar used in construction projects, depending on the project specifications. Since reducing all types of waste is crucial for a sustainable world, any effort toward reducing rebar-cutting waste is significant. It is evident that the results of this study could be beneficial for future studies aimed at reducing construction waste of all types of projects requiring rebar cutting.

Declaration

Funding

This research received no external funding.

Author Contributions

Ş. T. Güvel: Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Writing-Original Draft, Writing-Review & Editing; İ. Karataş: Conceptualization, Methodology, Writing-Original Draft, Writing-Review & Editing, Visualization.

Acknowledgments

Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

Not applicable.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

[1] Xu X, Wang Y, Tao L (2019) Comprehensive evaluation of sustainable development of regional construction industry in China. Journal of Cleaner Production 211: 1078–1087.

[2] Lu W, Yuan H (2011) A Framework for understanding waste management studies in construction. Waste Management 31: 1252–1260.

[3] Nadoushani ZSM, Hammad AW, Akbarnezhad A (2016) A framework for optimizing lap splice positions within concrete elements to minimize cutting waste of steel bars. In: 33rd International Symposium on Automation and Robotics in Construction (ISARC), Auburn, Alabama, USA, 392-398.

[4] Wanga J, Li Z, Tam VWY (2014) Critical factors in effective construction waste minimization at the design stage: A shenzhen case study China. Resources Conservation and Recycling 82: 1–7.

[5] Tam VWY (2008) On the effectiveness in implementing a waste-management-plan method in construction. Waste Management 28: 1072–1080.

[6] Nadoushani ZSM, Hammad AWA, Xiao J, Akbarnezhad A (2018) Minimizing cutting wastes of reinforcing steel bars through optimizing lap splicing within reinforced concrete elements. Construction and Building Materials 185: 600–608.

[7] Can G, Taş EF (2021) Analysis of non-physical waste causes affecting the construction process. Journal of the Faculty of Engineering and Architecture of Gazi University 36(2): 655–668.

[8] Khondoker TH (2021) Automated reinforcement trim waste optimization in RC frame structures using building information modeling and mixed-integer linear programming. Automation in Construction 124: 1-9.

[9] Zheng C, Yi C, Lu M (2019) Integrated optimization of rebar detailing design and installation planning for waste reduction and productivity improvement. Automation in Construction 101: 32–47.

[10] Benjaoran V, Bhokha S (2013) Trim loss minimization for construction reinforcement steel with oversupply constraints. Journal of Advanced Management Science 1(3): 313-316.

[11] Mortazavi A, Moloodpoor M (2021) Differential evolution method integrated with a fuzzy decision-making mechanism and virtual mutant agent: theory and application. Applied Soft Computing 112: 107808.

[12] Mortazavi A (2023) A fuzzy reinforced Jaya algorithm for solving mathematical and structural optimization problems. Soft Computing 1-26.

[13] Guvel ST, Karatas I (2021) Diversification of rebar standard lengths and optimization to reduce rebar waste rate. Journal of the Faculty of Engineering and Architecture of Gazi University 36(4): 2197-2208.

[14] Salem O, Shahin A, Khalifa Y (2007) Minimizing cutting wastes of reinforcement steel bars using genetic algorithms and integer programming models. Journal of Construction Engineering and Management 133(12): 982–992.

[15] Shahin AA, Salem OM (2004) Using genetic algorithms in solving the one-dimensional cutting stock problem in the construction industry.

Canadanian Journal of Civil Engineering 31(2): 321–332.
[16] Porwal A, Hewage KN (2012) Building information modeling-based analysis to minimize waste rate of structural reinforcement. Journal of Construction Engineering and Management 138(8): 943–954.
[17] Li Y, Yang Y, Zhou L, Zhu R (2009) Observations on using problem-specific genetic algorithm for multiprocessor real-time task scheduling. International Journal of Innovative Computing Information and Control 5(9): 2531–2540.
[18] Osman MS, Abo-Sinna MA, Mousa AA (2005) A combined genetic algorithm-fuzzy logic controller (GA-FLC) in nonlinear programming. Applied Mathematics and Computation 170(2): 821–840.
[19] Ustun SV, Demirtas M (2008) Optimal tuning of PI coefficients by using fuzzy-genetic for V/f controlled induction motor. Expert Systems with Applications 34: 2714–2720.
[20] Chu B, Kim D, Hong D, Park J, Chung JT, Chung JH, Kim TH (2008) GA-based fuzzy controller design for tunnel ventilation systems. Automation in Construction 17: 130–136.
[21] Zadeh LA (1965) Fuzzy sets. Information and Control 8: 338–353.
[22] Cordon O, Jose Del Jesus M, Herrera F (1998) Genetic learning of fuzzy rule-based classification systems cooperating with fuzzy reasoning methods. International Journal of Intelligent Systems 13: 1025–1053
[23] Laribi MA, Mlika A, Romdhane L, Zeghloul S (2004) A combined genetic algorithm-fuzzy logic method (GA-FL) in mechanisms synthesis. Mechanism and Machine Theory 39: 717–735.
[24] CutLogic 1D 3.0 (2019) Bilgisayar Programı, 5.6 Versiyon, Banska Bystrica (Slovakia): TMachines, s.r.o.
[25] Tahmasebi P, Hezarkhani A (2012) A hybrid neural networks-fuzzy logic-genetic algorithm for grade estimation. Computing Geoscience 42: 18–27.
[26] Shuvo AK, Sharmin S (2021) Carbon emission scenario of conventional buildings. Journal of Construction Engineering, Management & Innovation 4(3): 134-150.