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Assessment of Structural Rebar Wastage of Reinforced Cement Concrete Buildings: A Case Study of School Building Type Designs in Kathmandu

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Abstract

Economic growth and urbanization in developing countries have led to significant construction activities, resulting in large amounts of waste, which is recognized as a key problem in various cities. In this regard, the management of waste is recommended as an important and integrated task in project execution. In this study, rebar waste generated from construction activities of educational building projects in Kathmandu is examined. A qualitative approach was followed, using four types of school building designs as case studies. Site observations, data collection, and analysis of the selected buildings were carried out. The minimum and maximum cutting waste of structural rebar were found to be 11.52% and 15.21%, respectively. The results of each project are presented, and a cross-case analysis was conducted to compare similarities and differences in factors related to waste generation.

Keywords: *Cutting Waste, Rebar Offcuts, School Building, Sustainable Construction*

1 Introduction

The construction of reinforced concrete (RC) structures is accompanied by substantial consumption of concrete and rebar. It has been reported that global concrete consumption reached approximately 10 billion m^3 in 2012, with demand for RC structures increasing due to global economic development (Khondoker, 2021).Rebar, a key component of RC structures, is identified as a significant contributor to CO_2 emissions, with an embodied CO_2 (ECO_2) of 872 kg-ECO_2/t, which is approximately 9.2 times higher than that of concrete (Porwal & Hewage, 2012).The urgent need to minimize rebar-cutting waste is highlighted, as it directly influences greenhouse gas emissions and sustainability (Lee, et al., 2020). Research has indicated that cutting waste from rebar ranges between 3% and 8%, depending on construction practices and country-specific factors (Lee, et al., 2020).

The global rise in rebar off-cuts has been associated with unnecessary costs and increased CO_2 emissions during manufacturing, transportation, and processing (Kwon, et al., 2021). Near-zero cutting waste has been identified as a goal for researchers since the introduction of the Cutting Stock Problem (CSP) in 1939 (Nadoushani, et al., 2016). However, near-zero waste has not yet been achieved, particularly in Nepal, where sustainable construction practices and energy-efficient strategies are often neglected. The assessment of rebar waste is considered critical for understanding its environmental impact and supporting the formulation of policies aimed at promoting sustainable construction.

Rebar, typically supplied in standard lengths (e.g., 12m in Nepal), is often inefficiently utilized due to inconsistent cutting practices. Cutting decisions are typically made based on workers' judgment, leading to significant material wastage. In developing countries, construction and demolition waste is estimated to account for approximately 40% of total solid waste (Rode, et al., 2013), with 5%-8% originating from residential construction (Poon, et al., 2004). This waste is characterized by minimal salvage value, and improper handling has been associated with increased risks to workers. Minimizing such waste is considered essential for sustainable construction, as it reduces environmental impacts and enhances resource efficiency. The assessment of cutting waste is identified as a critical first step in achieving these goals (Danatzko & Sezen, M.ASCE, 2011).

Rebar cutting waste is modeled and quantified in this study to assess the embodied energy of rebar, and measures are proposed to minimize carbon emissions from construction activities.

2 Materials and Methods

2.1 Research Site:

Nepal is recognized as one of the most hazard-prone countries in the world, with earthquakes, landslides, and floods identified as the most severe hazards. The frequency and intensity of weather-related hazards, including landslides, floods, and droughts, are expected to increase due to climate change. Seismic events are known to trigger secondary hazards such as landslides, floods, and fires. Although massive earthquakes occur occasionally, they result in significant casualties, physical damage, and economic losses. The damages and losses caused by the devastating 2015 Gorkha earthquake were assessed at $7 billion, with 8,790 casualties, 22,300 injuries, 7,800 schools damaged, and approximately eight million people affected, accounting for nearly 29% of the population (National planning commission , Government of Nepal, 2015). It has been estimated that over 72% of the school buildings in the country's 35,000 schools were unsafe and required seismic retrofitting. The 2016 Structural Integrity Damage Assessment (SIDA) reported that 2,234 schools were heavily damaged and rendered unusable in fourteen districts severely affected by the 2015 earthquake (National planning commission , Government of Nepal, 2015) . For the reconstruction of schools, several design types were developed. Among these designs, 3-C-12, 3-C-9, 3-C-7, and 4-C-16 from the Kathmandu district were selected for this study. The general and structural parameters are presented below in Table 1 and Table 2 respectively.

2.2 Research Methodology:

The research was conducted using a pragmatic paradigm to assess the cutting waste of structural reinforcement steel bars during the construction of RCC buildings for the implementation of sustainable construction. Both qualitative and quantitative methods were employed, as they were deemed relevant for addressing research objectives. Data collection, analysis, and interpretation methods were applied.

The study was carried out based on an explanatory approach, incorporating a literature review and case study. Explanatory research, which focuses on understanding relationships between variables and their implications in the past and future, was employed to incorporate a quantitative approach. The variation trends of structural rebar cutting procedures and the environmental impacts of rebar waste were analyzed and compared. Subsequently, a case study site and building were selected to gather data on building materials, size, and other parameters required for rebar cutting waste analysis.

In this research, the cutting waste of rebar in RC school buildings was reviewed using the positivist paradigm. The bar bending schedule was analyzed using MS Excel and AutoCAD. The data obtained were further processed using the solver tool in MS Excel. These data were analyzed and compared. Cutting waste from a building's structural rebar was treated as quantitative data. The processed data was used to calculate the embodied energy to assess the environmental impact of structural rebar wastage. Based on the findings, an interpretive approach to building research was adopted to propose measures for minimizing reinforcement cutting waste. Measures for rebar optimization were proposed based on the findings from the analysis and literature review.

Table 1:General parameters of school building (Type designs).

Block ID	3-C-12	3-C-9	3-C-7	4-C-16
Structural Topology	RCC Frame Structure	RCC Frame Structure	RCC Frame Structure	RCC Frame Structure
No. of Story	G+2 (3 Storey)	G+2 (3 Storey)	G+2 (3 Storey)	G+3 (4 Storey)
Length of the Building	31 m	23 m	18 m	31 m
Breadth of the Building	9 m	9 m	8.5 m	9 m
Height of the Building	13.55 m	13.5 m	13.55 m	16.55 m
Wall Type	Brick Masonry in Cement Mortar	Brick Masonry in Cement Mortar	Brick Masonry in Cement Mortar	Brick Masonry in Cement Mortar
Floor Type	RCC Slab	RCC Slab	RCC Slab	RCC Slab
Door and Windows	Metal (Frame and Panel)	Metal (Frame and Panel)	Metal (Frame and Panel)	Metal (Frame and Panel)

Table 2:Structural parameters of school building (Type designs).

Concrete Grade	M20	M20	M20	M20
Column	500x500	500x500	500x500	500x500
Foundation Beam	230x355 mm	230x355 mm	230x355 mm	230x355 mm
Plinth Beam	230x355 mm	230x355 mm	230x355 mm	230x355 mm
Main Beam	350x550 mm	350x550 mm	350x550 mm	350x550 mm
Secondary Beam	230x400 mm	230x400 mm	230x400 mm	230x400 mm
Slab	125 mm	125 mm	125 mm	125 mm
Waist Slab	200 mm	200 mm	200 mm	200 mm
Footing	F1=2.7 x2.7m, F2=3.6 x 3.6m, CF1=5.8x3.2m, CF2=6.3x 3.8m	F1=2.7x2.7m, F2=3.5x 3.5m, CF1=5.67x3.0m ,CF2=6.4x3.8m	F1=2.9m x2.9m, F2= 3.7m x 3.7m, CF1=6.3mx3.6m , CF2=6.3mx 4.5m	F1=2.7x2.7m, F2=3.6x3.6m, CF1=5.8x3.2m ,CF2=6.3x 3.8m
Foundation Depth	1.2. m, 1.65 m (From ground level)	1.2. m, 1.65 m (From ground level)	1.2. m, 1.65 m (From ground level)	1.2. m, 1.65 m (From ground level)
Floor height	3.0 m	3.0 m	3.0 m	3.0 m
Soil Type	SBC 100kN/m^2, Type III as per IS1893:2002	SBC 100kN/m^2, Type III as per IS1893:2002	SBC 100kN/m^2, Type III as per IS1893:2002	SBC 100kN/m^2, Type III as per IS1893:2002
Wall Type	230 mm Brick Masonry	230 mm Brick Masonry	230 mm Brick Masonry	230 mm Brick Masonry
Floor Type	RCC Slab on all floors	RCC Slab on all floors	RCC Slab on all floors	RCC Slab on all floors

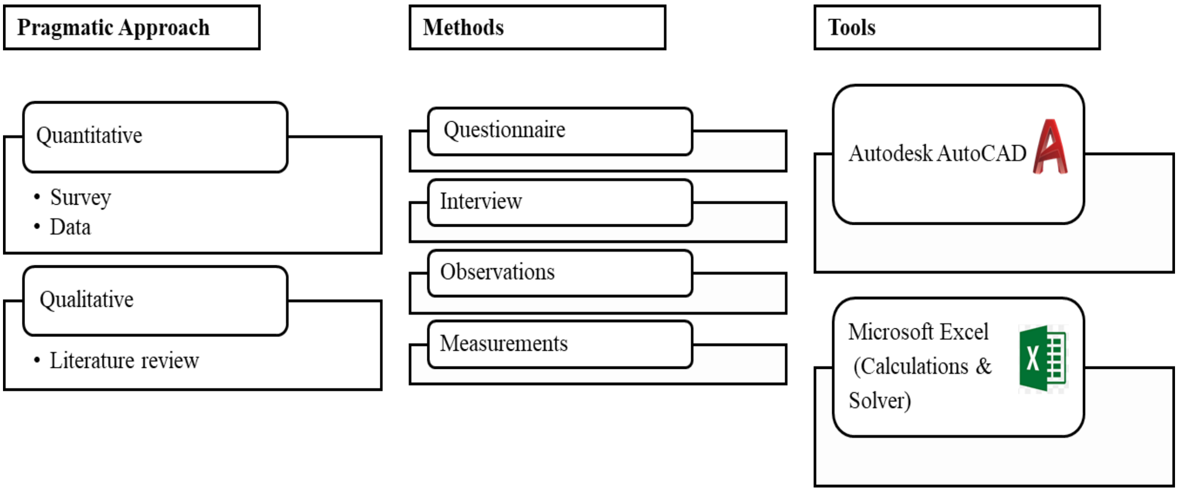

Figure 1: Research methodology

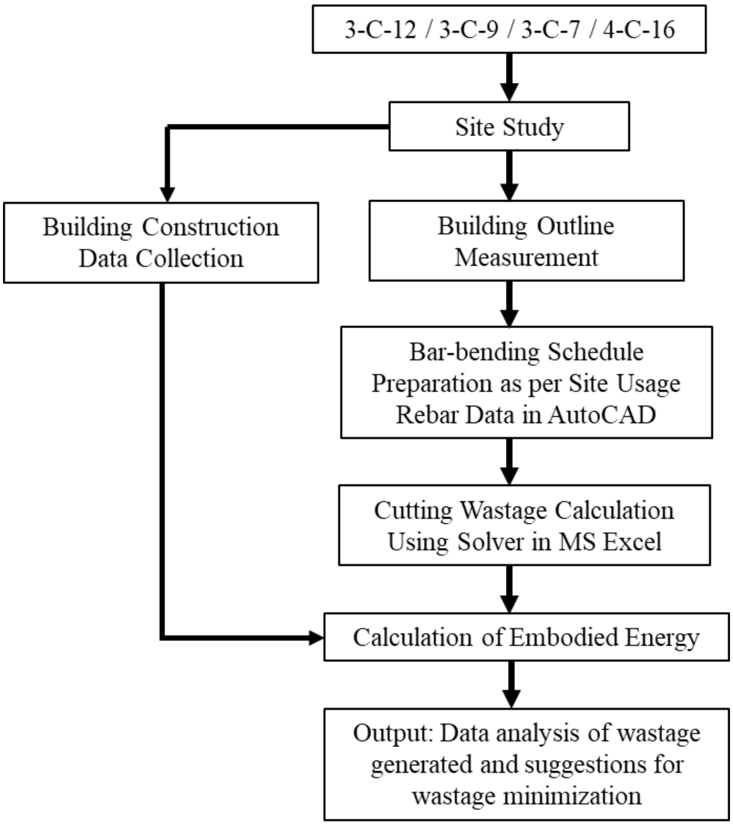

Figure 2: Working framework of study

2.3 Methods for Analysis:

For the assessment of cutting waste in structural reinforcement bars, the bar bending schedule for each type of design was prepared using data obtained from site measurements and drawings. The data were then analyzed using the solver tool in MS Excel.
An algorithm was proposed for solver to generate variants of cutting rods that resulted in the least waste. The algorithm involved analyzing all possible sets of bars of required lengths whose total length did not exceed the standard rod length. For each required bar length, the

maximum number of bars that could be obtained from a standard-length rod was calculated. For example, from a rod with a length of 12 m, a maximum of 12 bars of 1.0 m, 8 bars of 1.5 m, and 6 bars of 2.0 m could be obtained. The total number of combinations of these three bar types was calculated as 576, which is the product of the three numbers: 12, 8, and 6. In general, this number (K) was calculated using the formula provided by Matviyishyn and Janiak (Matviyishyn & Janiak, 2019).

$$K = \prod_{j=1}^{n} \frac{L}{d_j} \qquad (1)$$

Where,
L is the standard length of rods used for bar cutting (in the example presented L=12 m);
dj is the length of bar of j type.
n is the number of types.
All possible options for cutting rods into bars of the required lengths were generated using this algorithm. The algorithm was implemented in a Microsoft Excel spreadsheet through a developed VBA macro. The generated options varied in terms of the length of waste remaining after cutting the steel rod. The selection of combinations from these options was made based on the data regarding the required number of bars of specific lengths.

3 Results and Discussion

3.1 Scenario 1: 3-C-12

The total cutting waste obtained using solver is 7069 kg, which is 11.52% of the total stock rebar. Result thus obtained after calculations are presented below.

Table 3: Total cutting waste using solver in 3-C-12.

Rebar diameter	8mm	10mm	12mm	16mm	20mm	Total quantity(kg)
Stock weight(kg)	15779	14490	4486	19005	14654	68414
Finish weight(kg)	14536	13782	3941	17228	11859	61346
Scrap/offcut(kg)	1244	708	545	1777	2795	7069
Usage %	23.70%	22.47%	6.42%	28.08%	19.33%	100%
Scrap/offcut %	8.56%	5.14%	13.83%	10.31%	23.57%	11.52%

From the Table 3 , it is observed that the highest quantity of rebar used is 16 mm in diameter, accounting for 28.08% of the total, as it is incorporated into almost all structural components, including footings, columns, beams, and staircases. In contrast, the lowest quantity of rebar used is 12 mm in diameter, comprising 6.42%, and is primarily utilized in footings and beams. However, the highest offcut wastage is recorded in 20 mm diameter rebar (23.57%), which is employed in columns and beams. The most significant wastage occurs in columns due to restrictions on the lapping zone, which is permitted to extend only up to half the height of the column. Furthermore, no more than 50% of the rebar can be spliced at a single position (IS 13920:1993, n.d.), thereby limiting the optimization of rebar cut-offs.
Figure *3* illustrates the distribution of rebar usage and cutting waste by structural component. According to the figure, beams account for the highest rebar consumption, followed by columns and slabs. However, columns contribute the most to cutting waste, followed by beams and slabs.

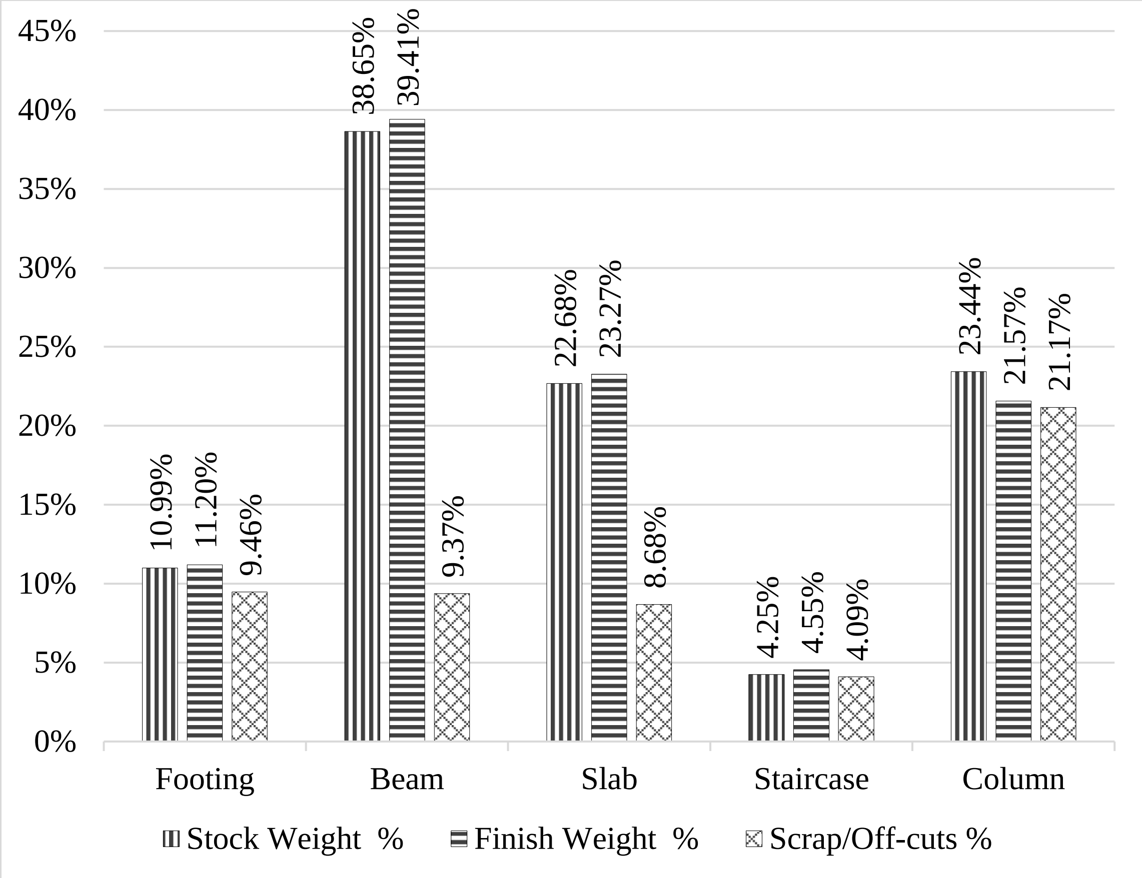

Figure 3: Cutting waste by structural component in 3-C-12.

3.1.1 Embodied energy of rebar

The embodied energy associated with the quantity of rebar obtained from bar bending schedule is shown below in the Table 4.

Table 4 : Embodied energy calculation of rebar in 3-C-12.

Embodied energy coefficient = 32.24 MJ/kg (Praseeda, et al., 2014)		
	Weight of Rebar (kg)	Embodied Energy (GJ)
Stock Weight (kg)	68414	2205.67
Finish Weight (kg)	61346	1977.79
Scrap/Off-cuts weight (kg)	7069	227.90

3.1.2 Cost rates for embodied carbon dioxide

Total embodied energy of off-cuts = 227.90 GJ

= 227.90 x 0.24 ton

= 54.69 ton

Environmental cost of the emission of one ton of CO_2 in 2022 =194.28 euros

Total environment cost of the emission of CO_2 = 54.69 x 194.28

= 10626.55 euros

3.2 Scenario 2 : 3-C-9

The total cutting waste obtained using solver is 6711 kg, which is 13.43% of the total stock rebar. Result thus obtained after calculations are presented below.

Table 5: Total cutting waste using solver in 3-C-9.

Rebar diameter	8mm	10mm	12mm	16mm	20mm	Total quantity(kg)
Stock weight(kg)	7740	11809	4124	16636	16371	56681
Finish weight(kg)	7379	11234	3534	15034	12790	49970
Scrap/offcut(kg)	362	576	590	1602	3581	6711
Usage %	14.77%	22.48%	7.07%	30.09%	25.59%	100%
Scrap/offcut %	4.90%	5.13%	16.68%	10.66%	28.00%	13.43%

From the Table 5 , it is observed that the highest quantity of rebar used is 16 mm in diameter, accounting for 30.09% of the total, as it is incorporated into almost all structural components, including footings, columns, beams, and staircases. In contrast, the lowest quantity of rebar used is 12 mm in diameter, comprising 7.07%, and is primarily utilized in footings and beams. However, the highest offcut wastage is recorded in 20 mm diameter rebar (28.00%), which is employed in columns and beams. The most significant wastage occurs in columns due to restrictions on the lapping zone, which is permitted to extend only up to half the height of the column. Furthermore, no more than 50% of the rebar can be spliced at a single position (IS 13920:1993, n.d.), thereby limiting the optimization of rebar cut-offs.

Figure 4 illustrates the distribution of rebar usage and cutting waste by structural component. According to the figure, beams account for the highest rebar consumption, followed by columns and slabs. However, columns contribute the most to cutting waste, followed by beams and slabs.

3.2.1 Embodied energy of rebar

The embodied energy associated with the quantity of rebar obtained from the bar bending schedule is shown below in Table 6.

Table 6: Embodied energy calculation of rebar in 3-C-9.

Embodied energy coefficient = 32.24 MJ/kg (Praseeda, et al., 2014)		
	Weight of Rebar (kg)	Embodied Energy (GJ)
Stock Weight (kg)	56681	1827.39
Finish Weight (kg)	49970	1611.03
Scrap/Off-cuts weight (kg)	6711	216.36

3.2.2 Cost rates for embodied carbon dioxide

Total embodied energy of off-cuts = 216.36 GJ

= 216.36 x 0.24 ton

= 51.92 ton

Environmental cost of the emission of one ton of CO_2 in 2022 =194.28 euros

Total environment cost of the emission of CO_2 = 51.92 x 194.28

= 10088.38 euros

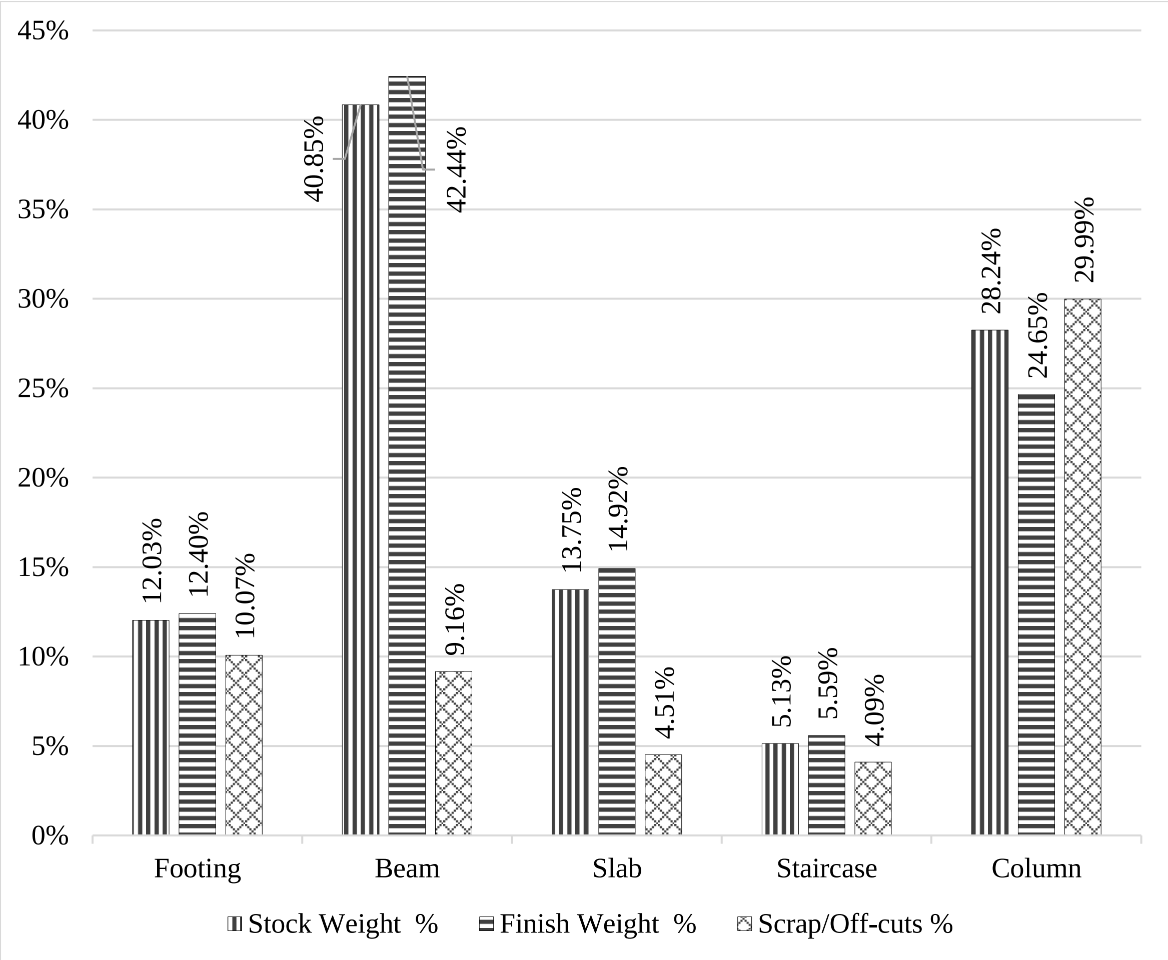

Figure 4: Cutting waste by structural components in 3-C-9

3.3 Scenario 3 : 3-C-7

The total cutting waste obtained using solver is 5090 kg, which is 12.49% of the total stock rebar. Result thus obtained after calculations are presented below.

From the Table 7 , it is evident that 16 mm diameter rebar constitutes the highest proportion (35.46%) of the total rebar used, as it is incorporated into nearly all structural components, including footings, columns, beams, and staircases. In contrast, 25 mm diameter rebar accounts for the lowest percentage (0.27%) and is entirely utilized in columns. However, the greatest offcut wastage is observed in 25 mm diameter rebar (65.52%), followed by 16 mm diameter rebar. This can be attributed to the increased lap length required for larger-diameter rebars and the use of 25 mm rebar in ground-floor columns, extending up to mid-height of the first floor. The positioning of lap splices for different rebar sizes results in significant offcuts for 25 mm rebar, as splicing restrictions prevent their full utilization, leading to greater material waste. Based on this analysis, it can be inferred that columns contribute the most to rebar wastage due to limitations in the lapping zone, where splicing is restricted to half the column height and no more than 50% of the rebar can be spliced at a single location (IS 13920:1993, n.d.).

Figure 5 presents the distribution of rebar usage and cutting waste across structural components. As depicted in the figure, beams account for the highest rebar consumption, followed by columns and footings. However, columns generate the most cutting waste, with beams and footings contributing comparatively less.

Table 7: Total cutting waste using solver in 3-C-7.

Rebar diameter	8mm	10mm	12mm	16mm	20mm	25mm	Total quantity(kg)
Stock weight(kg)	5792	10329	3783	16750	9000	185	45838
Finish weight(kg)	5368	9799	3341	14449	7679	112	40748
Scrap/offcut(kg)	424	529	442	2301	1321	73	5090
Usage %	13.17%	24.05%	8.20%	35.46%	18.84%	0.27%	100%
Scrap/offcut %	7.90%	5.40%	13.23%	15.92%	17.20%	65.52%	12.49%

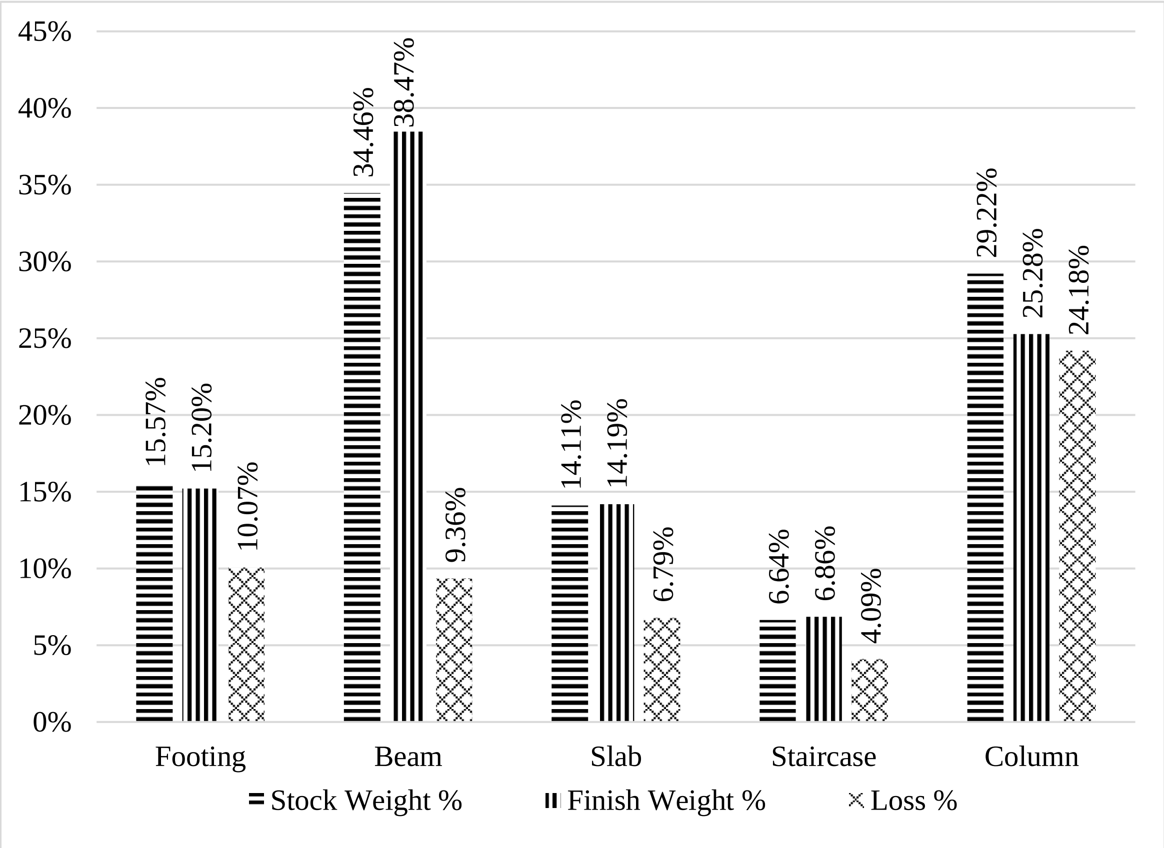

Figure 5: Cutting waste by structural components in 3-C-7.

3.3.1 Embodied energy of rebar

The embodied energy associated with the quantity of rebar obtained from bar bending schedule is shown below in the Table 8.

Table 8: Embodied energy calculation of rebar in 3-C-7.

Embodied energy coefficient = 32.24 MJ/kg (Praseeda, et al., 2014)		
	Weight of Rebar (kg)	Embodied Energy (GJ)
Stock Weight (kg)	43780	1411.45
Finish Weight (kg)	40748	1313.71
Scrap/Off-cuts weight (kg)	5090	164.10

3.3.2 Cost rates for embodied carbon dioxide

Total embodied energy of off-cuts = 164.10 GJ

= 164.10 x 0.24 ton

= 39.38 ton

Environmental cost of the emission of one ton of CO_2 in 2022 =194.28 euros

Total environment cost of the emission of CO_2 = 39.38 x 194.28

= 7651.59 euros

3.4 Scenario 4 : 4-C-16

The total cutting waste obtained using solver is 12323 kg, which is 15.21% of the total stock rebar. Result thus obtained after calculations are presented below.

Table 9: Total cutting waste using solver in 4-C-16.

Rebar diameter	8mm	10mm	12mm	16mm	20mm	25mm	Total quantity(kg)
Stock weight(kg)	20382	18814	4891	20236	22381	6661	93365
Finish weight(kg)	18770	17900	4277	18452	17263	4381	81043
Scrap/offcut(kg)	1612	914	614	1785	5118	2281	12323
Usage %	23.16%	22.09%	5.28%	22.77%	21.30%	5.41%	100%
Scrap/offcut %	8.59%	5.11%	14.35%	9.67%	29.65%	52.07%	15.21%

Table 9 indicates that the 8 mm diameter rebar constitutes the highest proportion (23.16%) of the total rebar used, followed by 16 mm (22.77%) and 10 mm (22.09%) diameter rebars. In contrast, 12 mm (5.28%) and 25 mm (5.41%) diameter rebars account for the lowest proportions. However, the highest cutting wastage is observed in 25 mm diameter rebar (52.07%), followed by 20 mm diameter rebar (29.65%). This can be attributed to the greater lap length required for larger-diameter rebars, as 25 mm rebar is primarily used in ground-floor and first-floor columns, extending up to the mid-height of the subsequent floor. The positioning of lap splices for 25 mm and 20 mm rebars results in higher offcuts, as splicing restrictions prevent complete utilization of these lengths, leading to increased material waste. Based on this analysis, it can be inferred that columns contribute the most to rebar waste, as the lapping zone is restricted to half the column height, and no more than 50% of the rebar can be spliced at a single location (IS 13920:1993, n.d.).

Figure 6 presents the distribution of rebar usage and cutting waste across structural components. According to the figure, beams account for the highest rebar consumption, followed by columns and slabs. However, columns generate the most cutting waste, followed by beams and footings.

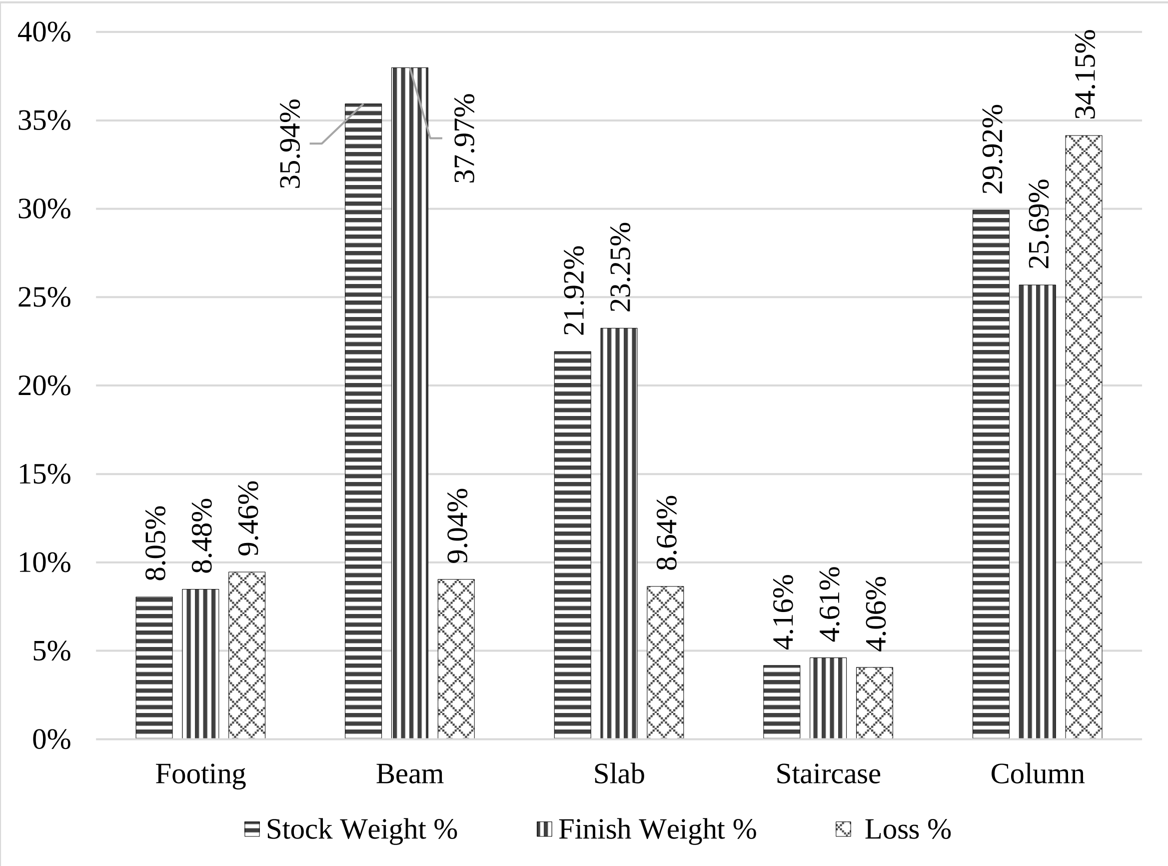

Figure 6: Cutting waste by structural component in 4-C-16

3.4.1 Embodied energy of rebar

The embodied energy associated with the quantity of rebar obtained from bar bending schedule is shown below in the Table 10.

Table 10: Embodied energy calculation of rebar in 4-C-16.

Embodied energy coefficient = 32.24 MJ/kg (Praseeda, et al., 2014)		
	Weight of Rebar (kg)	Embodied Energy (GJ)

Stock Weight (kg)	93365	3010.08
Finish Weight (kg)	81043	2612.82
Scrap/Off-cuts weight (kg)	12323	397.29

3.4.2 Cost rates for embodied carbon dioxide

Total embodied energy of off-cuts = 397.29 GJ

= 397.29 x 0.24 ton

= 95.35 ton

Environmental cost of the emission of one ton of CO_2 in 2022 =194.28 euros

Total environment cost of the emission of CO_2 = 95.35 x 194.28

= 18524.68 euros

3.5 Comparative analysis

Table 11 presents a comparison of the output for four different design types. From this comparison, it is observed that the highest rebar usage occurs in 4-C-16, followed by 3-C-12, 3-C-9, and 3-C-7, as the built-up area of 4-C-16 is the largest. The total cutting waste, including offcuts and scrap, is found to be the highest (15.21%) in 4-C-16. This is attributed to the use of 25 mm and 20 mm bars in the columns, as required by structural specifications, where stricter restrictions on lapping are imposed. The variation in rebar diameters across different floors and the limited space for lap splice positioning result in restricted lengths of 25 mm and 20 mm bars in columns, leading to longer offcuts in higher-diameter bars. If these offcuts cannot be utilized elsewhere, they are considered waste.

From the bar bending schedule for the 4-C-16 design type, it is identified that offcuts measuring 5040 mm in length, totaling 112 in number, are generated and remain unused, leading to the highest wastage of 25 mm bars. Similarly, offcuts measuring 5720 mm in length (104 in number) and 4810 mm in length (136 in number) are generated in 20 mm bars, contributing to significant wastage in column reinforcement. A similar pattern is observed in 3-C-7, where the cutting waste amounts to 12.49%. This design type is also a four-story building, incorporating 20 mm and 25 mm bars in its columns, further contributing to material wastage.

Similarly, both 3-C-9 and 3-C-12 are three-story buildings, with cutting waste observed at 13.43% and 11.52%, respectively. The higher ratio of wastage in 3-C-9 is attributed to design detailing in columns and beams. Based on the bar bending schedule, the percentage of offcuts in 20 mm bars is recorded as 52.30% in 3-C-9 and 36.5% in 3-C-12. As a result, the total wastage in 3-C-9 is nearly equivalent to that in 3-C-12, despite the built-up area of 3-C-12 being larger than that of 3-C-9.

The embodied energy and total environmental cost associated with rebar cutting waste are presented in the Table 11. The maximum environmental cost, calculated at €18,524, is obtained for 4-C-16. These values hold significant implications for project costs, particularly when such design types are constructed in large numbers by the government.

Table 11: Rebar usage, wastage, and embodied energy of type designs.

Type designs	3-C-12	3-C-9	3-C-7	4-C-16
Built-up area (sq.m)	824.4	648.12	556.51	1145.94
Typical floor plan	4 rooms	3 rooms	2 rooms	4 rooms
No. of storey	3	3	4	4
Building height (m)	13.55	13.55	13.55	16.55
Rebar usage (kg)	61346	49970	40748	81043
Cutting waste(kg)	7069	6711	5090	12323
Cutting waste (%)	11.52	13.43	12.49	15.21
Embodied energy of cutting waste (GJ)	227.9	216.36	164.1	397.29
Total environmental cost of emission of CO_2 due to cutting waste(euros/sq.m)	12.89	15.56	13.74	16.16

3.6 Data validation

From the findings the minimum and maximum rebar wastage are 11.52% and 15.21% respectively. From the literature it is known that the average rebar waste for educational buildings in Hong Kong is 9.01% (Shen & Tam, 2002) which suggest that the findings from this study is valid as the construction practice, design codes vary according to countries.

4. Conclusions

The assessment of structural rebar wastage reveals that key factors contributing to cutting waste include project size, design parameters (such as rebar size, lapping position, lap length, hook length, and floor height), and the level of awareness regarding bar bending schedules among designers. On-site, the most common sources of waste are design errors, poor handling and storage practices, substandard workmanship, residual cut-offs, and technical inaccuracies. Effective management of complex rebar work is essential to reduce wastage, as significant amounts of rebar can be saved through increased productivity. This can be achieved by aligning purchase orders, manufacturing, and installation processes with construction schedules and by preparing precise bar bending schedules to determine rebar details and optimal quantities. Government-implemented type designs (e.g., 3-C-12, 3-C-9, 3-C-7, and 4-C-16), used in constructing over 100 schools after the earthquake, could serve as exemplary cases. These efforts primarily emphasized structural stability through norms, codes, and policies. However, a critical gap remains in sustainable construction, energy conservation, and construction and demolition (C&D) waste management. Therefore, this research highlights the importance of assessing cutting waste to identify and implement reduction measures, as this is the most effective approach to achieving sustainable construction practices and efficient waste management.

Declaration of conflict of interest

The authors declare that there is no financial, professional, or personal conflict of interest that could influence the work reported in this paper.

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