The Development of a Web Application for Rebar Loss Optimization Using BIM Models

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Abstract

Reinforced concrete structures, prevalent in construction, face significant cost and environmental challenges due to reinforcement bar (rebar) waste, which can account for 16% of project costs and 8% of total construction waste. Conventional rebar cutting practices, which rely on manual engineering judgment, often fall short of minimizing rebar waste effectively. To overcome this issue, this study proposed a framework that integrates BIM models with an optimization technique to automate the generation of optimal rebar cutting schemes via a web application platform. Developed as a web application, the platform leverages a scalable cloud infrastructure on Amazon Web Services (AWS), facilitating the efficient extraction and processing of rebar detailing data directly from BIM, performing optimization calculations, and providing intuitive visualization of cutting scheme results in a dashboard. Validation was performed through a case study on a subway station project, where the system optimized rebar cutting for slab construction. The proposed approach achieved a significant reduction in rebar waste by 72.2% and a saving of 8.9% in total rebar stock procurement compared to conventional methods. Additionally, the cloud-based application enhances collaboration and decision-making by providing an intuitive platform for all project stakeholders, ensuring seamless integration between rebar detailing design and procurement.

Keywords: Rebar waste optimization; Building Information Modeling (BIM); Web application; Construction automation

1 Introduction

Reinforced concrete is a cornerstone of modern construction, yet the steel reinforcement bars (rebar) it requires represent a significant operational challenge. Rebar accounts for up to 16% of total project costs and 8% of construction waste, making efficient management a critical factor for project viability (Kim et al., 2004). Furthermore, with a high embodied CO_2 footprint compared to other materials, rebar waste reduction is not only an economic goal but an environmental imperative (Kwon et al., 2021). The primary source of this waste is the cutting process, where standard stock-length bars are cut into the various lengths required by structural designs. Traditionally, cutting plans are developed based on manual calculations and engineering judgment—a process that is often suboptimal and fails to guarantee minimal material loss. This inefficiency highlights the urgent need for a more sophisticated, automated approach to optimize rebar cutting.

This study addresses these challenges by presenting a novel framework that integrates Building Information Modelling (BIM) with a cloud-based optimization engine. We propose a web application built on a scalable cloud architecture on Amazon Web Services (AWS) that automates the generation of optimal rebar cutting plans directly from design data. This integrated system is designed to overcome the inflexibility and data discrepancies of conventional methods, creating a seamless and dynamic link between design, procurement, and fabrication. By leveraging this technology, we aim to enhance collaboration, improve decision-making, and deliver substantial reductions in both material waste and project costs.

2 Background

2.1 Rebar Cutting Stock Problem

The task of creating an optimal rebar cutting plan is a well-defined challenge known as the one-dimensional cutting stock problem (1D-CSP). In this problem, the objective is to determine how to cut a set of standard-length stock items (e.g., 12 m rebar) to yield a list of required piece lengths, all while minimizing the total waste or trim loss. A variety of mathematical and computational methods have been applied to the 1D-CSP, including rigorous techniques like Linear Programming and Integer Programming (Schrijver, 1998), as well as heuristic algorithms such as Genetic Algorithms (Salem et al., 2006) and Simulated Annealing (Porwal & Hewage, 2012), which are often used to find high-quality solutions more quickly.

2.2 Practical Gaps in Conventional Workflows

Despite the availability of these powerful optimization algorithms, their application in the construction industry is hindered by significant practical gaps in the conventional workflow:

- *Data Disconnection*: Optimization is typically performed as an isolated task, detached from the live design environment. When architectural or structural designs change, rebar schedules must be manually updated and re-submitted for optimization. This static, disjointed process is not only labour-intensive but also highly susceptible to errors and data inconsistencies.
- *Collaboration Friction*: The workflow often involves fragmented communication between designers, detailers, and fabricators. New cutting plans must be manually communicated to stakeholders after each design revision, creating delays and risking the use of outdated information on the fabrication floor.

These gaps reveal that an effective solution requires more than just an efficient algorithm; it demands a holistic system that integrates data, automates processes, and facilitates seamless collaboration among all project stakeholders.

3 Proposed Framework

To bridge the gaps identified above, we propose an integrated framework that establishes a cohesive, automated workflow from design to fabrication. The framework comprises four integral stages.

3.1 BIM-Based Rebar Design and Modeling

The process begins with the creation of a detailed, construction-ready rebar plan within a BIM environment. The BIM model acts as a single source of truth, centrally housing all critical design data, including rebar diameters, quantities, spacing, and precise 3D locations.

3.2 Automated Rebar Data Acquisition

Upon completion or modification of the design, all required rebar length and quantity data are automatically extracted from the BIM model and sorted by type. This automated acquisition eliminates manual data entry, prevents errors, and ensures that the optimization process is always based on the most current design information.

3.3 Cloud-Based Optimal Cutting Plan Generation

The extracted rebar data, along with a predefined catalog of available stock lengths, are sent to a web application for processing. The application leverages a cloud-hosted optimization engine to calculate the most efficient cutting patterns that satisfy the design demand. The resulting cutting plans are then presented in an intuitive, visual dashboard, making the complex data easily understandable for all stakeholders.

3.4 Results Filling for Fabrication

The optimized cutting plans are generated in a format directly usable for fabrication. A core advantage of this integrated framework is its dynamic nature. Any design modification within the BIM model automatically triggers a data update, ensuring that the generated cutting plan always reflects the latest design intent. This eliminates information discrepancies and aligns fabrication with the current project status.

4 Prototype Development

To validate the proposed framework, a functional prototype was developed using modern software and cloud technologies.

4.1 BIM model

The prototype utilizes Autodesk Revit® (Autodesk, 2024) to create 3D rebar models with a high level of detail (LOD), including specifications for lap splice lengths and locations. This level of detail ensures that 2D construction drawings are dynamically synchronized with the 3D model. Consequently, any modification to the 3D model is automatically propagated to all relevant 2D drawings, streamlining the design revision process and creating a consistent data pipeline from design through fabrication.

4.2 Optimization Algorithm

The rebar cutting plan is formulated as a 1D-CSP and solved using an Integer Programming model. The model's objective is to minimize trim loss subject to constraints that ensure all required rebar pieces are cut from the available stock lengths. For the implementation, we integrated Google OR-Tools (Google, 2025), a powerful and open-source software suite that provides a robust IP optimization solver.

4.3 System Configuration

The prototype's system architecture, shown in Figure 1, is built on Amazon Web Services (AWS) for scalability and operational simplicity.

- The frontend is a web application for data submission and results visualization, hosted on an Amazon EC2 instance.
- The backend logic is powered by AWS Lambda, a serverless compute service. Rebar data can be submitted in two ways: by uploading a file to an Amazon S3 bucket, which triggers the Lambda function, or by sending a data payload directly to a RESTful API managed by Amazon API Gateway.
- The Lambda function executes the optimization using the Google OR-Tools library and stores the results.
- For visualization, Amazon QuickSight is used to create interactive dashboards from the optimization results. These dashboards are embedded directly into the frontend web application, providing a seamless user experience.

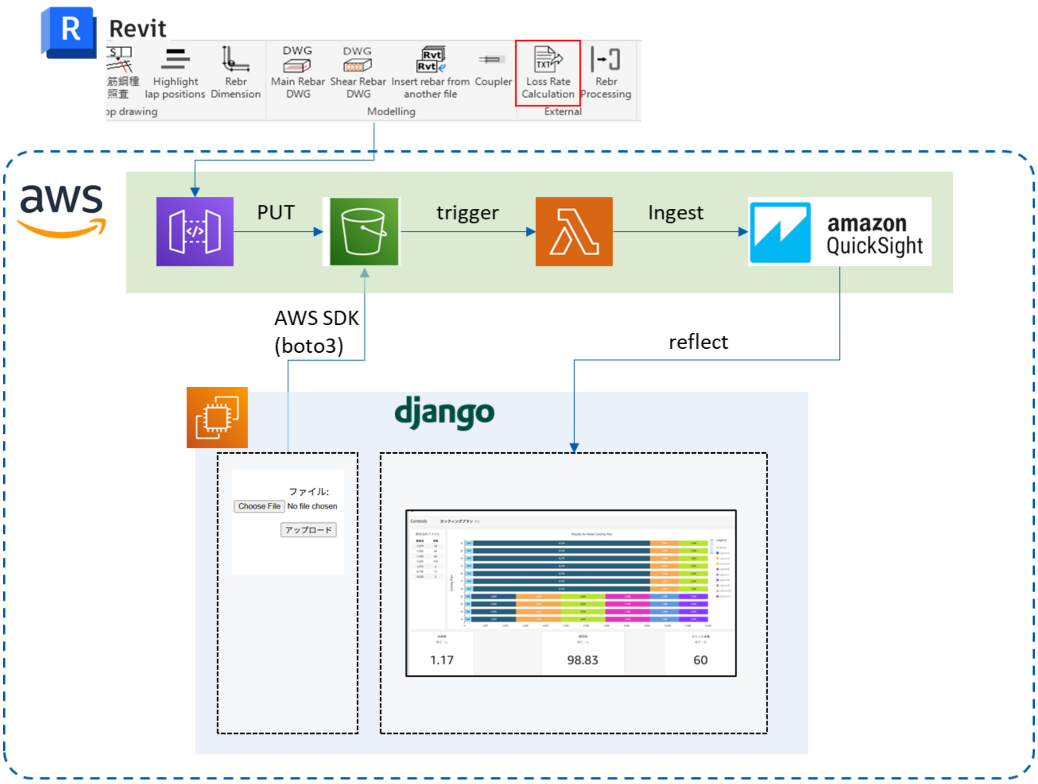


Figure 1. overall system configuration of a prototype development

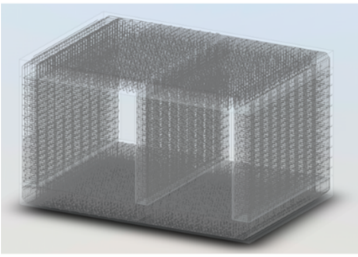
Additionally, a custom Revit add-in was developed using the Revit SDK. This tool allows users to select elements within their BIM model, extract the relevant rebar metadata, and send it directly to the backend API for optimization, further automating the data pipeline. This serverless, cloud-native architecture provides a streamlined and highly scalable solution for the acquisition, optimization, and visualization of rebar cutting plans.

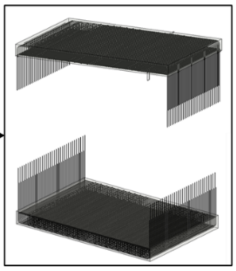
5 CASE STUDY

To validate the proposed framework and quantify its benefits, a case study was conducted on a construction-level BIM model of a box culvert structure.

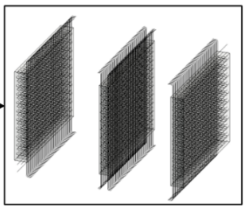
5.1 Target BIM model

The custom Revit add-in, described in Section 4.3, was used to test the system's end-to-end functionality. Rebar data for the structure's wall and slab components were extracted separately based on the user's selection of the host element. The add-in automatically compiled the required length and quantity information for all rebar instances (diameters D16, D19, and D22) and transmitted this data via an API POST request directly to the web application's backend. The optimization engine was configured to use a standard 12-meter stock length, reflecting common material availability in the market. This process successfully demonstrated a seamless, automated pipeline from a live BIM design environment to the optimization engine. Figure 2 illustrates the target BIM model as well as its host element-based input rebar data used for the subsequent evaluation process.





Slab (Top & Bottom)					
D22		D19		D16	
Length (mm)	Quantity	Length (mm)	Quantity	Length (mm)	Quantity
11964	209	5826	26	11974	65
11673	3	4448	26	9148	14
9450	31			9134	3
6207	93			6141	1721
5793	93			5859	1721
5214	93			4084	527
4466	15			3986	96
1948	29			3307	62
				2082	1107



Wall (Side & Middle)					
D22		D19		D16	
Length (mm)	Quantity	Length (mm)	Quantity	Length (mm)	Quantity
11964	210	4626	28	11988	95
7757	93	4448	28	11974	76
4243	93			11489	76
6700	20			7191	1826
5214	93			4809	1718
				4081	1826

Figure 2. A summary of input rebar data from slab and wall host elements

5.2 Performance Evaluation and Discussion

The efficacy of the optimization program was evaluated by comparing its results against a benchmark derived from a conventional, manual calculation method using Microsoft Excel. The comparison was based on three key performance indicators (KPIs): **material loss rate (%)**, **total amount of waste (m)**, and **total required stock (No. of bars)**. The overall results revealed a profound improvement over the manual method. As is shown in Table 1, the optimization program achieved a **72.2% reduction in total waste** (from 15,485 m down to 4,290 m) and an **8.9% decrease in the total required stock** (from

10,867 bars to 9,899 bars). A detailed analysis of the structural components provides insight into these aggregate figures.

For the **slab component**, the program delivered modest but consistent gains. For example, the loss rate for D22 rebar was reduced from 1.80% to 1.73%, and for D16, it fell from 1.49% to 1.26%. This demonstrates that even in scenarios of moderate complexity, the algorithm consistently identifies more efficient cutting patterns than manual planning, yielding valuable material savings.

Table 1. Comparison of cutting optimization results

Slab (Top & Bottom)						
	Excel Calculation			**Optimization Program**		
	loss rate (%)	**Σamount of waste (m)**	**Σstock required (No.)**	**loss rate (%)**	**Σamount of waste (m)**	**Σstock required (No.)**
D22	1.80%	134.3	621	1.73%	129.1	621
D19	8.62%	40.3	39	8.62%	40.4	39
D16	1.49%	692.4	3880	1.26%	587.1	3879
Wall (Side & Middle)						
	Excel Calculation			**Optimization Program**		
	loss rate (%)	**Σamount of waste (m)**	**Σstock required (No.)**	**loss rate (%)**	**Σamount of waste (m)**	**Σstock required (No.)**
D22	1.01%	72.6	600	1.01%	72.7	600
D19	8.62%	43.4	42	8.62%	43.5	42
D16	21.26%	14502.1	5685	6.04%	3417.5	4718
Total amount of waste (m)		15485			4290	
Total count of rebar stock			10867			9899
reduction in waste production (%)		(15485-4290) / 15485 = **72.2%**				
reduction in rebar stock procurement (%)		(10867-9899) / 10867 = **8.9%**				

The most dramatic improvements, however, were observed in the **wall component**, particularly for the **D16 rebar**. The manual Excel method resulted in an exceptionally high loss rate of **21.26%**, generating over 14,500 m of waste. In stark contrast, our optimization program slashed the loss rate to just **6.04%**, saving over 11,000 m of material and reducing the required stock by nearly 1,000 bars for this single category. This stark discrepancy highlights the critical failure point of manual methods when confronted with high combinatorial complexity. The large volume and diverse lengths of D16 rebar in the wall created a problem that was simply intractable for human-driven, heuristic approaches. The optimization algorithm, designed specifically to navigate this vast solution space, successfully unlocked efficiencies that would otherwise be impossible to find.

In conclusion, the case study validates that the proposed BIM-integrated framework not only functions as designed but also delivers substantial and quantifiable benefits. The results confirm that the value of such an automated system scales with project complexity, providing the most significant economic and environmental advantages in the very scenarios where they are most needed.

6 CONCLUSION

This study successfully demonstrates that a BIM-integrated, cloud-based framework can provide a comprehensive and effective solution for the rebar cutting stock problem, overcoming the limitations of conventional manual methods. We proposed and validated a holistic system that creates a seamless, automated workflow from the design phase to fabrication, addressing the critical gaps of data disconnection and collaboration friction. The framework, powered by a robust IP optimization algorithm and hosted on a scalable, serverless cloud architecture, consistently identifies optimal cutting patterns that are unachievable through human-driven calculations.

The case study provided compelling quantitative evidence of the framework's tangible benefits. The system delivered a **72.2% reduction in material waste** and a **nearly 9% decrease in total required stock** compared to a manual, spreadsheet-based method. These results confirm that the value of such an automated approach scales with complexity, yielding the most dramatic improvements in high-volume, combinatorially challenging scenarios.

This research contributes a validated, end-to-end solution that not only streamlines the rebar fabrication process but also promotes a more sustainable and economically viable construction practice. The automation of data extraction, coupled with the dynamic nature of the system, ensures that fabrication plans are always aligned with the latest design changes, thereby improving collaboration and reducing costly errors. By bridging the gap between design and fabrication through an integrated digital pipeline, this work paves the way for a more intelligent, efficient, and waste-conscious future for the construction industry.

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