Prototype development of an automated 3D shop drawing generation tool for reinforcement work

Kanae Miyaoka[1], Fumiya Matsushita[1] and Kazumasa Ozawa[1]

[1]School of Engineering, University of Tokyo, Japan
miyaoka@i-con.t.u-tokyo.ac.jp, matsushita@i-con.t.u-tokyo.ac.jp, ozawa@i-con.t.u-tokyo.ac.jp

Abstract –

In concrete structure projects, activities such as drawing, fabrication, and assembly related to the reinforcement substantially impact the schedules and costs. It is necessary to apply building information modeling (BIM) to smoothly share and distribute information regarding reinforcement among the diverse range of suppliers to streamline work.

This study aims to establish a BIM-based rebar information linkage system applicable across the reinforcement work supply chain. The paper reports on the prototype development and trial of an automated 3D shop drawing generation tool, which is one of the essential tools in the system. Through a trial conducted in a subway station construction project, it was validated that the tool led significant reductions in labor costs and timesaving compared with the conventional 2D-based drawing method. As future work, it will be necessary to define an information model for rebar in order to build a system that can promote information sharing and coordination across the supplier network during the construction phase.

Keywords –

BIM; Concrete reinforcement; Parametric modeling; Shop drawing

1 Introduction

Building information modeling (BIM) is a system designed to enhance the efficiency and sophistication of construction production and management. It achieves this by introducing 3D models from the planning and design stages and linking and developing these models throughout the construction and maintenance. This facilitates information sharing among the project stakeholders. BIM adoption for concrete structures is increasing rapidly, extending to large-scale infrastructure in civil engineering (e.g. railroads, highways, and bridges) [1] [2] [3]. In infrastructure projects, activities related to reinforcement (such as drawing, fabrication, and assembly) significantly impact the schedules and costs. Given the diverse range of suppliers involved, including contractors, subcontractors, and manufacturers, coordination is crucial for project execution. The use of BIM is likely to streamline this process.

However, notwithstanding the increasing adoption of BIM, only approximately 30% of users frequently model reinforcement elements [4]. This leaves scope for improvement in 3D modeling for reinforcement. Past applications of 3D rebar models include evaluations of interference, enhancement visibility for client–contractor agreements [5], quantity calculations [6] and generation of input data for rebar processing machines [7]. However, these applications are task specific. Moreover, research focused on improving efficiency throughout the supply chain is insufficient.

This study aimed to establish a BIM-based rebar information linkage system applicable across the rebar construction supply chain. This paper reports the development and trial of an automated 3D shop drawing generation tool.

2 Overview of BIM-based rebar information linkage system

2.1 Processes of conventional reinforcement work

Figure 1 illustrates conventional reinforcement work processes and the suppliers involved in the construction phase. The initial step in this phase is the generation of shop drawings that provide detailed information regarding the rebar, such as its shape, specifications, joint locations, and placement. These drawings also include section/plan drawings and bar bending schedules. Shop drawings are generated from technical drawings, considering construction plan elements such as temporary openings and beams. During the procurement stage, the contractor produces a rebar order sheet based on the bar bending schedules and sends it to the manufacturer. The manufacturer inputs this

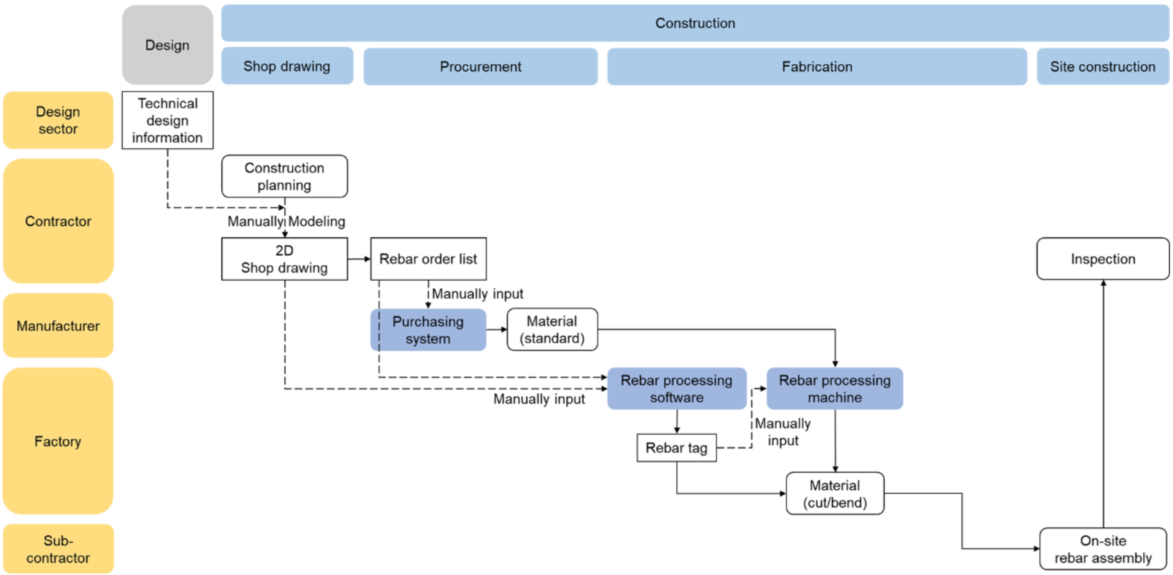


Figure 1. Conventional reinforcement work processes and the suppliers involved.

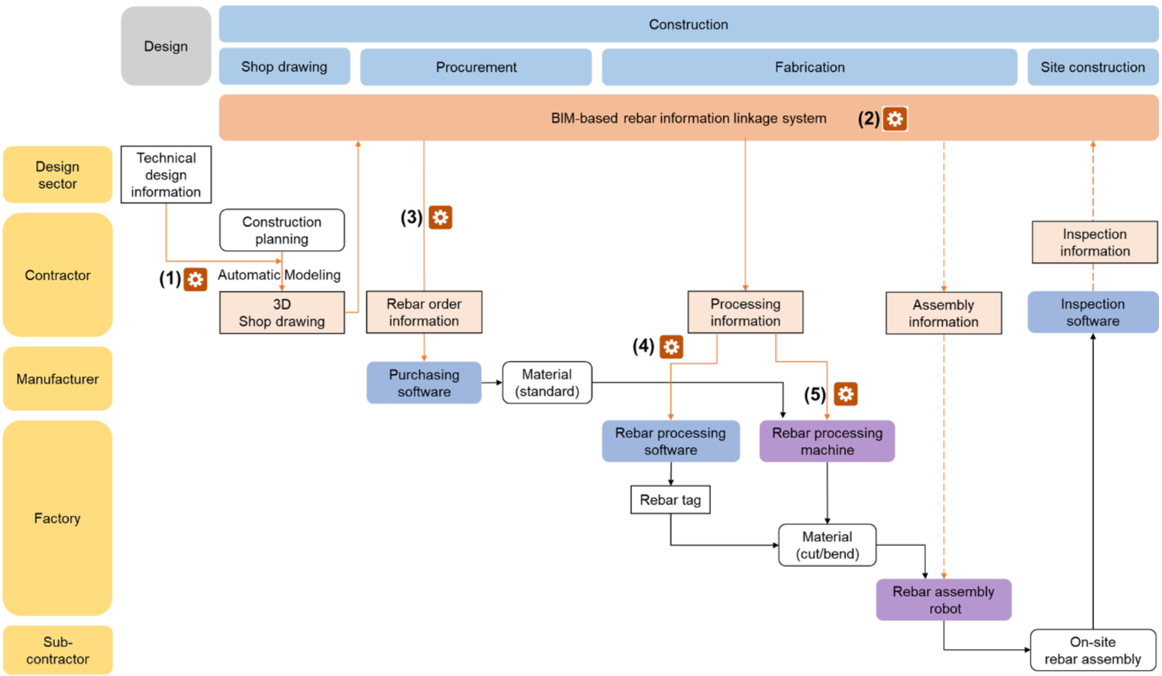


Figure 2. Overview of the BIM-based rebar information linkage system

information into the purchase system. In the fabrication stage, the rebar is cut and fabricated at the factory of the manufacturer or subcontractor. The processing-information management software at the factory receives details from the rebar order sheet and shop drawings and generates rebar processing tags for each processing line. Machine operators use these tags to process rebars. The recent introduction of automatic processing machines requires manual data input through touch panels. After processing, the materials are delivered to the construction site, inspected, and accepted. Subsequently, a subcontractor assembles the rebar. This is followed by an inspection by the prime contractor.

Conventional workflows encounter several challenges. First, generating and revising shop drawings is labor-intensive and vulnerable to errors owing to the frequent revisions based on modifications in the construction plan. Second, the communication between suppliers relies significantly on documents such as 2D drawings and order sheets. This results in inefficient information transfer between processes. Manually entering data into the purchasing and processing information management software further contributes to time-consuming processes. Third, the significant personnel requirements for rebar processing at factories and assembly sites, particularly in the large civil engineering field, pose a key obstruction in the overall process.

2.2 Overview of the proposed BIM-based rebar information linkage system

Figure 2 presents an overview of the BIM-based rebar information linkage system proposed in this study. Table 1 outlines the challenges in the conventional work process, in conjunction with the corresponding requirements and development items essential for resolving these issues.

The proposed system provides a user-friendly tool for generating 3D shop drawings (development item (1)). To effectively distribute and utilize information from these drawings in subsequent operations, it is necessary to define an information model to manage the rebar information (development item (2)). In the construction sector, information is organized along project timelines to facilitate the exchange of information between stakeholders and applications. A representative standard, ISO 12006-2, defines a framework for construction-sector classification systems and identifies a set of recommended classification tables and their titles for a range of construction object classes [8]. Based on ISO 12006-2, countries have introduced classification systems such as Uniclass-2015 and OmniClass [9]. There is various modeling software that handle rebar models and different applications used depending on the timeline of the work. However, by defining the information model for rebar, it is possible to exchange information among the parties and applications involved. Additionally, tools would be developed to extract and link the required information to various software applications such as purchasing systems and rebar processing information management software (development items (3) and (4)). Furthermore, enabling data linkage with machines such as rebar bending machines (development item (5)) and rebar assembly robots would expedite prefabrication in factories. This would reduce the labor required for processing and assembly. This research is also working actively on the data linkage represented by the solid line in Figure 2, with a forward-looking perspective on future connections between the rebar assembly robots and inspection systems indicated by the dotted line.

Table 1. Requirements and development items

Challenges	Requirements	Dev. item
Preparation of shop drawing	Convenient generation and modification of 3D shop drawing.	(1)
Information sharing	Sharing of rebar information across suppliers and distribution among software programs.	(2)
	Extraction and linkage of input data of each software program from 3D shop drawings.	(3) (4)
Processing and assembly work	Extraction and linkage of input data of machines such as processing machines to achieve pre-fabrication.	(5)

3 Prototype development of an automated 3D shop drawing generation tool

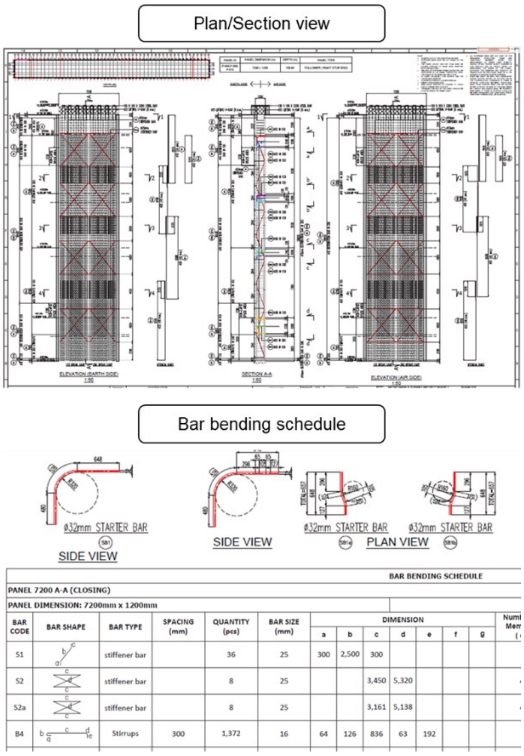
This paper presents a report on an automated 3D shop drawing generation tool. It is essential in this system. This chapter details the development of the tool. The next chapter presents its implementation and a verification of its effectiveness.

3.1 Previous studies and issues

In the conventional approach to generating shop drawings, designers convey the necessary information by incorporating it into basic design drawings. The CAD operators manually produce 2D shop drawings based on this information. These drawings encompass various elements such as the section/plan view drawings and bar-bending schedules for each construction block or pattern (see Figure 3). Frequent revisions are necessary because of the influence of construction plans, such as the placement of temporary structures and construction methods. Moreover, because shop drawings convey intricate rebar details, errors are likely to occur during drafting. The adoption of 3D models for rebar shop drawings effectively mitigates these challenges.

Existing technology enables the extraction of 2D drawings from 3D models, a feature implemented in software programs such as Revit [10] and Rhinoceros [11] (see Figure 4 (1)). When the construction plan undergoes alteration, modification of the 3D models automatically updates the linked 2D drawings.

However, the generation of 3D shop drawings poses several challenges. The complexity of drawings makes the modeling process time-consuming. Moreover, the quality depends on the skills of the BIM operator. Parametric modeling has emerged as an efficient technique for addressing these challenges. The method involves defining the dimensions and parameters in advance. This enables the generation and modification of 3D models by entering variable values. Unlike direct modeling, in which the operator manually draws the model irrespective of the operator's skills, the parameters and constraints should be considered effectively. Although certain automatic rebar placement functions exist in 3D modeling software such as Revit that use parametric modeling [12] [13], their user-configurable parameters are limited to basic design information (rebar diameter, length, rebar shape, spacing). Although there are examples of the application of parametric modeling to building structures and the rebar in previous studies [14] [15], it is difficult to model rebar to reflect the detailed information contained in the shop drawings, such as the type and location of rebar joints, changes in spacing, and arrangement of setup bars (see Figure 4 (2)). Given these considerations, there is a need to develop parametric modeling tools capable of handling the intricate reinforcement information available in shop drawings. This would ultimately facilitate the efficient generation of 3D shop drawings.



BAR BENDING SCHEDULE													
PANEL 7200 A-A (CLOSING)													
PANEL DIMENSION: 7200mm x 1200mm													
BAR CODE	BAR SHAPE	BAR TYPE	SPACING (mm)	QUANTITY (pcs)	BAR SIZE (mm)	DIMENSION a	b	c	d	e	f	g	Num Mem
S1		stiffener bar		36	25	300	2,500	300					
S2		stiffener bar		8	25			3,450	5,320				
S2a		stiffener bar		8	25			3,161	5,138				
B4		Stirrups	300	1,372	16	64	126	836	63	192			

Figure 3. Examples of shop drawing

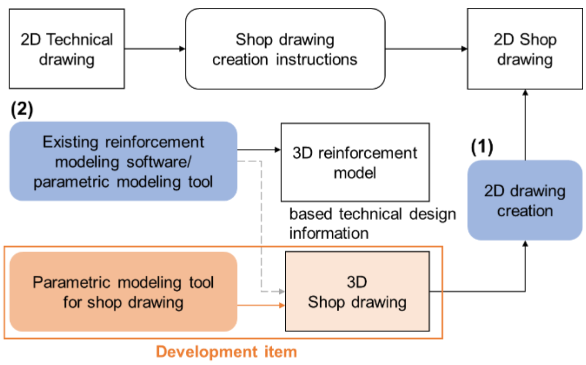


Figure 4. Existing technology and development item

3.2 Strategy to develop the tool

Figure 5 presents an overview of the automated 3D shop drawing generation tool. The tool leverages Revit for 3D modeling and Grasshopper (a plug-in compatible with Rhinoceros) for parametric modeling. The initial step involves preparing a 3D model outlining the basic concrete structure frame (referred to as the "concrete body model") using basic design information. In step 2, the parameter data for the shop drawings of the targeted

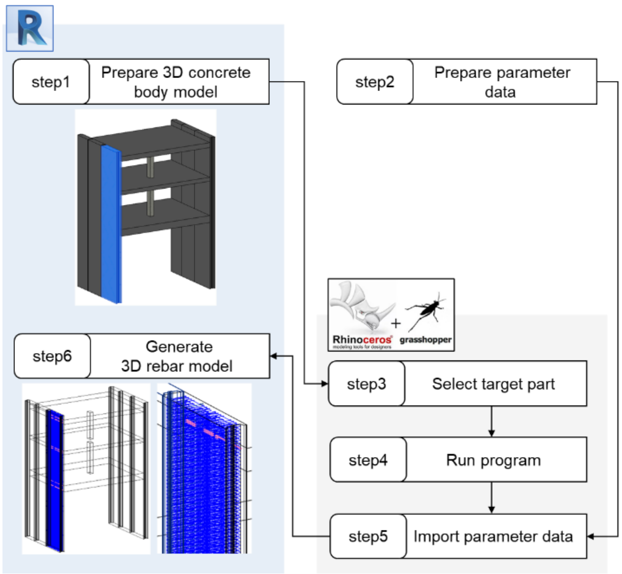


Figure 5. Overview of the developed tool

part is created. Details of the parameter data are explained in the next section. After that, a program for automated 3D shop drawing generation is opened on Grasshopper, and the target part is selected (step 3). Then, when the program is executed, the prepared parameter data is read (step 4 and 5), and a 3D rebar model is generated in Revit according to the parameter data (step6).

3.3 Prototype development

In this study, a prototype tool was developed for a subway station. The development process began by referencing 2D shop drawings from previous subway station projects and identifying the necessary parameters for modeling. An example of the parameter data for a wall (specifically a diaphragm wall) is presented in Table 2. The first line represents the fixed parameter, whereas the numerical values are entered by the user in the second line and beyond. As emphasized in Section 3.1, effective parameter settings are crucial for tool development. The parameters were configured to enable the model to convey shop drawing-specific information including the rebar cover in planes and sections, rebar shapes, joint locations and specifications, and arrangements of the set-up bars. Separate parameter data were established for each rebar type (main bar, reinforcement bar, shear reinforcement bar, etc.). The data were formatted as a CSV file.

Subsequently, a program for generating a 3D rebar model in Revit was constructed using Grasshopper. An example of the Grasshopper program is shown in Figure 6. The program includes buttons for generating models for each rebar type. When a button is pressed and the program executed, it reads the parameter data stored in the specified path folder and generates a 3D model in Revit. Testing of the developed tool using sample data verified the seamless generation of the 3D model in Revit, as depicted in Figure 7.

Additionally, a comparison between the parameters of the generated 3D rebar model and the input values from the parameter data in the CSV verified that the rebar was modeled accurately based on the specified parameter data values, as shown in Figure 8.

Table 2. Example of parameter data

name	z	xoffset	yoffset	shape code	Dia.	…
mainbar1	100	50	100	00	22	…
mainbar2	100	1600	100	01	19	…
mainbar3	…	…	…	…	…	…

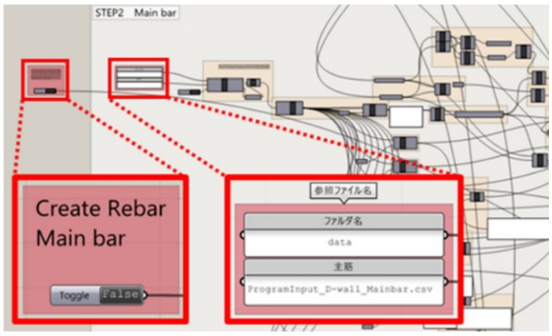


Figure 6. Example of Grasshopper program

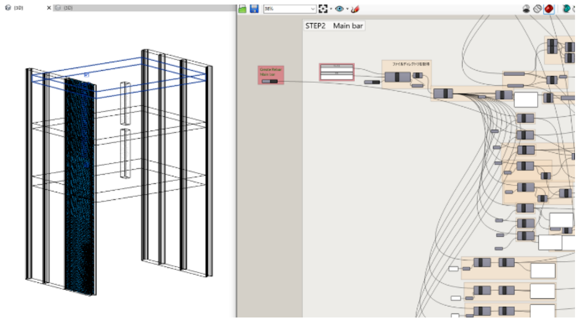


Figure 7. Screen during model creation

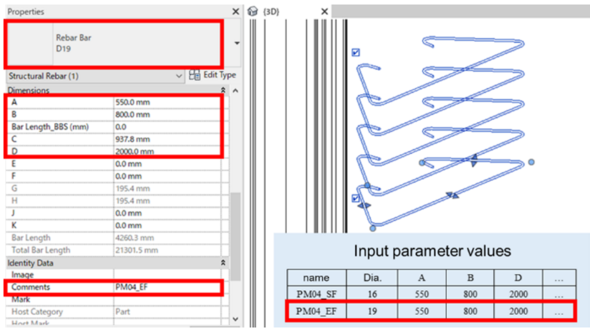


Figure 8. 3D model parameters and CSV input values

4 Trial of the developed tool and verification on effect

4.1 Trial of the developed tool

The developed tool underwent a trial run in a project involving the construction of three subway stations and connecting tunnels. The aim here was to elucidate the workflow involved in using the tool and validate its effectiveness in the context of the project. Specifically, the tool was employed to generate shop drawings of a diaphragm wall.

The workflow during the implementation of the development tool is shown in Figure 9. This sequence

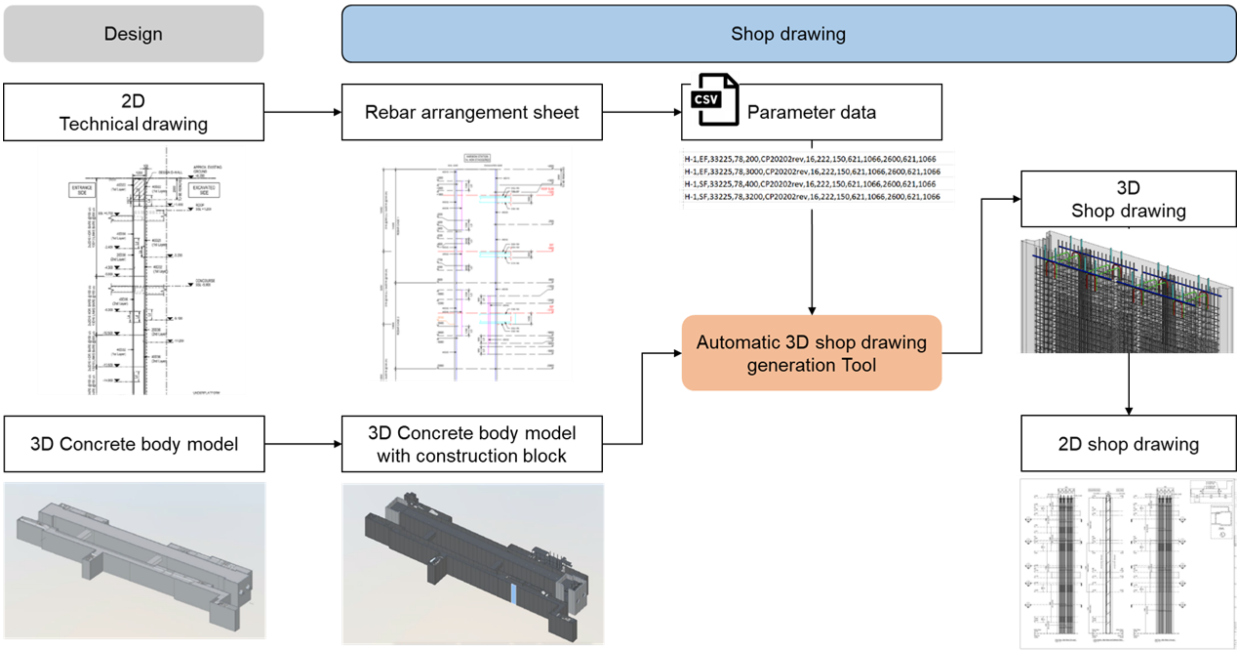


Figure 9. The workflow during the implementation of the development tool

was developed based on the activities of the shop drawing generation team involved in the subject project. It reveals the various steps preceding the preparation of the input data for the development tool (comprising the concrete body model and parameter data). The shop drawing generation team initially received 2D technical drawings from the design department. It was challenging to translate these directly into parametric data. To address this issue, a rebar arrangement sheet for each panel was first generated by extracting pertinent information from technical drawings. The rebar arrangement sheet includes essential details for shop drawings, such as the diameter, spacing, number of rebars, rebar shape, and joint locations and specifications. Subsequently, the parameter data to be imported into the tool were obtained from the information within the rebar arrangement sheet and cross-sectional drawings. With regard to the concrete body model, the 3D model obtained from the design department integrates various members such as walls and slabs. Consequently, during the shop drawing stage, it is necessary to segment the model into construction blocks. Following this process, 3D shop drawings were generated using the developed tool, and 2D shop drawings were extracted manually from the 3D model.

4.2 Validation on effects

Table 3 compares the work required to generate conventional 2D shop drawings and the utilization of the developed tool. The table reveals a labor reduction of 1.5/h/panel for the underground continuous wall when employing the developed tool, compared with the conventional method. With the construction project involving modeling of approximately 100 panels per station, the estimated cost savings amounted to approximately USD 52,500.00 per station (refer to Table 4). It is noteworthy that although the 2D drawings were extracted manually from the 3D model in this trial, the potential introduction of software functions to this process is likely to further decrease the workload.

Table 3. Comparison of the work required for a panel of diaphragm wall

Conventional 2D method		Method using the developed tool	
Instructions for CAD operator		Generating rebar arrangement sheet	1 day
2D drawing		Generating CSV parameter data	1 h
		3D model generation	5 min
		Generating 2D drawing from 3D model	4 h
total	3 days	total	1.5 days

Table 4. Cost effectiveness of the tool

Items	Effects
(1) Productivity-effect	1.5 day/panel
(2) Number of panels	100 panels/station
(3) Average cost of BIM operator	USD 350/day
Cost-effective: (1) × (2) × (3)	USD 52,500/station

5 Conclusion

This paper presents the development and trial of an automated 3D shop drawing generation tool as a component of a BIM-based rebar information linkage system during the construction phase. By incorporating the detailed information of the shop drawings into the parameter data, the tool succeeded in parametrically and automatically modeling the 3D shop drawings. A demonstration on a subway station construction project revealed that applying this tool can significantly reduce labor costs compared to traditional 2D-based drafting method. The ultimate goal is to establish a comprehensive system that seamlessly connects information on reinforcement arrangements during the construction stage. As future work, the linkage of rebar information will be focused. Particularly crucial in this endeavor is the consideration of an information model that is essential for facilitating the sharing and coordination of information across an entire supplier network. As noted in 2.2, the development of an information model allows for the integration of various BIM software and information processing applications. In order to increase the robustness of the proposed system, an information model will be developed with reference to the existing information classification system.

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