Planning of Formwork Accessories in a BIM-based Aluminum Formwork Layout Planning System

Guan-Yong Xiong[1], Tzong-Hann Wu[1], Shang-Hsien Hsieh[1], Kuan-Yi Chen[1], Budy Setiawan[2], and Wen-Tung Chang[2]

[1]Department of Civil Engineering, National Taiwan University, Taiwan
[2]FBC Formworks System Co., Ltd., Taiwan
percy948@gmail.com, tzonghannwu@ntu.edu.tw, shhsieh@ntu.edu.tw, ian890711@gmail.com, huangwenren88@gmail.com, tonylook@ms52.hinet.net

Abstract –

Formwork accessory planning plays an important role in fastening and supporting the formwork panels for construction safety. This research aims to improve the automation of formwork accessory planning of a BIM-based aluminum formwork layout planning system currently developed at the National Taiwan University for automating the layout planning of formwork panels. It has been proven to save engineers time in conducting formwork panel planning in several case studies. However, the engineers still need to spend a lot of time conducting formwork accessories planning manually in the system. Therefore, this research proposes an approach based on accessories planning rules to support automation for engineers in conducting prop generation, brace planning, waler planning, double waler planning, and quantity estimation of the accessories including waler bracket, pull tie, wedge, and pin. The case study result shows that the proposed approach can save engineers 87.5% of the time compared to the original process of conducting formwork accessory planning.

Keywords –

Planning Automation; Formwork Accessories; Aluminum Formwork Planning System; Building Information Modeling

1 Introduction

The aluminum formwork system represents a significant advancement in construction technology and offers many benefits compared to the traditional timber formwork system. Notably, the stiffness of the aluminum formwork system surpasses that of the timber formwork system, providing a more robust and stable structure [1]. Moreover, the aluminum formwork system has longer durability, enabling multiple reuses and reducing the overall cost of construction [2]. Easily installing and dismantling aluminum formworks also contributes to time efficiency, a critical factor in construction sites. Furthermore, the smooth surface of the aluminum formwork system often results in superior surface finishes on concrete structures, requiring no additional surface treatment. This advantage enhances the aesthetic and functional quality of the final product.

To fully use the advantages above, the implementation of the aluminum formwork system requires precise pre-planning, which is a time-consuming process for engineers. This formwork planning process includes panel planning and accessory planning. This research is focused on improving the automation of formwork accessory planning. The accessories play a crucial role in supporting and stabilizing the formwork, preventing significant displacement or even collapse during the concrete pouring process. Accessory planning must consider the type, size, and quantity of accessories, as well as their configuration. The primary objective of accessory planning is to ensure the stability and safety of the formwork system while optimizing construction efficiency.

However, few researches aimed at automating the accessory planning process. Furthermore, the prevailing practice in formwork accessory planning largely remains a manual endeavour, with engineers dedicating considerable time and resources to the task. This reflects a notable gap in automation, a fact underscored by the industry's reliance on traditional methods and the corresponding absence of advanced technological integration in this area. This lack of automation in the accessory planning process motivated the authors to propose a semi-automatic approach for the configuration and quantity estimation of accessories after the panel planning process. This approach is implemented in a BIM-based aluminum formwork layout planning system [3]. The proposed semi-automatic approach includes prop generation, brace planning, waler planning, double waler planning, and quantity estimation of the accessories including waler bracket, pull tie, wedge, and pin.

This paper presents the literature review in Section 2, the detail of the proposed approach in Section 3, the result and discussion from a case study in Section 4, and the conclusions in Section 5.

2 Literature Review

The authors reviewed research related to the advancements in formwork planning automation, specifically focusing on the integration of BIM technologies. Hyun et al. [4] initiated the automation in formwork design using spatial analysis of BIM. Lee et al. [5] developed prototype software for automating 3D layout planning of formwork using BIM data. Chen et al. [3] introduced a BIM-based approach that combines a semi-automated generation module with a manual refinement module. These studies contribute to automating formwork planning, particularly in panel planning.

From the literature review, the authors noted that current research on formwork planning automation primarily emphasizes panel planning rather than accessory planning. However, formwork accessory planning also takes considerable time. Therefore, this research aims to automate accessory planning to address this gap. The following section outlines the approach proposed for automating accessory planning.

3 The Proposed Approach

The authors interviewed formwork accessory planning engineers to realize their planning principles and rules. Then the authors aimed to obtain the required information for planning automatically from a BIM model and manual inputs. Finally proposed a semi-automatic formwork accessory planning approach. The proposed approach consists of two parts: accessory planning and accessory quantity estimation. The first part focuses on arranging various accessories integral to the formwork system, such as props, braces, walers, and double walers. Figure 1 illustrates the placement of the accessories. The second part estimates the quantity of wedges, pins, pull ties, and waler brackets. The arrangement aims to provide clear guidance to construction workers on accessories placement for construction efficiency. Quantity estimation serves to accurately determine the quantity of accessories needed, preventing extra transportation and management costs from secondary production. Also, it minimizes waste resulting from overestimation.

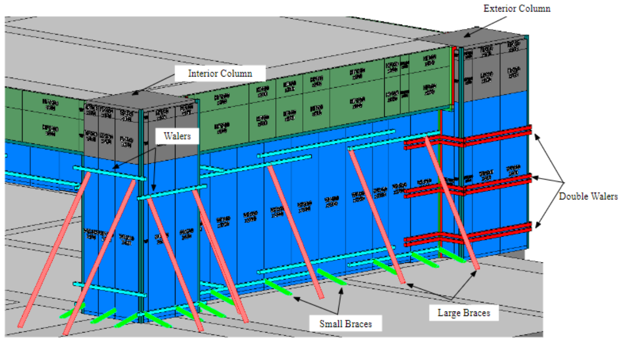

Figure 1: The placement of accessories.

To appropriately place accessories, we extract BIM parameters such as dimensions, locations, and orientations from formwork or structural components as the basis for our analysis. For example, to position a waler on a panel, we first need to obtain the panel's dimension and location information to determine the waler's placement and size.

Figure 2 outlines a sequential process for accessory planning. Double waler planning occurs after waler placement, as the positioning of double walers depends on the walers' locations. After positioning walers and double walers, we calculate waler bracket numbers and place braces, ensuring large braces align with waler positions. Consequently, we perform pin and waler bracket estimations, paving the way for the calculation of the wedge requirements. This systematic approach ensures each component is accurately placed and quantified, maintaining the integrity of the formwork system.

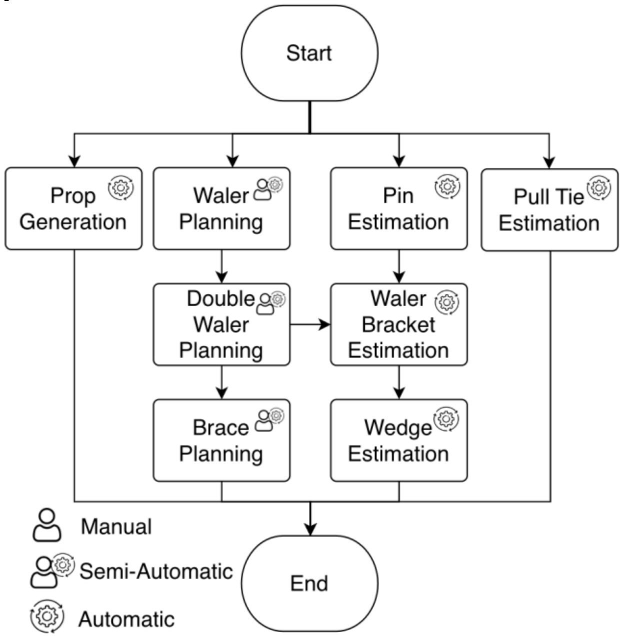

Figure 2: The flowchart for the proposed approach.

3.1 Accessory Planning

The proposed approach leverages Building Information Modeling (BIM) technology to automate the planning of formwork accessories, including props, braces, walers, and double walers. By extracting and analyzing parameters from BIM components, such as location, dimensions, and elevation, the system plans the positioning and estimates the quantities of the necessary accessories. This process ensures that all elements are appropriately arranged and quantified based on precise data extracted from the BIM model, minimizing manual intervention and enhancing construction efficiency. The subsequent sections will delve into the specifics of how the approach utilizes BIM parameters for comprehensive accessory planning and quantity estimation, showcasing the method's reliance on accurate BIM data to inform and streamline the planning process.

3.1.1 Prop Generation

A prop is a vertically adjustable support. It would be placed beneath a panel called PB (Beam Prop Head). The prop generation of this research builds upon a previous study [3], which only focuses on the generation of props. In this research, we further calculate props' heights and categorize them into groups based on their application purposes. Some props are designed to directly support the floor, while others are positioned on the windowsill, as shown in Figure 3. The actual height requirement for a prop is determined by subtracting the elevation of the underlying object from the PB elevation. Basically, props are entirely dependent on the PB and remain fixed in their positions during accessory planning. Therefore, we place props first in the planning process, ensuring they serve as references for conflict checks. When other accessories are introduced, they must be carefully placed to avoid any conflicts with the props.

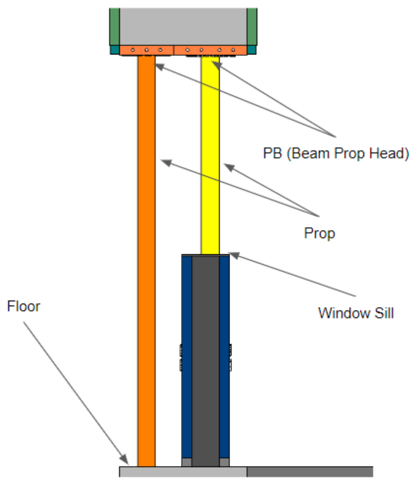

Figure 3: Props configuration.

3.1.2 Waler Planning

A waler is a square and elongated tube placed across several templates and secured by a waler bracket. Its purpose is to ensure the linearity and smoothness of the wall template after concrete pouring. The waler is configured on the wall formwork and the column formwork is located inside the building.

The planning rules of the waler are as follows:

- Adjacent walers need to be staggered and overlapped with a specific length determined by engineers.
- Walers come in standard sizes, e.g. L1, L2, L3, etc.

When planning the waler, the user needs to select all the formworks to be configured, and the software system will first group the formworks. Formworks that are connected along a horizontal line are grouped. Then, the waler is configured according to the total length of the formwork.

There are two types of formwork combinations. The first type is a panel combination in which the total length is greater than the longest standard length of a waler. In this situation, the longest possible waler is given priority in placement. The placement of the walers is staggered at two different heights. Moreover, the overlap of the two staggered walers needs to be larger than the specific length decided by engineers, as shown in Figure 4.

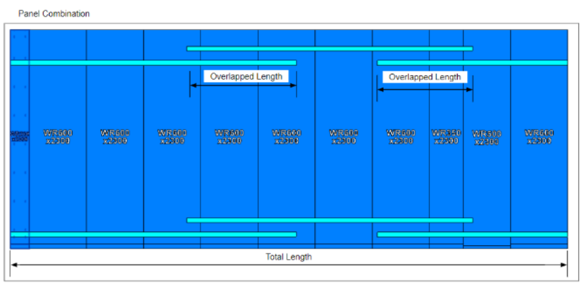

Figure 4: Walers configuration.

The second type is the panel combination less than the longest standard length and only one appropriate length of waler needs to be placed. There are three situations according to the corner conditions at both ends of the formwork combination, as shown in Figure 5. The corner conditions are divided into internal corners and external corners. The first situation is that both ends of the formwork combination are internal corners. In this case, if the length of the panel combination is not equal to the standard size of the waler, the waler needs to be cut to fit between the two internal corners. The second situation is that both ends of the panel combination are external corners. In this case, an appropriate length (the minimum standard size of the waler which is greater than the panel combination length) of the waler needs to be placed in the middle of the formwork combination, and there is no need to adjust the length of the waler. The last one is that the two ends are an internal corner and an external corner, respectively. In this case, a standard-size waler is used, but the waler must be aligned with the internal corner.

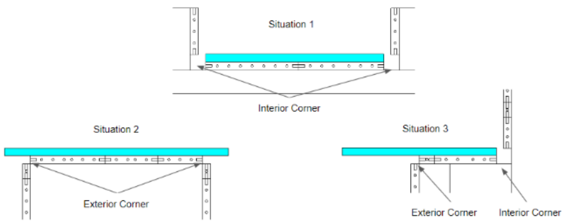

Figure 5: Three situations of walers. (1) Two interior corners. (2) Two exterior corners. (3) One interior corner and one exterior corner.

3.1.3 Double Waler Planning

Because exterior columns are difficult to secure with braces, a stronger double waler is used to maintain the stability of the column formwork. The example of double walers planning is shown in Figure 6.

The planning rules for double waler are as follows:

- To ensure the verticality of two horizontally adjacent panels at the corner where the column touches the wall panels, two double walers need to be welded into an L-shaped double waler combination.
- Double walers come in standard sizes, e.g. L_1, L_2, L_3, etc.

When configuring double walers, users only need to select all the formworks that need double walers and the software system would automatically place the L-shaped double waler at the interior corner of the external column and the wall, followed by prioritizing the configuration of the standard-size double walers on the remaining surfaces before the placement of non-standard-size double walers.

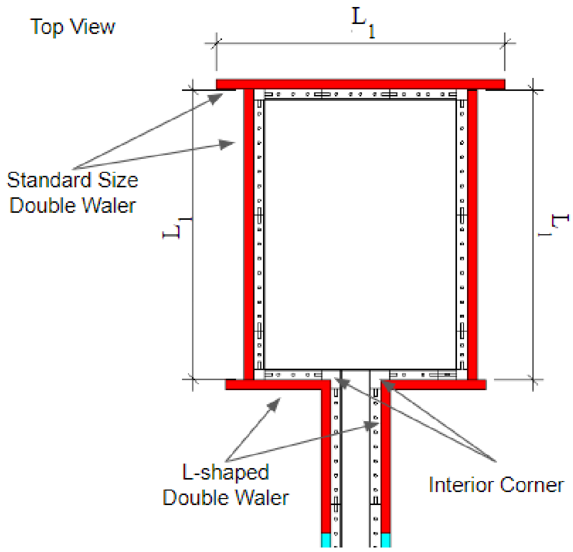

Figure 6: Double walers planning.

3.1.4 Brace Planning

A brace is used to control the verticality of a panel and the ground, and the panels on both sides of the same wall are tied by pull ties. Therefore, for a wall, only one side of the wall needs to be configured with a brace. The same applies to columns and only two adjacent faces need to be configured with braces. There are small braces and large braces. Small braces are placed in the gap between panels. Large braces are attached to the waler and connect the waler to the floor. Because the configuration rules of braces in contact with the column differ from those of the wall formworks, their planning rules for configuration are different.

The planning rules for braces for wall panels are as follows:

- The engineers should determine the specific distances (d_1, d_2, d_3) before planning. The maximum distance between small braces is d_1. The maximum distance between the endpoint and the large brace is d_2. The maximum distance between large braces is d_3.
- A small brace must be placed at both ends of each formwork combination, and the distance between each small brace needs to be less than d_1.
- A large brace needs to be placed less than d_2 from each end of each formwork combination, and the distance between each large brace in between needs to be less than d_3.
- There needs to be a floor near the wall to make sure the braces have some space to be fixed to the floor.
- A large brace needs to connect a waler to the ground, so the height of the large brace needs to be adjusted according to the height of the waler.

When configuring braces on a wall panel combination, users can choose the panels they want to configure with braces. The software system first configures small braces, chooses one end to start configuring, and places a small brace. Then, it places braces at intervals of d_1 until the remaining length is less than d_1. Then, it places a small brace at the other end. Next, it configures large braces, chooses one end to start configuring, and places a large brace d_2 from the endpoint. Then it places one brace at intervals of d_3 until the remaining length is less than d_3, Finally, it places a large brace d_2 from the other endpoint. Furthermore, the software system can automatically detect the waler nearby and adjust the large brace's height according to the height of the detected waler. An example of brace planning of wall panel combination is shown in Figure 7.

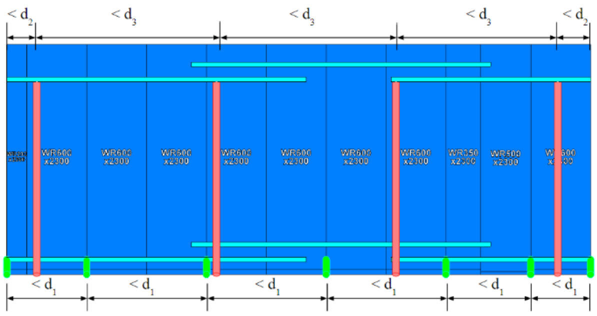

Figure 7: Brace planning of wall panel combination.

The planning rules for braces for column panels are as follows:

- The engineers should determine the specific length L for structural safety consideration before planning. If the total length of the column panel combination is larger than L, three small braces and two large braces need to be placed. If it is less than L, two small braces and one large brace need to be placed.
- There needs to be a floor near the wall to make sure the braces have some space to be fixed to the floor.
- The large brace needs to connect the waler to the ground, so the height of the large brace needs to be adjusted according to the waler above.

When configuring braces on column panel combination, users can choose the panels they want to configure with braces. When the total length is more than L, the software system places three small braces and two large braces at appropriate locations. Examples are shown in Figure 8. Furthermore, the software system can detect the waler nearby and adjust the large brace height according to the height of the detected waler.

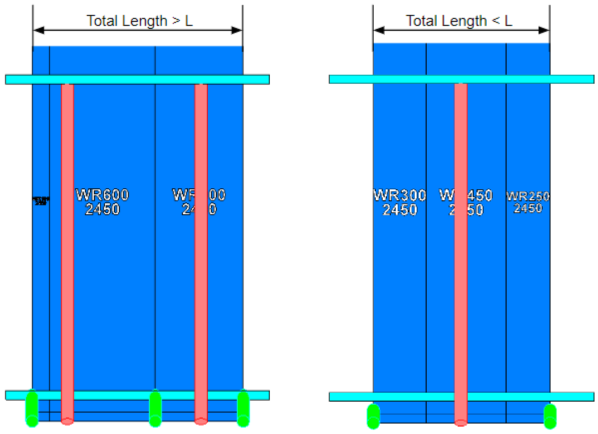

Figure 8: Brace planning of column panel combination.

3.2 Accessory Quantity Estimation

In addition to arranging props, braces, and walers, we also need to estimate the quantity of wedges, pins, pull ties, and waler brackets. Since these accessories are numerous and their positions are fixed, we do not need to plan their arrangement positions but only need to estimate their quantity as accurately as possible.

3.2.1 Pin Quantity Estimation

A pin is used for connecting and holding two formwork panels together by passing through the holes of two adjacent formwork panels. It is used with a wedge inserted into the hole at one end of the pin to achieve fixation. All the holes of formwork panels are fitted with pins. Therefore, when estimating the quantity of pins, we can sum up the quantity of all the holes on the formwork panels and divide it by two.

3.2.2 Waler Bracket Quantity Estimation

A waler bracket is an accessory used to place walers and double walers. It has a structure like a pin and allows the entire waler bracket to be fixed on the hole of the formwork panels. The waler bracket is placed between the formwork panels. All positions with walers and double walers need to be fitted with waler brackets. Different lengths of waler and double walers require different quantities of waler brackets. When estimating the quantity of waler brackets, we need to multiply the quantity of waler of each size by the corresponding quantity of waler brackets and sum up the multiplications.

3.2.3 Wedge Quantity Estimation

A wedge is an accessory used to fix the pin and the waler bracket on the hole. All positions with pins or waler brackets need to be fixed by wedges. When estimating the quantity of wedges, we only need to sum the quantity of waler brackets and pins.

3.2.4 Pull Tie Quantity Estimation

A pull tie is a thin steel sheet. Its length is determined by the thickness of the wall or column. During concrete pouring, it tightly pulls the panels on the opposite sides together. This prevents the panels from expanding or bursting, ensuring the quality of the construction. To estimate the quantity of pull ties, we can count the number of pull tie holes of formwork panels. Also, through the thickness of the wall and column, we can know the type of pull tie used.

4 Case Study

Figure 9 shows the panel planning result from a previous study [3]. We utilized this real case to evaluate the efficiency of the proposed approach by recording the time engineers used during the planning process and comparing it with manual operations. The operation time for different accessory planning approaches is listed in Table 1.

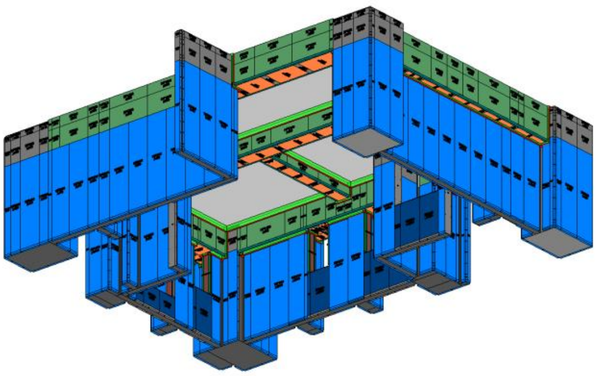

Figure 9: A real case [3].

4.1 Evaluation

In the traditional manual process, engineers spend 400 minutes reviewing accessory placement rules and manually positioning BIM accessory components in the model, ensuring each piece aligns with structural requirements and project specifications. A preliminary automatic approach [3], which only supports the generation of prop, takes 365 minutes. It only saves 8.75% of the time. Our semi-automatic approach supports (1) generation of prop, (2) planning of brace, waler, and double waler, (3) quantity estimation of the above-mentioned accessories, and (4) quantity estimation of the pin, waler bracket, wedge, and pull tie. With the proposed semi-automatic approach, the time is significantly reduced to only 50 minutes. This time includes the manual adjustment of conflicts between different accessories. The results indicate a timesaving of 87.5% for engineers, a significant improvement in efficiency. Furthermore, our approach allows for more precise planning of aluminum formwork accessories in a semi-automatic manner. This precision is crucial in ensuring the quality and safety of the construction process. It also reduces the risk of errors that could potentially lead to costly and time-consuming corrections.

4.2 Discussion

The evaluation primarily measures the efficiency of various planning approaches through time spent. Engineers dedicated most of the 50 minutes saved by our semi-automatic method to adjusting the placement of double walers, with the remainder used for verification. Enhancing the automation level of double waler planning could further reduce the time required.

Although time serves as our main evaluation metric, quality and error rates are equally critical. Future assessments will quantify these aspects to provide a more comprehensive evaluation of our system. Additionally, comparing the results in different scenes, and recording the adjustments made by engineers after running the program could offer insights into the system's quality, suggesting a direction for future enhancements to reduce manual interventions and improve overall system effectiveness.

Table 1: The operation time for different accessory planning approaches.

Operation Approach	Time (Minutes)	Timesaving (%)
Manually	400	0
Preliminary Automatic [3]	365	8.75
Semi-automatic (this research)	50	87.5

5 Conclusions

This paper proposes an approach for accelerating the planning and quantity estimation of aluminum formwork accessories. Through a real case study, we validate the effectiveness of the approach in improving the efficiency of engineers' accessory planning. The results show a significant timesaving of 87.5% for engineers, and this could have a profound impact on the overall project timeline and cost. While our approach has been proven effective in improving efficiency, the need for manual adjustments to resolve conflicts between different accessories could be further addressed by the integration of an automatic conflict identification and resolution feature in future iterations.

Acknowledgement

The authors would like to express sincere gratitude for the received financial support. The funding from the project (112HT511004) conducted by National Taiwan University and FBC Formworks Systems Co., Ltd. has supported the authors in conducting this research. The financial support from the Computer Usage Fee of the Department of Civil Engineering at National Taiwan University (113KC009) has facilitated the authors in publishing and presenting this article at the conference.

References

[1] Zhang, L. Exploring the Design and Construction of Aluminum Formwork Based on BIM Technology. IOP Conference Series: Earth and Environmental Science, 474, 072078, 2020. DOI: 10.1088/1755-1315/474/7/072078

[2] Rane, N. R., Achari, A., and Kadam, D. Evaluating the Selection Criteria of Formwork System (FS) for RCC Building Construction. International Journal of Engineering Trends and Technology, 71(3): 197-205, 2023. DOI: 10.14445/22315381/IJETT-V71I3P220.

[3] Chen, K. Y., Wu, T. H., Setiawan, B., Tandri, C. C., Hsieh, S. H., and Chang, W. T. A BIM-Assisted Planning Tool for Facilitating the Application of an Aluminum Formwork System to Beam-Column Buildings. In Proceedings of International Conference on Civil and Building Engineering Informatics, pages 176–183, Bangkok, Thailand, 2023.

[4] Hyun, C., Jin, C., Shen, Z., and Kim, H. Automated Optimization of Formwork Design through Spatial Analysis in Building Information Modeling. Automation in Construction, 95: 193–205, 2018. DOI: 10.1016/j.autcon.2018.07.023

[5] Lee, B., Choi, H., Min, B., Ryu, J., and Lee, D. E. Development of Formwork Automation Design Software for Improving Construction Productivity. Automation in Construction, 126, 103680, 2021. DOI: 10.1016/j.autcon.2021.103680