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STUDY ON THE AUTOMATIC GENERATION OF CONSTRUCTION PLANS UTILIZING BIM

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Abstract

In Japan's construction sites, there is a demand for increased productivity in construction management operations. Furthermore, the aging of engineers is progressing, and there is a need to inherit the know-how of veteran engineers efficiently. The use of digital technology is considered effective in addressing these challenges. In construction planning at construction sites, the visualization of construction plans using BIM is practiced in many construction sites. The advantage of this visualization is that it can clearly express the construction sequence. On the other hand, a challenge is that creating the model takes time. The authors are working on the development of tools to automate the planning of construction based on BIM, to improve productivity and quality in construction planning. So far, three planning support tools have been developed for structural construction: (a) Automatic Drawing Tool for Rebar Models, (b) Concrete Construction Planning Tool, and (c) Steel Frame Erection Planning Tool, confirming that it is possible to create a construction plan using an actual construction BIM model.

This report outlines the generation methods of construction plans developed for each tool. In the automatic drawing of the rebar model, the shape of the beam rebar can be automatically drawn based on the connection relationships of the members, significantly reducing the conventional drawing time. In the Concrete Construction Planning Tool, a method for automatically generating a division plan for the concrete placement area has been developed. As a planning support tool for steel frame erection work, a method has been developed to determine the order of erection work based on the connection relationships of steel frame members from the BIM model. The tools developed are considered effective for formulating the optimal construction plan by utilizing them in the initial stages of construction planning.

Keywords: BIM, construction planning, concrete placement work, steel frame erection work, rebar arrangement.

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1. Introduction

In the Japanese construction industry, there is an increasing demand to improve the productivity of construction management work. At the same time, the aging of engineering personnel is becoming a serious issue, highlighting the need for efficient transfer of knowledge and expertise from veteran engineers. The application of digital technologies is considered an effective means of addressing these challenges. Specifically, there are high expectations for Building Information Modelling (BIM), which has been widely adopted in many construction projects.

At construction sites, the visualization of construction sequences using BIM has become a common practice in construction planning [1],[2]. The primary benefit of this visualization is its ability to communicate the work sequence. However, a major challenge lies in the time-consuming nature of creating BIM models necessary for such applications.

To address this issue, the authors are developing an automated BIM-based construction planning tool aimed at enhancing both productivity and the quality of construction plans. This paper reports on a support method for construction planning that utilizes BIM, with a specific focus on the structural framework.

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2. Literature review

One of the most practical uses of BIM during the construction phase is in the structural framework. For example, in reinforced concrete buildings, BIM is commonly used to calculate the amount of concrete needed and to visualize how rebar is arranged. In steel-framed buildings, it is often used to simulate how steel frames will be assembled [2]. These practices are important because the progress of structural work greatly affects the timing of finishing work and the installation of mechanical, electrical, and plumbing (MEP) systems. As a result, using BIM to review construction plans in advance before the beginning of the construction is seen as a valuable way to reduce the risk of schedule delays.

However, creating BIM models and entering the necessary data can be time-consuming and labor-intensive. To solve this problem, researchers have proposed ways to automate construction planning by using the data already contained in BIM models. In rebar work, for example, tools have been developed to make rebar modelling more efficient [3][4]. In steel frame construction, some methods can automatically create erection sequences from BIM data [5].

This study builds on these previous efforts and aims to improve work efficiency by incorporating expert construction planning knowledge into the automation process.

3. Research goals and objectives

This study aims to formalize the construction planning know-how that has traditionally been based on the experience of construction site managers, thereby contributing to greater efficiency in construction planning operations. To achieve this formalization of planning know-how, the study proposes utilizing Building Information Modeling (BIM) to automatically generate construction plans. The research focuses on structural work and is being conducted in three steps toward the automatic generation of construction plans.

The first step aims to improve productivity through the standardization of BIM models. This involves linking BIM data created during the design phase to the construction phase to streamline construction planning operations. The second step focuses on enhancing productivity through automation. In this phase, construction planning know-how is embedded into the system to automate the creation of models and digital data necessary for construction planning. The third step aims to create added value by improving the quality of construction planning through the automatic generation of construction plans and the simulation of construction processes.

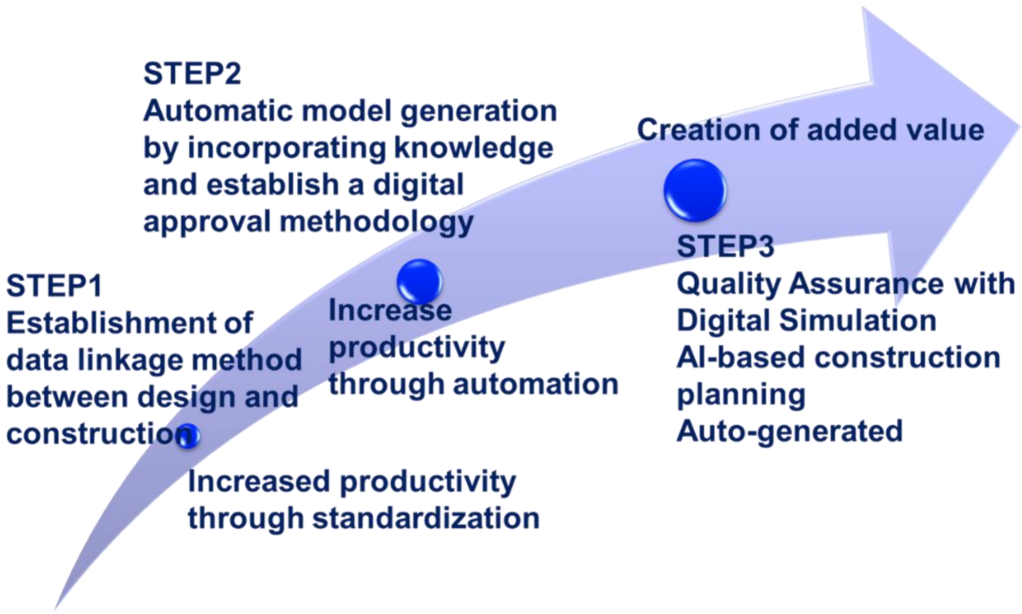


Fig.1 Research Goals and Steps

4. Methodology

In this study, an application is being developed to support construction planning operations for structural work, based on the three steps outlined above. The focus is on three major types of construction planning within structural work: (1) rebar work, (2) concrete placement work, and (3) steel frame erection work.

For each of these construction activities, programs were developed to automate the creation of construction planning models and work procedures based on the geometry and attribute information of BIM models generated during the construction phase. The validity of the developed programs was evaluated by comparing their outputs with those obtained using conventional methods.

This paper presents two case studies: as an example of Step 2, the automatic generation of rebar arrangement models for rebar work; and as examples of Step 3, the automatic generation of concrete placement plans for concrete work and steel frame erection plans for steel framework.

5. Case Study on the Automatic Generation of Construction BIM Models

5.1. Challenges in Utilizing BIM for Rebar Work

In rebar work, BIM is utilized for rebar arrangement reviews (Fig. 2). These reviews require checking both plan views and elevation/section views simultaneously. However, conventional 2D drawings often present challenges, as plan views and elevation/section views are not interlinked, leading to inconsistencies between drawings and increased workload during revisions.

By creating a 3D model of the rebar arrangement (hereafter referred to as the "rebar model"), these issues can potentially be resolved. The creation of such a rebar model requires accurately and efficiently drawing the shapes of rebar following prescribed standard specifications. As a solution to this need, several automatic drawing systems have been proposed in previous studies [3][4].

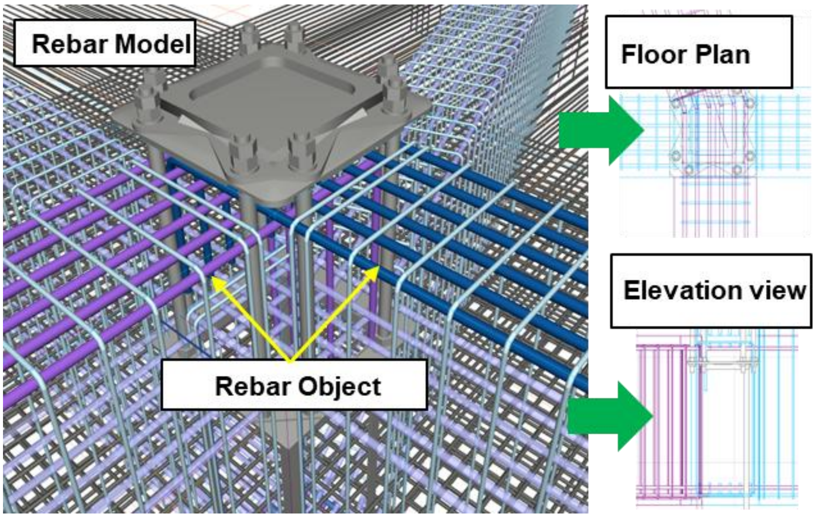


Fig. 2 Example of Rebar Model

5.2 Automatic Generation of Rebar Models

To efficiently conduct rebar arrangement reviews, it is important to reduce the workload involved in creating rebar models. This allows sufficient time for reviewing the arrangement and facilitates the identification and resolution of clashes or inconsistencies before quantity take-off and on-site assembly. To address this, a program was developed to automatically place rebar objects into a structural BIM model.

In conventional rebar modelling, significant effort was required to model the anchorage shapes of beam rebar, and BIM modelers with specialized knowledge of rebar arrangement were necessary. To overcome this, the modeling of anchorage shapes was automated. For automation, beam rebar anchorage shapes were classified into the following three types:

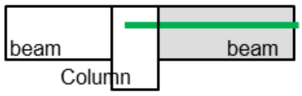
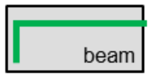
1. Straight anchorage of each main bar.
2. Bent anchorage within connected columns or beams, and
3. Bent anchorage within the beam itself, such as at the end of a cantilever beam.

The program selects the appropriate anchorage type for each beam in the BIM model based on the following two conditions (Table 2).

Condition 1: Presence of a parent member, whether a member (column or beam) is connected to the end of the beam
Condition 2: Presence of a continuous beam – whether there is another beam connected on the opposite side of the parent member

When tested using a 2×2 span model, it was confirmed that the automatic placement program could reduce modeling time by approximately four minutes per member compared to the conventional manual method.

Table 1: Method for Selecting Anchorage Shapes

No	Parent Member	Continuous Beam	Anchorage Shape (Section image)
1	○	○	
2	○	×	
3	×	—	

6. Case Studies on the Automatic Generation of Construction Plans

6.1 Concrete Placement Work Planning

(1) Challenges in Concrete Placement Planning: In construction sites, the planning of concrete placement areas on each floor is typically carried out by site managers based on their individual experience. This know-how has not been formalized, and each plan is created empirically.

This study proposes a method for automatically generating concrete placement area plans from architectural BIM models using a genetic algorithm (GA), one of the optimization techniques [6]. This approach aims to formalize the tacit knowledge involved in placement planning and improve the efficiency of the planning process.

(2) Generation of Concrete Placement Area Plans: The proposed method consists of several components responsible for generating and optimizing concrete placement area plans from BIM models. Below is an overview of the algorithms used in each component.

In the area generation component, the BIM model is divided into an arbitrary number of placement areas. This component was developed with reference to a previous study on supporting architectural layout generation [6]. The outline of the method is as follows:

First, the floor plan of the target BIM model is divided into a grid. Several starting points, each representing the center of a concrete placement area, are placed within the space according to the desired number of areas. Then, each starting point expands into adjacent cells to form distinct areas.

Figure 3 shows an example of an area division using an 8×8 grid. In this method, the set of starting points for each area is defined as the genetic information in the optimization process. For instance, the area division shown in Figure 1 can be represented as (2, B), (5, D), (3, F), (7, G).

In the optimization component, four objective functions are defined as evaluation criteria for the concrete placement area division. In all cases, smaller values indicate better solutions:

- **Objective Function 1:** Variation in concrete volume among placement areas
- **Objective Function 2:** Linearity of the division boundaries
- **Objective Function 3:** Cross-sectional area of the placement zones
- **Objective Function 4:** Penalty for exceeding allowable concrete volume per area

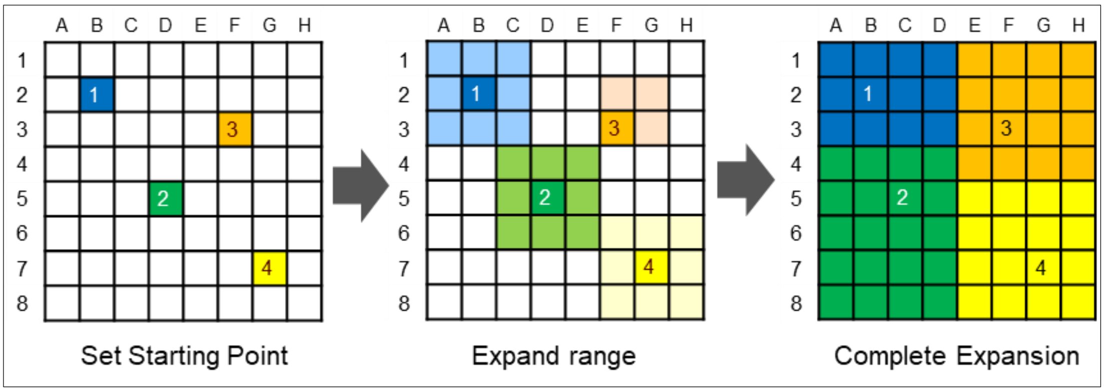


Fig.3 Sequence of generating concrete placement construction areas

The proposed method was implemented using *Rhinoceros* and *Grasshopper*. For the optimization component, *Octopus*, an optimization plugin for Grasshopper, was used. An evaluation experiment was conducted by dividing the BIM model shown in Figure 4, using the input conditions and parameters listed in Table 2 and Table 3, respectively.

Figure 4 shows examples of Pareto solutions from the 1st and 70th generations. In the 1st generation, the division lines in the central area are irregular, and in the lower-left area, the division cuts through the center of a beam. By contrast, in the 70th generation, these issues are resolved, and the proposed method successfully generated a more optimal solution.

Although the results shown in Fig. 4 were produced using the parameters in Table 3, when the mutation rate was set too low, the population size was small, and convergence occurred prematurely. This led to many similar, distorted solutions and local optima. By using relatively high values for both population size and mutation rate, the method was able to generate a broader variety of solutions in the early generations.

Table 2. Optimization Conditions Used in

Conditions	Value
Lower / Upper limit of Volume	$80m^3$～$220m^3$ / division
Grid Size	50m x 79m
Maximum number of divisions	6

Table 3. Optimization Parameters Used in the Experiment

Parameters	Value
Maximum generation	70
Population Size	100
Elitism	0.5
Mutation Rate	0.1
Crossover Rate	1.0
Multi-objective Optimization method	SPEA-2

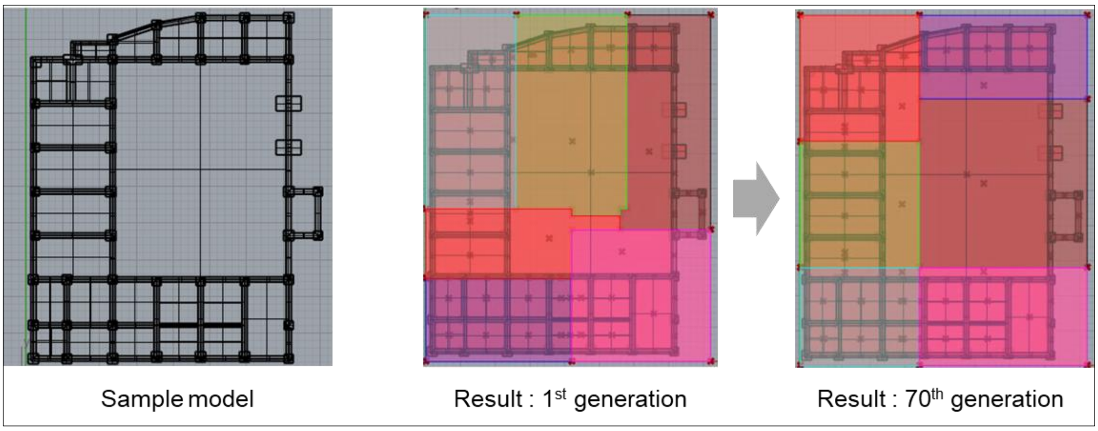


Fig.4 Example of Evaluation experiment results

6.2 Steel Frame Erection Work Planning

(1) Utilization of BIM in Steel Frame Erection Work Planning: The utilization of BIM in steel frame construction planning includes the visualization of the erection process and the selection of lifting machinery. To facilitate the selection of lifting machinery, a crane object creation tool and an automated lifting operation assessment tool were developed [7]. The features of the created crane object include the ability to easily represent the lifting posture through mouse operations and the ability to display the lifting capacity corresponding to the represented posture (Fig. 5).

(2) Crane Placement Support Method: To improve the efficiency of lifting operations, a function was developed to assess the lift ability of construction components on the BIM model. Traditionally, planners would check the comparison between component weights and rated load using drawings and spreadsheets. With the new method, this comparison is visually confirmed through color-coded displays on the model (Fig. 6).

Furthermore, by drawing the crane installation area within the BIM model, an object (Crane Location Visualizing Object) was developed to display the positions where all components within that area can be lifted. As shown in Fig. 7, lifting assessments are made at 1-meter intervals within the drawn installation area, with locations where all components can be lifted marked in light blue. If there is no position where all components can be lifted, the area is color-coded in red, supporting the optimal crane placement planning.

(3) Generation of Steel Frame Erection Sequence: In steel frame construction planning, there has been significant effort to create construction steps for each erection area using BIM. In this tool, the erection area is automatically generated by reading CSV files that contain the coordinated information of steel components output from the steel BIM model. The erection area is determined based on the placement and connection relationships of the steel components, and it is divided according to the number of pieces to be erected per day. The generated erection plan can be output as steps for each component using a viewer tool.

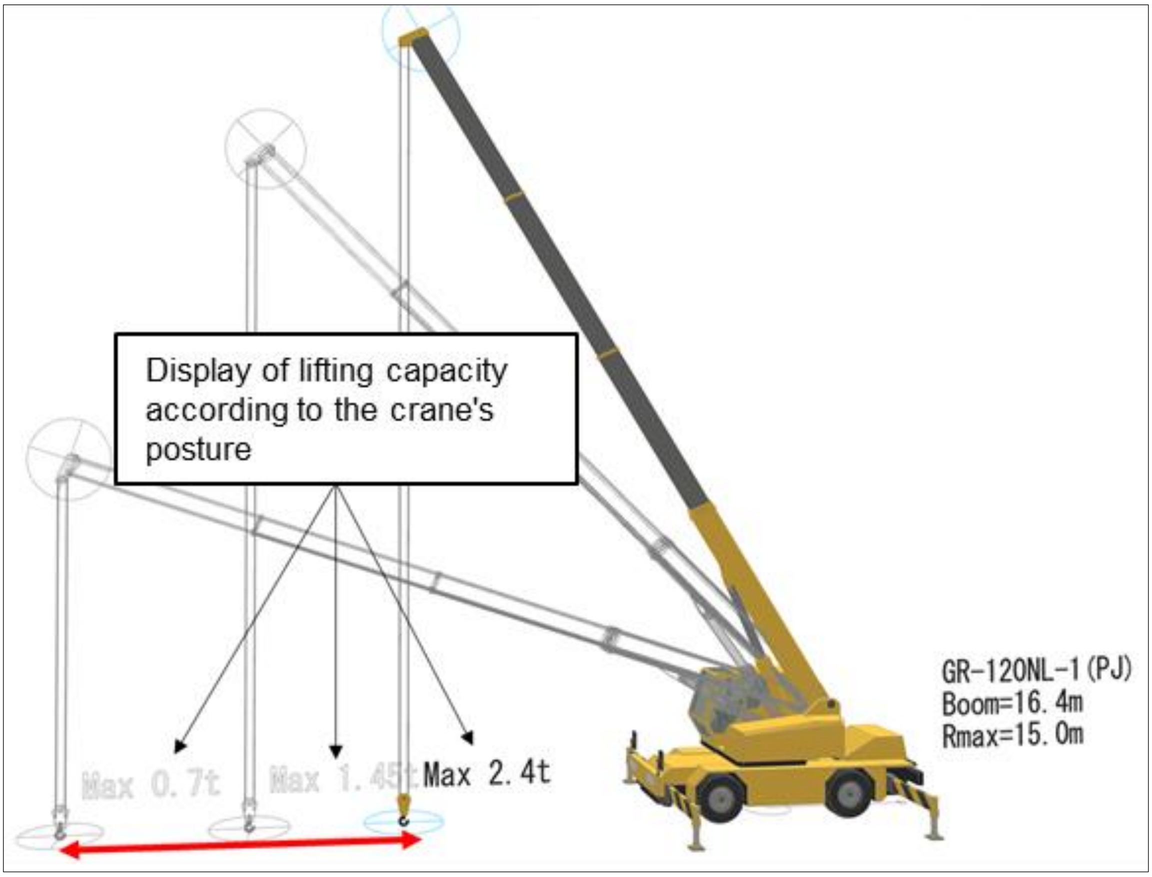


Fig.5. Example of Crane object

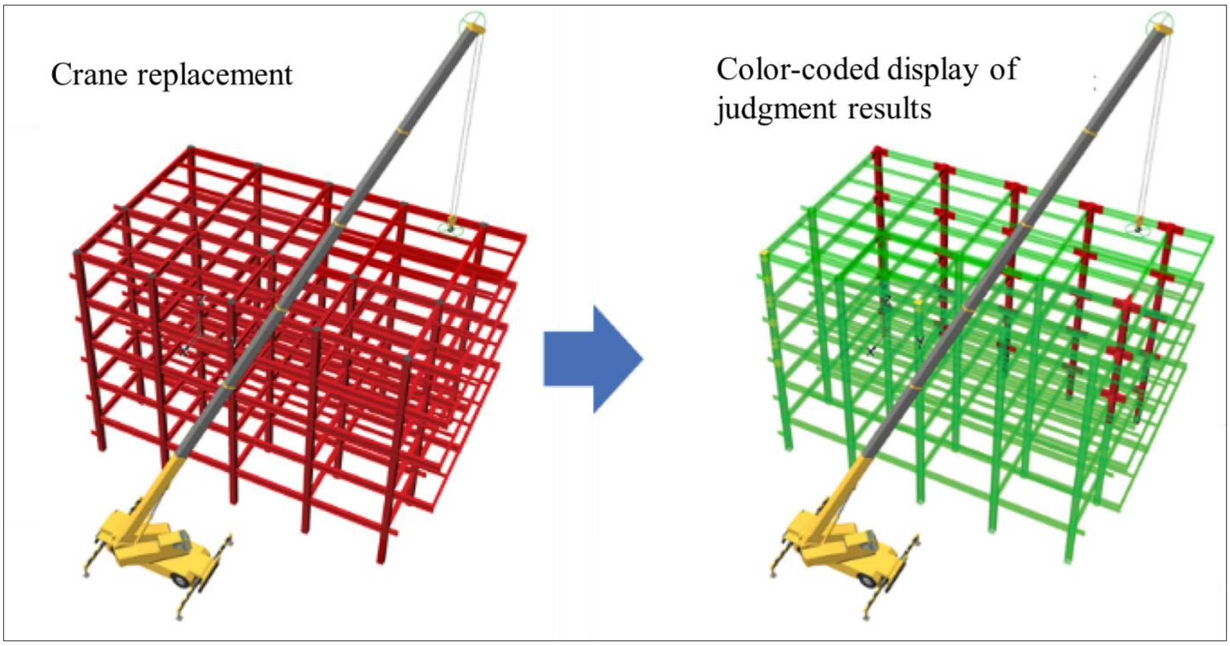


Fig. 6 Example of Lifting Capacity Assessment Using Crane Object

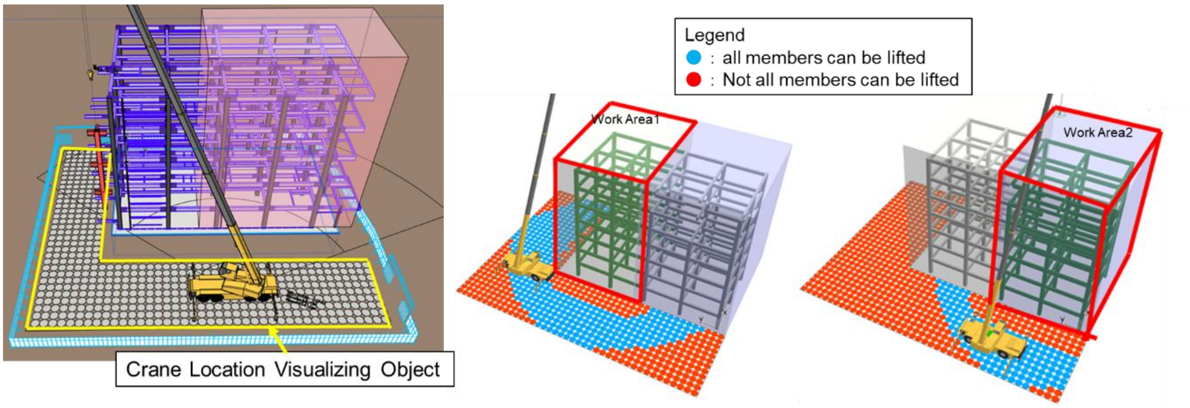


Fig. 7. Example of Displaying Liftable Crane Positions

7. Conclusion

As a method to support construction planning using BIM, examples were provided for: ① the automatic creation of rebar models in rebar work, ② the automatic generation of concrete placement areas in concrete placement work, and ③ the automatic generation of steel frame erection sequences and the visualization of crane placement ranges in steel work. In each method, it was confirmed that plans equivalent to conventional ones can be created using actual construction models. These examples demonstrate that, in addition to the quantitative information of structural components contained in the BIM model, the use of the connection relationships between columns and beams enables the creation of construction plans and detailed models. Currently, such connection relationship information is not included in the model, so it is generated by calculating based on the component placement coordinates. In the future, if information that represents the connection relationships between components is standardized in BIM models, it is expected to enhance the potential use of BIM in construction planning. Additionally, through the implementation of automation, it was confirmed that the construction planning know-how, which was previously based on individual knowledge, can be formalized. Our plan involves expanding the application scope and aiming to improve the efficiency of construction management tasks.

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