Applying an A-Star Search Algorithm for Generating the Minimized Material Scheme for the Rebar Quantity Takeoff

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Abstract –

Rebar engineering is a construction method for building structures that is critical to the earthquake resistance of the entire building. The construction process and quality of rebar have always been valued by the construction industry, and it is imperative to improve the quality of reinforcement construction to reduce injuries. In recent years, Building Information Modeling (BIM) technology has been widely applied in the stages of design, operation and maintenance, but less in the construction phase. For rebar works in the construction phase, a BIM model of rebar can facilitate the development of a solution because 3D visualization of the model makes it easier to understand the problem. However, to apply the rebar BIM model to practice, it is necessary to build a model with the rebar takeoff to meet the actual construction status. Thus, how to optimize the takeoff of rebar from the completed 3D model has practical research value. This study takes the on-site construction of rebar as an example. For the main component, a BIM model is built with Tekla software to produce practical rebar takeoff plans with an A-star algorithm based on legal norms and construction feasibility that can reduce the amount of excess rebar material. It also chooses the best rebar takeoff plan to build the rebar BIM model. As a result, the relevant personnel who use the rebar BIM model can correctly solve the actual problems with the BIM model.

Keywords –

Building Information Modeling; Rebar Takeoff; A-Star Search Algorithm; Construction Phase

1 Introduction

Rebar engineering is a construction technology for a building, and it is also a safety factor of the structure. The construction industry has committed to reducing the waste of rebar under safe conditions to decrease the cost of rebar. In traditional rebar engineering, a building is constructed according to a 2D design drawing. But the designed rebar diagram cannot be directly applied at construction sites. It is necessary to perform rebar quantity takeoff to carry out rebar cutting, transportation, construction and other steps to complete the work of rebar engineering. The rebar quantity takeoff work is generally problematic for most untrained construction workers, who have insufficient planning ability and professional knowledge. Problems with incorrect material cutting or improper lashing may result in poor construction quality. Even if the reinforced concrete material is completed, it is difficult to effectively understand whether the takeoff result is the best. In recent years, the introduction of BIM in each stage of the building life cycle has become more diverse through the visualization and parameterization of Building Information Modeling (BIM). For example, a 3D model established by BIM software can quickly show design defects before construction and prevent waste in reconstruction [1]. It can be used to simulate the estimation of cash flow, including equipment, manpower and materials, during construction [2]. It is also possible to conduct conflict analysis for various types of work in advance and as a cross-domain information communication interface [3, 4]. Building Information Modeling has the capability to automate a quantity take-off, which will reduce the time and costs required to estimate a project [5]. The system using Autodesk Revit API automatically generates rebar placement plans for a building structure and labels the placement sequence of each individual bar or set of bars with ascending numbers [6]. At present, most rebar BIM models are established according to the two-dimensional map. The completed BIM model only provides a reference for the relevant personnel to easily understand the conflict positions and quantities of the entire rebar project. Therefore, it is worthwhile to create a practical rebar BIM model and to explore how to continue to use the BIM model to optimize the rebar material quantity to decrease freight, increase the correctness of rebar construction, and mitigate the problems caused by the rebar construction process. Figure 1 shows the research workflow.

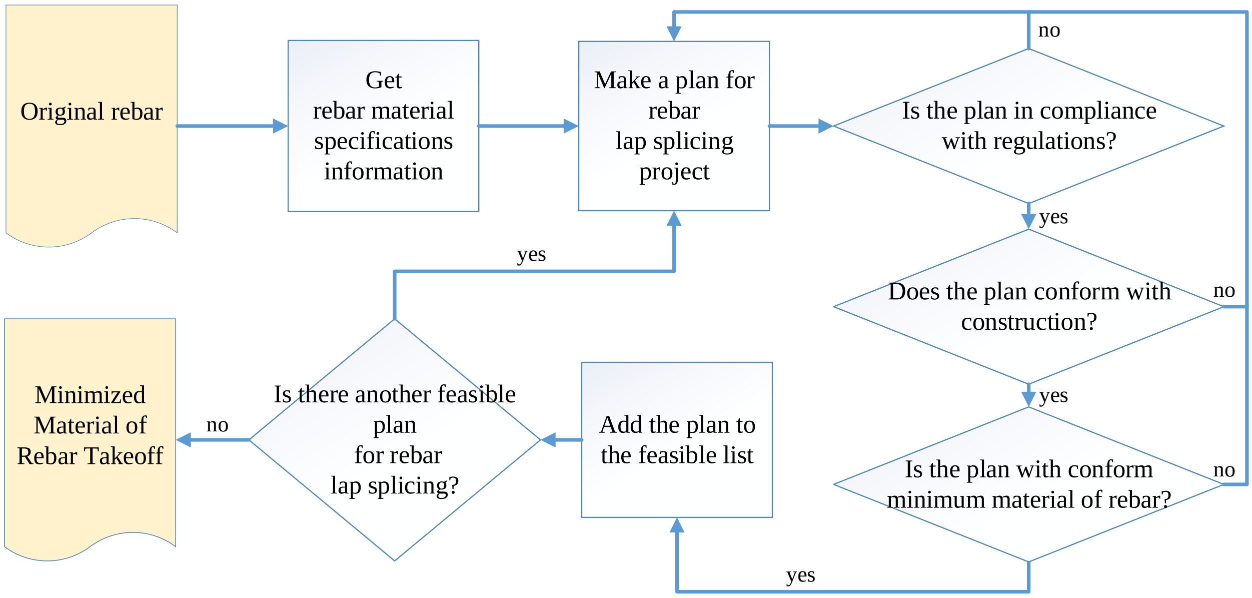


Figure 1. Research workflow

2 Application of Algorithm in Construction Engineering

Appling algorithms to solve problems in construction engineering has been discussed in related studies, which have examined using a genetic algorithm (GA) to optimize the RC beam rebar design to achieve the lowest construction cost [7]. A GA can be used to minimize the cost of RC columns in a reasonable time [8]. Also, a hybrid GA-HJ can be used to automatically generate optimized rebar under the BIM software model architecture. These studies have also solved some practical problems. The rebar cutting problem can use the Maze Problem (MP), for which the Pathfinding Algorithm is used to solve its path or shortest path. This was proposed by the Dutch computer scientist Edsger Wybe Dijkstra in 1956 [9].

Beam and column joint look like the intersection node of maze, we need consider to apply straight rebar or add a hook based on constructivity and cost analysis. According to these characteristics of problem, the A-star search algorithm used in this study is an improved algorithm based on Dijkstra’s algorithm [10], which is commonly used in the movement path control of non-player characters in role-playing games. The breakpoint position of the rebar is calculated according to its logic and the construction specifications. The process is summarized as follows: Step 1: Search for the information of rebar in a structural beam and convert it to a quantized node. Step 2: Start from point A and inspect all nodes adjacent to point A. At this time, the program will consider the rebar situation such like straight or hook, only the passable nodes are placed in the open list. Step 3: Set point A as the parent node and move it from the open list to the closed list. Temporarily set each node as the parent node A in the open list and calculate their estimation function,

$$f(A) = g(A) + h(A) \tag{1}$$

where g(A) is the actual distance from the start point to the current node A; h(A) is the estimated distance from the node A to the end point. There are many ways to estimate the distance, depending on the case being explored. Step 4: Select the node with the smallest value as the current node A and move it from the open list to the closed list, while the previous parent node is temporarily called A'. Step 5: Repeat steps 2 and 3, and put the passable node adjacent to point A into the open list. If node B already exists in the list, compare the actual distance of A'→B and the actual distance of A'→A→B. If the former is less than the latter, set the node B to the next point A and repeat this step. If it is more, repeat Steps 2 to 5. Step 6: Repeat steps 2 to 5 until the endpoint is found. Once the endpoint is found, each parent node can reverse its path. When node A' is extended to node A, it determines by node A' and node 2 whether node A is lapped or not. If it is lapped, calculate the lap location and the residual material of node A, i.e., g(A). At the same time, estimate the residual material, i.e., g(A), under the possible lapping conditions with node 3 and node 4. However, if the splicing form of node A is determined, an infeasible situation may occur. For example, node A' and node 2 need to be overlapped, but node A cannot find the offset position of 60 cm so it must be straight through.

The length of node 2 plus the length of node A will be too long and difficult to construct. At this time, it is necessary to re-adjust the splicing form of node A' or 2, and then continue to complete the rebar takeoff operation as shown in Figure. 2.

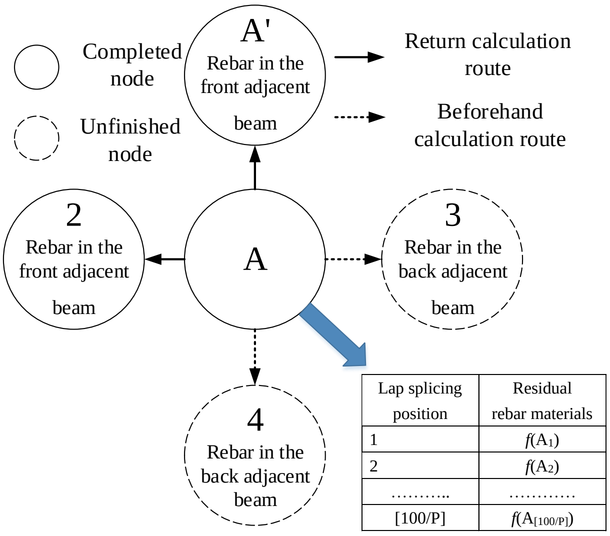
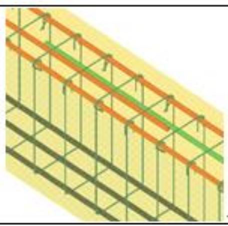
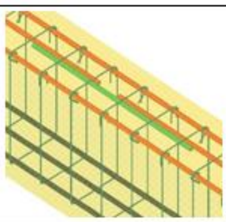
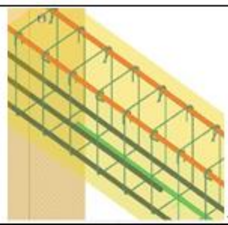
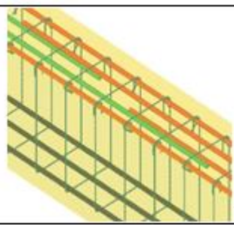


Figure 2. A-star search algorithm for rebar lap splicing scheme

3 BIM Model Combined with Algorithm for rebar takeoff

According to the structural member, the type of rebar lap splicing will be different. In this study, C# was used to program a method to calculate the minimum amount of rebar project and decide the main reinforcement splicing project to create and update the rebar BIM model. When the program needs to decide how to splice the main reinforcement, the length and location of splicing need to follow the law of the concrete construction design specifications. The splicing locations of beam members need to be located on the beam clear span L in the upper pressure zone, the range of L is between 1/4 and 3/4 of the center of the beam member, and the length of this range is 1/2 L. According to the beam clear span, the splicing method can be decided as the double-span for style 1 in Table 1 or the triple-span for style 2 in Table 1. The splicing location of a beam member needs to be located on the range of L from two sides of the beam member to 1/4 of the beam clear span, and the length of this range is 1/4 L. According to the above range, the splicing method can be decided as the cross-column lap for style 3 in Table 1. If the adjacent rebar overlaps, the overlap position can be staggered by 60 cm, as shown in style 4 of Table 1. Because multi-span continuous beam rebar lap splicing is more complicated than the single span beam in practice, the program design regulation needs to consider the following factors of adjacent beams: (A) the size of the section, (B) the quantity of the main reinforcement, (C) the location of the main reinforcement, and (D) the center line. So, in the judgment rule of the program design, the cross-sectional area dimensions (A), the rebar quantity (B), the rebar position (C), and the center line (D) of adjacent beams must be considered. The decided project is lap splicing or non-lap splicing, or anchor in the column member. This research conforms each factor to the decision tree in Figure 3. If the size of the adjacent beam section (A) is the same as the quantity of the main reinforcement, the adjacent main reinforcement can select the project of lap splicing or non-lap splicing.

Table 1. Diagram of rebar lap splicing

Lapping style	1	2	3	4
Lapping place	Beam upper	Beam upper	Beam lower	Beam upper
Rebar number	#7	#7	#7	#7
Rebar amount	7	8	6	9
3D				

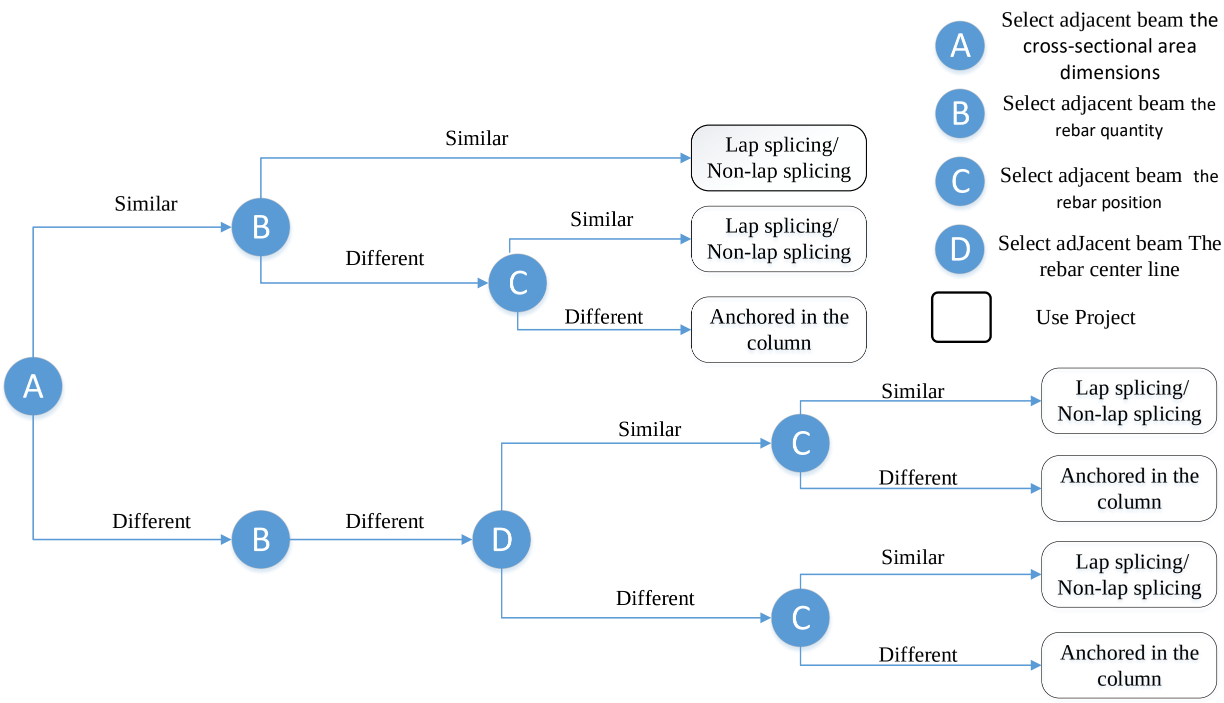


Figure 3. The decision tree about Rebar lap splicing

4 Example analysis

Consider the second floor of a three-story reinforced structure building, which consist of eleven beam members, and the double-span continuous beams are only three of them. This case is easier than most reinforced structure types. Its structural drawing and rebar model created by BIM software are shown in Fig. 4. The reinforcement situation of the multi-span continuous beam can be found by the beam number of the following structure reinforcement drawing, and this drawing can divide the reinforcement of each structure member into items such as the straight main reinforcement, which is in the top and bottom layers, the anchor in the left and right, the non-straight main reinforcement in the top layer, and the non-straight main reinforcement in the center of the bottom layer, and an Excel table can be designed. Finally, that information on reinforcement is inputted into Excel, and following the above, the rebar takeoff and quantity of rebar are calculated. The experimental results of fifty runs are listed in Table 2. Although the first run resulted in the minimum rebar remainders, the total needed rebar length is the maximum in the fifty runs. While the total length of original rebars in the twenty-seventh run is the lowest of the fifty runs, its rebar remainders are not the lowest. Accordingly, this study adopted the twenty-seventh run as the determined scheme due to the minimized material.The detailed cutting results of 3G1 and 3G2 for the twenty-seventh run are summarized in Table 3. Finally, the designer revised the rebar BIM model of structural elements, including columns, beams and walls, according to Table 3, and the results are shown in Fig. 5.

5 Conclusions

Rebar installation causes conflicts and higher costs in the construction stage of a building project's lifecycle. The A-Star search algorithm is applied to obtain the beam element rebar takeoff quantity to match the construction situation and constructability in a BIM model. According to the achievements of this study, the following conclusions can be drawn:

1. Recently, rebar takeoff model is modeled by 2D drawings, the model can not inflect the actual situation on site. Moreover, BIM model without considering rebar splicing and anchor that has the same problems with 2D drawings. Therefore, developing a practical Rebar BIM Model is importent.
2. The A star search algorithm can analyze the rebar splicing and anchor between structural elements and provide various possibilities of rebar takeoff. According to the result, engineers no longer need to operate by personal experience and can obtain the

overall information of rebar takeoff to reduce the rate of material waste and error.

3. At present, this research has only analyzed the situation of a single floor and provided a preliminary result on the rebar takeoff possibility plan. Based on this research, this topic can be extended to related research and BIM technology can be applied more widely.

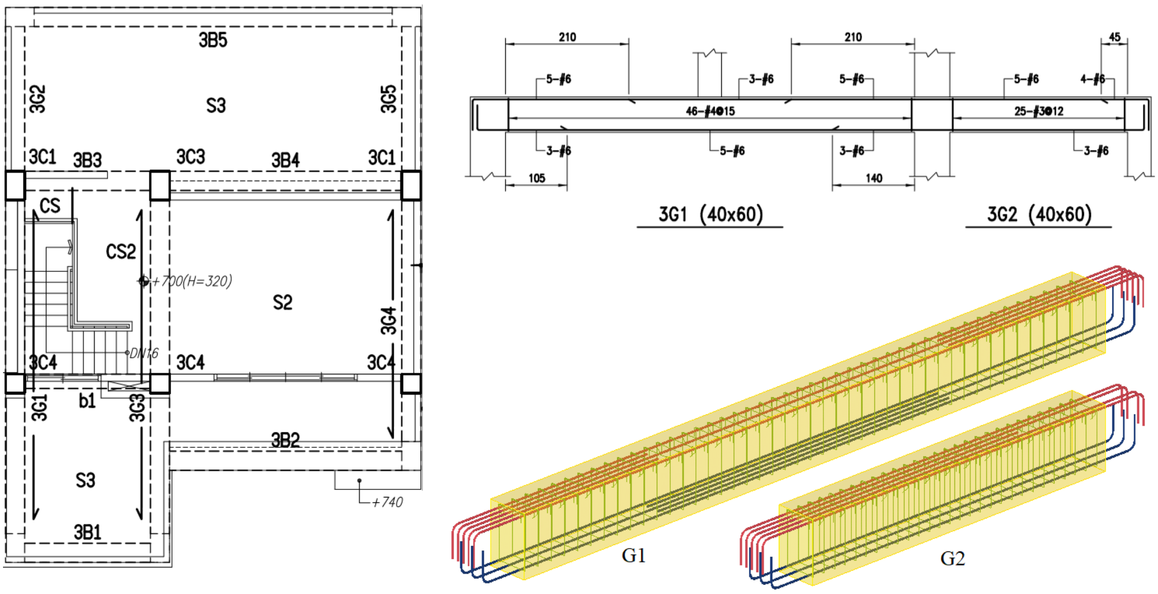


Figure 4. Beam structure and the part of the rebar BIM model

Table 2. The fifty experimental results sorted in ascending order of the cutting remainder lengths

Runs	Rebar No.	Remainders (cm)	Total lengths (cm)		Runs	Rebar No.	Remainders (cm)	Total lengths (cm)	
			Needed rebars	Original rebars				Needed rebars	Original rebars
1	#6	132.9	52167.1	52300	26	#6	264.9	51735.1	52000
2	#6	148.9	51951.1	52100	27	#6	292.9	50007.1	50300
3	#6	156.9	51843.1	52000	28	#6	264.9	51735.1	52000
4	#6	164.9	51735.1	51900	29	#6	296.9	51303.1	51600
....			....				....		
22	#6	212.9	51087.1	51300	47	#6	440.9	52059.1	52500
23	#6	228.9	50871.1	51100	48	#6	444.9	50655.1	51100
24	#6	240.9	52059.1	52300	49	#6	472.9	51627.1	52100
25	#6	264.9	51735.1	52000	50	#6	520.9	50979.1	51500

Table 3. The rebar takeoff results according to the twenty-seventh run

Project No	Element No	Object Sequence	Object Label	Rebar Type	Rebar No	Rebar Index	Is Splice	Has Left Anchor	Has Right Anchor	Splice Length	Splice Position	Left Length	Right Length
27	5	1	3G1	Upper	6	1	FALSE	TRUE	FALSE	0	0	814.65	0
27	5	2	3G2	Upper	6	1	FALSE	FALSE	TRUE	0	0	387.65	0
27	5	1	3G1	Upper	6	2	TRUE	TRUE	FALSE	108	422.55	559.2	363.45
27	5	2	3G2	Upper	6	2	TRUE	FALSE	TRUE	108	89.75	197.75	297.9
27	5	1	3G1	Upper	6	3	TRUE	TRUE	FALSE	108	364.35	393	529.65
27	5	2	3G2	Upper	6	3	FALSE	FALSE	TRUE	0	0	387.65	0
27	5	1	3G1	Lower	6	1	FALSE	TRUE	FALSE	0	0	814.65	0
27	5	2	3G2	Lower	6	1	FALSE	FALSE	TRUE	0	0	387.65	0
27	5	1	3G1	Lower	6	2	FALSE	TRUE	FALSE	0	0	814.65	0
27	5	2	3G2	Lower	6	2	FALSE	FALSE	TRUE	0	0	387.65	0
27	5	1	3G1	Lower	6	3	FALSE	TRUE	FALSE	0	0	814.65	0

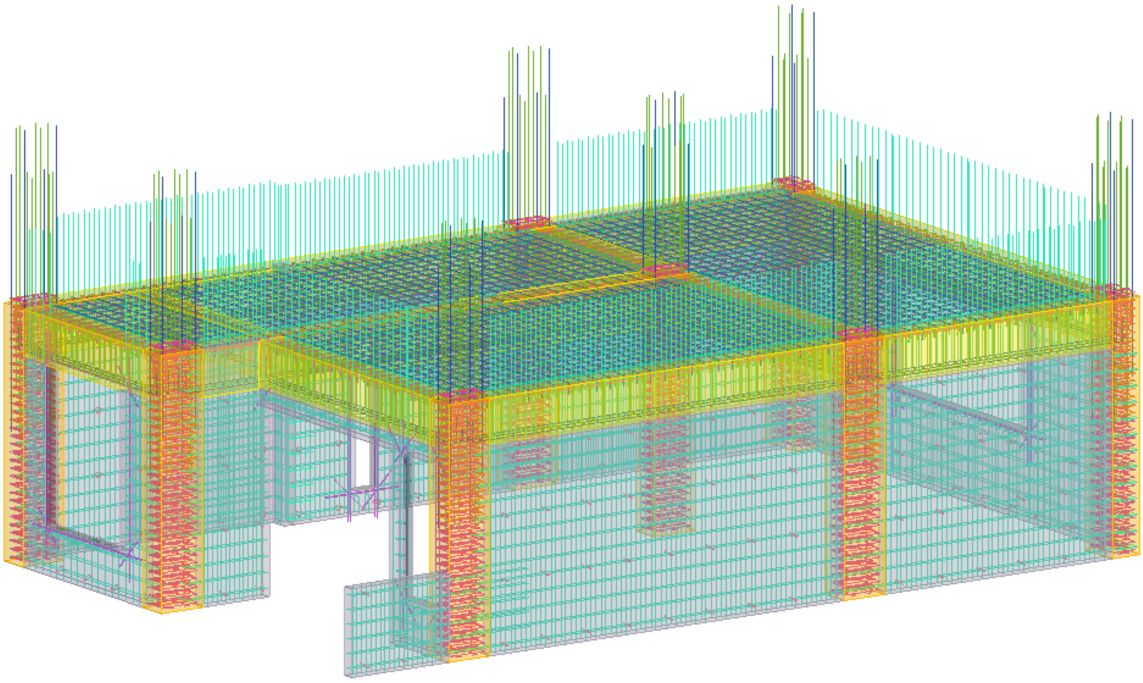


Figure 5. The rebar BIM model of the second floor

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