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APPLICATION OF BIM TECHNOLOGY COMBINED WITH GENETIC ALGORITHM IN CONSTRUCTION MANAGEMENT

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ABSTRACT

The construction industry includes multiple projects. The management in the construction process is an important factor in ensuring construction quality. This paper briefly introduced the relevant content of building information modeling (BIM) and the application of BIM combined with the genetic algorithm (GA) in optimizing the processing scheme in the cutting process of steel structure buildings. A grid-shaped steel shed in Zhengzhou, Henan, was taken as an example to compare the traditional scheme, particle swarm optimization (PSO) combined BIM optimization scheme, and GA combined BIM optimization scheme. The results showed that the GA combined BIM optimization scheme made the best use of raw materials with different specifications and had the highest economic benefits because of the highest utilization rate, the least number of processors, and the shortest working hours.

KEYWORDS

Building information modeling, Construction management, Genetic algorithm, Layout optimization

INTRODUCTION

People’s life is inseparable from clothing, food, housing, and transportation. The construction industry has always been very important. With the progress of various technologies, the production technology of the construction industry has also been improved [1]. However, in any case, the construction is a big project. The construction process involves a lot of related industries and departments. For example, before construction, it is necessary to do planning for the construction, coordinate the cost of building materials, and reduce the cost as much as possible under the premise of ensuring the quality; in the construction process, it is necessary to pay attention to the work allocation among various departments and the safety management of the construction site; after construction, it is necessary to monitor and maintain the building structure [2]. The works mentioned above are usually completed by workforce in the traditional method, but the diverse work items affect efficiency and consume a lot of workforce. The construction industry is different from the conventional industry. There is room for repeated modification of the design scheme in the architectural design process, but it will be difficult to modify the design scheme after the construction project starts, and the management costs involved will become additional costs [3]. Nowadays, the emergence of technologies such as the Internet of things, big data, and artificial intelligence makes construction management more intelligent and efficient. Building information modeling (BIM) technology is an auxiliary tool for construction management. BIM can establish a three-dimensional construction model and quickly count the building information to provide effective information for construction personnel. BIM cannot only use the model design scheme but also combine with artificial intelligence technology to optimize the project scheme at different stages in the construction process [4]. Liu et al. [5] proposed a genetic algorithm (GA) for resource constrained project scheduling problems and verified that the algorithm was effective through the simulation experiment.

Azadeh et al. [6] introduced a flexible GA-fuzzy regression method to predict future asphalt consumption. The experimental results showed that the algorithm was better than the traditional method as it had flexibility in the amount and uncertainty of input data and could be easily applied to the prediction of other materials and different construction projects. When faced with the resource balance problem (RLP) in construction management, Benjaoran et al. [7] proposed a new concept of RLP with relationship options and used the GA to optimize the solution. The simulation results showed that the model could calculate and arrange project schedules for all selected alternative relationship types, reducing resource demand fluctuation and the maximum resource demand level. Song et al. [8] studied a BIM-based structural framework optimization and simulation system for construction planning and schedule management. With this system, the construction process could be dynamically visualized. In addition, when inputting more than one construction schemes into the system, its simulation function could compare the advantages and disadvantages of construction schemes. In order to analyze the carbon performance of the building life cycle, Eleftheriadis et al. [9] established an embedded BIM method by using specific carbon indicators and the results of heuristic structural optimization. The experimental results verified that the structural optimization design could affect the life cycle of buildings. In this study, BIM and GA were combined to optimize the cutting processing scheme of steel structure buildings. Although GA alone can also optimize the cutting scheme, detailed building information needs to be collected, and the information cannot directly present the structure of the building. Therefore, in the BIM combined GA scheme used in this study, the importance of BIM is that BIM can intuitively present the structural information of the building, and it can also collect the structural information of the building more quickly and accurately, reducing the labour cost. Finally, an instance analysis was carried out by taking a grid-shaped steel shed in Zhengzhou city of Henan Province as an example to compare the traditional and BIM optimized schemes. The comparison results showed that the BIM and GA optimized scheme was more economical.

INTRODUCTION OF BIM

BIM is an information management platform that integrates different design types by specifying the same data specification based on 3D modeling technology. In the actual construction process, since BIM contains all the basic information of the construction project, the main units participating in the construction can communicate with the basic content of BIM through the Internet [10].

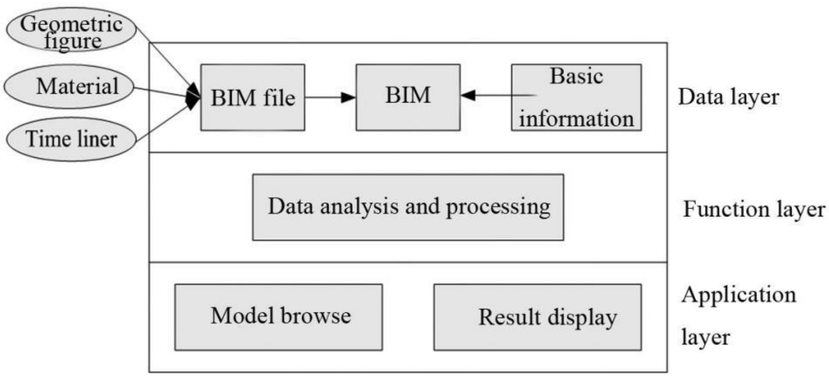

Fig. 1 – The basic framework of BIM

As a building information management platform, BIM has been widely used in the construction field, such as building effect display, construction process simulation, construction scheme optimization [11], etc. The basic framework of BIM is shown in Figure 1, divided into the data layer, function layer, and application layer [12]. The data layer is the bottom layer of the whole BIM framework, and its main function is to provide data support for the data analysis and processing of the function layer. The main data type in the framework is the BIM file, which contains related data, such as the geometry, material properties, and Timeliner. BIM is constructed according to BIM files and basic information. The content of basic information is determined by the content that BIM needs to process. For example, if the safety of building structures is monitored by BIM, then the basic input information includes building monitoring information. If the building scheme is planned or optimized by BIM, then the input basic information includes various constraints, budget, material allowance, etc.

The function layer is the middle layer of the system, and it is also the key structure layer of BIM to realize various construction project management optimization functions. The data analysis and processing module is the main component to realize the above functions. It calls the BIM model and basic information data in the data layer and then processes the data called. The algorithm used in the analysis and processing will change according to the application project of BIM.

The application layer is the top layer of the system, through which users can interact with the system. The application layer is divided into the result display module and model browsing module. The result display module displays the target result of BIM by calling the data of the data analysis and processing module in the function layer. The model browsing module uses NavisWorks and API encapsulation functions to visualize the BIM model, calls the data of the result display module, and marks the relevant processing information in the visualized BIM model. In this module, users can access the images of different positions in the BIM model and corresponding information [13].

APPLICATION OF ARTIFICIAL INTELLIGENCE IN BIM

The construction industry is an industry with many divisions of labour. There are many departments or projects in the construction industry. In project implementation, although the division of labour and cooperation can improve efficiency, it is easy to form an "information island" between various implementation projects, which will reduce the construction efficiency and the quality of construction. The emergence of BIM makes labour division have a referable standard building model information [14]. There are many kinds of construction projects, and different projects adopt different strategies when using BIM for management. Limited by the length of the paper, it is impossible to cover all aspects. Therefore, this paper mainly focuses on "artificial intelligence + BIM" for construction material cutting in construction management.

In recent years, the application of steel structure building is more and more extensive. Compared with the traditional concrete building, the steel structure building is relatively simple in the main structure construction. It does not need the operation of concrete mixing, steel bar erection, and bricklaying but only needs to connect and build the steel after processing. In the construction management of steel structure buildings, the optimization of the processing scheme for building materials (mainly steel) is also a kind of construction management. The traditional building materials processing scheme is to process as many raw materials as needed and to cut bars at will, which will produce a lot of surplus materials and waste. After using BIM, facing the cutting scheme of steel bars in steel structure building, firstly, according to the building scheme (including steel structure building information, such as the number and type of steel structure bar frame, welding ball joint connection, and bar welding), a three-dimensional model consistent with that after the completion of construction is rapidly generated [15], and then the material information of bars and parts required for the construction of steel structure buildings are input through BIM. The material information with the specified format can facilitate the staff in the workshop and construction site to find and process the bar and be used to quickly optimize the scheme of processing raw material to obtain bars [16].

When the processing scheme of raw materials in construction management is optimized by BIM, the data processing and analysis module in the functional layer will be applied. The optimization of processing schemes by BIM is usually carried out by artificial intelligence, and the GA and particle swarm optimization (PSO) algorithm are commonly used. In this paper, the scheme is optimized by a GA. GA is an imitation of the rule of survival of the fittest in nature. The optimization principle of GA for the problem to be optimized is as follows. The factors that can affect the solution of the problem to be optimized are regarded as gene fragments of chromosomes, and a chromosome is the factor set of a solution. Different chromosomes are generated in a random way. Through crossover and mutation, the chromosomes are iterated. Chromosomes are screened using the adaptive function that can reflect the excellent degree of chromosomes, making the population composed of chromosomes evolve in a better direction. Finally, the optimal chromosome is selected from the optimal population as the final scheme of the problem to be solved.

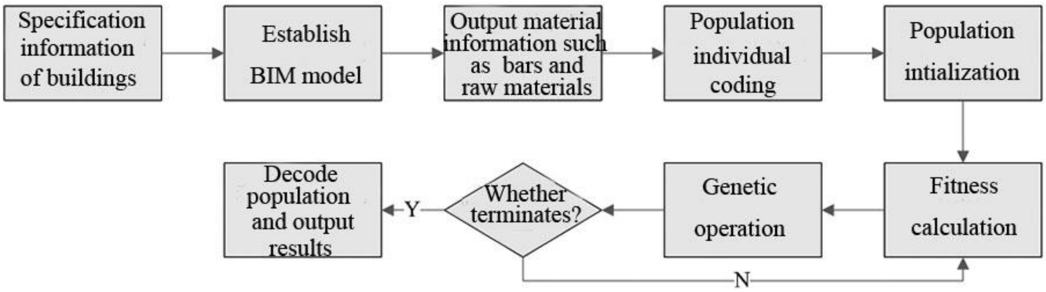

Fig. 2 – The optimization flow of the processing of steel structure building materials based on BIM combined with GA

Conventionally, steel structure bars are usually randomly taken from the raw materials before processing. For example, there are several five-meter long steel bars, and five four-meter long steel bars are needed in the construction project. In the traditional scheme, five steel bars are often taken for cutting for convenience, and the five one-meter long steel bars left will be wasted. However, if it is adjusted to the weldable form, only four five-meter long steel bars are needed, and there is no waste. Figure 2 shows the optimization flow of BIM combined with a GA to process steel structure building materials.

① Firstly, the BIM model of the steel structure building is established rapidly according to the design scheme. The design information includes project name, workpiece number, workpiece internal force, workpiece specification, node number, node coordinates, etc., which will be imported into BIM software in the form of "*. log". BIM software establishes the spatial coordinates of steel structure nodes by reading the "*. log" file and determines the relative position of bars in space according to the connection information of bars and nodes and the geometric parameters of bars. Due to a large number of bars and nodes in steel structure buildings and the complex modeling, the collision of bars cannot be predicted directly by simple space parameters. If bars are installed directly according to the design parameters, once the bars overlap, the construction process will be seriously affected. Therefore, after the preliminary construction of a BIM model, it is necessary to adjust using the Boolean operation, and the bar list will be generated and exported after the adjustment.

② According to the given material information, individuals in the population in the genetic algorithm are coded. Chromosome coding was used in the steel bar processing scheme using $I \times J$ character encoding [17]. I refers to the serial number of steel component to be processed, and J refers to the serial number of steel used for manufacturing components. For example, $A_1, A_2, A_3, \cdots A_I, B_1, B_2, B_3, \cdots B_J$ refers to processing $A_1 \sim A_I$ components on $B_1 \sim B_I$ materials in order. Genetic loci such as A_I and B_J contain the basic information of component and raw material, respectively. The genetic loci of components include the project name, serial number, specification, material, length, node name, and internal force of components. The genetic loci of raw materials include the project name, serial number, specification, material, length, processing sequence number, and whether there is surplus material. The genetic locus information of the above components and raw materials comes from the building material information obtained after establishing BIM.

③ Population chromosomes are initialized. The function of population initialization in this paper is to provide various steel bar material processing schemes. The initialization method is as follows.

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Firstly, according to the information of steel bars and raw materials given by BIM, they are sorted according to the length, from large to small, and given the initial codes. Then, two genetic loci are randomly selected in the component coding area to exchange. The raw material coding area is in the same way. The population initialization finishes after multiple times of random exchanges [18].

④ The fitness of chromosomes (processing scheme) in the population is calculated, but chromosomes in the population cannot be directly used for the fitness calculation. Before fitness calculation, it is necessary to decode the chromosome according to the set layout strategy [19] (i.e., the cutting rules to be followed when raw materials are used to manufacture steel bars). The fitness is calculated according to the decoded scheme. The calculation formula is:

$$f = \sum_{i=1}^{n} C_i \cdot L_i + \sum_{h=1}^{m} C_h \cdot L_h \qquad (1)$$

where f is the bar production cost under the individual chromosome scheme, C_i is the value of residual waste after raw material cutting, which depends on the specification and type of raw materials, C_h is the welding cost of a single welding line of steel bars, which depends on the specification and type of bar to be welded, and L_i and L_h are the residual length of the i-th raw material and the length of the h-th welding line respectively. The fitness calculation formula is the objective function of the layout optimization problem, and the ultimate goal is to minimize it. The layout strategy is the limiting condition, including: (1) only one welding seam is allowed for bars; (2) the number of bars with welding seams cannot exceed 20% of the total number of bars; (3) the bars connected by nodes cannot all be bars with welding seams; (4) the length of bars to be welded should be at least 300 mm. The above restricted conditions are converted to mathematical version, as follows.

Condition ①: whether it is a draw bar is determined according to the numerical value of the internal force of bar A_i in the generated chromosome coding. If the numerical value of the internal force is positive, then it is a draw bar, and welding seams are not allowed; if it is negative, then it is a compression bar or bending bar, and only one welding seam is allowed. If meet seams then jump to the next raw material B_{i+1}.

Condition ②: when $s > 0.2I$ (s is the total number of bars with welding seams, and I is the total number of bars), according to the number of welding seams on the bar at the node of the steel structure building, the bars are sorted in order. If meet bars with welding seams at the node then jump to the next bar during layout.

Condition ③: the number of bars with welding seams at the node where bar A_i is located is recorded. If the number exceeds 20% of the total number of bars at the node, then jump to the next raw material during layout.

Condition ④: when $L_{B_j} - L_{A_i} < 300mm$, the layout of A_{i+1} needs to be conducted on B_{j+1}.

⑤ Genetic operations, including selection, crossover and mutation, are carried out on chromosomes in the population. The single-point crossover is used in both the component coding region and the raw material coding region of chromosomes. As shown in Figure 3, two chromosomes are randomly selected, and a crossover position is randomly selected (the intersection position of two chromosomes is the same). The coding sequence before the position keeps the same. After being added to the region to be exchanged, it is also regarded as the region to be exchanged, and then the genetic codes of the regions to be exchanged of the two chromosomes are exchanged. Finally, the same genetic codes in the exchange region and the non-exchange region are removed.

Mutation operation adopted the single-point position exchange. One chromosome is randomly selected, and then two positions are randomly selected in the component coding region to exchange genetic code. The treatment for the material coding region is the same. To enhance the convergence of the algorithm, the “excellent chromosome reservation” strategy is implemented for both operations. Before crossover and mutation, the best and worst chromosomes are selected from the parent chromosome. Suppose the optimal chromosome is selected for crossover or mutation. In that case, the excellence of the filial generation is compared with that of the parental generation, and the more excellent one is reserved. The worst chromosome must be crossed or mutated and replaced by the filial generation, and the other chromosomes were crossed or mutated according to conventional crossover and mutation operations.

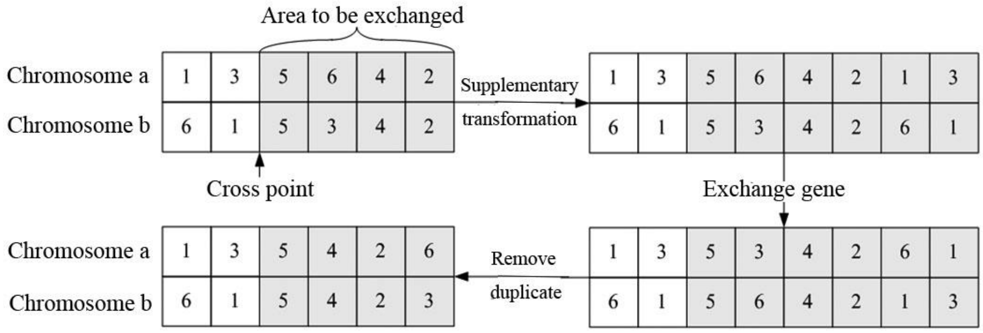

Fig. 3 – The flow of single-point crossover operation

⑥ Whether the algorithm terminates is determined. The termination conditions include the maximum number of iterations and population fitness convergence. If the termination condition is satisfied, the optimal solution is output and decoded according to the layout strategy. If the termination condition is not reached, it returns to step ④.

CASE ANALYSIS

Case overview

The construction management subject for case analysis in this study is a grid-shaped steel shed in Zhengzhou City, Henan, China, and its structure diagram is shown in Figure 4. The whole steel shed is composed of steel. The grid structure is adopted to ensure the strength of the roof. The grid structure which can be assembled and welded can reduce the construction difficulty. The distance between the supporting columns is 10 m, the height and diameter of the columns is 5 m, and the height of the roof is 1.5 m. To ensure the stability of the roof, the double-layer structure is adopted, and the staggered steel pipe structure is used between the upper and lower layers, and stable triangles are formed between the steel pipes. The diameter of the staggered steel pipe is 0.11 m. The diameter of vertical steel pipes used for supporting the roof on the roof beams and beams is 0.09 m. After modelling the steel shed with BIM, it was found that 535 steel joints and 3845 steel bars were needed in the construction process. The BIM software used in this study was Navisworks, and the GA needed by the layout scheme optimization was written in the VB language.

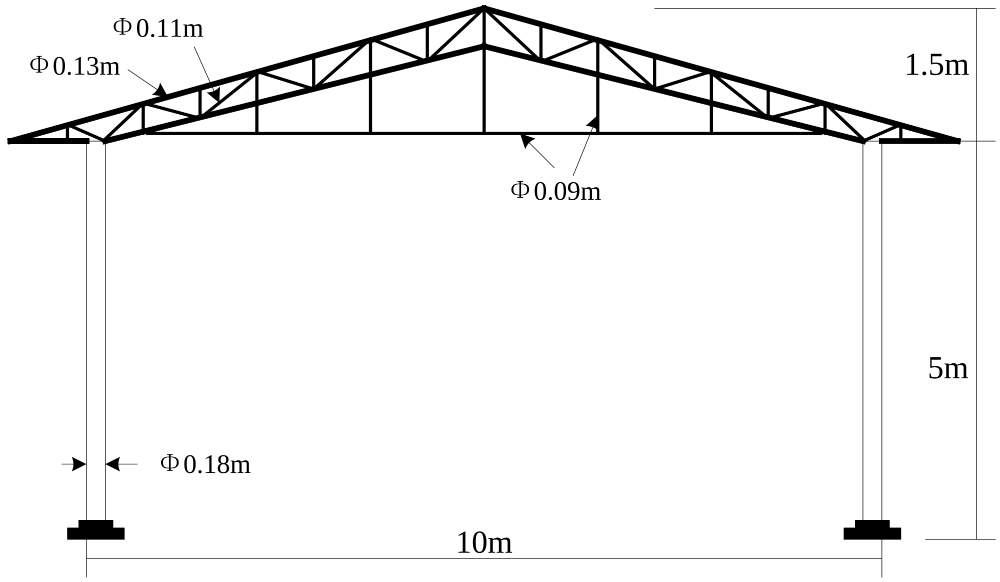

Fig. 4 – The structural diagram of the grid-shaped steel shed

Experimental setup

During the construction of the grid-shaped steel shed, it is an important construction management project to count the specification and number of steel bars and raw materials required for construction. In this construction management project, the scheme optimization of processing raw materials into steel bars was also included. Table 1 shows the basic parameters of steel members and raw materials required in the construction process of grid-shaped steel shed. It was seen from Table 1 that there were four specifications of steel bars, and the quantity required for each specification is described in Table 1. The basic specifications of raw materials used for making steel bars were also consistent with those of steel bars. Q235 steel was used as the material of steel bars [20]. The length of the bar was smaller than that of the raw material in Table 1.

Tab. 1 - Basic parameters of steel bars and raw materials needed in the construction of the grid-shaped steel shed

	Specification/mm	Number	Material	Length/mm
Steel bar	$\phi 180\times 6$	986	Q235	1200~4300
	$\phi 130\times 4$	887		100~4500
	$\phi 110\times 4$	1011		1100~4800
	$\phi 90\times 3$	961		1000~4300
Raw material	$\phi 180\times 6$	15		8000~12000
	$\phi 130\times 4$	10		7000~10000
	$\phi 110\times 4$	12		6000~11000
	$\phi 90\times 3$	10		5000~9000

In this study, the processing scheme of raw materials was optimized by the genetic algorithm. The parameters of the genetic algorithm are set as follows: population size: 70; maximum times of iteration: 500; crossover probability: 0.8; mutation probability: 0.2. When the genetic algorithm was used for optimization, the layout strategy adopted followed the following principles: 1) if welding was required for steel bars during manufacturing, only one weld was allowed; 2) steel bars without welding joints shall not be less than 80% of the total quantity; 3) at least one bar connected to any node had no weld; 4) the length of the bar to be welded shall not be less than 300 mm.

In addition to the GA, this study also used the PSO algorithm for comparison. In the PSO algorithm, the size of the population was 70, the maximum number of iterations was set as 500, two learning factors were both set as 1.5, and the inertia weight was set as 0.8. The coding and decoding modes of the population particles in the PSO algorithm were the same as the GA.

Experimental results

In the construction process of the grid-shaped steel shed, when using raw materials to make steel bars, it was necessary to select the corresponding specifications of raw materials according to the specifications of the bars. Therefore, in the design of the optimal scheme, the overall optimal result could be obtained as long as the optimal schemes under different specimens were considered. The utilization rate of raw materials in the traditional scheme and the scheme of BIM combined with the genetic algorithm is shown in Table 2 and Figure 5. It was seen from Table 2 that the utilization rate of the traditional scheme, the PSO combined BIM optimization scheme, and the GA combined BIM optimization scheme was 92.3%, 94.5%, and 99.7% under the specification of $\phi 180\times 6$, 93.1%, 95.1%, and 99.6% under the specification of $\phi 130\times 4$, 92.1%, 94.6%, and 99.5% under the specification of $\phi 110\times 4$, and 91.4%, 94.8%, and 99.4% under the specification of $\phi 90\times 3$. The overall utilization rate of the traditional scheme, the PSO combined BIM optimization scheme, and the GA combined BIM optimization scheme was 92.2%, 94.7%, and 99.6%, respectively. Figure 5 clearly shows that no matter what the specification was, the GA combined BIM optimization scheme had the highest utilization rate.

Tab. 2 - Utilization rates of raw materials in the traditional scheme and BIM optimized schemes

Material specification/mm	Traditional scheme	PSO combined BIM optimization scheme	GA combined BIM optimization scheme
$\phi 180\times 6$	92.3%	94.5%	99.7%
$\phi 130\times 4$	93.1%	95.1%	99.6%
$\phi 110\times 4$	92.1%	94.6%	95.5%
$\phi 90\times 3$	91.4%	94.8%	99.4%

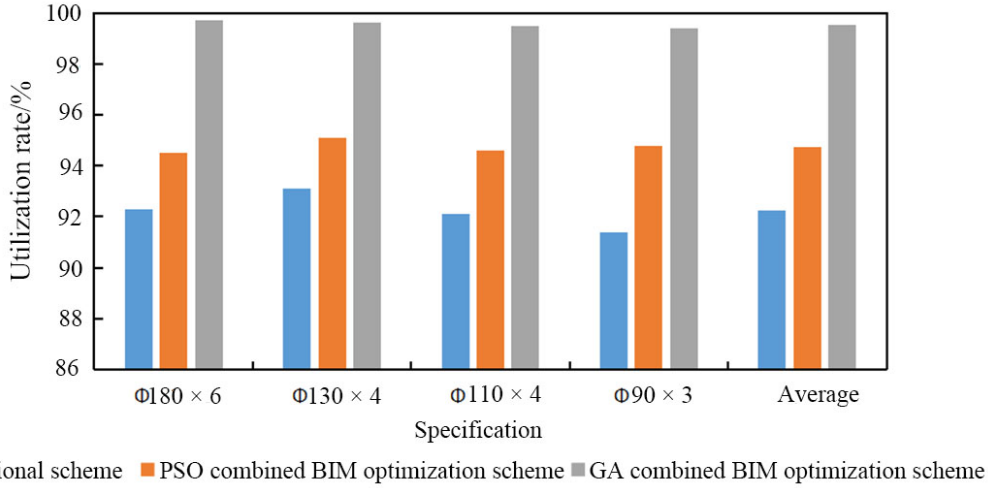

Fig. 5 – The utilization rate of raw materials with different specifications under the traditional scheme and the BIM optimization scheme

The economic comparison between the BIM optimized processing schemes and the traditional scheme is shown in Table 2, which indicates the total amount, unit price, and utilization rate of processing materials, construction drawing design, numerical control programming, and processing labour costs. The total amount of materials and unit price came from the pre-designed construction scheme. The salary of staff referred to the average salary of relevant works. The number of project participators in the traditional scheme referred to the number of participators originally involved in the construction project. The number of participators in the optimization schemes referred to the case study of the project. As the GA combined BIM optimization scheme had a higher utilization rate for materials, the waste was less; the reduced part was the saved cost, 49950 yuan. In the traditional scheme, more people were needed to design the plane drawing, and communication between people was also needed to avoid the description error of the same component in different drawings. In the BIM optimization schemes, the standard model could be obtained by inputting relevant data, and the description on the same component was more consistent, which saved the communication time; thus, the workforce and time consumption was less, and 27300 yuan was saved for the design of the construction drawing. In the traditional scheme, the numerical control programmers needed to write the control program of the processing instrument according to the drawing, while the BIM optimization schemes only needed to transform relevant data into the unified format that the numerical control instrument could recognize, which greatly reduced the workforce and time consumption and saved a numerical control programming cost of 3640 yuan. In the traditional scheme, the cutting and welding of materials were fresh, which did not take the waste and the reduction of welding work amount into account, while the BIM optimization schemes reduced the number of materials that needed to be cut and welded, which reduced the processing time and the number of workers and saved a cost of 15000 yuan. The GA combined BIM optimization scheme saved 95890 yuan and 30 days compared to the traditional scheme. The comparison between the PSO combined BIM optimization scheme and the traditional scheme is also shown in Table 3. The utilization rate of raw materials of the PSO combined BIM optimization scheme was 94.8%, and it saved 17500 yuan compared to the traditional scheme. The labour cost of the PSO combined BIM optimization scheme was consistent with that of the GA combined BIM optimization scheme. Although there was a difference in time between the two schemes because of the complex design of the steel structure, the difference was insignificant compared to the whole construction period. The labour cost of the above two schemes was lower than that of the traditional layout scheme, which was because BIM was used as an auxiliary. Finally, it was seen from Table 3 that the final cost saving of the GA combined BIM optimization scheme was more excellent than the PSO combined BIM optimization scheme.

Tab. 3:- Comparison of economic benefits between schemes

	Traditional scheme	PSO + BIM optimization scheme	GA + BIM optimization scheme	The saved cost of the PSO + BIM optimization scheme/yuan	The saved cost of the GA + BIM optimization scheme/yuan	The total saved cost of the PSO + BIM optimization scheme/yuan	The total saved cost of the GA + BIM optimization scheme/yuan	The total saved construction time of the PSO + BIM optimization scheme/day	The total saved construction time of the GA + BIM optimization scheme/day
The utilization rate of materials/%	92.2%	94.8%	99.6%	17500	49950	63440	95890	30	30
The total amount of materials/t	150								
Material unit price (yuan/t)	4500								
Number of people designing the construction drawing/n	10	3	3	27300	27300				
Design time of construction drawing/time	15	2	2						
Salary of construction drawing designer (yuan/day)	300								
Time of numerical control programming/day	8	1	1	3640	3640				
Number of numerical control programmers/n	4	2	2						
Salary of numerical control programmer (yuan/day)	260								
Processing time/day	10	10	10	15000	15000				
Number of processors/n	12	6	6						
Salary of processor (yuan/day)	250								

CONCLUSION

This paper briefly introduced the relevant content of BIM and the application of BIM combined with the genetic algorithm in optimizing the processing scheme in the cutting process of steel structure buildings. Finally, taking a grid-shaped steel shed in Zhengzhou, Henan, China, as an example, the study compared the traditional scheme, the PSO combined BIM optimization scheme, and the GA combined BIM optimization scheme. The results are as follows: (1) the construction of the grid-shaped steel shed needed four specifications of steel bars, including $\phi 180\times 6$, $\phi 130\times 4$, $\phi 110\times 4$, and $\phi 90\times 3$, and no matter which specification was, the GA combined BIM optimization scheme had the highest utilization rate of raw materials; (2) in terms of economic benefits, the GA combined BIM optimization scheme saved 9589 yuan and 30 days compared with the traditional scheme, which was more excellent than the PSO combined BIM optimization scheme. One of the limitations of this paper is that it only studied one artificial intelligence algorithm, i.e., the GA. Although the GA was compared with the PSO algorithm, research on the combination of BIM and intelligent algorithms was seldom. The other limitation is that the application of BIM combined with artificial intelligence in construction management was only applied to steel structure buildings. The future research direction is to combine more intelligent algorithms with BIM and expand its application in construction management to more kinds of buildings.

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