



## Application Research on Exploring the Realization Path of Intelligent Technology for Complex Node Connection Construction of Aluminum Tapered Core Composite Plate Curtain Walls

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**SUMMARY:** *With the rapid development of high-rise buildings in urban areas, curtain wall construction requires more efficient intelligent methods. Therefore, this paper proposes an intelligent scheduling method for curtain wall construction progress plans based on an improved genetic algorithm. Building on the exploration of intelligent technologies for curtain wall construction, an optimization model for curtain wall construction progress plans considering assembly principles was established. The improved genetic algorithm was applied to solve this model, yielding a construction progress plan with the shortest duration. The method was validated and applied in an actual 10-story office building project. The results show that this intelligent scheduling method can significantly reduce the construction schedule while considering various constraints. The total construction schedule for the aluminum cone-core composite panel curtain wall node connection project was 90 days, which was completed 5 days ahead of the contract-specified schedule. This method can provide a reference for the scheduling of similar curtain wall construction projects.*

**KEYWORDS:** *aluminum cone-core composite panel curtain wall; complex node connection; intelligent technology; improved genetic algorithm*

### 1 Introduction

In today's booming construction industry, the stability and reliability of building structures are critical to the safety of people's lives and property [1, 2]. Currently, aluminum cone-core composite panels have become one of the primary facade materials for building curtain walls, emerging as an ideal alternative to glass and stone curtain walls. They are increasingly recognized and adopted by architects and property owners [3-5]. Notable urban landmarks such as the Shenzhen International Trade Center, the Shanghai Oriental Pearl TV Tower, the Shanghai F1 International Circuit, and Beijing Capital International Airport have all extensively utilized aluminum-plastic composite panels as exterior wall decorative materials [6-8].

As a new material for exterior curtain walls, aluminum cone-core composite panels offer significant advantages in terms of environmental protection, cost savings, aesthetic appeal, construction speed, and safety. Additionally, they feature lightweight properties, moderate stiffness, vibration damping, sound insulation, and excellent decorative effects [9-12]. Their surfaces can undergo secondary treatments such as corrosion protection, embossing, painting, and printing, comparable to aluminum panels but at a much lower cost. After years of development, aluminum cone-core composite panels have become technically mature [13-15].

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The material is typically pre-treated at the factory to ensure a certain level of safety and reliability, such as corrosion resistance, weather resistance, impact resistance, bending resistance, and compressibility [16-18].

With the development of artificial intelligence, the construction of aluminum cone core composite panel curtain walls has also become increasingly intelligent, effectively reducing labor costs and improving construction quality and efficiency, especially in the construction of complex curtain wall node connections. The intelligent technologies adopted in complex node connection construction are primarily reflected in three-dimensional digital modeling and unit segmentation, fine-tuning support systems, and overall lifting [19-22]. Although aluminum cone-core composite panels offer numerous advantages, they remain a relatively new technology and still have some drawbacks [23, 24]. On one hand, governments need to maintain strict requirements and supervision of safety standards in the construction industry [25, 26]. On the other hand, to enhance the quality and stability of construction projects, curtain wall engineering should establish detailed plans, implement reasonable and effective construction measures, and utilize scientific techniques to address issues encountered during construction. This should be done while ensuring both economic benefits and the safety of people's lives [27-30].

This paper first analyzes the implementation path of intelligent technology for the construction of aluminum cone-core composite panel curtain walls and explores specific issues related to the scheduling of curtain wall construction progress plans using intelligent technology. Based on the principle of assembly, a mathematical model for optimizing curtain wall construction progress plans is established. Additionally, an improved genetic algorithm is proposed. This algorithm incorporates an elite strategy to enhance algorithm convergence, employs adaptive operators to improve solution quality, and utilizes a catastrophe operator inspired by the forbidden search algorithm to increase population diversity. The algorithm also integrates a construction schedule compilation method, enabling the automatic generation of optimal construction schedules. Finally, a specific case study is conducted using an actual 10-story office building project as the subject.

## **2 Implementation path for intelligent technology in the construction of aluminum cone core composite panel curtain walls**

### **2.1 Aluminum cone core composite panel curtain wall**

Aluminum cone core composite panels are three-dimensional composite decorative panels with an all-aluminum structure. They are manufactured through a continuous roll-pressing composite process, consisting of a surface aluminum sheet, a cone-shaped core layer, and a bottom aluminum sheet. The material was designed to integrate the advantages of four traditional curtain wall panels—aluminum-plastic panels, aluminum single panels, aluminum honeycomb panels, and stone—while avoiding their shortcomings, thereby creating a new type of environmentally friendly, high-performance building decoration material.

## **2.2 Intelligent construction technologies applied in building curtain wall installation**

This section provides a brief overview of the intelligent construction technologies applied in the construction of complex node connections for aluminum cone core composite panel curtain walls.

### **2.2.1 Automated Mechanical Technology**

The application of automated mechanical technology has made the construction of complex node connections in aluminum cone-core composite panel curtain walls more efficient, precise, and reliable. For example, high-precision automated lifting equipment, equipped with advanced positioning and control systems, can precisely lift and place curtain wall panels in their designated positions, significantly improving installation accuracy and efficiency. Intelligent material handling robots navigate the construction site with agility, transporting curtain wall materials along predetermined routes to the required locations with absolute precision, thereby replacing manual labor and reducing both physical strain and potential safety risks. Additionally, automated drilling and sealing equipment play a crucial role in ensuring that curtain wall installation quality reaches the highest possible standards.

### **2.2.2 CAD and CAM**

During the design phase, CAD systems are used to create 3D models of aluminum cone core composite panel curtain walls, enabling designers to visualize the overall appearance and details of the curtain wall. Leveraging powerful computational and graphical processing capabilities, designers can precisely design and optimize complex shapes and structures to meet diverse architectural styles and functional requirements. The CAM system is closely integrated with production equipment, directly transmitting designed data to production machinery to enable automated processing and manufacturing. Additionally, through data analysis and processing, it monitors and adjusts the production process, promptly identifying and resolving any issues that arise.

### **2.2.3 BIM Technology**

BIM, as an integrated information management technology, seamlessly connects all stages of a construction project—from design and construction to operations and maintenance—forming a comprehensive, dynamic data ecosystem.

Prior to the installation of aluminum cone-core composite panel curtain walls, the project team uses BIM technology to create a 3D model. This not only captures the geometric characteristics of the aluminum cone-core composite panel curtain walls but also incorporates multi-dimensional information such as material properties, cost estimates, and construction schedules, providing a basis for decision-making regarding the installation of aluminum cone-core composite panel curtain walls. More importantly, the application of BIM technology in curtain wall installation promotes collaboration among all stakeholders, including designers, engineers, contractors, and even owners, enabling real-time information sharing, effective communication, reduced misunderstandings and conflicts, and improved overall project efficiency and quality.

During the construction phase, the project team uses BIM technology to simulate construction processes and identify potential issues in advance, such as collision detection and unreasonable resource allocation, enabling them to take preventive measures to avoid delays and rework on-site, ensuring smooth curtain wall installation. Additionally, the BIM platform can automatically generate construction documents, such as drawings, lists, and reports,

reducing the burden of manual drafting and improving the accuracy and consistency of documents.

In the post-construction maintenance phase, BIM technology continues to play a role by providing detailed maintenance guidelines and historical records, helping managers efficiently manage facilities and troubleshoot issues, thereby extending the lifespan of the curtain wall and reducing operational costs.

#### **2.2.4 Sensing and Internet of Things Technology**

The application of sensor and IoT technology in the complex node connections of aluminum cone core composite panel curtain walls provides a new solution for intelligent monitoring and automated control during the construction process. Construction companies deploy various types of sensors, such as displacement sensors, pressure sensors, and temperature sensors, at the construction site to collect key data in real time during the construction process. This data is then transmitted to a central monitoring system via IoT technology. This system not only provides real-time feedback on construction status but also uses data analysis to predict potential risks and issues, enabling proactive intervention and adjustments. For example, during curtain wall installation, sensors monitor structural stress and displacement to ensure the safety and accuracy of the installation. IoT technology also enables intelligent control of equipment, such as automatically adjusting the operating parameters of construction machinery to adapt to different construction conditions and requirements.

### **3 Intelligent curtain wall construction schedule planning based on IGA**

To further improve the efficiency of complex node connections in aluminum cone core composite panel curtain wall construction, this chapter uses an improved genetic algorithm (IGA) to intelligently arrange the curtain wall construction schedule.

#### **3.1 Problem Description**

This issue essentially involves identifying the installation sequence for complex nodes of aluminum cone-core composite panel curtain walls that least deviates from assembly principles. Assembled buildings typically have multiple layers, which can be divided into several sub-assemblies based on the number of layers. Each sub-assembly's aluminum cone-core composite panel curtain wall is further divided into different construction segments, each containing various types of prefabricated components. Additionally, components of the same type may have different installation sequences, resulting in a vast number of possible installation sequences.

#### **3.2 Establishment of mathematical models**

##### **3.2.1 Assembly Rules**

In manufacturing, we analyze product models during the assembly process and summarize assembly rules based on the geometric constraints between parts and their spatial relationships during assembly. Similarly, in building curtain wall installation, by reviewing literature and consulting experts, we have identified five categories of prefabricated components that are generally prioritized for installation during construction, as follows:

- (1) Components serving as connectors are prioritized for installation.

(2) Components with exposed main reinforcing bars in relatively lower positions are installed first.

(3) Components that are closer in distance are installed first.

(4) Heavier components are installed first.

(5) Components that occupy more space are installed first.

### 3.2.2 Mathematical Model

In order to quantitatively calculate whether the assembly sequence of an aluminum cone core composite panel curtain wall complies with the assembly rules, we adopt the penalty strategy described above and define the penalty values for the five rules as follows:

(1) Connection-related priority principle

During installation, certain connection relationships must be adhered to for some connection components to prevent them from failing to install properly. Specifically, if the two ends of a prefabricated component are connected to the midpoints of two other prefabricated components, then this component should not be the last one installed among the three prefabricated components. If this principle is violated, a penalty value is generated, defined as the ratio of the difficulty of installing the component under the violating condition to the difficulty of installing the component under the compliant condition. Assuming the assembly sequence includes  $n$  components, denoted as  $M_1, M_2, \dots, M_n$ . Form a penalty matrix  $A$ , where the  $i$ th column  $A_i$  is defined as the ratio of the installation difficulty  $P_i$  of  $M_i$  under the rule violation scenario to the installation difficulty  $P_{i0}$  under the normal scenario, as shown in Equation (1):

$$A_i = \begin{cases} \frac{P_i}{P_{i0}} & \text{Component } i \text{ is a connecting} \\ & \text{piece but is installed last } , i = 1, \dots, n \\ 0 & \text{else} \end{cases} \quad (1)$$

(2) Priority principles related to exposed reinforcing bars

During installation, components with main reinforcing bars at the bottom are generally installed first, followed by components with main reinforcing bars at the top. If this principle is violated, a penalty value is generated, which is defined as the ratio of the difficulty of installing the component in the violation case to the difficulty of installing the component in the compliance case. Form a penalty matrix  $B$ , where the  $i$ th column  $B_i$  is defined as the ratio of the installation difficulty  $Q_i$  under the rule violation to the installation difficulty  $Q_{i0}$  under normal conditions, as shown in Equation (2):

$$B_i = \begin{cases} \frac{Q_i}{Q_{i0}}, & \text{Exposed reinforcing bars in} \\ & \text{component } i \text{ are installed first, } i = 1, \dots, n \\ 0, & \text{else} \end{cases} \quad (2)$$

(3) Distance-related priority rule

During installation, the component closest to the previously installed component should be installed first. If this principle is violated, a penalty value will be generated, defined as the ratio of the distance between the component and the previously installed component to the distance between the component and the closest component. Here, we define the distance between components as the distance between their geometric centers. Form a distance matrix  $c$ , where

the  $c_{ij}$  in the  $i$ th row and  $j$ th column is defined as the distance between  $M_i$  and  $M_j$ . Perform calculations to obtain the penalty matrix  $C$ , where the  $c_{ij}$  in the  $i$ th row and  $j$ th column is defined as the ratio of the distance  $c_{ij}$  between precast components  $M_j$  and  $M_i$  to the minimum distance  $c_{i(\min)}$  between all components and  $M_i$ , as shown in Equation (3):

$$C_{ij} = \begin{cases} \frac{c_{ij}}{c_{i(\min)}}, & c_{ij} > c_{i(\min)}, i = 1, \dots, n, j = 1, \dots, n \\ 0, & c_{ij} \leq c_{i(\min)} \end{cases} \quad (3)$$

#### (4) Weight-related priority rules

If a lighter component is installed before a heavier component, a penalty value is generated, defined as the ratio of the weight of the component to the weight of the previously installed component. A weight matrix  $d$  is formed, where the  $i$ th column is defined as the weight  $G_i$  of component  $M_i$ . Performing the calculation yields the weight ratios between components, forming a matrix  $D$ , where the  $D_{ij}$  in the  $i$ th row and  $j$ th column is defined as the ratio of the weight  $G_i$  of  $M_i$  to the weight  $G_j$  of  $M_j$ , as shown in Equation (4):

$$D_{ij} = \begin{cases} \frac{G_j}{G_i}, & G_j > G_i, i = 1, \dots, n, j = 1, \dots, n \\ 0, & G_j \leq G_i \end{cases} \quad (4)$$

#### (5) Space-related priority rules

If a component with a smaller footprint is installed before a component with a larger footprint, a penalty value is generated, defined as the ratio of the weight of the component to the weight of the previously installed component. Form a space-occupying matrix  $E$ , where the  $E_{ij}$  in the  $i$ th row and  $j$ th column is defined as the ratio of the volume  $V_i$  of  $M_i$  to the volume  $V_j$  of  $M_j$ , as shown in Equation (5):

$$E_{ij} = \begin{cases} \frac{V_j}{V_i}, & V_j > V_i, i = 1, \dots, n, j = 1, \dots, n \\ 0, & V_j \leq V_i \end{cases} \quad (5)$$

The aforementioned five rules exhibit certain contradictions during the assembly process; therefore, a weighted method is employed to impose constraints on these five rules. Let  $I$  denote an assembly sequence, and  $I(i)$  denote the  $i$ th prefabricated component in the assembly sequence. The weights of the five rules are set as  $w_1, w_2, w_3, w_4$ , and  $w_5$ , respectively. The objective function of the assembly sequence is shown in Equation (6):

$$\begin{aligned}
 \min N &= w_1 \sum_{i=1}^{n-1} A_i + w_2 \sum_{i=1}^{n-1} B_i + w_3 \sum_{i=1}^{n-1} C_{I(i)I(i+1)} \\
 &\quad + w_4 \sum_{i=1}^{n-1} D_{I(i)I(i+1)} + w_5 \sum_{i=1}^{n-1} E_{I(i)I(i+1)} \\
 w_1 &= w_2 = 10 \sum C_{ij} + \sum D_{ij} + \sum E_{ij} \\
 w_3 &= 10 \\
 w_4 &= w_5 = 1 \\
 w'_k &= \frac{w_k}{\sum_{k=1}^5 w_k}
 \end{aligned} \tag{6}$$

$N$  represents the degree of rule violation. To shorten assembly time and improve assembly quality, the degree of rule violation should be as small as possible. Therefore, the assembly sequence that minimizes  $N$  should be optimal. However, due to the limitations of the genetic algorithm's parameters, it can only guarantee that each search result is no worse than the previous one. Thus, the objective of this paper is to find a relatively satisfactory sequence rather than necessarily the optimal one.

Solutions screened by Rules 1 and 2 are feasible lifting sequence solutions, while solutions screened by Rules 3, 4, and 5 are satisfactory lifting sequence solutions. The adjusted objective function is shown in Equation (7):

$$\begin{aligned}
 \min N &= w'_1 \sum_{i=1}^{n-1} A_i + w'_2 \sum_{i=1}^{n-1} B_i + w'_3 \sum_{i=1}^{n-1} C_{I(i)I(i+1)} \\
 &\quad + w'_4 \sum_{i=1}^{n-1} D_{I(i)I(i+1)} + w'_5 \sum_{i=1}^{n-1} E_{I(i)I(i+1)}
 \end{aligned} \tag{7}$$

### 3.3 Mapping Principles

The optimization model for assembly sequences can be mapped to a genetic algorithm based on the following rules, with the assembly sequence serving as the solution vector for the genetic algorithm, where the number of prefabricated components is the dimension of the solution vector. Fitness is measured by the ease of construction, and the objective function is given by Equation (7). The population size is adjusted according to the number of components, and the optimization results improve as the population size increases, but the computation time also increases accordingly.

### 3.4 Improving Genetic Algorithm Design

This paper proposes an improved genetic algorithm [31] (IGA) that utilizes elite strategies, adaptive operators, and catastrophe operators to enhance the algorithm's global optimization capabilities, thereby effectively solving the construction schedule optimization model. Additionally, an LSM-based construction schedule planning method is incorporated into the IGA to generate construction schedule diagrams for each scheme. The IGA process is illustrated in Figure 1.

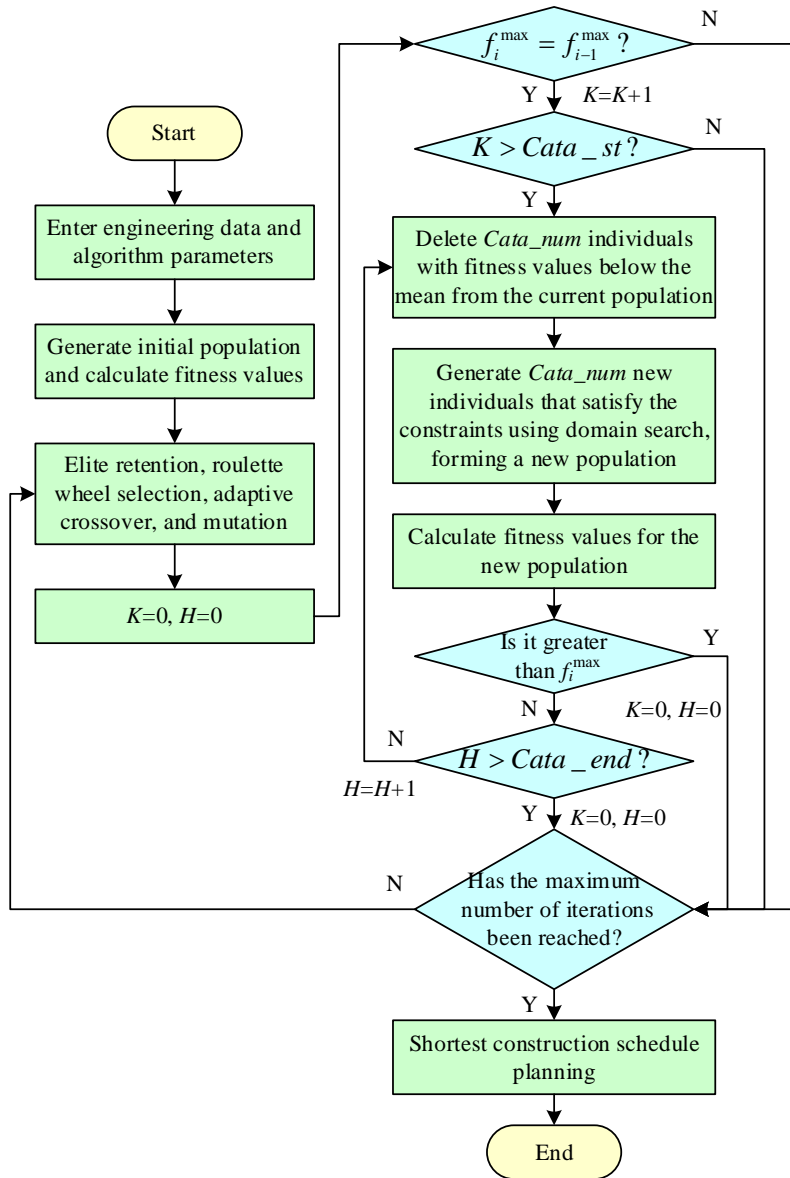


Figure 1: Flowchart of the improved genetic algorithm

### 3.4.1 Encoding and Generating the Initial Population

Since the decision variables in this paper are the construction mode and construction direction, the chromosomes are divided into two parts, and symbol encoding is selected. The chromosome diagram is shown in Figure 2. The first part represents the construction mode for linear activities. The  $j$ th gene value  $gene_j$  denotes the construction mode code corresponding to the  $I$ th activity in the  $J$ th construction unit, with an encoding length equal to the product of the number of project activities and the number of construction units ( $M \times N$ ). The second part represents the construction direction of linear activities. The  $I$ th gene value  $gene_I$  denotes the construction direction code  $P_I$  of the  $I$ th activity, with an encoding length equal to the number of linear activities  $M$ . To improve the convergence speed of the algorithm and eliminate invalid solutions,  $popsiz$ e chromosomes are randomly generated according to equations (8) to (10) to form the initial population  $GApop0$ :

$$I = \left\lfloor \frac{j}{N} \right\rfloor, J = j - (I - 1) \times N, j = 1, 2, \dots, M \times N \quad (8)$$

$$0 < gene_j < W_{IJ}, j = 1, 2, \dots, M \times N, gene_j \in Z \quad (9)$$

$$P_I = gene_{I} \in \{0, 1\}, I = 1, 2, \dots, M \quad (10)$$

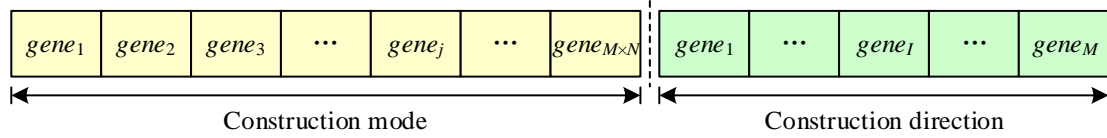


Figure 2: Schematic diagram of chromosomes

### 3.4.2 Calculating Fitness Values and Preparing Construction Schedule Charts

The goal of schedule optimization is to minimize the project duration while satisfying the constraints. Therefore, the reciprocal of the construction schedule duration  $T_{end}$  corresponding to each chromosome is used as the fitness value  $f$  of that chromosome.

Step 1: Calculate the earliest start time ( $ST_{con(bj)}$ ) and earliest finish time ( $ET_{con(bj)}$ ) of activity  $b$  in each construction unit based on the start constraint and continuity constraint. If activity  $b$  has no preceding activity, then this time is its construction time. Otherwise, proceed to Step 2.

Step 2: Based on the type of activity  $b$  and its preceding activity, calculate the earliest start time ( $ST_{bj}^{Pre_b}$ ) and end time ( $ET_{bj}^{Pre_b}$ ) of activity  $b$  in each construction unit under the time constraint.

Step 3: Activity  $b$  may not satisfy the construction continuity constraint even if it satisfies the time constraint. Therefore, according to equation (11), calculate the difference ( $shift_b^{Pre_b}$ ) in the construction time of activity  $b$  in each construction unit under the time constraint and construction continuity constraint based on the preceding activity, i.e., the time that needs to be delayed based on  $ST_{con(bj)}$ . Since an activity may have multiple preceding activities, the maximum difference ( $shift_b$ ) is calculated using Equation (12) to ensure that activity  $b$  satisfies the time constraints of all preceding activities and the continuity of each construction unit:

$$shift_{bj}^{Pre_b} = ST_{bj}^{Pre_b} - ST_{con(bj)}, Pre_b = \{\alpha, \beta, \gamma\}, \quad (11)$$

$$\alpha \in I_L, \beta \in I_S, \gamma \in I_B, j = N_b^S, \dots, N_b^F$$

$$shift_b = \max\{shift_{bj}^{Pre_b}\}, Pre_b = \{\alpha, \beta, \gamma\}, \quad (12)$$

$$\alpha \in I_L, \beta \in I_S, \gamma \in I_B, j = N_b^S, \dots, N_b^F$$

Step 4: Calculate the actual start and end times for activity  $b$  :

$$ST_{bj} = ST_{con(bj)} + shift_b, ET_{bj} = ST_{bj} + \sum_{w=1}^{W_{bj}} X_{bjw} \times \frac{Q_{bj}}{R_{bjw}}, \quad (13)$$

$$b \in \{I_L, I_S, I_B\}, j = N_b^S, \dots, N_b^F$$

Step 5: Calculate the fitness value of the construction plan:

$$f = \frac{1}{T_{end}} = \frac{1}{\max(ET_{ij})}, \quad (14)$$

$$i \in \{I_L, I_S, I_B\}, j = N_i^S, \dots, N_i^F$$

Finally, based on the construction time obtained in Step 4, the construction schedule chart corresponding to the plan is drawn based on the classification of activities in the LSM and their graphical representation in the construction schedule plan.

### 3.4.3 Select Operator

Using the fitness values calculated in equation (14) as a basis, individuals are selected from the population using the roulette wheel method [32], where the probability of each individual being selected,  $Pr_i$ , is proportional to its fitness value. At the same time, in order to effectively address the problem of premature convergence, an elite strategy is adopted to retain the best individuals in the population:

$$Pr_i = \frac{f_i}{\sum_{j=1}^{popsize} f_j} \quad (15)$$

### 3.4.4 Adaptive operators

Adaptive operators can improve the global search capability and convergence accuracy of genetic algorithms. The adaptive operator in this paper is shown in Equation (16):

$$P_c = \begin{cases} 0, & f' = f_{\max} \\ \sin\left(\frac{1}{2} + \frac{\max gen - i}{\max gen}\right) \\ \times \left(P_{c1} - \frac{(P_{c1} - P_{c2})(f' - f_{avg})}{f_{\max} - f_{avg}}\right), & f_{avg} \leq f' < f_{\max} \\ P_{c1}, & f' < f_{avg} \end{cases} \quad (16)$$

$$P_m = \begin{cases} 0, & f = f_{\max} \\ \sqrt{\sin\left(\frac{\max gen - i}{\max gen}\right)} \\ \times \left(P_{m1} - \frac{(P_{m1} - P_{m2})(f - f_{avg})}{f_{\max} - f_{avg}}\right), & f_{avg} \leq f < f_{\max} \\ P_{m1}, & f < f_{avg} \end{cases}$$

In the equation:  $\max gen$  is the maximum number of iterations of the algorithm,  $i$  is the current iteration number,  $P_{c1}$  and  $P_{c2}$  are the upper and lower limits of the crossover probability adjustment,  $P_{m1}$  and  $P_{m2}$  are the upper and lower limits of the mutation probability adjustment,  $f'$  is the larger fitness value in the crossover individual,  $f$  is the fitness value of the mutation individual,  $f_{\max}$  is the maximum fitness value in the current population, and  $f_{avg}$  is the average fitness value of the current population.

### 3.4.5 Cross operators and mutation operators

#### (1) Crossover operator

For the first chromosome segment, uniform crossover is selected, i.e., the probability  $Pr_j$  of randomly generating the  $j$ th gene is calculated. When this probability is greater than the exchange probability  $P$ , an exchange is performed. For the second chromosome segment, single-point crossover is selected, i.e., a crossover point is randomly selected, and the genes after the crossover point are exchanged. In this paper, the exchange probability  $P = 0.5$ , and the crossover operator is illustrated in Figure 3.

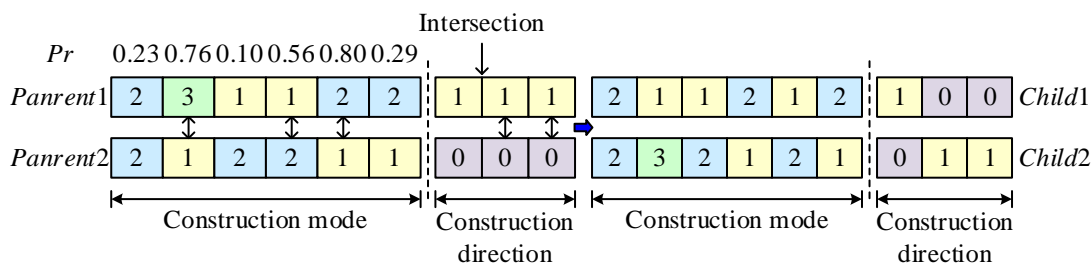


Figure 3: Schematic diagram of the crossover operator

#### (2) Mutation operator

Randomly select one part of the construction mode genes and one part of the construction direction genes, and regenerate their gene values according to equations (9) to (10).

Finally, judge the chromosomes after crossover and mutation according to the cost constraint, that is, they must not exceed the expected total direct cost of the project. If they do not meet the requirement, perform crossover and mutation again until they meet the requirement.

### 3.4.6 Catastrophe Operator

The catastrophe operator can be used when the optimal solution remains unchanged after multiple iterations of the algorithm. It randomly updates some of the poorer individuals in the population to search other regions of the individual set, thereby more effectively improving the diversity of the population. The catastrophe operator is designed as follows:

#### (1) Catastrophe conditions

When the cumulative number of iterations  $K$  when the maximum fitness value is equal is greater than the catastrophe threshold  $Cata\_st$ .

#### (2) Catastrophe method

Step 1: Determine the maximum number of catastrophe occurrences  $Cata\_end$  and the cumulative number of catastrophe occurrences  $H$ , setting  $H = 0$ .

Step 2: Calculate the fitness of the current population. If the number of individuals with fitness values below the mean  $Cata\_num$ , delete them.

Step 3: Introduce the idea of neighborhood search from the tabu search algorithm [33] to generate  $Cata\_num$  new chromosomes, add them to the current population, and form a new population. Specifically, for the optimal chromosome in the current population, in the construction mode part, randomly select a gene position and take a value different from the original value. In the construction direction part, take the opposite of the activities for which the construction direction can be selected. Then, evaluate the chromosomes after neighborhood search under the constraints of equations (8) to (10). If the constraints are satisfied, retain the chromosome; otherwise, regenerate it. Under this rule, generate  $Cata\_num$  new individuals.

Step 4: Calculate the fitness value of the optimal individual in the new population. If it is greater than the optimal individual in the old population, the catastrophe ends, and  $K$  and  $H$  are reset to zero. If it is not better than the optimal value of the old population but  $H > Cata\_end$ , the catastrophe ends, and  $K$  and  $H$  are reset to zero. Otherwise,  $H + 1$ , and return to Step 2.

### 3.4.7 Termination Conditions

The number of iterations affects the speed of computation and convergence. The maximum number of iterations is used as the termination condition, and the shortest construction period plan and its construction schedule diagram are output.

## 4 Case Study

### 4.1 Project Overview

A 10-story office building plans to install a modern aluminum cone-core composite panel curtain wall system to enhance the building's appearance and improve energy efficiency, optimizing natural lighting and thermal efficiency. The curtain wall structure is designed for a service life of 30 years. The seismic design intensity is 8 degrees, the design seismic group is Group 3, and the design basic seismic acceleration is 0.12g. The basic wind pressure value is considered based on a recurrence period of 60 years: 0.40 kN/m<sup>2</sup>. The basic snow load is 0.12 kN/m<sup>2</sup>, considered based on a 60-year recurrence period. The ground roughness category is Class B. The annual maximum temperature difference for the curtain wall is 75°C. The scope of the curtain wall project includes: architectural glass curtain walls, aluminum cone core panel curtain walls, grilles, rainproof louvers, canopies, decorative trim, etc., with a contract-specified construction period of 95 days.

The project includes glass curtain walls, stone decoration, and metal components. Each floor is divided into 3 horizontal construction zones, and the entire curtain wall installation project will be divided into 30 construction units. The project comprises 9 construction processes, each with its own logical constraints and must be carried out in a specific sequence. The curtain wall project will be implemented by 3 specialized construction teams.

### 4.2 Improving the application verification of genetic algorithms

This paper verifies the optimization effect of the construction plan for the connection of aluminum cone core panel curtain wall nodes in the construction industry, with the optimization objective of minimizing the construction period while keeping costs and quality within a certain range. The software operating parameters are shown in Table 1, including the improved genetic algorithm operating parameters and cost and quality thresholds.

Table 1: Software operating parameters

Parameters	Numerical value
Population size	800
Evolutionary Algebra	160
Real number encoding length	15
Binary encoding length	30
Cross probability	0.85
Mutation probability	0.08
Maximum cost /10 <sup>4</sup> yuan	240
Minimum quality	9.0

The number of individuals that meet and do not meet the constraints, as well as the proportion of individuals that do not meet the constraints in the entire population, are shown in Figure 4 as they change with the number of evolutionary generations. In the first generation, individuals are randomly generated, resulting in a high number of individuals that do not meet the constraints and a high proportion of such individuals in the population. As evolution progresses, the number of individuals that do not meet the constraints decreases rapidly due to the constraints imposed by the catastrophe operator. By the fourth generation, the number of individuals that do not meet the constraints has decreased to 28 and continues to decrease until the proportion of such individuals in the population is below 0.1%. As can be seen, during the evolutionary process, individuals that meet the constraints constitute the vast majority of the population, ensuring that optimal individuals can be generated through selection, crossover, and mutation operations.

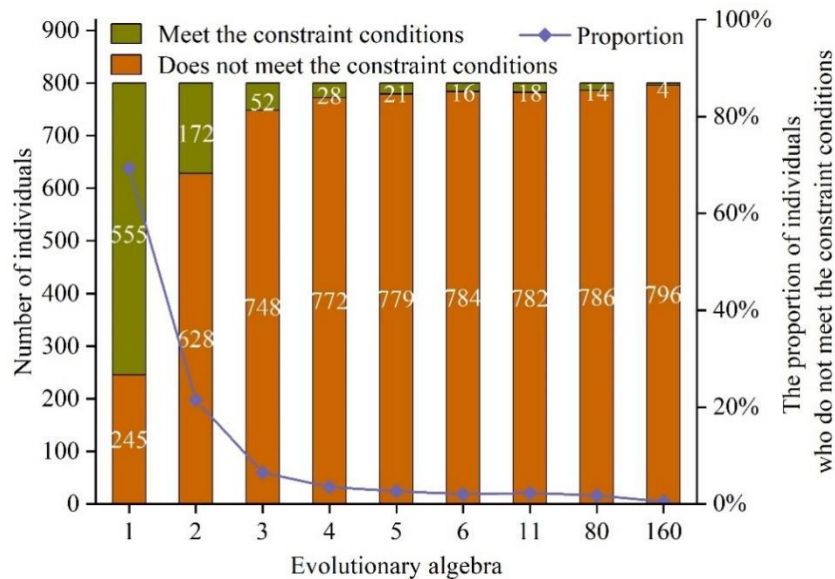


Figure 4: Population individual status

In the process of optimizing airport runway construction plans using an improved genetic algorithm, the curves showing the changes in optimal fitness and average fitness with the number of evolutionary generations are shown in Figure 5. It can be observed that the optimal fitness value remains constant from the first generation until the end of evolution. This indicates that the gene representing the optimal construction plan is generated in the first generation. Due to the use of adaptive operators, it is not disrupted during evolutionary operations such as selection, crossover, and mutation, and is passed on to the next generation of the population.

The average fitness value exhibits a rapid tendency to converge toward the optimal fitness value as evolution progresses, indicating that genes other than the optimal gene in the population tend to converge toward the optimal gene through genetic operations. This demonstrates that the use of adaptive operators can accelerate the convergence speed and improve the accuracy of optimization.

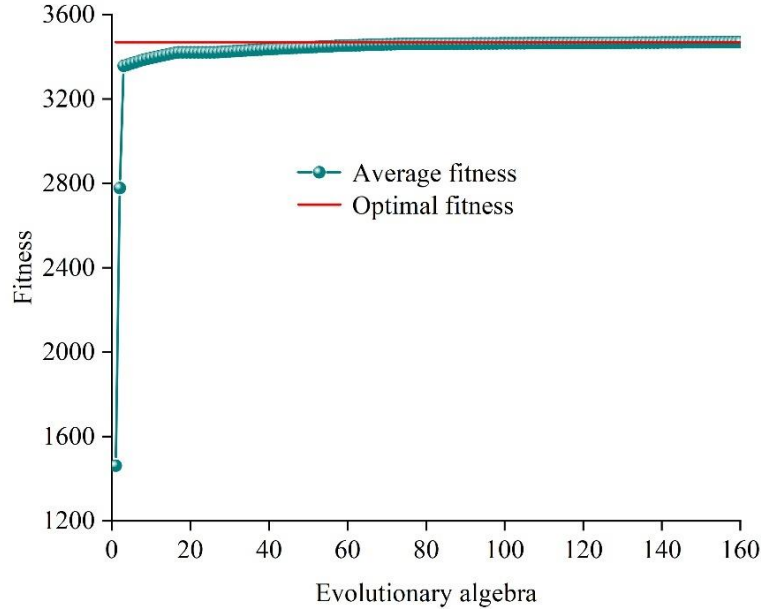


Figure 5: Fitness change curve

### 4.3 Solution results

To validate the effectiveness of the improved genetic algorithm (IGA) designed in this paper, the traditional genetic algorithm (GA) was also selected to optimize the construction schedule model for aluminum cone core composite panel curtain walls, and the results were compared. The algorithm parameters are set as shown in Table 2.

Table 2: Different algorithm parameter settings

Parameters	Algorithm			
	(1) GA	(2) IGA	(3) GA	(4) IGA
Population size	180	180	120	120
Cross probability	0.95	0.95	0.85	0.85
Mutation probability	0.12	0.12	0.06	0.06
Maximum number of iterations	800	800	500	500

The algorithm programming was implemented in Visual Studio Code. The computer configuration used in this paper was an Intel Core i7-4200H 2.8GHz CPU with 8.00GB of RAM. Input data was entered, and the model program was run 50 times. The results are compared in Table 3.

It can be seen that Algorithm (4) has the shortest average runtime, requiring only 9.72 seconds. Therefore, Algorithm (4) was ultimately selected for this study, and the Gantt charts for the construction progress plans of each construction area in each layer of the project are shown in Figure 6.

Table 3: Comparison of algorithm results

Algorithm	Average value /d	Minimum value /a	Average running time /s
(1)	83.64	79.38	15.28
(2)	80.65	78.50	10.45
(3)	85.40	82.34	12.06
(4)	84.35	81.42	9.72

Through case analysis, it can be seen that by applying the model and algorithms established in the preceding section for intelligent scheduling, the total construction period for the aluminum cone core composite panel curtain wall node connection project was 90 days. This approach also avoided conflicts between work teams and minimized discontinuous transitions between construction units. The project was completed five days ahead of the contractually agreed schedule, demonstrating the effectiveness of this method in addressing the issue of intelligent scheduling for construction progress plans in aluminum cone core composite panel curtain wall node connection projects. Compared to the previous method of manually scheduling construction progress plans based on experience, this approach is more efficient.

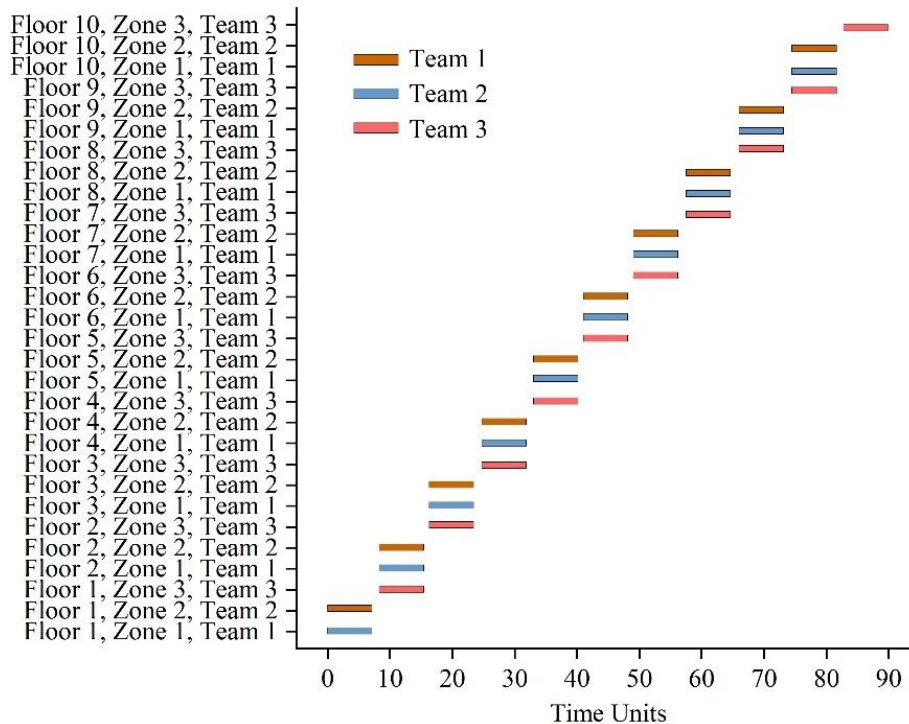


Figure 6: Construction schedule plan

## 5 Conclusion

This paper explores the intelligent technical implementation path for the construction of aluminum cone core composite panel curtain walls, establishes an optimization model for the construction schedule of the wall, and employs an improved genetic algorithm to solve the model.

Verification of the improved genetic algorithm used reveals that, during the evolutionary process, individuals meeting the constraint conditions account for the vast majority of the population, ensuring that optimal individuals are generated through selection, crossover, and

mutation operations. Additionally, genes other than the optimal gene in the population tend to converge toward the optimal gene through genetic operations, indicating that the use of adaptive operators can accelerate the convergence speed of optimization and improve its accuracy.

Furthermore, the improved genetic algorithm proposed in this paper significantly outperforms the traditional genetic algorithm in terms of computational results and average runtime. With a population size of 120, a crossover probability of 0.85, a mutation probability of 0.06, and a maximum iteration count of 500, the IGA algorithm achieved the shortest average runtime of 9.72 seconds. The total construction period for the intelligent scheduling of aluminum cone core composite panel curtain wall node connections was calculated to be 90 days, which is shorter than the contractually agreed period of 95 days, validating the effectiveness of the method proposed in this paper.

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