Advancing Assembled Building Construction Scheduling with Sustainable Development and Multi-Objective GA Algorithms Enriched by Digital Art

Shiyu Wang[1*]

[1]Department of Architecture and Engineering,Zhengzhou Urban Construction Vocational College, Zhengzhou, 450000, China

Corresponding Author:Shiyu Wang, Chengtaoshiyu@163.com

Abstract. The current conventional construction scheduling optimization methods for assembly buildings mainly focus on a single objective, and the constructed construction scheduling models lack comprehensive synergy. In this regard, a construction scheduling optimization method based on multi-objective GA algorithm is proposed in the assembly building. The method uses RF identification technology to realize real-time collection of assembly building data, and combines the GA algorithm to build a multi-objective optimal scheduling model, and solves the model to realize optimal scheduling of building construction. In the experiments, the scheduling performance of the proposed method is verified. The experimental results show that the construction delay rate is significantly reduced after the proposed method is used to optimize the scheduling of building construction data, and it has a more desirable scheduling performance.

Keywords: multi-objective optimization algorithm; GA algorithm; assembly building; construction optimization scheduling; Enriched by Digital Art
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1 INTRODUCTION

With the advantages of fast construction speed, good product quality, low labor intensity and green construction and reduced environmental pollution, assembled buildings are a symbol of the development of the construction industry toward industrialization[14] . However, due to the confusion in scheduling, unreasonable resource allocation, lack of skilled labor, technical problems in the construction process, immaturity of the construction supply chain, and ineffective coordination among various disciplines in all phases of the project, the construction cost of assembled buildings is high, and it is difficult to reflect the advantages of shorter construction period and higher resource utilization than traditional cast-in-place buildings[20] . The assembled building project is different from the traditional construction model in terms of construction and installation processes, resource requirements and management modes in each phase, and requires multiple operational spaces such as production workshops, logistics and transportation, and construction sites for collaborative project management. How to provide the components to the construction assembly site in the right quantity at the right time according to the requirements of the construction unit and the design unit is an issue to be studied in depth, which is not only related to the quality, schedule and cost of the project, but also related to the saving of resources and the protection of the site environment. Different stages of project construction require different types and numbers of construction personnel, and sometimes even require the coordination of multiple personnel. For example, in the steel construction process, in order to complete the task according to the construction plan, the number of steel personnel in each phase needs to be adjusted in a timely manner to control labor costs and ensure the construction progress[23] . However, when developing personnel scheduling programs in current projects, they often only consider the needs of the next phase, while lacking a grasp of the overall demand for the entire planning period. For this reason, construction management knowledge should be combined to develop optimal scheduling solutions to provide decision support for project managers. The current level of informationization in the construction industry has improved, and has also improved productivity to some extent. However, the information acquisition ability of the execution link is still relatively weak, and the information generated by the construction process cannot be entered into the management system in a timely and fast manner, resulting in the system and enterprises getting lagging and inaccurate information when making decisions, and naturally they cannot make accurate judgments when making construction planning decisions. In addition to the vast majority of construction companies are still using the manual collection of construction data during construction, and then manually input the data into the computer for processing and analysis, the resulting decisions will be lagging behind, and the information will not correctly reflect the current construction conditions[11] . Using such decisions to guide construction will inevitably have an impact on the construction schedule through long time accumulation. The lack of timely and complete collection of underlying data, the lack of feedback mechanisms, and the inability to effectively integrate multiple sources of information are the main factors contributing to the low management capability. Under the traditional construction model, managers usually arrange and schedule the project based on past experience, which often leads to unscientific production scheduling due to the limitation of lack of global information understanding and unreasonable resource allocation. Such scheduling solutions not based on global dynamics eventually lead to construction chaos and schedule delays. In the actual assembly process, dynamic events are inevitable, such as perturbation of assembly time of components, shortage of components, schedule change, equipment failure, etc. These uncertainties will have an impact on the time cost of assembled buildings. Especially the complex scheduling problem with logical relationship of construction processes and resource constraints, which then requires reasonable matching and arrangement of site resources and construction processes. To address the above problems, this paper will first realize real-time collection of assembly building data by using RFI technology, establish dynamic scheduling strategies, and optimize construction plans by using GA algorithms[8]. Digital art could be used to enhance communication and understanding in construction projects.

2 REAL-TIME DATA COLLECTION FOR ASSEMBLED BUILDINGS

In the assembly construction process, if the useful information needed for construction scheduling is not fed back to the scheduling system in a timely manner, it will lead to the scheduling system not being able to make timely and accurate responses and errors based on the actual construction status. A complete assembly construction process should involve three links, namely construction preparation, construction scheduling and construction execution, in which construction data are continuously generated and exchanged[4] . The types of data generated and exchanged in these three stages are construction planning data, component assembly process data, component list data, construction equipment data, construction schedule data, process arrangement data, component status data and assembly group status data, etc., as shown in Figure 1.

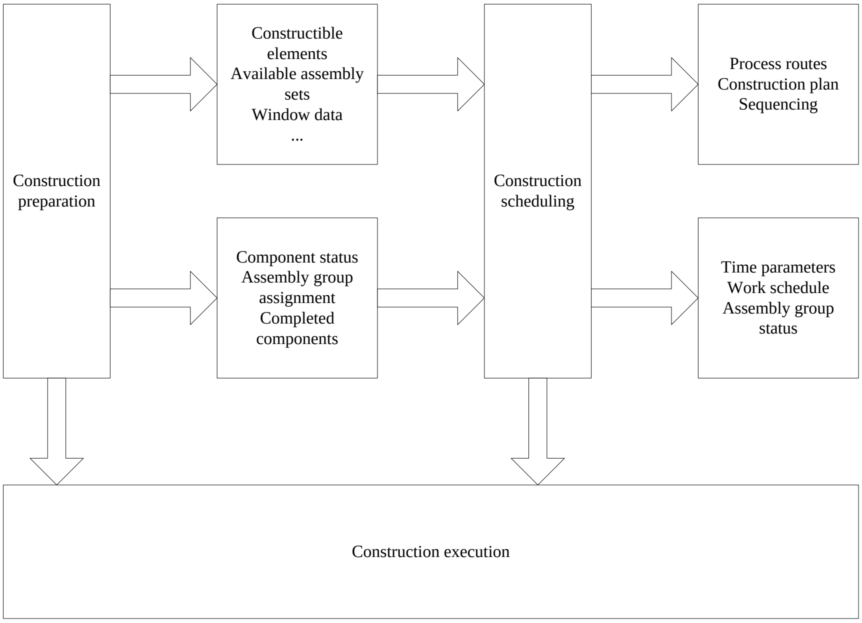

Figure 1 : Data Collection Process of Assembled Building.

In this paper, the data collection object is mainly the construction execution data used for feedback to the construction scheduling link, according to the actual situation of the assembly building, this kind of data is mainly the component state data and assembly personnel data, and then carefully divided into component type data, construction process data and assembly personnel data[3] .

1. Building component data

Building component data is some basic attribute data of the components currently being assembled, including name, number, quantity, installation position, planned assembly time and assembly progress, etc., where the components being assembled can be multiple components or single multiple components[1] . The front-end device sends the collected building component information to the system, and the system will pre-process each collected component information. If a component conflicts with other components in order, the system will optimize according to the pre-set optimization scheduling rules[24] .

2. Construction process data

The construction process data includes the assembly process route data, process parameter data, process status data and time status data of each component. Process status data includes completed process, online process and subsequent process.[2] . The time status data includes the scheduled process completion time, process start time, current time and end time. By collecting these data, we can monitor the current construction progress and optimize the schedule.

3. Assembly personnel data

The assembler data can include basic attributes such as assembler's name, number, and job type. But what is more important is the collection of the current status data of the construction personnel, because the optimization of the construction schedule is actually a problem of resource allocation, and the construction personnel exist as resources[10] . Only when the resources are allocated scientifically and reasonably can they play their proper role.

According to the above analysis of assembly building data types, this paper chooses to apply electronic tags to assembly building data in order to facilitate the acquisition of real-time information in the building process, and the specific design requirements of the electronic tags are shown in Table 1.

Label design requirements	*Specific description*
Fixity	*No changes to the label information are allowed to ensure the quality and safety of the product*
Uniqueness	*The ID is cured in the electronic label before the product leaves the factory to prevent forgery*
Identification distance	*To facilitate the identification of components, the longer the distance, the better.*
Years of data retention	*The life span of the electronic tag must not be less than the life span of the building itself*
Confidentiality	*Confidentiality is to prevent others from accessing and copying building information at will*

Table 1: Electronic Label Design Requirements.

The ID encoding of the electronic label can refer to the Code 128 encoding form of the one-dimensional bar code, including the component type code, project code, product number (can be composed of production date and batch or compiled by the enterprise itself), location number and expansion area, or other forms of compilation can be used. However, in the development of ID should be noted that each electronic tag ID should be unique, and tag ID should be as short as possible in order to reduce the identification time when the tag identification, reduce the impact on the reader recognition performance[7] . Try to use the prefix sequence code to different products for classification code, so that in the subsequent recognition can be all products according to different product categories for group identification and can realize the directional recognition, greatly improve the recognition efficiency. Component coding format as shown in Figure 2.

1. Component type code

The component type code is located in the 1st to 2nd position, which can be composed of the first capital letter of the Chinese character name of the component. The component code is placed at the top to facilitate future directional search. Common component names and codes are shown in Table 2.

2. Project code

The project code is located in the 3rd to 6th position, which is also composed of the first letter of the Chinese character Pinyin capitalization of the project abbreviation, in order to distinguish the projects that are independent of each other.

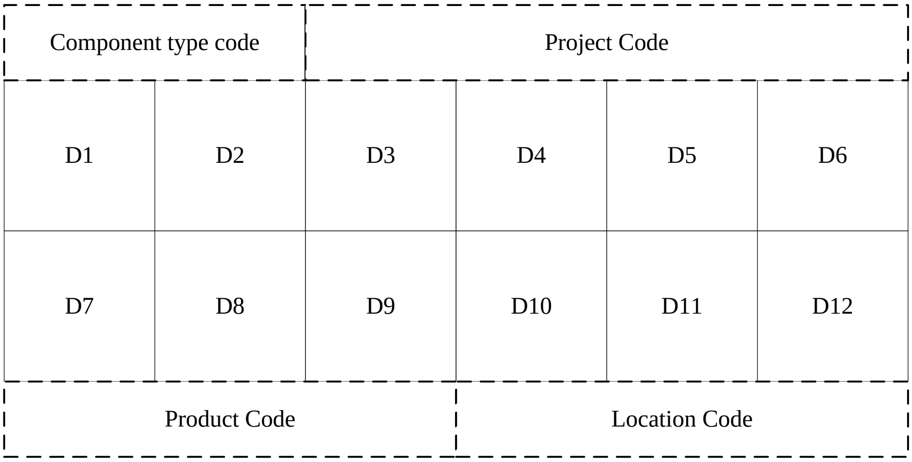

Figure 2: Component Coding Format.

Name of component	*Component code*
Floor slab	*LB*
Steel column	*GZ*
Steel beam	*GL*
Internal wall	*NQ*
External walls	*WQ*
Stairs	*LT*
Balconies	*YT*

Table 2: Common Component Names and Codes.

3. Product number

The product number is located in bits 7 to 9 of the code and can be composed of Arabic numerals to distinguish between components of the same type[18] .

4. Position number

The location number is located in bits 10 to 11 of the code and may consist of Arabic numerals, which can be used to distinguish multiple components with different location attributes within the same type of component.

5. Expansion area

At the end of the whole code, two bits can be temporarily set as the expansion area to prevent the code bits from being insufficient, and the specific number of bits can be arranged according to the specific situation, and "0" can occupy the space when no expansion is needed.

In the binary search algorithm there is a way of dynamic grouping query for known identical high bits, called dynamic binary search algorithm. And this paper proposes in the tag ID coding design requirements, tag ID should try to use prefix sequence code by building component category, which is based on this dynamic algorithm consideration. The purpose is that grouping by different building component categories can improve the identification efficiency[25] . For example, the building components can be divided into four categories: floor, steel column, wall and steel beam, which are coded and set in the front of the tag ID. When identifying the tags, the reader can send REQUEST commands with a certain product prefix code in order to make only the tags with that product prefix code in the tag ID respond, such as identifying the collision bit in the response tag, and then processing the collision tag according to the binary search algorithm. When all the components of this category are identified, other categories of components can only be identified. Setting the product prefix code to the tag ID not only can classify and identify a large number of construction products to reduce the burden on the reader, but also can conduct a certain category of product query to improve the identification efficiency[6] .

3 ESTABLISHMENT OF MATHEMATICAL MODEL FOR CONSTRUCTION SCHEDULING OF ASSEMBLED BUILDINGS BASED ON MULTI-OBJECTIVE GA ALGORITHM

The site construction space determines the construction schedule according to the component resources on site and then places an order to the production space for the component resources required for construction[15] . After receiving the order, the production space arranges the production of the components and requests the transportation space to transport the components to the site before the next phase of construction, and the result of the collaborative scheduling will restrict the realization of the construction schedule on site, and so on, until the construction is completed.

This chapter analyzes the parallel and collaborative scheduling of three operation spaces in an assembly building project. The process of building a standard floor is simulated as a typical analysis object, and the scheduling process is simulated with the project progress as the horizontal axis and each stage of construction as the vertical axis, on which the scheduling model can clearly reflect the interaction and coordination between the operation spaces. The whole scheduling process of the three spaces is expressed by the logical relationship in Figure 3[22].

To simplify the analysis, the construction process of an assembled building can be simplified as follows:

1. In time period t1 the construction site is prepared for the foundation part, and the assembly of prefabricated components has not yet begun, but orders are sent to the production workshop of prefabricated components, which makes arrangements for the production and transportation of components at this time.

2. In the time period t2-tn the construction site starts the lifting work of prefabricated components, while containing the work of three working spaces, at this time the construction of each standard layer can be regarded as constantly repeated scheduling projects with the same duration[17] .

3. Only the last work content of the site construction in the time period t(n+1).

Scheduling of assembled building projects is a resource-constrained multi-project collaborative scheduling problem, which is undoubtedly a difficult and complex task if the whole construction cycle of assembled buildings is adjusted throughout[5].

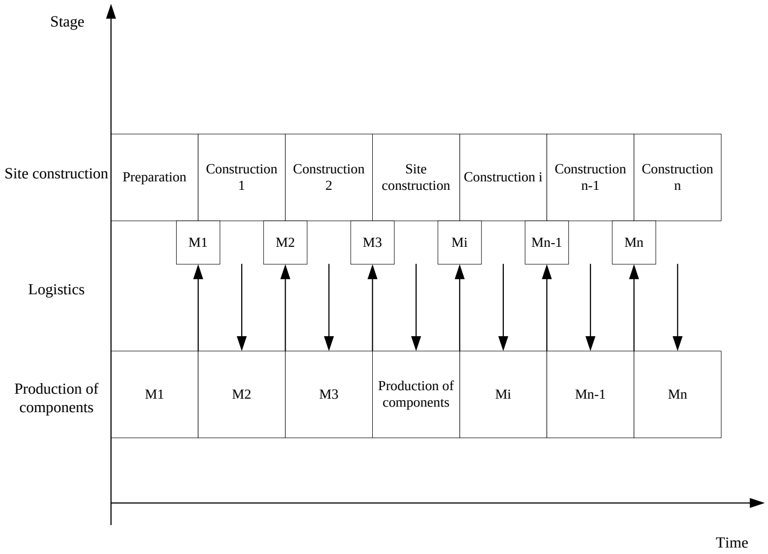

Figure 3: Schematic Diagram of the Whole Process of Scheduling for Assembled Building Projects.

In order to simplify the model for analysis, the project construction process is divided into several construction units, so that the construction process of consecutive standard floors can be regarded as a collaborative scheduling process of three spatially repeated jobs with the same duration. In this paper, only one of the construction units is analyzed, and before building the mathematical model, it is necessary to make the following assumptions about the model in the optimization process for the collaborative scheduling problem of assembly building production and construction:

1. Collaborative operation of multi-space for component production, transportation and on-site construction

The assembled construction projects are mainly carried out in three spaces, production, transportation and construction, with resources and schedules as the carrier to achieve mutual constraints, there is no competition and conflict in resources, and they are complementary relationships. Production space products belong to the resources of on-site construction space, so to ensure the normal construction schedule must strictly control the spatial collaboration relationship[19] . It is assumed that in a standard floor construction process, the production cycle and logistics transportation cycle of component production are no greater than the shortest construction cycle on site, and the amount of builds transported to the construction site is no less than the amount of components required for construction.

2. Logical relationship setting between processes

Assume that each activity in the three spaces is of the finish-once-start type, and there is only one work pattern for each subproject at the same moment. The logical relationship between the sequence of each process is determined, and the activity cannot be stopped midway through the construction process; there is no relationship between the activity's demand for resources and duration. The construction process is numbered to ensure that the immediately preceding work number of process J must be less than J and the immediately following work number must be greater than J.

3. Resource constraint relationship setting

The construction phase of an assembled building involves many different types of resources, and it is assumed that the availability of resources is limited at various times during the total construction period, such as limited available space on the construction site for stacking prefabricated components, limited rates of technicians and transport personnel and hiring skilled crews, limited number of cranes and auxiliary equipment, and limitations on the maximum number of units per transport[13] .

4. Certainty assumption

It is assumed that the collaborative scheduling model of assembly building in this paper is carried out in a deterministic environment, without taking into account the perturbation factors of environmental uncertainty that exist in the collaborative scheduling process of the three spaces, or the changes brought by these factors to the construction schedule.

Therefore, the three operation spaces can be set as three subprojects $i = 1, 2, ..., N$, which represent the site construction, production space, and transportation space, respectively; each subproject is composed of a collection of activities represented by $J_i = \{0, 1, ..., n, n+1\}$, where the virtual activities j = 0 for and j = n + 1 represent the start and end activities of the project, respectively, and their resource requirements and durations are 0. The symbolic descriptions are shown in Table 3.

Symbols	*Description*
i	*Sub-item serial number*
j	*Work sequence number, the set of activities for each subproject*
k	*resource number, where the set K contains all resources*
di	*the duration of the task of subproject i*
sij	*Start time of process j of subproject i*
pij	*the duration of process j of subproject i*
cij	*the completion time of process j of subproject Z*
Vij	*the set of activities immediately following the jth activity of project i*
At	*the set of activities of item i that are in the ongoing state at moment t*
Rk	*Renewable supply of resource k*
rj	*The demand for resource k by process J*

rk	*Sum of the usage of resource k at moment t in the execution of project i*

Table 3: Project Scheduling Mathematical Model Parameter Symbols.

1. Site construction work space scheduling model

The site construction is subproject 1, i.e. i=l, and the task duration of this project is denoted by d_1 . The deadline is T_1 , with the shortest on-site construction duration as the optimization objective, while ensuring that the cost of renewable resources used and the integrated cost of the management time window are minimized, so the objective function expression of the construction space is shown below.

$$\min T = \min \max(c_i J_i) \tag{1}$$

$$\min P_1 = \sum_{k=1}^{K} r_k \tag{2}$$

$$x_{ijk} \in \{0,1\}, \forall i, j, t \tag{3}$$

$$\sum_{t=0}^{T} x_{ijk} = 1, \forall i, j \tag{4}$$

$$\sum_{t=0}^{T} \left(t - p_{ij}\right) \cdot x_{ijk} \geq 0 \tag{5}$$

$$R_k - \sum_{i=1}^{N} r_{ijk} - r_{jk} \geq 0, \forall i, j \tag{6}$$

$$\max\{r_{ijk}\} \leq r_k(t) \leq R_k \tag{7}$$

$$c_{ij} = s_{ij} + d_{ij} \tag{8}$$

where equation (1) is the objective function for minimizing the total duration of the project; equation (2) is the objective function for minimizing the cost of resources used at the construction site and the cost of managing the time window; equation (3) defines the decision variables x_{ijk} , whether the processes of project i are executed at moment t; equation (4) requires that each process cannot be interrupted after it starts; equation (5) is a logical constraint on the internal priority relationships between processes, where The set of processes p_{ij} is all the immediately preceding activities of process j. Process j must finish executing all immediately preceding activities before it can start executing[9] . Eqs. (6) and (7) are the resource constraints between each process, where the set K contains all resources, and for each updatable resource k, the maximum usage at any moment must not exceed the resource limit ; R_k r_{ijk} represents the demand for resource k by process j, and r_{jk} represents the sum of the usage of resource k at moment t during project execution. Equation (8) indicates that the activity completion time is equal to the start time plus the duration, where the start time of each process is represented by s_{ij} , the duration is represented by c_{ij} , and the task completion time is represented by d_{ij} .

4 SCHEDULING MODEL SOLVING

In the process of solving the whole process collaborative scheduling model for assembled construction projects, two solution problems are involved, which are the solution of construction schedule duration and the solution of collaborative scheduling model. The core of the schedule optimization problem in the on-site construction workspace is the scheduling optimization problem in the component assembly construction process, which can be solved by using the single project scheduling method; the collaborative scheduling model can be solved by linking the production scheduling of the component production space with the on-site construction workspace as the main scheduling space and the transportation workspace as the articulation space, which can be considered as the collaborative scheduling of multiple projects with linked relationships[16] .

1. Solve the site construction schedule

Using the improved multi-objective GA algorithm to solve the scheduling plan for the shortest duration of the assembly building construction site, the relationship between the variables in the problem and the variables in the particle swarm optimization algorithm should be clarified first. Assuming that the feasible solution space in the target problem is the n-dimensional search space of particles, the set J of processes in a project indicates the size of particles, and a particle corresponds to a number of processes, when scheduling starts, the AON network plan diagram is constructed according to the logic and resource constraints of the construction space on site in the construction process, and among the several candidate processes in front, the one with the highest priority is found according to the priority rule as the earliest After the task is completed, it enters the set of completed tasks, and then finds the one with the highest priority among the next tasks to be executed according to the priority rules to start the execution, and repeats the priority rules to find the best until the whole project plan is completed. In order to improve the optimization effect of the algorithm in the project scheduling, the algorithm can be run several times to adjust and improve the parameters, from which the optimal[21] is selected.

2. Solving for just-in-time supply of production space

The goal of production and transportation is the on-time delivery of prefabricated components to the construction site. Therefore, under the time constraint, the scheduling plan for solving the production and transportation space can be based on the time window using the algorithm of inverse serial schedule generation. The algorithm can be defined starting from the completion time of the last task, which is the upper time limit of the production space. The upper limit of the latest task completion time c_j is the minimum start time of the activity immediately after it, and EF_j is the earliest completion time of the activity determined according to the critical line. The feasible scheduling plan that satisfies the algorithm's priority rules is solved by selecting the activity numbers in descending order[12] .

5 EXPERIMENT AND ANALYSIS

5.1 Experimental Preparation

In order to prove that the construction scheduling optimization method based on multi-objective GA algorithm proposed in this paper is better than the conventional construction scheduling optimization method in assembly buildings in terms of optimization effect, an experimental session was constructed to test the optimization effect of the method in this paper after the design of the theoretical part was completed. In order to improve the reliability of the experimental results, in addition to the method of this paper, two conventional methods were selected as the experimental control group, and the test results of the three groups were compared to verify the effectiveness of the method of this paper. The control systems selected in this paper are the construction scheduling optimization method based on RFID technology and the construction scheduling optimization method based on genetic algorithm in the assembly building.

This experiment selects a standard floor of an assembly building project to carry out an example analysis, sorts out and analyzes the workflow of component production, transportation and on-site construction, establishes a single code network diagram for each spatial activity, and then manages the component production scheduling and component transportation scheduling in cooperation with the on-site construction situation. The names of site construction activities and their parameters are shown in Table 4.

Task number	*Task name*	*Penalty Factor*
1	*Preparation for construction*	*0*
2	*Draw lines, position and measure elevations*	*3*
3	*Lifting of facade elements*	*3*
4	*Installation of inclined support positions*	*9*
5	*Sleeve filling*	*4*
6	*Pre-embedding of plumbing and electricity*	*4*

Table 4: Name and Parameters of On-Site Construction Activities.

Three scheduling methods were used to schedule and optimize the construction of the data from the above assembly building project. After the scheduling was completed, MATLAB software was used to simulate the construction delay rate and compare the actual scheduling performance of the three methods.

5.2 Analysis of Test Results

The comparison standard selected for this experiment is the construction scheduling performance of the method, and the specific measurement index is the construction delay rate, the lower the value represents the actual scheduling performance of the method, and the specific experimental results are shown in Figure 4.

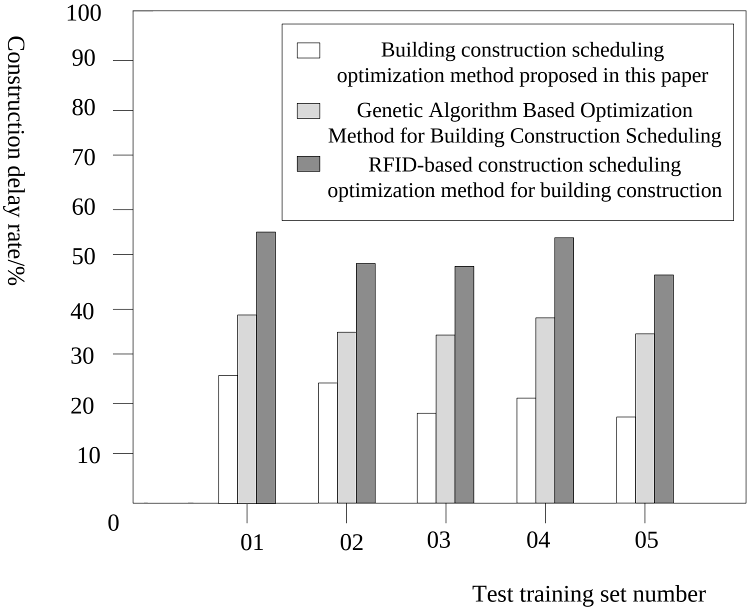

Figure 4: Construction Delay Rate.

From the experimental results, it can be seen that the construction delay rate varies for different scenarios when simulating the scheduling for different construction data. The numerical comparison clearly shows that the construction solution proposed by the multi-objective GA algorithm-based construction scheduling optimization method in assembly buildings in this paper has a lower construction delay rate, can effectively improve the construction efficiency, and has a better dynamic scheduling performance.

6 CONCLUSION

This paper combines the multi-objective GA algorithm to schedule and optimize the building construction data, and the experiments show that the scheduling method has certain optimal scheduling performance. However, in this paper, the dynamic scheduling is carried out only with the objective of minimizing the maximum completion time, but the experimental analysis shows that the actual scheduling results may have multiple optimal solutions at the same time. Therefore, it is also a direction for future research to ensure that the maximum completion time is minimized while other objectives are also optimized.

Shiyu Wang, https://orcid.org/0009-0000-0025-1262

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