

Article

Research on Construction Period Optimization of High-Rise Buildings Based on Integrated Building Platform Applications

Shuqiang Wang, Chenxi Hu * and Qingqing Wu

School of Civil Engineering, Architecture and Environment, Hubei University of Technology,
Wuhan 430068, China; wsq_921@163.com (S.W.); 102211004@hbut.edu.cn (Q.W.)

* Correspondence: 15665782305@163.com

Abstract

This study optimizes high-rise residential construction schedules using Integrated Building Platforms and genetic algorithms. By analyzing process sequences and overlapping relationships, a schedule optimization model is developed to overcome inefficiencies in traditional sequential methods. The model leverages multi-layer collaboration, enabling parallel and interwoven processes while considering overlapping logic and time constraints. Validated with a real case, the model reduced standard-floor construction from 6 to 4 days (33.3% efficiency gain) and cut idle time by 41%. The approach breaks traditional limitations, maximizing platform advantages for improved resource allocation and process management. The research offers a scientific, efficient scheduling solution for high-rise construction, demonstrating significant theoretical and practical value. It presents a novel optimization method for the building industry.

Keywords: integrated building platform; construction schedule optimization; process logic relationship; overlapping network planning; genetic algorithm



Academic Editor: Ahmed Senouci

Received: 3 July 2025

Revised: 17 August 2025

Accepted: 5 September 2025

Published: 15 September 2025

Citation: Wang, S.; Hu, C.; Wu, Q. Research on Construction Period Optimization of High-Rise Buildings Based on Integrated Building Platform Applications. *Buildings* **2025**, *15*, 3338. <https://doi.org/10.3390/buildings15183338>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

China's urbanization has driven demand for high-rise buildings, but new height restrictions (banning structures over 500 m and strictly regulating those over 250 m) require the industry to adapt [1]. Traditional construction platforms (cantilevered scaffolding, attached lifting scaffolds, etc.) face safety risks, long setup times, and high labor costs. In recent years, the accelerated growth of the global economy has spurred a significant increase in the construction of high-rise and super-tall buildings. For the core structural development of these skyscrapers, conventional construction approaches have predominantly relied on scaffold-based formwork systems [2–4] and attached lifting scaffold technology [5]. Nevertheless, these conventional construction approaches are often plagued by multiple limitations, including technological obsolescence, elevated safety hazards, suboptimal working conditions, and inefficient productivity.

The Integrated Building Platform (IBP)—a next-generation solution for buildings under 100 m (residential) or 200 m (public)—offers a safer, more efficient alternative [6]. Comprising five core systems (support, platform, hanging frame, power, and functional), it is assembled on the ground, reducing high-altitude risks and delays. The IBP consolidates multiple functions (scaffolding, climbing formwork, material hoisting, etc.) into a single “1 = N” system, improving efficiency.

After structural work, the platform lowers for façade finishing, separating structural and exterior workflows. This lean approach shortens schedules, enhances quality, and

reduces space usage. Complying with height policies while meeting high-rise construction needs, IBP provides a safer, more economical, and more efficient solution [7]. The architectural integrated platform construction diagram of this paper is shown in Figure 1. The reference comparison of construction methods for high-rise buildings [8] is presented in Table 1.

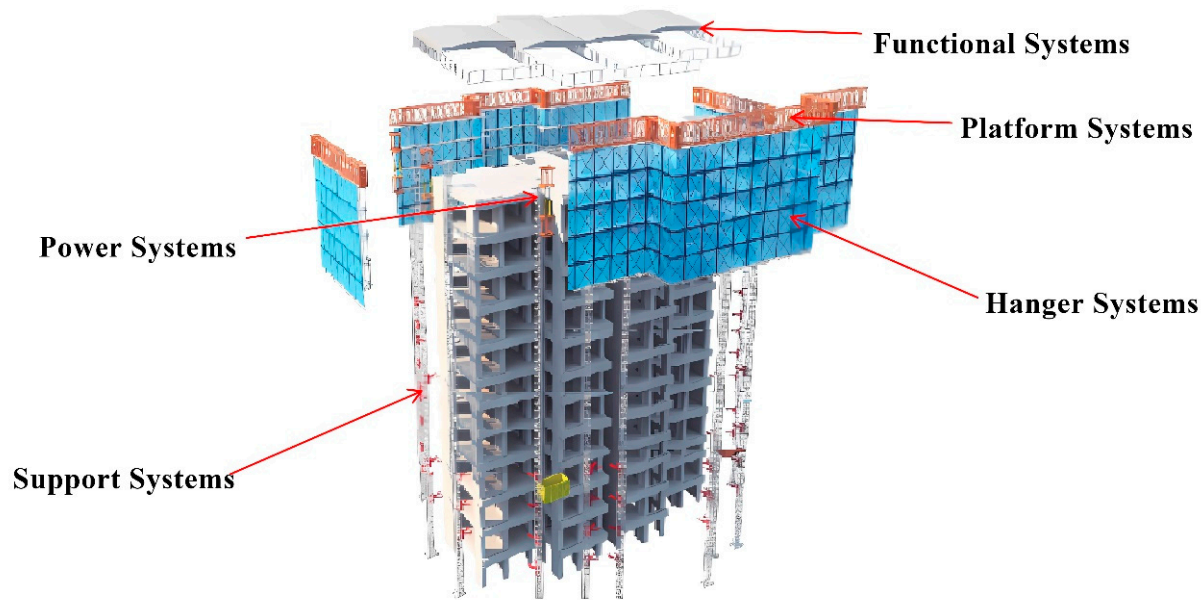


Figure 1. Architectural integrated platform construction diagram.

Table 1. Reference comparison of construction methods for high-rise buildings.

Aspect	Traditional Methods	Integrated Platform Methods
Safety	Lower	Enclosed workspace, higher safety
Efficiency	Moderate	High, leveraging automation and digital technologies
Sustainability	Limited	Better, reusable components
Quality	High	Higher

Schedule management is crucial in construction projects, impacting cost, quality, and resource allocation. However, traditional methods struggle with increasing project complexity. This study aims to develop a genetic algorithm (GA)-based optimization model for high-rise residential construction scheduling under Integrated Building Platforms (IBPs). The model specifically addresses the following: (1) parallel process coordination across multiple structural layers ($N + 1$ to $N - 2$), (2) overlap time-window constraints, and (3) labor resource allocation (Equation (6)), with the objective of minimizing standard-floor duration while maintaining safety and workflow continuity. The construction of main structural standard layers involves multiple interdependent levels, resulting in a highly intricate workflow. Furthermore, the proposed construction duration optimization model for standard floors is a multivariable, multi-constraint mathematical model. The genetic algorithm is selected for its simplicity in principle, strong logical structure, robust global search capability, and ease of implementation. These characteristics allow the GA to flexibly handle multiple constraints—such as process logic, spatial limitations, and workforce allocation—while efficiently optimizing construction schedules.

By analyzing interspersed workflows in main structure construction, the research addresses inefficiencies in traditional process and labor arrangements. Optimizing workflow coordination and jacking operations improves parallel efficiency, reducing time costs. The goal is to leverage the P's advantages—streamlining processes, shortening schedules,

and ensuring quality and safety—to maximize economic and social benefits. As shown in Figure 2, this is the simulation model of the Integrated Building Platform.

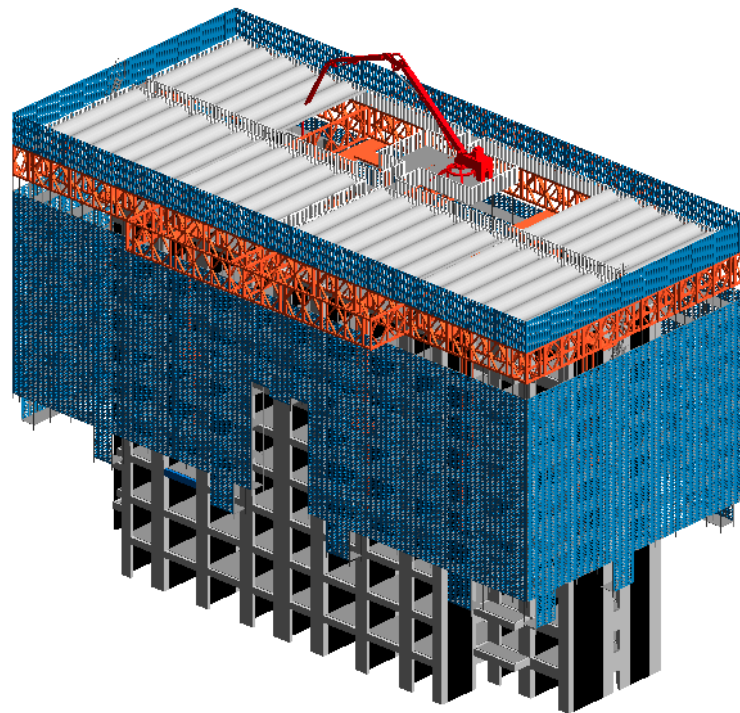


Figure 2. Simulation model of the Integrated Building Platform.

Despite advancements in Integrated Building Platforms and construction scheduling optimization, significant gaps persist in existing research. First, traditional scheduling methods predominantly rely on sequential workflows, failing to exploit the full potential of IBPs for parallel and interspersed processes across multiple structural layers. While prior studies have focused on safety and equipment design, few address the systematic optimization of process logic relationships under IBPs to minimize idle time and enhance resource utilization. Second, although genetic algorithms (GAs) have been applied to project scheduling, their integration with overlap network planning for high-rise construction remains underexplored, particularly in resolving the complex constraints of multi-layer workflows (e.g., STS/FTS relationships and labor–resource allocation). This study bridges these gaps by achieving the following:

1. Developing a novel GA-based optimization model that integrates overlap network theory to enable parallel, multi-layer construction processes under IBP constraints, addressing both intra- and inter-layer workflow dependencies.
2. Providing empirical validation through a real-world case study, demonstrating a 33.3% reduction in standard-floor duration and 41% idle-time reduction—outcomes surpassing traditional sequential methods.
3. Advancing practical applications by defining ten standardized workflow states to guide dynamic resource allocation, a contribution absent in prior IBP literature.

2. Literature Review

Currently, the application of building integration platforms is gradually increasing in China, and many construction enterprises and schools have carried out relevant research. Liu Xinzhaoh [9] researched the key system and construction technology of intelligent construction machines for super-high-rise buildings and evaluated the safety of the integrated platform through numerical analysis, simulation analysis, and on-site tests by relying on

the actual project in Xi'an. Foreign countries have also conducted relevant research on Integrated Building Platforms. As early as in the early 1990s, Japan made a preliminary attempt on the fully automated building construction system (ABCS: Automated Building Construction System) for ultra-high-rise buildings and applied it for the first time to the new construction of middle- and high-rise buildings with 10 floors above ground in 1993, which improved productivity and safety under the comfortable working space in the factory [10]. Hao Huimin [11] researched the climbing technology of the super-high-rise building module system, introduced the climbing principle of the overall module system in detail, researched the key technology of digital climbing, and optimized the construction period and climbing safety with the help of numerical analysis. Li et al. [12] investigated the application of aluminum formwork combined with hydraulic climbing formwork technology in high-rise building construction. Their study focused on the construction methodology of core tube structures using this integrated system, while also examining frame safety measures and specialized node treatments. The research highlighted the rapid advancement of this construction technique in modern high-rise projects. While China currently leads in IBP deployment volume, the technology represents a global construction modernization pathway, with distinct regional adaptations reflecting local construction ecosystems: 1. North America: Modular IBP variants have gained traction in Canadian mass timber projects, achieving 25% faster erection cycles than conventional steel. The U.S. Department of Energy's 2023 initiative further incentivizes IBP adoption through tax credits for projects achieving 40%+ embodied carbon reduction. 2. Southeast Asia: Singapore's Housing Development Board has mandated IBP use for all public housing projects above 30 stories since 2021, demonstrating 18% labor productivity gains. Malaysia's IBS score system similarly rewards IBP implementations with density bonuses.

In the field of R&D of Integrated Building Platforms, although China's start is a little behind the international level, the large scale of the domestic construction market, especially the strong demand for high-rise buildings, has prompted domestic enterprises and scientific research institutes to optimize the performance and functions of the integrated platforms through continuous technological innovation and engineering practice so as to make them better fit the specific conditions and needs of domestic building construction. As a result, China's Integrated Building Platform technology has realized rapid development and has reached or even surpassed the international advanced level in some key technical indexes [13]. The "international leading position in some aspects" mentioned here is reflected in the fact that Chinese engineers have developed unique technologies such as the micro-convex pivot point jacking module system to address the challenges of ultra-high-rise building construction, such as the transportation of materials and the control of risk of working at heights above 300 m, which not only improve construction efficiency but also enhance the efficiency of the construction process. These technologies not only improve the construction efficiency but also enhance the safety of construction. In the field of mechanized construction of high-rise buildings, China's construction equipment technology has experienced significant upgrading. The first generation of integrated platforms using steel structure frame systems, mainly used in ultra-high-rise core tube construction, is limited by the volume of equipment and functional integration; it is difficult to realize multi-process co-operation, and facade construction still needs to set up scaffolding twice. This generation of integrated platform breaks through the modular assembly technology and can be applied to ordinary high-rise residential buildings, realizing efficient three-dimensional streamlined operation of facade structure, masonry, heat preservation, decoration, and other multi-processes, which significantly improves the work efficiency, effectively improves the on-site operating environment, and greatly improves the degree of mechanization and the level of intellectualization [14]. Based on theoretical analysis and finite element simulations, the

load transfer mechanism between the tower crane and its critical load-bearing components has been enhanced through optimization, resulting in reduced weight and steel material consumption for the integrated formwork construction system [15]. This system employs a hydraulic support mechanism to enable integrated vertical lifting, functioning as an efficient mobile elevated construction platform. In contrast to conventional construction methods, this building machinery has undergone rapid advancements in high-rise construction applications, substantially enhancing productivity. It features high-level system integration and multifunctional capabilities, while exhibiting intelligent operation, adaptive versatility, and synchronized multi-task coordination during construction processes [7,16]. The advent of building machinery has effectively overcome the limitations of conventional construction methods in high-rise building structural work, while simultaneously creating optimal technical conditions to fulfill UN Sustainable Development Goal 11. This critical objective focuses on developing inclusive, safe, disaster-resilient, and sustainable urban environments and human settlements [17].

The formulation of the project material demand program depends on the optimization of the schedule, which is the basis for ensuring the reasonable allocation of project resources and smooth implementation, and plays a key role in saving costs and shortening the construction period. Exact methods provide mathematically guaranteed optimal solutions but face scalability challenges in complex construction environments: 1. Integer Linear Programming (ILP) and 2. Dynamic Programming (DP). They also face several IBP limitations: 1. cannot natively model overlap relationships without binary variable explosion; 2. fail to handle dynamic resource pooling in IBPs; and 3. assume sequential workflows (violates IBP's parallel $N + 1/N - 2$ logic). Currently [18], in the study of project schedule optimization, it is usually based on the network diagram to clarify the logical relationship between the tasks, and then a mathematical model is established with the duration, cost, and other factors as the goal, and finally, through the application of specific algorithms, it is solved in order to come up with the optimal schedule and the corresponding material allocation strategy. Since Gantt pioneered the “crosswalk diagram method” in the early 20th century, people have gradually adopted the crosswalk diagram to represent the progress plan of engineering projects, and the introduction of this tool has opened up the road of continuous exploration of the optimization of engineering project programs. Exact methods provide mathematically guaranteed optimal solutions but face scalability challenges in complex construction environments: Integer Linear Programming (ILP)—In 1956, the U.S. DuPont Company developed the critical path method (CPM), which not only provides a complementary and perfect progress plan but also brings project management to the project. Heuristics offer rule-based approximations for rapid decision-making but lack adaptability to IBP complexities: 1. Priority Rule-Based Scheduling; 2. Constraint Satisfaction Heuristics; and 3. Cluster Scheduling. The IBP limitations are as follows: 1. cannot optimize jacking cycles requiring synchronous pauses; 2. no mechanism to balance labor across platform zones; and 3. fixed clusters conflict with IBP's dynamic work envelopes. Damci et al. [19] established nine different objective functions and solved them with genetic algorithms, respectively, and finally obtained the optimal objective function under the consideration of resource equilibrium and resource constraints. Bettemir et al. [20] proposed an improved annealed genetic hybrid algorithm, which improved the search capability of the algorithm, and used a bridge project as a case for project scheduling. Tirkolaee E B et al. [21] constructed a mathematical model with maximum NPV and minimum duration as dual objectives and analyzed the optimization problem of the project scheme under multiple modes by assigning multiple alternative work modes to each job according to the actual situation of the project under the consideration of resource constraints. Hadeel et al. [22] combined the particle swarm algorithm to reduce the computation time of schedule simu-

lation. Ma, Zhiqiang [23] also focused on robust scheduling and realized the optimization of the project schedule by designing a weighted time difference and robustness index to control the construction plan. Jing Tian et al. [24] focused on the robustness problem due to the uncertainties of the work period and resources, constructed a mathematical model including work period and resources, designed a mathematical model containing work period and resources, and designed a new model to optimize the project schedule. They constructed a mathematical model including schedule and resources and designed a multi-stage genetic algorithm to optimize the schedule of this project. Ujong et al. [25] used an artificial neural network to predict the cost and duration of building construction and combined it with MATLAB software to develop intelligent modeling to predict the duration risk intelligently. Rifat et al. [26] proposed a hybrid optimization approach to optimize the resources and duration with an innovative genetic algorithm. Shwetank et al. [27] analyzed various parameters of delayed schedules and analyzed them with the help of expert parameter scoring and modularity to catch the key factors, which is helpful to curb the risk of schedule, and Feng et al. [28] established a multi-objective model by using a genetic algorithm and proved the superiority of the genetic algorithm application. Chen ZY et al. [29] used the particle swarm algorithm to obtain several optimal and suboptimal solutions for the construction schedule.

Therefore, this study attempts to explore and study the optimal construction effect by optimizing the process path under the building integration platform to save construction time and promote construction efficiency from the perspective of making the duration time the shortest.

3. Methods

In this study, for the construction schedule optimization problem of high-rise buildings, we use a genetic algorithm to construct a schedule optimization model, combined with the theory of overlap network planning, and analyze in detail the logical relationship of processes and the type of overlap within and between each structural layer under the application of the building integration platform. Verified by actual cases, the model takes into account the type of lap logic between processes, the constraints on the value of lap spacing and other constraints, and the parallel interspersed construction of processes, aiming to improve construction efficiency and shorten the construction period. The research flow of this paper is shown in Figure 3.

In this paper, analyzes the current situation of the initial plan for the construction period of the standard layer of the main structure based on the integration platform, and for the problems of empirical construction period arrangement, lack of parallel thinking of the work processes and insufficient advantages of the integration platform in the initial plan, proposes an optimization strategy based on the integration platform covering the construction characteristics of the five structural layers, which includes the analysis of the sequential logical relationship of the work processes within the structural layers and among the layers, and the analysis of the work relationships that can be adjusted. It mainly includes the analysis of the logical relationship between the construction processes within and between the structural layers and the adjustable working relationship. It specifies the construction work contents that can be carried out in parallel, establishes a schedule optimization model based on the constraints of the relationship between the overlapping, the time window of the overlapping time distance, and the resources, and aims at minimizing the total construction period of the standard layer of the main structure, and conducts the design solution based on the genetic algorithm to optimize the duration of the construction period.

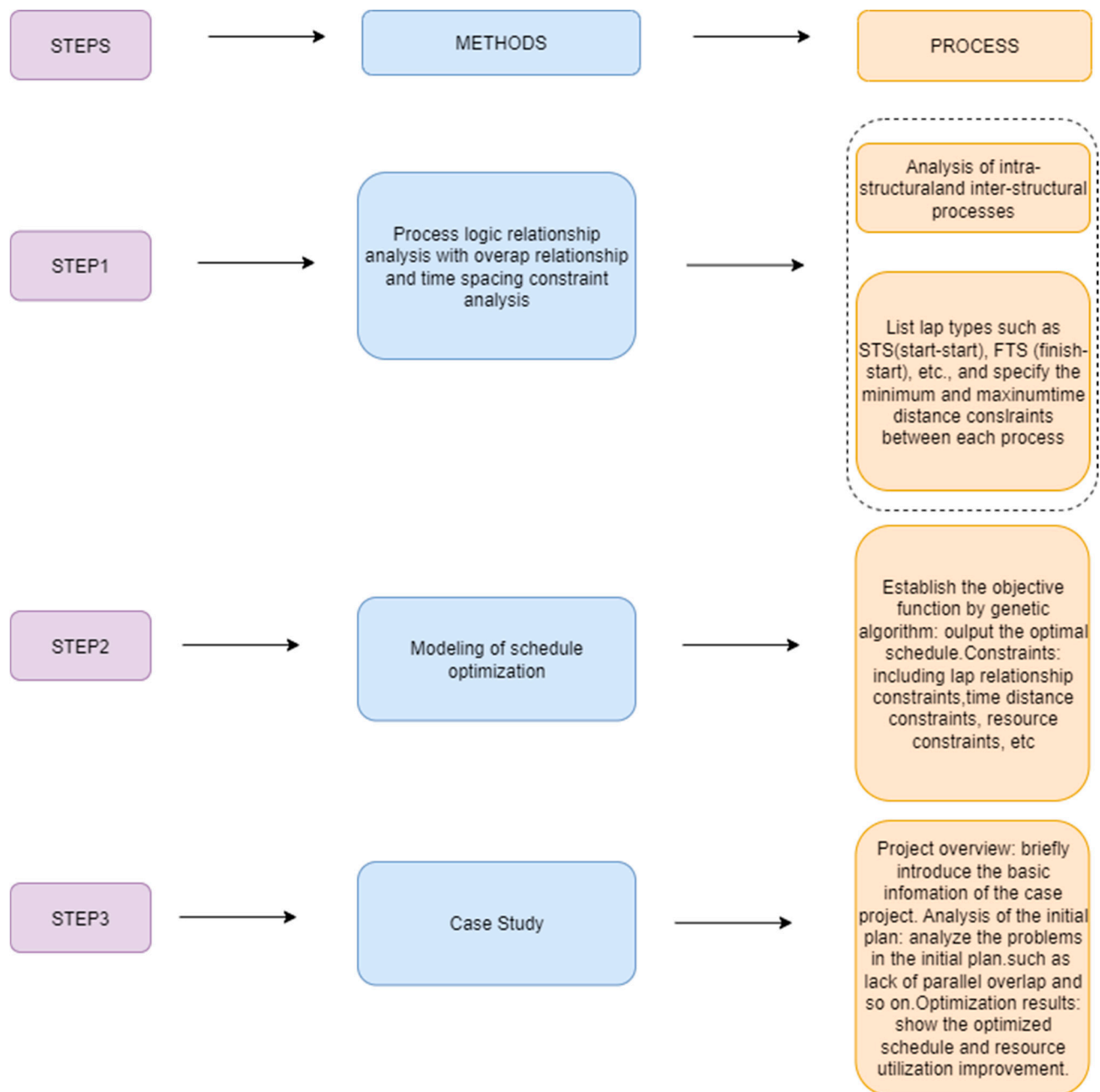


Figure 3. Flowchart of the research methodology and applications.

The construction duration optimization model in this study is solved using a genetic algorithm (GA), with the specific algorithmic design detailed as follows:

1. Encoding and Decoding

In genetic algorithms, common encoding methods include binary encoding and real-valued encoding, among others. This study adopts real-valued encoding, where each individual (chromosome) consists of multiple genes. The chromosome length corresponds to the total number of overlapping time lags (δ_{ij}) between all intra-layer and inter-layer construction processes. The chromosome represents the δ_{ij} values for all overlapping relationships, with each gene corresponding to the time lag δ_{ij} between a pair of processes. The value range of each gene is determined by the given constraints. For instance, in the case of six overlapping relationships (δ_{12} , δ_{23} , δ_{34} , δ_{45} , δ_{56} , and δ_{67}), the encoded δ_{ij} values form a chromosome as illustrated, where each block represents a gene locus.

Through the δ_{ij} parameters encoded in each chromosome, the algorithm calculates the start times (S) for all construction activities, ultimately yielding the total project duration (T). This evaluation procedure guarantees that all activity precedence constraints and labor resource requirements are strictly satisfied.

In genetic algorithms, common encoding methods include binary encoding and real-valued encoding, among others. This study adopts real-valued encoding where each chromosome is represented as a vector of time lags (δ_{ij}) between overlapping processes. For a project with m overlapping relationships, the chromosome structure is defined as follows:

$$\text{Chromosome} = [\delta_{12}, \delta_{23}, \dots, \delta_{nm}]$$

where each gene δ_{ij} corresponds to the time lag between processes i and j , constrained by its feasible window $\delta_{ij} \in [\delta_{ij\min}, \delta_{ij\max}]$.

Variation mechanisms:

- Crossover: Uniform crossover exchanges δ_{ij} values between parent chromosomes using a randomly generated mask.
- Mutation: Each gene δ_{ij} has a 10% probability of being regenerated as a random value within $[\delta_{ij\min}, \delta_{ij\max}]$.

Example: For the six overlap relationships in Figure 4, a chromosome would be encoded as $[\delta_{12} = 3.2, \delta_{23} = 1.5, \delta_{34} = 0, \delta_{45} = 2.1, \delta_{56} = 4.7, \delta_{67} = 0]$ (units: days), where each value satisfies the corresponding constraints.

δ_{12}	δ_{23}	δ_{34}	δ_{45}	δ_{56}	δ_{67}
---------------	---------------	---------------	---------------	---------------	---------------

Figure 4. Schematic diagram of the chromosome.

2. Initial Population Generation

The initial population is constructed by randomly generating each gene of every individual within the feasible time window constraints of the corresponding δ_{ij} . This uniform random sampling approach ensures that individuals are diversely distributed across the feasible solution space while maintaining solution validity.

3. Fitness Function Design

In genetic algorithms, the fitness function quantitatively evaluates the quality of each individual solution. This study employs a fitness function defined as $\text{fitness} = \frac{1}{T}$, where T represents the objective function (total project duration). This formulation ensures that a smaller T (shorter duration) yields a higher fitness value, thereby indicating a superior individual solution in the optimization process.

The fitness evaluation process consists of four steps:

- (1) Decoding: Extract all δ_{ij} values from the chromosome.
- (2) Schedule Calculation:
 - Initialize $S_1 = 0$.
 - Compute each $S_j = \max (S_i + D_i + \delta_{ij})$ for all predecessor processes i .
- (3) Duration Calculation:
 - $T = \max (S_i + D_i) \forall i \in \text{processes}$.
- (4) Fitness Assignment:
 - $\text{Fitness} = 1/T$ (if all constraints are satisfied).
 - $\text{Fitness} = 0$ (if any constraint is violated).
- (5) Constraint Checking:

- Verify $\delta_{ijmin} \leq \delta_{ij} \leq \delta_{ijmax}$.
- Check resource usage $\sum Rr \leq Cr$ at each time t (Equation (6)).

4. Alternative Formal Phrasing

The selection process combines tournament selection with elitism preservation. In each selection event, a subset of three candidate individuals is randomly sampled from the population, with the highest-fitness individual being selected as a parent. This tournament-based evaluation repeats until the new population reaches its predetermined size, ensuring preferential propagation of high-quality solutions while maintaining population diversity.

5. Crossover Operation

This study used the uniform crossover method to complete the crossover operation, where two individuals from the parent generation exchanged genes through a randomly generated mask. The mask is a random Boolean value with a probability of 0.5, which determines whether each gene comes from parent 1 or parent 2. Mask 0: Offspring 1 takes the gene from parent 1, and Offspring 2 takes the gene from parent 2. Mask 1: Offspring 1 takes the gene from parent 2, and Offspring 2 takes the gene from parent 1. According to the masking rule, combine the parent genes to form two new offspring. This crossover method can effectively mix the genes of the parents and increase the diversity of the population.

6. Mutation Operation

The proposed algorithm employs uniform mutation with a fixed 10% probability for each gene. When mutation is triggered, the target gene value is completely reset and regenerated as a new random value within the feasible range defined by the corresponding time lag constraint δ_{ij} .

7. Termination Criteria and Algorithmic Flow

The algorithm terminates when reaching the predefined maximum iteration count ($G = 300$ generations). During each iteration, the population is progressively updated through offspring generation until meeting the termination criterion, at which point the optimal solution T is outputted. Uniform crossover schematic diagram is shown in Figure 5 below.

- Step 1: Initialize basic parameters. Including the basic information of each process, the labor resource demand R of each process, the total labor resource Cr , the overlap relationship between processes, and the constraint of the overlap time window δ_{ij} . The initial population size NP , maximum iteration times G , tournament selection scale k , crossover probability Pc , mutation probability Pm , and other basic information of the genetic algorithm.
- Step 2: Population initialization. According to the encoding strategy, randomly generate an initial population $P(0)$ of N chromosomes.
- Step 3: Calculate fitness. For each chromosome in population $P(g)$, calculate its fitness value according to the formula.
- Step 4: Select the operation. Using the tournament selection operator, N individuals are selected from population $P(g)$ to form the intermediate population $Q(g)$.
- Step 5: Cross operation. Perform a uniform crossover operation on individuals in population $Q(g)$ based on crossover probability Pc to generate new individuals.
- Step 6: Mutation operation. Perform a uniform mutation operation on individuals in population $Q(g)$ based on mutation probability Pm to generate new individuals.
- Step 7: Update the population. Merge individuals in $Q(g)$ with individuals in $P(g)$, select N optimal individuals based on fitness values, and form a new population $P(g + 1)$.

Step 8: Termination condition judgment. If the maximum iteration count G is reached, stop the calculation; otherwise, let $g = g + 1$. Return to step three. The flowchart of genetic algorithm optimization design and implementation is shown in Figure 6.

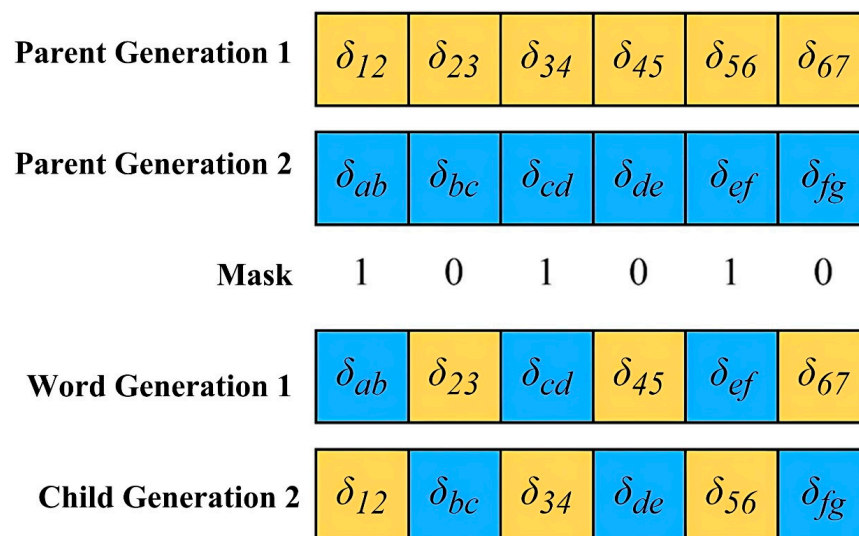


Figure 5. Uniform crossover schematic diagram.

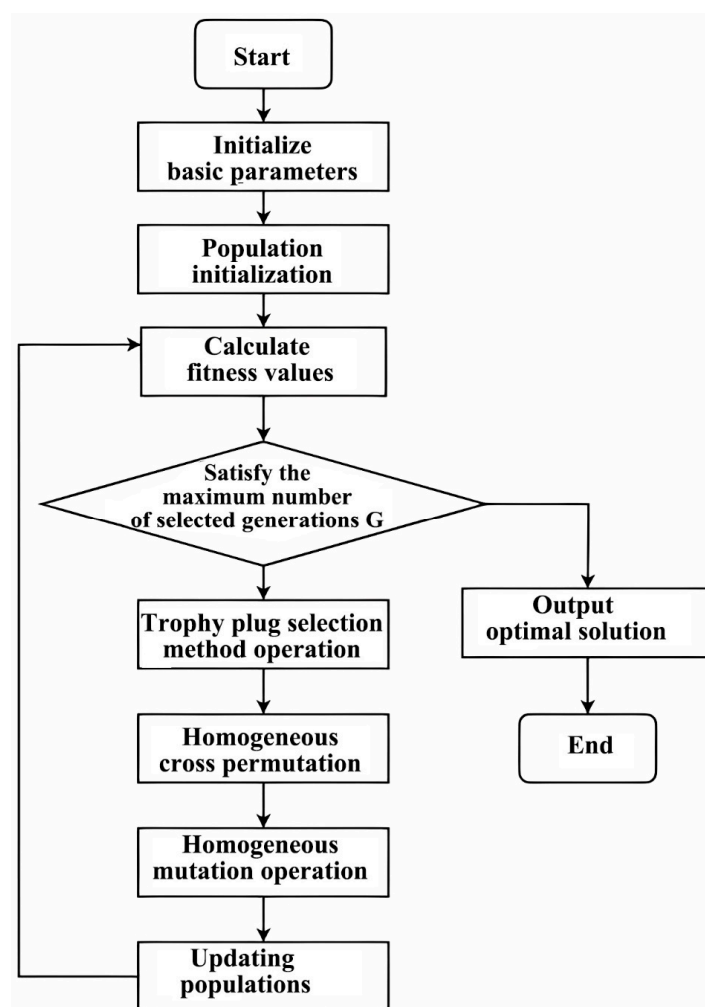


Figure 6. Flowchart of genetic algorithm optimization design and implementation.

4. Analysis of Process Logic and Overlapping Relationships

Based on the application of the construction integration platform, the optimization strategy of the construction period of the standard layer of the main structure based on the integration platform is proposed: firstly, the analysis of the logical relationship between the construction sequence of the work processes, and then the analysis of the adjustable working relationship between the work processes to realize the parallel overlapping of the work processes.

4.1. Analysis of the Logical Relationship Between the Construction Sequences of Work Processes

In main structure construction using an integrated platform, process sequencing is critical. Each step follows a strict logical order (e.g., wall reinforcement must precede formwork installation). Adhering to these sequences ensures construction consistency and safety—arbitrary changes are unacceptable.

(1) Analysis of the contents of construction operations within each structural layer

The integrated platform spans multiple structural layers, each involving complex construction tasks when jacking up a standard layer. Analyzing these tasks in detail helps clarify the construction process and establishes a foundation for optimizing workflow sequencing.

(2) Process sequential logical relationship analysis

Analyzing the construction tasks across $N + 1$, N , and $N - 2$ structural layers during jacking operations clarifies workflow sequences both within and between layers. This ensures construction continuity and safety.

The specific main structure standard layer construction process logical sequence relationship is shown in Table 2.

Table 2. Logical relationship between the sequence of construction processes of the standard floor of the main structure.

Structural Layer	Serial Number	Process Name	Pre-Processing
N + 1 floor	A	Elevation of N + 1 floor platform moldings	M
	B	Measurement and placement of the N + 1 floor	A
	C	Vertical reinforcement binding and acceptance at the N + 1 level	A, B
	D	N + 1 floor vertical reinforcement co-molding	A, C
	E	N + 1 floor riser support	D, O
	F	Horizontal formwork laying for N + 1 floor roof slabs	E, P
	G	N + 1 floor top slab beam and plate reinforcement binding	F
	H	N + 1 layer wire box burial	F
	I	N + 1 floor piping pre-reservation and pre-embedding	G, H
	J	N + 1 floor top plate slab reinforcement binding and acceptance	I
	K	N + 1 floor top slab, vertical concrete pouring	J
N-layer	L	N-story top slab, N-story vertical concrete pouring	/
	M	Removal of vertical formwork at N level	L
N – 2nd floor	N	Removal of N – 2 floor supports	/
	O	N – 2 level support reversal	N, D
	P	Removal and transportation of horizontal formwork at the top of the N – 2 floor	O, E

4.2. Adaptable Working Relationship Analysis

This study analyzes process sequencing to identify adjustable overlaps (STS, FTS, etc.) and optimize scheduling. Using overlap network planning, it examines intra-layer logic (e.g., STS between mold lifting and rebar tying) and inter-layer coordination (e.g., bracket removal and formwork transport). By defining parallel tasks and overlap types while adhering to safety constraints, it enables efficient interspersed construction.

In this study, the following activity relationship abbreviations are adopted:

- STS: Start-To-Start;
- FTS: Finish-To-Start;
- FTF: Finish-To-Finish;
- STF: Start-To-Finish.

(1) Analysis of work overlap relationships within structural layers

The key construction task for the N + 1 floor involves jacking up the integrated platform's mold frame. This process synchronizes with vertical rebar measurement and tying acceptance (STS relationship). During jacking, the steel platform lifts the suspended aluminum formwork system, completing the N + 1 layer's vertical rebar enclosure—also an STS-type sequence. The specific N + 1 layer process lap logical relationship analysis is shown in Table 3.

Table 3. Analysis of the logical relationship between process overlaps within the N + 1 layers.

Working Procedure	Process Number	Overlapping Work	Connecting Logical Relationships
Elevation of N + 1 floor platform moldings	A	B	STS
		C	STS
		D	FTS
Measurement and placement of the N + 1 floor	B	C	STS
Vertical reinforcement binding and acceptance at the N + 1 level	C	D	FTS
N + 1 floor vertical reinforcement co-molding	D	E	STS
N + 1 floor riser support	E	F	STS
Horizontal formwork laying for N + 1 floor roof slabs	F	G	FTS
		H	FTS
N + 1 floor top slab beam and plate reinforcement binding	G	/	/
N + 1 layer wire box burial	H	G	FTF
		I	FTS
N + 1 floor pipeline pre-reservation and pre-embedding	I	J	FTS
N + 1 floor top plate slab reinforcement binding and acceptance	J	K	FTS
N + 1 floor top slab, vertical concrete pouring	K	/	/

The N layer is mainly two processes: N-layer top slab and vertical concrete pouring and N-layer vertical formwork demolding. N-layer concrete pouring is completed before the vertical formwork demolding; the lap logical relationship formed between the two is the FTS type. The specific N-layer process lap logical relationship analysis is shown in Table 4.

Table 4. Logical relationship analysis of process overlap within the N-layer layer.

Working Procedure	Process Number	Immediately After Work	Connecting Logical Relationships
N-story top slab, N-story vertical concrete pouring	L	M	FTS
Removal of vertical formwork at N level	M	/	/

The main construction work at the $N - 2$ level is the removal and inverting of formwork support poles and the removal and inverting of the horizontal formwork of the roof slab. The logical relationship between the two is of FTS type, and the logical relationship between the two is also of FTS type. After the completion of formwork support inverting, the removal and inverting of the horizontal formwork of the roof slab will be carried out. The specific $N - 2$ layer process lap logical relationship analysis is shown in Table 5.

Table 5. Analysis of logical relationship of process overlap within layer $N - 2$.

Working Procedure	Process Number	Overlapping Work	Connecting Logical Relationships
$N - 2$ nd floor Bracket removal	N	O	FTS
$N - 2$ level support reversal	O	P	FTS
Removal and transportation of horizontal formwork at the top of the $N - 2$ floor	P	/	/

(2) Analysis of overlap relationships between structural layers

After N-layer concrete pouring reaches stripping strength (FTS relationship), $N + 1$ layer construction begins. Key workflow relationships include the following: (1) N-layer formwork removal and $N - 2$ bracket demolition operate concurrently (STS); (2) platform jacking requires prior N-layer formwork removal (FTS); (3) $N + 1$ rebar work aligns with $N - 2$ bracket transport (STS); and (4) $N + 1$ upright erection synchronizes with $N - 2$ horizontal formwork recycling (STS), optimizing formwork turnover efficiency. The logical relationship of process overlap between structural layers is shown in Table 6.

Table 6. Analysis of the logical relationship of process overlap between structural layers.

Working Procedure	Process Number	Overlapping Work	Connecting Logical Relationships
Elevation of $N + 1$ floor moldings	A	/	/
Measurement and placement of the $N + 1$ floor	B	/	/
Vertical reinforcement binding and acceptance at the $N + 1$ level	C	/	/
$N + 1$ floor vertical reinforcement co-molding	D	O	STS
$N + 1$ floor riser support	E	P	STS
Horizontal formwork laying for $N + 1$ floor roof slabs	F	/	/
$N + 1$ floor top slab beam and plate reinforcement binding	G	/	/
$N + 1$ layer wire box burial	H	/	/
$N + 1$ floor pipeline pre-reservation and pre-embedding	I	/	/
$N + 1$ floor top plate slab reinforcement binding and acceptance	J	/	/

Table 6. *Cont.*

Working Procedure	Process Number	Overlapping Work	Connecting Logical Relationships
N + 1 floor top slab, vertical concrete pouring	K	/	/
N-story top slab, N-story vertical concrete pouring	L	B	FTS
Removal of vertical formwork at the N level	M	A N	FTS STS
Removal of N – 2 floor supports	N	A	STS
N – 2 level support reversal	O	E	STS
Removal and transportation of horizontal formwork at the top of the N – 2 floor	P	F	STS

(3) Constraints on the value of lap spacing between processes

Based on the initial schedule for standard layer construction, this study optimizes the timeline by analyzing the following: (1) integrated platform technical parameters; (2) process durations and logical relationships (STS/FTS); (3) workload quantities; (4) safety/spatial constraints; and (5) labor ergonomics—covering all intra-layer and inter-layer construction data requirements. The constraints on the value of the lap spacing between work processes are shown in Table 7.

Table 7. Constraints on the value of lap spacing for all processes within and between floors of each structural level.

Working Procedure	Overlapping Work	Connecting Logical Relationships	$\delta_{ij}^{\min}$	$\delta_{ij}^{\max}$
A	B	STS	2	4
A	C	STS	2	4
A	D	FTS	0	/
B	C	STS	0.5	1.5
C	D	FTS	0	/
D	o	STS	0	8
D	E	STS	2	8
E	P	STS	0	8
E	F	STS	0	8
F	G	FTS	0	/
F	H	FTS	0	/
H	G	FTF	0	/
H	I	FTS	0	/
I	J	FTS	0	/
J	K	FTS	0	/
L	B	FTS	12	/
L	M	FTS	12	/
M	A	FTS	0	/
M	N	STS	0	6
N	A	STS	0	10
N	O	FTS	0	/
O	P	FTS	0	/
O	E	STS	2	4
P	F	STS	2	4

5. Duration Optimization Model Based on Genetic Algorithm

According to the analysis of the construction period optimization strategy of the standard layer of the main structure, the construction period optimization model of the standard layer of the main structure based on the integrated platform is established.

The meaning of each conformity and symbol associated with the model is shown in Table 8.

Table 8. Meaning of symbols and notations in the model.

Notation	Hidden Meaning
i	denotes the process i
j	denotes the process j
S_i	denotes the start time of process i
S_j	Indicates the start time of process j
D_i	denotes the duration of process i
D_j	denotes the duration of process j
R_{ir}	denotes the demand of process i for resource r
C_r	total resources for labor resources r
$Active(t)$	the set of processes that are under construction at time t
δ_{ij}	denotes the constraint on the value of the lap spacing between process i and process j .
T	indicates the total duration (objective function to be minimized)

(1) Analysis of constraints

Lap parallelism of processes by adjusting work relationships to optimize the duration is achieved by considering constraints such as the type of lap logic between processes, constraints on the value of the lap spacing between processes, and the demand for labor resources.

① Lap relationship constraints

For each pair of processes i and j with overlapping relationships, constraints are defined according to the type of overlap:

STS (Start-To-Start)-type lap relationship, with the following constraint equation:

$$S_j \geq S_i + \delta_{ij}, STS(i, j) \quad (1)$$

The FTS (Finish-To-Start)-type lap relationship is constrained by the following equation.

$$S_j \geq S_i + D_i + \delta_{ij}, FTS(i, j) \quad (2)$$

FTF (Finish-To-Finish)-type lap relationship, whose constraint equation is as follows:

$$S_j + D_j \geq S_i + D_i + \delta_{ij}, FTF(i, j) \quad (3)$$

The STF (Start-To-Finish)-type lap relationship is constrained by the following equations:

$$S_j + D_j \geq S_i + \delta_{ij}, STF(i, j) \quad (4)$$

This type of lapping relationship is not addressed in this study, so the subsequent model is constructed without this constraint.

② Lap spacing time window constraint

For each pair of processes i and j with a lap relationship, the lap time distance δ_{ij} must satisfy the lap time distance time window constraint equation as follows:

$$\delta_{ij}^{\min} \leq \delta_{ij} \leq \delta_{ij}^{\max} \quad (5)$$

③ Resource constraints

When adjusting work relationships, all processes in the overlap process occur at the same time to occupy each labor resource and cannot exceed the total amount of labor resources to ensure that parallel processes will not be interrupted due to resource conflicts.

At any moment t , the total use of each of the labor resources r does not exceed the total of the resources in the following formula:

$$\sum_{i \in \text{Active}(t)} R_{ir} \leq C_r \quad \forall r, t \quad (6)$$

(2) Objective function analysis

All processes aim at the minimum completion time of the construction duration of the standard floor of the main structure under the constraints of lap relationship constraints, lap time distance constraints, and resource constraints. The formula for minimizing the total duration is as follows:

$$\min T = \max(S_i + D_i) \quad \forall i \quad (7)$$

(3) Construction of a construction period optimization model for the standard floor of the main structure

According to the analysis of the objective function and constraints, the construction duration optimization model of the standard layer of the main structure based on the integrated platform established in this paper is as follows:

$$\min T = \max(S_i + D_i) \quad \forall i \quad (8)$$

$$\text{s.t.} \begin{cases} S_j \geq S_i + \delta_{ij}, STS(i, j) \\ S_j \geq S_i + D_i + \delta_{ij}, FTS(i, j) \\ S_j + D_j \geq S_i + D_i + \delta_{ij}, FTF(i, j) \\ \delta_{ij}^{\min} \leq \delta_{ij} \leq \delta_{ij}^{\max} \\ \sum_{i \in \text{Active}(t)} R_{ir} \leq C_r \quad \forall r, t \end{cases} \quad (9)$$

6. Case Study

6.1. Project Overview

In order to verify the applicability and effectiveness of the framework constructed in this paper, a typical high-rise residential building in Wuhan is selected for analysis, which is a key project of urban renewal and transformation in Wuhan, with a total land area of about 58,000 square meters and a total building area of 326,900 square meters. There are a total of 11 buildings in the project, and this case takes the construction application of the building integration platform for Building #1 as an example.

6.2. Analysis of Problems with the Standard Floor Construction Schedule Program

Residential Building #1 (45 floors) employed a single integrated platform from the 5th floor onward after installing the system post-fourth floor roof slab completion. The $N + 1$ standard floor construction involves platform jacking, vertical structure work, and horizontal structure work. The platform's work surface spans five layers during operations: $N + 1$ (construction layer), N (curing layer), $N - 1$ (formwork removal layer), $N - 2$ (bracket removal layer), and $N - 3$ (completed layer). The elevation of a single platform covering the main structural level is shown in Figure 7.

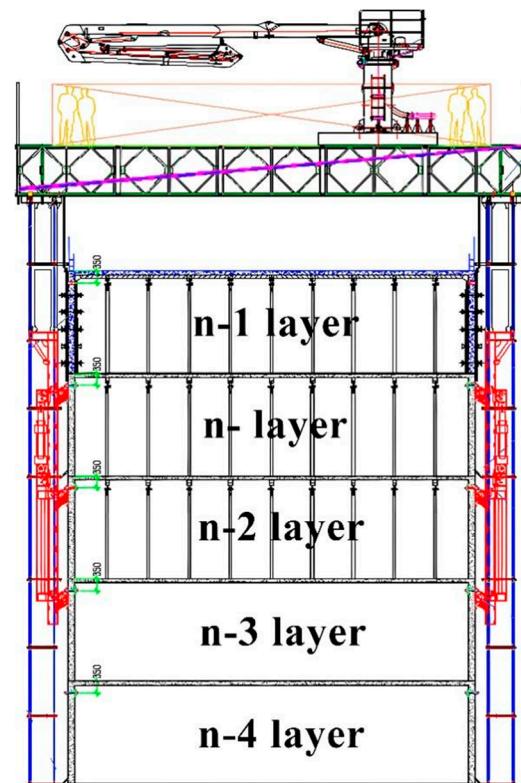


Figure 7. Elevation of a single platform covering the main structural level.

The construction manager schedules standard layer operations using traditional experience, determining process start times and durations. The original schedule is shown in Figure 8.

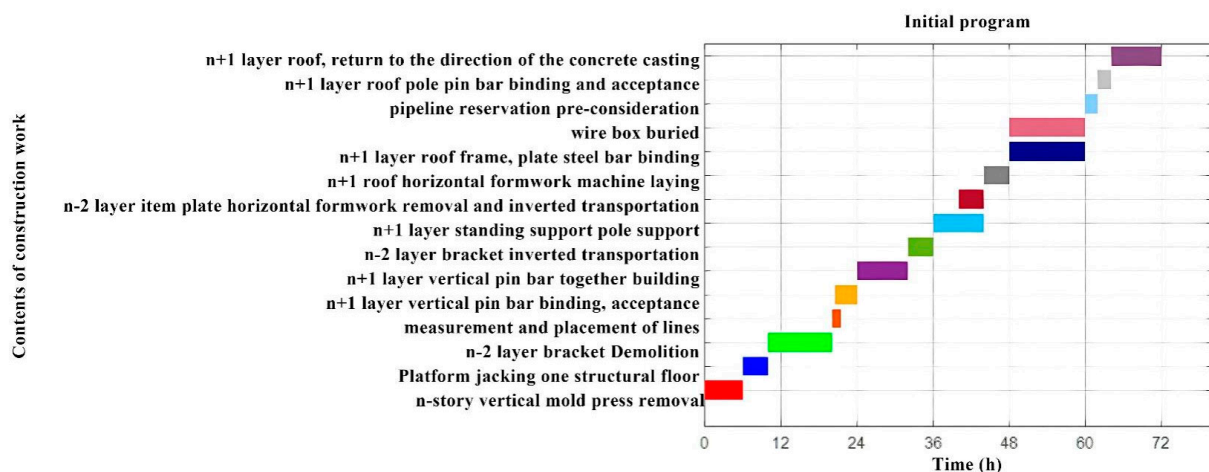


Figure 8. Initial program Gantt chart.

The construction period for the standard floor of the main structure under the integrated platform application is 6 days, with construction hours from 6:00 to 18:00, in 12-h days. The initial scenario of the main structure standard floor construction duration schedule is presented in Table 9.

Table 9. Initial scenario of the main structure standard floor construction duration schedule.

Contents of Construction Work	Start Time–End Time	Operating Time/h
Removal of vertical formwork at the N level	1 d/06:00 to 1 d/12:00	6
Integrated platform mold jacking	1 d/12:00 to 1 d/16:00	4
Removal of N – 2 floor supports	1 d/16:00 to 2 d/14:00	10
N + 1 measurement and release	2 d/14:00 to 2 d/15:30	1.5
Vertical reinforcement binding and acceptance at the N + 1 level	2 d/14:30 to 2 d/18:00	3.5
N + 1 floor vertical reinforcement co-molding	3 d/06:00 to 3 d/14:00	8
N – 2 level support reversal	3 d/14:00 to 3 d/18:00	4
N + 1 floor riser support	4 d/06:00 to 4 d/14:00	8
Removal and transportation of horizontal formwork at the top of the N – 2 floor	4 d/10:00 to 4 d/14:00	4
Horizontal formwork laying for N + 1 floor roof slabs	4 d/14:00 to 4 d/18:00	4
N + 1 floor top slab beam and plate reinforcement binding	5 d/06:00 to 5 d/18:00	12
N + 1 wire box burial	5 d/06:00 to 5 d/18:00	12
N + 1 piping reservation and embedding	6 d/06:00 to 6 d/08:00	2
N + 1 floor top plate slab reinforcement binding and acceptance	6 d/08:00 to 6 d/10:00	2
N + 1 floor top slab and vertical concrete pouring	6 d/10:00 to 6 d/18:00	8

The original schedule has the following three key limitations: (1) unscientific planning relying on empirical parameters without adapting to the integrated platform’s dynamic capabilities (e.g., missed synchronization opportunities during jacking); (2) serial process sequencing ignores parallel workflow potential, reducing efficiency; and (3) underutilization of the platform’s multi-layer construction advantages, failing to implement interspersed construction across its five-layer coverage despite its theoretical capacity for vertical workflow optimization.

6.3. Optimization Results and Analysis Based on Genetic Algorithm

The mathematical model of construction period optimization for the standard floor of the main structure applies MATLAB 2023b software to achieve genetic algorithm optimization by editing the program code, and the CPU model of the computer running the program is Intel® Core™ i7-14650HX (Intel Corporation, Santa Clara, CA, USA) with a main frequency of 2.20 GHz and 16 GB of RAM.

The relevant parameters of the genetic algorithm were set as follows: the initial population size was 50, the maximum number of iterations was set to 300, the tournament selection size was 3, the crossover probability was 1, and the mutation probability was 0.1. The GA parameters were selected through a systematic calibration process to balance exploration (avoiding local minima) and convergence efficiency. The population size (50) and maximum iterations (300) were determined via preliminary trials, ensuring sufficient diversity while maintaining computational feasibility. Tournament selection (size = 3) was chosen over roulette wheel selection to reduce stochastic bias, and crossover probability ($P_c = 1$) was set to maximize solution-space exploration, as lower values ($P_c < 0.8$) risk premature convergence. Mutation probability ($P_m = 0.1$) was tuned to introduce diversity without destabilizing convergence, guided by empirical studies in construction scheduling. Sensitivity analyses confirmed that these settings consistently avoided local minima across 10 independent runs (see Figure 6 for stable convergence).

- Population size (50): Determined via incremental testing (20–100), where 50 achieved a balance between diversity and computational cost.
- Crossover ($P_c = 1$): Adopted studies to ensure thorough solution-space exploration.
- Mutation ($P_m = 0.1$): Validated through sensitivity analysis (Figure 9), with higher values (>0.2) causing divergence.
- Termination (300 iterations): Selected after observing convergence plateaus beyond 250 iterations in 90% of trials.

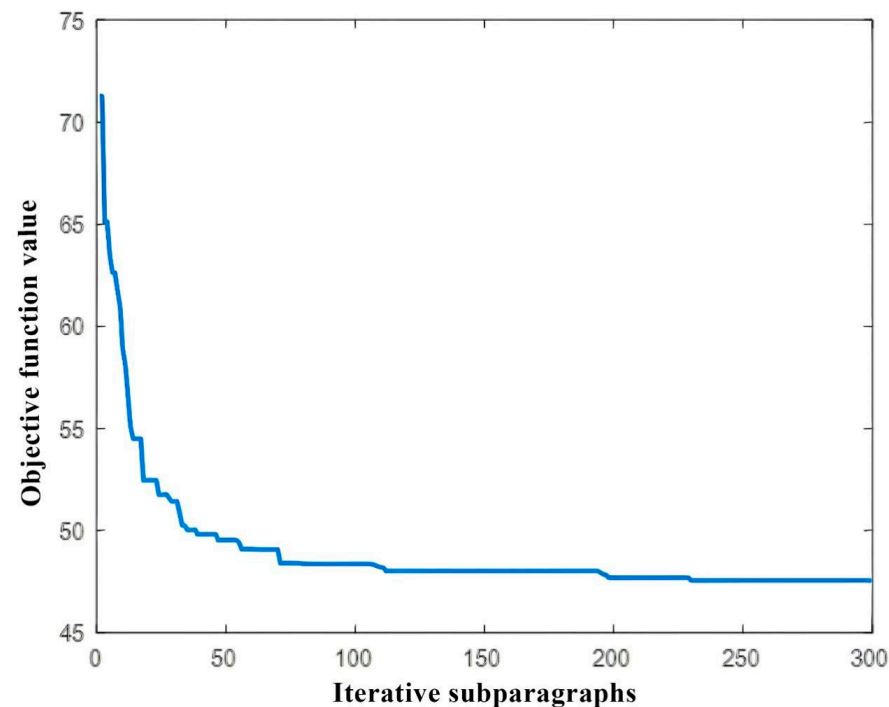


Figure 9. Adaptation graph.

The algorithm outputs optimized overlap timings for all intra- and inter-layer processes. Results include the following: (1) fitness function convergence curve (Figure 9), (2) optimized Gantt chart for interspersed construction (Figure 10), and (3) a schedule table detailing ten key workflow states during platform–structure integration. The optimized duration schedule is presented in Table 10.

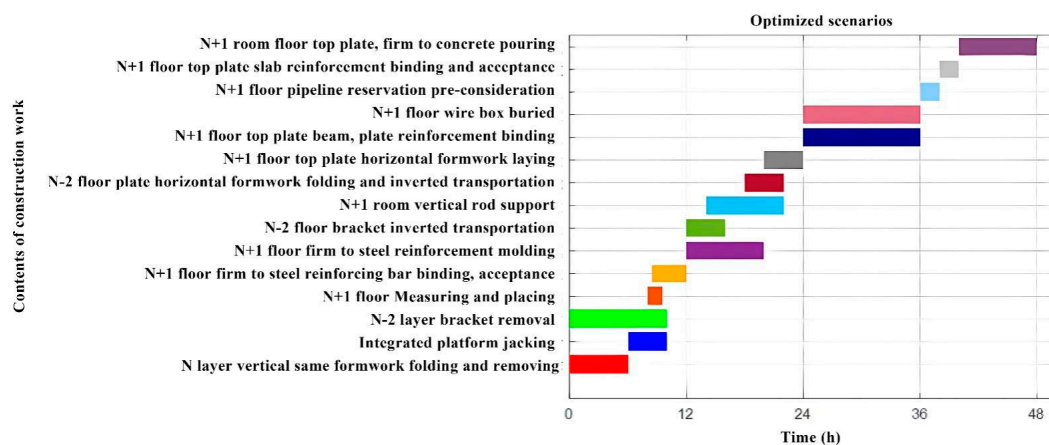


Figure 10. Gantt chart of the optimized solution for interspersed construction of standard floors of the main structure.

Analysis reveals the following: (1) the algorithm converges reliably (Figure 8), reducing standard floor duration from 6 to 4 days (33.3% efficiency gain); (2) the optimized

Gantt chart (Figure 9) shows 12 key processes (e.g., N + 1 rebar work and N – 2 bracket removal) operating synchronously across five layers, cutting idle time by 41% through “vertical–horizontal” workflow integration; and (3) the schedule defines 10 standardized states (Table 11) with precise time windows, enabling multi-process coordination. Results demonstrate significantly improved 3D platform resource utilization through logic-based optimization.

Table 10. Duration schedule after optimization of interspersed construction of standard floors of main structure.

Contents of Construction Work	Timing
Removal of vertical formwork at the N level	1 d/06:00 to 1 d/12:00
Removal of N – 2 floor supports	1 d/06:00 to 1 d/12:00
Platform mold jacking	1 d/12:00 to 1 d/16:00
Removal of N – 2 floor supports	1 d/12:00 to 1 d/16:00
Measurement and placement of the N + 1 floor	1 d/14:00 to 1 d/15:30
N + 1 floor vertical reinforcement binding and acceptance	1 d/14:30 to 1 d/18:00
N + 1 floor vertical reinforcement co-molding	2 d/06:00 to 2 d/14:00
N – 2 level support reversal	2 d/06:00 to 2 d/10:00
N + 1 floor partially supported by uprights	2 d/8:00 to 2 d/12:00
N + 1 floor riser support	2 d/12:00 to 2 d/16:00
Removal and transportation of horizontal formwork at the top of the N – 2 floor	2 d/12:00 to 2 d/16:00
Horizontal formwork laying for N + 1 floor roof slabs	2 d/14:00 to 2 d/18:00
N + 1 floor top slab beam and plate reinforcement binding	3 d/06:00 to 3 d/18:00
N + 1 layer wire box burial	3 d/06:00 to 3 d/18:00
N + 1 floor piping pre-reservation and pre-embedding	4 d/06:00 to 4 d/08:00
N + 1 floor top plate slab reinforcement binding and acceptance	4 d/08:00 to 4 d/10:00
N + 1 floor top slab and vertical concrete pouring	4 d/10:00 to 4 d/18:00

Table 11. Standard construction process for interspersing the integrated platform with the main structure.

State of Affairs	Timing	Contents of Construction Work
Status I: Initial state	1 d/10:00 to 1 d/18:00	N-story top slab and N-story vertical concrete pouring
Status II: Vertical demolding	1 d/06:00 to 1 d/12:00	Removal of vertical formwork at the N level and removal of bracing at the N – 2 level
Status III: Ejector mold frame	1 d/12:00 to 1 d/16:00	Mold jacking one structural level and N – 2 level bracket removal (continued)
Status IV: Vertical reinforcement binding	1 d/14:00 to 1 d/18:00	Measuring and placing; N + 1 floor vertical reinforcement binding and acceptance
Status V: Vertical formwork closing	2 d/06:00 to 2 d/14:00	N + 1 floor vertical reinforcement molding, N – 2 floor support inverted, and N + 1 floor part of the vertical rod support
Status VI: Horizontal formwork removal and laying	2 d/12:00 to 2 d/18:00	N + 1 floor erection of vertical rods, removal and transportation of horizontal formwork for N floor roof, and laying of horizontal formwork for N + 1 floor roof
Status VII: Beam and slab reinforcement binding	3 d/06:00 to 3 d/18:00	N + 1 floor roof beam, plate reinforcement binding, and wire box embedding
Status eight: Pipeline pre-reservation and pre-embedding	4 d/06:00 to 4 d/08:00	N + 1 floor pipeline pre-reservation and pre-embedding
Status IX: Reinforcing steel binding and acceptance	4 d/08:00 to 4 d/10:00	N + 1 floor top plate slab reinforcement binding and acceptance
Status Ten: Concrete pouring	4 d/10:00 to 4 d/18:00	N + 1 floor top slab and vertical concrete pouring

7. Discussion

In this study, the construction process logic relationship under the building integration platform is optimized by a genetic algorithm, which achieves a significant reduction

in the construction period of the standard floor and verifies the validity of the model. However, there are still issues that need to be discussed in depth between theory and practical application. The following discussion is based on four aspects: optimization effect, technical advantages, limitations, and future direction.

The GA-optimized schedule reduced standard-floor duration by 33.3% ($6 \rightarrow 4$ days) compared to the initial sequential plan, while CPM-based schedules (without parallel process optimization) averaged 5.5 days for similar projects. This improvement stems from the GA's ability to exploit overlapping workflows (e.g., STS relationships in Table 3) that CPM cannot natively model. The optimized schedule (Figure 10) enables synchronous execution of 12 processes (e.g., $N + 1$ rebar work and $N - 2$ bracket removal) across five layers, cutting idle time by 41% via integrated vertical–horizontal workflows.

Traditional methods incurred 41% higher idle time due to rigid sequential dependencies (e.g., waiting for formwork stripping before rebar work). In contrast, the GA model's multi-layer coordination allowed concurrent tasks (e.g., $N + 1$ rebar work alongside $N - 2$ formwork removal).

While the proposed model demonstrates significant efficiency gains in the Wuhan Building #1 case, its applicability to other project types warrants further discussion. The model's core framework—integrating genetic algorithms with overlap network planning—is theoretically adaptable to diverse high-rise structures (e.g., commercial towers, mixed-use buildings) due to its modular constraint system (Equations (1)–(9)). However, scalability depends on two factors: 1. Structural Similarity: The current workflow logic (Section 4.1) assumes repetitive standard-floor designs typical of residential high-rises. For irregular geometries (e.g., tapered towers), process dependencies (Table 2) may require recalibration. 2. Platform Compatibility: The IBP's five-layer coverage (Figure 7) is optimal for buildings with 3–5 concurrent work zones. Projects with larger floor plates or non-uniform layouts may need adjustments to spatial constraints ($\delta_{ij}^{\max}$ in Table 7).

While data specificity (Wuhan case) requires broader validation, this study advances prefabricated construction by integrating overlap networks and genetic algorithms—complementing prior safety-focused research on intelligent equipment. Next-phase research will achieve the following: develop lightweight edge computing protocols to enable real-time GA rescheduling on active construction sites, addressing latency limitations in existing Active BIM systems [30]; develop eco-friendly solutions addressing material waste/carbon reduction; and expand optimization methodologies to advance sustainable construction practices.

While the GA model demonstrates robustness in simulation, real-world uncertainties (e.g., 10–15% duration variability due to weather or labor shortages) may require dynamic recalibration. A sensitivity analysis revealed that mutation rates > 0.2 risk premature convergence, suggesting a trade-off between exploration and stability. Future work should integrate real-time IoT data to mitigate these uncertainties.

While this study demonstrates the effectiveness of the GA-optimized scheduling model for high-rise construction, several limitations should be acknowledged: 1. The resource constraints (Equation (6)) assume stable labor and material availability. In practice, supply chain disruptions or labor shortages—common in developing countries—could impact the optimized schedule's executability. 2. The model's full benefits depend on the deployment of advanced BIPs. Projects using conventional construction methods may not achieve comparable efficiency gains due to a lack of parallel workflow capabilities. 3. The GA parameters, though calibrated (Section 6), were optimized for this specific case. Different project scales (e.g., super-tall buildings over 300 m) might require alternative optimization algorithms to handle increased complexity.

Comparison with established studies: This study breaks through the serial logic limitation of traditional methods and solves the complexity of process interspersing in assembled buildings through the combination of overlapping networks and genetic algorithms. Compared with Liu Xinzhaoh [9] and other scholars, the research on the safety of intelligent construction machines provides a methodological supplement for the efficient application of the integrated platform.

8. Conclusions

This study focuses on the application of building integration platforms in residential building construction, and through the study of construction process logic relationships, overlapping relationships, and schedule optimization models, combined with practical case studies, the following main conclusions are drawn:

- (1) Through detailed analysis of integrated platform construction workflows, this study establishes clear sequential relationships between intra- and inter-layer processes (e.g., N-layer concrete pouring as a prerequisite for platform jacking). These defined logic rules prevent construction conflicts while ensuring safety and workflow continuity.
- (2) Applying overlap network theory, the research identifies adjustable process overlaps (e.g., STS-type between platform jacking and rebar work) across vertical and horizontal dimensions. This precise mapping of parallel potentials enables targeted schedule compression.
- (3) A genetic algorithm model incorporating process logic, spacing constraints, and labor demands was tested on Wuhan Building #1. Results show that standard floor duration was reduced to 33.3% (6 → 4 days), process idle time was cut by 41%, and 3D platform resource utilization was significantly enhanced.
- (4) Building on this study's framework, future research should focus on the following: 1. Extend the GA model to simultaneously optimize duration, cost, and carbon emissions, aligning with sustainable construction goals. 2. Test the model's adaptability to diverse building types (e.g., steel-framed offices, irregular mixed-use towers) by recalibrating process logic relationships (Table 2) and spatial constraints (Table 7). 3. Develop automated workflows to translate BIM 4D/5D data into model inputs (e.g., auto-generating process dependencies in Table 2), reducing manual calibration efforts.

Author Contributions: C.H., S.W. and Q.W. wrote the main manuscript text. C.H. prepared Figures 1–10. S.W. prepared Tables 1–7. Q.W. prepared Tables 8–11. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included within this article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Wang, H.Y. Green design of high-rise buildings under the “double carbon” target. *Sichuan Shuini* **2023**, *5*, 172–174.
2. Kim, K.; Teizer, J. Automatic design and planning of scaffolding systems using building information modeling. *Adv. Eng. Inform.* **2014**, *28*, 66–80. [[CrossRef](#)]
3. Kim, K.; Cho, Y.K.; Kim, K. BIM-based decision-making framework for scaffolding planning. *J. Manag. Eng.* **2018**, *34*, 04018046. [[CrossRef](#)]
4. Yu, Z. The road to development of scaffolding and formwork technology. *Chin. Build. Met. Strut.* **2008**, 38–40.
5. Xu, M. Application of Attached Lifting Scaffold in Construction Technology of High-rise Building. *Jiangxi Build. Mater.* **2022**, *8*, 270–272.

6. Guo, F.Y.; Liu, S.P.; Fu, S.; Xu, J.; Sun, J. Digitalization paths for aerial building machine construction technology. *Sci. Technol. Eng.* **2025**, *25*, 3840–3850.
7. Lian, J.; Jiang, J.D.; Liu, H.; Zhang, B.Y.; Liu, K.; Hu, Z.M. Application of residential building making machine in construction process. *Constr. Technol.* **2022**, *51*, 45–48.
8. Zhu, J.W.; Ouyang, M.Y. Explore the super high-rise construction tool jacking platform system. *Constr. Architect.* **2018**, *20*, 64–66.
9. Liu, X.Z. Research on the analysis and construction technology of key system of intelligent construction machine for super high-rise buildings. *Xi'an Univ. Technol.* **2023**.
10. Wang, H. Research and application of key construction technology for high-rise residential buildings. *Residence* **2024**, *6*, 56–59.
11. Hao, H.M. Research on digital climbing technology of integral molding system for super high-rise buildings. *Qingdao Univ. Technol.* **2023**.
12. Li, S.; Yu, Z.; Meng, Z.; Han, G.; Huang, F.; Zhang, D.; Zhang, Y.; Zhu, W.; Wei, D. Study on construction technology of hydraulic climbing formwork for super high-rise building under aluminum formwork system. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *769*, 032062. [\[CrossRef\]](#)
13. Wakisaka, T.; Furuya, N.; Inoue, Y.; Shiokawa, T. Automated construction system for high-rise reinforced concrete buildings. *Autom. Constr.* **2018**, *9*, 229–250. [\[CrossRef\]](#)
14. Xu, G.W.; Deng, H.W.; Chen, D.; Liu, K.; Li, L. Application of lightweight swingable high-efficiency construction integrated platform in house building construction. *Constr. Technol.* **2021**, *50*, 9–11+18.
15. Gong, J.; Fang, T.; Yang, D.; Feng, Y.; Zhu, Y. Research on Integrated Technology of Integral Aerial Building Formwork Equipment and Large Tower Crane. *Structures* **2024**, *60*, 105771. [\[CrossRef\]](#)
16. Liao, H.; Du, F.; Yuan, Y. Design and Construction Technology of Integrated Construction Platform System of Chongqing IFS. *Constr. Technol.* **2016**, *45*, 117–120.
17. Oltra-Badenes, R.; Guerola-Navarro, V.; Gil-Gómez, J.-A.; Botella-Carrubi, D. Design and implementation of teaching–learning activities focused on improving the knowledge, the awareness and the perception of the relationship between the SDGs and the future profession of university students. *Sustainability* **2023**, *15*, 5324. [\[CrossRef\]](#)
18. Hong, Q.; Dong, X.B. Research on the application of critical chain technology in project schedule management. *Light Text. Ind. Technol.* **2017**, *46*, 30–31.
19. Damci, A.; Polat, G. Impacts of different objective functions on resource leveling in construction projects: A case study. *J. Civ. Eng. Manag.* **2014**, *20*, 537–547. [\[CrossRef\]](#)
20. Sonmez, R.; Bettemir, O.H. A hybrid genetic algorithm for the discrete time-cost trade-off problem. *Exp. Syst. Appl.* **2012**, *39*, 11428–11434. [\[CrossRef\]](#)
21. Yuan, Y.; Ye, S.; Lin, L.; Gen, M. Multi-objective multi-mode resource-constrained project scheduling with fuzzy activity durations in prefabricated building construction. *Comput. Ind. Eng.* **2021**, *158*, 107316. [\[CrossRef\]](#)
22. Alsayegh, H.; Hariga, M. Hybrid meta-heuristic methods for the multi-resource leveling problem with activity splitting. *Autom. Constr.* **2012**, *27*, 89–98. [\[CrossRef\]](#)
23. Ma, Z.; Demeulemeester, E.; He, Z.; Wang, N. A computational experiment to explore better robustness measures for project scheduling under two types of uncertain environments. *Comput. Ind. Eng.* **2019**, *131*, 382–390. [\[CrossRef\]](#)
24. Tian, J.; Hao, X.; Gen, M. A hybrid multi-objective EDA for robust resource constraint project scheduling with uncertainty. *Comput. Ind. Eng.* **2019**, *130*, 317–326. [\[CrossRef\]](#)
25. Ujong, J.A.; Mbadike, E.M.; Alaneme, G.U. Prediction of cost and duration of building construction using artificial neural network. *Asian J. Civ. Eng.* **2022**, *23*, 1117–1139. [\[CrossRef\]](#)
26. Sonmez, R.; Gurel, M. Hybrid optimization method for large-scale multimode resource-constrained project scheduling problem. *J. Manag. Eng.* **2016**, *32*, 04016020. [\[CrossRef\]](#)
27. Parihar, S.; Bhar, C. Project scheduling management: Analyzing the risks present in the on-time project completion in electrical power distribution projects. *FILB Bus. Rev.* **2015**, *4*, 80–90. [\[CrossRef\]](#)
28. Feng, C.W.; Liu, L.; Burns, S.A. Using genetic algorithms to solve construction time-cost trade-off problems. *J. Comput. Civ. Eng.* **1997**, *11*, 184–189. [\[CrossRef\]](#)
29. Chen, Z.Y.; Du, Z.D.; Zhou, H. Resource leveling optimization for construction projects based on particle swarm algorithm. *China Civ. Eng. J.* **2017**, *2*, 93–96.
30. El-Diraby, T.; Krijnen, T.; Papagelis, M. BIM-based collaborative design and sociotechnical analytics of green buildings. *Autom. Constr.* **2017**, *82*, 59–74. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.