Training Model of High-Rise Building Project Management Talent under Multi-Objective Evolutionary Algorithm

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***Abstract*—In order to meet the development needs of the construction engineering industry and further optimize and improve the talent training mode, this paper studies the talent training model of high-rise construction project management under the multi-objective evolutionary algorithm. The cognitive ability model of management talent is constructed, and the learning ability of management talent is analyzed. With the optimization objectives of minimizing the construction period, minimizing the project cost, and maximizing the benefit of skill growth in high-rise building projects, and taking the conditions of average proficiency and average duration of construction as constraints, the mixed immune genetic algorithm with the introduction of the double-island model is adopted to carry out multi-objective evolution of management talent training, so as to obtain the best training scheme for management talent in high-rise building projects. The experimental results show that after the optimization of this model, the skill proficiency of project management personnel can be effectively improved, construction time can be effectively reduced, construction efficiency can be improved, and construction costs can be improved.**

***Keywords*—Multi-objective evolution; high-rise building; engineering project; management personnel training; skill proficiency; project cost**

I. Introduction

High-rise buildings are one of the symbols of urban modernization. They can provide more office space, commercial space, and housing space for cities to meet the growing population and economic needs [1]. The construction of high-rise buildings can promote the development and urbanization of cities. Due to the limited land resources, high-rise buildings can create more functional space on the restricted land area and improve the efficiency of land use [2]. Compared with traditional low-rise buildings, high-rise buildings can provide more usable area under the same floor space, thus saving valuable land resources [3]. At the same time, high-rise building projects will drive a lot of investment and consumption in the construction process, thus promoting local economic development [4]. After the completion of high-rise buildings, it can also provide commercial rents and real estate sales income, bringing considerable financial benefits to investors. Moreover, high-rise buildings often become urban landmarks and landmark buildings, which can enhance the image and attractiveness of the city [5]. The design and construction level of high-rise buildings directly reflects the comprehensive strength and development level of a town, which can enhance the performance of the city's culture, art, and modernization and improve the competitiveness of the city on a global scale [6]; High-rise building projects also provide opportunities for promoting green buildings and sustainable development. Innovations in architectural design, building materials selection, energy conservation, and environmental protection can reduce energy consumption, reduce carbon emissions, and promote sustainable development.

The construction process of high-rise building projects is usually characterized by high complexity and risk, and these projects need to coordinate the work of multiple professional teams, such as architectural design, structural engineering, electromechanical engineering, decoration engineering, etc. [7]. Therefore, the current construction enterprises urgently need to cultivate high-level management talent. By developing talent with management skills, potential risks can be identified and evaluated in advance, and corresponding risk management measures can be formulated to reduce project risks and ensure the smooth implementation of the project [8]. Cultivating talent who can effectively coordinate and manage teamwork can improve the team's cooperation ability and efficiency and ensure the seamless connection between various majors [9]. At the same time, the cultivation of high-rise building engineering management talent can also promote engineering innovation and technological progress. They have a keen awareness of new technologies and innovative methods, can introduce new engineering management concepts and technical methods, improve work efficiency and quality, and promote the development of the high-rise building engineering industry [10]. However, there are some defects in the current training of construction engineering talent, and construction projects need to master a series of professional skills, including skills in design, construction, management, etc. However, the existing talent training pays insufficient attention to skills training and pays more attention to knowledge transmission, ignoring the cultivation of practical operation and practical skills [11] Due to the continuous development and changes in the construction engineering industry, the docking of talent training and industry demand is not close enough. To this end, many scholars have put forward different talent training programs. For example, Klipkova, O et al. [12] studied the optimization of personnel management mechanisms based on intergenerational theory. This method is based on the three-dimensional method of employees, enterprises, and external conditions, and applies certain leadership theories and team cooperation principles to effectively manage the personnel of the enterprise, thereby achieving talent cultivation in the enterprise. However, this method cannot guarantee the improvement of enterprise operating costs, leading to excessive burden on the enterprise; for example, Nguyen, D. A et al. [13] studied the use of neural networks to model the labor productivity of high-rise building construction projects. Through the optimization of neural networks, the labor productivity of construction enterprises can be improved, thereby accelerating construction efficiency. However, this method cannot guarantee the cultivation of personal skills of employees; for example, Hudyakova, E et al. [14] studied the problems and solutions in the configuration of management personnel in agricultural and industrial complexes. This method deeply planned the responsibilities that enterprise management personnel should fulfill and cultivated the required skills for different responsibilities. However, the training plan of this method does not apply to multiple fields, and it focuses more on learning knowledge content in the process of talent cultivation, resulting in neglecting the cultivation of personal skills of employees. A multi-objective evolutionary algorithm is an algorithm used to solve multi-objective optimization problems. Different from the traditional single-objective optimization algorithm, a multi-objective evolutionary algorithm can simultaneously optimize multiple conflicting objective functions in a set of solutions [15]. To effectively realize the optimization of management personnel training, this paper puts forward a high-rise building project management personnel training model based on a multi-objective evolutionary algorithm. It recognizes the optimization of management personnel training schemes by using a multi-objective evolutionary algorithm.

II. High-Rise Building Project Management Personnel Training Optimization Model Design and Research

A. Overall Description of High-Rise Building Project

A large high-rise building construction project usually consists of several single projects. A single project can be decomposed into multiple unit projects, such as civil engineering water and electricity installation engineering [16]. Each unit project is further decomposed into several sub-projects, such as civil engineering, which can be divided into basic engineering, main engineering, roofing engineering, and decoration engineering [17]. Sub-projects can be subdivided into sub-projects, such as foundation projects, which can be divided into earthwork excavation, foundation treatment and testing, concrete foundation, and other sub-projects. A sub-project can be regarded as a relatively independent activity (or task) that is completed by a large number of technicians. It is a separate dispatching unit and also the basic activity of dispatching [18]. Therefore, the training of high-rise building project management talent can enhance the construction efficiency of building projects.

Human resources in high-rise building projects include managers at different levels and various workers involved. The management personnel of the construction project department mainly include the project director (project manager), technical director, production director, builder, machine controller, safety officer, quality inspector (sampler), material engineer, cost engineer, etc. At the same time, these personnel are also professional and technical management personnel. These personnel are the main managers of engineering construction, and their management ability will directly affect the safety, progress, quality, and cost of engineering construction, which is related to the survival and development of construction enterprises [19]. Therefore, effective ways must be adopted to train the project managers of high-rise buildings. Table I shows a comparison of the proposed work in experimental analyses with similar research works and state-of-the-art research studied as part of the literature review.

B. Modeling and Design of Employees' Cognitive Ability

In order to optimize the training scheme of high-rise building project management talent, this paper puts forward a model of employees' cognitive ability based on a learning-forgetting curve, which can fully consider the learning effect and forgetting degree of employees in the learning process so as to obtain the skill proficiency of a high-rise building project management talent.

1) Analysis of learning effect and learning curve: Before modeling employees' cognitive ability, it is necessary to analyze employees' learning effects and the change in the learning curve. Only by using this analysis result can the employees' mental ability model be effectively built based on a learning-forgetting curve. The learning effect, also known as the learning phenomenon, refers to the effect that the accumulated experience through long-term work leaves a memory in employees' minds, which helps employees improve the same or similar work efficiency [20]. Long-term research shows that the study of the learning effect basically needs to follow three hypotheses. (1) For repeated construction tasks, the time consumption of a single construction operation decreases with the increase of construction repetitions. (2) The learning effect can gradually reduce the time consumption of a single construction operation and the absolute efficiency. (3) The existence of the learning effect can be predicted and applied scientifically. Therefore, the learning curve can generally be expressed by Formula (1):

$$Y_x = Cx^b \tag{1}$$

In the Formula (1), $x$represents the cumulative completion of construction;$Y_x$represents the working hours or costs of the$x$construction task;Cindicates the operating hours or price of the first construction task;$b$represents the learning index, with a value less than or equal to zero,$b = log\ s\ /\ log\ 2$， s indicates the learning rate, which is an index used to describe the learning curve. When the learning effect is better, the learning efficiency is lower.

TABLE I. COMPARING THE PROPOSED WORK IN EXPERIMENTAL ANALYSES WITH SIMILAR RESEARCH WORKS AND STATE-OF-THE-ART RESEARCH STUDIED AS PART OF THE LITERATURE REVIEW

Aspect	Proposed Work	Similar Research Works
Scope and Focus	Training model for high-rise building project management talent under a multi-objective evolutionary algorithm	Optimization of personnel management mechanisms, labor productivity modeling, and configuration of management personnel in various industries
Objective Function	Balances project duration, cost, and skill growth rate	Varies based on research: personnel management mechanisms, labor productivity improvement, skill cultivation and task allocation
Methodology	Multi-objective evolutionary algorithm	Intergenerational theory, neural networks, management personnel configuration
Analysis Techniques	Learning and forgetting curves, cost optimization, human resource utilization	Various techniques including optimization algorithms, productivity modeling, skill proficiency analysis
Evaluation Metrics	Employee efficiency, construction cost, human resource utilization, skill proficiency	Employee proficiency, project cost, resource utilization, skill growth rate
Experimental Setup	Application to a specific high-rise building project	Not specified in the provided text
Results and Findings	Enhanced project efficiency, cost savings, improved human resource utilization	Varies based on research: potential improvements in management efficiency, productivity, and skill development
Conclusion	Provides a scientific and effective method for talent training in high-rise building project management	Varies based on research: suggests improvements in talent training methods and strategies

The learning effect can generally be expressed by describing the relationship between the cumulative construction quantity and the input factor quantity of unit construction quantity. The learning curve is also called the starting curve, experience curve, or improvement curve. The learning curve was first put forward by Wright in 1936. Through the learning curve, it is revealed that with continuous construction, the processing time of unit construction tasks will be gradually shortened, and the learning curve is widely used in industrial production. The learning curve can be expressed by Formula (2):

$$T_x = T_1 x^{-l} \tag{2}$$

In the Formula (2), T_x represents the time required for processing the construction of the $x$task, values of x are 0, 1, and 2,. T_1 indicates the time needed to handle the first construction task, and l indicates the learning efficiency of employees. With the continuous construction work, the time spent on the completion of unit construction tasks is decreasing, and with the constant learning of employees, the construction skills are also rising. At the same time, the processing time of unit construction tasks has a lower bound, which means that the processing time of unit construction tasks will not decrease indefinitely, which means that the skill value of employees is limited. Employees can continuously improve their skill value through construction work, but it will not increase excessively.

With the application of the learning curve in various fields and its development in different degrees, some scholars suggest that the longer employees use a skill, the higher the construction efficiency of the skill will be, and assume that employee p participates in construction tasks k, then the learning curve formula can be expressed by Formula (3):

$$\bar{E}_n = \bar{E}_1 n^b \tag{3}$$

In Formula (3), n represents the total time spent by employee$p$in the construction task$k$; $\bar{E}_1$represents the average efficiency of employee p on starting the construction task; $\bar{E}_n$ represents the accumulated average efficiency of employee p after spending n cycles in the construction task k; $b = -\frac{ln(r)}{ln\,2}, (0 < r \leq 1)$, b represents a learning factor, r represents the percentage of learning. The smaller the value of r, the greater the value of b, the higher the learning efficiency.

2) Modeling of employees' cognitive ability based on learning-forgetting curve model: In order to accurately understand the cognitive level of high-rise building project management talent, combined with the learning curve of the above research, the learning-forgetting curve model of employees' cognitive ability is constructed by using the LFCM (Learning and Forgetting Curve Model) model. This model is a perfect model based on the classic WLC learning curve model, which reveals the relationship between learning and forgetting degree and interruption time by comparing the forgetting effect with the learning effect [21]. Based on LFCM theory, the calculation method of skill proficiency considering learning-forgetting impact is shown in Formula (4):

$$\beta_{pki}^{f} = \beta_{pki}^{s} + L \cdot T^{a_k} - F \cdot T'^{b_k} \tag{4}$$

In Formula (4), β_{pki}^{f} indicates the proficiency of the employee p using the skill$k$before performing the construction task$i$;Tindicates the duration of the employee$p$using the skill k; T'indicates the difference between the initial moment of the employee$p$use skill$k$to perform the construction task$i$and the end moment of the last previous use skill$k$, that is, the time when the employee is idle; L represents the learning curve coefficient, F represents the coefficient of forgetting curve, which is related to the initial skill proficiency. Usually, the lower the skill level, the faster the level will improve because of the lower difficulty in learning basic knowledge, and the knowledge will not be easily forgotten. When the skill level is high, the learning difficulty of deep expertise is relatively high, the speed of level improvement will slow down, and knowledge is easy to forget. Under normal circumstances, the forgetting rate of employees is less than the learning speed, and the article stipulates that $L = -ln(\beta_{pki}^s/2)/10$, $F - ln(3\beta_{pki}^s)/15$. The greater the initial skill proficiency, the smaller the learning curve coefficient and the larger the forgetting curve coefficient;a_{pk}represents the learning factor of employee$p$for construction skills$k$,$a_{pk} = -ln(\lambda_{pk})/ln(2)$, $\lambda$is the learning rate,λ generally is between 75%~95%, the greater the learning factor, the stronger the learning effect; b_{pk} represents forgetting factor of employee p for skills k , $b_{pk} = ln(1-\mu_{pk})/ln(2)$, μ is the forgetting rate,μgenerally is between 3%~15%. The greater the forgetting factor, the weaker the forgetting effect. The learning rate and forgetting rate are closely related to employees' factors. Considering the limitations of people's physiological conditions, there is a learning upper limit $\hat{\beta}$ for skill proficiency, and ignoring the lower limit$\breve{\beta}$.$\Delta\beta(T) > \Delta\beta(T')$, $T = T'$means that the learning effect of employees is stronger than the forgetting effect at the same time. In addition, the learning effect and forgetting effects of employees change after each interruption. With the improvement of skill proficiency, the learning speed slows down, and the forgetting rate accelerates.

C. High-Rise Building Project Management Personnel Training Optimization Model Construction

1) Design of objective function: Combined with the employee as mentioned above cognitive ability modeling, this paper constructs a multi-objective function of the training model for project managers of high-rise buildings, aiming at minimizing the project duration, minimizing the project cost, and maximizing the benefit of skill growth, and constructs a multi-objective function model, as shown in Formula (5), Formula (6) and Formula (7):

$$min\, T = \sum_{i \in A} T_i \tag{5}$$

$$min\, C = m \cdot w + \sum_{i=1}^{n\Sigma} \sum_{k=1}^{r\Sigma} (\bar{\beta}_{ki} \cdot c_{ki}^{max}()) \tag{6}$$

$$max\, R = \sum_{i=1}^{n} \sum_{k=1}^{r} \sum_{p=1}^{m} \varepsilon_k \cdot (\beta_{pki}^f - \beta_{pki}^s) \tag{7}$$

Among the above formulas, Formula (5) represents the objective function of minimizing the project duration, and the total time is the sum of the durations of tasks on the critical path.T represents the project duration,Arepresents a collection of functions on a critical path,$A = \{a_1, a_2, \ldots, a_x\}$, $a_x \in [1, n]$, T_i represents the duration of the task i ; Formula (6) represents the objective function of minimizing the project cost. The project cost is the sum of the salaries paid to all employees, including the basic salary and the commission. The basic salary is fixed and consistent for all employees, and the commission is positively related to the average efficiency of completing the work.Crepresents the project cost,$\bar{\beta}_{ki}$represents the average proficiency workJ_{ki}, describes the basic salary of employees, m represents the employee's commission salary,c_{ki}^{max} represents the highest commission for a job, which means the remuneration received by an employee with skill proficiency of 1 completes the jobJ_{ki}; Formula (7) represents the objective function of maximizing the benefit of skill growth, and the total benefit is equal to the sum of the skill proficiency appreciation of all employees after participating in various jobs. R indicates that benefit of skill growth, ε_k represents the development weight of skill k that refers to the importance of skills to enterprises.β_{pki}^s represents the skill proficiency of an employee$p$start workJ_{ki}, describes the skill proficiency of an employee$p$finish workJ_{ki}.

In order to ensure the optimization effect of the article on the talent training scheme, according to the above objective function, the following optimization constraints are constructed:

a) Average working proficiency: Formula (8) is used to express the average working proficiency of employees:

$$\bar{\beta}_{ki} = \frac{\sum_{p=1}^{m} \beta_{pki}^s \cdot X_{pki}}{d_{ki}} \tag{8}$$

In the Formula (8), X_{pki} is the number of employees required for workJ_{ki};$d_{ki}$is 1 if the employee$p$is involved in workJ_{ki}, otherwise, the value is 0.

b) Duration of construction task: the duration of the construction task is constrained by Formula (9):

$$T_i = max_{k \in K}\{T_{ki}\}, T_{ki} = \frac{T_{ki}^{min}}{\bar{\beta}_{ki}} \tag{9}$$

In the Formula (9),T_{ki}^{min}represents the minimum duration of workJ_{ki}that refers to the time required for employees with skill proficiency of 1 to complete the work;T_{ki}represents the duration of employmentJ_{ki}.

c) Formula (10) is used to express the logical constraint condition of the construction task, that is, the task can only be started after all the tasks immediately before it is finished:

$$B_i - B_j \geq T_j, \forall i \in I, \forall j \in PF_i \tag{10}$$

In the Formula (10),$B_i$represents the commencement time of the construction task$i$;B_j represents the end time of the construction task$i$;I represents the collection of a task$i$, $I = \{1, 2, \ldots, n\}$; PF_i represents a set of immediate tasks of task$i$.

d) Formula (11) is used to express the calculation method of skill proficiency of employees at the beginning of work:

$$\beta_{pki}^s = \begin{cases} \beta_{pk}^s, \forall x_{pki'} \neq 1, i' \in PF_i \\ \beta_{pk}^f, argmin_{i' \in PF_i}, \{B_{ki} - (B_{ki'} + T_{ki'})\}, \exists x_{pki'} = 1, i' \in PF_i \end{cases} \tag{11}$$

In the Formula (11), x_{pki} indicates that if employee p participates in work J_{ki}, the value is 1; if the employee$p$has skills$k$but does not participate in work J_{ki}, the value is 0; if the employee$p$does not have skills$k$, the value is -1;B_{ki} indicates the start time of work J_{ki};β_{pk}^s represents the proficiency of employee$p$using skill$k$at the beginning of the project, representing employee productivity, $\beta_{pk} \in [0,1]$, if the employee p does not have skill k, the value is 0; β_{pk}^{f} indicates the ability of employee p using skill k at the end of the project.

e) Calculate the skill proficiency of employees at the end of work by Formula (12), and specify that the upper learning limit of skill proficiency is 1 and the lower forgetting limit is 0.3. If the calculated proficiency value is greater than 1 or less than 0.3, reset the value to the upper or lower limit:

$$\beta_{pki}^{f} = \begin{cases} \beta_{pki}^{s} + L \cdot T_{ki}^{a_{pk}}, \forall x_{pki'} \neq 1, i' \in PF_{i'} \\ \beta_{pki}^{s} + L \cdot T_{ki}^{a_{pk}} - F \cdot \left(\min_{i' \in PF_{i'}} \{B_{ki} - (B_{ki} + T_{ki'})\} \right)^{b_{pk}} \\ \quad , \exists x_{pki'} \neq 1, i' \in PF_{i'} \end{cases} \quad (12)$$

$$L = -\ln\left(\beta_{pki}^{s}/2\right)/10, F = \ln\left(3\beta_{pki}^{s}\right)/15$$

In the Formula (12), L represents the learning curve coefficient; b_{pk} represents the learning factors for an employee p to skills k, a_{pk} represents the learning efficiency of an employee p to skills k.

f) Formula (13) indicates that when there is a situation where the same employee is assigned to complete multiple tasks in parallel tasks, and there is a human resource conflict in job assignment, the employee is first given the job with a higher priority, that is, the position with higher priority starts first:

$$B_{ki} - B_{kj} \geq T_{bj}, \varphi_{kj} \geq \varphi_{ki}, PF_i = PF_j, S_{ki} \cap S_{kj} \neq \emptyset \quad (13)$$

In Formula (13), φ_{ki} represents the priority of work J_{ki} , $\varphi_{ki} \in [1, j]$; S_{ki} represents assignment to a job. J_{ki} represents a collection of employees; F represents the forgetting curve coefficient.

g) By Formula (14), the number of employees assigned to task i using skill k shall be equal to the number of employees required to complete task i using skill k:

$$\sum_{p=1}^{m} X_{pki} = d_{ki} \quad (14)$$

h) Restrict each employee to participate in only one job at any time by Formula (15):

$$\sum_{i=1}^{n} \sum_{k=1}^{r} y_{pkit} \leq 1 \quad (15)$$

In the Formula (15), y_{pkit} represents an employee p participates in the work J_{ki} at time t, the value is 1, otherwise the value is 0.

i) The range and relationship of the three decision variables are expressed by Formula (16), Formula (17) and Formula (18):

$$x_{pki} \in \{0,1,-1\}, y_{pkit} \in \{0,1\}, X_{pki} \in \{0,1\}; \forall p, k, i, t \quad (16)$$

$$x_{pki} = \begin{cases} 1, \forall t, y_{pkit=1} \\ 0, \forall t, y_{pkit=0} \\ -1, \alpha_{ki} = 0 \end{cases} ; \forall p, k, i \quad (17)$$

$$X_{pki} = \begin{cases} 1, x_{pki} = 1 \\ 0, x_{pki} \neq 1 \end{cases} ; \forall p, k, i \quad (18)$$

In the above formula, K represents a collection of skill k, $K = \{1,2,\ldots,r\}$; P represents a collection of employees p , $P = \{1,2,\ldots,m\}$; J_{ki} represents the work performed in a task i using skills k, $j = \sum_{i=1}^{n} \sum_{k=1}^{r} \alpha_{ki}$.

Through the above methods, the constraint conditions of the optimization goal of high-rise building project management personnel training are constructed, which provides a reliable guarantee for multi-objective optimization.

D. Optimization of Personnel Training Model based on Multi-Objective Genetic Algorithm

The Genetic algorithm is a highly parallel adaptive search algorithm based on the "survival of the fittest" mechanism. In 1967, some scholars applied genetic evolution to multi-objective optimization problems for the first time; thus, the research on multi-objective optimization problems entered a new era, and the search idea using genetic evolution later became the basis for a large number of scholars [22]. Because the article constructs a variety of objective functions of talent training optimization in the above chapters, in order to realize these multi-objective optimizations, this paper uses a multi-objective genetic algorithm to find out the best management talent training scheme through multi-objective optimization.

All genetic algorithms (GA) follow a similar basic framework, which was put forward by Holland and called a simple genetic algorithm [23]. The main flow of the algorithm is as follows:

- According to the modeling results of the above-mentioned objective function, the chromosome coding of the training target of management talent in high-rise building projects is carried out, and the initial population of management talent training targets is randomly generated.
- Judge whether the evolutionary algebra meets the requirements, if it meets the requirements, outputting the training target population of the last generation of management talent and ending the test; otherwise, enter step (3).
- Calculate the fitness value of the target population for training management talent, replace it with the "two-person competition" method (including male parent and female parent), and cross it with some rules to produce offspring; after the crossover is completed, the parent mutates with a certain probability to produce offspring (in order to preserve population diversity, the mutated parent is kept.) Merge the crossed and mutated offspring with the parent, and recalculate the individual fitness value of the target population of management talent training.

- Judge whether the number of the target population for training management talent is greater than the initial set value, and if it exceeds the set value, put forward the inferior solution through the "three-person championship" according to the fitness. Evolutionary algebra Gen+1, and return to step (2).

Because the above steps are only the basic framework of the genetic algorithm, the state of the actual management personnel training goal optimization is not considered. Therefore, the calculation process of chromosome coding, crossover, mutation, and fitness function is analyzed through the following contents.

1) Management personnel training target chromosome coding and decoding.

a) Chromosome Coding: Each individual in the target population of management personnel training represents a feasible optimization scheme. Because it is necessary to arrange the construction sequence and human resource allocation at the same time, each possible solution is set to contain two chromosomes, namely the construction task chromosome and the employee chromosome, and they should have the same number of genes. The construction task chromosome is the arrangement of all tasks in a high-rise building project under the immediate constraints, that is, each construction task must be located after all its quick activities; This chromosome shows the sequence of all construction tasks in a feasible optimization scheme of management personnel training objectives [24]. The gene of the employee chromosome indicates the employee's situation of construction task assignment. Let$list_r_{jk}$be the set of employees where the chromosome uses skill$k$in the$j$th construction task, andα_{jk}be the overall tacit understanding of the set of employees serving the construction task$j$skill$k$, so the forms of the chromosome and the construction task are shown in Fig. 1.

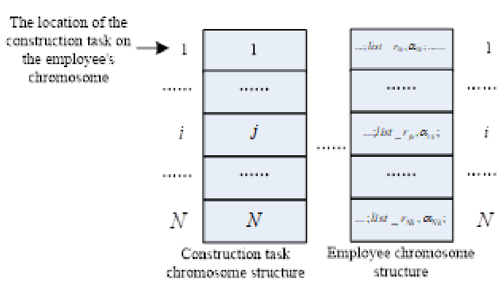

Fig. 1. Chromosome structure analysis diagram.

b) Population Initialization: Initializing the target population of management talent training is to initialize the construction task and employee chromosome, that is, to determine the completion order of the construction task first, and then assign the corresponding employees according to the construction order arranged on the chromosome of the construction task. The specific steps are as follows:

Inserting the construction tasks into the chromosome of the construction tasks one by one by adopting a serial scheduling method, and ensuring that the immediately preceding tasks are placed in the chromosome when each construction task is added; For parallel tasks, they are randomly arranged in chromosomes [25].

Assign employees to each construction task according to the gene sequence on the chromosome of the construction task, and the specific employee allocation steps are as follows:

- Set in time$t = 0$, the scheduled construction task set is$S = \phi$, the scheduling construction task set is$D = \phi$, the corresponding completion time of each construction task$j$in D ish_j, and the current scheduled set meeting the logical relationship is E_v . If set $E_v = \phi$, the employee assignment is over, the t at this time is makspan. The unoccupied employee collection is E_r, assigning the following steps for each of E_v of the construction tasks.
- If set $E_v = \phi$, then select in D the minimum h_j construction task of j', update $t = h_{j'}$, the construction task $S = j' \cup S$ and return to step a; Otherwise from the collection$E_v$choose the construction task$j$, and conduct employee evaluation for each skill required for its implementation.
- Select the skill k without employee assessment in the construction task j, initialize the tacit understanding factor$factor = 1.0$, skill quantity$amount = 0.0$.
- If there is no employee with skill$k$inE_r, the employee does not meet the requirements of construction task, put the employee of each employee setb_{jk}in construction task$j$back toE_r, then empty the setb_{jk}, finally remove the construction task j from E_v and return to step b; otherwise randomly select the employee r with skill k in E_r , put it into the employee set S_{jk} of the skill k required in a construction task j , and remove from E_r , the corresponding skill quantity $amount = amount + a_{rk}$, update the collaboration factor$factor$.
- Judge whether$amount \times factor$is greater thanb_{jk}. If the conditions are not met, return to step d; otherwise, it indicates the constraint judgment is completed of the construction task j with skill k , and then determine whether the other skills of the construction task$j$have been judged, if not, return to step c, otherwise, explain the construction task$j$meet the staff constraints, will be assigned to the construction task$j$put all employees in the occupied state, and put the construction task$D = j \cup D$, and calculate the completion periodh_j, return to step b.

Because each step is selected in a randomized way, the diversity of the target population for initial management personnel training is ensured. Repeat the above steps until the number of the initial management personnel training target population isPOP.

c) Chromosome Coding: The serial schedule generation mechanism is used to decode the chromosome to generate the solution. The serial schedule generation mechanism needs to meet the task sequence constraint (forward scheduling) of the employee chromosome and the resource constraint of the corresponding construction task in the employee chromosome [26]. Specifically, before the next construction task starts, all its immediate tasks must be completed, and the employees assigned to it are available. At this point, the earliest start time of the construction task can be obtained. It should be noted that only one feasible scheduling scheme can be obtained in the process of decoding the target chromosome of management personnel training. The project duration is received in the above initialization process. Then, the multi-objective solution can be used to calculate the objective function value of the remaining management talent training.

2) Design of fitness function for optimization of management personnel training objectives.

The main difference between a multi-objective evolutionary algorithm and a single-objective evolutionary algorithm lies in the fitness function, which is caused by the different number of solutions. Therefore, the relative non-dominance of solutions is usually used to measure the quality of solutions obtained by multi-objective evolutionary algorithm, that is, the Pareto solution or approximate Pareto solution is used as the solution set of multi-objectives. Pareto solution is a collection of non-dominant solutions, and the concept of a dominant solution is defined as follows:

Assume that X and Y are two feasible solutions of management talent training objectives, and each possible solution of management talent training objectives is a ternary vector $x = (x_1, x_2, x_3)$， x_1、x_2、x_3 are three target values (assuming that the bigger the better), then x dominant solution y can be defined as the following formula (19):

$$x \succ y \Leftrightarrow \forall x_i \geq y_i, \exists i\{1,2,3\}, x_i > y_i \tag{19}$$

In Formula (19), the non-dominant solution is defined as that any other individual does not dominate an individual, that is, for other management personnel training target individuals, the result of one goal of the management personnel training target individual is always better than other individuals (excluding duplicate individuals).

The fitness value of the target individual of management talent training is determined by the number of other individuals who dominate it and the number of individuals adjacent to it. Set $d(x)$ be the number of other individuals controlling the individual x, and $s(x)$ is the number of individuals adjacent to x, as defined in Formula (20) and Formula (21):

$$d(x) = |x' \in P: x' \succ x| \tag{20}$$

$$s(x) = \left| x' \in P, x' \neq x: \frac{|f_i(x) - f_i(x')|}{f_i(x')} \right|, i = 1,2,3 \tag{21}$$

In Formula (20) and Formula (21), P is the management of the population of target individuals, $f_i(x)(i = 1,2,3)$ represents the target individual x of management talent training of the i th target value, shared distance $\sigma_i(i = 1,2,3)$ is a constant.

The assignment process of individual fitness of management talent training target $\phi(x)$ is as follows:

- Calculate $d(x)$ and $s(x)$ for each management talent training target individual in population P.
- According to $d(x)$ to assign value to the target individuals of management talent training;

$$\phi(x) = d(x) + 1 \tag{22}$$

- To $d(x)$ with the same management talent training target individual set (that is, the unique set that does not dominate each other), according to the values of $s(x)$, sorted from small to large, and the serial number is n; The number of the same $d(x)$ management talent training target individuals is num, $\Delta = \frac{1}{num}$, then there is:

$$\phi(x) = \phi(x) + n * \Delta, n = 0,1, \ldots, num - 1 \tag{23}$$

According to the definition of fitness value, the smaller the fitness value, the better the solution is.

3) Management personnel training objectives optimization, crossover and mutation operation.

a) Parent selection: In this paper, the "two-person competition method" is used to select the father for pairing to produce offspring. Select two target chromosomes of management personnel training from the population, take the excellent target individuals of management personnel training as the male parent, and repeat this step to find the female parent until POP/2 pairs of fathers are produced. The advantage of this method is that it can combine relatively good parents to make better offspring and improve convergence.

b) Crossing: Cross operation refers to the process of exchanging and recombining the genes of the male parent and the female parent, and then producing offspring. Because crossover operation can combine and keep the best genes of parents, it plays a core role in genetic function. Given crossover probability P_c (generally 0.4~1), which means that parents P_c take the probability of crossing. Through the following contents, the detailed operation steps of crossing the construction task chromosome and the employee chromosome are given.

Cross operation of construction task chromosomes: The two-point cross method is adopted for the cross of construction task chromosomes. Firstly, two integers are randomly generated q_1、q_2, they meet $1 \leq q_1 \leq q_2 \leq J$. In the construction task sequence of the first generation $1 \sim q_1$ is up to the mother, $q_1 + 1 \sim q_2$ inherit from my father, $q_2 + 1 \sim J$ inherit from mother; Descendant 2 inherits in the opposite way to descendant 1.

Generate a random number v in the interval of [0,1] through a random number generator according to the construction task sequence on the chromosome of the offspring construction task obtained by crossing, if $v \leq 0.5$, then the daughter resource chromosome 1 inherits the employee chromosome gene of the construction task number corresponding to the daughter construction task chromosome 1 from the parent, and the daughter resource chromosome 2 inherits the employee chromosome gene of the construction task number corresponding to the daughter construction task chromosome 2 from the parent; if $v > 0.5$, the inheritance order is exchanged.

c) Mutation operation: Chromosome mutation operation of construction task: given mutation constant P_m , each individual has the probability of mutation occurs P_m, and for the mutated individuals, the construction task i in the individual construction task chromosome is randomly selected and inserted into a new position (mutation occurs); The role of mutation is related to its immediate pre-task and immediate post-task, that is, the position of mutation must be between the immediate pre-task and immediate post-task; In order to ensure the feasibility of the employee chromosome, the resource chromosome corresponding to the mutation construction task is changed in the same position.

Mutation operation of employee chromosomes: each individual has the probability of mutation P_m, for the mutated individual, the simple way of randomly selecting a skill in the construction task and redistributing employees is used to complete the mutation of employee chromosomes. Considering the diversity of Pareto solutions, the parents of the mutated individuals are reserved.

d) Choose: After the crossover operation, a large number of offspring will be produced. In order to keep the target population number of management talent unchanged, the "three-person championship method" is adopted to eliminate the poor individuals. The selection method of three-person championship is random selection, proportional selection, and the expansion method of double competition. The specific process is to randomly select three chromosomes, namely I_1、I_2、I_3. If Formula (23) is satisfied:

$$\phi(I_1) \geq \phi(I_2) \text{且} \phi(I_1) \geq \phi(I_3) \tag{24}$$

Then individual I_1 is eliminated from the population, and the operation is repeated until the population becomes the initial set value POP again; if the target population number of management talent training is not greater than POP before the substitution operation, the operation will not be carried out.

E. Optimization Process Design based on Hybrid Immune Genetic Algorithm

The multi-objective genetic algorithm (MOGA) is one of the adaptive heuristic algorithms used to solve multi-objective problems, but it has a great disadvantage: it is premature. Aiming at this problem, this paper proposes a hybrid immune genetic algorithm. Immunity is an important physiological behavior of living things. Its main function is to resist viruses, bacteria, etc., that may cause discomfort from the outside and maintain the homeostasis of the body. It recombines genes through complex and intense mechanisms to cope with invading antigens, produce antibodies, and eliminate antigens. The immune process can improve the diversity of the population, expand the search range of the population, and then improve the quality of people. Combining these two algorithms is of great significance to solve the problem of premature convergence of genetic algorithms in theory and improve the diversity of non-inferior solutions.

At the same time, some Japanese scholars put forward the double island model to improve the lethal chromosome in the process of evolution. In each generation of the evolutionary algorithm, many poor-quality chromosomes will be produced, and the double island model will separate the excellent and inferior chromosomes. In this model, the lethal chromosomes are put together (called "dead islands"). The chromosomes in the "dead island" are crossed and mutated, and finally, the excellent chromosomes are put back into the genetic process. However, in this process, only the lethal chromosomes in the "dead island" are manipulated, and the effect is not significant. Introducing the immune process is helpful in solving this problem, so this paper presents the immune process in the two-island model. By combining the two-island model with the immune process, a hybrid immune genetic algorithm is formed. The algorithm is actually carried out in two aspects: on the one hand, the "dead island" is immunized; on the other, the individuals on the "living island" are crossed and mutated. Before the evolution of each generation, it is necessary to inoculate the individuals in the "dead island" to produce excellent individuals, and then move these individuals into the "living island" for evolutionary operation, and perform this step circularly until the constraint conditions are met.

The specific flow of the algorithm is as follows:

1) Coding chromosomes according to the modeling result of the training objective function of high-rise building project management talent and randomly generating the initial population of the training objective of management talent.

2) Judging whether the evolutionary algebra meets the requirements, if it meets the requirements, outputting the training target population of the last generation of management talent, and ending the test; otherwise, entering step (3).

3) Calculate the fitness value and average fitness value of the target population for training management talent, and move the individuals with higher-than-average fitness into the "dead island" and those with lower-than-average fitness into the "living island." Inoculate the chromosomes in the "dead island" and put the excellent individuals into the "living island" after injection. For the crossover and variation of individuals in the "living island," the individual fitness value of the population is recalculated.

4) Judge whether the number of the target population for training management talent is greater than the initial set value, and if it exceeds the set value, reject the inferior solutions according to the fitness. Evolutionary algebra Gen+1, and return to step (2).

Steps (1), (2), and (4) in the above steps are the same as the basic genetic algorithm, and the selection rule of parents still adopts the "two-person economic law," and the "three-person championship" method is selected when the redundant individuals in the population are eliminated. The difference is that the "double island model" and inoculation process are added in step (3).

Through the optimization of this method, the best training scheme can be found for project management talent of high-rise buildings.

III. Experimental Analyses

In order to evaluate the application effect of the high-rise building project management talent training model designed in this paper, the model is applied to a high-rise building project. The total height of this high-rise project is 269.7m, and the entire construction area is 172,000 $m^{2,}$ with 57 floors above ground and three floors underground. The overall building structure is frame+facade support+tube structure. A total of 157 constructors+managers are employed in this project. The management talent used in the construction of this high-rise building project is trained, and whether the training model designed in this article has a certain use effect is analyzed.

Select an employee from the project managers of high-rise buildings and analyze the changes of the learning curve, forgetting curve, and learning forgetting curve of the employee at different times so as to verify the evaluation effect of the article on employees' cognitive ability. The results of the analysis are shown in Fig. 2.

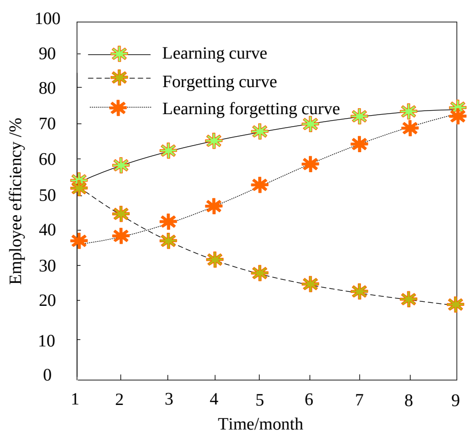

Fig. 2. Employee learning curve, forgetting curve, and learning forgetting curve.

According to Fig. 2, through the evaluation of employees' cognitive ability by this model, it can be seen that the employee's learning curve maintains about 50% employee efficiency in the initial stage, and with the continuous progress of the learning process, the employee efficiency increases to about 70%, but this curve does not consider the employee's forgetting degree; Through the analysis of forgetting curve, it can be seen that the employee efficiency has gradually decreased from the initial 50% to about 20%, which leads to the degree of forgetting obviously affecting the employee's work efficiency; Therefore, this model combines the learning and forgetting curve to analyze, and it is known that when employees' forgetting problem is considered, the employee efficiency gradually starts to rise from the initial 30%~40%, and can reach more than 60% with the continuous learning process. Through the analysis of this model, it is possible to accurately know the influence of employees' learning and forgetting methods on their efficiency.

This paper analyzes the changes in the total project construction cost before and after the optimization of the training of high-rise building project management talent by using this model so as to verify the optimization ability of this model to the cost target, and the analysis results are shown in Fig. 3.

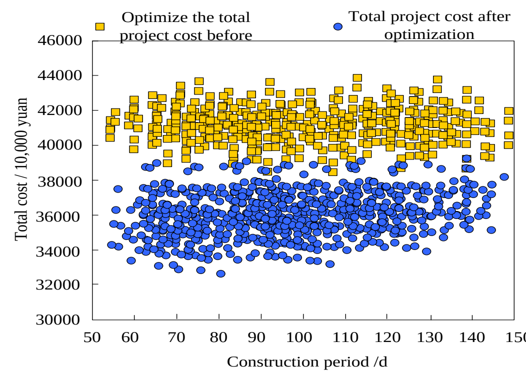

Fig. 3. Analysis of total cost optimization results.

According to Fig. 3, through comparison, it can be seen that the total cost of this high-rise building project has always remained at a high level before being optimized by this model, which leads to a large amount of expenses in the construction of this project. When this model optimizes the management talent, the construction strategy of this project has been improved, which makes the total construction cost of this project decline. It can be seen that when the model is optimized, the total cost of the project is no more than 400 million yuan, which can obviously save a lot of expenses. Therefore, the model has a good optimization effect.

Select different tasks from the overall project construction and analyze the human resource utilization ratio of other tasks before and after optimizing management talent so as to verify the effect of this model on different talent training. The analysis results are shown in Table II.

From the analysis in Table II, it can be seen that the utilization rate of human resources in this project is always at a low level for different construction tasks before the model is adopted for optimization. Among them, the utilization rate of human resources in foundation treatment construction, pile cap construction, and fence construction tasks can reach the highest, but it is only 57%. After the model is optimized in this paper, the management personnel are effectively trained, and the utilization rate of human resources in construction is also increased. Among them, the utilization rate of human resources in each task is above 85%, and the highest utilization rate is 92%, which shows that human resources can be fully utilized in the construction process, thus ensuring construction efficiency. Therefore, the model has excellent optimization ability.

Select an employee from different employees and analyze the changes in the employee's proficiency in technical ability, planning and organization ability, and cost control ability during the training process so as to verify the evolutionary power of the model. The results of the analysis are shown in Fig. 4.

TABLE II. ANALYSIS OF HUMAN RESOURCE UTILIZATION IN DIFFERENT TASKS

Serial number	Construction task	Human resource utilization before optimization /%	Human resource utilization rate /% after optimization in this paper
1	Construction preparation and temporary facilities	54	89
2	Foundation treatment	57	91
3	Cut earth	48	92
4	Pile driving	49	88
5	Backfill and lightning protection grounding works	53	87
6	Pile cap construction	57	93
7	Column reinforcement and lightning belt construction	55	86
8	Ground concrete cushion construction	46	91
9	Roof beam plate formwork construction	47	90
10	Concrete placement construction	52	89
11	Power threading construction	56	88
12	Plastering works	53	92
13	Ceiling works	54	87
14	Drainage engineering construction	55	89
15	Wall construction	57	90
16	Electrical installation and construction	48	87
17	Plastering of exterior walls	49	89
18	Exterior wall coating construction	50	87
19	Defect repair construction	52	89

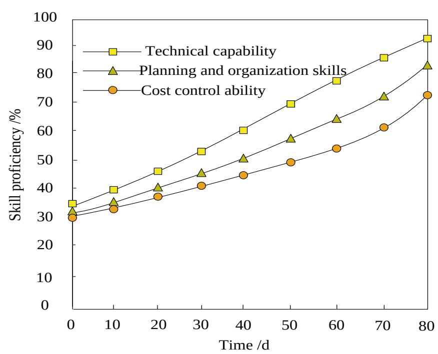

Fig. 4. Analysis of employee skill proficiency.

According to Fig. 4, with the continuous increase of time, the employee's proficiency in different skills began to increase. Among them, the employee's technical ability always maintained a high proficiency, while the employee's planning and, organization ability and cost control abilities were relatively weak. However, when the time reached 80 days, the employee's proficiency in different skills reached more than 70%, indicating that the employee had a high proficiency in skills at this time. Therefore, after the model was optimized,

Analyze the changes in skills growth benefits of the optimized talent training model under different project durations and project costs, and the analysis results are shown in Fig. 5.

The benefit of skill growth refers to all kinds of advantages and benefits brought by learning and developing new skills. According to Fig. 5, through the optimization of the model in this paper, the skills growth benefit can be maintained at different project duration and project costs. It can be seen that the model can improve the problem-solving ability of project management talent, stimulate employees' creativity and innovation ability, maximize employees' self-value, and thus enhance the overall benefits of enterprise construction projects.

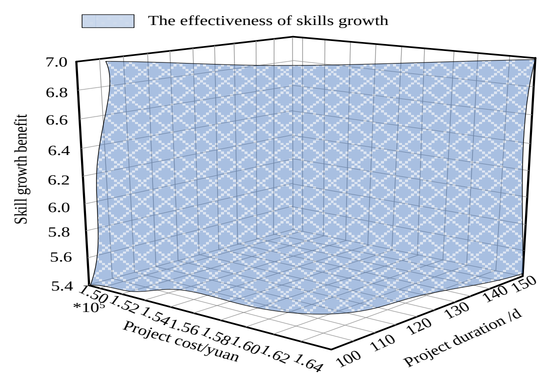

Fig. 5. Skill growth benefit analysis.

This paper analyzes the influence of traditional genetic algorithms, multi-objective genetic algorithms, and genetic algorithms based on mixed immunity on the construction period of the project under different optimization times so as to evaluate the optimization effect of the model on the construction period index and the analysis results are shown in Fig. 6.

According to Fig. 6, after the iterative evolution of different algorithms, the construction period of high-rise buildings has decreased. When the number of iterative developments reaches 800 times, the optimized construction period of the three algorithms has reached the lowest state. Among the three algorithms, the construction period optimized by the traditional genetic algorithm has remained above 670d, and it has maintained the highest level among the results optimized by the three algorithms. After the optimization by the multi-objective genetic algorithm, although the construction period has decreased, it is still higher than the result of optimization based on the hybrid immune genetic algorithm in this paper. Under the optimization of this model, project management talent has been trained efficiently, thus effectively reducing the construction period. When the number of iterations reaches 800, the optimization result of this model only takes about 620d days to complete the project construction so that the total construction period can be effectively shortened after the optimization of this model.

After applying this model to optimize multi-objectives, the construction quality and actual construction duration of different project tasks are analyzed to verify the multi-objective optimization effect of this model. The analysis results are shown in Table III.

According to the analysis in Table III, after multi-objective optimization with this model, the construction can be completed within the specified time range when dealing with different construction tasks, and the actual construction time of most tasks is lower than the specified time. At the same time, when the construction is completed, it can be seen that the construction quality of different tasks meets the construction standards. Therefore, under the optimization of this optimization model, the technical level of high-rise building project management personnel can be effectively improved to ensure smooth construction.

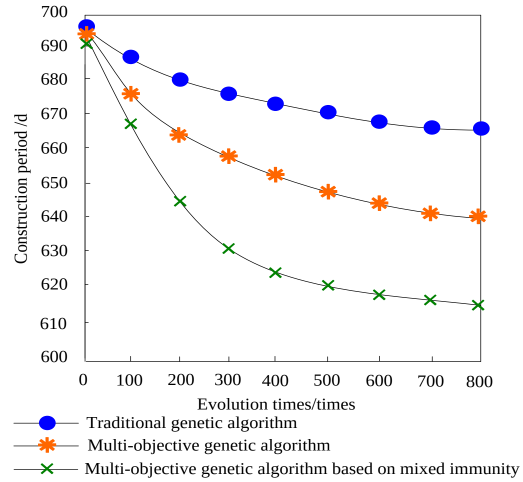

Fig. 6. Changes in the construction period after optimization.

TABLE III. ANALYSIS OF CONSTRUCTION QUALITY AND ACTUAL CONSTRUCTION TIME IN DIFFERENT TASKS

Serial number	Construction task	Estimated standard construction time /d	Actual completion time /d	Construction quality inspection
1	Temporary electricity construction	9	8	The quality meets the construction standard
2	Site clearing	14	12	The quality meets the construction standard
3	Erection test pile	4	3	The quality meets the construction standard
4	Erection column	18	14	The quality meets the construction standard
5	Site formation construction	5	5	The quality meets the construction standard
6	Pile head preparation	10	8	The quality meets the construction standard
7	Immersed pipe pouring concrete and pile cap construction	11	10	The quality meets the construction standard
8	Construction of the embedded underground pipeline	12	10	The quality meets the construction standard
9	Backfill construction	6	5	The quality meets the construction standard
10	Concrete bedding and waterproof construction	1	1	The quality meets the construction standard
11	Underground pillar construction	6	6	The quality meets the construction standard
12	Stairwell construction	10	9	The quality meets the construction standard
13	Ceiling plaster	8	7	The quality meets the construction standard
14	Plaster the walls	10	8	The quality meets the construction standard
15	Ground waterproof layer construction	5	5	The quality meets the construction standard
16	Cement mortar protective layer construction	10	8	The quality meets the construction standard
17	Wiring construction	15	13	The quality meets the construction standard
18	Water pipe installation	7	6	The quality meets the construction standard
19	Natural gas pipeline installation and construction	8	7	The quality meets the construction standard
20	Decoration and beautification construction	10	8	The quality meets the construction standard

IV. Conclusion

This paper studies the training model of high-rise building project management talent under a multi-objective evolutionary algorithm. The research results show that the model can effectively evaluate and optimize the training scheme of project management talent. In this paper, firstly, an objective function with multiple objectives is constructed, including project duration, project cost, and skill growth rate. By adopting a multi-objective evolutionary algorithm, these indexes can be optimized at the same time, and a balanced training scheme among different objectives can be obtained. Secondly, this model is used to optimize the training scheme of real high-rise building project management talent. The results show that by adopting a multi-objective evolutionary algorithm, a more practical training scheme can be achieved. At the same time, the feasibility and flexibility of the model were also verified through case analysis. Generally speaking, this research has developed and verified the talent training model of high-rise building project management, which provides a scientific and effective method for talent training. This model can not only help decision-makers formulate reasonable training strategies but also provide an innovative idea and plan for talent training in the field of high-rise building project management.

Competing of Interests

The authors declare no competing of interests.

Authorship Contribution Statement

Pan qi: Writing-Original draft preparation, Conceptualization, Supervision, Project administration.

Data Availability

On Request

Declarations

Not applicable

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