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Construction and Application of Prefabricated Architectural Design Teaching Platform Based on CAD Technology

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Abstract. In recent years, prefabricated buildings and computer-aided design technology have become the focus of attention in my country's construction industry. The country has issued a series of policies to promote building informatization and industrialization. Among them, for the innovative talent training mode, colleges and universities are clearly encouraged to set up courses related to prefabricated buildings, but at present, most colleges and universities have not set up courses in prefabricated buildings, which cannot meet the industry's demand for industrialized professionals. To this end, the application results of computer-aided design technology in construction site management are extended to the architectural design teaching platform, and the prefabricated architectural design model is constructed based on the CAD-related software platform. According to the typical structure of prefabricated buildings, the multi-agent reinforcement learning algorithm is used. Automatic realization of obstacle avoidance layout design for prefabricated building construction. Through professional construction simulation technology, 4D animation is generated to simulate the on-site construction process, so that students can fully understand the prefabricated building. In the end, the teaching efficiency of prefabricated architectural design has been greatly improved. At the same time, the relevant curriculum system and build a new open teaching platform, which has far-reaching significance for helping the industrialization of buildings.

Keywords: CAD Technology; Prefabricated Construction Design; Teaching Platform.
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1 INTRODUCTION

With the progress of society, science and technology have had an important impact and brought unprecedented changes to all aspects of society. The digital simulation technology brought by the development of computer technology has become an indispensable method in scientific research work. For example, the progress of revolutionary changes to the production tools and management modes of the manufacturing industry, electronics industry and other industries [1]. Combined with the current development requirements and goals of my country's construction industry from high energy consumption, heavy pollution to low energy consumption, low pollution, and sustainable development, the realization of information technology in my country's construction industry is to complete the construction industry's sustainable development strategy and achieve the goal of sustainable development [2].

The gradual popularization of computer applications, computer-aided software tools have been widely used in the stages of planning, design, construction, operation and maintenance of construction projects. Table 1 shows the commonly used typical computer-aided design core software [3]. The current domestic project construction process leads to the input of construction project-related data is still relatively scattered, Fragments, the various applications are not fully connected, which increases the risk of related data errors and affects the work efficiency of the entire project [4].

Software company		*Core modeling software*	
Autodesk	Revit Architecture	Revit Structure	Revit MEP
Nemetschek Graphisoft	ArchiCAD	ALLPLAN	Vector works
Gery Technology	Digital Project	CATIA	
Tdkla	Tekla Structures	Tekla Structures Designer	Tekla Tedds

Table 1: Typical CAD core modeling software.

In this context, in recent years, China has gradually introduced computer aided design (CAD) technology into the construction industry. The three-dimensional visual model established by Lazzarini et al. [5] through computer-aided design technology reduces the design changes caused by component conflicts found in later construction. Due to the wide application fields of CAD system, it is impossible to have a CAD system to solve all problems, so there are different CAD systems in engineering practice. According to the working mode and function of CAD system, Leyva et al roughly divides it into three types: retrieval CAD system, automatic CAD system and interactive CAD system [6]. Prefabricated components are assembled from pre customized components. Li et al. [7] found that they have the characteristics of simple operation, low production cost and high production efficiency in the actual use process. However, the existing yet targeted in the design of prefabricated buildings, and it is of far-reaching significance to build a teaching platform for prefabricated architectural design based on CAD technology.

2 STATE OF THE ART

In recent years, computer-aided design technology has been promoted in colleges and universities in the form of various competitions. Students have a high degree of participation and have a strong ability to accept emerging technologies. Prefabricated buildings have just developed from first-tier cities and gradually began to spread to China. Sun et al. [8] has been promoted on a large scale, but there is a serious shortage of talents with computer-aided design technology and prefabricated building skills. Therefore, the existing prefabricated component architectural design software teaching. Xiao and Bhola [9] have built a teaching platform for prefabricated component architectural design. Constantly innovate the teaching methods of architectural courses to improve the reserve ability of prefabricated component talents in colleges and universities.

2.1 Prefabricated Buildings and Their Teaching Status

Liu et al. [10] believed that prefabricated buildings are buildings assembled from pre customized components, and their prefabricated components are assembled at the construction site. This process mainly adopts integrated, information-based collaborative design, assembly, specialization, fine construction and information management. As shown in Figure 1, prefabricated components: rising slab survival building. Less labor, less environmental impact, higher quality, simple operation, low production cost, and high production efficiency. Some traditional construction workers were replaced by mechanical operators. Therefore, the focus of construction is the assembly of building components. This transformation requires prefabricated building participants to have a better understanding of technology and operation.

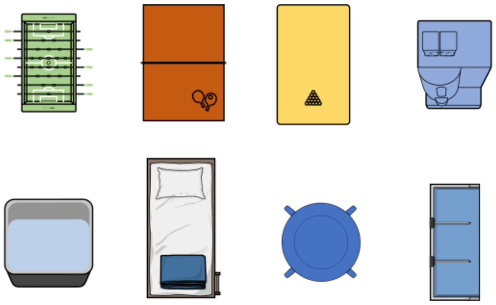

Figure 1: Main types of prefabricated components of prefabricated buildings.

Students are vulnerable to frustration in the process of "internalization and absorption" due to the lack of guidance and support from teachers and the lack of communication and help from classmates after class. So as to lose motivation and sense of achievement and reduce learning enthusiasm.

2.2 Computer-Aided Design Technology and Its Characteristics

Based on the architectural design of computer-aided design CAD, in the project, all participants and disciplines can exchange and share all kinds of information to support the simulation and analysis of safety, economy and energy consumption. This provides a scientific basis for various decisions in the environment and other aspects of the project. And improve the quality of the design scheme, government management departments, construction and material equipment and other units to quickly communicate and feedback information, and complete construction projects with high quality and efficiency. As shown in Figure 2, the design process based on computer-aided design technology is far more efficient than traditional methods, and has become the mainstream of today's social design.

A complete computer-aided design model can comprehensively display the architectural information of each stage of the project, and its main features are as follows: Visibility. Visibility is a form of "seeing what we see", and for the construction industry, computer-aided design provides a visual way of thinking that allows one to form various types of prefabricated elements. Displaying 3D graphics of three-dimensional objects in front of people; visualization referred to by computer-aided design. In the whole process of building analysis creation, many states need to be communicated. In the predictable results, the construction operation needs to be rendered. Different projects can produce better results after visual rendering and analysis.

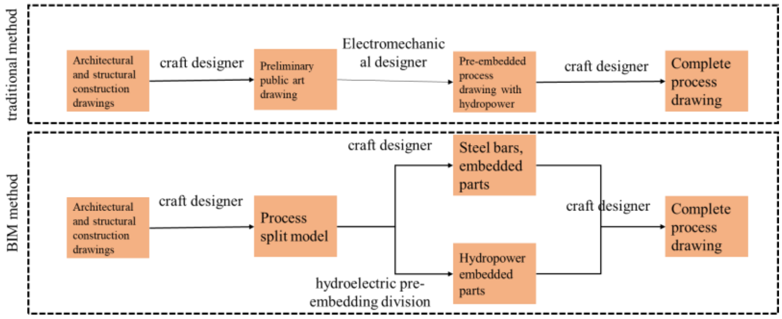

Figure 2: Comparison of design processes based on computer-aided design.

2.3 Functional Design of Prefabricated Architectural Design Teaching Platform

The construction personnel can watch the overall construction of the prefabricated building in an all-round way through the construction simulation function. process. Through the self-assembly function, the construction personnel can lap the prefabricated panels, select the tower crane and arrange the construction personnel according to the construction process learned in the construction simulation, so as to understand the lap mode of the prefabricated panels of the prefabricated building.

Figure 3 shows the layout demonstration diagram of a simulated construction site in the prefabricated teaching platform.

Figure 3: Structural model of the simulated construction site.

Table 2 shows the commonly used size adjustment parameters. The operator can design the same type of system with different attributes and different parameters. Components, you can also design components with the same attributes and different categories as system components, and assemble the established components in the system model.

General component type		*Parameter*	
Prefab wall	Exterior wall	Holeless exterior wall	Length, height
		Single-hole exterior wall	Opening length, opening height, window height, length, height
		Double-hole exterior wall	Opening 1 length, opening 2 length, opening height, window height, length, height

	Interior wall	Interior wall without holes	Length, height
		Wall with holes	Wall length, wall height, door width, door height
Prefabricated column	Prefabricated rectangular column		Width, depth, height
	Prefabricated circular column		Radius, height
Prefabricated composite beams			Width height
Prefabricated floor	Prefabricated laminate		Thickness, width, length
	Prefabricated balcony panels		Horizontal slab thickness, horizontal slab width, horizontal slab length, vertical slab length, vertical slab thickness, vertical slab height h1, vertical slab height h2
Prefab stairs	Prefab stair sections		Stair net width, section length, section height
	Prefabricated rest platform		Width, length

Table 2: Dimensional parameters of commonly used constructions.

3 METHODOLOGY

The collision problem of components in the design of prefabricated buildings in three-dimensional space, this paper takes the collision of steel bars constructed by reinforced concrete as an example, and specifically introduces how to design the obstacle avoidance arrangement of steel bars in concrete beam-column joints and in prefabricated exterior wall panels. The problem is transformed into a multi-agent path planning problem. Figure 4 shows the calculation framework of the automatic obstacle avoidance arrangement design of steel bars.

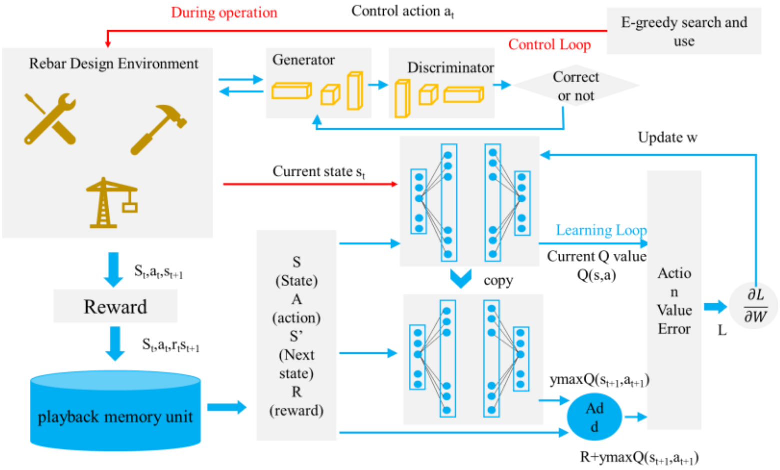

Figure 4: Design of automatic obstacle avoidance arrangement for steel bars based on deep reinforcement learning.

3.1 Description of Rebar Obstacle Avoidance Arrangement Design Problem

In order to implement Multi-Agent Reinforcement Learning (MARL), the reinforced concrete elements within the Building Information Model (BIM) must be a rasterized environment. Therefore, the BIM model of the reinforced concrete member is converted into a grid environment to represent the geometric information of the model and the known boundary conditions. The start and end points of the agent in each task are defined by $S_{ht,\max}$, $S_{ht,\min}$ (S_{ht}, is the horizontal spacing of longitudinal tension bars) $S_{hc,\max}$ and $S_{hc,\min}$ (S_{hc} is the horizontal spacing of longitudinal compression bars). Each small grid in the environment is a square grid of the same size, and the side length D can be calculated as:

$$D_i = \max(d_c, d_t) \tag{1}$$

$$Sz = floor(\frac{D}{D_i}) \tag{2}$$

where D represents the dimension of the reinforced concrete member, which can be the length, width or height of the reinforced concrete member.

$$S_{hc} \geq 30 \quad and \quad S_{hc} \geq 1.5d_{c,\max} \tag{3}$$

$$S_{ht} \geq d_{t,\max} \tag{4}$$

As the longitudinal tensile reinforcement, which can be calculated from formula (5):

$$A_s = \sum_{i=1}^{N_t} \frac{\pi d_{t,i}^2}{4} \tag{5}$$

$$n_{t,\min} = \frac{b-2c}{S_{ht,\max}} \tag{6}$$

$$n_{t,\max} = \frac{b-2c}{S_{ht,\min}} \tag{7}$$

Similarly, other parameters can be calculated.

3.2 Multi-Agent Reinforcement Learning Algorithm

By interacting and learning with the environment, the agent adjusts the behavior of the agent itself to adapt to the environment. The process of the agent interacting by Markov process.

$$P[S_{t+1} | S_t] = P[S_{t+1} | S_1, S_2, \cdots, S_t] \tag{8}$$

$$P_{SS'} = P[S_{t+1} = s' | S_t = s] \tag{9}$$

The Markov reward process MRP is based on the Markov process MP with the addition of the decay coefficient r and the reward function R, which can be described by a four-tuple (S, P, R, r). The reward function represents the expected reward obtained at the next moment in the state of the current moment:

$$R_s = E[R_{t+1} | S_t = s] \tag{10}$$

Since the observed state will change after the agent takes action, after the agent takes action a, it will transfer to the probability distribution of state St+1 at the next moment, the formula is:

$$P_{SS'}^a = P[S_{t+1} = s' | S_t = s, A_t = a] \tag{11}$$

The environment returns the agent the behavior of the agent, and the agent updates the policy according to the reward value.

$$R_S^a = E[R_{t+1} \mid S_t = s, A_t = a] \tag{12}$$

After a series of exploration and learning, the agent can finally learn the optimal behavior strategy. When the accumulated reward value obtained by the agent no longer increases, the reward function will gradually convergence.

$$G_t = R_{t+1} + \gamma R_{t+2} + \cdots = \sum \gamma^k R_{t+k+1} \tag{13}$$

The policy π in the Markov decision process MDP starting from the current state's, and the formula is expressed as follows:

$$v_\pi(s) = E_\pi[G_t \mid S_t = s, \pi] \tag{14}$$

$$q_\pi(s,a) = E_\pi[G_t \mid S_t = s \mid A_t = a, \pi] \tag{15}$$

$$\pi_*(a \mid s) = \begin{cases} 1 & if \quad a = \max q(s,a) \\ 0 & otherwise \end{cases} \tag{16}$$

The basic steps of the MARL algorithm are shown in Table 3.

1:	Initialization: Generate and initialize m agents
2:	While(task end condition not met)
3:	For each agent
4:	If(the agent has not failed or has reached the end point)
5:	Implement the Q-learning algorithm
6:	Else
7:	stop training
8:	End if
9:	End For
10:	End While

Table 3: Multi-agent reinforcement learning MARL.

4 RESULT ANALYSIS AND DISCUSSION

4.1 Experimental Parameter Setting

To ensure the validity of the experimental verification, 40 independent simulation verifications are carried out for each experimental case, and each verification includes 1000 training algebras. The parameter settings of MARL for multi-agent reinforcement learning are shown in Table 4. The knowledge and experience stored in the Q-Table are cleared in each simulation. Also, the start and end points of multiple agents, and the positions of obstacles are reset in each simulation. A success is defined when an agent successfully reaches the target point without colliding with an obstacle or exceeding the specified running time.

MARL parameter settings	
Temporal Difference Learning Rate α	0.05
Attenuation coefficient γ	0.7
Q-Table initial value	0
ε -greedy Explore parameter settings ε initial value	 0.6
ε decay rate	0.0004

Table 4: MARL parameter settings.

4.2 Comparison and Analysis of Experimental Results

Using the design method to design the steel rebar model, the average success rate of 40 independent simulation verifications (each verification includes 1000 training algebras) is shown in Figure 5. As the training progresses, the multi-agent gradually finds a reasonable rebar The path reaches the end point without collision, and the final convergence is 100%, which shows that the proposed computing framework based on BIM and multi-agent reinforcement learning has successfully realized the collision-free design of three typical beam-column joints.

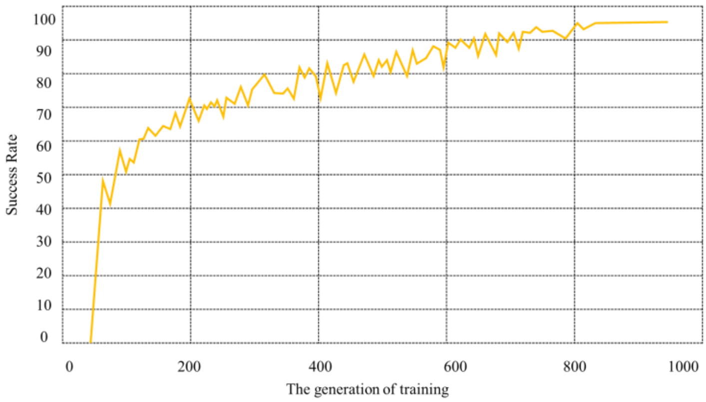

Figure 5: Success rate of multi-agent reinforcement learning training process.

The design method is used to design the reinforcement in the reinforced concrete member, and the path generated by the multi-agent reinforcement learning MARL is compared with the average time (minutes) of the engineer's manual modeling. The results are shown in Figure 6. A total of 40 structural engineers were invited to participate in the test. These structural engineers have more than two years of engineering experience and come from well-known design institutes or engineering consulting units.

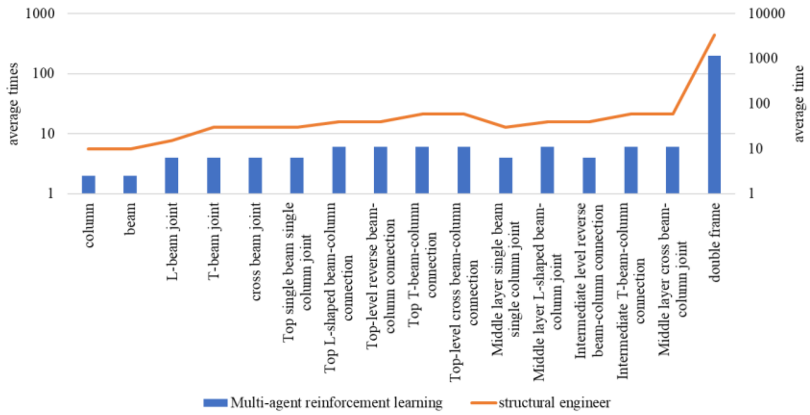

Figure 6: Comparison of the average time spent in the design of steel bars in reinforced concrete members (changed to a double column chart).

Figure 7 shows the comparison results of the time used to construct the design of the structure type. In the construction and design tasks of different types of results, the method framework proposed in this paper saves about 90% of the time compared to manual work, so the method framework can provide high-efficiency collision-free rebar design.

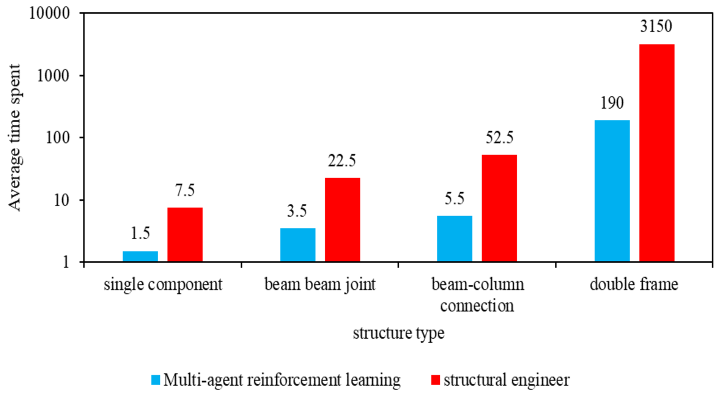

Figure 7: Time-consuming comparison of different structural steel bar designs.

Taking a 16-story residential unit (frame-shear assembly system with a building area of 10000M2) as an example, the traditional method and the computer-aided design method are respectively used for process design. The time-consuming results are shown in Figure 8.

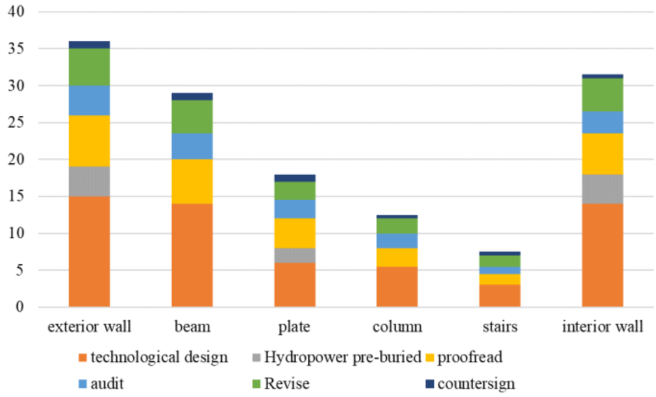

Figure 8: Time-consuming prefab design of a single residential unit (changed to a stacked bar chart).

Through analysis, the improvement of computational design efficiency is shown in Figure 9. Under a series of efficiency improvement methods, the computer-aided design method compared with the traditional method, the design efficiency of concrete precast components is increased by a minimum of 47%, a maximum increase of 89%, and an average increase of about 47%. 65%, the design efficiency has been improved several times.

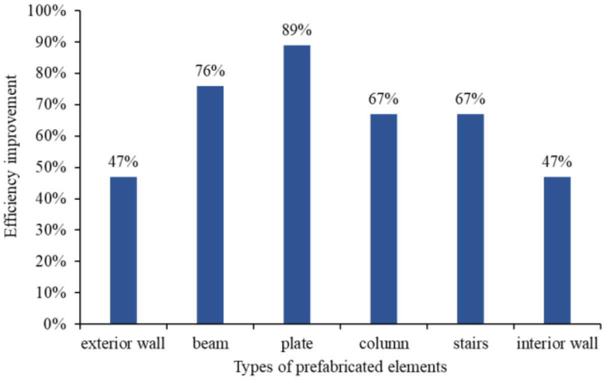

Figure 9: Efficiency improvement ratio.

5 CONCLUSION

This paper establishes a teaching platform based on computer-aided design, which can not only enhance students' participation and interaction, promote theoretical knowledge and practice, but also help teachers improve their professional level. Through the design of CAD platform for prefabricated buildings, this paper introduces the application of computer aided design technology in the teaching of prefabricated buildings. Practice shows that students can learn the relevant knowledge of prefabricated buildings independently and operate in a "real" environment, which can greatly improve the teaching effect. This paper has promoted the construction of informatization and industrialization. The assembly of buildings continues to develop with the improvement of modern engineering technology. From the perspective of the whole construction industry, usually mature construction factories will use prefabricated structures to match and analyze the engineering construction. Through the predetermined solution of technical problems, the purpose of reducing labor costs is achieved.

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