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Review on Optimization of Construction Project Scheduling Using Metaheuristic Algorithms

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Abstract

This review paper presents a comprehensive analysis of the application of metaheuristic algorithms for optimizing construction project scheduling. Various algorithms including Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Simulated Annealing (SA), Grey Wolf Optimizer (GWO), Firefly Algorithm (FA), and hybrid metaheuristic approaches are critically reviewed. The study examines their effectiveness in minimizing project duration, reducing overall cost, balancing resource allocation, and managing project risks under deterministic and uncertain environments. Furthermore, this paper categorizes existing research based on problem formulation, objective functions, constraint handling techniques, and algorithm performance metrics. Comparative insights into single-objective and multi-objective scheduling models are discussed, highlighting strengths, limitations, and computational efficiency of each approach. Current research gaps, challenges in real-world implementation, and future research directions—such as hybrid intelligent models and integration with software are also identified. This review aims to provide researchers and practitioners with a structured understanding of metaheuristic-based scheduling optimization and a foundation for developing advanced decision-support tools in construction project management.

Keywords: Scheduling, Genetic algorithms, Delays, Project management, Optimization technique.

1. INTRODUCTION

The scheduling and sequencing of operation is a decision making issue with a wide range of applications in manufacturing and service systems. In today's competitive atmosphere, an efficient scheduling and sequencing system is an essential and inevitable requirement for survival in the business environment. Scheduling and sequencing operations, as a decision making process, plays an integral role in most manufacturing and producing systems as well as most services environments. A survey of the relevant literature indicates that the issue of scheduling should be taken into account at different levels of decision making, whether short term, medium term and long term [1].

The resource-constrained project scheduling problem (RCPSP) is to schedule project activities in order to complete a project in the minimum possible time under the presence of precedence and resource constraints. Numerous method algorithms have been proposed for solving the RCPSP. If the modes consist of a discrete set and the cost of an activity is decreasing in its processing time, we have a discrete time-cost tradeoff problem. Time-cost tradeoff problems are often classified according to objective function type. Many of the

recent researches in project scheduling focus on maximizing the NPV of the project using the sum of positive and negative discounted cash flows throughout the life cycle of the project. NPV is defined as the difference between cash inflows and outflows, taking into account the time value of money by discounting the cash flows. The presence of the NPV criterion results in a more complicated model called MRCPSP with discounted cash flows. The Contractor's cash outflows associated with an activity can occur anywhere throughout the activity. However, it is assumed here that they will be discounted to the starting time of the activity. The cash inflows for the contractor, which represent the cash outflows for the client, occur at predetermined equal time intervals. In this context, the earned value for the contractor corresponds to the payments regarding the activities completed within that specific period of time.

II. CONSTRUCTION PROJECT SCHEDULING

The scientific formulation of construction progress plan is the premise of the smooth implementation of engineering construction projects. After the initial preparation of the completed progress plan, although the duration and relationship of each process has been determined, it is also necessary to take the cost factor into account, and comprehensively consider the progress-related indicators to make further optimization of the project progress. Genetic algorithm is a kind of intelligent optimization method, which is formed by referring to the evolution and inheritance of species in nature, simulating the selection, crossover and mutation occurring in the process of heredity and evolution of organisms, and establishing mathematical model for the problem in order to complete the process of adaptive search for the optimal solution of the problem.

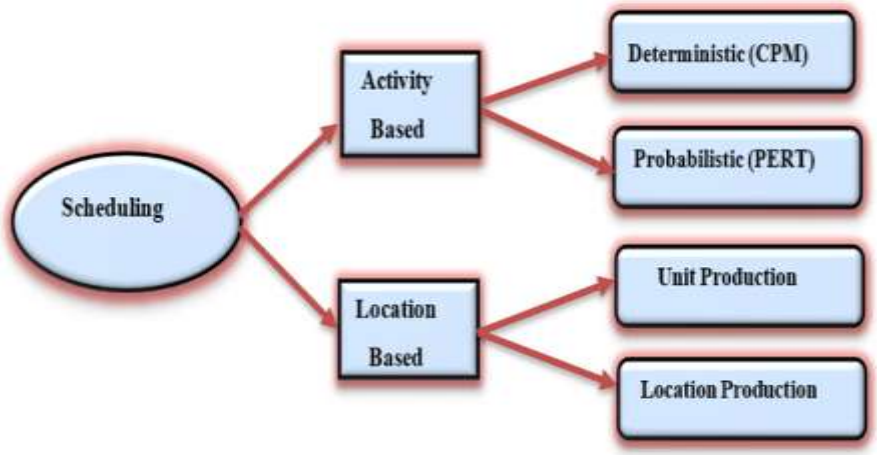

Fig.1 Construction Project Scheduling.

As a global optimization search algorithm, genetic algorithm is simple and easy to use, and it can solve the optimization problem more easily and satisfactorily, and it is widely used in various optimization problems and models such as artificial intelligence. Constructing the construction schedule optimization model needs to take the rationality of construction resources, the calculability of the key lines of the schedule and the stability of the

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construction environment into consideration, so the following assumptions are put forward [3]:

(1) After adjusting the duration of the work, the key work and the non-critical work will not be transformed into each other, the duration of each work is greater than or equal to the limiting time and is less than or equal to the normal time, and the direct cost incurred by the various jobs is between the normal cost and the limiting cost;

(2) For the construction tasks that have already started, there can be no interruption;

(3) There is no shortage of resources affecting the construction progress;

(4) The direct cost shows a non-linear relationship with time, and the overhead rate is a fixed value;

(5) The influence of the construction environment, technology, and management level on the construction progress is ignored;

(6) If there is a construction process that has more than one pre-process, it should be ensured that the pre-processes do not affect each other, and that failure to complete a pre-process in accordance with the requirements will have an impact on the subsequent process. Adopting increased resource inputs and new technologies and methods to shorten process duration is accompanied by an increase in direct costs. The more the process is compressed, the faster the direct costs will increase due to increased labor and machinery costs.

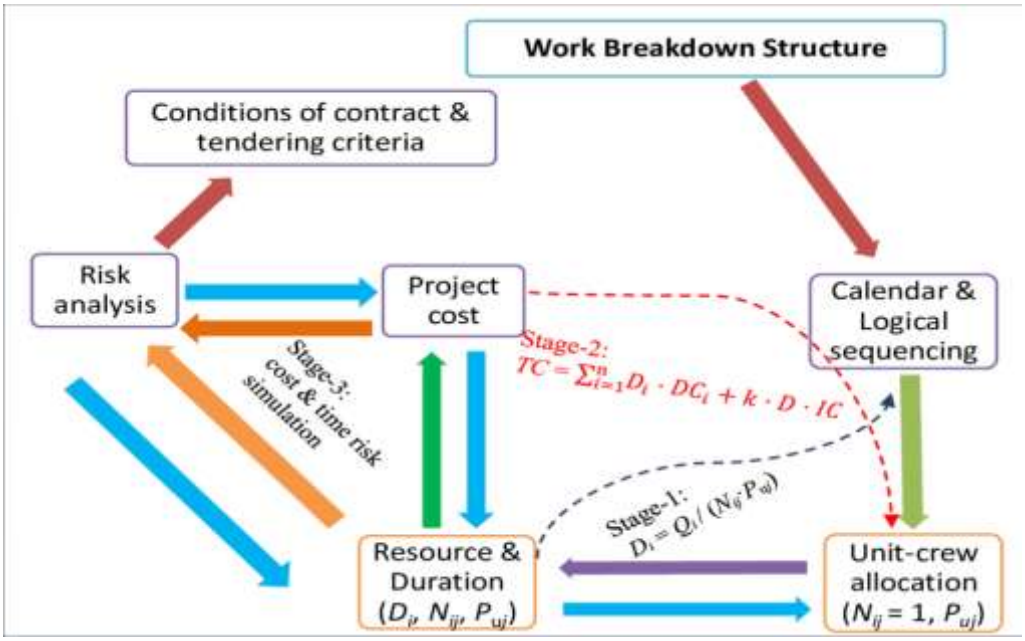

Fig.2 Efficient Procedure to Scheduling Construction Projects

III. MULTI OBJECTIVE OPTIMIZATION

Multi-objective optimization considers multiple competing objectives to determine the optimal solution for a given problem [4]. Unlike singleobjective optimization, which focuses on one goal, multi-objective optimization aims to identify Pareto-optimal solutions that represent the best trade-offs between conflicting objectives [5]. This approach is crucial for decision-makers who must balance competing goals in real-world projects, making it an essential tool for informed decision-making. Its applications span various fields and require

comprehensive understanding of multiple objectives [6-8]. The methodologies used range from classical mathematical programming techniques to advanced metaheuristic algorithms, facilitating the exploration of solution spaces to find NDS that offer optimal compromises [5].

IV. PROBLEM IDENTIFICATION

Construction project scheduling plays a vital role in ensuring timely project completion, efficient resource utilization, and cost effectiveness. Despite the availability of traditional scheduling techniques such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), construction projects continue to suffer from frequent delays, cost overruns, and inefficient resource allocation. The increasing size and complexity of construction projects, coupled with uncertainties such as weather conditions, labor productivity variations, equipment availability, and unforeseen site constraints, have exposed the limitations of conventional scheduling methods.

Traditional methods are largely deterministic and single-objective in nature, making them inadequate for addressing real-world construction scenarios that involve multiple conflicting objectives such as time–cost–quality trade-offs and resource leveling. Moreover, these techniques lack adaptability and fail to efficiently explore large and complex solution spaces, often resulting in sub-optimal schedules. Additionally, challenges such as constraint handling, convergence speed, scalability for large-scale projects, and integration with real-time project data remain unresolved. Limited practical implementation and insufficient linkage between optimization models and modern construction technologies such as Building Information Modeling (BIM) further widen the gap between academic research and industry practice Therefore, there is a strong need to systematically identify, review, and analyze optimization-based scheduling approaches using metaheuristic algorithms to address these challenges. This motivates the present review, which aims to highlight existing limitations, research gaps, and future opportunities in the optimization of construction project scheduling.

V. RESEARCH SIGNIFICANCE

This research is significant as it reviews the role of metaheuristic optimization algorithms in improving construction project scheduling, where traditional methods often fail to handle complex, multi-objective, and uncertain project environments. By systematically analyzing algorithms such as GA, PSO, ACO, and hybrid approaches, the study highlights their effectiveness in minimizing project duration, cost, and resource conflicts. The review bridges gaps in existing literature, supports informed algorithm selection, and provides valuable insights for researchers and practitioners aiming to adopt intelligent and efficient scheduling techniques in modern construction project management.

VI. RESEARCH MOTIVATION AND CONTRIBUTIONS

In today's rapidly evolving landscape of science and commerce, the significance of timing cannot be overstated [1,2]. This importance is particularly evident in domains such as transportation, production, and project management, where precise scheduling is crucial for efficiency and competitiveness [3 and 4].Among the myriad scheduling challenges in these fields, the multi-skill project scheduling dilemma stands out as a

well-recognized conundrum [5]. This dilemma revolves around the allocation of resources and the coordination of various skills required to complete a set of tasks [6]. Real-time scheduling issues have emerged as a critical consequence of this evolving complexity in project management [4].In the realm of construction projects, manpower allocation typically unfolds in three key stages: project selection, project scheduling, and resource allocation [7]. Notably, the literature identifies three distinct labor modalities: single-skill labor, high-skill labor, and multi-skill labor with proficiency in two or more specialized fields [8 and 9].While machinery, equipment, and tools may be readily acquired with the necessary funds, specialized labor remains a unique and invaluable resource for organizations [10]. The expertise of a company's workforce is its primary asset, differentiating it from competitors. Effective resource management, enhanced performance, and innovation are achievable only when employees possess the knowledge and intelligence to drive these outcomes [11].

VII. OBJECTIVES

1. Develop Metaheuristic Algorithms for construction project planning and scheduling.
2. Implement Algorithms to analyse and interpret construction-related data.
3. Enable real-time adjustments to project schedules based on changing conditions.

VIII. LITERATURE REVIEW

Min-Yuan Cheng et al.[1] The Artificial Satellite Search Algorithm (ASSA), a novel physics-based metaheuristic algorithm designed to emulate the dynamic motion of satellites within a search space, is introduced in this study. The ASSA uses satellites as candidate solutions, which dynamically update their positions to navigate toward the optimal solution. The algorithm simulates satellite behavior using medium Earth orbit and low Earth orbit trajectories, facilitating more effective exploration and exploitation of the search space by accounting for the diverse scenario's satellites encounter relative to the Earth over time. In addition, orbit control mechanism and quantum computing technique are incorporated into the ASSA to further enhance the computational efficiency.

J. Vahidi et al.[2] This study proposes a novel method for generating construction schedules from BIM data using the Sine Cosine Algorithm (SCA). Traditional scheduling techniques, such as the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT), often struggle to capture the spatial and temporal interdependencies in complex construction projects. The proposed SCA-based method addresses these limitations by optimizing construction sequencing based on both spatial and temporal constraints. In the tested BIM model, the method achieved a 100 % constructability score, meaning that all identified spatial and temporal dependencies were fully satisfied.

Le Ngoc Bao et al.[3] Long As global trade via maritime transport increases annually, competition among seaports necessitates dynamic scheduling in operational management to optimize port performance. Quay crane scheduling problem (QCSP) is a typical optimization problem for container terminal operations on the quayside. This paper proposes a modern approach based on model-free deep reinforcement learning (DRL) named proximal policy optimization (PPO), a gradient-based framework with a shared actor-critic network structure.

Besides, a novel hybrid metaheuristic combined with a greedy randomized adaptive search procedure (GRASP) and ant colony optimization (ACO) is employed as an alternative approach. The performance of the artificial intelligence (AI) -powered solutions is verified through numerical simulation for single- and multi-agent scenarios with different starting positions. The results highlight the intelligent approach's remarkable performance in solving complex optimization problems and its flexibility compared to traditional metaheuristics, as it does not require clear insights into the system's dynamics.

Yan Li et al.[4] Prefabricated construction has become an increasingly important focus area in the development of the construction industry. Determining an optimal construction process scheduling program is an urgent challenge during the project execution stage. This paper presents a multi-objective optimization problem with the objective function of minimizing the total construction time and maximizing the coordinated scheduling coefficient, and proposes a non-dominated sorting genetic algorithm based on the subspecies differentiation strategy (SD-NSGA) to solve the problem. The algorithm extends the competition phenomenon at the individual level to the subpopulation level in the traditional genetic algorithm (GA).

Reza Rajabi et al.[5] The construction industry faces significant financial risks due to inflationary pressures and economic boom-and-bust cycles, which can result in negative cash flow and reduced profitability for project portfolios. Although various cash flow optimization models exist, many do not adequately address the combined effects of inflation, economic boom-and-bust cycles, and capital injection strategies. This gap limits their effectiveness in real-world conditions, particularly for organizations managing large construction portfolios.

Zhiyuan Hu et al.[6] This paper focuses on the cost minimization of the multi-mode resource-constrained repetitive project scheduling problem with multiple crews, crew interruptions, and soft logic. The resource allocation of each crew is considered. To explore the impact of different construction strategies on project costs, mixed-integer linear programming (MILP) and constraint programming (CP) models are developed representing different construction scenarios. A relax-and-solve (R&S) algorithm, incorporating a rolling horizon and constraint programming, is proposed to obtain near-optimal solutions within reasonable time limits.

Wen-chuan Wang et al.[7] Flooding is one of the most destructive natural disasters in the world, posing a serious threat to socio-economic and livelihood security. With the intensification of climate change, the frequent occurrence of extreme flood events not only highlights the challenges of reservoir flood control scheduling in terms of accuracy, timeliness, and multi-scenario adaptability but also exacerbates the urgent need for effective flood control solutions. Although traditional optimization methods, such as dynamic programming and linear programming, are widely used in reservoir scheduling, they often face the problems of dimensionality disaster and insufficient processing capacity constraints when dealing with complex constraints and diverse scenarios, which make it difficult to meet the actual needs.

Bladimir Toaza et al.[8] Activity-based scheduling optimization is a combinatorial problem built on the traveling salesman problem intending to optimize people schedules considering

their trips and the available transportation network. Due to the difficulty of scheduling, traditional and exact methods are unable to provide appropriate solutions. Hence, new approaches have been introduced in the literature to settle these complex problems. One group of new techniques is known as metaheuristic algorithms, which provides a robust family of problem-solving methods created by mimicking natural phenomena. Although these new techniques might not find an optimal solution, they can find a near-optimal one in a moderate period. Furthermore, a myriad of novel algorithms has been introduced making it tedious for academics to select the appropriate technique.

Chi-Yun Liu et al.[9] This paper introduces a hybrid optimization algorithm, Pilgrimage Walk Optimization - Differential Evolution (PWO-DE), inspired by Taiwan's cultural traditions, to fine-tune large language models (LLMs) for government procurement legal consulting. Addressing the unique requirements of Traditional Chinese, this research develops two tailored LLMs, Llama3-TAIDE and Taiwan-LLM, which significantly enhance automated legal advisory systems. Through rigorous comparative evaluations, the PWO-DE algorithm demonstrates superior performance against various well-established single and hybrid metaheuristic algorithms, ensuring effective decision-making and risk management in government procurement.

Milad Baghalzadeh Shishehgarkhaneh et al.[10] In the construction industry, project managers ought to balance various resources due to their limitations while considering the projects' time, cost, risk, quality, and environmental impacts. The current chapter introduces a framework for resource trade-offs in construction project scheduling considering Building Information Modeling (BIM) process. The prominent proposed Whale Optimization Algorithm (WOA) algorithm is employed for optimization purposes. To present the proposed framework and BIM-based modeling of a five-story building, Revit software is used parametric using Dynamo.

Michał Tomczak et al.[11] Scheduling repetitive construction projects is a challenge due to computational complexity. The authors aim to construct a scheduling system to facilitate the optimization of such projects. First, they formulate a mathematical model of a project composed of any combination of units to be delivered in a fixed order or whose order is to be optimized. With ancillary variables added to the project network, the model proves simple enough to facilitate computations related to schedule optimization. A particle swarm optimization (PSO) algorithm with a unique method to prevent stagnation of the results is proposed to solve the bi-criteria schedule optimization problem. The resulting scheduling system is tested on an actual project to expand an intermodal terminal. The results point to the practical potential of the system. Complemented with a user-friendly interface, it is a ready scheduling support tool. Future research may include incorporating more optimization criteria and making the system risk-aware.

Mahdi Azizi et al.[12] In the animal kingdom, a mutually-beneficial ecosystemic coexistence and partnership in predation between wolves and ravens, known as the wolf-bird relationship, is observed in various cultures. The Wolf-Bird Optimizer (WBO), a novel metaheuristic

algorithm inspired by this natural zoological relationship, is proposed. This method is developed based on the foraging behaviors of ravens and wolves, wherein the intelligence of ravens in finding prey and sending signals to wolves for assistance in hunting is considered. Furthermore, a framework for resource tradeoffs in project scheduling using metaheuristic algorithms and the Building Information Modeling (BIM) approach is established in this research.

Jingjing Wang et al.[13] This study investigates a project scheduling problem of prefabricated building (PB) construction in an uncertain environment. Different from the traditional scheduling models in PB construction, we consider a complex multi-stage cooperation system including the production, transportation and assembly (PTA) phases. In this system, both activity durations and resource amounts are stochastic variables. By applying the reliability theory to the stochastic scheduling model innovatively, we formulate a duration reliability model to maximize the probability of non-delayed project completion, within the resource constraints.

Achini Peiris et al.[14] Modular construction (MC) is an increasingly important construction technique. However, it also requires the use of sophisticated scheduling algorithms. A comprehensive literature review of different scheduling systems used for prefabricated construction, was conducted using the PRISMA methodology. Over 500 relevant papers were analysed and 59 critical applications of production scheduling metaheuristics were closely examined. However, very few of these were for modular construction. This paper provides a deep analysis of GA applications in scheduling and the newer techniques using PSO, SA and ACO. The results of the review suggest 6 directions for future research namely, (i) Consideration of added complexities, (ii) Responsiveness of the scheduling system to new tenders or work, (iii) Integrating production scheduling with Manufacturing Execution and Control Systems, (iv) Dynamic scheduling, (v) Simulation-based optimization techniques for MC, (vi) Use of AI and machine learning concepts for MC. This paper will inform better production scheduling of MC projects.

Maedeh Taghaddos et al.[15] Efficient scheduling and resource allocation for large-scale industrial projects is challenging due to their size and complexity, especially with fast-track contracts, which often lack detailed information during the early planning phase. This paper introduces a data-driven workface planning framework to enhance scheduling and resource allocation while accommodating uncertainties and constraints (e.g., minimum and maximum resource allocation curves, dynamic predecessor relationships, congestion limits). This framework employs an integrated approach, combining time-stepped simulation with graph-based optimization. By leveraging historical data and expert knowledge, the data-driven framework mitigates certain subjective assumptions, including durations and resource allocations. In practical application, the framework generates near-optimal schedules, even with limited information. Applying the framework to a fast-track industrial construction project case study demonstrated enhanced resource allocation. These findings offer practical benefits to industrial projects regarding time and cost savings and serve as a foundation for future research in data-driven project planning approaches.

IX. CONCLUSION

This review paper has presented a comprehensive evaluation of metaheuristic optimization techniques applied to construction project scheduling. The study highlights that traditional scheduling methods such as CPM and PERT are often inadequate for addressing the complex, dynamic, and multi-objective nature of modern construction projects. Metaheuristic algorithms including Genetic Algorithm, Particle Swarm Optimization, Ant Colony Optimization, Grey Wolf Optimizer, and hybrid approaches have demonstrated significant potential in minimizing project duration and cost, improving resource utilization, and handling uncertainty more effectively.

The review reveals that no single metaheuristic algorithm is universally optimal for all scheduling problems; rather, algorithm performance depends on project size, objective formulation, constraint handling, and computational requirements. Hybrid and multi-objective optimization models show superior performance in balancing time–cost–resource trade-offs. However, challenges remain in terms of scalability, convergence efficiency, real-world implementation, and integration with advanced construction technologies.

Overall, this paper concludes that metaheuristic-based optimization offers a promising direction for enhancing construction project scheduling. Future research should focus on hybrid intelligent frameworks, real-time data integration, and enabled optimization models to bridge the gap between academic research and practical construction project management.

Reference

1.Cheng, M. Y., & Sholeh, M. N. (2025). Artificial satellite search: A new metaheuristic algorithm for optimizing truss structure design and project scheduling. Applied Mathematical Modelling, 143, 116008.

2.Vahidi, J., & Golmaei, S. M. (2025). Optimizing Construction Scheduling Using the Sine Cosine Algorithm (SCA) with Building Information Modeling (BIM). Results in Engineering, 107100.

3.You, S. S., Cuong, T. N., & Kim, H. S. (2025). Optimizing quay crane scheduling using deep reinforcement learning with hybrid metaheuristic algorithm. Engineering Applications of Artificial Intelligence, 143, 110021.

4.Li, Y., Wu, J., Hao, Y., Gao, Y., Chai, R., Chai, S., & Zhang, B. (2024). Process scheduling for prefabricated construction based on multi-objective optimization algorithm. Automation in Construction, 168, 105809.

5.Rajabi, R., & Yakhchali, S. H. (2025). Optimizing cash flow in construction portfolios: A metaheuristic approach from the organization's perspective. Ain Shams Engineering Journal, 16(2), 103259.

6.Hu, Z., Wang, F., & Tang, Y. (2025). Cost optimization of repetitive project scheduling through a constraint programming-based relax-and-solve algorithm. Automation in Construction, 176, 106272.

7.Wang, W. C., Tian, W. C., Zang, H., & Zhang, X. T. (2025). Comprehensive Performance Assessment of State-of-the-Art Metaheuristic Algorithms for Multi-Scenario Reservoir Flood Control Optimization. Results in Engineering, 107132.

8.Toaza, B., & Esztergár-Kiss, D. (2023). A review of metaheuristic algorithms for solving TSP-based scheduling optimization problems. Applied Soft Computing, 148, 110908.
9.Liu, C. Y., & Chou, J. S. (2025). Automated legal consulting in construction procurement using metaheuristically optimized large language models. Automation in Construction, 170, 105891.
10.Shishehgarkhaneh, M. B., Basiri, M., & Azizi, M. (2024). Whale Optimization Algorithm (WOA) for BIM-based resource trade-off in construction project scheduling. In Handbook of Whale Optimization Algorithm (pp. 329-346). Academic Press.
11.Tomczak, M., & Jaśkowski, P. (2024). Customized particle swarm optimization for harmonizing multi-section construction projects. Automation in Construction, 162, 105359.
12.Azizi, M., Shishehgarkhaneh, M. B., Basiri, M., Moehler, R. C., Fang, Y., & Chan, M. (2025). Wolf-Bird Optimizer (WBO): A novel metaheuristic algorithm for Building Information Modeling-based resource tradeoff. Journal of Engineering Research, 13(2), 763-785.
13.Wang, J., Liu, H., & Wang, Z. (2023). Stochastic project scheduling optimization for multi-stage prefabricated building construction with reliability application. KSCE Journal of Civil Engineering, 27(6), 2356-2371.
14.Peiris, A., Hui, F. K. P., Duffield, C., & Ngo, T. (2023). Production scheduling in modular construction: Metaheuristics and future directions. Automation in Construction, 150, 104851.
15.Taghaddos, M., Mousaei, A., Taghaddos, H., Hermann, U., Mohamed, Y., & AbouRizk, S. (2024). Optimized variable resource allocation framework for scheduling of fast-track industrial construction projects. Automation in Construction, 158, 105208.