SCHEDULING REPETITIVE CONSTRUCTION PROCESSES USING A SWARM ALGORITHM

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Abstract
This article presents a method for multi-criteria optimization of repetitive construction processes schedules. Considering the limitations in planning the realization of such projects using classical tools and methods, the use of swarm algorithm for finding non-dominated solutions to the problem was proposed. An example of the application of the particle swarm optimization algorithm to the development of a schedule for the repetitive construction processes realization and the selection of work crews in order to minimize the realization time of the project and downtime in the work crews was also presented.

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1. Introduction

The realization of construction projects often includes the execution of a number of repetitive processes on the objects of a given construction project or their parts, referred to as working units. In literature, this type of projects are described as repetitive [1]–[3]. Due to the specific nature of the realization conditions, the classical planning methods (critical path method, PD method or PERT) are not adapted to support the management of this type of projects [4]–[6]. Therefore, a number of methods have been developed dedicated to the design of repetitive construction projects realization, such as LSM (Linear Scheduling Method) [7], RSM (Repetitive Scheduling Method) [8] or TACT and e-TACT methods [9]. One of the more popular approaches to support the management of repetitive construction projects when seeking multi-criteria optimization is mathematical modelling of construction management's preferences regarding optimization goals, taking into account the imposed realization constraints, and then solving the developed model using exact or heuristic (usually of high computational complexity), or meta-heuristic methods – in the case of complex scheduling problems occurring in practice. Meta-heuristic algorithms provide a general scheme for solving an optimization problem, based on processes occurring in nature, e.g. adaptation in the evolution process. An example of meta-heuristic algorithms, often used to solve scheduling problems, especially in industry, are swarm algorithms, for which an attempt was made in this paper to apply them to solve the problem under study.

2. Literature review

2.1. Meta-heuristic swarm algorithms

Optimization of schedules for repetitive construction projects is a difficult and complex process due to the following problems [10]–[12]:

- the number of possible solutions in the search area is so large that it makes it impossible or meaningless to use a comprehensive search to find the best solution,
- the model of the problem usually includes many constraints, which makes it difficult to generate even one acceptable solution, let alone find the optimal solution,
• the problem is so complex that in order to obtain a solution with a reasonable amount of computational time, it is necessary to use problem models so simplified that any solution is practically worthless,

• the value of the criterion function is affected by many decision variables, therefore it is necessary to review many solutions acceptable for various combinations of their values,

• the person solving the problem usually does not have the appropriate knowledge and skills in solving complex mathematical models.

Due to the aforementioned difficulties in finding solutions to the problem of scheduling repetitive construction projects, more and more perfect algorithms are constantly being sought to find an approximate, but still useful solution. One of the most popular approaches to finding suboptimal solutions to real problems is the use of meta-heuristics algorithms. Many of them are inspired by phenomena occurring in nature – the observation of behavior occurring in nature makes it possible to transfer existing phenomena to algorithmic procedures [13]. Among the numerous methods belonging to this group, the following can be mentioned:

• evolutionary algorithms, including genetic ones, based on the mechanisms of natural evolution,

• quantum genetic algorithms using the laws of quantum physics,

• artificial immune systems based on processes occurring in the immune system,

• artificial neural networks, imitating the processes in the human brain,

• simulated annealing algorithms resembling the annealing phenomenon known from metallurgy,

• herd algorithms, also called swarm algorithms, which derive from the so-called swarm intelligence of social organisms living in colonies.

Swarm algorithms have become increasingly popular in recent years. One of the reasons for this is their very large variety and the ability to adapt to the problem under consideration. Organism communities are a decentralized system composed of autonomous individuals, which can be described by certain probabilistic behavior – reactions to stimuli. The basic rules of their behavior are the result of local interactions and guarantee the spread of information within the colony and affect the attitudes of each individual. In herd behavior, coordination within a group of individuals corresponds with the organization of tasks required to solve a particular problem, while proper communication helps to make the best choice by exchanging information between individuals [13]. Table 1 summarizes the types of organisms and the type of herd behavior on which optimization in previously developed swarm algorithms is based.

The general scheme of the swarming algorithm can be written as follows [13]:

• coding and initialization of the initial population of solutions and evaluation of their quality,

• until the stopping criteria of the algorithm are met, cyclically repeat the following steps:
  
  ○ identification of the vicinity of current individuals,
  
  ○ selection of individuals representing the best solutions from the vicinity,
  
  ○ acceptance or rejection of candidate solutions,
  
  ○ creating a new population of solutions,

• decoding the best solutions found.
Table 1. Types of herd organisms on whose behavior swarming algorithms are based (based on [14])

<table>
<thead>
<tr>
<th>Organism</th>
<th>Type of herd behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>ants</td>
<td>foraging</td>
</tr>
<tr>
<td>particles</td>
<td>aggregating</td>
</tr>
<tr>
<td>bees</td>
<td>foraging</td>
</tr>
<tr>
<td>masses</td>
<td>gathering</td>
</tr>
<tr>
<td>wolves</td>
<td>preying</td>
</tr>
<tr>
<td>bats</td>
<td>echolocation</td>
</tr>
<tr>
<td>bacteria</td>
<td>growth</td>
</tr>
<tr>
<td>fish</td>
<td>aggregating</td>
</tr>
<tr>
<td>birds</td>
<td>mating</td>
</tr>
<tr>
<td>dolphins</td>
<td>clustering</td>
</tr>
<tr>
<td>monkeys</td>
<td>climbing</td>
</tr>
<tr>
<td>fruit fly</td>
<td>gathering</td>
</tr>
<tr>
<td>firefly</td>
<td>gathering</td>
</tr>
<tr>
<td>cockroaches</td>
<td>foraging</td>
</tr>
<tr>
<td>cuckoos</td>
<td>brooding</td>
</tr>
<tr>
<td>krill</td>
<td>herding</td>
</tr>
<tr>
<td>frogs</td>
<td>jumping</td>
</tr>
</tbody>
</table>

2.2. Repetitive construction projects

In the unusually rich literature on the subject, one can find various tools tailored to optimize construction schedules of repetitive projects. The most frequently used methods of optimizing the schedules of repetitive projects include exact methods of solving mathematical models in the form of linear [15]–[16] or dynamic programs [17], as well as heuristic and meta-heuristic methods, e.g. genetic algorithms [18]–[19] and other more advanced ones [20]–[21]. Approaches using fuzzy logic are also being developed [22]. Some works have developed methods for determining construction schedules under risk conditions using simulation [23].

Regardless of the method of solution or modelling, the problem of scheduling repetitive projects was formulated with the following objectives in mind: minimizing the total project realization time [24]–[25], ensuring that the project deadline is met [26], minimizing the total cost of the project [27], seeking a compromise between the time and cost of the project [28], maximizing work efficiency [29], schedule resilience and reliability [30], ensuring the continuity of resources (minimizing downtime) [4, [16], minimizing the cost of breaks in the crews work [19] a combination of these criteria [5], [31]–[32].

For example, Sroka et al. [33] presented a model for scheduling repetitive construction projects in order to support the selection of the appropriate method of their realization and optimize the general contractor’s profit, taking into account the amount of direct and indirect costs, as well as contractual penalties and the cost of downtime of work crews and credit service costs. The model was solved using a hybrid algorithm using a simulated annealing algorithm and a genetic algorithm. The operation of the proposed model was presented on a calculation example, and the results obtained in the model are fully satisfactory.

In turn, Tran, Chou and Luong [34] developed a stochastic model minimizing the realization time of a repetitive construction project, taking into account the different priorities of process significance. A new fuzzy hybrid evolutionary approach, called the artificial bee colony approach, was used to solve the developed model. Experimental results indicate that the proposed method provides the shortest average project realization time and the smallest standard deviation in relation to the optimal solution among the model algorithms considered in the work.
The same authors developed a method of finding compromise schedules due to the time and cost of realization. In [21] an adaptive multi-criteria search algorithm for symbiotic algorithms was developed. Two case studies were analyzed to validate the scheduling method, as well as to demonstrate the possibility of using the new algorithm to generate solutions. The obtained results indicate that the proposed algorithm is more effective in comparison with the basic search algorithm for symbiotic organisms and others analysed in this work.

The model developed by Wang et al. [35] makes it possible to search for a compromise between the time, cost and quality of repetitive construction projects. The authors used the NGSA (Non-Dominated Sorting Genetic Algorithm) to find non-dominated solutions to the developed problem model. An undoubted advantage of their approach is the quantitative consideration of the quality of the realized works.

The genetic algorithm was also used by Altwaim and El-Rayes [19] to simultaneously minimize the duration of a repetitive construction project, the downtime of work crews and the cost of these interruptions. The algorithm for solving this problem includes four modules: optimisation, initial scheduling, intermediate scheduling and determining the cost of downtime for crews.

3. USING THE SWARM ALGORITHM FOR SCHEDULING REPETITIVE CONSTRUCTION PROCESSES – EXAMPLE

New methods of scheduling repetitive construction projects have been developed very dynamically in the last decade based on increasingly modern and advanced techniques. Nevertheless, it is very difficult to find in the literature examples of the use of swarm algorithms for scheduling the realization of repetitive construction projects. These algorithms are an extremely flexible and effective tool for finding suboptimal solutions to even very complex computational problems. Therefore, in this publication one of the swarm algorithms (particle swarm optimization algorithm) was used to determine the schedule of an exemplary construction project. The block diagram of this algorithm is shown in Figure 1.

The analyzed project consists of seven real processes and two fictitious ones: the beginning and the end of the project. The project includes the realization of three identical working buildings, being separate working units. The same processes are performed on each of them. Sequence relationships between processes within one working unit are shown in Figure 2. Two crews are available: crew B1 and crew B2. They can be assigned to realize different processes. The realization times of individual processes are shown in Figure 2 (the realization times of processes on individual work plots are the same). Due to the use of the learning effect, the crew assigned to realize a particular process will realize it on all work plots.

Fig. 1. Block diagram of the particle swarm optimization algorithm (based on [36])
As an example, the project realization schedule was simultaneously optimized in terms of three criteria:

- minimizing the realization time of the project
- minimizing the downtime of working crews,
- minimizing the realization time of construction facilities, remaining in relationship with the reduction of downtime on work fronts assuming that they are equivalent.

The example was solved using a particle swarm optimization algorithm. The calculation time was 46.53 seconds. The resulting schedule is shown in Figure 3 in the form of a beam graph. Crews B1 and B2 work without breaks, the realization time of the entire project was 57 working days, and the realization of each building object averaged 46 working days.

The developed algorithm can also be used for scheduling the realization of processes repeated on heterogeneous units, finding the optimal order of plot realization. Extensive examples of its use are presented in [37].

4. Summary

The article presents a method of scheduling repetitive construction projects using one of the swarm algorithms – the particle swarm optimization algorithm. The method presented in the article makes it possible to obtain compromise solutions due to three optimization criteria: minimizing the realization time of construction objects (work units) and the entire project, and minimizing the downtime of crews work. The obtained results indicate that the use of swarm algorithms for scheduling repetitive construction projects generates very good results and can support construction managers in finding solutions to this complex problem.
Fig. 3. Beam project realization schedule (solution for equal weights of optimization criteria)

Acknowledgements

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