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Conference Paper

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Publication date:
2017

Permanent link:
https://doi.org/10.3929/ethz-b-000227366

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Originally published in:
Procedia Engineering 196, https://doi.org/10.1016/j.proeng.2017.08.030
BIM-based Applications of Metaheuristic Algorithms to Support the Decision-making Process: Uses in the Planning of Construction Site Layout

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Abstract

The use of Building Information Modeling (BIM) is affecting the way in which construction projects are planned, designed, executed and operated. One of the main goals of BIM is to provide, based on a 3D model, an accurate information model in a digital format to give different project participants better tools when evaluating different options to support their decisions about the project at a given phase. With this in mind, BIM provides a suitable framework to support the decision-making process by aggregating the necessary information at the right time, and clarifying details and existing conditions; however, the different elements required to make an optimized decision need additional consideration. To address that, this paper explores the value of metaheuristic algorithms for reaching an optimized solution. The use of metaheuristic algorithms is well known in various aspects of knowledge optimization. This paper provides an overall review of the applications of metaheuristic algorithms in BIM-based optimized decisions in the construction industry and focuses on applications to the planning of construction site layout. Based on the findings from this paper, research gaps in this area have been identified and suggestions for future research to address those gaps are suggested.

Keywords: Building Information Modeling, Metaheuristic Algorithms, Optimization, Site Layout

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1. Introduction

After years of gradual development, a great revolution has occurred in the construction industry. This revolution is fueled by Building Information Modeling (BIM), a 3D model in digital format integrating with tools of management and visualization project. BIM presents a 3D digital model of the project and serves as a rich resource of information giving different project participants a reliable tool for decision-making during the life cycle of project. This full digital model of the project shows all issues very soon and allows making changes before construction starts. BIM saves time and cost; and enhances productivity and safety in construction industry [1]. Since different complex variables influence the decision-making process, BIM provides an intelligent tool containing a lot of useful information as input data and facilitates this process by clarifying details and existing conditions. BIM can quickly analyze any change before any operation is carried out for its impact on the project [2].

The various decision-making problems can be described as an optimization problem with different variables confined by existing conditions and constraints [3]. To solve complex optimization problems existing in different fields, from engineering design to economics, metaheuristic algorithms are needed to find good solutions (cannot guarantee the optimal solution) within a reasonable amount of time. Since time, money and other resources are always limited, the optimal use of these accessible resources is very significant. Optimization problems are strongly nonlinear and multimodal which are restricted by a set of complicated constraints. Most of the time, different objectives of a single problem are in conflict. Generally, finding an optimal result is not easy [4]. BIM containing important data is a comprehensive model to optimize different construction processes. Therefore, BIM is a useful tool for all the stages in a construction project [5]. BIM provides a suitable framework to support the decision-making process by aggregating the necessary information at the right time, and clarifying details and existing conditions; however, additional considerations must be applied for any optimized decision about each parameter.

One of the most important optimized decision-making processes in construction is the planning of site layout. The site layout can enhance productivity by facilitating the movement of labor and materials. Apart from time and cost, other elements are important for the success of a construction project [6]. BIM is able to assist during the planning of the construction site layout [7]. Since there are many important decisions to be made in this phase and many interlocked factors influence the site layout problem, finding an optimal planning is complicated [8]. In the BIM-based planning of construction site, the site facilities’ parameters and other required input data are read automatically from the BIM model; therefore, the amount of the essential data for simulation having to be entered manually is reduced [9].

This paper aims to introduce BIM-based applications of metaheuristic optimization algorithms to support the decision-making process. In the first part of the paper, the overall view and classification of metaheuristic algorithms are described. The second part of the paper presents the BIM-based application of metaheuristic algorithms for optimization in the construction industry, especially in site layout planning. Finally, a summary is given and future work is described.

2. The overall view and classification of Metaheuristic algorithms

Optimization is a method to find the best solution. To solve an optimization problem, first, it has to be modeled, meaning that the problem is described by variables in a mathematical form. These problems require optimization techniques to get to the best solution in different fields. Although small dimension problems can be solved without the need of computers, special methods and computer simulation for greater and more complex problems are typically required. Optimization can be utilized in different fields such as engineering, economy, social problems, etc. Since our resources are usually limited, the optimal use of these accessible resources is very significant. Most of these problems are nonlinear and under complicated constraints. Most of the time various objectives of a problem are in

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1 Although there is a difference between metaheuristic (general and problem-independent framework that provides guidelines to generate heuristic optimization algorithms) and heuristic (specific and problem-dependent processes), in this paper the term metaheuristic is used to refer to problem-specific implementation of a heuristic optimization algorithm based on the guidelines from a given specified framework.
conflict. Therefore, it is not easy to obtain an optimal solution. Optimization algorithm can be used to solve such problems. These algorithms are general methods to achieve proper solutions. According to the focus and characteristics of the algorithm, there are different ways to categorize the optimization algorithms [4] (Figure 1.). Since the number of feasible configurations can be significant and getting to the optimized solution is not possible by exact methods, utilization of smart tools is needed to solve these problems. Metaheuristic algorithms appear as effective methods to solve the complex optimization problems. These algorithms show proper compatibility with many engineering optimization problems [10, 11]. Optimization algorithms can be categorized into two classes: trajectory-based and population-based algorithms. There is a main difference between these two; in the trajectory-based algorithm a single agent tracing out a single path is used and the iterations continue to get to the optimal solution, but in population-based multiple agents tracing out the multiple paths are used. Also by considering their search ability, algorithms can be classified in two categories: local and global search algorithms. Local search algorithms lead to a local optimum and do not have the ability to escape from it. It is necessary to utilize global search algorithms to get to the global optimum. In most cases, metaheuristic algorithms are suitable to find the global optimum [12].

Many metaheuristic algorithms exist in literature such as Genetic Algorithms (GA) [24-26], Particle Swarm Optimization (PSO) [11], Artificial Neural Network (ANN) [44], Bee Colony Algorithm (BCA) [23], and Firefly Algorithm (FA) [27].

3. BIM-based applications of metaheuristic algorithms

In recent years, a few studies are trying to implement the use of metaheuristic algorithms in BIM-based optimized decisions in the construction industry. The previous research concentrates on the impact of BIM in different phases of construction and utilizes one of the metaheuristic algorithms, such as GA, PSO, FA, etc. for optimization. One of the most important optimized decision-makings in construction phases is the planning of site layout. Previous studies are classified into two categories. The first part shows the BIM-based applications of metaheuristic algorithms during the planning for the layout of a construction site, and second part presents a brief overview of BIM-based applications of metaheuristic algorithms to support the decision-making process for other applications in construction projects.

3.1. BIM-based applications of metaheuristic algorithms during the planning for the layout of a construction site

In recent years, a number of site layout planning models have been developed to address different issues such as productivity, safety and security in construction sites. These models have a conventional goal of creating the best
layouts restricted by existing conditions and constraints. The underlying assumptions made throughout the developed models, however, seem heterogeneous and clearly recognizable [13]. “Site space is considered a limited resource in construction projects, besides materials, equipment, labor, time, and money” [14]. Since 2014, the number of publications addressing BIM-based site layout planning has increased (Table 1). In addition, although various metaheuristic algorithms can be used to solve this optimization problem, genetic algorithms have been the most commonly used in previous studies (in 80% of the publications considered, Table 1).

Table 1. Summary of articles by year of publication in the field of BIM-based planning of construction site layout and type of algorithm used

<table>
<thead>
<tr>
<th>Reference number</th>
<th>Year of publication</th>
<th>BIM-based planning of construction site layout</th>
<th>Type of algorithm used</th>
</tr>
</thead>
<tbody>
<tr>
<td>[8]</td>
<td>2014</td>
<td>✓</td>
<td>none</td>
</tr>
<tr>
<td>[29]</td>
<td>2014</td>
<td>✓</td>
<td>none</td>
</tr>
<tr>
<td>[17]</td>
<td>2015</td>
<td>✓</td>
<td>Genetic Algorithm</td>
</tr>
<tr>
<td>[27]</td>
<td>2015</td>
<td>✓</td>
<td>Firefly Algorithm</td>
</tr>
<tr>
<td>[7]</td>
<td>2016</td>
<td>✓</td>
<td>none</td>
</tr>
<tr>
<td>[25]</td>
<td>2016</td>
<td>✓</td>
<td>Genetic Algorithm</td>
</tr>
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<td>✓</td>
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<td>✓</td>
<td>Genetic Algorithm</td>
</tr>
<tr>
<td>[30]</td>
<td>2016</td>
<td>✓</td>
<td>other*</td>
</tr>
</tbody>
</table>

* Computational method using mixed-integer programming

In general, researchers have considered the front-end planning of the construction site layout. There is a tight interaction between site layout planning with other construction management fields like scheduling, planning, and cost estimating. Unsuccessful planning of site layout may lead to an unproductive project, extra costs and schedule delays [15, 16]. Generally, site layout planning is a significant phase in construction procedures increasing productivity while considering time, cost and safety [17]. Since the site layout problem is influenced by many interlocked factors, its planning is a difficult task [8]. In general, computers are needed for generating an optimal plan due to the complexity and multiplicity of factors [18]. Various mathematical optimization algorithms are utilized in this field [8]. In recent years, studies are trying to use the advantage of BIM techniques for site layout planning. In fact, an important issue is to identify and expand BIM-based method in order to generate a powerful information model of construction site [17]. “Generally, construction site layout planning is performed in two phases: BIM-based generation of 3D-site layout plan, and simulation-based evaluation of the site layout plan” [8].

The site layout problem is modeled in two types: static layout and dynamic layout models. In static layout models, it is supposed that all facilities are planned at the beginning, and remind throughout the entire construction phases [19-21]. Dynamic layout models consider the required duration of each facility [22, 23]. To get the optimum planning, dynamic layout models are much better than static layouts, because they let the site planner make change to the site facilities as required in order to reuse site space. Not all facilities are required in all the phases of a construction project. Therefore, at each stage of the construction, first unnecessary facilities are dismantled, and new required facilities are planned for new available areas [24].

Akamnu et al. [25] proposed the integration of BIM, genetic algorithm and a radio frequency identification (RFID) system creating a developed system reporting the proper object locations in real-time to achieve the optimal planning of site layout and schedule tracking.

A* algorithms, used to find the shortest route between multiple points, combined with genetic algorithms, are utilized in order to optimize the BIM-based dynamic site layout models. Since usually there are some obstacles in the construction site, following the straight-line paths may be impossible; therefore, computing the actual travel distances is beneficial. The actual travel paths computed using A* algorithms are the bases for the optimized planning of site
layout. Planners do not need to enter the input data manually since the required information is automatically obtained from the BIM model. Any changes are reflected in the final results [24].

Marzouk and Abubakr [26] have presented BIM-based framework for tower cranes planning in construction projects. It includes the decision-making model for selecting the most proper type of tower crane as required; the optimization model determining the number of required tower cranes, the optimum planning of these cranes and characteristics of them; and BIM-based model and genetic algorithms used to verify the tower crane locations, prevent the clash and develop 4D plan. In another study, BIM has been integrated with FA to create an optimal planning of tower crane automatically. In fact, the required data are read from the BIM model for optimization model and by the FA algorithm utilization, the optimal planning is led [27].

Yu et al. used a BIM-based dynamic model and genetic algorithm in order to identify the optimal dynamic plan indicating how the materials should be supplied [28]. Deshpande and Whitman [29] have discussed using the suitable metaheuristic algorithm to optimize the materials and personnel movements.

Krepp et al. [7] discussed the characteristics of BIM-model and utilization of BIM information for input data and constraints for optimized layout problem. Their manuscript presents different optimization algorithms and simulation models used in recent studies.

In previous research, the travel frequencies between facilities have been estimated based on previous experiences. Since this estimation may not be an actual show of movement, a BIM-based framework to find travel frequencies at various construction phases by using the information of BIM and project schedules has been presented by Hammad et al. [30]. The estimated frequencies improve the optimized model of site layout.

3.2. BIM-based applications of metaheuristic algorithms to support the decision-making process for other applications in construction projects

By integrating BIM product models with PSO algorithms, optimized activity level construction schedules are generated automatically [31]. Hyounseok et al. suggested a BIM-based 4D model to minimize overlapping activities by using a genetic algorithm to obtain an optimal construction schedule [32]. Moon et al. focused on a BIM-based simulation system and a genetic algorithm in order to minimize schedule and workspace interface simultaneously [33]. In another study a genetic algorithm by using the geometrical information of a project from the BIM model is utilized to develop and generate construction schedules [34]. In order to support BIM and automate critical procedures in the construction project, an efficient genetic algorithm technique has been designed. This technique using hardware with field-programmable gate arrays is utilized to improve the speed and power of computation [35]. In another study, a system has been presented to optimize the temporal distribution resources in the planning of projects by using BIM and a genetic algorithm and considering workspace constraints [36]. Nour et al. [37] have developed a BIM-based approach to save energy in order to optimize the Life Cycle Cost (LCC) of building by using a genetic algorithm. Liu suggested a BIM-based system, which can improve the sustainability and save cost by integration BIM model and multi-objective particle swarm optimization (MOPSO). By combining BIM and MOPSO, the conflict between the cost and carbon emission of projects could be evaluated [38]. To optimize designs and improve the sustainability of building, a BIM-based method was suggested. For this purpose, the trade-off between life cycle carbon emission (LCCE) and life cycle costs (LCC) of building designs is searched by using a PSO algorithm. The result shows that this method is helpful to find optimal design in order to achieve environmental-friendly and economic scheme [39]. Marzouk and Metwie presented a framework to assure the sustainability in Low Income Housing Projects in Egypt. This framework integrates BIM with a genetic algorithm in order to minimize the cost and duration of construction [40]. Integration of BIM with a genetic algorithm is used to multi objectives. These objectives are the optimization of cost, time and environmental impact (in terms of CO2 emissions) of construction [41]. Rafiq and Rustell presented an Interactive and Visual Clustering Genetic Algorithm (IVCGA) with BIM to generate different design alternatives. During the stage of design, using this approach enhances the capacity of design team in multi decision-making [42]. The combination of genetic algorithms with other algorithms in order to achieve optimized cost and energy in a shorter time that is analyzed through an in-house BIM tool has been shown by Fritsche and Lafer-Sousa [2]. BIM is used to provide the required information as input data for the metaheuristic algorithms in order to reduce the computational time in building fire emergency response operation [43]. García de Soto et al. [44] used a Tabu-search optimization
algorithm to develop an optimal construction project schedule, where optimality is defined as the best trade-off between project costs, duration, and fluctuation of resources. The optimized scheduled was further refined (including changes in sequence) using visualization software. Modifications made from visualization are run through the Tabu-search optimization algorithm for further improvements and development of robust 4D models.

4. Conclusions and future work

This paper presents a review of metaheuristic algorithms to support the decision-making process of construction projects with a focus on the BIM-based application of metaheuristic algorithms used during the planning of the layout of a construction site. Site layout planning consists of identifying, sizing and locating temporary facilities in the available spaces by considering site conditions and constraints in relation to optimum cost outcomes. Previous research has shown that proper site layout enhances productivity and safety in construction site and saves cost and time. In addition, it allows for the optimization of the movement of labor and materials. However, this is a complex combinatorial optimization problem and needs the use of metaheuristic algorithms to find near-optimal solutions.

In addition, BIM can be used to support the optimized decision-making process by aggregating the necessary information at the right time. Therefore, the BIM-based optimized decision in the planning of construction site layout is also introduced along with the appropriate metaheuristic algorithms used.

Recent studies have focused on the use of genetic algorithms to develop heuristics to tackle the site layout problem. The authors plan to evaluate other heuristic optimization algorithms in combination with BIM to compare their performance and identify advantages and disadvantages. In addition, another interesting investigation will be to compare the results from different simulation types to model the layout of construction sites.

References


