Theory and Building Practice
Vol. 6, No. 1, 2024

https://doi.org/10.23939/jtbp2024.01.001

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PLANNING OF CONSTRUCTION SITES USING INFORMATION TECHNOLOGIES

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Planning construction sites involves determining the layout of temporary facilities on the site and significantly impacts the safety and efficiency of construction activities. However, such planning is a complex combinatorial problem that encompasses multiple objectives and becomes more challenging with an increasing number of objects and constraints on work execution conditions. To reduce the complexity of creating such solutions, the use of intelligent design systems is facilitated.

The study analyzed existing information modeling technologies for finding optimal solutions based on adopted efficiency criteria and identified drawbacks in such systems. Through theoretical research, the conclusion was drawn that current information technologies for optimizing construction site planning address issues only in isolated aspects, such as minimizing the areas of administrative or storage facilities or reducing costs for unproductive resource movements.

Key words: construction site; construction master plan; schedule plan; information modeling technologies; decision search algorithm; optimal planning.

Introduction

The planning of construction sites involves determining the composition of temporary objects and significantly influences the safety and efficiency of construction activities. Rational planning of a construction site allows (Anumba C., 1997; Ushatskyi S., 2007; Dorosh A., 2011; Hryhorovskyi P., 2010; Gaido A., 2017; Chary S., 2004; Kumar S., 2015; Whitlock K., 2018; Sadeghpour F., 2015; Papadaki I., 2015):

– reduce production costs
– minimize the movement time of labor, materials, and equipment on the site
– improve construction productivity
– enhance the safety and quality of work execution

Optimizing the planning of a construction site can be achieved by reducing the required resource areas on the construction site and minimizing the distance or eliminating unnecessary movement of resources using proper material handling methods (Shawki K., 2014).

It is known that optimizing the planning of various activities on the construction site contributes to increased operational efficiency, reduces waste by 20–40 %, and allows for cost reduction up to 80 % (Shawki K., 2014). The sorting of recyclable and reusable materials on-site can also reduce operational costs.

An analysis of scientific research (Muralidhar P., 2018; Xu M., 2022; Ioanna N., 2016; Zavari M., 2022; Yi W., 2018; Schwabe K., 2019; Zolfagharian S., 2014) aimed at reducing construction costs through the optimization of decisions made during the design of construction master plans reveals the existence of two main directions:

I. Minimization of the required areas of construction site elements through the optimization of resource utilization, including:

a) reducing the maximum number of workers (redistribution) involved in the work, thereby decreasing the necessary areas for sanitary and administrative facilities;

b) decreasing the required storage areas by adjusting the material usage period through refining the adopted construction method (e. g., transitioning from on-site assembly to assembly using “wheels”).

II. Rational planning of the construction master plan (operational efficiency) by minimizing the distances for resource movement within the construction site.

Analysis of parameters of construction facilities (Mudryy I., 2023) in the design of construction master plans reveals a complex interdependence among them. Consequently, most scientific works are focused on finding optimal solutions in the context of schedule planning. The optimization of schedule planning allows for the indirect minimization of the areas of administrative and domestic premises by reducing the number of workers simultaneously involved. However, optimization of schedule planning is typically aimed at reducing resource peaks (R_peak → min) and involves the following:

1) determining the resource peak in the standard construction plan;
2) using load leveling procedures before the standard construction plan;
3) identifying the tasks causing the resource peak;
4) evaluating the resource peak in the work schedule;
5) adjusting (revising) resource profiles.

Reducing peak loads allows for minimizing the areas of sanitary and domestic premises and decreases the costs of organizing construction camps. The methodology for minimizing resource peaks requires the use of interactive information technologies, particularly MS Project. When leveling peak loads, MS Project selects processes that need to be delayed or shifted, taking into account time reserves, task priorities, constraints, directive deadlines, etc. However, applying this methodology in practice is only possible at the stage of developing work execution projects, with known organizational and technological solutions for construction.

Thus, optimizing a construction site is a complex and resource-intensive task that increases design costs. Reducing the number of options is facilitated by the use of intelligent design systems. However, in practice, optimal planning of a construction site, considering comprehensive management of health, safety, and environmental issues, especially with the assistance of intelligent technologies, receives little attention. In domestic practice, decisions regarding construction site planning are typically made by the project engineer based on existing regulations and personal experience. Therefore, it is advisable to define the main criteria for searching for an optimal solution in the planning of a construction site using information technologies.

Variant design of a construction site requires the creation of various planning models, increasing design costs. Construction sites have different shapes, and elements placed in open spaces have their own shapes, which may not always allow for their placement, especially in constrained construction conditions. To reduce the complexity of these processes, creating information models of construction sites in a common project model (Project Information Model – PIM) can be utilized. The use of information technologies in the design practice allows (Trach R., 2018; Mudryy I., 2020, 2021):

– reduce the cost of design documentation by 10 %;
– shorten project implementation timelines by 7–15 %;
– increase the accuracy of cost estimates by 3 %;
– reduce the development time of design documentation by 80 %;
– decrease waste and defects in construction production by 30 %.

To analyze existing information technologies for optimizing construction site planning to minimize resource costs.

Materials and methods

The analysis of the construction site planning (for residential and public buildings with a building area up to 700 m^2), considering all elements of the construction infrastructure depicted in Fig. 1, reveals the following:

– areas occupied by engineering elements of the construction site and utilized in the technological process of construction, including temporary roads, administrative and domestic structures, and warehouses, account for less than 18 % of the total construction site area (varying within the range of 12 to 17 %).

– the areas “not occupied” on the construction site are proportional to the areas occupied by the planned structures;

– the “not occupied” areas (44–56 %) are conditional, as they partially include hazardous zones during work execution.

The provided analysis indicates that approximately 50 % of the area on the construction site is not involved in the technological process and may be allocated for various reasons, including:

– security zones for engineering networks and infrastructure objects;
– areas formed by the configuration of the land plot;
– opportunities for organizing access to the site;
– terrain relief.

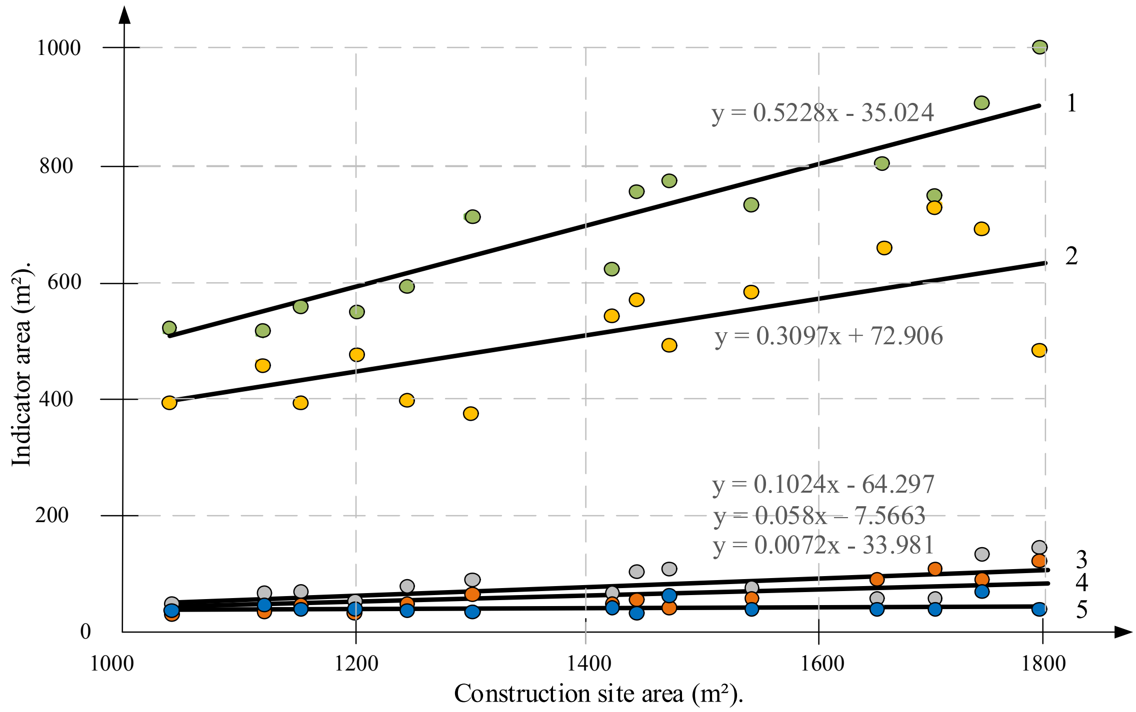

Fig. 1. Distribution of areas of construction infrastructure elements on the construction master plan for the sample objects: 1 – "not occupied" areas; 2 – an area of planned structures; 3 – an area of temporary storage yards; 4 – an area of temporary roads on the construction site; 5 – an area of temporary sanitary and domestic facilities

The analyzed construction sites were formed without implementing optimization measures to minimize costs for their organization and were designed by adhering to the existing regulatory requirements. The areas of engineering infrastructure elements (administrative and domestic premises and storage yards), which are typically subject to optimization (Fig. 1), account for up to 10 % of the total construction site area. The "not occupied" areas will affect the distances of unproductive movements within the site.

When optimizing temporary roads, two parameters are considered:

– the construction of the temporary road, which depends on the weight of the machinery used and the intensity of vehicle traffic;

– the area of the temporary road, which depends on the organizational and technological scheme of construction and the conditions of internal compactness of the construction site.

The search for optimal planning of temporary roads is a multivariate problem, as it requires decisions not only from the perspective of planning the construction site but also from the choice of an efficient construction technology. Additionally, minimizing costs for setting up temporary roads may not necessarily result in a reduction of overall construction expenses.

Results and discussion

The tasks of construction site planning typically involve the placement of a list of temporary engineering objects in specific locations within the construction site, simultaneously optimizing the overall planning goals and meeting existing health and safety constraints. Optimal construction site planning is crucial for project management as a whole, as it reduces transportation time within the site, enhances productivity, and improves safety conditions. The planning tasks for a construction site usually include determining the list of temporary objects necessary to support construction work, defining their sizes, shapes, and optimal placement in unoccupied areas within the construction site.

The issue of Construction Site Layout Planning (CSLP) with the application of information technologies is receiving attention in international construction practices (Xu M., 2022; Ioanna N., 2016; Marzouk M., 2016). This is because it contributes to enhancing the efficiency and quality of real-time on-site management. Planning is typically a complex combinatorial optimization problem involving multiple objectives, further complicated by an increasing number of objects and constraints on work execution conditions. Additionally, the process of information planning for construction site layout is practically complex, and its modeling using optimization methods does not guarantee the creation of an optimal solution. Optimization methods do not consider various operational factors, such as interdependencies between individual elements of the construction site, resource allocation, production speed, and downtime of construction equipment.

Algorithms applied in Construction Site Layout Planning (CSLP) optimization technology can generally be classified as Artificial Intelligence (AI), Evolutionary Algorithms (EA), and Swarm Intelligence (SI) methods. All these algorithms focus on finding solutions to the given problem but may not necessarily develop practical data for real-world application, as they often do not consider all conditions of actual production (often simplifying them). They prioritize finding compromise results between site organization costs and safety requirements.

In general, Construction Site Layout Planning (CSLP) models involve the zoning of construction facilities on the site with the aim of minimizing overall construction costs. However, in practice, the placement of these elements may depend on other factors. For instance, positioning meeting rooms close to the entrance of the construction site for minimal movement within the area and quick evacuation in case of emergencies. Additionally, such models often do not consider the time parameter associated with changes in organizational and technological schemes and work execution conditions, such as altering access zones to the site and the subsequent measures involved (relocating gates, roads, changing traffic organization, etc.).

Research on the efficiency of construction site planning, achieved through reducing inefficient resource movements between construction facility elements, demonstrates a decrease in operational costs by up to 23 % (Mudryy I., 2020). The "CRAFT" algorithm was utilized to find optimal site planning. Based on the initial layout of the construction site, this algorithm systematically replaces the locations of elements to minimize transportation costs. Essentially, a new project is formed based on the initial (existing) solution of the construction master plan. Although the algorithm allows consideration of whether elements can be located together (adjacency based on safety, environmental considerations, accessibility, etc.), it only facilitates planning in conditions of simple sites using rectangular-shaped facility elements, forming a solution based on minimizing resource movement costs.

Conclusions

Existing information technologies for optimizing construction site planning address issues only in specific aspects, such as minimizing the area of administrative or residential buildings or warehouse yards, or reducing costs related to non-productive movements. Consequently, there is a need to develop an algorithm for finding an optimal solution that considers all these aspects collectively. In general, the search for optimal construction site planning should be based on the condition:

$$C_м = \sum_{i=1}^{n} S_{п.i} C_п + \sum_{j=1}^{n} S_{c.j} C_c + \sum_{k=1}^{n} L_k C \quad \rightarrow min,$$

$C_м$ – is the cost of organizing the construction site; S_n – represents the area of administrative and residential premises for variants 1 to n; C_n – is the cost per unit area of administrative and residential premises; Sc denotes the area of warehouse yards for variants 1 to n; C_c – is the cost per unit area of warehouse yards; L_k – is the distance of movement between construction site objects for variants 1 to n; C – is the cost of movement per unit distance.

The development of enhanced information modeling technologies for the creation of construction master plans will necessitate the introduction of new requirements:

– the formation of a construction master plan should be carried out according to the sequence or stages of constructing individual parts (sections) of complexes at specific points in time (aligned with the construction schedule);

– the placement of warehouse yards (areas) should vary depending on the adopted organizational and technological scheme of construction;

– implementation of dynamic constraints on work execution conditions (constraints on areas not involved in production), the positioning of work zones (areas for work execution) in space and time;

– optimization of decisions regarding construction master plan planning (based on a baseline solution), with the aim of minimizing expenses for construction.

Further research is needed to develop a comprehensive methodology for optimizing the planning of construction sites based on the criterion of minimizing construction costs.

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ПЛАНУВАННЯ БУДІВЕЛЬНИХ МАЙДАНЧИКІВ З ВИКОРИСТАННЯМ ІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ

Планування будівельних майданчиків передбачає визначення складу тимчасових об’єктів на майданчику та істотно впливає на безпеку та ефективність виконання будівельних робіт. Планування будівельного майданчика можна оптимізувати за рахунок: зменшення необхідних площ ресурсів, розміщених на будівництві, та мінімізації шляху, тобто уникнення непотрібного переміщення ресурсів у межах його території. Але такий процес планування є складною комбінаторною задачею, що охоплює кілька цілей і ускладнюється зі збільшенням кількості об’єктів і обмежень на умови виконання робіт. Зменшити трудомісткість створення таких рішень дає змогу використання інтелектуальних систем проєктування. Оптимальному плануванню будівельного майданчика, з урахуванням комплексного управління питаннями охорони здоров’я, безпеки та навколишнього середовища, особливо за допомогою інтелектуальних технологій, приділяють мало уваги. У вітчизняній практиці рішення щодо планування будівельного майданчика, як правило, приймає інженер-проєктант на підставі чинних нормативів та власного досвіду.

У роботі проаналізовано технології інформаційного моделювання щодо пошуку оптимального рішення планування будівельного майданчика, відповідно до прийнятих критеріїв ефективності, проаналізовано недоліки таких систем.

На основі теоретичних досліджень зроблено висновок: використовувані інформаційні технології оптимізації планування будівельного майданчика розглядають питання лише в окремих частинах: мінімізація площ адміністративно-побутових приміщень або складських майданчиків чи зниження витрат на непродуктивне переміщення ресурсів. Обґрунтовано потребу в створені алгоритму пошуку оптимального рішення, який би враховував усі ці питання. Сформовано додаткові вимоги до формування будівельних генеральних планів в умовах інформаційного моделювання.

Ключові слова: будівельний майданчик; будівельний генеральний план; календарний план; інформаційні технології моделювання; алгоритм пошуку рішення; оптимальне планування.