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Construction site layout planning considering traveling distance between facilities: Application of particle swarm optimization[1]

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Abstract. Distance is essential factor while designing a good construction site layout planning (CSLP). This study offers the development of a site layout planning model that is capable minimizing the total distance of interaction on the site. For this purpose, this study uses the Particle swarm optimization algorithms (PSO). The present model was developed in four main phases:

(1) Investigate and develop objective criteria to enable minimizing the total distance of interaction.

(2) Modeling the site layout practical optimization constraints.

(3) Implementing the model as a particle swarm optimization algorithm application.

(4) Evaluating and verifying performance of the model by the grid search method.

An application case study of a residential building project is presented to demonstrate the benefits of the usage of the model.

Key words. Optimization, construction site layout planning, particle swarm optimization.

1. Introduction

Site layout planning is one of the significant tasks of the site management. The large projects which involve the high number of manpower, subcontractors and equipment involved could result in extensive time loss and cost overruns in the absence of effective and systematic approach to site planning. Site layout and location of temporary facilities which is comprehensively planned can enhance the management by reducing travel time, allowed time and increasing employee morale by ensuring better and safer working environment. The site layout planning problems were thoroughly discussed in this paper as considering its importance (Harris [1]). Construction site layout planning comprises determining, sizing and placing

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of the temporary facilities in the boundaries of the construction site. Many factors such as project type, scale, design, location, and organization of construction work are essential for the temporary facilities and their fields (Hedley [2]).

The current study aims to develop a site layout planning model which would minimizing the construction distance. The current study also showed that presented models that are suitable for as follows:

1. Fitting any user-defined construction projects.

2. Recommended a comprehensive minimize the total distance of interaction, the major target of the present system is to provide practical automated support for construction planners who want to optimize the design of site layout plans.

3. Using the grid search method for model assessment and results from affirmation.

Ning and Lam [3] suggested a multiobjective optimization (MOO) model utilizing modified Pareto-based ant colony optimization (ACO) algorithm. Because the model could find a Pareto solution (trade-off layout), the requirement of reducing cost is fulfilled and the site safety level is improved simultaneously. Zouein and Tommelein (1999) introduced a hybrid incremental algorithm to solve the restricted dynamic layout problem. The aim of the numerical problem formulation is to minimize transportation and relocation costs of resources which are subject to 2D geometric restrictions.

In the recent times, construction site layout optimization has become one of the main concerns in the field of construction management because a suitable design and optimization have a large impact on project time, cost. It is offered in this research that the development of an expanded site layout planning model which is competent decreasing the total distance of interaction on the site. The different algorithms such as neural network, artificial intelligence, and genetic algorithm, and ACO algorithm were used to solve various CSLP problems as seen in the literature reviews. In this study, we used Particle Swarm Optimization (PSO) Approach to solve the model proposed, because this algorithm very rare were used to solve various CSLP problems as seen in the literature reviews.

2. Materials and methods

In the recent times, construction site layout optimization has become one of the main concerns in the field of construction management because a suitable design and optimization have a large impact on project time, cost. It is offered in this research that the development of an expanded site layout planning model which is competent decreasing the total distance of interaction on the site. The different algorithms such as neural network, artificial intelligence, and genetic algorithm, and ACO algorithm were used to solve various CSLP problems as seen in the literature reviews. In this study, we used PSO approach to solve the model proposed, because this algorithm very rare were used to solve various CSLP problems as seen in the literature reviews.

2.1. Formulation of the model to minimize the distance between facilities on the site

The optimization target of the present model is to reduce the traveling cost of resources to a minimum because of the distance between the facilities of the sites. This may be obtained when the proximity weights are used as depending on the desired closeness between the facilities. Table 1 shows one common scale used for the current problem which was also used in industrial facility layout planning (Hegazy and Elbeltagi [5]) and the convenient scales were chosen by the experts.

Table 1. The six-value scale commonly used in industrial facility layout

Desired closeness between facilities	Proximity weights for various facilities relationships (w_{ij})
Absolutely necessary (A)	$6^5 = 7776$
Especially important (E)	$6^4 = 1296$
Important (I)	$6^3 = 216$
Ordinary closeness (O)	$6^2 = 36$
Unimportant (U)	$6^1 = 6$
Undesirable (X)	0

The traditional measure used to calculate a specific layout is a weighted sum of all travel distances as follows (Sanad et al. [6]):

$$\text{Minimize}: \sum_{i=1}^{p-1} \sum_{j=i+1}^{p} w_{ij} d_{ij}, \tag{1}$$

where

$$d_{ij} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \tag{2}$$

Here, w_{ij} denotes the proximity weights representing the actual transportation cost per unit distance between facilities i and j (see Table 1), d_{ij} are the distances between facilities i and j (their values being attained from plans), X_i, Y_i stand for the coordinates of the center of gravity of facility i and X_j, Y_j are the same coordinates of facility j (these values are also attained from the plans). Finally, p is the total number of facilities on the site.

2.2. Optimization constraints

In the present model, two types of constraints are imposed on the generated solutions to assure the improvement of practical site layout plans: (1) boundary constraints and (2) overlap constraints. Boundary constraints are required to ensure that temporary facilities are located within the site boundaries, on the other hand, avoiding the overlap of facilities on site is essential for overlap constraints.

2.2.1. Boundary constraints. In this model, boundary constraints are investigated for each solution using the following four-step algorithm so as to provide that each facility is located within the boundaries of the site.

For each temporary facility i the gap between facilities and boundary in the X and Y directions are determined according to the coordinates of its center of gravity (X_i, Y_i), and its length in the X direction L_{xi} and width in the Y direction W_{yi}.

In the X-direction, the boundary constraints are satisfied if

$$X_i + L_{xi}/2 + \delta \leq U_X, \; X_i - L_{xi}/2 - \delta \geq L_X \,, \tag{3}$$

where δ denotes the gap between facilities and boundaries in the X and Y directions, U_X is the right boundary of the site space and L_X is the left boundary of the site space.

In the Y-direction, the boundary constraints are satisfied if

$$Y_i + W_{yi}/2 + \delta \leq U_Y, \; Y_i - W_{yi}/2 - \delta \geq L_Y \,. \tag{4}$$

Here, U_Y is the upper boundary of the site space and L_Y is the lower boundary of the site space.

When all the positions in directions X and Y are satisfied, then the facility i is compatible with the boundary constraints. In the opposite case, this type of constraint is violated, so it should be dismissed (Khalafallah [7]).

2.2.2. Overlap constraints. In order to ensure that no overlap occurs between facilities on site, the overlap constraints are examined using the following steps:

$$|X_i - X_j| \geq (L_{xi}/2 + L_{xj}/2)/2 + \delta \,, \tag{5}$$

and in the Y-direction, the overlap constraints between the facilities i and j are satisfied if

$$|Y_i - Y_j| \geq (L_{yi}/2 + L_{yj}/2)/2 + \delta \,. \tag{6}$$

If overlaps are encountered in X-direction or Y-direction, then there is an overlap between the two facilities and therefore this solution should be precluded. Otherwise, the overlap constraints are satisfied.

3. Research and discussion

The principal research results of this study were examined and divided into three main sections, as follows:

1. Site layout optimization system. 2. Application example. 3. Model evaluation and results verification.

3.1. Site layout optimization system

This section presents the structure of the developed model for site layout optimization. This section analyzes the structure of a developmental model for site layout optimization. The principal purpose of the present system is to provide convenient automated support for the construction planners who need to optimize the design of site layout plans. The system is implemented and integrated into three main modules:

(1) A comprehensive optimization module that optimizes and integrates entire effects of site layout planning to minimize the total distance of interaction.

(2) A relational database module to promote the storage and retrieval of construction site layout data and the produced optimization results.

(3) A user interface module in order to facilitate the input of project data and the analysis of the produced optimal site layout plans (see Fig. 1).

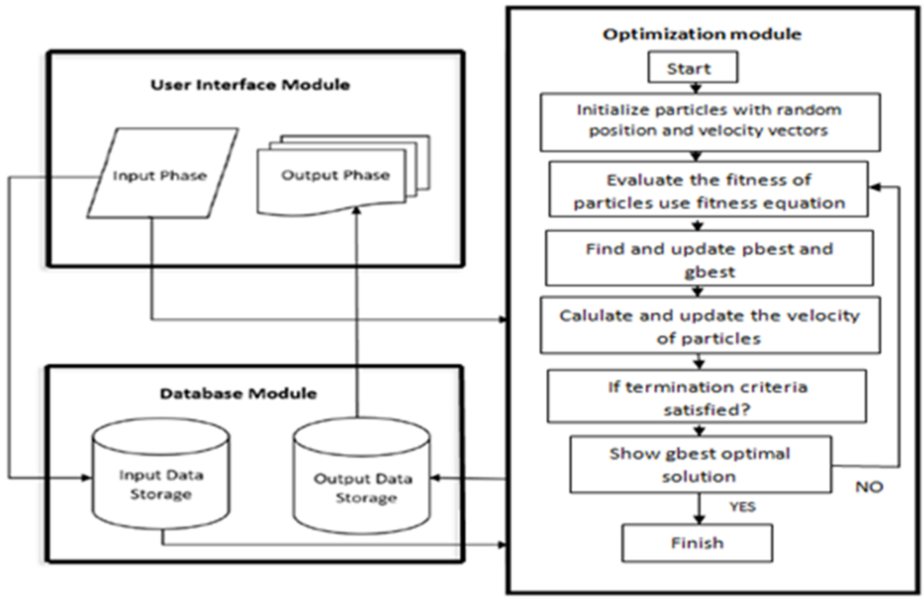

Fig. 1. Optimization module

3.2. Application example

A comprehensive application example is analyzed to illustrate the competencies of the developed system in minimization of the traveled total distance between the temporary facilities. In order to ensure the practicability of the developed model, real-life site layout planning data were obtained from an engineering team working on a residential building project. Input data of the application example are summarized in Tables 2 to 5 (project dimension is as follows: length (m) and width (m) are respectively 189.28 m and 159.59 m).

Table 2. Permanent facilities

Symbol		Facility Name	Length (m)	Width (m)	Location in site
F1	■	Tower crane	6	6	(94.44,64.83)
F2	■	Building 1	25.7	20.65	(106.88,24.50)
F3	□	Building 2	25.7	20.65	(65.95,32.05)
F4	□	Building 3	25.7	20.65	(25.30,27.70)
F5	□	Building 4	25.7	20.65	(27.30,74.20)
F6	■	Building 5	25.7	20.65	(59,117.94)
F7	■	Building 6	25.7	20.65	(111.93,87.30)
F8	□	Building 7	25.7	20.65	(138.98,50.8)

Table 3. Temporary facilities

Symbol		Facility Name	Length (m)	Width (m)
F9	□	Welding workshop	10	18
F10	■	Contractor office	10	8
F11	■	Rest room	10	10
F12	■	Parking	17	17
F13	■	WC	6	6
F14	■	Fuel stock	6	5
F15	■	Tool stock	10	12
F16	■	Generator	2	2

Finally, the optimization process starts and runs through a number of cycles. In this example, the system was run for 5 times (to increase the number of repetitions in stochastic approaches contributes to access the most reliable solutions).

3.3. Model evaluation and results verification

Model evaluation and results verification were performed by analyzing and testing the performance of the model in the application example. The results are analyzed in order to illustrate the use of the present model and demonstrate its capabilities in optimizing construction site layouts and generating optimal minimizing the total distance of interaction, see Xu and Li [8]. In this article, it is confirmed by the results of this analysis for the application example that increase of the iterations leads to improved quality of the solution in the metric (see Figs. 2 and 3).

Moreover, the results emphasize that increase of the population sizes leads to improved quality of the solution in the metric. Although some fluctuations happened in the two metrics, the final result has not been affected. The generated optimal site layout solutions for any project will provide optimum distance of resources.

Table 4. Proximity weight facilities

	Facility (i)															
Facility (j)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16
F1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F2	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F3	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-
F4	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
F5	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-
F6	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-
F7	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-
F8	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
F9	1296	1	1	1	1	1	1	1	0	-	-	-	-	-	-	-
F10	1	36	36	36	36	36	36	36	36	0	-	-	-	-	-	-
F11	1	36	36	6	6	6	6	6	6	6	0	-	-	-	-	-
F12	1	6	6	6	36	6	6	6	6	36	6	0	-	-	-	-
F13	1	1	1	1	1	1	1	1	6	6	6	6	0	-	-	-
F14	1296	1	1	1	1	1	1	1	1	1	1	1	1	0	-	-
F15	1296	1	1	1	1	1	1	1	1	1	1	1	1	1	0	-
F16	1	6	6	36	36	6	6	6	6	6	6	6	6	6	6	0

Note: — = equivalent values in this symmetric matrix.

Table 5. Weight of experts

Expert	**Background**	**Weight**
Expert 1	Project manager	0.25
Expert 2	Construction manager	0.22
Expert 3	Senior engineer	0.20
Expert 4	Site engineer with 15 years experience	0.18
Expert 5	Site engineer with 8 years experience	0.15
Total		0.25+0.22+0.20+0.18+0.15=1

4. Conclusion

The present research study was focused on optimization of site layout planning for residential building projects.The model is designed to search and generate optimal site layout plans that provide optimal distance of interactions satisfying all

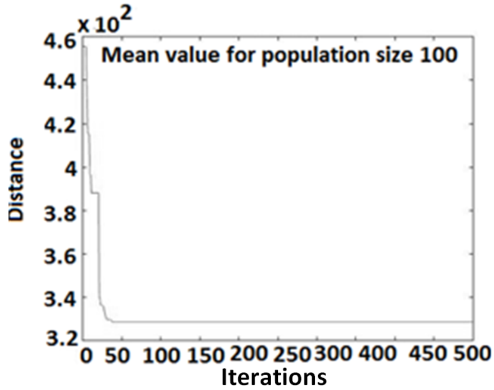

Fig. 2. Mean values for population size 100

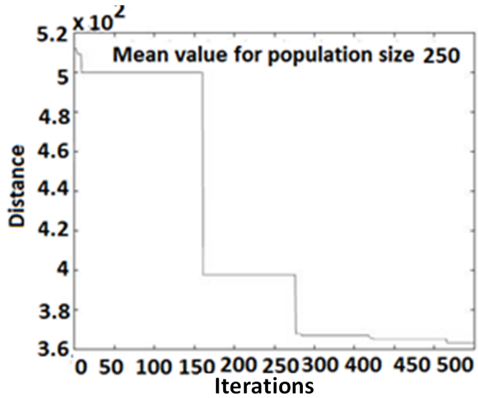

Fig. 3. Mean values for population size 250

convenient constraints in this construction problem. The system is designed not only to optimize the above-mentioned objectives, but also to enable supporting improved visualization of the generated optimal site layout solutions. The primary research developments of this study contribute to the improvement of current practices in construction site layout planning and can lead to a competitive advantage for contractors utilizing the developed system due to increasing the efficiency of construction operations.

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