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A Comparative Study on Bio-Inspired Algorithms in Layout Optimization of Construction Site Facilities

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Abstract

A good arrangement of site layout on construction projects is a fundamental component in the project efficiency. Optimization on site layout is necessary to reduce the transportation cost of resources or personnel between facilities. Recently, the use of bio-inspired algorithms has received considerable critical attention for solving the engineering optimization problem. Thus, this study compares the performance of particle swarm optimization (PSO), artificial bee colony (ABC), and symbiotic organisms search (SOS) algorithms in optimizing the site layout planning problems. Three real-world case studies of layout optimization problem have been used in this study. Obtained results show that SOS has a better performance in comparison to the rest of algorithms.

Keywords: site layout, optimization, metaheuristic, particle swarm optimization, artificial bee colony, symbiotic organisms search

Introduction

The arrangement of site layout on construction projects greatly affects the efficiency of project cost. The goal of site layout is to find the minimum operational cost with a set of site layout composition. A layout can be labeled good if it can produce the most efficient operation that can reduce the overall project cost. On construction projects many factors can affect the operational cost of the project, for example the distance and frequency of traveling between each facility, the route used, etc [1]. Generally, project managers tend to use intuition and previous experiences as a reference for layout planning of the project facilities. However, this does not always guarantee the optimal layout planning solution. This encourages researchers to develop a number of methods that have the potential to produce an efficient project site layout.

Over the past years, research regarding facility layout optimization have been conducted . Site layout problem is classified as a quadratic assignment problem (QAP), which is categorized as a non-linear optimization problem [2]. Many studies have utilized metaheuristic algorithms to solve different types of QAP. Hence, for the past few years, researchers have tried to solve the site layout problem by metaheuristic algorithms. One of the examples of an early research is the site layout optimization conducted by Yeh [3]. Yeh used the simulated annealing (SA) algorithm to solve the site layout problem. Another research have been conducted by Li and Love [4] using the genetic algorithm (GA) to find the solution of the site layout optimization problem. Li and Love concluded that GA had an advantage in terms of global search compared to local search. Thus, the use of metaheuristic algorithms enables the site layout problem to be solved well and at the same time uses a reasonable computation cost.

Recently, many researchers have been rigorously investigating the comparative performance between multiple metaheuristic algorithms in addressing the site layout problems. Adrian, Utamima and Wang [5] compared the performance of three metaheuristic algorithms to solve the site layout problem, namely GA, particle swarm optimization (PSO), and ant colony optimization (ACO). Adrian, Utamima and Wang [5] was comparing the results from these three methods. The result showed that the ACO method was able to obtain the optimum solution with a lesser time in comparison with PSO and GA. Yahya and Saka [6] used artificial bee colony (ABC) and ant system (AS) to solve the layout planning problem of residential building and private hospital projects with multiple objective criteria. It was shown that the ABC outperformed the AS. Prayogo, Cheng and Prayogo [7] utilized differential evolution (DE), PSO, and symbiotic organisms search (SOS) to search for the best site layout of caisson structure fabrication. The result showed that SOS achieved the best overall performance.

Bio-inspired optimization algorithms that exist now are diverse with its own characteristics. Metaheuristic algorithms that are commonly used such as PSO, ABC, and SOS have strengths and weaknesses when compared with each other. As construction projects become larger, the complexity of site layout problem increases. For every site layout problem, every metaheuristic method may produce different performance. Thus, it is worthwhile to continue investigating the best possible method that can solve the more complex layout planning problem.

Bio-inspired Optimization Algorithms

To reach the project facility site layout optimization process is not simple that in this research bio-inspired optimization algorithm is used. It is an algorithm inspired by natural events that happen around us. For over three decades, various methods have been developed to help researchers solve the optimization methods. In this research, the metaheuristic algorithms used are particle swarm optimization (PSO), artificial bee colony (ABC), and symbiotic organisms search (SOS).

Particle Swarm Optimization

First introduced by Kennedy and Eberhart [8], PSO adopts the principle of social group intelligence between living things. PSO imitates the behavior of a group of living things such as birds or fish when looking for food, where the behavior of each individual will affect one another. Particles will be generated on the first phase randomly and will spread at a certain search location, each particle represents a possible solution of a problem. On each iteration, every particle will move according to a speed vector and is always renewed by a mathematical operator that models a social group relation shown on equation (3). If a particle reaches a more optimum location. Then the position and objective value of that location will be saved as pBest (personal best). In each iteration, the global best of all particles is saved as gBest (global best).

$$V_i = W * Vi + rand(0,1) * C_1 * (pbestX_i - X_i) + rand(0,1) * C_2 * (gbestX - X_i) \quad (1)$$

where V_i is the speed of particle i, W is the inertia weight parameter, C_1 is the cognitive factor parameter, $pbestX_i$ is the location coordinate of *pbest*, X_i is the coordinate of particle *i*, C_2 is the social factor parameter, $gbestX$ is the location coordinate of *gbest*. The PSO algorithm calculation process flowchart is shown in Fig 1.

Algorithm 1 Particle Swarm Optimization

```
Initialize PSO parameters
Initialize a population of random particles (solutions)
Evaluate the objective value of each particle
Determine initial pbest and gbest
while termination criteria are not satisfied do
    for each particle do
        Update the velocity for the particle
        Update the new location for the particle
        Determine the objective value for the particle in its new location
        Update pbest if required
    end for
    Update gbest if required
end while
```

Fig 1. Pseudo-code of PSO

Artificial Bee Colony

ABC is one of the swarm intelligence based algorithm introduced by Karaboga [9] in 2005. ABC imitates the behavior of a bee colony in search for food source. First, the ABC algorithm initializes the food source randomly containing a random variable as a candidate solution. After the food source have been determined, ABC enters the first phase, which is the employed bees, on this stage, employed bees make modifications on the candidate solution by looking for alternative solutions around it. The modified solution will first be measured the objective value as an information that will later be shared to the onlooker bees through waggle dance as seen in equation (2). On the onlooker bees phase, the solution modified by the employed bees will be chosen randomly with a certain probability. Then, the onlooker bees will do further modification to the solution based on the information gotten from the employed bees. On the scout bees phase, the employed bees will turn into scout bees that will look for an alternative solution is the solution does not get better in a period of time. ABC will stop the optimization process if a certain objective value is obtained ot have reached the maximum iteration.

$$newFood_i = Food_i + rand(-1,1) * (Food_i - Food_j) \tag{2}$$

where $Food_i$ is the food source at i, $newFood_i$ is the modified food source at i after the onlooker bees phase, $Food_j$ is the food source at j chosen at random. The pseudo-code of ABC algorithm is shown in Fig 2.

Algorithm 2 Artificial Bee Colony

```
Initialize ABC parameters
Initialize a population of random food sources (solutions)
Evaluate the objective value of each food source
while termination criteria are not satisfied do
    Assign Employed Bees to the food source
    Assign Onlooked Bees to the food source
    Determine the objective value for the particle in its new location
    Assign scout bee if the food source has been sufficiently exploited
    Memorize the best solution obtained so far
end while
```

Fig 2. Pseudo-code of ABC

Symbiotic Organisms Search

SOS was first introduced by Cheng and Prayogo [10] in 2014, SOS is one of the bio-inspired algorithms that simulates different symbiotic interactions done by a pair of organisms in an ecosystem. In the SOS algorithm, these symbiotic interactions are defined in three phases namely: mutualism phase, commensalism phase, and parasitism phase. The SOS algorithm is commonly used to solve continuous-based problems. Different from evolutionary–based algorithm, the SOS algorithm does not produce offspring. However, like population-based algorithms, initially SOS will create a population (called ecosystem) and through various search operators will try to modify the population iteratively to produce an optimum variables solution (called organism). From the time it was introduced in 2014, many studies utilized SOS to solve many optimization problems from engineering research fields [7, 11-16].

During the mutualism phase, organism i (O_i) will interact in a mutualism interaction with another organism (Oj) in a random manner in an ecosystem to improve each of their own quality in the ecosystem. Afterwards, two variable solutions with be formed, $newO_i$ and $newO_j$ through a modification phase using the following mathematical equations.

$$newO_i = O_i + \text{rand}(0,1) * [\, O_{best} - (\, O_i + O_j\,) / 2 * (1 + \text{round}\,(\text{rand}(0,1))\,] \tag{3}$$

$$newO_j = O_j + \text{rand}(0,1) * [\, O_{best} - (\, O_i + O_j\,) / 2 * (1 + \text{round}\,(\text{rand}(0,1))\,) \,] \quad (4)$$

O_{best} are involved in these two mathematical equations, which is the organism with the best objective value in the ecosystem. If the objective values of the variable solutions $newO_i$ and $newO_j$ are more optimum than the objective values of O_i and O_j, then the organisms O_i and O_j will be renewed.

During the commensalism phase, the organism O_i will interact in a commensalism interaction with another organism O_j that is randomly chosen. In this phase, organism O_i takes the advantage from the iteraction with Oj, but organism O_j is not given an advantage nor is given a disadvantage. Variable solution $newO_i$ is formed in this phase from a mathematical equation as follows.

$$newO_i = O_i + \text{rand}(-1,1) * (\, O_{best} - O_j\,) \quad (5)$$

If the objective value of the variable solution $newO_i$ from the modification process is more optimum from the objective value of O_i, then the organism Oi will be renewed.

During the parasitism phase, organism O_i will produce an artificial parasite called $O_{parasite}$. It is created as a result of the combination of cloning of the organism O_i and random variables. Organism O_j acts as a host and is chosen at random from the ecosystem. After the objective evaluation, the objective value between $O_{parasite}$ and organism O_j will be compared. If the objective value of the $O_{parasite}$ is better than the organism O_j, then the $O_{parasite}$ will replace the position of O_j in the ecosystem. Otherwise, the organism O_j will retain its position if its objective value is better. The SOS algorithm calculation process flowchart is shown in Fig 3.

Algorithm 3 Symbiotic Organisms Search

```
Initialize a population of random organisms (solutions)
Evaluate the objective value of each organism
Identify the best organism
while termination criteria are not satisfied do
    for each particle do
        Simulate mutualism phase
        Simulate commensalism phase
        Simulate parasitism phase
        Update best organism
    end for
end while
```

Fig 3. Pseudo-code of SOS

Construction Site Layout Planning Optimization

Mathematical optimization model

Site layout of construction facilities greatly affects the productivity of construction personnel, therefore, determining the optimization model of layout planning problem is necessary. In designing the site layout of facilities, the identification proses of distance and frequency between each facility, and the number of workspace available are needed. There are two conditions in site layout placement; unequal-area facility site layout and equal-ara facility site layout. Unequal-area facility site layout is a condition where the number of workspaces is not proportional to the number of project facility, thile equal-area facility site layout is a condition where the number of workspaces is proportional to the number of project facility [4]. The main purpose of construction facility site layout planning is to determine the project facility placement (n) on the available workspace (m) that minimizes the workers' traveling distance between each facility. Construction site layout planning problem is modeled as a quadratic assignment problem that uses the traveling distance and traveling frequency of workers as the main key to obtain the optimum result.

Minimize $$TD = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl} \quad (6)$$

Subject to $$\sum_{j=1}^{n} x_{ij} = 1, \quad i = 1,2,3,\ldots,n \quad (7)$$

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 1,2,3,\ldots,n \quad (8)$$

$$x_{ij} \in \{0,1\}, \quad i = 1,2,3,\ldots,n, \; j = 1,2,3,\ldots,n \quad (9)$$

n is the total number of facilities that will be placed, d_{ij} is the distance between the location of facility i and facility j, meanwhile f_{ij} is the traveling frequency between facility i and facility j. If two facilities are placed next to each other, then the traveling distance between the two facilities are measured from the midpoint of the two facilities. If not, then the traveling distance between the two facilities can be measured by the total segmental distance between the two facilities, as an example, the distance between facility 1 and 3, then the distance between the two is the total of distance between facility 1 and 2 and the distance between facilities 2 and 3.

Experimental Results

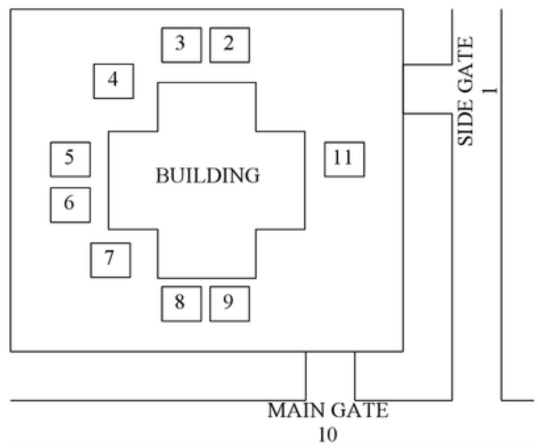
This research compares the ability of three bio-inspired algorithms, namely PSO, ABC, and SOS with using three case studies. The first case study is a hypothetical case taken from Li and Love [12], with 11 facilities and 11 locations. The second case study is a layout problem with 10 facilities and 10 locations from an apartment building project in Surabaya obtained from Prayogo, Gosno, Evander and Limanto [13]. The third layout problem is obtained from a hotel building project in Surabaya, with 14 facilities and 14 locations. Every case study has several permanent locations that acts as a constraint to determine the facility location. The parameters used in each algorithm is shown in Table 1.

Every algorithm is simulated for 30 times to remove the random bias with 30 iterations for each simulation. The result obtained by running the three algorithms is the total traveling distance or the best traveling distance by arranging the locations of each facilities to be the most effective for workers as shown in Eqs. (6) - (9).

Table 1. Parameter of Metaheuristic Algorithms

PSO	ABC	SOS
$C_1 = 2$	*limit* = 100	*popsize* = 30
$C_2 = 2$	*popsize* = 30	*maxiter* = 30
$W = 0.4 - 0.9$	*maxiter* = 30	
popsize = 30		
maxiter = 30		

Case Study 1: Layout Planning Problem with 11 Facilities



1. Site office (SO)
2. Falsework shop (SG)
3. Labor residence (LR)
4. Storeroom 1 (S1)
5. Storeroom 2 (S2)
6. Carpentry workshop (CW)
7. Reinforcement steel workshop (RW)
8. Side gate (SG)
9. Electrical, water, and utility control room (UR)
10. Concrete batch workshop (BW)
11. Main gate (MG)

Fig 4. Site Layout of Case Study 1

The first case study was introduced by Li and Love [17] and has 11 facilities to be arranged in 11 locations. The side gate is placed permanently in location 1 and the main gate is placed permanently in location 10. The locations of the facilities are shown in Fig 4. The traveling distance and the traveling frequencies between each location are shown in Table 2 and Table 3 respectively.

Table 2. Traveling Distance Between Each Location for Case Study 1

	1	2	3	4	5	6	7	8	9	10	11
1	0	15	25	33	40	42	47	55	35	30	20
2	15	0	10	18	25	27	32	42	50	45	35
3	25	10	0	8	15	17	22	32	52	55	45
4	33	18	8	0	7	9	14	24	44	49	53
5	40	25	15	7	0	2	7	17	37	42	52
6	42	27	17	9	2	0	5	15	35	40	50
7	47	32	22	14	7	5	0	10	30	35	40
8	55	42	32	24	17	15	10	0	20	25	35
9	35	50	52	44	37	35	30	20	0	5	15
10	30	45	55	49	42	40	35	25	5	0	10
11	20	35	45	53	52	50	40	35	15	10	0

Table 3. Traveling Frequency Between Each Location for Case Study 1

	SO	FS	LR	S1	S2	CW	RW	SG	UR	BW	MG
SO	0	5	2	2	1	1	4	1	2	9	1
FS	5	0	2	5	1	2	7	8	2	3	8
LR	2	2	0	7	4	4	9	4	5	6	5
S1	2	5	7	0	8	7	8	1	8	5	1
S2	1	1	4	8	0	3	4	1	3	3	6
CW	1	2	4	7	3	0	5	8	4	7	5
RW	4	7	9	8	4	5	0	7	6	3	2
SG	1	8	4	1	1	8	7	0	9	4	8
UR	2	2	5	8	3	4	6	9	0	5	3
BW	9	3	6	5	3	7	3	4	5	0	5
MG	1	8	5	1	6	5	2	8	3	5	0

For the first case, each algorithm is run with 30 iterations. The comparison of the results are shown in Table 4. The location for each facility and the optimum traveling distance are shown in Table 5.

Table 4. Total Traveling Distance Comparison for Case Study 1

Method	Minimum (m)	Maximum (m)	Average (m)	Standard Deviation
PSO	12546	12840	12583	70.321
ABC	12546	13190	12812,07	169.552
SOS	12546	12714	12560,07	39.953

Table 5. Location and Optimum Traveling Distance Value Comparison for Case Study 1

Methods	SO	FS	LR	S1	S2	CW	RW	SG	UR	BW	MG	Traveling Distance
PSO	9	11	5	6	7	2	4	1	3	8	10	12546
ABC	9	11	4	5	7	6	3	1	2	8	10	12546
SOS	9	11	4	6	7	5	3	1	2	8	10	12546

Case Study 2: Layout Planning Problem with 10 facilities

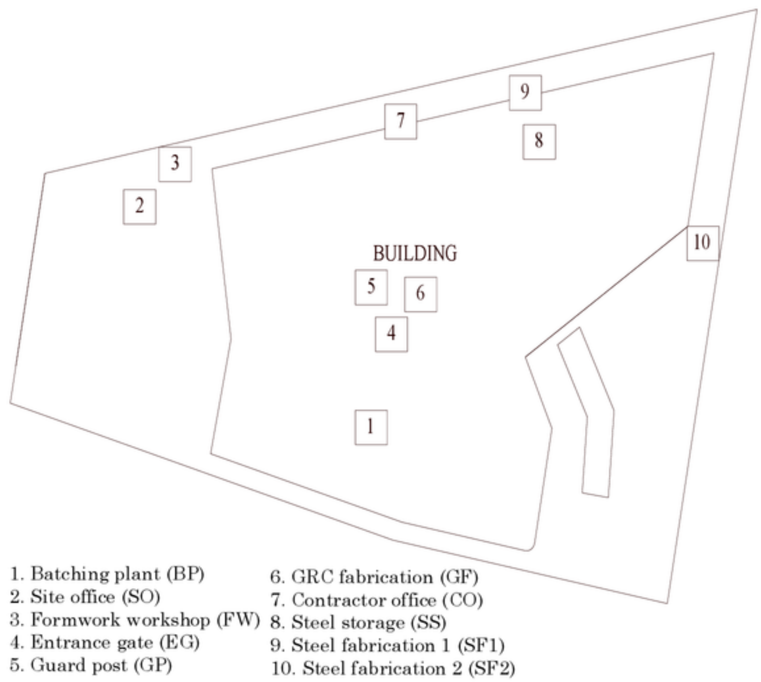


Fig 5. Original Site Layout of Case Study 2

The second case study was introduced by Prayogo, Gosno, Evander and Limanto [13] and has 10 facilities to be arranged in 10 locations. The entrance gate is placed permanently in location 4 and the guard post is placed permanently in location 5. The locations of the facilities are shown in Fig 5. The traveling distance and the traveling frequencies between each location are shown in Table 6 and Table 7 respectively.

Table 6. Traveling Distance Between Each Location for Case Study 2

	1	2	3	4	5	6	7	8	9	10
1	0	139	156	33	39	49	139	170	174	150
2	139	0	19	106	100	112	128	160	165	188
3	156	19	0	125	119	131	112	144	148	207
4	33	106	125	0	12	23	111	143	147	123
5	39	100	119	12	0	12	99	131	135	111
6	49	112	131	23	12	0	89	121	125	101
7	138	128	112	111	99	89	0	32	36	104
8	170	160	144	143	131	121	32	0	9	42
9	174	165	148	147	135	125	36	9	0	102
10	150	188	207	123	111	101	104	42	102	0

Table 7. Traveling Frequency Between Each Location for Case Study 2

	BP	SO	FW	EG	GP	GF	CO	SS	SF1	SF2
BP	0	10	8	9	3	9	0	0	0	0
SO	10	0	8	12	8	9	11	5	0	1
FW	8	8	0	4	3	8	0	0	0	0
EG	9	12	4	0	6	15	10	10	8	5
GP	3	8	3	6	0	9	5	3	2	1
GF	9	9	8	15	9	0	0	0	0	0
CO	0	11	0	10	5	0	0	7	7	10
SS	0	5	0	10	3	0	7	0	25	27
SF1	0	0	0	8	2	0	7	25	0	16
SF2	0	1	0	5	1	0	10	27	16	0

For the second case, each algorithm is run with 30 iterations. The comparison of the results are shown in Table 8. The location for each facility and the optimum traveling distance are shown in Table 9.

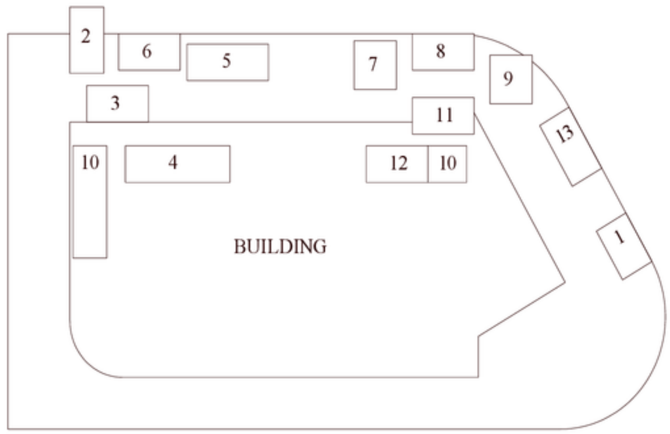
Table 8. Total Traveling Distance Comparison for Case Study 2

Methods	Minimum (m)	Maximum (m)	Average (m)	Standard Deviation
PSO	39184	40736	39327,07	303.011
ABC	39184	46698	41733,77	2013.849
SOS	39184	40666	39243,4	274.206

Table 9. Location and Optimum Traveling Distance Value Comparison for Case Study 2

Methods	BP	SO	FW	EG	GP	GF	CO	SS	SF1	SF2	Traveling Distance
PSO	2	6	3	4	5	1	10	7	9	8	39184
ABC	2	6	3	4	5	1	10	7	9	8	39184
SOS	2	6	3	4	5	1	10	7	9	8	39184

Case Study 3: Layout Planning Problem with 14 Facilities



1. Main gate (MG)
2. Site gate (SG)
3. Guard post (GP)
4. Office (O)
5. Workers toilet 1 (WT1)
6. Wiremesh storage (WS)
7. Tower crane (TC)
8. Workers toilet 2 (WT2)
9. Power source (PS)
10. Health post (HP)
11. Material storage (MS)
12. Workers barrack (WB)
13. Reinforcement fabrication (RF)
14. Formwork fabrication (FF)

Fig 6. Original Site Layout of Case Study 3

This case study has 14 facilities to be arranged in 14 locations. The main gate is placed permanently in location 1, the side gate is placed permanently in location 2, the tower crane is placed permanently in location 7, and the power source is placed permanently in location 9. The locations of the facilities are shown in Fig 6. The traveling distance and the traveling frequencies between each location are shown in Table 10 and Table 11 respectively.

Table 10. Traveling Distance Between Each Location for Case Study 3

	MG	SG	GP	O	WT1	WS	TC	WT2	PS	HP	MS	WB	RF	FF
MG	0	65	60	43	38	37	25	17	10	8	11	17	0	51
SG	65	0	7	14	15	7	23	33	51	45	40	36	47	15
GP	60	7	0	7	12	4	20	30	43	37	31	28	45	8
O	43	14	7	0	9	9	12	23	26	20	15	11	32	6
WT1	38	15	12	9	0	2	4	14	22	23	15	14	34	18
WS	37	7	4	9	2	0	8	18	26	25	19	18	35	12
TC	25	23	20	12	4	8	0	2	10	10	6	10	12	28
WT2	17	33	30	23	14	18	2	0	8	9	5	13	10	38
PS	10	51	43	26	22	26	10	8	0	12	5	15	1	42
HP	8	45	37	20	23	25	10	9	12	0	1	9	6	36
MS	11	42	34	15	15	19	6	5	5	1	0	6	4	36
WB	17	36	28	11	14	18	10	13	15	9	6	0	15	27
RF	0	47	45	32	34	35	12	10	1	6	4	15	0	51
FF	51	15	8	6	18	12	28	38	42	36	36	27	51	0

Table 11. Traveling Frequency Between Each Location for Case Study 3

	MG	SG	GP	O	WT1	WS	TC	WT2	PS	HP	MS	WB	RF	FF
MG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SG	0	0	1	1	1	30	1	1	1	3	15	2	2	0
GP	0	1	0	1	0	0	1	1	1	1	1	1	1	0
O	0	1	1	0	3	1	1	1	1	2	2	3	2	2
WT1	0	1	0	3	0	0	1	0	0	2	0	4	0	0
WS	0	30	0	1	0	0	0	1	0	4	2	4	4	0
TC	0	1	1	1	1	0	0	1	1	1	0	1	0	0
WT2	0	1	1	1	0	1	1	0	1	2	2	2	2	2
PS	0	1	1	1	0	0	1	1	0	0	0	1	0	0
HP	0	3	1	2	2	4	1	2	0	0	3	3	2	2
MS	0	15	1	2	0	2	0	2	3	3	0	2	15	2
WB	0	2	1	3	4	4	1	2	3	3	2	0	2	2
RF	0	2	1	2	0	4	0	2	2	2	15	2	0	0
FF	0	0	0	2	0	0	0	2	2	2	2	2	0	0

For the third case, each algorithm is run with 30 iterations. The comparison of the results are shown in Table 12. The location for each facility and the optimum traveling distance are shown in Table 13.

Table 12. Total Traveling Distance Comparison for Case Study 3

Methods	Minimum (m)	Maximum (m)	Average (m)	Standard Deviation
PSO	4276	4973	4553.933	159.392
ABC	4391	4932	4662.467	157.698
SOS	4281	4531	4398.4	67.027

Table 13. Location and Optimum Traveling Distance Value Comparison for Case Study 3

Methods	MG	SG	GP	O	WT1	WS	TC	WT2	PS	HP	MS	WB	RF	FF	Traveling Distance (m)
PSO	1	2	8	5	10	3	7	12	9	4	6	11	14	13	4276
ABC	1	2	6	11	12	3	7	10	9	4	5	8	14	13	4391
SOS	1	2	5	8	13	6	7	12	9	4	3	11	14	10	4281

Conclusion

This research presents a comparative study of bio-inspired algorithms on solving the facility layout planning problem of construction projects. Three bio-inspired algorithms, namely PSO, ABC, and SOS, have been used to solve three different case studies. It is found that the SOS algorithm is the best out of the three algorithms because it is able to find the most optimum solution. Thirty simulations have been conducted for each study. According to the results, most of the algorithms can find the best site layout of each case study. It is worth noting that SOS is the best performer in terms of consistency. SOS can find the lowest mean and standard deviation value for each problem.

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