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Comparison of Genetic Algorithm (GA) and Particle Swarm Optimization Algorithm (PSO) for Discrete and Continuous Size Optimization of 2D Truss Structures

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ABSTRACT

Optimization of truss structures including topology, shape and size optimization were investigated by different researchers in the previous years. The aim of this study is discrete and continuous size optimization of two-dimensional truss structures with the fixed topology and the shape. For this purpose, the section area of the members are considered as the decision variables and the weight minimization as the objective function. The constraints are the member stresses and the node displacements which should be limited at the allowable ranges for each case. In this study, Genetic Algorithm and Particle Swarm Optimization algorithm are used for truss optimization. To analyse and determine the stresses and displacements, OpenSees software is used and linked with the codes of Genetic Algorithm and Particle Swarm Optimization algorithm provided in the MATLAB software environment. In this study, the optimization of four two-dimensional trusses including the Six-node, 10-member truss, the Eight-node, 15-member truss, the Nine-node, 17-member truss and the Twenty-node, 45-member truss under different loadings derived from the literature are done by the Genetic Algorithm and Particle Swarm Optimization algorithm and the results are compared with those of the other researchers. The comparisons show the outputs of the Genetic Algorithm are the most generally economical among the different studies for the discrete size cases while for the continuous size cases, the outputs of the Particle Swarm Optimization algorithm are the most economical.

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1. Introduction

Trusses, as simple structure and rapid analysis, are often used to examine and compare different optimization algorithms. Therefore, optimal design of truss structures is an active branch of optimization research. Truss structures are widely used for cost-effectiveness, ease of implementation, the need for specialized equipment for execution, and the need for today's human to be used for structures with large openings without central columns. The optimization of a design is the main purpose of any designer who tries to choose a combination of different factors or to make a decision or to produce a device in such a way as to meet a set of requirements and criteria. Generally, truss structures are optimized in three ways:1-Optimizing the size or optimizing the cross-section, in which case the cross-section of the members is selected as the design variable and the coordinates of the nodes and the topology of the structure are fixed [1]. 2-Optimization of the shape in which the coordinates of nodes are considered as design variables [2]. 3-Optimization of the topology, in which case how the nodes connect together by members is examined [3].

Natural-based methods try to regulate the random search process using the rules governing nature. One of the most prominent methods is genetic algorithm and particle swarm optimization algorithm. The idea of an evolutionary algorithm was first raised by Rechenberg in 1960. His research was about evolutionary strategies. Later, his theory was examined by many scholars to lead to the design of a genetic algorithm(GA). Genetic algorithm is, in fact, a computer search method based on optimization algorithms based on the structure of genes and chromosomes that was introduced by John Holland in 1975 at the University of Michigan [4], and developed by a group of his students such as Goldberg and Ann Arbor. Particle Swarm Optimization(PSO) algorithm is an optimization technique based on a population of initial responses. This technique was first designed by Kennedy and Eberhart in 1995 based on the social behavior of bird and fish species [5,6].

The PSO demonstrates its proper functioning in many areas, such as finding optimal functions for functions, training neural networks, controlling fuzzy systems, and other issues where genetic algorithms can be applied to them. Many scientists and engineers are currently developing and improving these algorithms at universities and research centers around the world. There has been a lot of research on optimization of truss structures.

In 1992, Rajeev and Krishnamoorthy, based on Goldberg's research, used a simple genetic algorithm to optimize trusses [7]. In 1995, Hajela and Lee provided a two-step method for optimizing trusses [8]. In 1998, the Camp and other colleagues presented the optimal design of two-dimensional structures using the genetic algorithm [9].

In 2002, Fourie and Groenwold optimized the size and shape of truss structures by particle swarm algorithm [10]. In the same year, Li and colleagues, by means of the particle swarm algorithm, in various ways, optimized truss structures [11].

Kaveh and Talatahari using the algorithm called Big Crunch Algorithm optimize the size of truss structures in 2009 [12]. Kaveh and Malakouti Rad introduced a hybrid genetic algorithm and particle swarm in 2010 for power analysis and design [13]. In the same year, Kaveh and Talatahari designed the optimal design of skeletal structures through an algorithm called the Charged System Search Algorithm and the optimal design of skeletal structures using the Imperialist Competitive Algorithm [14,15].

Kaveh and Abbasgholiha, using an algorithm called the Big Crunch Algorithm in 2011, optimized steel frames [16]. Martini, in 2011, optimized the size, shape, and topology of truss structures using the Harmony Search Method [17]. Hajirasouliha and colleagues, in 2011, optimized the topology for seismic design of truss structures [18].

Richardson and colleagues Contributed to the optimization of the multi-objective topology of truss structures with the kinematic stability repair in 2012 [19]. Miguel, in 2012, optimized the shape and size of truss structures with dynamic limitations using a modern initiative algorithm [20]. Makiabadi and colleagues in 2013 designed the optimal design of truss bridges using an optimization algorithm based on training techniques [21]. Leandro and colleagues Assisted in optimizing the size, shape and topology of truss structures in 2013 [22].

In 2014, Gandomi offered a new approach to optimization using an algorithm called the Interior Search Algorithm [23]. Kazemzadeh Azad and Hasancebi in 2014 presented a method for optimizing the size of truss structures based on An Elitist Self-Adaptive Step-Size Search Algorithm [24]. In 2014, Kaveh and Mahdavai presented a new, highly innovative method of Colliding Bodies Optimization for the optimal design of truss structures of continuous size [25]. Kaveh and colleagues in 2015, used an algorithm called An improved magnetic charged system search for optimization of truss structures with continuous and discrete variables [26].

The purpose of this study is to optimize the discrete and continuous size of two-dimensional trusses with topology and fixed shape. For this purpose, two genetic algorithms and a particle swarm algorithm are used and the efficiency of each of the algorithms is investigated in a few case studies of discrete and continuous truss size. In the following, a general overview of the genetic algorithm and particle swarm algorithm is presented. Then the truss design optimization model formulation is expressed and by introducing the trusses, the results of the two algorithms are presented and compared with the results of previous researchers.

2. Genetic algorithm (GA)

In this algorithm, each point (solution) of the decision-making space is replicated to a chromosome, so that each chromosome is composed of decision-making variables sub-strands that contain multiple genes. The general trend of the genetic algorithm is that initially a primary population of chromosomes is generated randomly. Then, the Crossover and Mutation operators affect the primary population and create a chosen population. Then, the selection operator selects among the selected population, according to the merits of a new population called children. This population replaces the primary population and forms the population of the next generation. This process is repeated so that the conditions for reaching the final answer are provided. The convergence condition can be repeated up to a certain generation or non-response to several generations.

2.1. Coding and how to form chromosomes

Encoding is largely dependent on the problem, and for each particular issue, its aspects must be measured and an efficient way used. In this study, chromosome genes can include integers or real numbers according to the size of the design (discrete or continuous). For example, to design a 15-member (Eight-node) truss loop of 16 sizes available, each gene can be one of the numbers from 1 to 16 and with continuous size, the real numbers between the minimum and the maximum available size.

2.2. Crossover operator

One of the main operators of the genetic algorithm is the crossover operator. The crossover process is the ability to change the feature of the scheme among the members of the population in order to improve the suitability of the next generation of designs. This is similar to the transfer of genetic traits to the processes of the birth of living beings, which are formed by RNA and DNA. The crossover operator leads searching in the space you decide. In this process, locations are randomly determined along the chromosome, and the genes of these chromosomes are replaced with two new chromosomes.

The proportion of the population of the children due to the Crossover is called the percentage of Crossover, which is considered to be 80% in this study. In the event of high cross-link rates, most chromosomes participate in the next generation. On the one hand, with a decrease in the rate of Crossover, a relatively large number of chromosomes appear to be present in the next generation.

2.3. Mutation operator

The goal of the mutation is to create more dispersion within the exploration space of the design. A mutation operator randomly changes one or more genes of a chromosome. This allows you to check other spatial searches. In the event of a small mutation rate, the practical purpose of the mutation is violated and it does not have the desired effect. If the mutation rate is large, the genetic algorithm is led to a disorder and its convergence will be considerably reduced.

In the mutation operator, the gene is randomly determined from the length of the chromosome, and then the amount is randomly changed. The ratio of the mutated population to the population is called the percentage of Mutation, which is considered to be 30% in this study. In addition, the ratio of the number of selected chromosome genes to the mutation that changes in this process is the total number of chromosome genes known as mutation rates and according to the surveys is 0.3 in this study.

2.4. Generation of second-generation population

There are several methods to produce next generation population. In this paper, the population of the current generation, the population of the children caused by the Crossover, together with the mutated populations, forms a population that needs to be selected from the population, from the point of view of fitness and population size, as chromosomes of the next generation.

2.5. Selection operator

For the processes of Crossover and Mutation, it is necessary to select a number of chromosomes from the population of the present generation of chromosomes. For this purpose, there are different methods such as Roulettle wheel method, Tournoment method, random method, etc. In this study, the Roulettle wheel selection method is used. In this method, the probability of selecting a chromosome i (P_i) is proportional to the fitness of that chromosome (F_i) which can be expressed as follows:

$$P_i = \frac{F_i}{\sum_{i=1}^{n_p} F_i} \quad (1)$$

Which n_p is population size, and in this study the size of the population is 100. The fitness level of each chromosome is determined further. On the Roulettle wheel, each section that has more area, has a greater chance to choose.

3. Algorithm of particle swarm optimization (PSO)

Like all other evolutionary algorithms, the PSO optimization algorithm also begins by creating a random population of solutions, which is herein referred to as a group of particles. The specification of each particle in a group is determined by a set of parameters whose optimal values should be determined. In this method, each particle represents a point of the issue space. Each of the particles has memory, which remembers the best position in the search space. Therefore, the motion of each particle occurs in two directions:

1-To the best position that the particle has been chosen so far.

2- To the best position that all particles have taken.

In this way, changing the position of each particle in the search space is influenced by the experience and knowledge of itself and its neighbors. Suppose that in a particular problem that, D-dimensional space, and the i particle of the group can be represented by a vector of velocity and a position vector. Changing the position of each particle is possible by changing the structure of the position and the previous velocity. Each particle contains information that includes the best value so far(Personal best) and has the position of $X^i_{j,t}$. This information is the result of a comparison of the efforts that each particle makes to find the best answer. Each particle also finds the best answer so far received in the whole group, comparing the optimal values of different particles(Global best).

Each particle tries to change its position using the following information to achieve the best answer:

Current Location ($X^i_{j,t}$)

Current Velocity ($V^i_{j,t}$)

The distance between the current and the optimal Personal situation (Xpbestij)

The distance between the current position and the Global optimal (Xgbestj)

Thus, the velocity of each particle and, consequently, its new position change as follows:

$$V^{i}_{j,\,t+1} = w \times V^{i}_{j,\,t} + c_1 \times r_1 \times \left(Xpbest^{i}_{j} - X^{i}_{j,\,t}\right) + c_2 \times r_2 \times \left(Xgbest_{j} - X^{i}_{j,\,t}\right) \quad (2)$$

$$X^{i}_{j,\,t+1} = X^{i}_{j,\,t} + V^{i}_{j,\,t+1} \quad (3)$$

In this case ,$V^{i}_{j,t+1}$, $V^{i}_{j,t}$, $X^{i}_{j,t}$, $X^{i}_{j,t+1}$, $Xpbest^{i}_{j}$, $Xgbest_{j}$, are respectively the variation velocity of the j-th decision of the i-th particle in the new repetition, the velocity of the j-th decision of the i-th particle in the current repetition, the variable value of the j-th decision, the i-th particle in the new repetition, the best value of the j-th decision variable of i-th particle it has chosen and the best value of the j-th decision variable of the best particle (the best position ever taken by all the particles). Figure (1) shows the motion of a particle and updates its velocity.

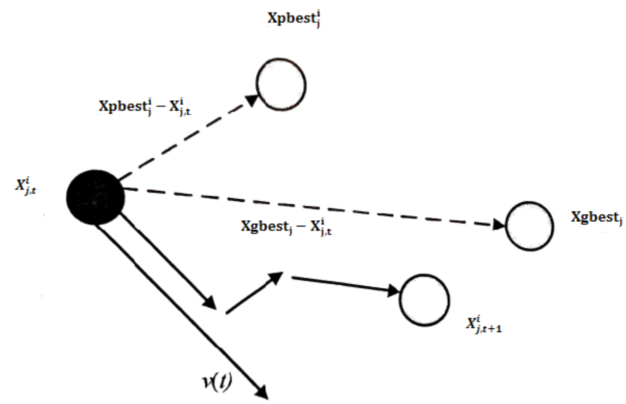

Fig. 1. Move a particle and update the Velocity.

r_1 and r_2 are random numbers between zero and one that are used to preserve diversity and variety of the group.

c_1, c_2 are cognitive and social parameters, respectively. Choosing the appropriate value for these parameters will accelerate the convergence of the algorithm and prevent early convergence in local optimizations.

The parameter w is the weighted inertia used to ensure convergence in PSO. Weighted inertia is used to control the effect of previous Velocity records on current Velocities. In this study, according to the studies, the values of the parameters c_1, c_2 and w are considered to be 2, 2, 1, respectively.

4. Formation of optimization model

4.1. The objective function

In an optimization problem, design variables are obtained in such a way that, while satisfying all design constraints, the objective function has the lowest possible value. The objective function in this paper is the weight of the truss structure and is defined as follows:

$$W = \sum_{j=1}^{J} \rho \times L_j \times A_j \tag{4}$$

Where j is the number of members of the truss, ρ the density of the members of the trusses, L_j the length of the member of j-th of truss and the A_j is the cross section of the j-th member of the truss.

4.2. Terms and constraints of truss structures design

4.2.1. Criteria and constraints related to axial stresses of truss members

Because the structure is truss so, only the force in the structure is axial force. As a result, the Axial stress must be less than the permitted stress and:

$$f_a \le F_a \tag{5}$$

In which the f_a is existing stress (force on the cross-section of the element) and the F_a is permitted axial stresses.

4.2.2. Criteria and constraints related to displacement truss nodes

In truss structures, the displacement of truss nodes is important, which is usually limited. can be stated as:

$$u_x \le U_x \tag{6}$$

$$u_y \le U_y \tag{7}$$

Where u_x, u_y, U_x and U_y are respectively the existing displacement of i-th node in the x direction, the existing displacement of i-th node in the y direction, allowed displacement of i-th node in the x direction, and allowed displacement of the i-th node in the y direction.

4.3. Penalty function

The calculation of the genetic algorithm and the particle swarm algorithm are set for unbound functions. Therefore, in order to apply this method, the objective function of the target function set and the governing constraints must be converted to an equivalent free function. The most common method for forming an equivalent free function is the penalty function. In this paper, the definition of the penalty function is as follows:

$$\text{Penalty} = \lambda \times \sum_{k=1}^{K} V_k \tag{8}$$

In these relations, λ, the coefficient of the penalty function, V_k indicates the degree of violation of the constraint of k-th and k represents the number of constraints of the optimization model.

4.4. Penalized objective function

To penalty-tune the objective function, the method of sum has been used. This method is such that the target function is combined with the penalty function of the violation of the constraint and if the violation function is zero (that is, all constraints are satisfied), the result is acceptable and otherwise the result is not acceptable. Given the above, the value of the penalized objective function, according to the following equation:

$$W_p = W + \text{Penalty} \quad (9)$$

4.5. Fitness function

In the literature of the genetic algorithm they use a function called fitness, which acts in the minimization problem unlike the objective function. In this study, the fitness function for each chromosome of a population is determined according to the following exponential relation:

$$F = \exp\left(-\frac{W_P}{W_{P-\max}}\right) \quad (10)$$

In the above relation, $W_{P\text{-}max}$ is the maximum value of the objective function of the fined chromosomes of the current generation.

5. Convergence condition

In this paper, the condition for convergence is the passage of a certain number of repetitions in the Particle Swarm Optimization and Genetic Algorithm. If this number is reached, the best answer of this repetition is given as an optimal response. Determining the number of repetitions to terminate the optional algorithm can only be determined based on the experience of the program implementation.

6. Design examples

In order to verify the validity of the results and demonstrate the effectiveness of the proposed algorithms, several examples of scientific papers have been evaluated. In this study, OpenSees software [27] was used to analyze the structure and obtain the forces of members and displacement of the nodes, and the code for optimizing the genetic algorithm and the particle swarm algorithm was written in the Matlab software [28] programming environment.

6.1. Six-node two dimensional truss (10 members)

In the first example, the Six-node two dimensional truss was evaluated. Figure (2) shows the geometric properties, loading, and support conditions for this truss. The materials used in this truss have an elastic modulus(E) of 10000000 lb/in^2 and density(ρ) of 0/1 lb/in^3. Maximum allowed stress (F_{all}) ±25000 lb/in^2, Maximum allowed node displacement (U_{max}) in both vertical and horizontal directions is ±2 in.

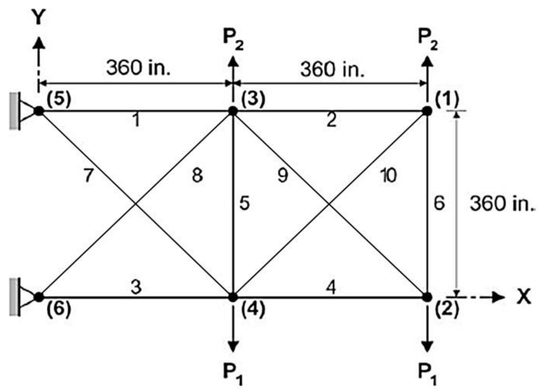

Fig. 2. Six-node two dimensional truss.

This truss is divided into three different sizes in discrete or continuous size and loaded as follows:

1- Mode 1

Loads of p_1 and p_2 are 100000 and zero and the sections used to design this truss from the set of section lists (A) selected as follows:

A={1.62, 1.80, 1.99, 2.13, 2.38, 2.62, 2.63, 2.88, 2.93, 3.09, 3.13, 3.38, 4.47, 3.55, 3.63, 3.84, 3.87, 3.88, 4.18, 4.22, 4.49, 4.59, 4.80, 4.97, 5.12, 5.74, 7.22, 7.97, 11.50, 13.50, 13.90, 14.20, 15.50, 16.00, 16.90, 18.80, 19.90, 22.00, 22.90, 26.50, 30, 33.50} (in^2)

Table 1
Comparison of optimal Six-node two dimensional Truss-Mode 1.

Design variables (in^2)	Rajeev et al. [7]	Coello et al. [31]	Camp et al. **[9]**	Nana korn et al. [30]	Li et al. **[11]**	Li et al. [11]	Li et al. [11]	Kazemzadeh Azad et al. [29]	This study	
	Mathematical algorithm	Mathematical algorithm	Mathematical algorithm	Mathematical algorithm	PSO	PSOPC	HPSO	GSS	GA	PSO
A_1	33.5	30	30	33.5	30	30	30	30	33.5	33.5
A_2	1.62	1.62	1.62	1.62	1.62	1.8	1.62	1.62	1.62	1.62
A_3	22	22.9	26.5	22.9	30	26.5	22.9	22.9	22.9	22.9
A_4	15.5	13.5	13.5	15.5	13.5	15.5	13.5	13.9	14.2	15.5
A_5	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62
A_6	1.62	1.62	1.62	1.62	1.8	1.62	1.62	1.62	1.62	1.62
A_7	14.2	13.9	7.22	7.22	11.5	11.5	7.97	11.5	7.97	7.22
A_8	19.9	22	22.9	22.9	18.8	18.8	26.5	22.9	22.9	22.9
A_9	19.9	22	22	22	22	22	22	22	22	22
A_{10}	2.62	1.62	1.62	1.62	1.8	3.09	1.8	1.62	1.62	1.62
Weight (lb)	5613.84	5586.59	5556.9	5499.3	5581.76	5593.44	5531.98	5533.66	5490.74	5499.3

In Table 1, a summary of the best designs presented so far is presented with the results of this research. As shown in Table 1, the amount of weight obtained from the genetic algorithm is much less than the particle swarm algorithm and other algorithms used by other researchers. In addition, the path of the convergence of the genetic algorithm and the particle swarm algorithm for the Six-node two dimensional truss-mode 1 are shown in Figures (3) and (4).

In these forms, the structure weight reduction process with the Number of Function Evaluation (NFE) is observed during the execution of the algorithm.

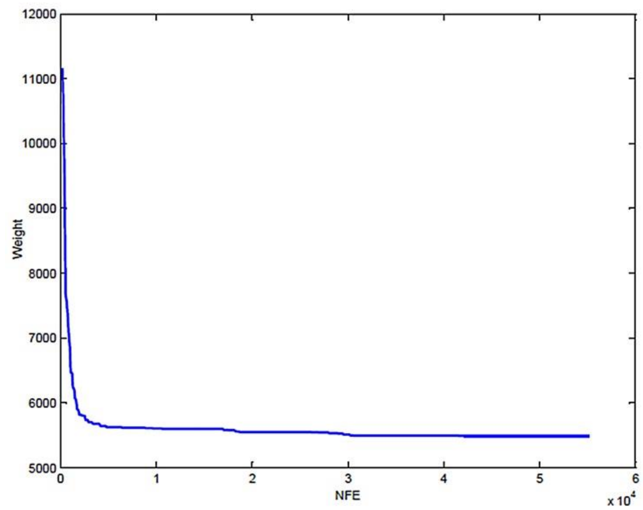

Fig. 3. Convergence pattern of the Genetic Algorithm for Six-Node two dimensional truss-Mode 1.

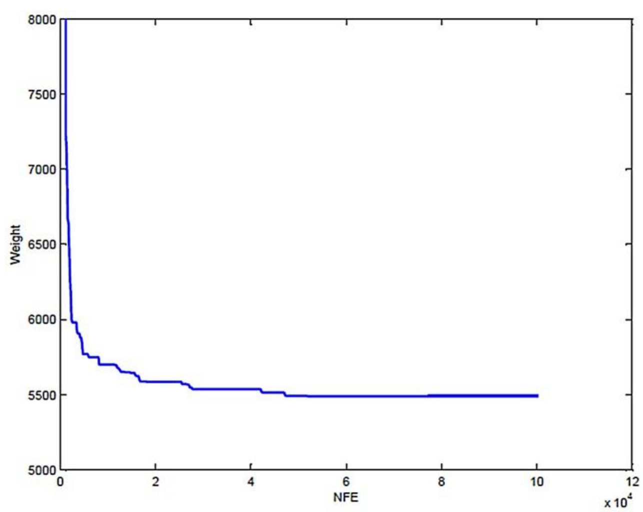

Fig. 4. Convergence pattern of the particle swarm algorithm for Six-node two dimensional truss-Mode 1.

2- Mode 2

Loads of p_1 and p_2 are 100000 (lb) and zero and The members of the structure are selected from the interval of the series (A) as follows:

$0.1 \leq A \leq 35$ (in^2)

In Table 2, a summary of the best designs presented so far is presented with the results of this research.

As shown in Table 2, the amount of weight obtained from the particle swarm algorithm is far less than the genetic algorithm and other algorithms used by other researchers.

In addition, the path of the convergence of the genetic algorithm and the particle swarm algorithm for the six-node two dimensional truss mode- 2 are shown in Figures (5) and (6). In these forms, the structure weight reduction process is observed with the Number of Function Evaluation.

Table 2
Comparison of optimal Six-node two dimensional truss-Mode 2.

Design variables (in^2)	Koohestani and Kazemzadeh Azad[37]	Li et al. [36]	Hadidi et al. [35]	Hadidi et al. [35]	Kaveh and Rahami [34]	Kaveh& Kalatjari [33]	Kaveh& Malakouti rad [13]	Eskandar et al. [32]	This study	
	ARCGA	HPSO	ABC	MABC	FMGA	FMGA	HGAPSO	WCA	GA	PSO
A_1	30.5984	30.704	34.3057	30.6573	30.67	29.50	30.63	30.53	30.3653	30.598
A_2	0.1002	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.100066	0.1
A_3	23.1714	23.167	20.6728	23.0429	22.87	23.50	23.06	23.05	23.3523	23.171
A_4	15.1958	15.183	14.5074	15.2821	15.34	15.50	15.01	15.03	15.075	15.1958
A_5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.100009	0.1
A_6	0.5409	0.551	0.6609	0.5626	0.46	0.5	0.59	0.56	0.560738	0.54084
A_7	7.4625	7.46	7.8696	7.4721	7.48	7.50	7.49	7.48	7.44587	7.46250
A_8	21.0346	20.978	20.3461	21.0084	20.96	21.50	21.10	21.12	21.0846	21.0346
A_9	21.5182	21.508	22.0232	21.5094	21.70	21.50	21.56	21.63	21.5954	21.5182
A_{10}	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Weight (lb)	5060.90	5060.92	5095.33	5060.97	5061.90	5067.30	5061.40	5061.02	5061.0067	5060.86

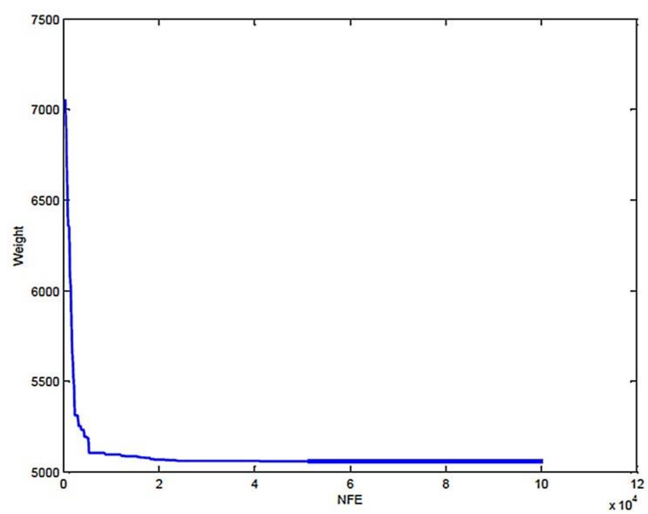

Fig. 5. Convergence pattern of the Genetic Algorithm for the Six- node two dimensional Truss-Mode 2.

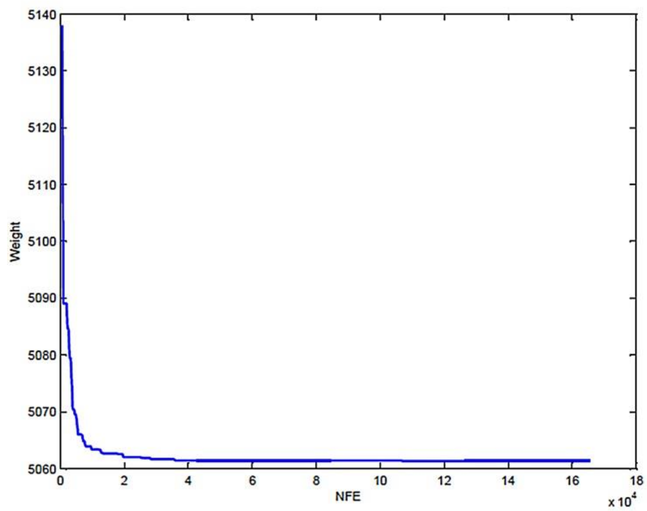

Fig. 6. Convergence pattern of the particle swarm algorithm for the Six-node two dimensional Truss-Mode 2.

3- Mode 3

Loads of p_1 and p_2 are 150000 (lb) and 50000 (lb) and the members of the structure are selected from the interval of the series (A) as follows:

$0.1 \leq A \leq 35$ (in^2)

In Table 3, a summary of the best projects presented so far is presented along with the results of this research. As shown in Table 3, the amount of weight obtained from the particle swarm algorithm is far less than the genetic algorithm and other algorithms used by other researchers. In addition, the path of the convergence of the genetic algorithm and the particle swarm algorithm for the six- two dimensional truss-mode 3 are shown in Figures (7) and (8). In these forms, the structure weight loss process is observed with the Number of Function Evaluation.

Table 3
Comparison of optimal Six-node two dimensional truss-Mode 3.

Design variables (in^2)	Khan et al. [38]	Li et al. [36]	Koohestani and Kazemzadeh Azad [37]	Hadidi et al. [35]	Hadidi et al.[35]	This study	
	Mathematical algorithm	HPSO	ARCGA	ABC	MABC	GA	PSO
A_1	24.72	23.353	23.5986	24.8143	23.6383	23.8709	23.6383
A_2	0.1	0.1	0.1009	0.1	0.1	0.1	0.1
A_3	26.54	25.502	25.1175	26.0480	26.3237	25.0552	25.3230
A_4	13.22	14.25	14.5383	14.8772	14.4108	14.6923	14.41
A_5	0.108	0.1	0.1001	0.1	0.1001	0.100008	0.1
A_6	4.835	1.972	1.9713	2.0055	1.9707	1.96982	1.970
A_7	12.66	12.363	12.3923	12.4467	12.3781	12.443	12.3780
A_8	13.78	12.894	12.7439	12.6835	12.7739	12.78170	12.7738
A_9	18.44	20.356	20.3697	18.8669	20.2678	20.0339	20.2678
A_{10}	0.1	0.101	0.1	0.1	0.1	0.1	0.1
Weight (lb)	4792.52	4677.29	4677.24	4691.07	4677.06	4677.655	4676.96

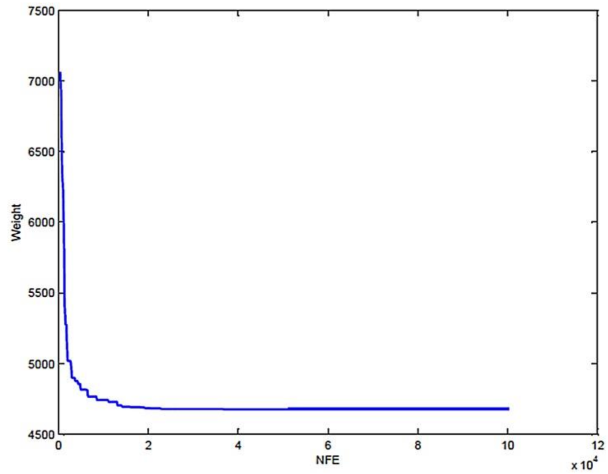

Fig. 7. Convergence pattern of the Genetic Algorithm for the Six-node two dimensional truss-Mode 3.

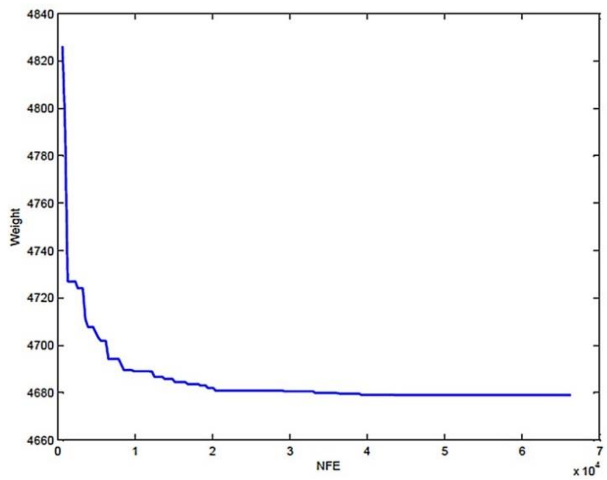

Fig. 8. Convergence pattern of particle swarm algorithm for Six-node two dimensional truss-Mode 3.

6.2. Eight-node two dimensional truss (15 members)

In the second example, the Eight-node two dimensional truss is evaluated. Figure (9) shows the geometric properties, loading, and support conditions for this truss. The materials used in this truss have an elastic modulus(E) of 200 GPa and density(ρ) 7800 kg/m^3. Maximum allowed stress (F_{all}) ±120 MPa, Maximum allowed node displacement(U_{max}) in both vertical and horizontal directions ±10mm and load P is 35 KN.

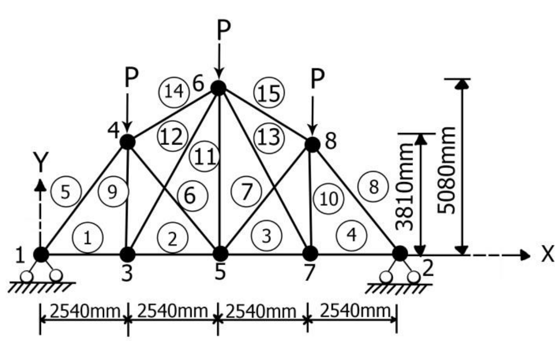

Fig. 9. Eight-node two dimensional truss.

For the design of the eight-node two dimensional truss, members of the structure are selected from the set of section lists (A) as follows:

A={113.2, 143.2, 145.9, 174.9, 185.9, 235.9, 265.9, 297.1, 308.6, 334.3, 338.2, 497.8, 507.6, 736.7, 791.2, 1063.7} (mm^2)

In Table 4, a summary of the best designs presented so far is presented with the results of this research. As shown in Table 4, the amount of weight obtained from the genetic algorithm is much lower than the particle swarm algorithm and other algorithms used by other researchers. In addition, the path of the convergence of the genetic algorithm and the particle swarm algorithm are shown for the eight-node two dimensional truss in forms (10) and (11). In these forms, the structure weight loss process is observed with the Number of Function Evaluation.

Table 4
Comparison of optimal results of Eight-node two dimensional truss.

Design variables (mm^2)	HGA[41]	Li et al. [11]	Li et al. [11]	Li et al. [11] Sabour et al. [39] Sadollah et al. [40] Eskandar et al. [32]	This study	
	Mathematical algorithm	PSO	PSOPC	HPSO ICA ICACO MBA WCA	GA	PSO
A_1	308.6	185.9	113.2	113.2	113.2	185.9
A_2	174.9	113.2	113.2	113.2	113.2	113.2
A_3	338.2	143.2	113.2	113.2	113.2	143.2
A_4	143.2	113.2	113.2	113.2	113.2	113.2
A_5	736.7	736.7	736.7	736.7	736.7	736.7
A_6	185.9	143.2	113.2	113.2	113.2	143.2
A_7	265.9	113.2	113.2	113.2	113.2	113.2
A_8	507.6	736.7	736.7	736.7	736.7	736.7
A_9	143.2	113.2	113.2	113.2	113.2	113.2
A_{10}	507.6	113.2	113.2	113.2	113.2	113.2
A_{11}	297.1	113.2	113.2	113.2	113.2	113.2
A_{12}	174.9	113.2	113.2	113.2	113.2	113.2
A_{13}	297.1	113.2	185.9	113.2	113.2	113.2
A_{14}	235.9	334.3	334.3	334.3	113.2	334.3
A_{15}	265.9	334.3	334.3	334.3	113.2	334.3
Weight (kg)	142.117	108.84	108.96	105.735	95.9401	108.84

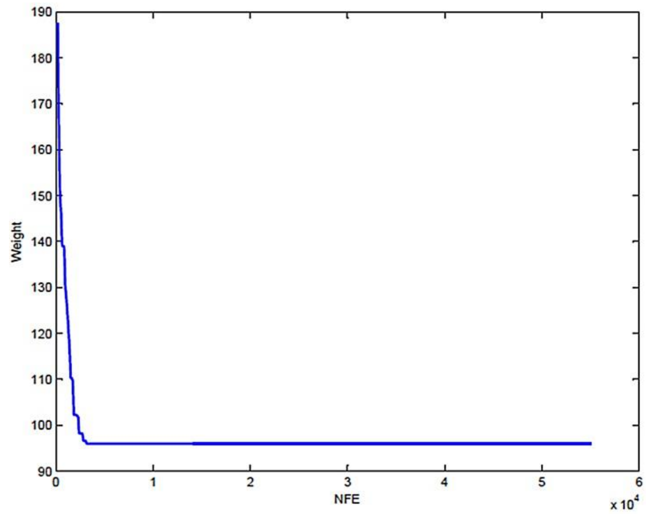

Fig. 10. Convergence pattern of the Genetic Algorithm for the Eight-node two dimensional truss.

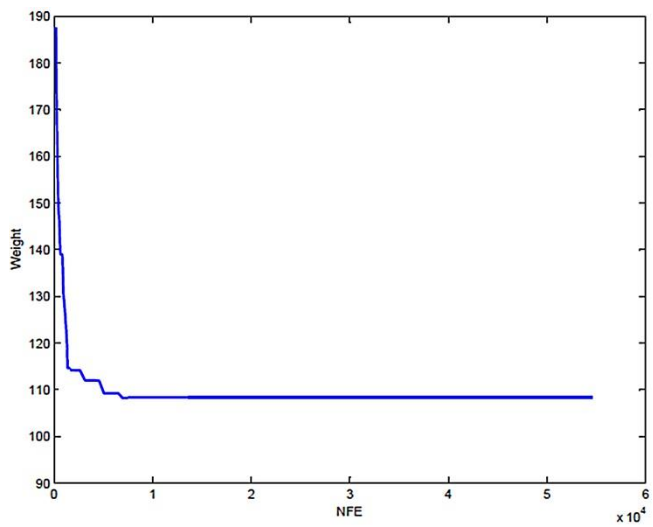

Fig. 11. Convergence pattern of the particle swarm algorithm for the Eight-node two dimensional truss.

6.3. Nine-node two dimensional truss (17 members)

In the third example, the Nine-node two dimensional truss has been evaluated. Figure (12) shows the geometric features, loading, and supporting conditions for this truss. The materials used in this truss have an elastic modulus(E) of 30000000 lb/in^2 and density(ρ) 0.268 lb/in^3. Maximum allowed stress (F_{all}) ±50000 lb/in^2, maximum allowed node displacement (U_{max}) in both vertical and horizontal directions ±2 in and load P is 100000 lb.

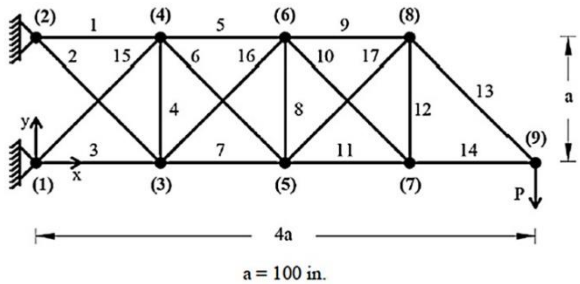

Fig. 12. Nine-node two-dimensional truss.

For the design of the nine-node two dimensional truss, members of the structure are selected from the set of section lists (A) as follows:

$0.1 \leq A\ (in^2)$

In Table 5, a summary of the best designs presented so far is presented with the results of this research. As shown in Table 5, the amount of weight obtained from the particle swarm algorithm is far less than the genetic algorithm and other algorithms used by other researchers. In addition, the path of the convergence of the genetic algorithm and the particle swarm algorithm for nine nodes two dimensional truss are shown in forms (13) and (14). In these forms, the structure weight loss process is observed with the Number of Function Evaluation.

Table 5
Comparison of Optimal Nine-node two-dimensional Trusses.

Design variables (in^2)	Koohestani and Kazemzadeh Azad [37]	Hadidi et al.[35]	Hadidi et al. [35]	Kazemzadeh Azad and Hasancebi[24]	This study	
	ARCGA	ABC	MABC	ESASS	GA	PSO
A_1	15.891	12.9587	15.6762	15.9324	16	15.93
A_2	0.105	0.1	0.1	0.1	0.1	0.1
A_3	12.101	11.5965	12.0491	12.0193	12.299	12.070
A_4	0.1	0.1	0.1	0.1	0.1	0.1
A_5	8.075	6.3320	8.1312	8.1001	8	8.066
A_6	5.541	6.5356	5.62020	5.53	5.52090	5.562
A_7	11.97	12.4792	11.8822	11.9209	11.903	11.933
A_8	0.1	0.1	0.1	0.1	0.1	0.1
A_9	7.955	9.0901	8.0517	8.0128	7.91538	7.945
A_{10}	0.1	0.1	0.1	0.1	0.1	0.1
A_{11}	4.07	5.1578	4.0912	4.0715	4.0522	4.0545
A_{12}	0.1	0.1	0.1	0.1	0.1	0.1
A_{13}	5.705	6.4197	5.6746	5.6726	5.66065	5.657
A_{14}	3.975	4.0553	3.9864	4.0154	3.96854	4
A_{15}	5.516	5.7984	5.6792	5.5286	5.56092	5.558
A_{16}	0.1	0.1	0.1	0.1	0.1	0.1
A_{17}	5.563	6.8470	5.4907	5.5739	5.51966	5.579
Weight(lb)	2581.95	2642.45	2582.27	2581.93	2582.0672	2581.88

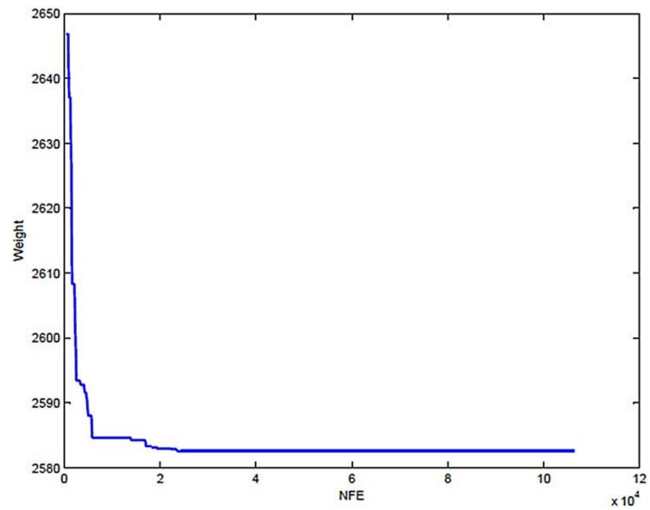

Fig. 13. Convergence pattern of the Genetic Algorithm for the Nine-node two dimensional truss.

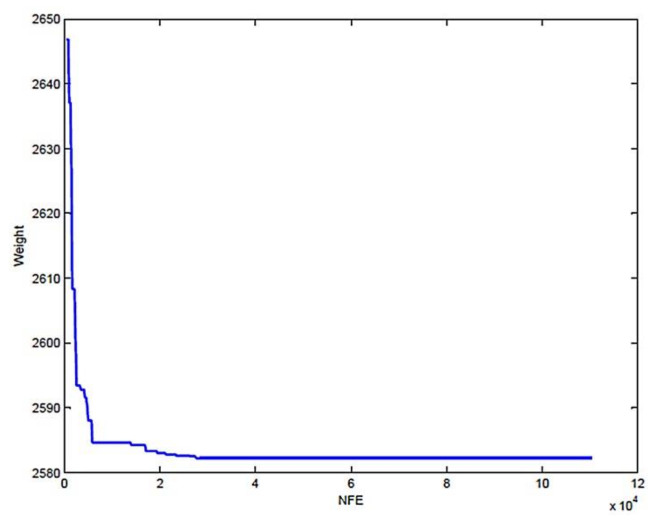

Fig. 14. Convergence pattern of the particle swarm algorithm for the Nine-node two dimensional truss.

6.4. Twenty-node two dimensional truss (45 members)

In the last example, the Twenty-node two dimensional truss was evaluated. Figure (15) shows the geometric properties, loading, and support conditions of this truss. The materials used in this truss have an elastic modulus (E) of 30000000 lb/in^2 and density (ρ) 0.283 lb/in^3. Maximum allowed stress (Fall) ±30000 lb/in^2, Maximum allowed node displacement (U_{max}) in both vertical and horizontal directions ±2 in and load P is 100000 lb.

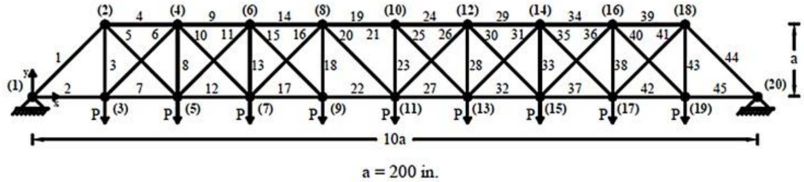

Fig. 15. Twenty-node two dimensional truss.

For the design of the twenty-node two dimensional truss, members of the structure are selected from the set of section lists (A) as follows:

$0.1 \leq A$ (in^2)

In Table 6, a summary of the best designs presented so far is presented with the results of this research. As shown in Table 6, the amount of weight obtained from the particle swarm algorithm is far less than the genetic algorithm and other algorithms used by other researchers. In addition, the path of the convergence of the genetic algorithm and the particle swarm algorithm for the twenty node two dimensional truss are displayed in shapes (16) and (17). In these forms, the structure weight reduction process is observed with the Number of Function Evaluation.

Table 6
Comparison of optimal results of Twenty nodes two dimensional truss.

Design variables	members (in^2)	Hadidi et al. [35]	Hadidi et al. [35]	Kazemzadeh Azad and Hasancebi [24]	This study	
		ABC	MABC	ESASS	GA	PSO
A_1	1,44	5.4746	4.5996	4.6052	4.6996	4.605
A_2	2,45	4.5989	3.7966	3.7083	3.80	3.7082
A_3	3,43	4.1703	3.0497	3.1919	3.05	3.1919
A_4	4,39	3.7872	3.2841	3.2756	3.28	3.27558
A_5	5,41	0.1	0.1069	0.1	0.104	0.1
A_6	6,40	4.1735	3.9279	3.9896	3.93	3.9896
A_7	7,42	0.9497	0.9649	0.8916	0.96	0.8916
A_8	8,38	1.5902	1.2133	1.2170	1.21	1.2170
A_9	9,34	6.2656	7.6553	7.7323	7.65	7.7323
A_{10}	10,36	2.2039	2.1993	2.2227	2.198	2.2227
A_{11}	11,35	1.3925	1.1929	1.1803	1.19	1.1803
A_{12}	12,37	0.1	0.1001	0.1	0.1	0.1
A_{13}	13,33	0.1	0.1008	0.1	0.1	0.1
A_{14}	14,29	9.0689	9.5360	9.3901	9.50	9.3901
A_{15}	15,31	1.5310	1.2173	1.2149	1.21	1.214895
A_{16}	16,30	1.6245	1.4190	1.3322	1.41	1.332196
A_{17}	17,32	2.9146	2.5513	2.6056	2.55	2.605595
A_{18}	18,28	0.1	0.1	0.1	0.1	0.1
A_{19}	19,24	9.0685	11.5439	11.6266	11.50	11.62655
A_{20}	20,26	1.6352	1.2807	1.2406	1.28	1.240596
A_{21}	21,25	0.1	0.101	0.1	0.1	0.1
A_{22}	22,27	4.4798	3.7598	3.7923	3.75	3.792295
A_{23}	23	0.1	0.1017	0.1	0.1	0.1
Weight(lb)		8267.21	7968.95	7967.98	7969.20	7967.89

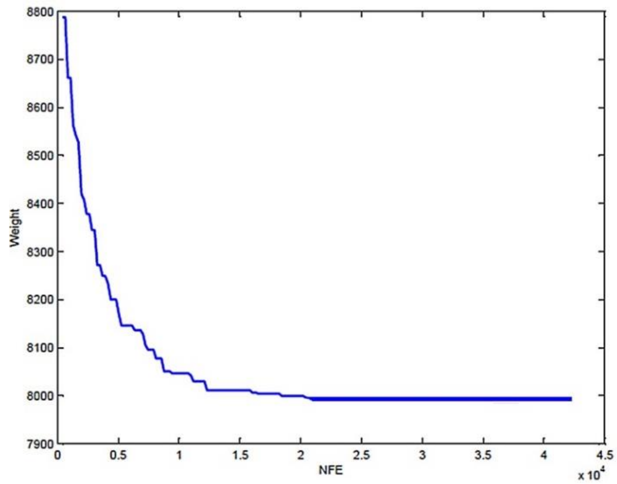

Fig. 16. Convergence pattern of the Genetic Algorithm for a Twenty-node two dimensional truss.

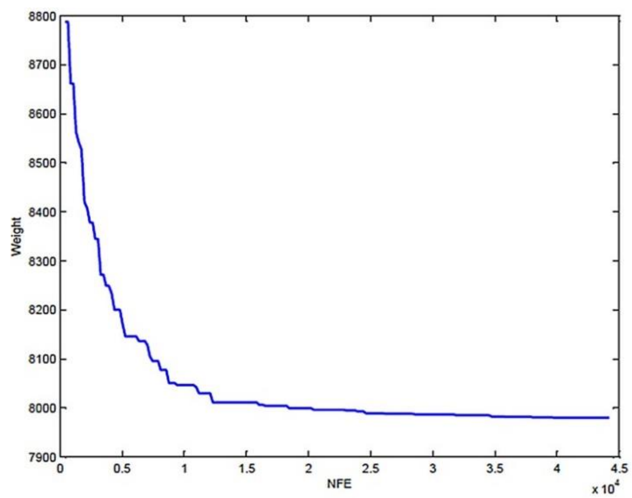

Fig. 17. Convergence pattern of the particle swarm algorithm for Twenty-node two dimensional truss.

7. Conclusion

In this study, the discrete and continuous size optimization of two-dimensional trust was investigated using genetic algorithm and particle swarm algorithm. To illustrate the effectiveness of these two algorithms, the results were compared with the design results of other researchers. In this study, four types of two-dimensional truss (Six-node, Eight-node, Nine nodes and Twenty nodes) were investigated under varying degrees of discrete or continuous size and loading, and the results obtained in this study are presented as follows:

1-The solved examples show that the genetic algorithm and the particle swarm algorithm have the potential and the ability to solve the optimized optimization problems and also have good convergence velocity.

2-Comparison results show that in discrete sizes, the designs derived from the genetic algorithm are far more economical than other designs, and vice versa in continuous measurements, the designs derived from the particle swarm algorithm are far more economical than other designs.

3-Comparison of weight loss diagrams in terms of number of simulations (NFE) shows that the convergence of the genetic algorithm to the optimum solution of the particle swarm algorithm is faster.

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