9	57, 58, 59, 60, 61, 62	24	171, 172, 173, 174, 175, 176
10	64, 67, 70, 73, 76	25	178, 181, 184, 187, 190
11	44, 45, 47, 48, 50, 51, 53, 54, 65, 66, 68, 69, 71, 72, 74, 75	26	158, 159, 161, 162, 164, 165, 167, 168, 179, 180, 182, 183, 185, 186, 188, 189
12	77, 78, 79, 80	27	191, 192, 193, 194
13	81, 84, 87, 90, 93	28	195, 17, 198, 200
14	95, 96, 97, 98, 99, 100	29	196, 199
15	102, 105, 108, 111, 114		

4 Conclusions

According to the results of the proposed method integrated with analyses of truss structures, the proposal is a comparative method according to the other documented methods. Comparing to the other methods using metaheuristic algorithms, the method is effective in the computational effort.

For example, the total optimization period is only 2.69 s for the proposed method. At the same computer system, a structural analysis in metaheuristic based methods is 0.1512 s long. In that case, the FPA based method [21] is effective to find the similar optimum value in 1232.13 s. Similarly, the optimum result of the second example is found in 11.64 s while FPA [21] is effective to find an optimum value in 1067.23 s by using the same equipment. It must be noted that the other methods need more analyses than the FPA based method.

For the last example, the duration of the optimization is 550.99 s which is significantly more than the other examples for the proposed method. Since the problem is big, the duration of an analysis (0.2138 s) is nearly two times of the second example. In that case, the FPA based method [21] is effective to find the optimum value in 2284.453 s. For this example, several methods may be effective in reduction of optimum weight, but minor constraint violations may occur in the metaheuristic algorithm based methods.

As a conclusion, the proposed strategy for the optimum sizing of truss structures is a quick and effective tool. By using this rapid method, it will be possible to find better member grouping options than the proposed ones in the documented methods. In that case, economical and practical solutions can be found. This issue will be considered in the future studies.

TABLE VIII. THE OPTIMUM RESULTS OF THE 200-BAR STRUCTURE

Element group	HS [13]	GA [4]	SA [9]	HPSACO [23]	HS [12]	TLBO [15]	CSP [18]	HPSO [17]	TLBO [16]	FPA [21]	Present study
1	0.1253	0.3469	0.1468	0.1033	0.1540	0.1460	0.1480	0.1213	0.1135	0.1425	0.1069
2	1.0157	1.0810	0.9400	0.9184	0.9410	0.9410	0.9460	0.9426	0.9484	0.9637	0.9154
3	0.1069	0.1000	0.1000	0.1202	0.1000	0.1000	0.1010	0.1220	0.1078	0.1005	0.2094
4	0.1096	0.1000	0.1000	0.1009	0.1000	0.1010	0.1010	0.1000	0.1000	0.1000	0.1000
5	1.9369	2.1421	1.9400	1.8664	1.9420	1.9410	1.9461	2.0143	1.9345	1.9514	1.9154
6	0.2686	0.3470	0.2962	0.2826	0.3010	0.2960	0.2979	0.2800	0.2889	0.2957	0.3175
7	0.1042	0.1000	0.1000	0.1000	0.1000	0.1000	0.1010	0.1589	0.2116	0.1156	0.1006
8	2.9731	3.5650	3.1042	2.9683	3.1080	3.1210	3.1072	3.0666	3.0903	3.1133	3.1105
9	0.1309	0.3470	0.1000	0.1000	0.1000	0.1000	0.1010	0.1002	0.1031	0.1006	0.1007
10	4.1831	4.8050	4.1042	3.9456	4.1060	4.1730	4.1062	4.0418	4.0903	4.1100	4.1138
11	0.3967	0.4400	0.4034	0.3742	0.4090	0.4010	0.4049	0.4142	0.4502	0.4165	0.4102

12	0.4416	0.4400	0.1912	0.4501	0.1910	0.1810	0.1944	0.4852	0.1007	0.1843	0.1571
13	5.1873	5.9520	5.4284	4.9603	5.4280	5.4230	5.4299	5.4196	5.4798	5.4567	5.4243
14	0.1912	0.3470	0.1000	1.0738	0.1000	0.1000	0.1010	0.1000	0.1011	0.1000	0.1000
15	6.2410	6.5720	6.4284	5.9785	6.4270	6.4220	6.4299	6.3749	6.4798	6.4559	6.4332
16	0.6994	0.9540	0.5734	0.7863	0.5810	0.5710	0.5755	0.6813	0.5329	0.5800	0.5759
17	0.1158	0.3470	0.1327	0.7374	0.1510	0.1560	0.1349	0.1576	0.1325	0.1547	0.2940
18	7.7643	8.5250	7.9717	7.3809	7.9730	7.9580	7.9747	8.1447	7.9445	8.0132	7.9988
19	0.1000	0.1000	0.1000	0.6674	0.1000	0.1000	0.1010	0.1000	0.1005	0.1000	0.1000
20	8.8279	9.3000	8.9717	8.3000	8.9740	8.9580	8.9747	9.0920	8.9444	9.0135	9.0063
21	0.6986	0.9540	0.7049	1.1967	0.7190	0.7200	0.7065	0.7462	0.7011	0.7391	0.8194
22	1.5563	1.7639	0.4196	1.0000	0.4220	0.4780	0.4225	0.2114	1.3777	0.7870	0.4748
23	10.9806	13.3006	10.8636	10.8262	10.8920	10.8970	10.8685	10.9587	11.2394	11.1795	11.1442
24	0.1317	0.3470	0.1000	0.1000	0.1000	0.1000	0.1010	0.1000	0.2287	0.1462	0.1279
25	12.1492	13.3006	11.8606	11.6976	11.8870	11.8970	11.8684	11.9832	12.2394	12.1799	12.1455
26	1.6373	2.1421	1.0339	1.3880	1.0400	1.0800	1.0360	0.9241	1.6849	1.3424	1.1763
27	5.0032	4.8050	6.6818	4.9523	6.6460	6.4620	6.6859	6.7676	4.9136	5.4844	5.9177
28	9.3545	9.3000	10.8113	8.8000	10.8040	10.7990	10.8111	10.9639	9.7190	10.1372	10.3697
29	15.0919	17.1740	13.8404	14.6645	13.8700	13.9220	13.8465	13.8186	15.0219	14.5262	14.2756
Best Weight (lb)	25447.1	28544.0	25445.6	25156.5	25491.9	25488.2	25467.9	25698.9	25664.0	25521.8	25542.98
Number of structural analyses	48000	-	9650	9875	19670	28059	31700	14406	-	10685	Duration 550.99 s

References:

[1] H. Adeli, O. Kamal, Efficient optimization of space trusses, Computers and Structures 24(3) (1986) 501–11.

[2] G. Cao, Optimized design of framed structures using a genetic algorithm, PhD thesis, The University of Memphis, 1996.

[3] F. Erbatur, O. Hasançebi, I. Tütüncü, H. Kiliç, Optimal design of planar and space structures with genetic algorithms, Computers and Structures 75 (2000) 209–24.

[4] V. Togan, A.T. Daloglu, An improved genetic algorithm with initial population strategy and self-adaptive member grouping, Computers and Structures 86 (2008) 1204–1218.

[5] C.V. Camp, B.J. Bichon, Design of space trusses using ant colony optimization, Journal of Structural Engineering 130(5) (2004) 741-751.

[6] C.V. Camp, Design of space trusses using big bang–big crunch optimization, Journal of Structural Engineering 133(7) (2007) 999–1008.

[7] L.J. Li, Z.B. Huang, F. Liu, Q.H. Wu, A heuristic particle swarm optimizer for optimization of pin connected structures, Computers and Structures 85(7–8) (2007) 340–9.

[8] R.E. Perez, K. Behdinan, Particle swarm approach for structural design optimization, Computers and Structures 85 (2007) 1579–88.

[9] L. Lamberti, An efficient simulated annealing algorithm for design optimization of truss structures, Computers and Structures 86 (2008) 1936–53.

[10] A. Kaveh, S. Talatahari, Size optimization of space trusses using big bang–big crunch algorithm, Computers and Structures 87(17–18) (2009) 1129–40.

[11] M. Sonmez, Artificial bee colony algorithm for optimization of truss structures, Applied Soft Computing 11(2) (2011) 2406–18.

[12] S.O. Degertekin, Improved harmony search algorithms for sizing optimization of truss structures, Computers and Structures 92–93 (2012) 229–41.

[13] K.S. Lee, Z.W. Geem, A new structural optimization method based on the harmony search algorithm, Computers and Structures 82 (2004) 781-98.

[14] C.V. Camp, M. Farshchin, Design of space trusses using modified teaching–learning based optimization, Engineering Structures 62–63 (2014) 87–97.

[15] S.O. Degertekin, M.S. Hayalioğlu, Sizing truss structures using teaching-learning-based optimization, Computers and Structures 119 (2013) 177–188.

[16] T. Dede, Y. Ayvaz, Combined size and shape optimization of structures with a new meta-heuristic algorithm, Applied Soft Computing 28 (2015) 250–258.

[17] A. Kaveh, T. Bakhshpoori, E. Afshari, An efficient hybrid Particle Swarm and Swallow Swarm Optimization algorithm, Computers and Structures 143 (2014) 40-59.

[18] A. Kaveh, R. Sheikholeslami, S. Talatahari, M. Keshvari-Ilkhichi, Chaotic swarming of particles: a new method for size optimization of truss structures, Advances in Engineering Software 67 (2014) 136-147.

[19] A. Kaveh, V.R. Mahdavi, Colliding bodies optimization method for optimum design of truss structures with continuous variables, Advances in Engineering Software 70 (2014) 1-12.

[20] A. Kaveh, M. Ilchi Ghazaan, Enhanced colliding bodies optimization for design problems with continuous and discrete variables, Advances in Engineering Software 77 (2014) 66-75.

[21] G. Bekdaş, S.M. Nigdeli, X.S Yang. Sizing optimization of truss structures using flower pollination algorithm, Applied Soft Computing 37 (2015) 322-331.

[22] A. Kaveh, M. Khayatazad, Ray optimization for size and shape optimization of truss structures, Computers and Structures 117 (2013) 82-94.

[23] A. Kaveh, S. Talatahari, Particle swarm optimizer, ant colony strategy and harmony search scheme hybridized for optimization of truss structures, Computers and Structures 87(5–6) (2009) 267–83.

[24] The Math Works Inc. MATLAB R2010a. Natick, MA, USA, (2016).

[25] Fiacco, A.V., McCormick, G. P.: Nonlinear programming: sequential unconstrained minimization techniques. John Wiley & Sons (1969).