Optimization of plane frames using the search group algorithm for economically efficient structural design

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Abstract. This paper presents a design procedure that leverages the Search Group Algorithm (SGA) to optimize discrete planar steel frames. SGA, a robust global optimization heuristic, orchestrates search groups to systematically explore the design space on a global scale, subsequently fine-tuning their exploration in localized optimal regions. The algorithm's application revolves around solving a structural optimization problem focused on obtaining steel frames with minimum weight, all while meeting requirements for both strength and displacement of the set. This is achieved through the selection of appropriate sections from a standardized set of steel sections as outlined by ABNT NBR 8800. Demonstrating the procedure's efficacy, a steel frame example is transformed into two distinct designs, maintaining consistent spatial arrangements. By conducting a comparative analysis, they are examined to verify the effectiveness of the SGA for similar problems, and compared to see which design performed better.

Keywords: SGA, Plane Frames, Structural Optimization, Heuristic Algorithm, economic design

1 Introduction

Optimization of steel frames stands as a significant and ongoing challenge within the field of engineering. Algorithms such as the Search Group Algorithm (SGA) play a pivotal role in guiding design decisions and evaluating their efficiency [1]. It's important to recognize that numerous systems can achieve a similar goal, albeit with varying levels of effectiveness. Complex system design demands extensive data processing and a multitude of calculations. Often, diverse systems can achieve comparable objectives. These approaches generally fall into two categories: conventional techniques and metaheuristic techniques [2].

In a metaheuristic approach, the pursuit of an optimal solution involves the application of rules and controlled randomness. These elements collaborate to navigate the solution process towards the global optimum. The algorithm from this approach, exhibit a remarkable aptitude for resolving intricate, discrete, highly non-linear, and non-convex optimization problems, frequently encountered in real-world engineering scenarios [3].

The methodological approach is performed out by thirty runs of the Search Group Algorithm, with generate multiple structural models with different element distributions and total mass. The SGA balances exploration and exploitation, enabling effective design refinement in both global and local phases [3].

2 Proposed Frameworks and Optimum design problem

2.1 General frame design

The general frame work can be seen as it follows in Fig. 1

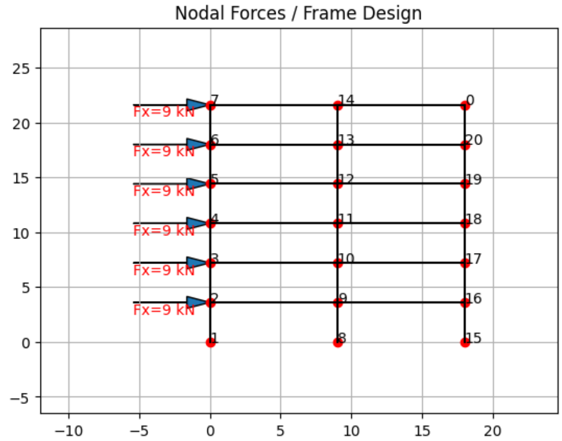

Figure 1. Framework design

The model frame in question is a two-bay, six-story, and was divided in two design groups: beams and columns. It has a vertical force of 9 kN at each node on its left face and a load of 6 kN evenly distributed along all beam elements of the frame. This design is inspired by the models proposed by Wood et al. [4] and Pezeshk et al. [5]. However, the structure has been expanded and merged in order to introduce additional complexity for the SGA analysis.

2.2 Proposed Analyses

The analysis in question will consider the same portal frame model; however, with a different distribution of elements in each case.

In the first evaluated structural model, the distribution will take into account three distinct elements for each floor: equivalent external columns, central column, and equivalent beams. For the second structural model, the same distribution of elements as the first model will be adopted. However, they will be replicated on the upper floor, in a pattern of 3 identical pairs. They can be illustrated by the following Fig 2.

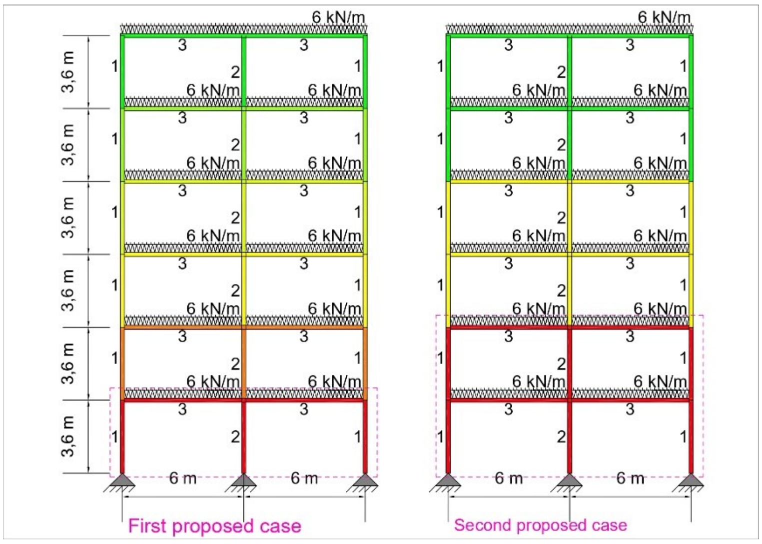

Figure 2. Evaluated Scenarios

The main objective is to compare the different distributions between them and achieve the economically efficient design, evaluating both cases and making a comparative analysis between them.

3 Structural optimization design using SGA

The SGA represents a metaheuristic approach with the objective of achieving a well-balanced harmony between exploring and exploiting the design domain, guiding it to the global optimal solution [2]. Initially, during the early iterations of the optimization process, the SGA is geared towards identifying promising domains within the design space.

As subsequent iterations unfold, it progressively hones in on refining the optimal design within each of these promising domains. This dichotomy leads to a division of the optimization process into two distinct phases: global and local [3]. This section succinctly outlines the pivotal stages of the method's application to the optimization of steel frames.

3.1 Functionality of SGA

The algorithm functionality involves a perturbation constant that regulates the process. A mutation operator creates new designs, distinct from the current search group's, utilizing multiple W profiles obtained through the ABNT NBR 8800 standards. This mutation is performed by a subset of the population called the search group [2].

The algorithm interactions are based on five main steps: Initializing the population; selecting the initial search group; mutating the search group; generating design families; and selecting the updated search group. Further details to be explored in a work proposed by Gonçalves, Lopez and Miguel [3].

The initial population, can be exemplified in Fig.3, where each point characterizes an individual from the initial population in a two-dimensional design domain.

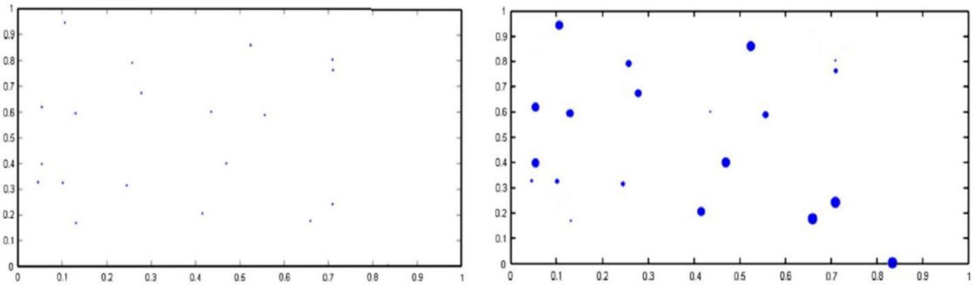

Figure 3 Evaluation of the objective function of the initial population (Gonçalves et al., 2015).

The influence of parameters on the SGA is significant. The initial population is randomly generated in a defined domain. A search group is selected based on objective function values, affecting design exploration. Mutation enhances global search by replacing individuals. Each search group member generates a family using perturbation, regulated by the n_{mut} parameter [3].

In each iteration, the value of α decreases, leading the individuals generated by a particular search group member to cluster around its neighborhood. This phenomenon enhances refinement during the local phase, as depicted in Fig 4.

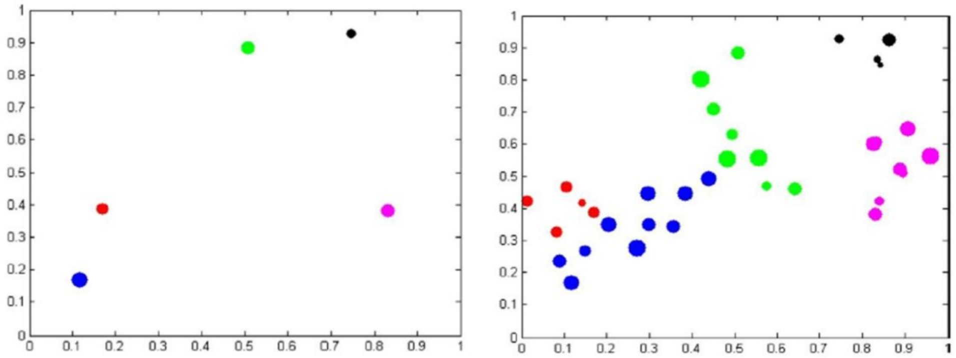

Figure 4 Families generation of the search group member in a latter iteration (Gonçalves et al., 2015).

3.2 Adopted parameters

The algorithm parameters that were adopted for both scenarios can be seen in the following Tab 1.

Table 1. Coefficients utilized in the algorithm

Parameters	Nomenclature	Value
Number of Interactions	$n_{interaction}$	1000
Interaction Ratio	It_{Ratio}	0.3
Population Size	n_{pop}	45
Initial Alpha	α_0	3
Minimal Alpha	α_{min}	0.02
Mutation operator	n_{mut}	2
Search Group Ratio	n_g	0.1
Tournament Size	T_s	5

Due to interactions and parameters listed above, the algorithm favors better-ranked members, generating more individuals for quality exploration. Control vectors guide family size, maintaining design evaluation and prioritizing better solutions [3].

3.3 Obtained Results

After processing both frame models thirty times, using the SGA with the previous defined parameters, the obtained results can be visualized in Tab. 2:

Table 2. Results obtained by the two designs

First Case	
	Weight (Kilograms)
1	11464.73
2	12065.25
	...
14	11910.45
15	8926.54
16	12809.81
	...
29	9926.55
30	10208.99
μ:	11397.42
σ:	1440.23

Second Case	
	Weight (Kilograms)
1	12223.16
2	10522.92
	...
14	13054.04
15	10267.09
16	11583.03
	...
29	13211.95
30	9236.42
μ:	11299.92
σ:	1261.19

The optimal values achieved from all algorithm iterations were 8926.54 kg for the first scenario and 9144.17 kg for the second scenario. It's worth noting that the differences between the means (μ) and standard deviations (σ) are 97.50 kg and 179.05 kg, respectively.

The average computational time for each run in the first scenario was approximately 1067.22 seconds, whereas in the second scenario, it amounted to 1012.09 seconds. These computations were conducted on a 9-core 2.90 GHz computer.

4 Conclusions

When conducting a comparative analysis between the two scenarios, no frame demonstrated superior performance when considering the lighter structural approach for economic efficiency.

Throughout the thirty analyses, the second case achieved a slightly lighter structural weight. This reduction was accomplished while maintaining a similar average value (μ) and pattern deviation (σ).

The similarity in pattern deviation (σ) suggests that the SGA is a concise and reliable method. It demonstrated the ability to uphold a consistent value for the same evaluated parameters, resulting in a succinct disparity of outcomes. This emphasizes the effectiveness and dependability of the SGA, as showcased by its capability to maintain comparable parameter values and generate more consistent results.

Staying within the context of comparative analysis, it can be inferred that while the first structural arrangement involves more effort in terms of assembly, this choice does not offer sufficient justification. This is mainly attributed to the slight disparity observed between the mean values generated by the algorithm runs in both cases.

In order to advance the study and explore additional scenarios, it is suggested to investigate critical loadings, explore alternative parameter settings, and apply diverse structural typologies to accommodate varying objectives. The SGA has demonstrated itself as a robust metaheuristic method for optimizing truss structures, showcasing commendable performance. It stands as a highly applicable algorithm.

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Authorship statement. The undersigned authors affirm that they are solely accountable for the authorship of this manuscript. All content incorporated within this paper is either the rightful intellectual property of the authors or has been included with explicit permission from the respective owners.

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