1 INTRODUCTION

Nature is a major source of inspiration, and many scholars have been encouraged to practice optimization methods for structural optimization through nature. For example, a natural topology, a coconut tree (wood), has porous material at center and dense at the circumference, which is gradually distributed from center axis to the circumference. Similarly, a bone topology increases structural strength and supports body load in an optimum way (Sigmund, 1994). Thus, such structures are lightweight in nature and offer a significant resistance against failures such as buckling and bending.

Gordon defined the structure as “Any assemblage of material, which is intended to sustain loads” (Christensen and Klarbring, 2009). Galileo in 1638 defined shape optimization problem of a beam in his novel envisioning sketch (Arora, 2007). Maxwell (1894) stated pioneering work in the field of structural optimization. He presented some basic principles of a minimum-weight structure for specified loads and materials. Michell (1904) published key literature on topology optimization on least weight layout trusses based on his derived method called optimal criteria (Rozvony, 2009). Optimal criteria method is governed by stress and displacement. However, optimal criteria is an analytical method and have limited applications. Dorn, Gomory, and Greenberg (1964), pioneer of ground structure method had demonstrated all possible connection of nodes in truss structure and unlocked broad way of truss topology optimization (TTO). Sheu and Schmit (1972) used an extensive search method in topology optimization. Kirsch (1989) presented optimal topologies of truss structures using optimal criteria.

A truss is a two- or three-dimensional structure composed of linear elements connected at nodes to sustain load and are subjected to tension or compression. Truss optimization becomes a fast-emerging research field of structural optimization since last three decades. Truss optimization can be classified into three categories: size optimization, shape optimization, and topology optimization. In size optimization, the aim is to find the optimum cross-sectional areas of elements of the truss. Figure 1.1 illustrates that cross-sectional areas are used for size optimization of the truss. Shape optimization reflects shifting position of nodal coordinates of the truss (As shown in Figure 1.2, nodal coordinates are employed for shape optimization of the truss), whereas topology optimization works on addition and removal of elements and nodes (As presented in Figure 1.3, many elements are removed from the ground structure for topology
optimization of the truss). The topology optimization is the most challenging problem of this field, because, it deals with all generated different topologies rather than a particular topology and results in a significant saving of weight by searching finest topology. Moreover, simultaneous consideration of topology, shape, and size (TSS) optimization is the best to obtain lighter truss. Figure 1.4 illustrates that the truss is optimized with simultaneous consideration of TSS variables.

![Fig. 1.1 10-bar truss](image1)

Fig. 1.1 10-bar truss (a) Ground structure and (b) Size optimization

![Fig. 1.2 52-bar truss](image2)

Fig. 1.2 52-bar truss (a) Ground structure and (b) Shape and size optimization
Most of the truss topology optimization (TTO) problems reported in the literature considered only stress and displacement constraints. However, few studies have been reported by considering frequency constraint along with stress and displacement constraints. The natural frequency of a truss is an essential parameter when the truss is subjected to dynamic excitations.
Many engineering trusses are subjected to dynamic excitations due to its operational conditions and certain unpredicted circumstances, which may lead to unwanted vibration and noise. Such state becomes dangerous if the dynamic response produces resonance hence, some convinced restrictions should be enforced on natural frequencies to protect a truss. Moreover, frequency constraints increase the complexity of TTO problems. Buckling can also have an adverse effect, and it includes additional complexity, which makes TTO problems more challenging. Moreover, the simultaneous consideration of natural frequencies and buckling constraints adds more complications to TTO problems. On the contrary, these constraints cannot be neglected to assure practicability. Kinematic instable and invalid trusses are key obstacles in the course of the TTO. Therefore, it needs to identify and handle efficiently to avoid a large number of unwanted analyses.

Analytical or numerical methods to calculate the optimum values of a function have been applied to optimize engineering problems for a long time. Although, these methods may perform well in some simple cases, they may fail in more complex design situations. In TTO problems, a number of design variables can be large, and their effect can be difficult. Due to the presence of multiple loading along with stress, displacement, buckling, frequency, and kinematic stability constraints the truss optimization problems become more challenging for optimization methods. To overcome these difficulties, an efficient method is required to solve such problems. Such problems cannot be handled by classical optimization techniques, or they only compute local extrema. In such complex problems, advanced metaheuristic algorithms can offer solutions to problems, because they search a solution near to the global optimum with less computational effort.

Optimization techniques can be classified into two distinct categories as given below:

a) Classical metaheuristic techniques: These are analytical algorithms, which work on methods of differential calculus in finding the optimum solution. These techniques have been in practice for quite some time and have been successfully applied to many engineering design problems. These techniques include linear/nonlinear programming, geometric programming, quadratic programming, dynamic programming, integer programming, etc. However, classical optimization techniques have limited scope in real-world applications.

b) Advanced metaheuristic techniques: These techniques are heuristic in nature with probabilistic transition rules based on biological behaviors, physical laws, social hierarchies, neurobiological systems, etc. These techniques are comparatively new and emerging as popular
techniques for optimizing complex engineering problems. These techniques include genetic algorithm (GA), simulated annealing, differential evolution, particle swarm optimization, biogeography-based optimization, artificial bee colony, artificial immune algorithm, etc.

Although classical optimization techniques have been employed to solve optimization problems in TTO problems, these techniques have following limitations:

• Classical optimization techniques do not fare well over a broad spectrum of problem domains (Yang, 2010; Pholdee and Bureerat, 2014).
• Classical optimization techniques are not suitable for solving multi-modal problems, as they tend to obtain a locally optimal solution (Arora, 2007; Miguel, Lopez, and Miguel, 2013).
• Classical optimization techniques are not ideal for solving multi-objective optimization problems (Su et al., 2011; Pholdee and Bureerat, 2013).
• Classical optimization techniques are not suitable for solving problems involving a large number of constraints (Zuo et al., 2014).
• Classical optimization techniques are not suitable for solving problems involving a large number of constraints. Considering drawbacks of classical optimization techniques, attempts are being made to optimize TTO problems by using advanced metaheuristic techniques.
• Moreover, according to the no free lunch theorem, there is no metaheuristic best suited for optimizing all types of problems. One algorithm can be expected to outperform another in solving one set of challenges, but it may be a poor performer on a different set of problems. Therefore, efforts must be continued to use more recent optimization techniques and to modify existing algorithms, which are more powerful, robust and able to provide an accurate solution.

This research work is therefore carried out keeping in view the following objectives:

• To suggest applications of ten advanced metaheuristic techniques developed after 2011 to solve TTO problems.
• The dragonfly algorithm (DA) (Mirjalili, 2016a), multi-verse optimizer (MVO) (Mirjalili, Mirjalili, and Hatamlou, 2016), sine cosine algorithm (SCA) (Mirjalili, 2016b), whale optimization algorithm (WOA) (Mirjalili, and Lewis, 2016), ant lion optimizer (ALO) (Mirjalili, 2015), heat transfer search (HTS) (Patel and Savsani, 2015), passing vehicle search (PVS) (Savsani and Savsani, 2015), symbiotic organisms search (SOS) (Cheng and Prayogo, 2014), and grey wolf optimizer (GWO) (Mirjalili, Mirjalili, and Lewis, 2014) algorithms are recently developed algorithms, and it is required to explore such methods for the challenging SO problems, whereas the Teaching–learning-based optimisation (TLBO) (Rao et al., 2011; 2012) algorithm is an effective technique and has an effective impact on different engineering optimization problems. Moreover, considered metaheuristics have distinct search mechanisms,
and it is virtually impossible to forecast the influence of the modification for each of applications and metaheuristics.

- In metaheuristics, the population might change very small, when the population is nearer to each other. This state outcome in premature convergence and local optimal solution because the population remains almost close to the same place. Moreover, if the population does not improve further, the search may be considered as trapped local optima. At such instance, the population should have a right balance between exploration and exploitation to search a better solution and to avoid local optima traps. Therefore, a random-mutation-based search and random-migration-based search techniques are incorporated into proposed algorithms to answer stated issues.
- To study and develop modified optimization algorithms using a mutation model, a migration model, an adaptive method and a simultaneous search method.
- To propose new benchmark problems on simultaneous topology, shape, and size optimization by consideration of static and dynamic constraints with continuous and discrete element cross-sections.

This report is structured as follows: Chapter 2 presents the detailed literature review of structural optimization using classical methods and advanced metaheuristic algorithms. This chapter also investigates identification of research gap of TTO problems. In addition, chronological classification of applications of TTO problems is also presented. Chapter 3 presents a methodology and problem formulation of TTO problems. Design problems are set to minimize structural mass subjected to static and dynamic constraints. A ground structure method is applied to handle truss topology. Structural analysis is carried out by means of a finite element approach to find the objective and constraint functions. Chapter 4 gives details of used advanced metaheuristic algorithms (the DA, MVO, SCA, WOA, ALO, HTS, PVS, SOS, GWO, and TLBO algorithms) used in this thesis work and modifications incorporated in these algorithms. A random-mutation-based search technique, random-migration-based search technique, adaptive model, and simultaneous analysis methods are incorporated in proposed algorithms to improve their performance in TTO. The simulated annealing based selection is also used to extract its merits. Chapter 5 presents results and discussion on applications of existing advanced metaheuristic algorithms and proposed modified/improved metaheuristic algorithms to TTO problems. Chapter 6 simulates validation of proposed methodologies using ANSYS software, and Chapter 7 presents general conclusions of the thesis work.

The next chapter presents detailed, comprehensive representation of the investigation on truss topology optimization that has been done in the past, and that is on the way.