LAYOUT OPTIMIZATION OF TRUSSES WITH MANUFACTURING CONSTRAINTS

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1. Introduction

Computational layout optimization procedures, first developed for trusses over half a century ago [1], have been the subject of increasing interest in recent years. In a computational layout optimization problem the design domain is discretized using a grid of nodes which are interconnected with discrete line elements, forming a 'ground structure'. Linear optimization can then be used to identify the subset of elements forming the minimum volume structure required to carry the applied loading, with adaptive solution techniques ensuring solutions can be obtained rapidly [2]. Geometry optimization, which involves adjusting the positions of the nodes using a non-linear optimization step, can subsequently be undertaken to simplify and/or improve on the solution (Figure 1) [3].

However, when accurate solutions are required, fine nodal grids must be employed. This often leads to solutions that are complex in form, largely due to the nature of the optimal solutions being sought. Although rapidly developing additive manufacturing (AM, or '3D printing') techniques can be used to fabricate truss designs which are considerably more complex than can be fabricated using conventional techniques, limitations still exist, requiring manufacturing constraints to be considered in the optimization process. The nature of these constraints depends on the manufacturing process involved.

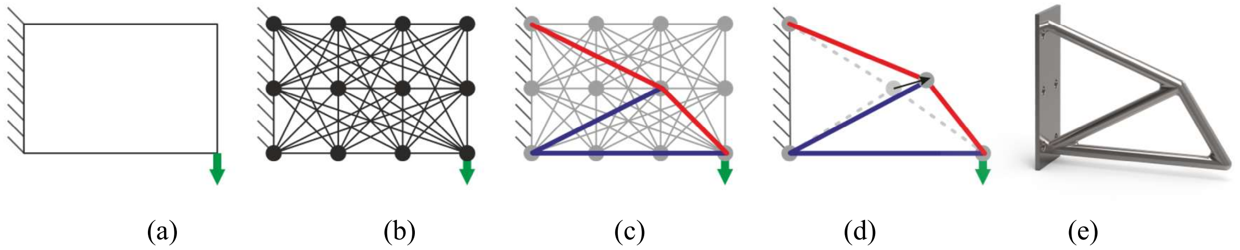

Figure 1: Stages in the truss layout optimisation process: (a) design domain, loads & supports; (b) nodes distributed across the design domain & potential truss element connections; (c) resulting minimum volume truss; (d) positions of nodes modified using geometry optimisation to further improve the result; (e) truss elements replaced with solid elements (e.g. cylinders) and joints added to create a watertight (for AM component design)

2. Manufacturing constraints

Two types of trusses are considered here: (i) trusses forming components to be produced via AM; (ii) trusses used to form large structures, such as those in canopy roofs or building frames.

Considering first the design of AM components: layout optimization is useful when the degree of design freedom is high, as truss-like forms are typically found to be very structurally efficient. Simple rules can be used to automatically transform a line element layout into a 3D continuum ready for AM [4], as indicated in Figure 1(e).

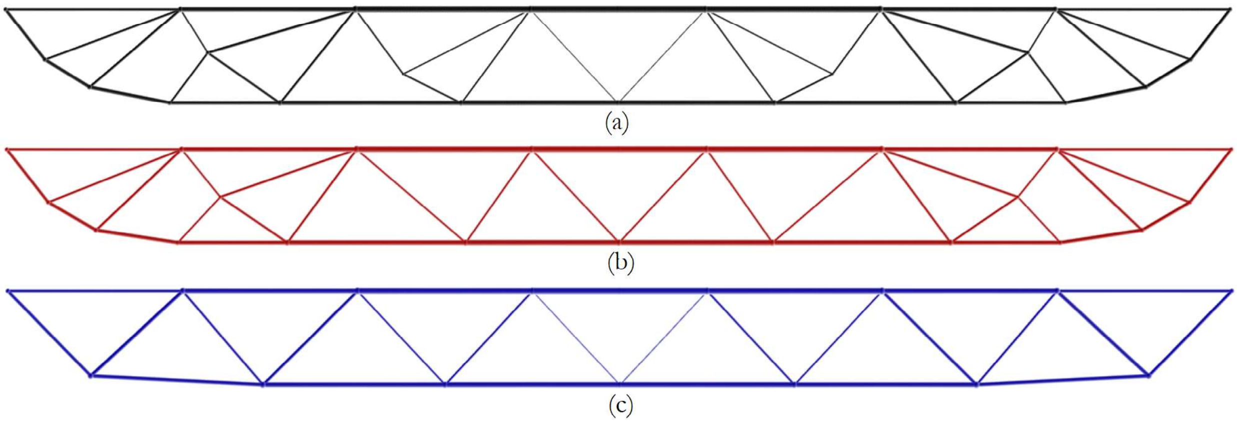

Figure 2: Sample optimized layouts for simply supported transfer truss: (a) obtained using layout and geometry optimization; (b) with MILP constraint on minimum cross-sectional area; (c) with MILP constraint on maximum number of joints.

However, with many AM processes elements inclined at shallow angles to the horizontal are difficult to fabricate without support structures. This issue can be addressed via introduction of hard and soft constraints, as will be described in this contribution.

Considering next the design of trusses used to form large structures: in this case there is a need to minimise the number and complexity of joints, and to e.g. avoid excessively thin structural members. Various means of addressing this will be outlined, from vertex enumeration and Mixed Integer Linear Programming (MILP) formulations for small and medium sized problems, to heuristic methods for larger problems. Figure 2 shows sample MILP solutions for a 21m span, 1.8m high, simply supported transfer truss carrying 6 equally spaced loads from intersecting beams.

3. Conclusions

Computational layout optimization is a powerful technique that can readily be adapted to take account of manufacturing constraints. In this contribution constraints relevant for the design of small-scale AM components and the design of large-scale structural frames are both considered.

Acknowledgements The authors acknowledge the financial support of EPSRC under grant reference EP/N023471/1.

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