Layout Optimisation for Building Structures

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Introduction
In structural design, the overall shape and layout of a structure is most commonly chosen based on the precedents of existing structures and the engineer's past experience. Additionally, often, little is done to assess how material-efficient a structure could theoretically be or to assess the impact each decision made by the design team has on structural weight.

The main aims of this project are to:

- Establish **benchmarks** to inform how efficient a structure is,
- Provide tools to help designers understand the implications of each **design choice** on structural weight,
- Offer methods to **rationalise** the designs produced by optimisation methods to comply with fabrication constraints.

Here initial findings made on a real-world case study are presented.

A practical case study
The case study considers the design of a **steel transfer structure** with a 50m span, which needs to fit within a 10m deep design domain. The structure is to be constructed from hollow square sections, fabricated from S355 steel.

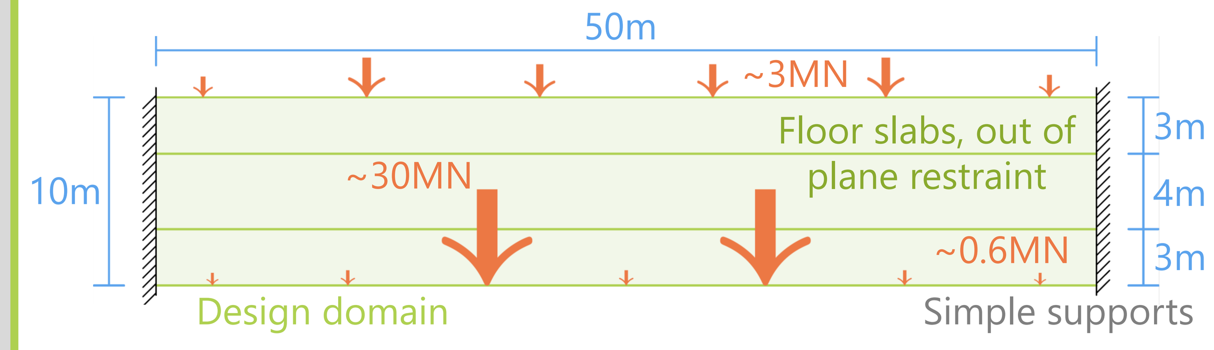

Figure 1: Problem description, loading values un-factored.

The structure must resist the loads shown in Figure 1, and comply with an increasingly restrictive set of constraints designed to increase its buildability.

The structure is modelled as a pin jointed truss. As it is a planar truss, resistance to out-of-plane buckling must be provided. This is available at the floor slabs.

Details of optimisation methodology
The method of optimisation used is called Layout Optimisation. In this, the design domain (Figure 2a) is filled with nodes (2b), which are then connected in all possible pairings to give a 'ground structure' of potential truss members (2c). Linear programming algorithms are then used to find the globally optimal set of these members (2d) to support the loads.

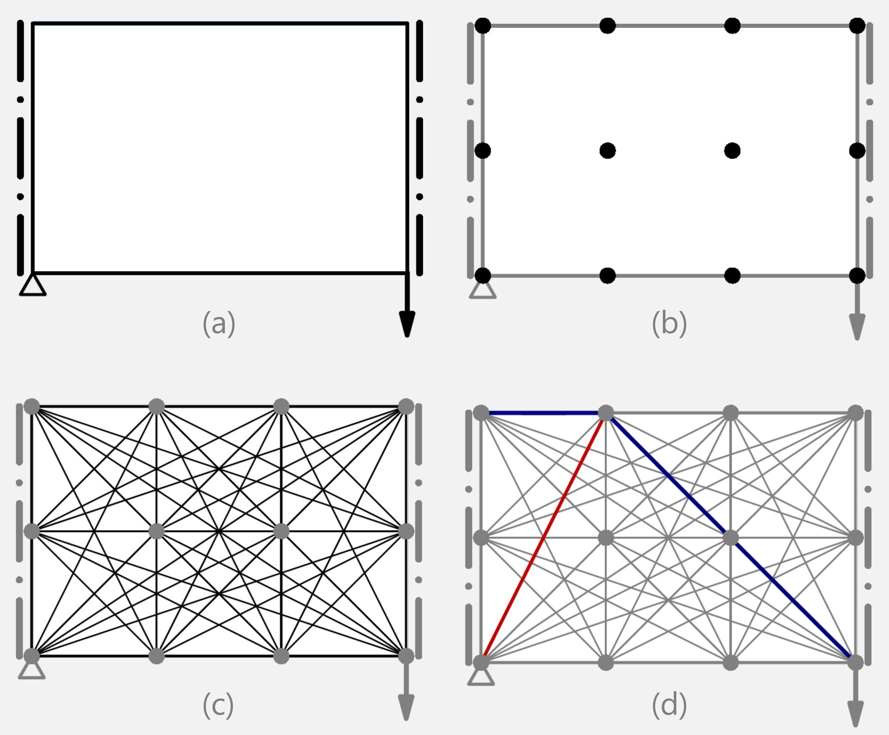

Figure 2: The stages of the layout optimisation process.

The output of this technique applied to the current case study with nodes at 0.25m spacing (32 million possible members) is shown in figure 4 row (a). The complexity of this structure is common in the outcomes of optimisation processes, this is a major factor in the low uptake of optimisation techniques in structural design practice

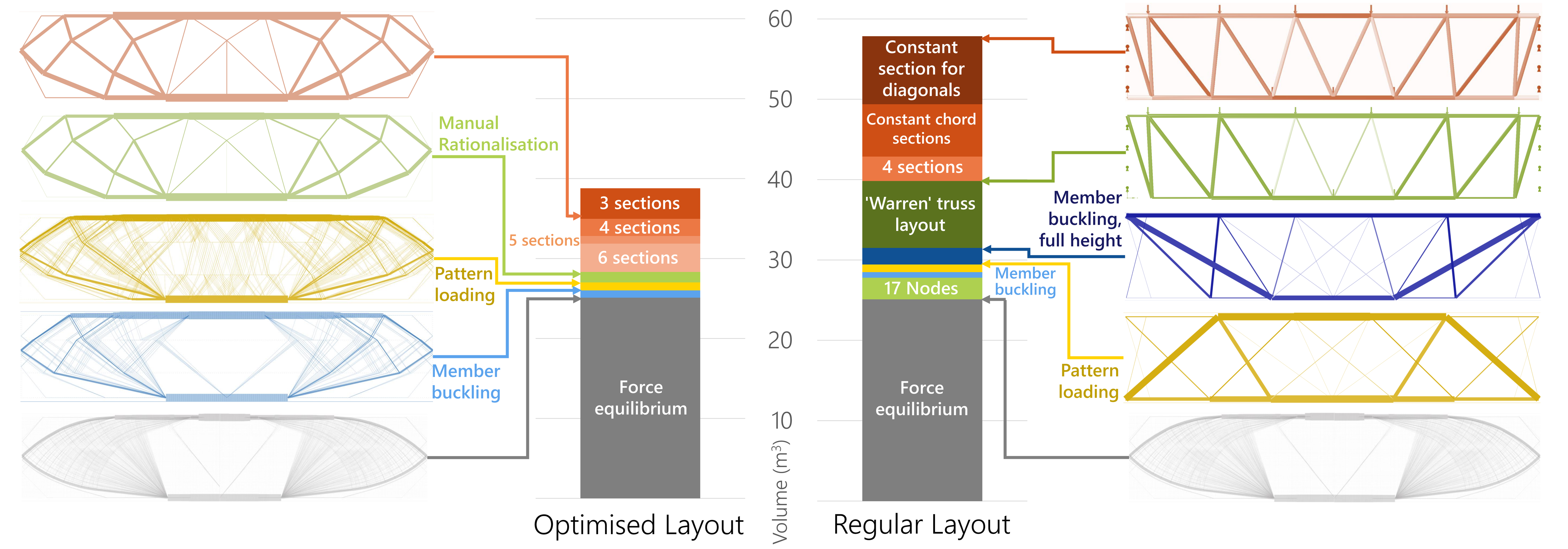

Figure 3: Chart comparing optimised and traditional forms at various levels of rationalisation. Blue steps relate to the modelling of buckling, Yellow refers to pattern loading, green to rationalisation of form and orange to section/size rationalisation.

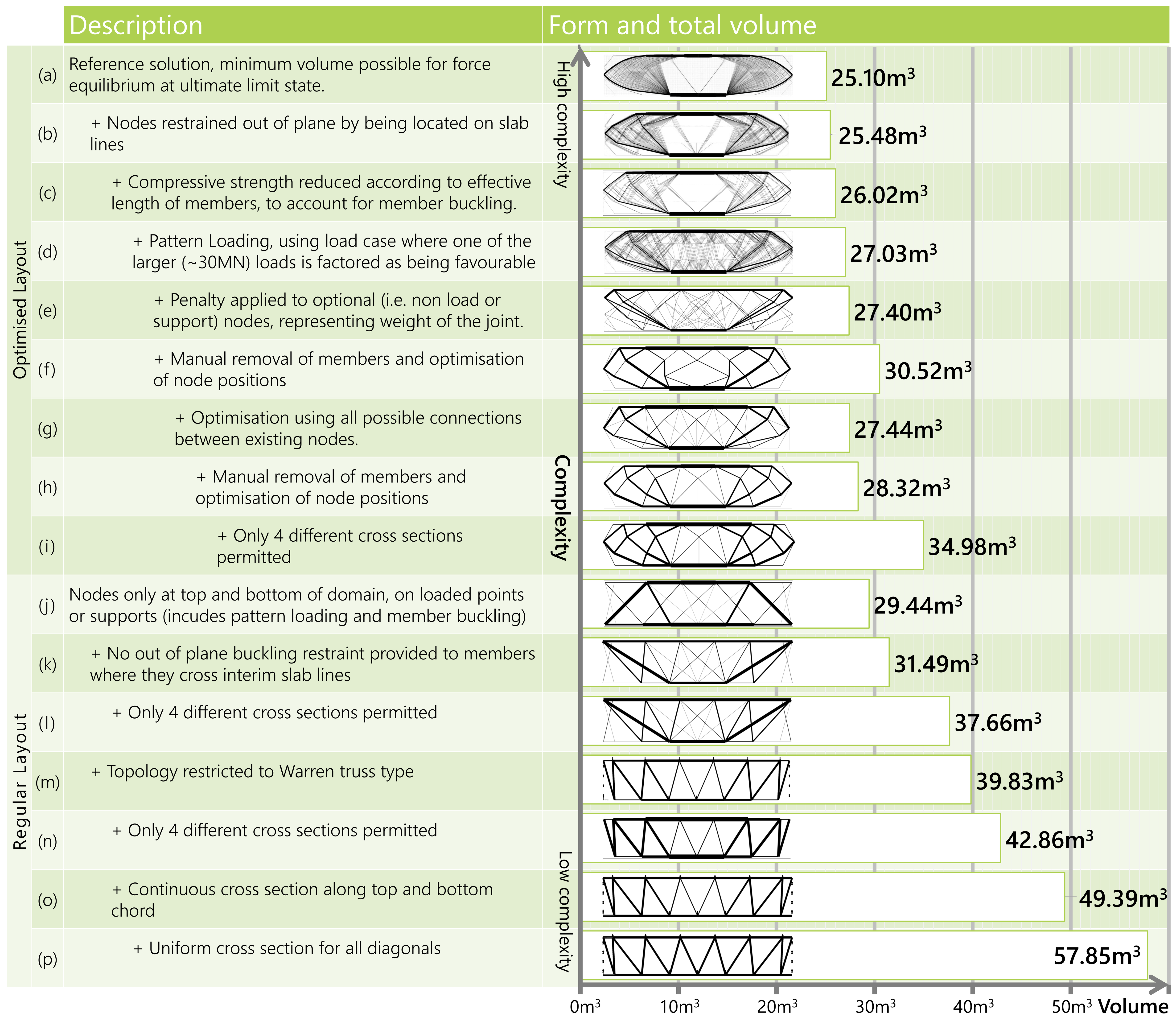

Figure 4: Resulting structures for example problem from most complex theoretical structures to increasingly constrained forms.

Details of rationalisation methods
The complex structures in figure 4, row (d) and earlier are simplified using an iterative procedure combining optimisation techniques with manual intervention using the Limistate:Form software developed at Sheffield University. This procedure is described in figure 5.

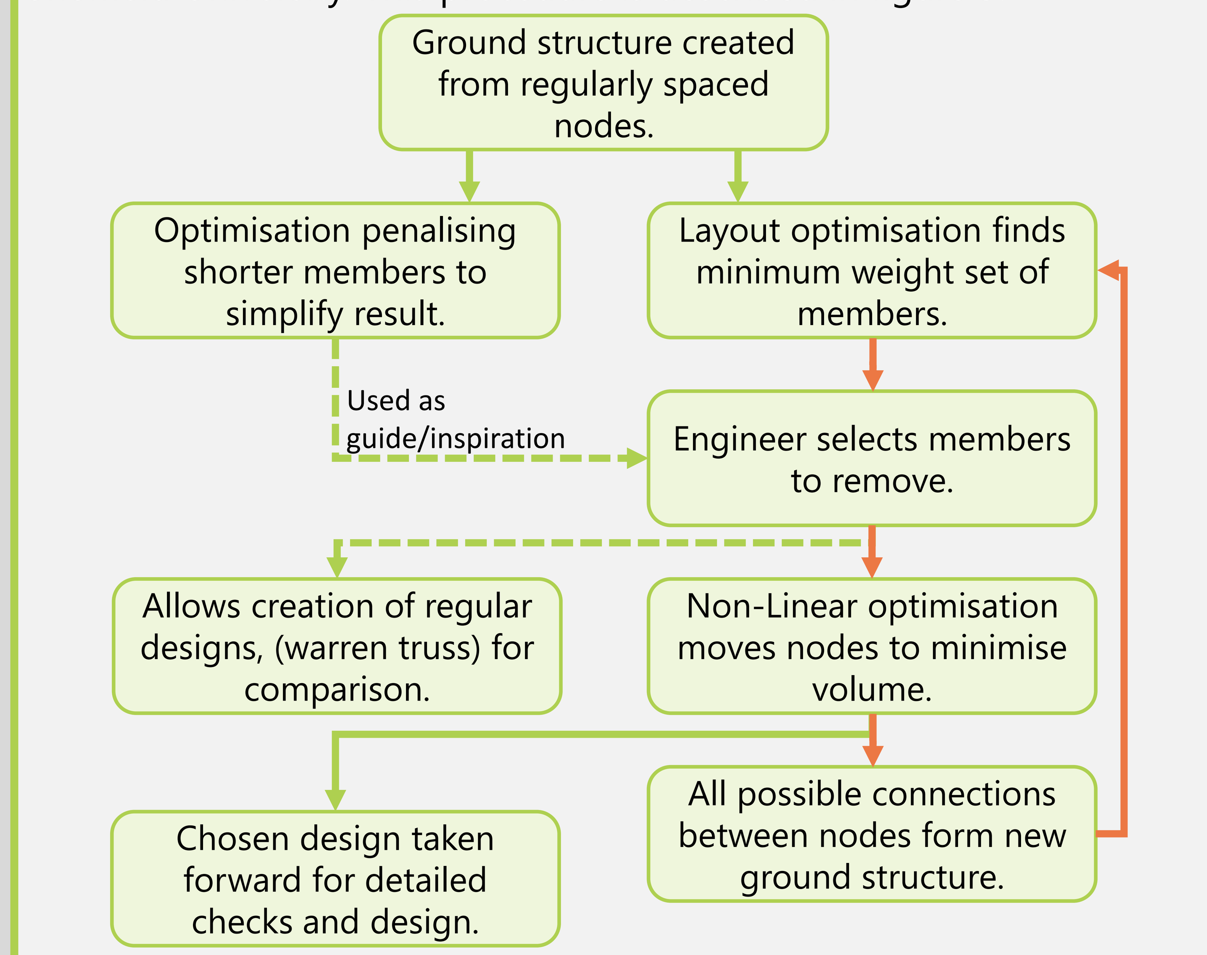

Figure 5: Rationalisation method incorporating manual intervention. The loop in orange is carried out as many times as required to produce a solution which satisfies all desired fabrication constraints.

After this process, forms using a limited number of different cross sections are found. This is currently done as a post processing step and the node locations and topology are not changed.

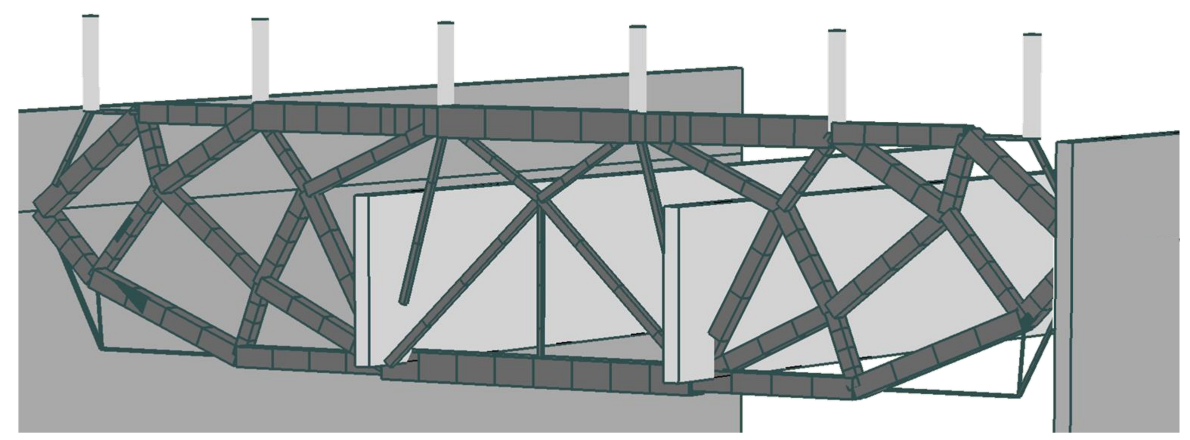

Figure 6: Rationalised truss using optimised topology (dark grey), showing supporting walls (mid grey) and main loading sources (light grey)

Results
Figures 3 and 4 show the resulting potential structures found for the current problem. In figure 3 they are separated into optimised and regular layout. This allows a visual representation of the significance of the different **design choices**.

Figure 4 shows the changes in form and volume as additional constraints are added. Note that with the chosen cross section and modelling type (i.e. pin jointed) lines 4(a) to 4(c) are not resistant to buckling. Further work will be required if a **benchmark** which does not depend on design decisions is desired.

Rows 4(f) and 4(g) of show some of the structures produced during the iterative **rationalisation** process described in figure 5. Row 4(h) shows the chosen design which was used for the studies to reduce the numbers of cross sections, and is shown in figure 6. The proposed method allows flexible interpretation of fabrication constraints, and this is just one of many potential designs available to the designer.

This case study has shown that these methods can produce a wide range of structural options for a design team, with the potential for significant material savings, even once fabrication constraints are considered. This will allow informed decisions to be made when considering design choices, and may provide additional options which make use of highly efficient structural forms which are not yet commonly considered.