

FORM: A PRACTICAL LAYOUT OPTIMIZATION TOOL FOR CIVIL AND STRUCTURAL ENGINEERS

*** Wael Darwich¹, Matthew Gilbert² and Andy Tyas³**

Computational Limit Analysis & Design Unit, Dept Civil & Structural Engineering,
University of Sheffield, Mappin Street, Sheffield S1 3JD, UK.

Email: ¹w.darwich@sheffield.ac.uk, ²m.gilbert@sheffield.ac.uk, ³a.tyas@sheffield.ac.uk

Web: <http://cladu.shef.ac.uk>

Key Words: *Structural Engineering, Layout Optimization, Plastic Design.*

ABSTRACT

At present civil and structural engineers normally rely on their intuition to initially determine ‘optimum’ arrangements of structural members in structures such as canopies and long span roofs. Though member layouts may subsequently be modified as part of an iterative conceptual design→analysis→re-design loop, this process is time-consuming and costly. However, given the skeletal nature of the structures typically dealt with by civil and structural engineers, the volume fraction of the design domain occupied by the final structure will normally be very small, limiting the usefulness of the continuum based topology optimization methods now in use in other engineering sectors (e.g. for component design). This implies that discrete rather than continuum optimization methods are likely to be more appropriate. Furthermore, civil and structural engineers are very often required to modify existing structures rather than to design completely new ones. (In developed countries typically around half the annual construction spend is on repair and rehabilitation rather than on new construction.) However, despite its importance, to date very little attention has been devoted to retrofit design scenarios by the structural optimization research community.

In an attempt to address this, a new software application, *form*, is being developed specifically for civil and structural engineers at the University of Sheffield, in collaboration with spin-out company LimitState Ltd. *form* makes use of a modified version of the classical plastic Linear Programming (LP) formulation put forward over four decades ago by Dorn et al.¹. This formulation involves the use of a so-called ‘ground structure’ which contains all possible discrete member connections between nodes laid out across the design space, with the optimum structure then being formed from a subset of these members. This formulation, which in its basic form involves only equilibrium and stress constraints, has received little attention in recent years. However, the combination of modern computer power, recently developed interior point LP solvers and the adaptive ‘member adding’ scheme presented by Gilbert and Tyas² (which permits use of a sparsely connected initial ground structure) allows problems involving many millions of potential members to be solved rapidly on a desktop PC, thus providing a platform for a practically useful design optimization tool.

For situations where an existing structure requires strengthening or other modification, existing structural elements can be imported into the software. The software can then identify the optimal arrangement of additional structural elements required in order to satisfy the design requirements. An important

advantage of using the classical plastic LP formulation is that structural problems involving e.g. masonry blocks can be treated without difficulty, despite the fact that uniaxial contacts will in this case be involved if the tensile strength of the masonry is negligible (e.g. see Figure 1).

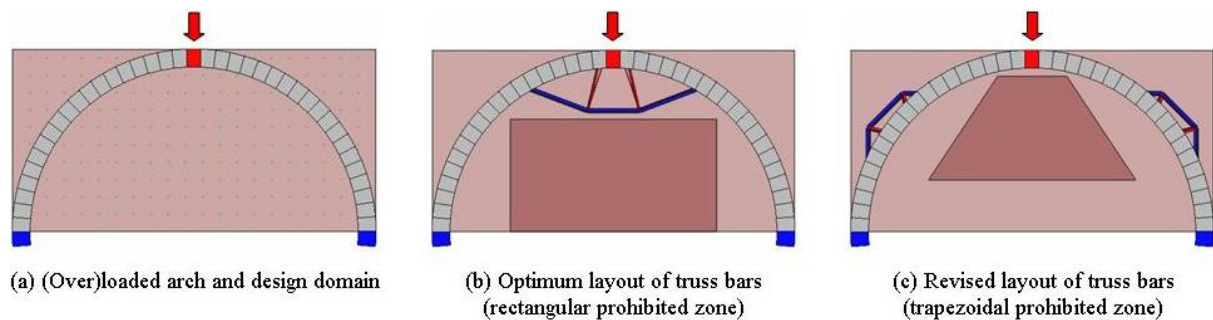


Figure 1: Example of a masonry arch reinforced using truss bars

The *form* software is being designed to allow users to:

1. Rapidly define multiple design domain zones interactively or via a wizard. Zones can be concave in shape and can be defined as either ‘permissible’ or ‘prohibited’ to respectively allow or exclude members.
2. Assign supports and specify either fixed or transmissible loads (the latter are used to avoid fixed load positions dictating structural form³).
3. Assign different materials and joint costs spatially across design domains (to penalize potentially expensive members and/or joints).
4. Perform an optimization and then interactively modify properties (e.g. the extent of a permissible design domain zone) before optimizing again. The objective of the optimization is to minimize the cost of the structure, taking account the cost of materials (i.e. the overall volume of the structure) and also costs associated with fabricating complex joints or placing members.
5. Import existing structural elements, including steel trusses and beams, reinforced concrete beams, and/or masonry blocks.
6. Export results to other applications (e.g. frame analysis software to permit elastic analysis).

To be a practically useful tool, flexibility and ease of use are important. The software will be demonstrated at the minisymposium and current and recent developments to the software will be described. Additionally a demonstration version of the software is expected to be available by the time of the conference, from: <http://www.limitstate.com/form/demo>

REFERENCES

- [1] W.S. Dorn, R.E. Gomory and H.J. Greenberg. “Automatic design of optimal structures”, *J. de Mechanique*, Vol. 3, 25–52, 1964.
- [2] M. Gilbert and A. Tyas. “Layout optimization of large-scale pin-jointed frames”. *Engng. Comput.*, Vol. 20, 1044–1064, 2003.
- [3] M. Gilbert, W. Darwich, A. Tyas and P. Shepherd, “Application of large-scale layout optimization techniques in structural engineering practice”, *Proc. 6th WCSMO*. Rio de Janeiro, Brazil, 2005.