# STRUCTURAL OPTIMISATION IN BUILDING DESIGN

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## ABSTRACT

This paper aims to contribute to the reduction of the significant gap between the state of-the-art of structural design optimisation in research and its practical application in the building industry.. The research objective has been aided by collaboration with structural designers at Arup. It is shown how Evolutionary Structural Optimisation can be adapted to improve applicability to practical bracing design problems by considering symmetry constraints, rules for element removal and addition, as well as the definition of element groups to enable inclusion of aesthetic requirements. Optimally-directed designs. The method developed consistently finds the global optimum for a small 2D planar test problem generates high-performance designs for larger scale tasks and shows the potential to generate designs meeting user-defined aesthetic requirements.

## I. INTRODUCTION

The research objective is achieved through the investigation ofthree optimisation methods: Evolutionary Structural Optimisation, Pattern Search with Optimality Criteria for simultaneous section-size optimisation and Genetic Programming using design modification operators, all applied to test problems in the field of topological bracing design for lateral stability of steel building frameworks. At the start of each chapter, research questions are posed, with corresponding proposals stated and subsequently developed in detail. Significant research contributions are made in each of these studies, discussion of the state-of-the-art of structural optimisation in research and practice.

Major themes in this work are generating a range or selection of high performance designs for assessment according to unmodelled criteria, such as aesthetics and the integration of size and topology optimization.

Design optimisation is loosely defined by Papalambros and Wilde (2000) as the selection of the "best" design within the available means. When stated so simply, optimisation seems an obvious objective of any design task. Yet when the problem is ill-structured (defined by Simon (1973) as lacking definition in some respect), including a possible absence of appropriate tools and knowledge, or if the expenditure in finding an optimal solution places a high premium on the design cost, a good design that meets a defined tolerance on all requirements is generally accepted. The American political scientist and pioneer of Artificial Intelligence, Herbert Simon, coined the term "satisficing" to describe the process of finding such designs (Simon 1955). Indeed, this is the standard approach adopted in manual design.

## II. THE DESIGN PROCESS FOR BUILDING STRUCTURES

It is vital to the successful implementation of optimisation in structural design that the optimisation tasks detailed above are linked to the appropriate phase of the design process. The structural design process essentially follows the same progression as any other design task. However, the interdisciplinary nature of building design, with input from clients, architects and structural and building services engineers, serves to complicate the process and may lead to a large number of iterations and revisions, even revisiting earlier design phases. With reference to design of topology and form and section allocation, it is useful to consider the corresponding stage in the design process for each of these tasks.

Structural systems and topologies are developed earlier in the design process, with the optimisation problem less well-defined, the design space larger and hence a greater range of possible solutions. Section sizes are not finalised until the latter stages of the design process. Although section-size optimisation is a much more straightforward task, a strong driver for optimisation prior to this stage is provided by estimates suggesting that up to four-fifths of the total resources in an engineering project are committed in the early design stages (Deiman 1993).

## III. DISCRETE TOPOLOGY OPTIMISATION METHODS

The Ground Structure approach, first proposed by Dorn et al. (1964), effectively reduces the complexity of a topology optimisation problem by considering a fixed grid of nodes, initially with a high degree of connectivity (in extreme cases each node may be connected to every other node) as exemplified in figure These links between nodes are potential structural members.

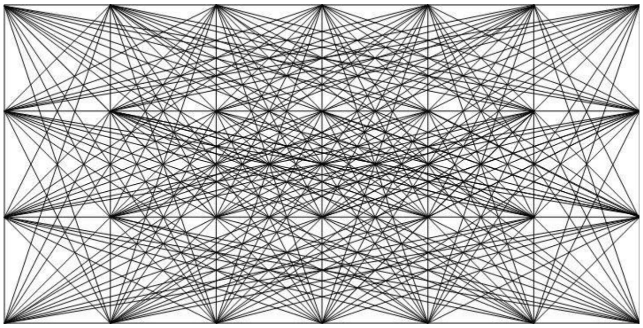
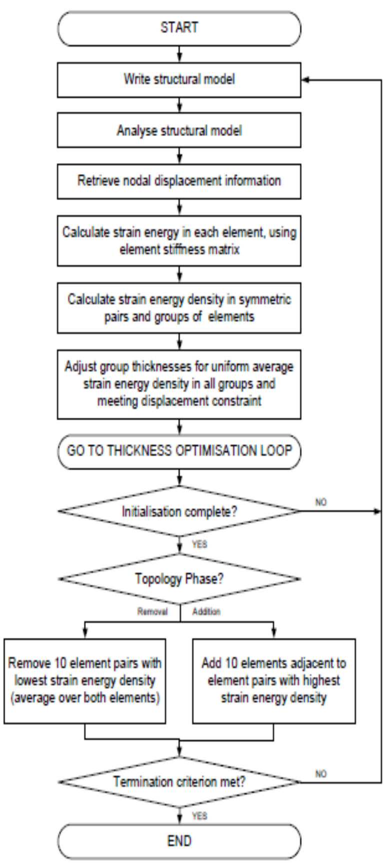


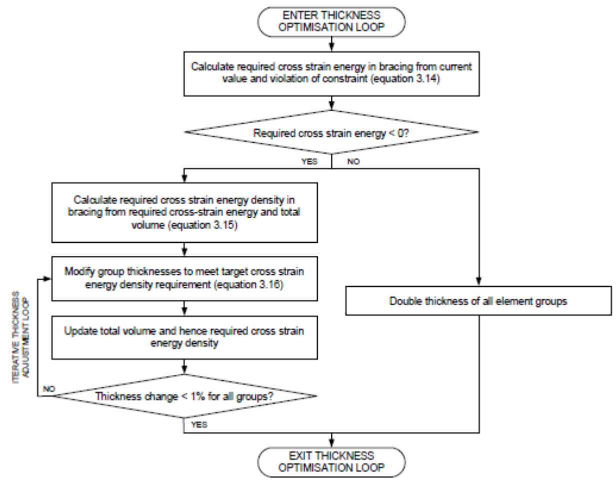
Figure Fully-connected ground structure for a relatively simple (3x6) grid

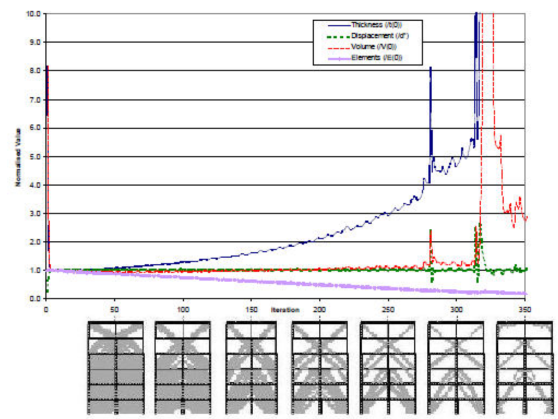
## IV. INCLUDING OPTIMISATION OF DOMAIN THICKNESS

The topological diversity observed in designs resulting from variation of domain thickness indicates that solutions are not globally optimal. In this section we explore the concept of varying domain thicknesses in such a way as to maintain the maximum The continuous designable domain elements may be divided into a number of groups, with a single thickness variable used for all elements in any one group.




Variation of domain thickness was previously considered by Liang et al. (2000a), but in the simple context of exploiting the linear relationship between displacement and thickness in a structure consisting purely of a single designable domain. This approach is invalid for any design which includes a non-modifiable framework or multiple groups of elements which may be assigned different thicknesses.

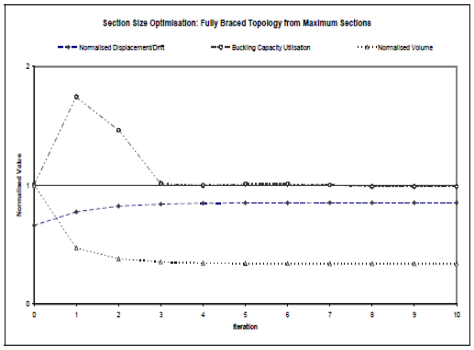


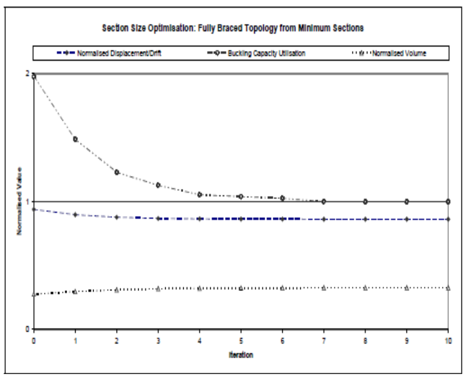



## V. SIZE OPTIMISATION

This section considers the section size optimisation of bracing members for a given topological configuration through the Optimality Criteria method (Borkowski 1990). It would be possible to extend the method to include size optimisation of the remainder of the structure, but the illustrative purposes of this section are adequately served by keeping sections in the skeleton structure fixed. The subsequent argument considers pin-jointed bracing members, carrying only axial force under applied wind loading, although they will also carry bending moment and shear force in ultimate limit state load cases due to directly applied distributed loading.

## VI. SIZE OPTIMISATION OF FULLY BRACED CONFIGURATION




## VII. CONCLUSIONS

In response to the research question posed at the start of this chapter, it has been demonstrated how the established Hooke and Jeeves (1961) search method can be applied to a practical topology problem, by simplifying the task to consider a fixed set of variables. Through stochastic search and varying starting points a range of optimally-directed designs can be found, avoiding single local optima and allowing unmodelled criteria, such as aesthetics, to influence final design selection. Simultaneous optimisation of size and topology was efficiently carried out by performing a single iteration of the Optimality Criteria method at each topological step. This integrated approach offered substantial volume reductions when compared to sequential topology and size optimisation. Focusing this research on a practical problem has revealed a number of crucial considerations and obstacles relevant to the application of structural optimization techniques in the building industry.

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