# Inventory-Constrained Structural Design Optimisation


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## Aim:

Develop design and optimisation approaches for spatial structures when the dimensions and mechanical properties of a limited inventory of available elements are known at early-stage design.

## Objectives:

1. Develop analytical methods to gain intuition and insight into a specific inventory-constrained structural design scenario when the characteristics of the inventory are known.
2. Develop computational methods for generating "assignments" of inventory elements to a given structural design while satisfying inventory and structural constraints.
3. Test the above computational methods in two inventory-constrained structural design scenarios:
    a. The use of "whole timber" elements in spatial structures.
    b. The component reuse of steel elements in new spatial structures.

## Inventory-Constrained Structural Design Procedure

**Source of Inventory Material** → **Inventory** → **Inventory-Constrained Design** → **Structure**

### Whole Timber Construction

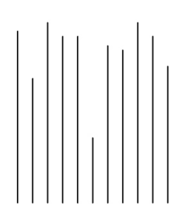
**Forest**

**Felled Whole Timber**

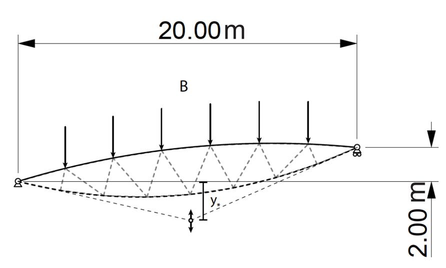
**Whole Timber Structure**[1]

### Steel Component Reuse

**Structure to be Deconstructed**[2]



**Steel Element Inventory**



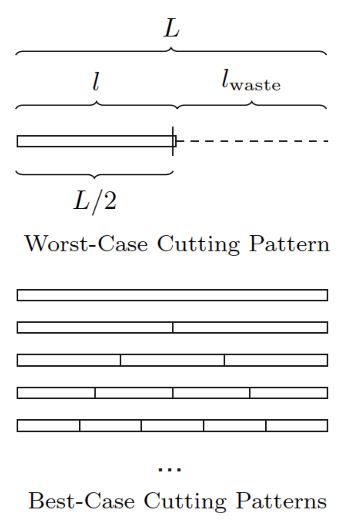

**New Structure Using Steel Elements**

1: Muroto Indoor Stadium, in Muroto Japan, built 2017. Photograph Courtesy of Prof. Katsuhiko Imai
2: London Olympic Stadium. CC: https://commons.wikimedia.org/wiki/File:Olympic_Stadium,_London,_14_June_2011_cropped.jpg

## Analytical Methods

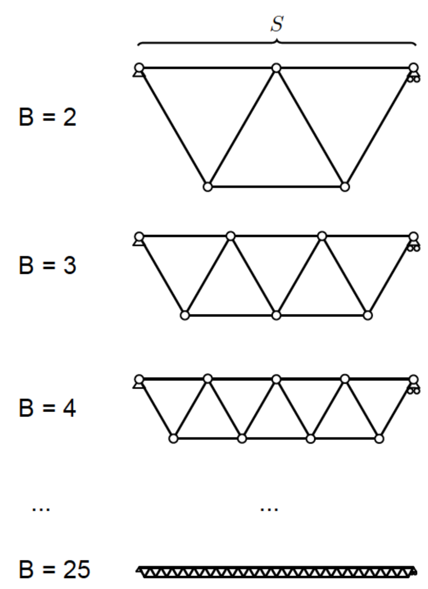
### Method Summary:

By comparing the life-cycle impact of worst-case and best-case cutting pattern efficiencies for repetitive spatial structures, the relative importance of geometry and topology optimisation with respect to cutting pattern efficiency can be quantified before design for such structures. This allows designers to choose appropriate design and optimisation methods for given structural design problems.




| | l | $M_I$ | $M_W$ |
|---|---|---|---|
| Worst-Case Cutting Pattern | $l \to_{>} L/2$ | $\to_{<} 2M_S$ | $\to_{<} M_S$ |
| Best-Case Cutting Patterns | $l = L/k$ $\forall k \in \mathbb{N}_{>0}$ | $M_S$ | 0 |

Worst and best cutting patterns for cutting a set of identical structural elements of length $l$ from inventory elements all of some length $L$. $M_S$ : Structural mass. $M_I$: Inventory mass consumed. $M_W$ : Offcut waste mass produced.




Planar truss for a fixed span consisting of $B$ bays of elements all of a single length used for illustrating worst and best-case cutting pattern efficiencies.

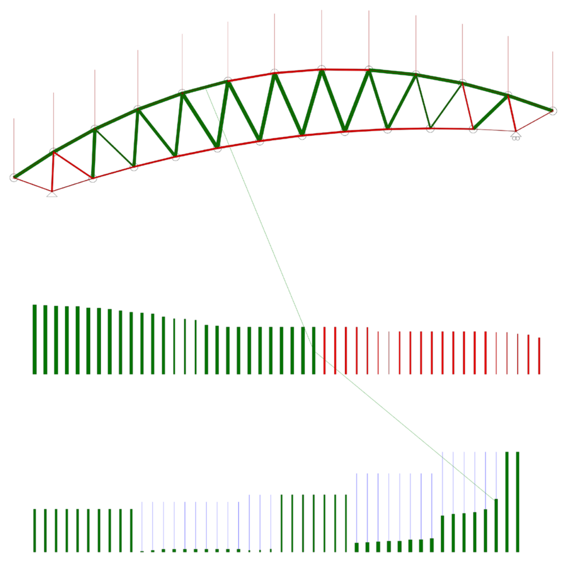
### Findings Summary:

For steel structures, assumptions regarding the life-cycle impact or recycling potential of offcut waste significantly affect the importance of cutting pattern efficiency. For timber structures, connection life-cycle impacts dominate, meaning that cutting pattern efficiency is of relatively low importance.

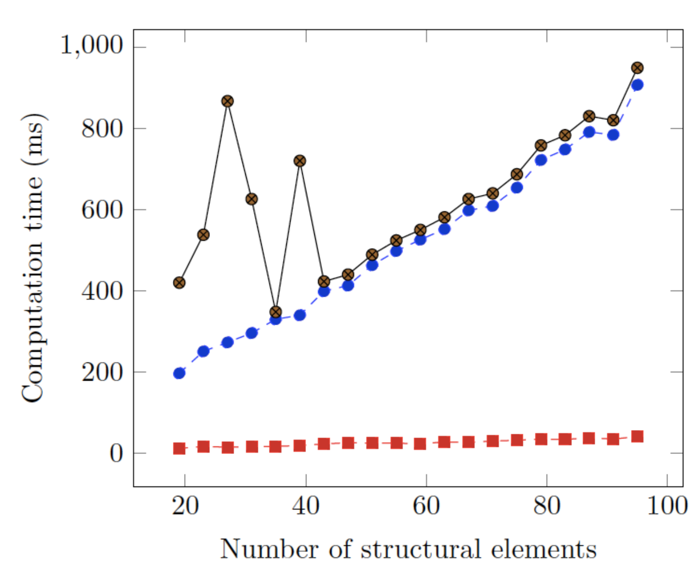
## Computational Methods

### Method Summary:

An efficient computational heuristic is introduced for generating assignments of an inventory of elements to a given structural geometry and topology subject to member ULS and a global deflection constraint, intended for use in early-stage structural design.



Visualisation of computational assignment of inventory elements (bottom row) to structural locations (top row) for a planar truss (top).




Assignment computation times for a planar truss structure consisting of 20-100 structural elements, for an inventory consisting of 150 elements. Blue: single assignment. Red: single analysis. Brown: total calculation time.

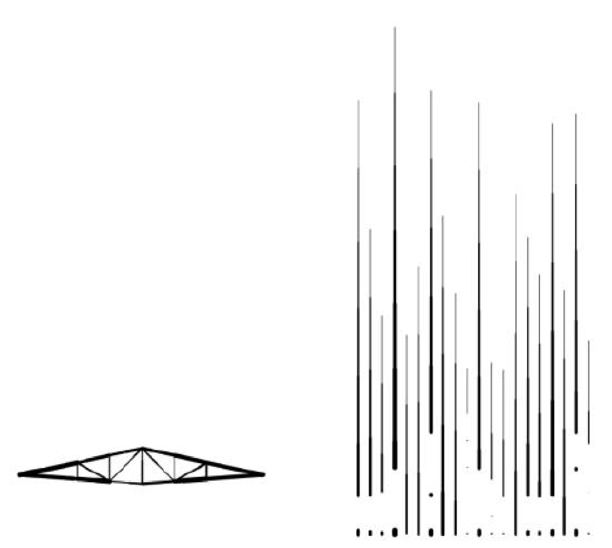
### Findings Summary:

Computational heuristic assignment methods are efficient for structures with low degrees of static indeterminacy, however suffer from slow convergence in structures with high degrees of static indeterminacy. Grouping strategies for members could help to improve convergence in future implementations.

## Case Studies

### Method Summary:

Variations of the computational assignment heuristic developed as part of this research were applied to the design of planar trusses using 1) reclaimed steel elements 2) whole timber elements.



Assignment of an inventory of whole timber elements to a planar whole timber truss subject to member ULS constraints. Shown: random pre-sorting of structural locations, pre-sorting of inventory elements by base diameter.


Assignment of reclaimed steel elements to a planar truss subject to member ULS constraints, before and after refinement procedure to reduce global deflections to within serviceability limits.

### Findings Summary:

Presorting strategies appear to be effective for guiding assignment heuristics for whole timber designs such that members are utilised relatively efficiently. When offcut disposal impacts are low or negative, however, the heuristic approach employed results in over-sizing of some members. Grouping strategies could help to control assignment and reduce over-sizing through the use of offcuts where they would be under-utilised.

## Publications


Bukauskas, A., Mayencourt, P., Shepherd, P., Sharma, B., Mueller, C., Walker, P., Bregulla, J., 2019. Whole timber construction: A state of the art review. Construction and Building Materials 213, 748–769. https://doi.org/10.1016/j.conbuildmat.2019.03.043

Bukauskas, A., Shepherd, P., Walker, P., Sharma, B., Bregulla, J., 2018. Inventory-Constrained Structural Design: New Objectives and Optimization Techniques, in: Proceedings of IASS Annual Symposia: Creativity in Structural Design. Presented at the International Association of Shell and Spatial Structures 2018, Cambridge, Massachusetts, USA.

Bukauskas, A., Shepherd, P., Walker, P., Sharma, B., Walker, P., 2017. Form-Fitting Strategies for Diversity-Tolerant Design, in: Proceedings of IASS Annual Symposia. Presented at the International Association of Spatial Structures 2017, Hamburg, Germany.

Bukauskas, A., 2017. Computational Form-Fitting Strategies for Non-Standardised Elements, in: Creativity and Collaboration. Presented at the IABSE Conference, International Association of Bridge and Structural Engineers, Bath.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