Conference or Workshop Item:
Grekavicius, L, Hughes, J and Tsavdaridis, KD orcid.org/0000-0001-8349-3979 (2016) Novel Morphologies of Aluminium Cross-Sections through Structural Topology Optimisation Techniques. In: The Institution of Structural Engineers.

The Institution of Structural Engineers

Undergraduate Research Grant 2015/16

Novel Morphologies of Aluminium Cross-sections through Structural Topology Optimisation Techniques

Students: Jack Hughes and Lukas Grekavicius, MEng Civil and Structural Engineering
Supervisor: Dr Konstantinos Daniel Tsavdaridis, Associate Professor of Structural Engineering

UNIVERSITY OF LEEDS
School of Civil Engineering

INTRODUCTION

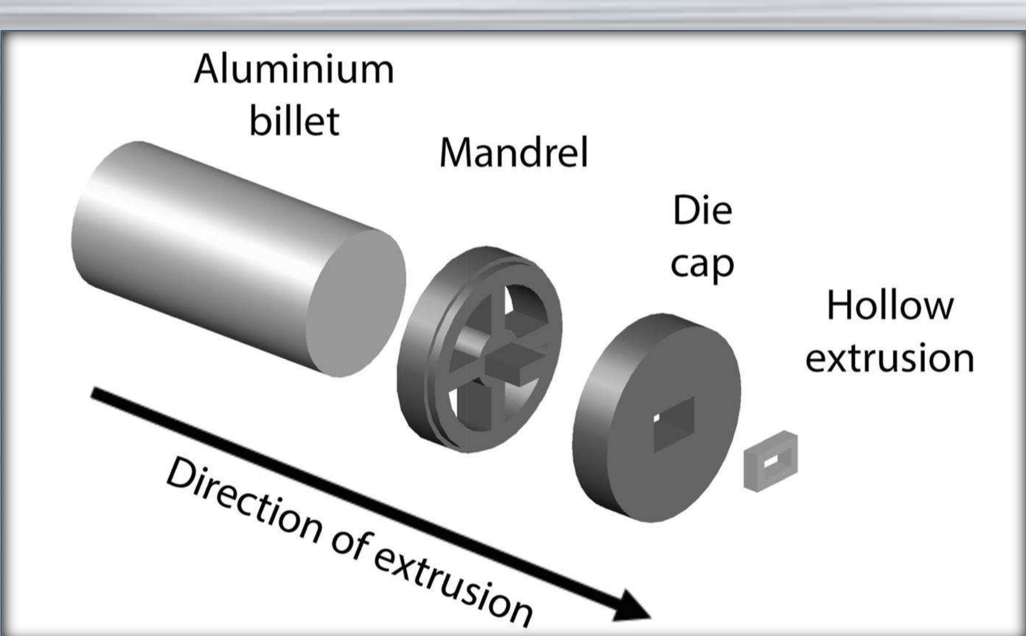
In the last decades, the deployment of aluminium and its alloys in civil engineering fields has been increased significantly, due to supportive technological and industrial developments and the **material's special features**:

- Low density
- Excellent corrosion resistance
- Flexible manufacturing (extrusion) process

However, the extent of aluminium structural applications in building activities is still rather limited by the material's **low elastic modulus**, creating barriers related to **strength and stability issues.**

Inherent deficiencies of aluminium can be overcome though appropriate design of cross-sections.

- The manufacturing process allows sections to be formed in an almost **unlimited range of shapes**
- Employment of structural topology optimisation techniques can result in sections with **minimum weight-to-stiffness ratio.**



AIMS & OBJECTIVES

The primary aim of the research is to develop a series of unique cross-sectional profiles for structural aluminium members with minimum mass and maximum stiffness, having a three-fold benefit:

- **Reduce deflections** and overcome aluminium's low modulus of elasticity.
- Enhance the **environmental and economic sustainability** of aluminium during manufacture and construction.
- **Promote more wide-spread use** of aluminium and topology optimisation in the structural engineering discipline.

The secondary aim of the project is to subsequently **evaluate the performance** of some of the optimised cross-sections, through nonlinear finite element analysis. This will provide a much needed comparison of novel, conventional and optimised profiles upon which future work and further optimisation may be based.

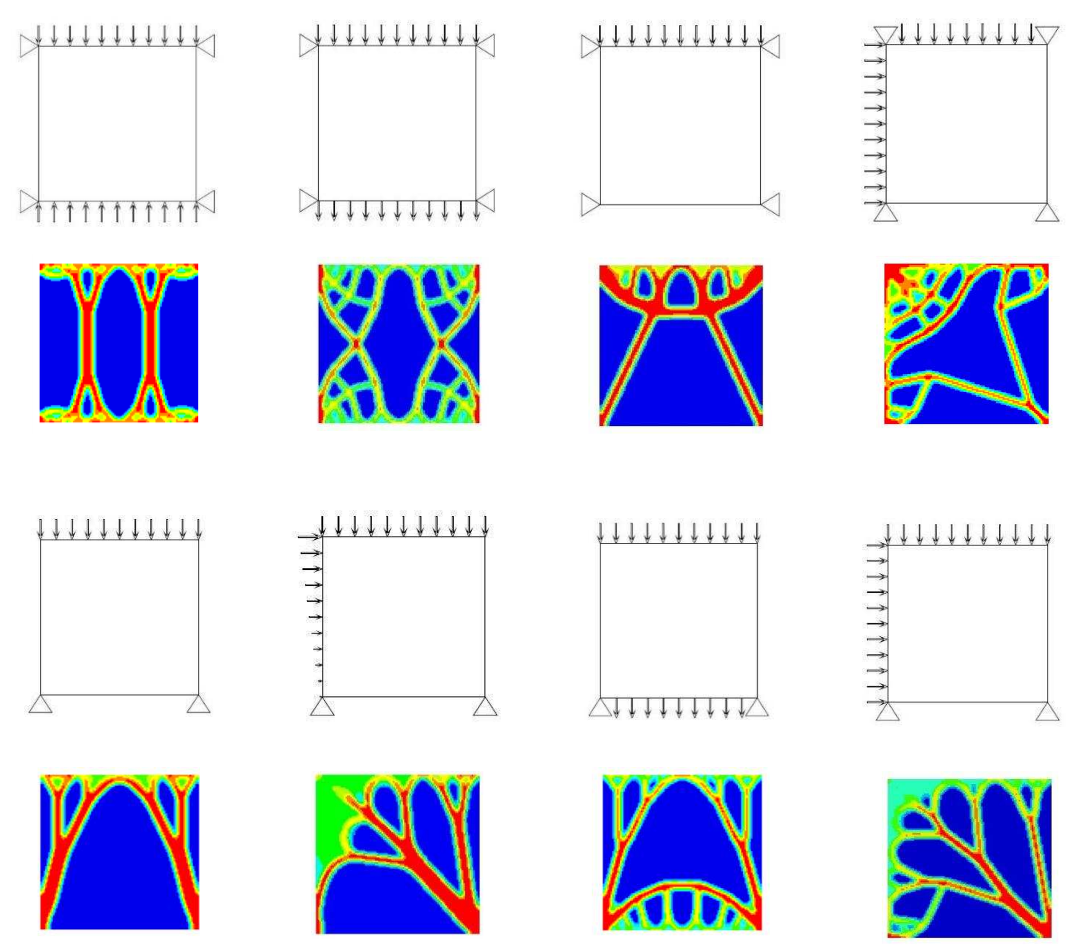
TOPOLOGY OPTIMISATION

Structural topology optimisation software **Altair HyperWorks** was implemented within the study to produce novel column cross-sectional profiles. Through the use of the **SIMP technique**, with a minimum compliance approach, a series of unique topologies were generated based on different loading and support conditions.

BEAM AND COLUMN TOPOLOGY OPTIMISATION RESULTS

2D Cross-sectional models

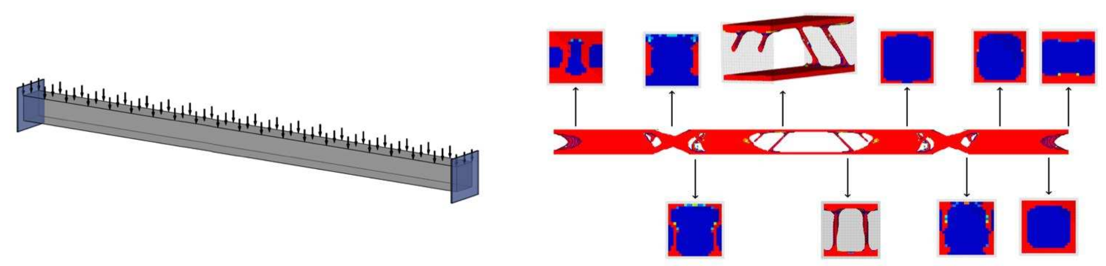
- **100x100 mm** sections considered.
- **Shell elements** with nominal size of **1** mm utilised.
- Various loading and support conditions considered.
- Loading conditions based on Eurocode provisions.
- **A total of 40 loading types** tested for both beams and columns.



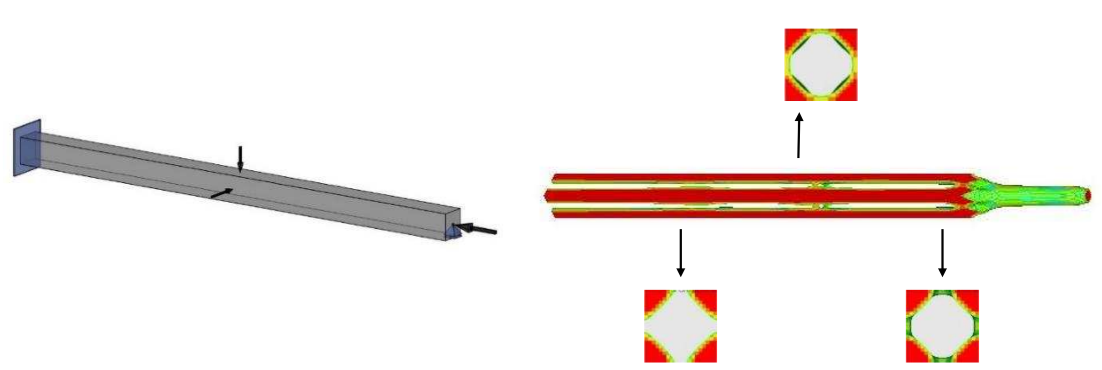
Optimisation of Beam and Column Sections

3D Cross-sectional models

- Optimisation performed on **2 m extruded members.**
- **Solid elements** with nominal size of 5 mm utilised.
- Uniform pressure with fixed end supports used for beam optimisation.
- Axial compression in addition to one and two plane trigger loads with fixed-pinned as well as pinned-pinned supports applied to column optimisation.



Optimisation of an extruded Beam

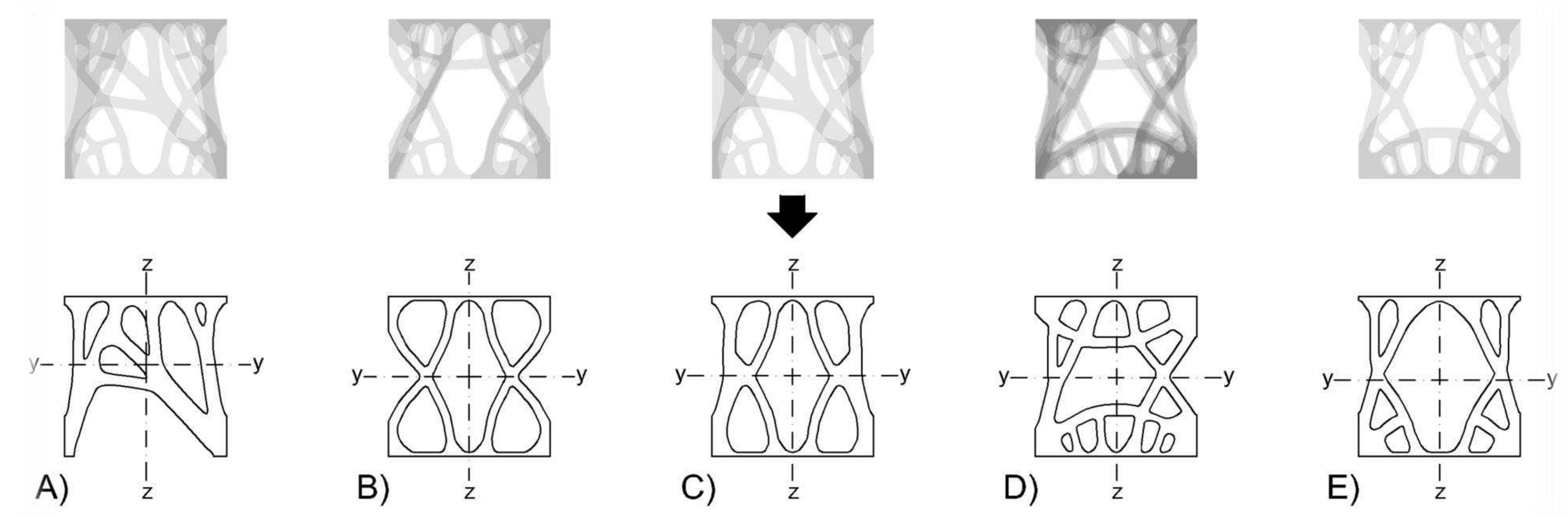


Optimisation of an extruded Column

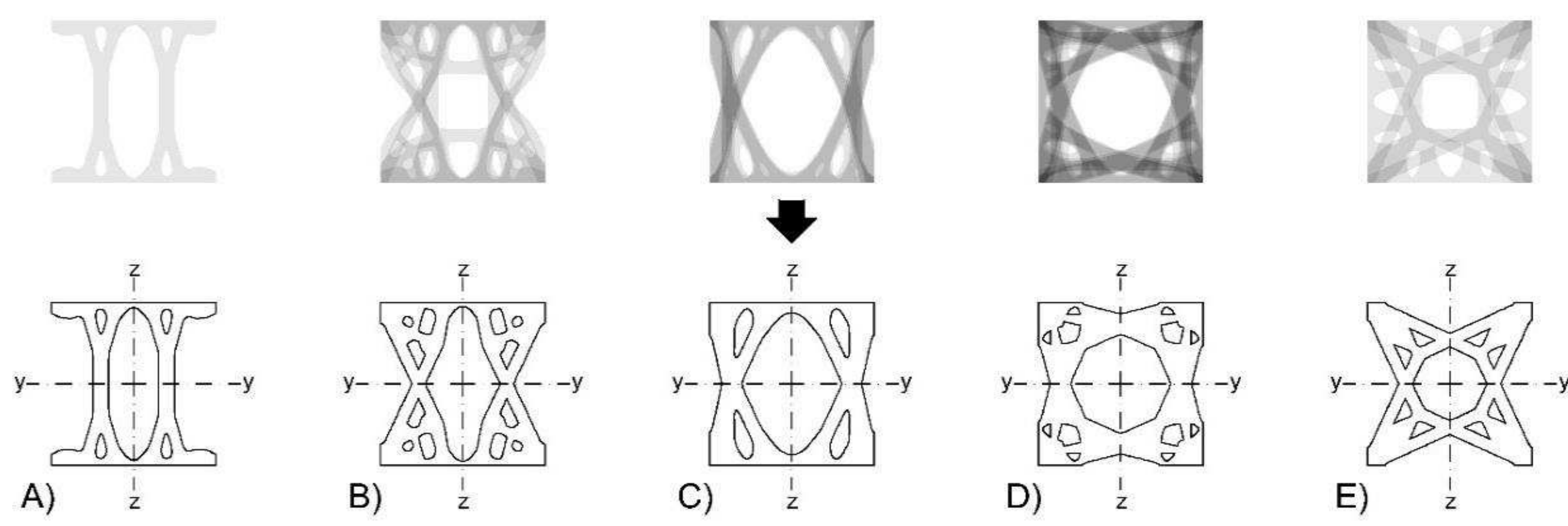
POST-PROCESSING

Tailored post-processing approach used to produce novel cross-sectional profiles from the density plots. Due to the large number of plots produced, the technique is suitable, as it accounts for many loading scenarios.

- The approach takes into account both **stability and manufacturability** criteria.
- The interpretation is highly subjective and involved **manually forming the new shapes** by identifying high concentrations of material.
- The new obtained shapes theoretically **resistant to multiple failure modes.**



Final Beam Cross-sections



Final Column Cross-sections

CONCLUDING REMARKS

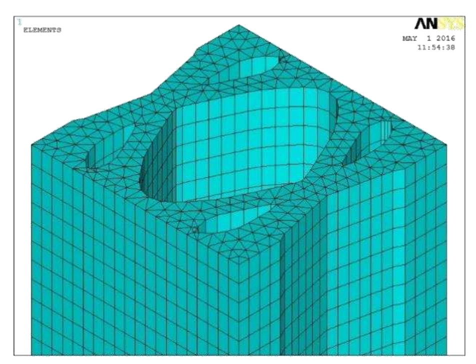
- **A series of unique topologies** for a square cross-section have been generated, subject to a variety of more than 40 loading and support conditions.
- The tailored post-processing technique resulted in a series of **complex hollow sections** with various central opening shapes.
- As a result of the square design domain, all optimised cross-sections typically feature a **similar moment of inertia and stiffness about both axes.**
- The novel shapes are thus **well suited to resisting minor-axis effects** such as lateral torsional buckling, however a major limitation is the **lower moment of inertia about the major bending axis.**
- A direct FE comparison of different cross-sectional profiles revealed that **serviceability limits on deflection are dominant in beams.**
- Most of the optimised **beam cross-sections** are out-performed by conventional profiles due to a direct correlation between moment of inertia and deflection.
- Evaluation of **column** buckling capacities demonstrated that some of the optimised sections out-performed standard sections.
- Effectiveness of topology optimisation in **column cross-section design** was identified.

FUTURE WORK

- Future work is likely required in order to develop cross-sectional profiles in an iterative manner.
- Having performed an initial topology optimisation, the possibility now exists to **perform more extensive experimental and FE studies** to increase the performance of the sections.
- **Manufacturing constraints**, in particular die shape design, have to be addressed when finalising section designs for use in practice.
- **Design equations to be incorporated** within Eurocode 9 to employ the optimum cross-sectional shapes in practice.

PARAMETRIC FINITE ELEMENT ANALYSIS

- All geometries compared are constant in depth and cross-sectional area, with a **span-depth ratios of 10 and 20.**
- Aluminium alloy 6063-T6 considered due to suitability in structural engineering applications.
- **Geometric and material non-linearity** included.
- All models were created using 5 mm **SOLID185** eight node elements, with a uniform cross-sectional mesh along the length.
- Novel, standard and other optimised sections compared.



RESULTS

Beam Sections

- Large mid-span deflections before failure
- Local buckling experienced around high stress concentrations at the supports

Column Sections

- All members failed due to flexural buckling
- Largest deflections slightly above mid-span
- Stress distribution follows lines of principal stresses