POLITECNICO MILANO 1863 | DEPARTMENT OF AEROSPACE SCIENCE AND TECHNOLOGY | DEPARTMENT OF MECHANICAL ENGINEERING

SPACE IT UP!

Simplified approach for modeling of defects in lattice structures

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Introduction

Lattice Structures for Space Applications

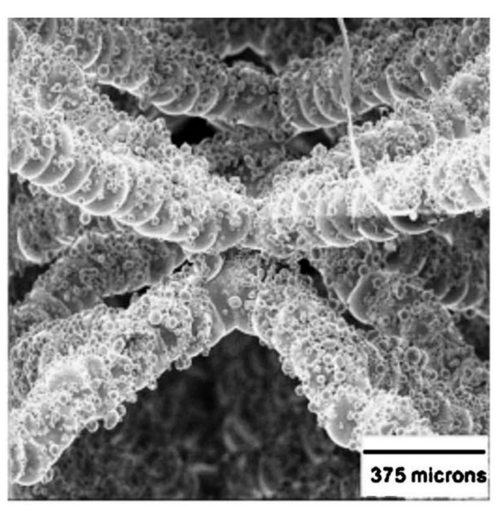
- **Lattice structures offer high structural efficiency**, while **additive manufacturing** (AM) enables **highly flexible and innovative designs** tailored to the unique requirements of space missions.
- **AM processes inherently introduce dimensional inaccuracies**, surface defects, and porosity. Studies show that these defects can significantly influence both linear and nonlinear structural responses.
- **Existing modelling approaches are often computationally expensive**, making them unsuitable for early design stages and for large structures.

Efficient Modelling Through Beam Models

- **Finite element analyses of 3D imperfect struts** are used to derive the **constitutive law for simplified beam models**.
- The resulting modelling framework enables **fast prediction of nonlinear behavior** and supports efficient design and optimization of imperfect lattice structures.

Modelling of defects

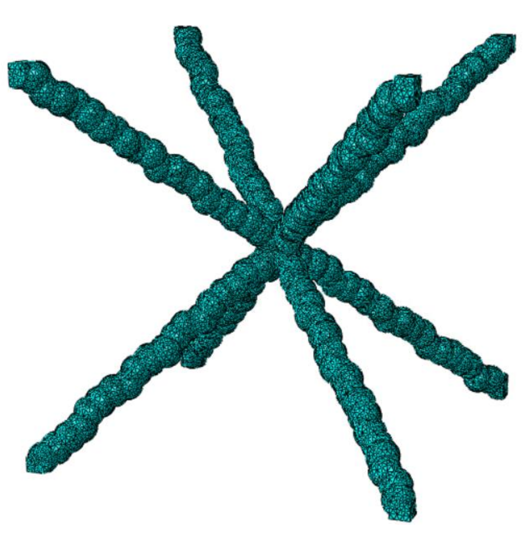
The struts formed by melting powder layers inevitably have some imperfections, in particular: **radius variation**, **strut waviness**, **surface roughness** and **porosity**.



Close up image of a lattice cell: surface irregularities

Struts are represented by the **union of multiple spheres** whose **radius**, **offset**, and **spacing** vary randomly following statistical distributions obtained from CT scans.
A code has been developed to **automatically generate lattice configurations** using **Abaqus with Python scripting**.

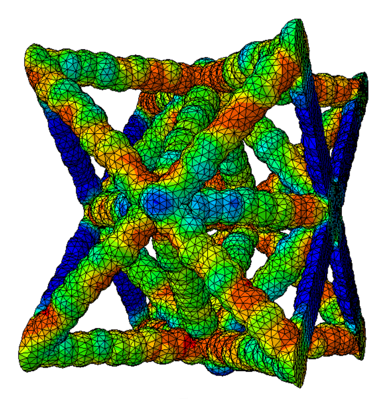
Mesh of a single strut

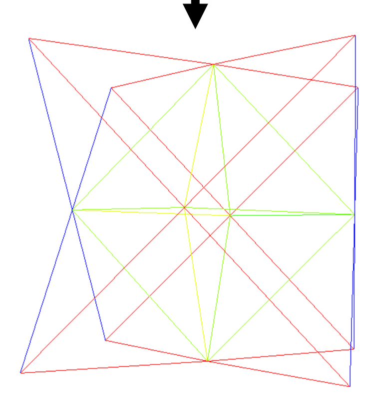


Mesh of a BCC cell

Simplified models

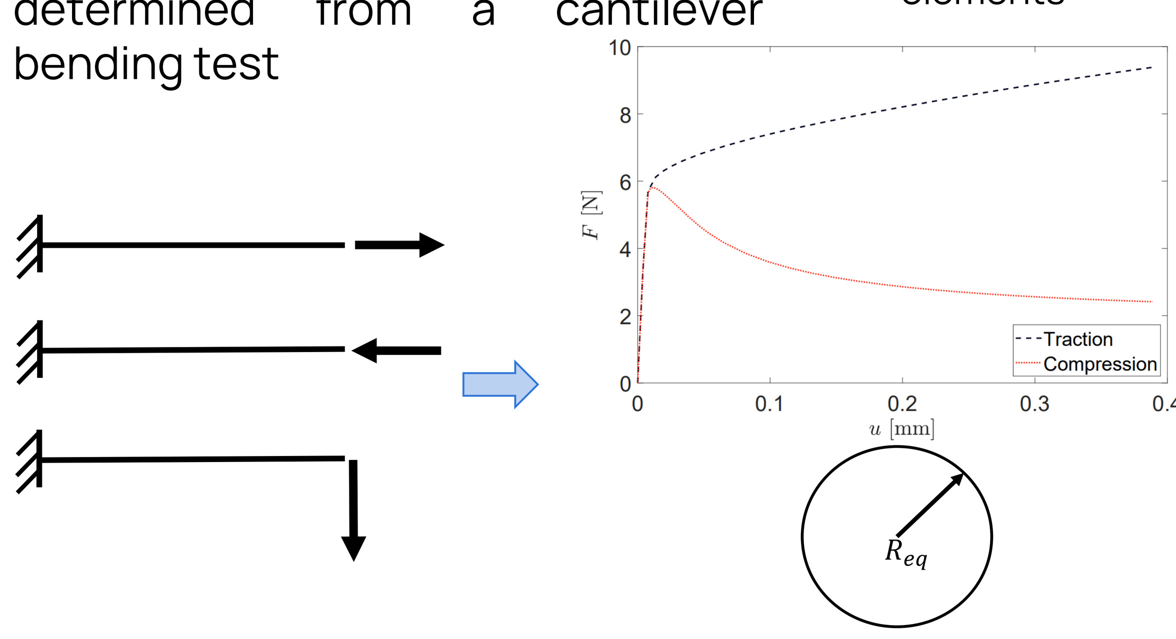
The **3D models** provide a refined description of the manufacturing imperfections. However, **the large number of degrees of freedom** resulting from the generation restricts the applicability of this approach.
For this purpose, a **simplified modelling strategy** based on **1D beam elements** is proposed.





Simplified modelling strategy with 1D elements

Both the **material and geometric nonlinearities are embedded in the constitutive law**, which is defined by the force–displacement response of an **imperfect strut** under **tension or compression**. The equivalent section is determined from a cantilever bending test

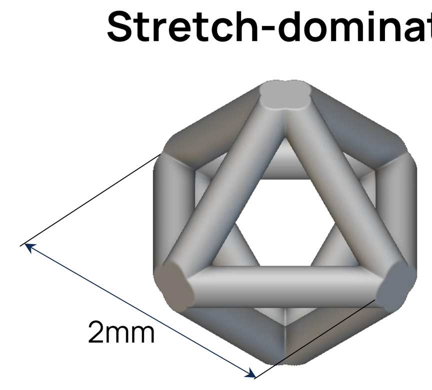


Compressive and tensile load curve for the constitutive law of the struts, bending test for the equivalent section

Identification of imperfections and geometrical non-uniformity

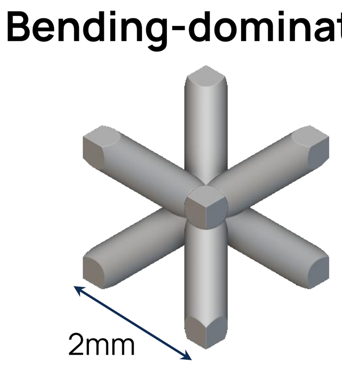
The data extrapolation process is based on lattice structures derived from two representative unit cell topologies at different relative density (20%-30%).

Stretch-dominated



Octahedron

Bending-dominated

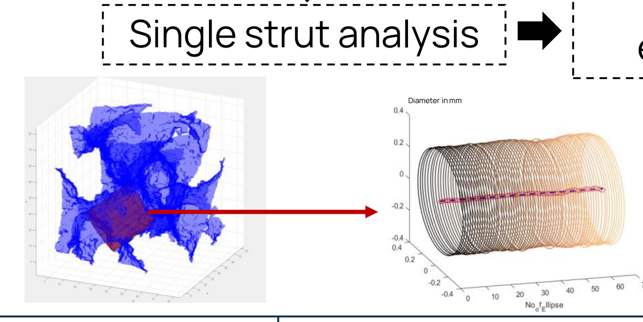


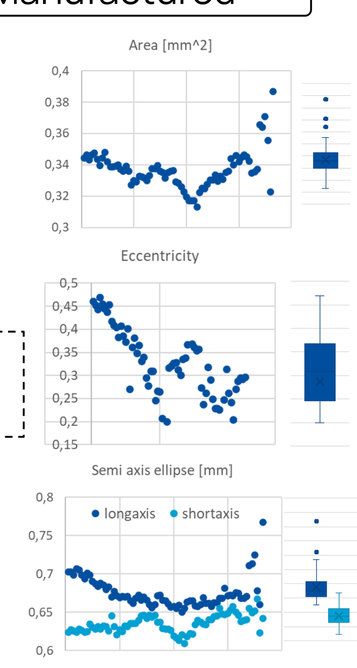
BCC

Identification of Geometrical differences
- Variation of the strut's cross section
- Cross-section elongation along the building direction
- Cross-section eccentricity
- Strut's waviness
- Variation of the strut's inclination

Comparison CAD - Manufactured

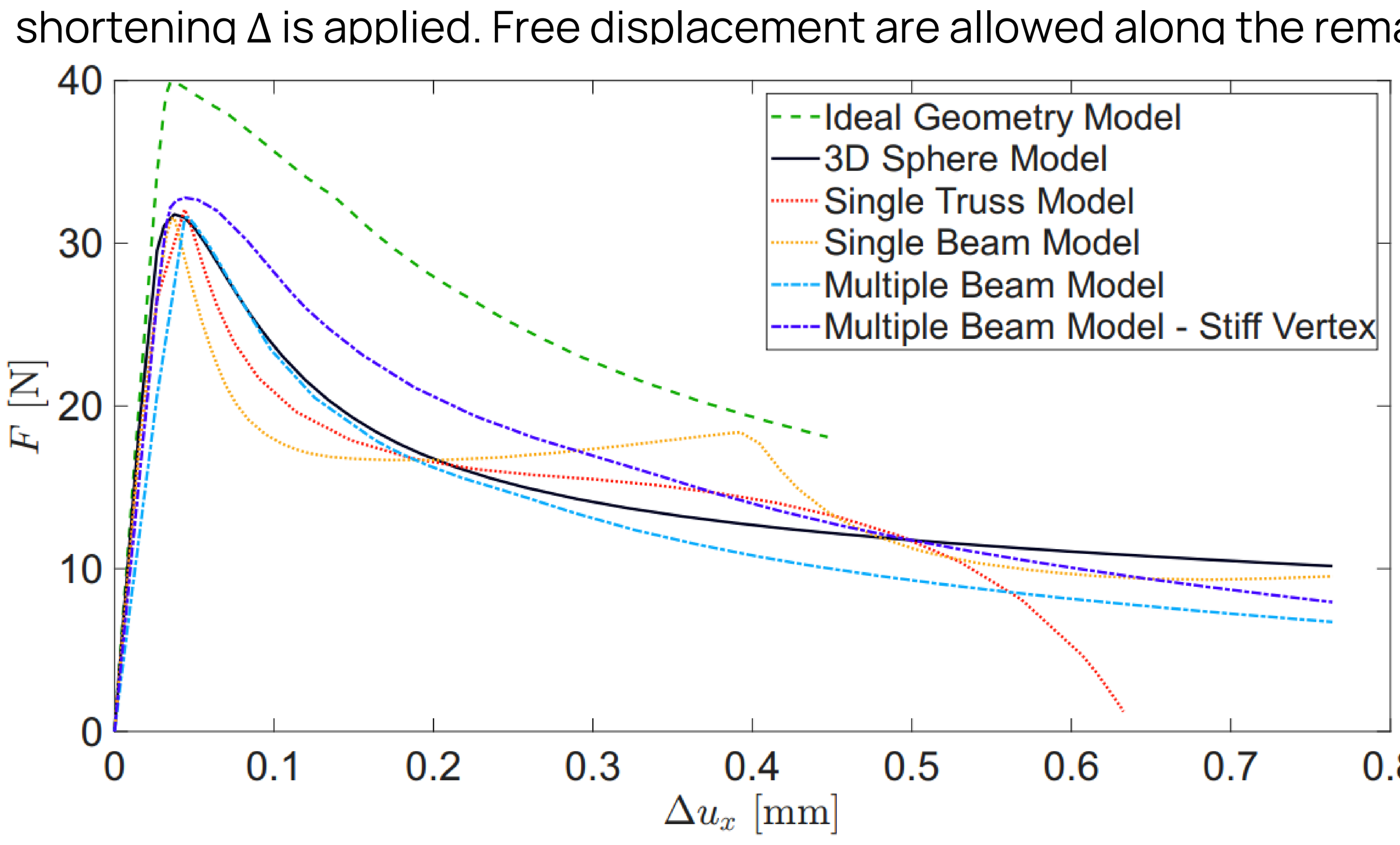
CT Scan raw data → Stack image analysis → Unit cell data manipulation → Single strut analysis → Feature extraction



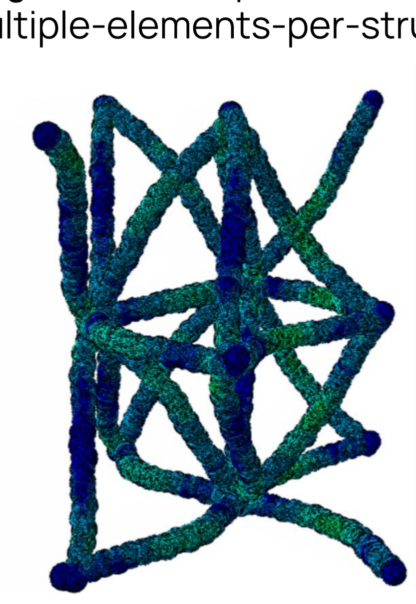


Results

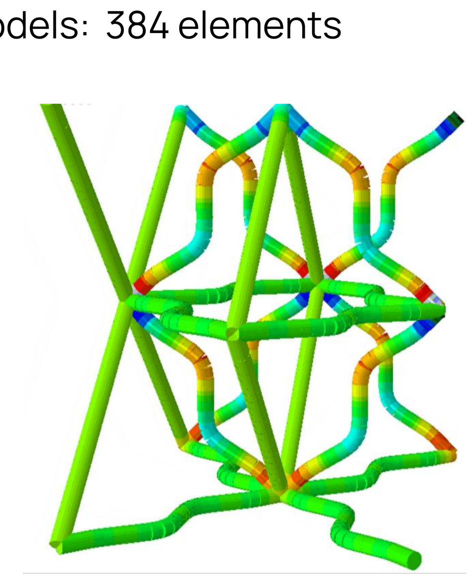
A **compression analysis** is performed on the **periodic octet cell** for 6 different models: a model with the ideal geometry, the sphere model generated with defects, a one-truss-per-strut model, a one-beam-per-strut model, a multiple beam-per-strut model with stiffened vertexes and a multiple-beam-per-strut model without stiffened vertexes.
The cell consists of 24 struts with the typical defect distribution and periodic boundary. Along the compression axis, a shortening Δ is applied. Free displacement are allowed along the remaining two axes, with identical values for each face.



3D sphere model:	1 200 000 elements
Single-element-per-strut models:	24 elements
Multiple-elements-per-strut models:	384 elements



Sphere model: deformed octet cell



Beam model: deformed octet cell

- For the **single element-per-strut models**, the **initial stiffness** and **maximum load** are **captured accurately**. However, the post-peak deformation is not represented correctly, as the model is inherently limited by the adoption of a single element per strut.
- Among the **multi-element-per-strut models**, only the configuration with a **stiffer region near each vertex reproduces the initial stiffness accurately**.
- Both **multi-element models**, **capture the post-peak deformation** with good agreement to the 3D solid-element model.
- The **ideal geometry model overestimates** the overall **structural strength**.

Conclusions

- A numerical framework has been developed to model the mechanical response of lattice structures produced by additive manufacturing, accounting for geometrical and material imperfections.
- The results demonstrate that imperfections significantly reduce the maximum load under compression.
- The simplified 1D models reproduced the overall compression behavior of the octet cell in good agreement with the high-fidelity 3D solid model, while requiring drastically lower computational cost.

Next steps

- Results from CT scans will be used for the numerical generation of struts once available.
- Comparison with experimental data
- The framework will be exploited for lattice structures optimization