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Title	Data-driven multiscale framework for architected cellular materials
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Research project description:

Social & scientific context. The tendency to shift towards cellular materials in lightweight application is mainly inspired by bio-mimicking. Nature have already evolved cellular materials like beaks and bones of birds that consist of thin solid skins attached to a highly porous core. The rapid development of additive manufacturing *e.g. Selective Laser Melting* (SLM), opened the door for the topological optimization and in particular creation of lattice-type materials. Ability to « print » a material with the chosen lattice architecture leads to high specific structural efficiency where strength and stiffness scale proportionally with the solid volume fraction. Thus, the principal application of lattice materials is in transport (aerospace, *e.g.* Fig. 1) and industry with the most stringent criteria related to mass reduction, energy absorption (crash) and thermal management. The tendency to shift towards cellular materials in lightweight application however requires a dedicated tool for their design and prediction of their specific behavior. Classical computational tools based on finite elements (FE) together with high-fidelity models lead to time-consuming simulation of lattice-type materials on the structural scale.

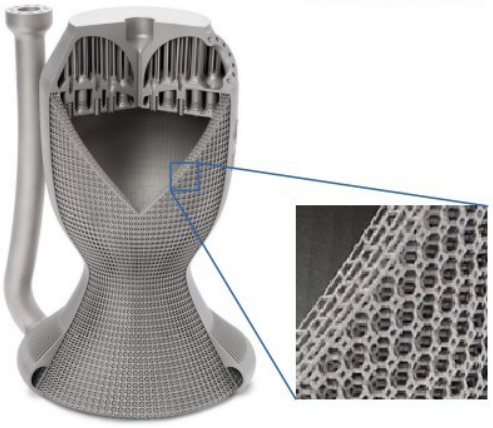

Fig 1: 3D printed rocket engine, cellcore.com

Methods. A promising alternative is the multi-scale (MS) modeling [1] permitting to obtain the material behavior on the macro-scale from the simulation of the representative part of the high-fidelity micro-scale with fine FE mesh and all the geometrical/material details. The principal downside of MS modeling based on the computational homogenization [2] is that the computationally expensive micro-simulation has to be run for every load step and integration point leading to tremendous repetitive computations. A solution for the problem of repetitive and never re-used computations is proposed recently [3, 4] and resides on combining data-driven approach [5, 6] and computational homogenization in order to: 1. Promote the coupling between different scales hoping to increase predictiveness of higher scale models, 2. Facilitate the coupling between experimental data and simulation since they are from the point of view of data-driven approach indistinguishable points in the data set, 3. Increase the structuring and re-usage of high-fidelity simulation results across scales to increase efficiency of computation.

Within so-called data-driven multiscale (DD-MS) framework we must have a good material database whose creation based on numerous micro-simulations still represents a very high computational cost.

On top of that non-negligible cost comes the key challenge which is to efficiently sample the database in the case of varying micro-scale geometry. These variations occur either intentionally, to achieve a location specific cellular structure, or accidentally due to defects related to the limitations of the manufacturing process. In the proposed project we will deal with the defects, which inevitably form during material layer deposition and alter the ideal (CAD, as-designed) lattice architecture to real (as-manufactured) architecture (Fig. 2) and finally govern the overall lattice behavior, together with the cell topology.

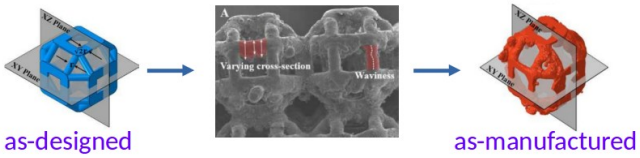

Fig. 2. Defects inevitably forming during material layer deposition with SLM alter the as-designed architecture to as-manufactured [7].

Objectives. The principal objective of the thesis is the development of the efficient data-driven multiscale approach for the prediction of the non-linear behavior of as-manufactured metallic lattice structures. To that end the development of the framework for the parallel computing and computational homogenization of the large number of high-fidelity lattice simulations is envisaged consisting of the in-house python code in combination with non-invasive use of commercial FE code *Abaqus* and HPC platform (*CALMIP*). To make DD-MS approach efficient, the development of the algorithm able to learn the material database variations as a function of the geometry variations is necessary. To that end, the work envisaged within the thesis is related to the analysis and classification of the defect's morphology, development of the compact parametrization of geometry variations together with the scheme to incorporate geometric imperfections into the computational models. The key open questions are related to the efficiency of the database sampling, speeding up DD solver and time dependent behavior.

Candidate profile. Highly motivated candidate with the applied mathematics or mechanical engineer profile and the interest for the computational mechanics is welcome to apply. The experience in finite elements and programming (python) is required.

The candidates should send their CV and motivation letter to thesis advisors Eduard MARENIC (ICA, marenic@insa-toulouse.fr), Jean-Charles PASSIEUX (ICA, passieux@insa-toulouse.fr).

Period: 2023-2025. **Institution :** ICA UMR CNRS 5312

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