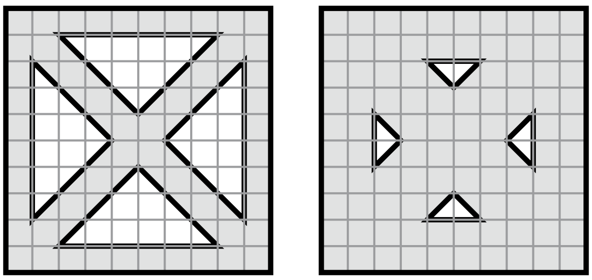
Chair of Computational Solid Mechanics
TUM School of Engineering and Design
Technical University of Munich

# Integrating Convolutional Neural Networks with Finite Cell Method for Efficient Computational Modeling of Unit Cells

## 1 Description

For many solid mechanics problems, high-fidelity simulations (HFS) can capture the most important physical phenomena. The finite element method (FEM) is a well-known time-tested method used to perform the HFS to predict the behavior of the relevant quantities of the design. An alternative formulation of FEM is the finite cell method (FCM) [4]. The FCM combines high-order elements with an unfitted domain, decoupling the physical domain from the discretization solution. Even for complex geometries, FCM generates a simple structured mesh and a solution with high convergence rates, avoiding the time-consuming meshing process without sacrificing accuracy. Additionally, because of the FCM discretization, the same underlying mesh can be used across multiple geometries. These characteristics make FCM attractive for the simulation of cellular structures' unit cells (UC) [1]. In Fig. 1, two different unit cells are discretized with the same FCM mesh. However, HFS are computationally expensive, creating a bottleneck in the design process. This is particularly true during the optimization phase, where multiple design variables are varied to find the best performance. To evaluate the performance of each design, HFS are carried out. A parametric reduced order model (pROM) can be generated for each new simulation to accelerate the process.



**(a)** Low thickness value **(b)** High thickness value

**Figure 1** Strut-based unit cells

The pROM can generate models, allowing the designer to run multiple fast simulations for different designs without running additional HFS. Each of these designs has different material and geometry properties. Existing research has extensively employed deep learning as a data-driven pMOR approach. In recent years, convolutional neural networks (CNNs) [3] have been developed to predict the mechanical behaviour of structures [2, 5]. The input data for the CNNs is, in general, a matrix; to construct this matrix, the domain is discretized on a regular grid, with each grid element assigned a value based on its location. This process is similar to the FCM assembly process. Thus, making it attractive to combine CNNs with FCM.

This work aims to develop a framework that combines state-of-the-art convolutional neural network architectures with the finite cell method to create parametric model order reduction techniques for unit cell geometries.

## 2 Student Profile

We are seeking a motivated master's student who possesses an interest in model order reduction, machine learning, and finite element methods in computational mechanics. The candidate should be able to work independently and maintain a systematic approach to their work. A fundamental understanding of finite elements and neural networks is required, and any prior experience with Python and AI is highly valued.

## 3 Scope of the Work

- Understand the basic principles of the finite cell method.
- Research on different types of unit cells for cellular structures.
- Literature review on the state-of-the-art convolutional neural networks and similar architectures for solid mechanics.
- Implementation of different deep learning methods, whose inputs come from FCM simulations.
- Comparative analysis of the accuracy and the computational cost of the obtained results.
- Documentation and presentation of results.

## 4 Application

If you are interested in this project or have further questions, please email juan.vargas@tum.de with your CV and transcript of records.

## 5 Supervision

Juan Angelo Vargas Fajardo M.Sc.
Room: N6 2632
+49 (89) 289 - 22655
juan.vargas@tum.de

## References

[1] Aamer Nazir, Kalayu Mekonen Abate, Ajeet Kumar, and Jeng-Ywan Jeng. A state-of-the-art review on types, design, optimization, and additive manufacturing of cellular structures. 104(9–12):3489–3510, 2019.

[2] Zhenguo Nie, Haoliang Jiang, and Levent Burak Kara. Stress Field Prediction in Cantilevered Structures Using Convolutional Neural Networks. *Journal of Computing and Information Science in Engineering*, 20(1):011002, February 2020.

[3] Keiron O'Shea and Ryan Nash. An Introduction to Convolutional Neural Networks, 2015.

[4] Jamshid Parvizian, Alexander Düster, and Ernst Rank. Finite cell method: h- and p-extension for embedded domain problems in solid mechanics. *Computational Mechanics*, 41(1):121–133, September 2007.

[5] Mohammad Rezasefat and James D Hogan. A finite element-convolutional neural network model (FE-CNN) for stress field analysis around arbitrary inclusions. *Machine Learning: Science and Technology*, 4(4):045052, December 2023.