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Cellular Solids in sea urchin spines: Numerical analyses and parametric modelling

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Micro Abstract
Sea urchin spines show a complex hierarchical lightweight structure which consists of porous calcium carbonate. They can resist high mechanical loads and when getting compressed, they show a graceful failure behavior. Numerical analysis starts with generating models of sea urchin spine parts based on CT-images. The second approach is based on parametric modelling, to create cellular solids with varied parameters. These are then used in simulations to analyze the influence of the microstructure.

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Introduction

The sea urchin species *Heterocentrotus Mamillatus*, the slate pencil urchin, can grow up to 12 cm long and 1 cm thick spines which consist of highly porous Mg-enriched calcium carbonate. These sea urchins live in the warm sea of the Indo-Pacific region in depths up to 25 meters and fix themselves in the rocks with the help of the spines. Interestingly the spines show a very complex hierarchical and lightweight structure and can resist high mechanical loads. When getting compressed, they show a graceful failure behaviour [1].

The analysis starts with a step of image processing methods to generate a model of a part of the sea urchin spine. Basis for that are computer tomography (CT-) images. With this method, a high accuracy of the shape transformation into the model can be accomplished. This involves different steps in image processing like converting the images, denoising, definition of different regions with thresholds of grey values and finally transferring the structures in geometrical voxel models. In a last step, the models get meshed and are analyzed in FEM (finite element method) analyses to calculate e.g. stresses or forces and to compare the results with experimental ones. With that approach, only voxel models are produced, because these are less computationally demanding than models with a much higher accuracy. Nevertheless if different regions inside the sea urchin spine are compared, one can find e.g. regions where the microstructure can resist a higher force with the same amount of porosity.

In a second approach, the porous microstructure is transferred from high resolutions CT images into highly detailed numerical models. Because of the high amount of structural information, only small parts of the structure can be analysed with FEM at one time. This enables to find the influence on the different strut sizes and their connections and relationships between different shapes of pores.

The results need to be analysed in a way to show the influence of different microstructures or gradients of the porosity found at different places in the sea urchin spine through e.g. statistical methods like the Weibull distribution. Through a correlation of microstructure and resulting mechanical response, principles can be extracted and transferred into new materials for the use not only in architecture which will be produced later on. The abstracted and simplified cellular structures are also under investigation (Compare Figure 1). E.g. parametric studies of

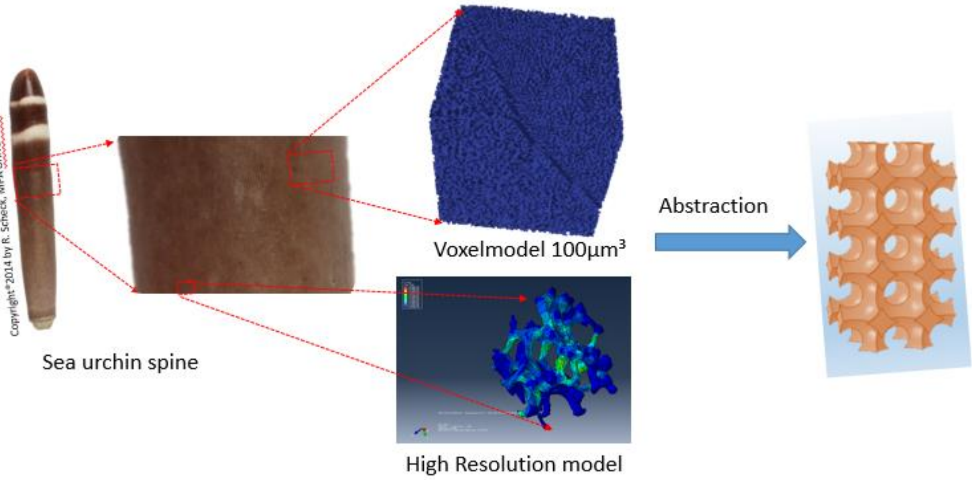

Figure 1. Steps to get an an parametric model based on the role model.

the pore and /or strut sizes and gradients inside the structures are sued to generate a better understanding of these structures and enable the transfer into architecture. In the ongoing research, not only the mechanical properties are of interest, but also the possibilities to use the same or an adapted microstructure to transfer e.g. heat, or even water for the use in buildings.

Conclusions

Detailed models on the basis of high resolution computer tomography images are usable for the analysis of the general geometry and to get information about the most stressed parts of the structure. In compression test, small cuts of the microstructure of the sea urchin spine were analyzed in compression. The parametric modeling approach enables the creation of variations of the microstructure, abstracted from the role model.

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