Diatoms are unicellular, photosynthetic microalgae with complex hierarchical shell morphologies and features. The unique, three-dimensional anatomy of their silica exoskeletons (frustules) contain structure features ranging from the nano-, submicro- to the micrometer-scales (Figure 1). Due to their extraordinary properties, these frustules have drawn attention from a variety of research fields and they have been proposed to be used in a range of applications, including templates for drug delivery carriers, oil and water separation membranes, optical devices, metal alloy components as well as metamaterials designs. Several studies have shown that diatom frustules show unique mechanical properties such as high specific strength and resilience against fracture. Most of these properties arise from the hierarchically arranged structural features.

In this work, we will show in-situ nanoindentation experiments on specific positions of single diatom frustules. Nano-X-ray computed tomography (nXCT) imaging has been conducted at exactly the same frustule structures. Based on this 3D nXCT data ultra-fine real geometry Finite Element twins of the frustules have been created. Consequently, the real in-situ nano-indentation experiments have been repeated at the digital FEM twin of the experiment. The analysis and comparison between experiment and simulation then was used to shed light on the mechanics of didymosphenia geminata frustules.

The method described in this study holds great potential to explain how morphology is pivotal to the mechanical performance of the frustules’ hierarchically arranged structures and provides helpful insight for the design of damage-tolerant lightweight engineering materials.