# State of the art and challenges in computational scale-bridging

**Jörg Schröder, Lisa Scheunemann, Matthias Labusch and Carina Nisters**

Institute of Mechanics, Faculty of Engineering
University of Duisburg-Essen
Universitätsstraße 15, 45141 Essen, Germany
e-mail: j.schroeder@uni-due.de, web page: http://www.uni-due.de/mechanika/

## ABSTRACT

The present talk focuses on the two-scale simulation of macroscopic boundary value problems with attached microstructures which satisfy the assumption of scale separation. The direct homogenization scheme is based on the fundamental works on multilevel FEM developed in the late 1990s. The main idea of the so-called FE²-Method [1,2] is to attach representative volume elements (RVEs) at each macroscopic integration point, instead of deriving a macroscopic constitutive model. This approach involves the localization of the macroscopic process variables on the underlying microstructure and a homogenization step, in addition a consistent linearization of the macroscopic constitutive quantities and the determination of the effective overall properties are performed. The goal of this talk is to demonstrate the applicability of the computational scale-bridging for a variety of fields, such as the simulations of hyperelastic composites, polycrystalline materials, porous media and magneto-electro-mechanical compounds. Homogenization schemes of geometrically nonlinear problems can be accompanied by stability problems like buckling; consequences of this are discussed in [3]. A current field of application is the homogenization of complex microstructures of e.g. Dual-Phase steels, whose effective material behaviour is governed by the interaction of the soft ferritic matrix material with hard martensitic inclusions embedded therein. A reduction of computational costs can here be achieved through the use of statistically similar RVEs (SSRVE) instead of real microstructures [4]. A more accurate estimation of the critical field quantities is possible on the basis of a physically motivated micromechanical model for the ferritic matrix phase, like crystal plasticity [5]. Another important field is the design of composites with a magneto-electric (ME) coupling effect, a product property arising artificially in composites combining materials with different ferroic characteristics in the individual phases, which do not exhibit any magneto-electric coupling effects. In these two-phase compounds, the ME-effect is strain-induced due to the microstructural interaction and depends on the microscopic morphology. The homogenization approach within the FE²-Method yields the desired ME-coefficient [6]. Future work will relate to these research activities in both the investigation of coupling phenomena of microstructures as well as the representation of complex microstructural by means of SSRVEs. Furthermore, the computation of overall responses of a 3D fluid saturated porous microstructure using a fluid-structure-interaction approach is in alignment with the research in the aforementioned fields and forthcoming work.

## REFERENCES

[1] R.J.M. Smit, W.A.M. Brekelmans and H.E.H. Meijer, *Predictions of the mechanical behavior of nonlinear heterogeneous systems by multi-level finite element modeling*, *Computer Methods in applied mechanics and engineering*, Vol. 155, 181-192 (1998).

[2] C. Miehe, J. Schröder and J. Schotte, *Computational homogenization analysis in finite plasticity simulation of texture development in polycrystalline materials, Computer Methods in applied mechanics and engineering*, Vol. 171 (3), 387-418 (1999).

[3] C. Miehe, J. Schröder and M. Becker, *Computational homogenization analysis in finite elasticity: Material and structural instabilities on the micro- and macro-scales of periodic composites and their interaction, Computer Methods in applied mechanics and engineering*, Vol. 191, 4971-5005 (2002).

[4] D. Balzani, L. Scheunemann, D. Brands and J. Schröder, *Construction of two- and three-dimensional statistically similar RVEs for coupled micro-macro simulations*, Computational Mechanics, Vol. 54, 1269-1284 (2014).

[5] C. Miehe, *Exponential Map Algorithms for Stress Updates in Anisotropic Multiplicative Elastoplasticity for Single Crystals*, International Journal for Numerical Methods in Engineering, Vol. 39, 3367-3390, (1996).

[6] J. Schröder, M. Labusch and M.-A. Keip, *Algorithmic two-scale transition for magneto-electro-mechanically coupled problems. FE²-scheme: Localization and homogenization*, Computer Methods in Applied Mechanics and Engineering, Vol. 302, 253-280 (2016).