Several different approaches are available in order to describe material behaviour. Considering material on the higher (macro) level of observation constitutes the macroscopic approach. However, the key to understand a macro materials behaviour lies in its mesostructure. As such the mesoscopic approach can be used which is based on the detailed material description of the lower (meso) observational level.

The main focus of this dissertation is the combination of the two above techniques - the multi-scale approach. The idea is, by means of a hierarchical multi-scale procedure, to bring the homogenised information of the detailed mesostructural description to the macro-level in the form of effective properties. Thus, the homogeneous macrostructural behaviour is driven by the heterogeneous mesostructure.

Traditionally, the size of a Representative Volume Element (RVE) of the material on the meso-level is chosen as a model parameter within the multi-scale framework.

Two questions arise: what should this size be and how stable is this multi-scale model based on an RVE?

As an answer to the first question, a unique procedure to determine the RVE size is proposed in the dissertation. An extensive study of this size sensitivity to different test and material parameters, both deterministic and stochastic, has been discussed. With knowledge of the RVE size, the multi-scale procedure can be introduced, in which the meso-level RVE plays the role of a macro-level length-scale parameter.

However, the answer to the second question is not always positive. As an example the material behaviour due to mechanical loading can be considered. Although the results are stable and reliable in the linear-elastic and hardening regimes, the picture changes in softening. This is caused by the material developing strain localisation and as a consequence losing its statistical homogeneity. For such a material a Representative Volume cannot be found and as an inference cannot be used in the multi-scale framework.

A conceptually new so-called coupled-volume multi-scale approach is introduced, based on abandoning the separation of scales principle. This approach does not require an RVE be a model parameter. The idea of the approach is to uniquely link the size of the mesostructural unit cell and element size of the discretised macrostructure.

The results of this coupled-volume approach show stable and reliable behaviour in all mechanical regimes.