# COMPARISON OF DIFFERENT DUAL SCALE METHODS FOR NUMERICAL PERMEABILITY PREDICTION

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## Abstract

Permeability is a crucial material parameter for the simulation of a large variety phenomena and processes involving fluid flow through porous structures. In composite manufacturing using Liquid Composite Molding processes, it quantifies the conductance of the fiber structure to liquid flow. Numerous studies have already addressed modeling and numerical permeability prediction of resin flow through composite fiber reinforcement structures. Various approaches deal with the dual scale nature of textiles have been proposed, i.e. how to consider flow within the fiber bundles (microscale) and between them (mesoscale), but none of them have been able to improve the accuracy of the predicted permeability to the desired level of accuracy. In this study, we compare three methods to consider microscale flow in mesoscale simulations (fig. 1).

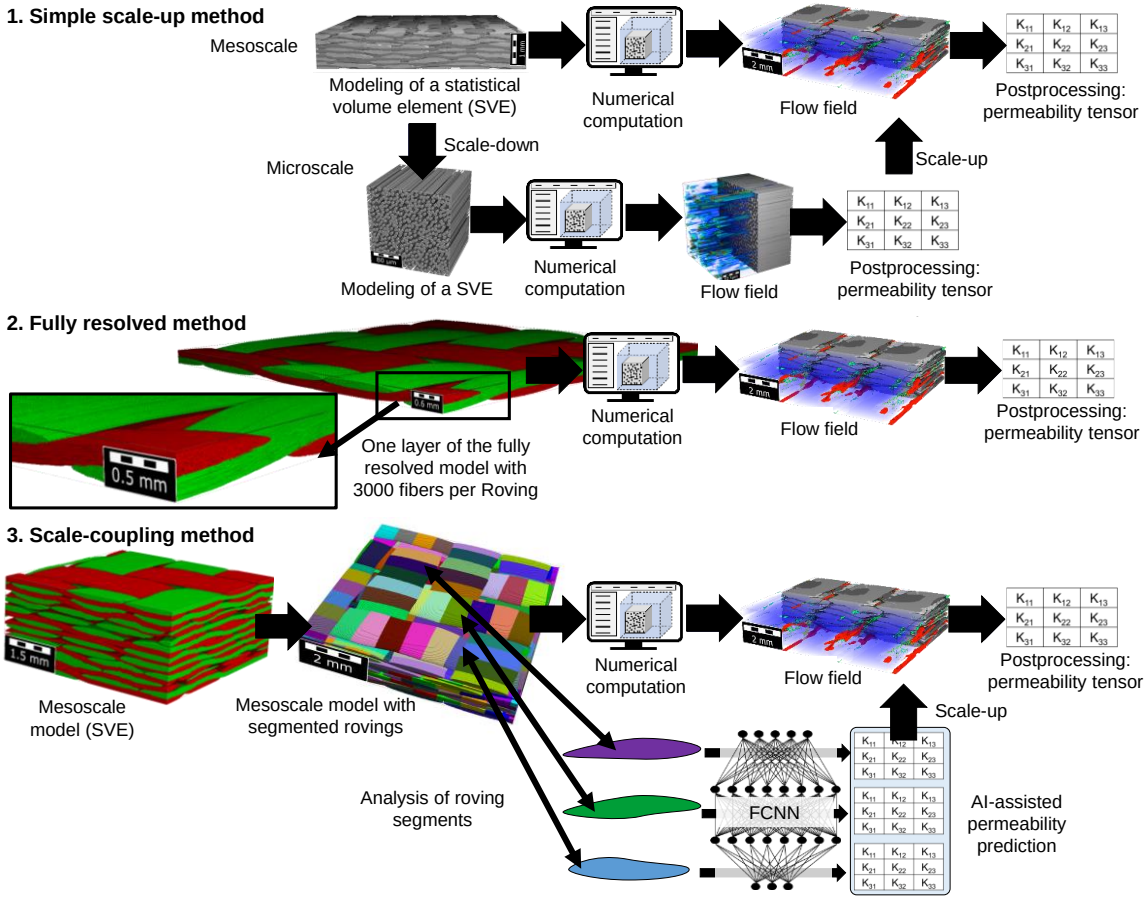


**Figure 1**: *Three dualscale approachs for numerical permeability prediction of textile reinforcement strucures: 1. "Simple scale-up method", 2. "Fully resolved method" and 3. "Scale-coupling method"*

The first approach, referred to as the “simple scale-up method”, represents the current state of research. Here, the microscopic permeability is first determined for a microscopic structure representative of the entire mesomodel and the anisotropic microscopic permeability is then assigned to the rovings in the mesomodel, which are modeled using continuum elements. The anisotropic micropermeability is therefore taken into account in the mesoscopic model, neglecting the local roving orientation and local compaction. In the second approach, the permeability is calculated using a mesoscopic structural model in which the micro level is also modeled to a sufficient level of detail. This method is called the “fully resolved method” and requires very high computing resources due to the extremely large models. Here, the micro- and mesoscale are considered in one model and thus the dual-scale permeability is calculated in a single simulation. The third method is called the “scale-coupling method”. Here, a mesomodel is created where the rovings are divided into segments. These segments are analyzed with regard to both fiber volume content and roving orientation. Based on this, the micropermeability is predicted using a machine learning (ML) model. These locally adapted microscopic permeability properties are assigned to the mesomodel and the permeability of the mesomodel is determined. This approach therefore first involves scaling down in order to derive the microscopic properties from the structure of the mesomodel and then scaling up and assigning the microscopic permeability to the mesomodel. This scale coupling therefore allows the determination of the dual-scale permeability of the structure. As reference, a model of the simple scale-up method is also simulated with impermeable rovings. These results do not show a clearly definable difference, but show deviations that can range between 5 % and 300 % depending on the size and number of mesoscopic flow channels present in the model.
All three methods offer different advantages and disadvantages. Approach one is an established method in the field of research, but a large number of simplifications are made which inevitably influence the permeability result. Nevertheless, this method is used as the reference. Method two enables the simultaneous permeability determination on the micro- and mesoscopic scale level and thus avoids errors due to simplifications during scale-down and scale-up. Depending on the model size and resolution, this method is time-consuming and computationally intensive and can therefore only be carried out on a computing cluster. At 1 µm resolution and a comparable size to method 1, the calculation of a model requires 4 days and 2 TB RAM. With a model approximately half the size and a resolution of 2.33 µm, the duration is around 20 h and 100 GB RAM, although the results deviate significantly from the reference values as the FVC increases. Method three is the most efficient method, can be automated and the microscale property inference occurs in a few milliseconds using ML methods. However, this method is significantly more complex than methods one and two and also requires a trained ML model. With trained neural networks, the additional effort is negligibly higher compared to the pure calculation of permeability using method one. A comparison of the first results of this method with the reference results shows a slight difference. These methods are currently being systematically investigated. In summary, all three methods provide plausible permeability values, but the third method offers the greatest potential due to its computational efficiency and high level of accruacy.