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Simulation-Supported Decision Making in Mechanized Tunneling: From TBM Steering to Urban Tunnel Alignment Design

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Urban tunnels are increasingly built with tunnel boring machines (TBMs) that pass close beneath existing buildings, and the resulting ground movements can damage these structures. Two decisions largely determine this risk: the tunnel alignment in the design stage and the operation of the machine during construction. Detailed three-dimensional simulations can predict the consequences of these decisions, but a single simulation takes many hours. In the design stage, this limits the analysis to a few selected alignments. During construction, simulation results are not available within the short time in which the machine must be adjusted to unexpected ground conditions.

This dissertation develops a framework that makes high-fidelity tunneling simulations usable for decisions in both stages. It builds on a finite cell model of the mechanized tunneling process, in which soil layers, tunnel alignments and buildings share one structured mesh, so new geometries require no remeshing. The model is generated automatically from project data, including borehole records, building footprints and construction process data, and validated with monitoring data from a tunnel project in The Hague, the Netherlands.

Surrogate models based on proper orthogonal decomposition and radial basis functions (POD-RBF) then replace the full simulation, predicting settlements, lining forces and building damage within seconds instead of hours.

These components are combined into two applications. In the design stage, an interactive tool evaluates thousands of tunnel alignments along a 1.4 km urban corridor with more than 2,500 buildings. It uses domain decomposition and multi-objective optimization to balance construction cost, curve radius and building safety. In the construction stage, the SMART assistant supports the selection of TBM operational parameters when unexpected ground conditions are encountered, predicting around two million result values per scenario in a few seconds.

The results show that detailed numerical simulation can move beyond isolated pre-construction studies and directly support interactive decisions throughout a tunnel project.

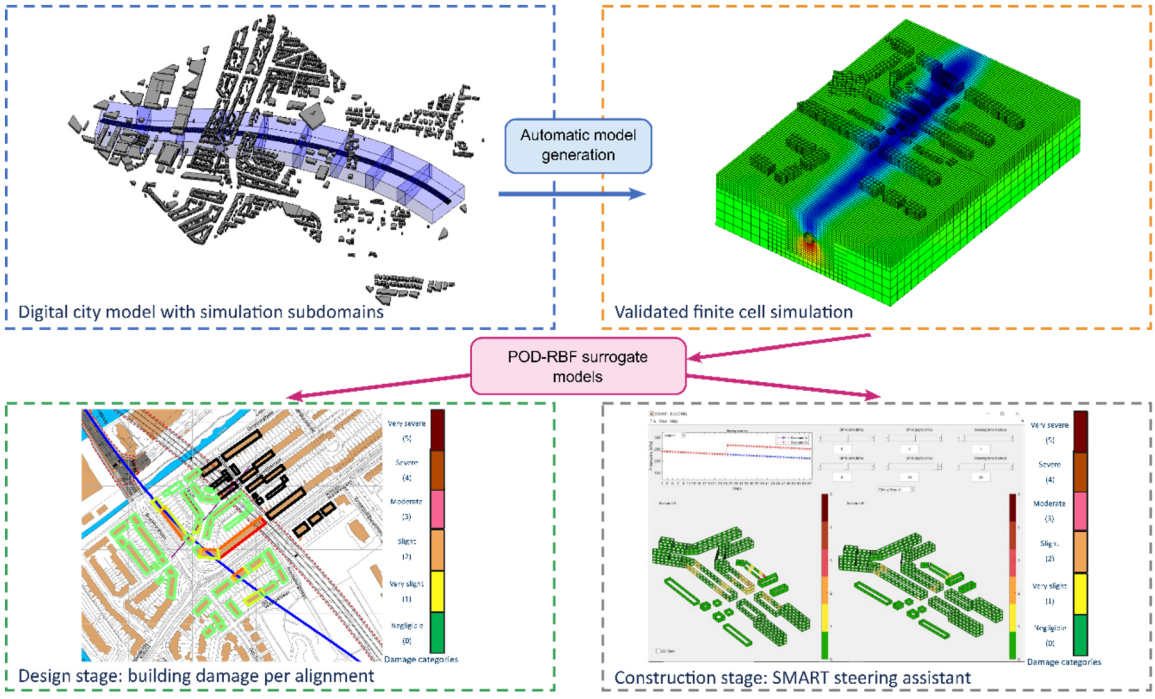


Figure: From data to decisions in mechanized tunneling: project data are converted automatically into finite cell simulation models and replaced by POD-RBF surrogate models. These support decision-making in the design stage, by evaluating tunnel alignments and building damage, and in the construction stage, by selecting TBM operational parameters with the SMART assistant.