Chair of Computing in Civil and Building Engineering
Chair of Concrete and Masonry Structures
Department of Civil and Environmental Engineering, School of Engineering and Design
Technical University of Munich

Master Thesis Proposal

Digital twinning of annular gap grouting simulation setup

General background

In mechanized tunneling, a TBM (tunnel boring machine) carries out the excavation and the construction of the segmented tunnel lining. Because of multiple process related specifications, the diameter of the excavation (hence the diameter of the cutterhead) must be greater than the outer diameter of the tunnel lining. The thereby created void between the excavation surface and the tunnel lining is called annular gap and has a thickness in the range of 10 – 20 cm, depending on the TBM geometry and ground properties[1].

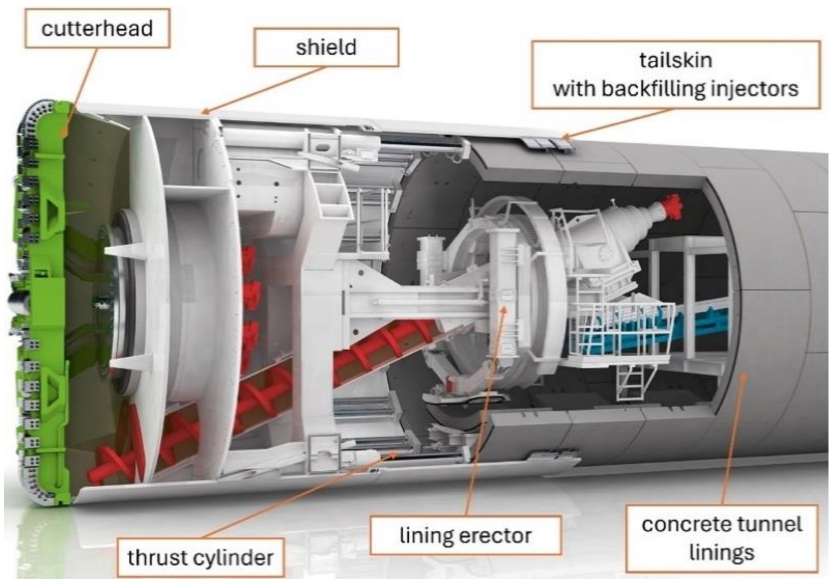

Figure 1: Cross-section of a TBM (adapted from https://www.herrenknecht.com/en/products/productdetail/epb-shield/)

To ensure the stability of the tunnel and to minimize settlements of the surface above the tunnel, a process called backfilling is executed to fill up the annular gap. Proper backfilling plays a vital role in the mechanized construction of tunnels by enhancing the tunnel linings stability, minimizing deformations of the ground and the tunnel and ensuring the safety of the structure and buildings on the surface. Especially in soft soil, the backfilling of the annular gap is realized by injecting highly specialized grouts. The annular gap grout must develop a shear resistance within seconds after injecting to guarantee the position stability of the concrete lining segments in the construction phase while at the same time, workability must be ensured. After the construction phase, it must develop a high enough compressive strength and Young`s modulus to be able to transfer the loads between the tunnel and the surrounding ground. Since tunnels have a life expectancy of more than a hundred years, the grout must be stable and resistant against groundwater and chemical influences of the ground over a long time. Different state-of-the-art grout systems exist to meet these requirements, of which two-component grouts are used increasingly. These mixtures are usually tailored to the special requirements of each project. [3, 4]

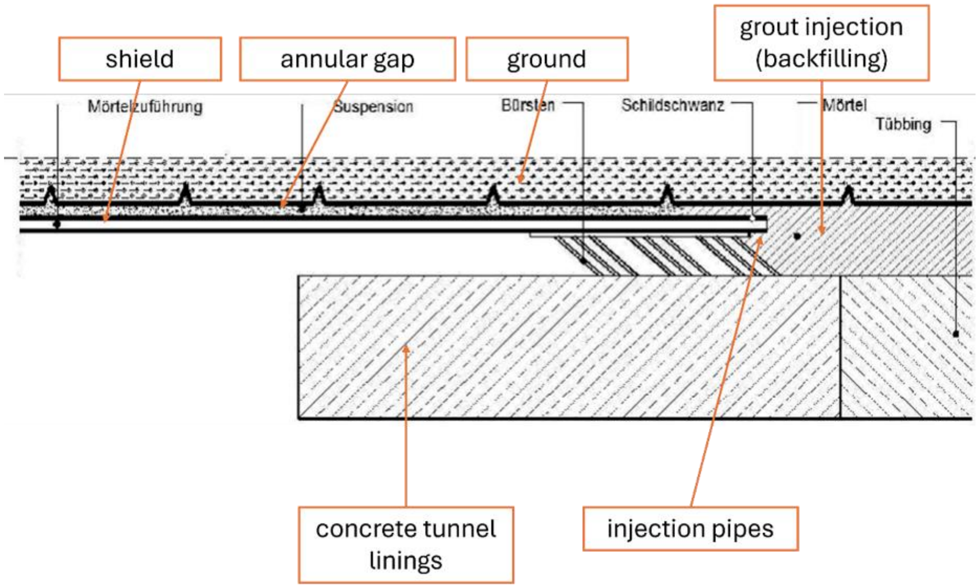

Figure 2: Close-up on the tailskin with a grout injection of the annular gap (adapted from [2])

Description

As part of a research project, a novel two-component grout mixture is being developed. To test the properties of this mixture, an experimental setup for the simulation of the grout injection process under the presence of (ground-)water pressure was designed. Further, this setup is used for the observation of the long-term behavior and the effectiveness of novel grout mixture depending on the requirements resulting of project specifications.

Figure 3 Annular gap grouting experimental system (Proprietary and patented technology)

Constructed from heavy-duty metal components, this one-of-a-kind experimental box is engineered to withstand high pressures and provide a leak-proof environment for the grout injection experiments. It typically features multiple bolted sections, inlet and outlet ports, and pressure fittings to facilitate the controlled introduction and monitoring of grout mixtures. In experimental contexts, this grouting box is essential for:

- Assessing the flow, setting, and hardening characteristics of different grout mixtures.
- Simulating field conditions such as soft soil to study grout penetration
- Evaluation of the workability of the mixture
- Observation of the grout pressure
- Measuring parameters like permeability development of compressive strength and shear strength over time and durability of the grouted body.
- Long-time behavior with and without water

Digital twinning in civil and building engineering refers to the creation of dynamic, interactive virtual replicas of physical assets – such as buildings, infrastructure, or construction components – that are continuously updated with real-time data from sensors, IoT devices, and BIM models. These digital twins enable engineers and project teams to monitor, simulate, and analyze the performance and condition of structures throughout their lifecycle, from design and construction to operation and maintenance

Task

This project focuses on developing a digital twin [5] of the grouting box by integrating advanced 3D scanning, computational geometry, and parametric modeling techniques. The process begins with generating a high-resolution point cloud of the physical grouting box using 3D laser scanning or photogrammetry, capturing its geometric and structural attributes. Next, point cloud processing methods, such as noise filtering, segmentation, and feature extraction, will refine the raw data to isolate critical components [6, 7]. Geometric processing algorithms will then convert the point cloud into a precise mesh or solid model, reconstructing the topology and spatial relationships. Parametric modeling techniques will further enhance the digital twin by embedding adjustable design parameters. [8, 9] The final digital twin may be used to dynamically simulate grout flow, cure behavior, and distribution of stress, enabling predictive analysis and optimization of grouting processes.

Figure 4 Scanning process with a hand-held scanner

Chair of Computing in Civil and Building Engineering
Chair of Concrete and Masonry Structures
Department of Civil and Environmental Engineering, School of Engineering and Design
Technical University of Munich

Supervisors

Matthias Rosa, Chair of Concrete and Masonry Structures
(matthias.rosa@tum.de)

Stavros Nousias, Chair of Computing in Civil and Building Engineering
(stavros.nousias@tum.de)

Konstantinos Gkrispanis, Chair of Computing in Civil and Building Engineering
(konstantinos.gkrispanis@tum.de)

References

[1] Maidl, B., Herrenknecht, M., Maidl, U., Wehrmeyer, G., 2011. Maschineller Tunnelbau im Schildvortrieb, 1st ed. Wiley. https://doi.org/10.1002/9783433600757
[2] Thewes, M., 2013. Tunnelbau im Schildvortrieb – Verfahrenstechniken und Planungsgrundlagen, in: Beton-Kalender 2014. John Wiley & Sons, Ltd, pp. 121–169. https://doi.org/10.1002/9783433603352.ch6
[3] Gehwolf, P., Schulte-Schrepping, C., Behnen, G., Camós-Andreu, C., Hammer, A., Zougou, D., Breitenbücher, R., Fischer, O., Thewes, M., 2022. Erfahrungsstand zur Ringspaltverfüllung bei einschaligen Tunneln mit Schwerpunkt deutsche Eisenbahntunnel. Taschenbuch für den Tunnelbau 2022 53-136-53–136. https://doi.org/10.1002/9783433611043.ch2
[4] Thewes, M., Budach, C., 2009. Mörtel im Tunnelbau. Stand der Technik und aktuelle Entwicklungen zur Verfuellung des Ringspaltes bei Tunnelvortriebsmaschinen. BAUPORTAL 121.
[5] Montlahuc, J., SHAH GHAZANFAR, A., PERNOT, J.P. and POLETTE, A., 2019. As-scanned point clouds generation for virtual reverse engineering of cad assembly models.
[6] Liu, Y., Obukhov, A., Wegner, J.D. and Schindler, K., 2024. Point2CAD: Reverse engineering CAD models from 3D point clouds. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 3763-3772).
[7] Zhou, L., Sun, G., Li, Y., Li, W. and Su, Z., 2022. Point cloud denoising review: from classical to deep learning-based approaches. *Graphical Models*, *121*, p.101140.
[8] Sarker, S., Sarker, P., Stone, G., Gorman, R., Tavakkoli, A., Bebis, G. and Sattarvand, J., 2024. A comprehensive overview of deep learning techniques for 3D point cloud classification and semantic segmentation. *Machine Vision and Applications*, *35*(4), p.67.
[9] Uy, M.A., Chang, Y.Y., Sung, M., Goel, P., Lambourne, J.G., Birdal, T. and Guibas, L.J., 2022. Point2cyl: Reverse engineering 3d objects from point clouds to extrusion cylinders. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition* (pp. 11850-11860).