From prognosis Ground Model to Tender Model and Tunnel Construction Framework Plan with Tunnel Information Modelling

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ABSTRACT: This article presents a concept for a digital ground model usable throughout all project phases and visualizes causalities between geological conditions and the tunnel structure. Specifically, a dynamic modeling approach is introduced to represent the geological conditions from design to construction. Three process phases are dealt with: (i) a preliminary phase defining the model area, (ii) the geological prognoses, including parameterization and schematization along the alignment as a base for further planning steps, and (iii) the creation of a cumulative tunnel construction model. A schematic, parameterized, small-scale tunnel excavation element model is the basis for a dynamic adaptation of geology. In addition, detailed predictions modeled along the alignment are introduced to represent the predicted geology in higher detail, adjustable in the event of changes, and thus represent the current geological information in the construction area. These models form the basis for a tender model and a digital tunnel construction framework plan.

Keywords: TIM, framework plan, ground model, design process.

1 INTRODUCTION

In conventional and mechanized tunneling, face stability is one of the constantly prevailing questions relevant to tunneling. Different tunneling methods, unique construction methods, support elements, and varying work steps are required depending on the geological conditions to achieve and maintain tunnel safety standards. The framework conditions from geology, geotechnics and tunneling and their tunneling relevant parameters contribute to developing and preparing a combined tunneling framework plan (Austrian Society for Geomechanics 2010).

Model-based design, based on – and in interaction with – a valid ground model, as part of an infrastructure information model (iiM) as a holistic, interdisciplinary and up-to-date representation of the tunnel structure in the form of a digital twin, facilitates the answer to the initial question (Flora et al. 2020). Furthermore, the progressing application of BIM in tunnel and infrastructure design (Tunnel Information Modelling - TIM), shows that there are still limits to implementing the BIM method. Implementing the digital twins and its defined goals, which further depend on its definition, is not always satisfactory.

This article describes a solution that can currently be implemented to meet the requirements in planning concerning the creation of a model-based tunnel construction framework plan and to create the basis for updating the geotechnical implementation planning.

2 OBJECTIVES

2.1 Research question

A literature review was conducted on tunnel construction framework plans in TIM international (Mahsa Ghaznavi 2013) (Muhammad Shoaib Khan, In Sup Kim, Jongwon Seo 2023) and within the DACH region. So far, almost no solutions for model-based tunnel construction framework plans have been sufficiently described (Wenighofer et al. 2022). Furthermore, it showed that there are approaches to solutions in individual planning disciplines (Jonas Weil 2020). However, a model-based, all subsections linking, readable representation of the geological-geotechnical and tunnel construction conditions does not yet exist in the DACH region. A 3D-model-based representation of the classic 2D tunnel construction framework plan has not yet been produced. Implementing this possible requirement was evaluated concerning the Austrian Society for Geomechanics (OeGG) guidelines for the geotechnical design of underground structures with conventional and mechanized excavation (Austrian Society for Geomechanics 2010 & 2014).

This resulted in the research questions:

- How can a model-based representation of the geological baseline information be carried out with the current means and methods?
- How can these methods be used to update geotechnical design during construction?

2.2 Scope

To answer the questions mentioned above, the framework is given within the OeGG – guidelines (Austrian Society for Geomechanics 2010) (Österreichische Gesellschaft für Geomechanik 2014), but implementation as a TIM process is still outstanding. Therefore, a new dynamic approach was developed. This maps the geological-geotechnical conditions and the tunneling-relevant information from design to construction according to the OeGG – guidelines in a TIM model and is based on the classical 2D planning processes.

Three process phases are dealt with: (i) a preliminary phase for the definition of the geological model area, (ii) the geological prognosis, parameterization, and schematization close to the alignment as a basis for the further geotechnical and tunneling design steps and (iii) the final phase of the generation a cumulative model-based tunnel construction tender model.

This is achieved with two fundamental new approaches. First a schematic, parameterized, small-scale excavation element model forms the basis for the dynamic adjustment of the geology, among other things as the basis for geotechnical design. Additionally, detailed 2D profiles depicting the geology near the tunnel axis are generated for visualizing the projected terrain. These profiles can be modified as per the requirements in case of any changes in the geological structure. This ensures that the geological information in the construction zone is always up-to-date and aligned with the target objectives. A hybrid digital near-axis ground model (3D and 2D) is created, which can be used and updated for geotechnical and tunnel construction changes during design (e.g. for considering of different cross-section scenarios).

3 RESULT

After identifying the pertinent questions and objectives, we developed a geological design process that outlines a model-based plan for tunnel construction (refer to Figure 1). To ensure a comprehensive approach, we outlined three distinct process phases based on the available data, including the geological basis model, laboratory and field exploration data, and alignment and clearance profile. This approach allows for a thorough analysis and construction plan.

3.1 Process description

Phase 1: During Phase 1 of the process, the model area is defined. In traditional 2D planning, this occurs after geological basics have been surveyed in the field (such as mapping and explorations) and the alignment is available. The creation of a longitudinal section related to the axis and a geological horizontal section in the area of the planned structure are part of this phase. These sections help determine the geological conditions in and around the excavation area, which are required for geotechnical design. For example, in tunnel design, geotechnically effective surroundings are two to three times the excavation diameter. The model area must be reduced accordingly when implemented in TIM. In contrast to the basic geological model, the near-axis ground model only includes the area of the planned structure and its geotechnically effective surroundings. Existing structures in the immediate vicinity and, in the case of shallow tunnels, the ground surface must also be considered. The geology basis model is not adapted in the forecast to avoid constant unnecessary over-processing.

Phase 2: This phase involves the detailed preparation of geological baseline data for tunnel design. After preparing axis-related geological prognoses sections along the alignment and detailed forecasts at intersections, cross-section changes, geological transitions, or weak zones, ground types and homogeneous areas are defined. These specifications help determine behavior types, face behavior, tunneling method, system behavior, and tunneling classes. A digital geological prognostic longitudinal section is created based on the near-axis ground model (phase 1). This section assesses and predicts the geology close to the structure, considering exploration results and a professional model and plausibility check

Point of Information Need (POIN) areas can result from this detailed examination. These areas need to be evaluated in detail for further planning, such as construction areas with low geological prognosis reliability, areas with low coverage, fault zones, or existing structures in the vicinity. A structure-related cross-section is then created from the near-axis ground model for a detailed analysis of these POINs. The results are presented in great detail, showing possible variances by using one to several cross-section scenarios. The near-axis ground model is not adapted to this level of detail, but is supplemented with detailed cross-section scenarios. These detailed analyses may also result in a need for further exploration at the POIN for the project, should the information situation not be sufficient for further planning.

From the synopsis of the geological basics and the detailed cross-section scenarios, a structure-related geological prognosis results, as well as the definition of ground types. A small-scale excavation element model is then created based on this geological prognosis data. This model-based approach includes a sub-model separate from existing basic models but linked to them. Geological-geotechnical relevant properties are assigned to model excavation elements, and due to the small-scale processing, a station-specific assessment, evaluation, and necessary adjustment/supplementation of the properties are possible at any time. The distribution of information can be graphically displayed via color coding of individual model properties, which allows for easy evaluation. The excavation element model is the basis for the geotechnical design, which takes place between phases 2 and 3.

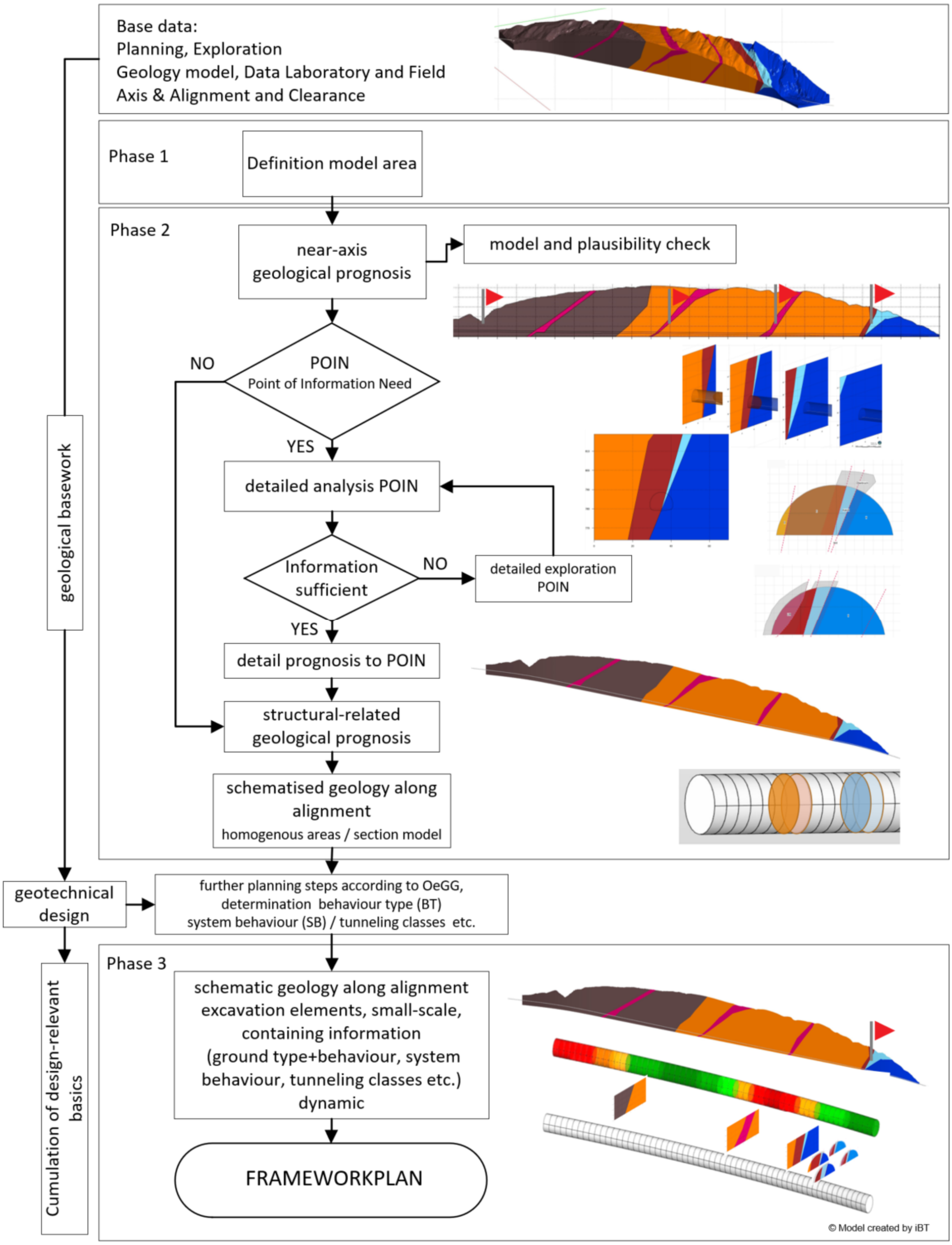

Figure 1. Process for the creation of a model-based tunnel engineering framework plan.

Phase 3: Finally, the geological prognosis and the geotechnical and tunnel construction design based on it are combined. The individual design results are integrated as properties into the existing small-scale excavation element model. The additional information can also be displayed via heat maps and visually supplement the near-axis ground model and data-related in the sense of evaluation bands. The linked cross-section scenarios supplement the digital tunnel construction prognosis section with detailed information at the designated POIN.

3.2 *Example application Perjentunnel fault-zone Innvalley-fault*

To demonstrate the model-based framework plan for tunnel construction, the Innvalley-fault in the second tube of the Perjentunnel is cited as an example. The southern second tube was designed based on geological base maps and explorations, and was excavated in 2016-2017. Using LEAPFROG® Works software, the geological basis model and near-axis ground model for phase 1 were created, allowing for the derivation of longitudinal and cross sections at any station (POIN). The sheets for phase 2 were exported as a PDF plan and .dwg file for further processing. Detailed prognoses for the excavation area were prepared using TUGIS.NET® Suite V7.0 software and exported as a .dwg-file. The excavation element model for phase 2 was parameterized using Autodesk Revit® software, and geotechnical and tunnel construction attributes were added for phase 3. Figure 2 displays the model-based tunnel construction framework plan for the Perjentunnel fault zone - Innvalley-fault, based on the described process phases.

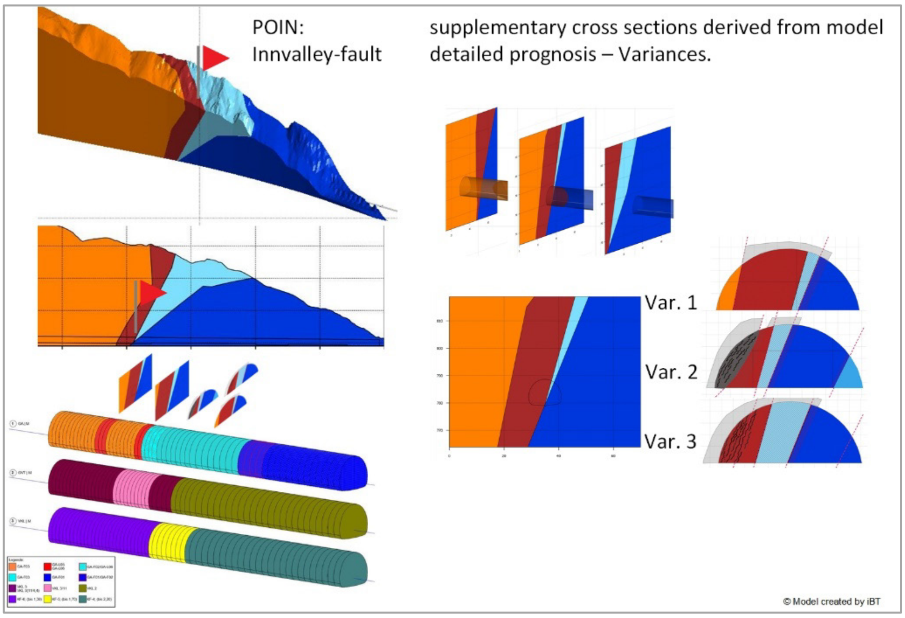

Figure 2. Representation of model-based tunnel construction framework plan.

The color-coded representation of any property results in a station-accurate visual representation of causalities between the ground and the structure. The cross sections created as plan derivation from the near-axis ground model, or the detailed supplementary profiles with a higher degree of information than the existing geological 3D models, enable a better assessment of the excavation situation.

4 DISCUSSION

To successfully implement the proposed concept, it is essential to have reliable geological data based on the guiding principles of good exploration, documentation, and interpretation (gE-gD-gI). A thorough data structure, collaboration, and constant exchange of information are necessary to establish causal relationships between the ground and the structure throughout the project. However, the current methods fall short of representing the detailed geological prognosis, which is often required for specific construction phases, in the ground model. Therefore, the proposed concept involves a hybrid representation of the near-axis ground model using 3D and 2D detail models at POINs. This allows for the visualization of relevant properties by storing information on the excavation element model's objects, enabling easy access to all geological, geotechnical, and engineering information at any station and time. This approach offers a comprehensive overview of the fundamentals, making it possible to visualize variant designs more quickly and promote interdisciplinary cooperation while increasing transparency throughout the project.

5 SUMMARY & OUTLOOK

The small-scale schematic preparation of the geological-geotechnical-tunneling basics in combination with the near-axis ground model enables the station-accurate prognosis, prognosis adjustment and recent documentation as well as the updating of the geotechnical design during the construction phase. There is no need to continually adjust the geological base model, as good, adaptable detailed prognoses are available. The existing near-axis ground model is – depending on the client's requirements – only adapted based on the documentation data of the excavation. Necessary updates of the geological prognosis, and document and changes in the tunnel drive are carried out via the excavation element model. The integration of the information obtained during the excavation work provides the basis for a constant target/actual comparison and for updating the work estimate.

To further develop the project, it is crucial to place a transparent frame of the schematic near-axis ground model around the structure model, with its effective geotechnical range. Any BIM/TIM software can generate geometrically simple elements, including 3D geometry and attribution, and can be used as a general information carrier. This will allow non-geometrical information from any project participant to be included, even those without BIM/TIM practices, such as information about a chainage based on simple lists. However, referencing several schematic models with their data in modeling software can result in a bad performance, and identical schematic overlays can make it difficult to find the needed data. Thus, bundling information of several project participants in one element can provide an efficient solution in terms of managing the model and its size. As the amount of information increases, it is vital to structure the information to ensure organized and efficient data management.

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