# Information Modelling based Tunnel Design and Construction Process

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**Abstract - The present development situation of 3D and BIM based process model for tunnel design and construction methods has been studied. Tunnel design is generally done using traditional 2D drawing based working methods. As a basement for the research, the new specifications developed in Finland for national BIM requirements for infra sector were used. However, underground tunnels are not yet considered in these specifications. In a research project, a new concept how to use intelligent information modelling in tunnel works have been under development. For comparison, five different tunnel design and construction projects and work areas were studied and evaluated. A technical-economic evaluation for the future model of tunnel design and construction is also presented.**

**Keywords - 3D, BIM, tunnel design**

## 1 Introduction

In Finland, a special effort has been focused on the development of Building Information Modelling (BIM) based process model and guidelines for infra industry including roads, streets, railways and bridges (www.infrabim.fi) [5]. Due to the resource limitations, underground tunnels in road and railway construction projects or in mining have remained to be out of this work, which was one reason to perform this study. In the world, we have found only one similar activity, which has been done a little bit earlier in Norway with HB138 specifications for infra sector as well [3]. In addition, University of Oulu and VTT Technical Research Centre of Finland have an active project called FlexiMine (Flexible Optimization of Mine Production) that aims to the same area of information modelling and automation based development of current work methods and technologies in tunnelling and underground mining.

The HB183 information modelling specifications of Norway determine also tunnel works including guidelines for documentation, how to model existing situation, models of new structures as well as roles and task for practical works. Tunnels are considered as underground objects, to which a determined level of uncertainty is allowed for 3D coordinates. According to HB 138, the 3D geometry of tunnels has to be modelled in its entirety. There are also accurate specifications set for the information transfer from design software used to the LandXML standard based open information transfer file. [3]

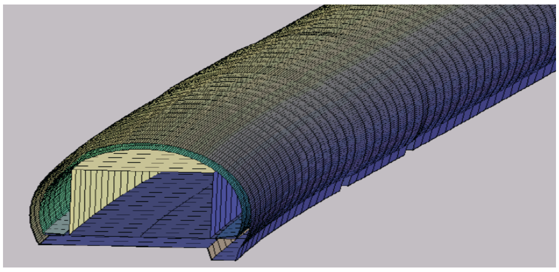

Figure 1. A example for tunnel modelling by Norwegian HB 138 specification [3].

McHattie (2013) examines the intelligent mine concept provided by Bentley. Intelligent mining implies the application of information technology at every phase of the mining value chain, from exploration and geological modelling to equipment, operations and maintenance, and logistics and transportation. According to the paper, the fundamental idea is that the operator of mine has a complete 3D digital representation of the physical world, i.e. the digital asset of the mine. For the infrastructure information exchange, Bentley offers i-model, which gathers all the different information gathered together. [4]

Two major tunnelling projects, the first in London (Crossrail, 21 km tunnels, 37 new stations, value about £15 billion) and the second in Stocholm (Bypass, 18 km tunnels, 3 lanes in each direction, the largest road tunnel project in the world, value about £3 billion) do presently apply and utilize Bentley concept. A BIM Academy has been established for the support Crossrail project needs. In UK, the

Goverment Construction Strategy 2011 announced the intention to require collaborative 3D BIM with all project and asset information, documentation and date being electronic on its projects by 2016.

## 2 Methods

As a part of our Fleximine research project, a new concept for intelligent information modelling and management for tunnelling and underground mining is to be developed. The principles and different parts and examples of the concept are here introduced. In this future concept, continuous 3D initial data models are measured and automatically modelled including digital terrain model, underground soil model and rock model. The accuracy of measurement is any time evaluated and saved to be transferred with the measured information models. The soil model includes all of the different soil material layers (rock, moraine, sand, silt, clay, etc.), their geomechanical and workability features. All of this information is connected to a combined information model using advanced classification, numbering, nomenclature and information structure. This initial information model is saved using open and intelligent format, which is a wide used international standard.

Tunnel design will be done using fully 3D and information modelling based methods and the measured 3D initial data model as a starting point. For the construction operations, different intelligent 3D machine control models (production models) are created and saved to the database of the construction project. Each of the machine control systems pick up automatically the machine control models from the database. Site managers and foremen use dynamic site control system for the guidance and control tasks of the whole work site. Every moving machine and human are continuously positioned using an accurate underground 3D measurement system. Information transfer is done using wireless network. Automated machine control is based on operator assisted or autonomous and unmanned control principle.

In the experiments, the development and utilization situation in five different tunnel design and construction projects and work areas were studied and evaluated: a tunnel part of West Metro (Länsimetro) project in Helsinki (Pöyry Oy, YIT Construction), Finland, Rantatunneli project in Tampere (A-Insinöörit Oy, Lemminkäinen Infra Oy, Tampere City, Finnish Transport Agency, Saanio & Riekkola Oy [6]), Finland, tunnel works in the Crossrail project in London (UK), tunnel design process in the Stockholm Bypass project in Sweden, and tunnelling works in Outokumpu Kemi Mine in Kemi, Finland.

## 3 Results

The current design and construction methods in West Metro project of Helsinki and Espoo was studied by interviewing the main design consultant office Pöyry and the tunnel contractor YIT. The design method used was traditional 2D drawing based according to the special tunnel design specification of Helsinki City. Designer has typically created no deliverable 3D design model. For some special examinations, 3D models have, however, been designed, most often to compare the measurement result of 3D laser scanning with the designed tunnel geometry. In these cases, the tunnel parts have had to model after the design work to enable the deviation calculations and tolerance checking. The contractor has used a typical ground based 3D laser scanning system for the measurements. A special illustration method has been developed for the deviation examinations. In the method, the 3D designed tunnel model is opened to 2D level, where colours illustrate the calculated 3D deviations.

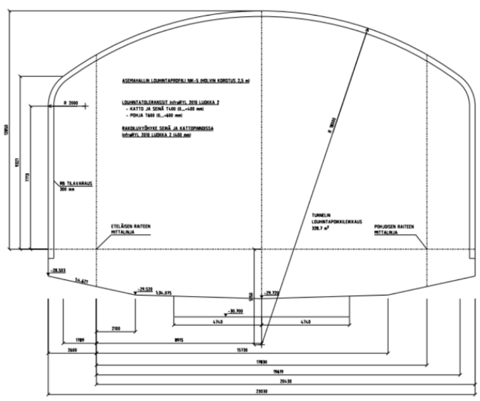

Figure 2. A cross section of West Metro as an example of traditional design process.

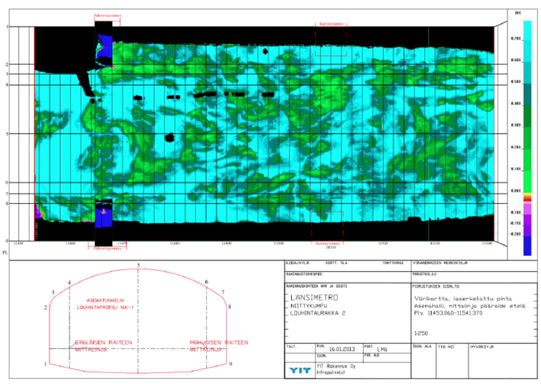

Figure 3. A comparison of measured 3D as-built model with designed model. The 3D design model needed to be extruded afterwards during construction work for the calculations.

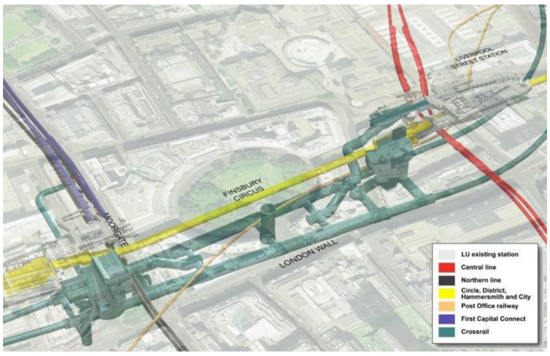


Figure 4. An example of BIM based coordination in tunnel design (Liverpool Station, Crossrail, London, UK).

In the Crossrail (London, UK) project, BIM is utilized largely to integrate data for design, construction and operation. The project uses a project wide consistent approach to flow and production of information (information management) and 3D models are produced by all team members to common level of detail using common tools (information modelling). Direct benefits of BIM have been reduced waste, improved efficiencies, reduced information loss, improved safety, reduced programme risk, improved performance, collaborative model transfer from designer to contractor, and innovative asset management possibility. According to a Crossrail presentation, in the design of only one station (Farrington Station), a cost of £120k was used to develop the 3D model, but it saved over £8 million from risk contingency due to interfacing complexity. The process model used in the Crossrail project is based on the British Standard BS1192.

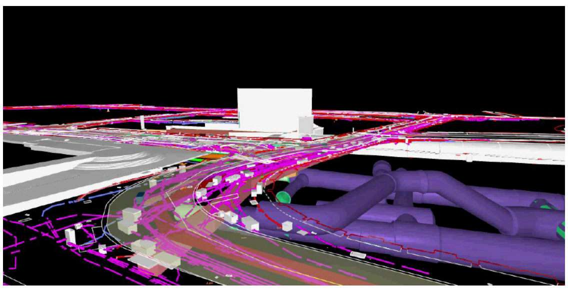

Figure 5. An example of BIM in tunnel design (Crossrail, London, UK).

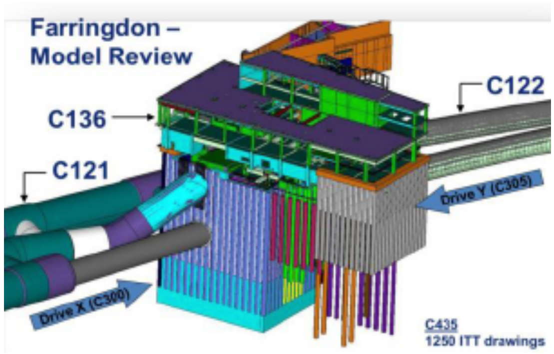


Figure 6. An example of coordination model (Farrington Station, Crossrail, London, UK).

In the Stocholm Bypass project, 3D spatially coordinated and integrated design models are used. This was seen to be necessary for the large project with very demanding 3D tunnel geometry as well as for very international organization for the project activities (over 500 engineers, 19 disciplines, 7 European countries). The main objective of the use of BIM is to create a collaborative project working environment. Also satellite machine guiding systems will be used. Even thought the project locates in Sweden, the process model is based on the same British Standard BS1192.

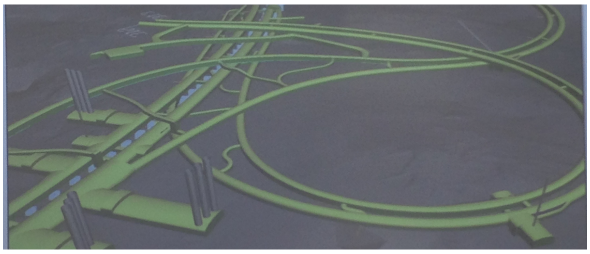

Figure 7. An example of complicated ramps and interchanges in a tunnel model of Stocholm Bypass (URS, London 2014).

The underground Kemi Mine has been evaluated to be one of the most intelligent mine in the world [4]. Currently this mine includes about 50 km underground tunnels. After mining and rock extraction new tunnel parts have been systematically measured using 3D laser scanning systems. All the measured 3D data has been combined into 3D mine model that forms the basement for the whole mine production control. There are a number of wlan base stations that enable the fluent information transfer in the underground mine part as well. A special underground production control center uses the 3D mine model as a base user-interface for the control of all of the mining tasks.

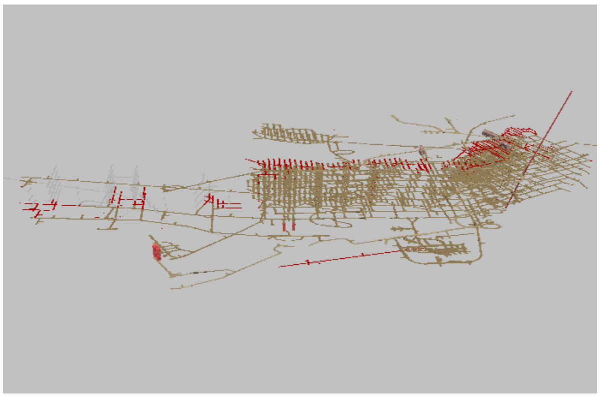

Figure 8. 3D Kemi Mine model.

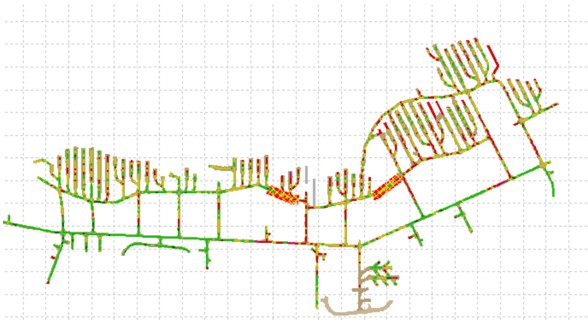

Figure 9. Examination of the measured rock strengths on the level -400 m using the mine model (blue – good areas, red – weak areas).

Rantatunneli project in Tampere, Finland, is executed as an alliance project. The alliance project is planned and carried out together by all parties from the development phase to the implementation phase. The alliance enables better co-operation, information sharing and innovation between the alliance parties. [6]. Roads are designed using 3D modelling and the Infra BIM guidelines. Also bridges and challenging interfaces of different structures (road junctions and tunnel endings) are 3D modeled carefully, but tunnels not. That was not considered to be necessary or cost-effective. According to the contractor, there have been planned some flexible tolerances for tunnel structures that BIM modeling was not needed.

## 4 Conclusions

The Finnish Infra BIM guidelines do not yet determine the process model and detailed specifications for tunnel design and construction work phases. Instead, the corresponding Norwegian HB138 does determine some basics for the BIM process of tunnels. In principle, the specifications are similar as the guidelines for road structures.

The findings of the considered tunnel work in Europe shows diversity in -design and construction methods: typically in small projects the design method is still traditional 2D drawing based like in West Metro and Rantatunneli projects in Finland. Currently, contractors do not see clear and direct benefits in the utilization of BIM methods. Instead, in more large Crossrail and Bypass projects everything information management has been clearly based on the BIM based method and solutions. Significant savings and benefits have already been reported and shown in the Crossrail project. The British Standard BS1192 seems to be important for implementing the functional information modelling based process into practice. The information mobility concept provided by Bentley offers many new possibilities into the development of information modelling, management and utilization of tunnel works. In the well-established Kemi mine underground environment, the advanced production control uses the accurate 3D mine model as the main user-interface to the information management. There are different challenges to develop wireless information transfer as well as 3D positioning.

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