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BIM and Tunnelling – a Norwegian application: the Sotra Link Project

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Abstract – The adoption of the BIM approach (Building Information Modeling) is an established practice for infrastructure design in Nordic countries and is gradually becoming a mandatory requirement for big projects in other developed countries such as Italy. The current paper deals with the application of BIM to the Sotra Link Project (SLP), a complex project of several underground and surface structures between Sotra island and the city of Bergen (Norway), including a 900 m-long suspension bridge and 12.5 km of tunnels. Adopted from the Early Design to the Detail Design of Sotra Link Project, BIM allowed a fruitful information exchange between design teams and client, the creation of a comprehensive design database, and so ensuring design consistency across disciplines, cost optimization and time saving. Within the frame of tunneling, the implementation of innovative discipline-specific workflows including project databases, BIM modeling and computational design software enabled the creation of a comprehensive geotechnical/structural model of all the tunnels involved in the SLP, which constituted a unified data source for deliverables, bill of quantities, and validation of the final design.

Keywords: BIM; underground structures; project database; collaborative design; parametric design; computational design.

1. Introduction

The widespread adoption of BIM in the construction industry is relatively recent, although its roots can be traced back to the birth of 3D solid modeling CAD systems. The main difference between a traditional design process 2D-drawings-based and the BIM approach lies in the fact that a BIM model has a higher level of information than a traditional drawing. Indeed, a BIM model has always some fundamental characteristics that distinguish it from other forms of representation ([1]), mainly: *i*) it is digital, *ii*) it is three-dimensional, *iii*) it consists of objects containing both geometric and alphanumeric data, *iv*) BIM data are "comprehensive" (e.g. they describe different aspects of the components of the model, such as geotechnical, structural or performance aspects) and "consistent" (changes to a component are represented in all views of that component). The success of BIM in the building industry has recently led to its adoption also in infrastructure design ("InfraBIM") or in large civil engineering projects, among them earthworks, underground infrastructures (tunnels), and complex geotechnical structures such as tailing dams. It has been proved that the adoption of BIM methodology drastically reduces the uncertainty of the design of earthworks involving cut and fill activities ([2]). By ensuring better communication between parties and thus reducing costs and errors ([2]), the adoption of BIM methodology enables better management of all the design/construction aspects related to tailing dams, whose high rate of collapses can lead to serious environmental and economic damages ([3]-[4]-[5]-[6]-[7]-[8]). Finally, other Authors ([9]) focused on other advantages offered by the BIM methodology in infrastructure design. Compared to a traditional design process based on 2D drawings, the BIM approach, being based on 3D models, ensures reduction of misinterpretations, better checking of clashes between components, and a better management of the construction and maintenance phase, due to the possibility of monitoring and elaborating the data contained in the model.

The aim of the current paper is to give a general overview of the adopted BIM methodology, showing its advantages in the context of an extensive and complex geotechnical project located in Norway.

2. The Sotra Link Project

The ongoing Sotra Link Project (SLP) represents one of Norway's priority infrastructure projects. It includes the design, construction, financing, and maintenance of a road system between the island of Sotra and the city of Bergen in the western county of Vestland, Norway ([10]). The whole project includes 9 km of highway and a suspension bridge (30 m wide/900 m long, including towers 144 m high) between the municipalities of Øygarden and Bergen. The road system includes 12.5 km of tunnels (i.e. Nye Kolltveit, Straume, Knarrevik, Drotningsvik and ramp tunnels from/to the main Drotningsvik tunnels), 19 roads and pedestrian underpasses, 23 tunnel portals, 22 bridges and viaducts, and 14 km of pedestrian and bicycle paths (Fig. 1 and Fig. 2). The SLP adopts a BIM approach for the entire design process for all underground, surface works and retaining structures.

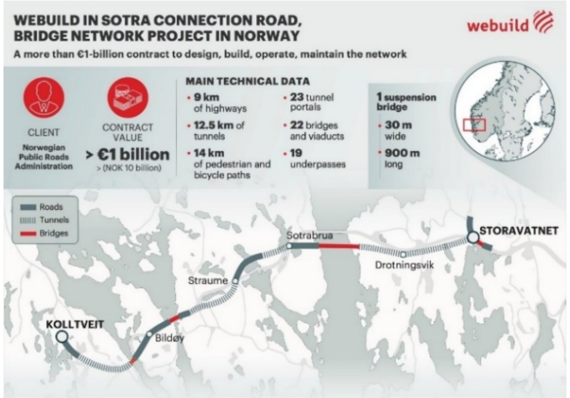


Fig. 1: The Sotra Link Project ([11]).

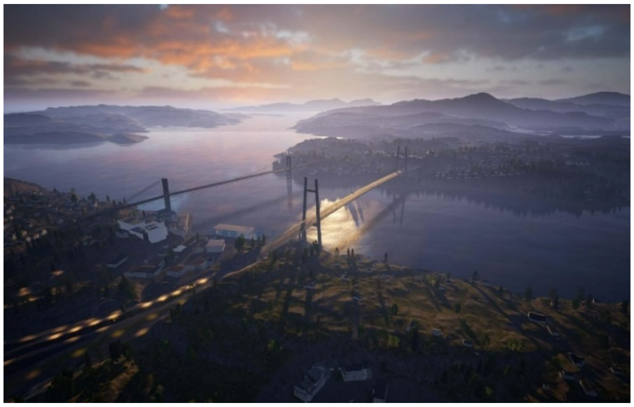


Fig. 2: Rendering of the project ([11]).

2.1. BIM organization in the Sotra Link Project

The BIM approach has been adopted for the Sotra Link Project and it involved all phases of the design process of all the geotechnical structures. The main document that describes the strategy for development and delivery of information, as well as roles and responsibilities of each design team, is the "BIM Execution Plan" (BEP). To keep the whole SLP manageable, the various design tasks are organized following a specific "Object Breakdown Structure" (OBS) that organized all the SLP project's data in hierarchical levels (i.e "Area"). The BIM activities of the various design teams were aimed to produce digital, 3D "models" that contain all the data for each specific Discipline, Design Phase, and Area. Each design team developed its own "Discipline Models", that are periodically uploaded on a digital shared platform for model coordination and clash detection. Finally, the models related to a given discipline and area are stored and linked together into "Container Models", which are then combined on the shared environment into a general digital database ("Coordination Model"), allowing the inter-disciplinary coordination of the whole SLP project.

2.2. Pini Group's activities and BIM responsibilities

In the general BIM organization of the project, Pini Group Ltd. was in charge of all the design and BIM activities related to the discipline of underground structures, namely the tunnels of the A02 (Kolltveit), A04 (Straume), A06 (Knarrevik) and A10 (Drotningsvik) areas of the Sotra Link project. These activities included geologic characterization of rock and soil, geotechnical and structural design of the tunnels, creation of the BIM models of the underground structures, activities on site.

3. The Adoption of BIM methodology for underground structure design

The SLP is a complex project involving multiple disciplines and competencies. The use of the BIM approach allowed the collaboration between different design teams and the integration of the project's multiple disciplines (geology, geotechnical/structural/infrastructural engineering, etc.) involved in the design of all the underground infrastructures involved in Sotra Link Project. This aim was reached through the creation of a centralized project database consisting of a series of BIM models linked together. The creation of the digital models was based on a processing scheme, in which data is created, processed, and integrated in the BIM models (Fig. 3). The process was partially iterative and allowed an easy update of the model every time a change in project data occurs, thanks to a well-structured workflow.

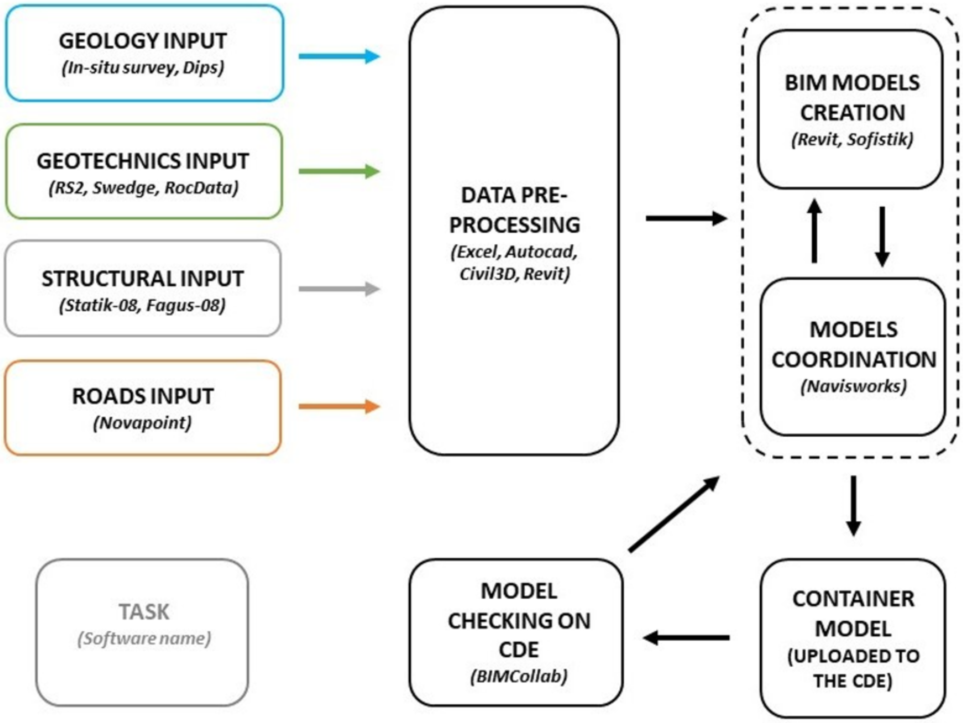


Fig. 3: Data processing base scheme.

As highlighted in Fig. 3, the adopted BIM workflow consisted of the following phases, each of which involved specific procedures, methods and tools:

1) Production of data inputs (geological data, geotechnics data, structural data, road data);
2) Data pre-processing;
3) BIM modelling and internal model checking;
4) Creation and upload to the CDE of the output model (the "Container Model") from the single models of a given area;
5) Model checking on the CDE ("Coordination Model").

3.1. Input Data

Geological, geotechnical and structural inputs were pre-processed by the BIM Specialists to obtain information in a format that allows it to be properly employed in the creation of BIM models. Geological data were integrated within a geological model made up by homogeneous units, depending by the estimated "Q-value" ([12]). The "rock classes" and their respective "rock support" were then defined along the tunnel alignments. The BIM models were also implemented from the detailed geotechnical inputs provided in terms of retaining structures consisting mainly of soil nailing, rock bolts and soil reinforced walls. Finally, the BIM models were finalized by the structural and infrastructural inputs obtained from the design of the steel reinforcement concrete structure of each tunnel and portals.

3.2. Pre-processing of data

All input data were pre-processed for use within the BIM software environment, and then processed during the creation of the BIM model. The adopted workflow is shown in Fig. 4 and ensured that all data were stored in a single, comprehensive model (one for each type of structural component for a given area), thus reducing the occurrence of errors due to the large amount of information and the geometric complexity of the components.

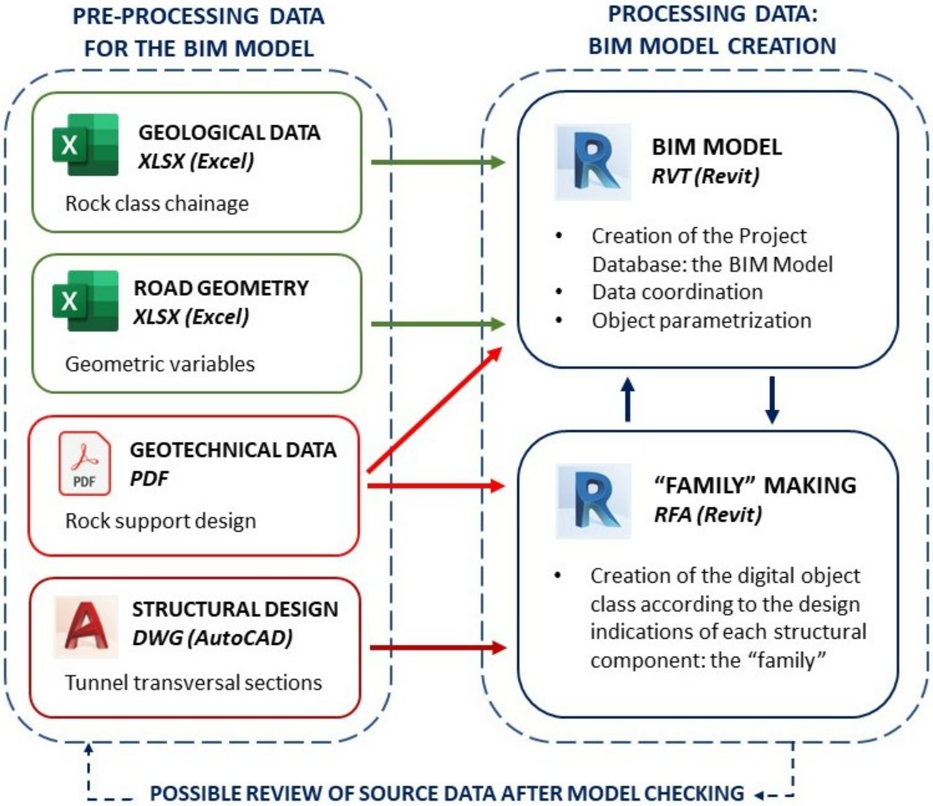


Fig. 4: From pre-processing data to the BIM model creation.

3.3. "Family" creation: parametric components for the BIM model

The first step in the creation of BIM models was to build a database made up of "families", consisting in three-dimensional, parametric components that represent a specific type of construction element ([1]): for instance, a specific type of bolt, whose dimensions and geometric rules followed the geotechnical/structural inputs. The families are "parametric" because, to give an example, certain characteristics of the single bolt are modified in the model through specific "parameters", such as its positioning relatively to the rock surface.

3.4. Creation of the BIM models and design automation

The creation of families forms the basis for the implementation of georeferenced BIM models, to enable linkage between models in the coordination phase. The fact that the families are "parametric" makes it possible to automatize the creation of certain model elements. Small programs can be created *ad hoc* for a specific modelling or parametrization purpose. The software Dynamo Revit was used for this purpose, a "visual programming" environment within the BIM software Revit that can automatically perform both modelling and parametrization of parametric components ([13]). To give an example, the bolt "family" contains a special point called "adaptive point" that controls the bolt's position. To automatically create the bolts within the BIM model, a set of sub-horizontal lines was created on the rock surfaces; the Dynamo script automatically created the bolts along the support lines, with a constant spacing along the line (Fig. 5, Fig. 6).

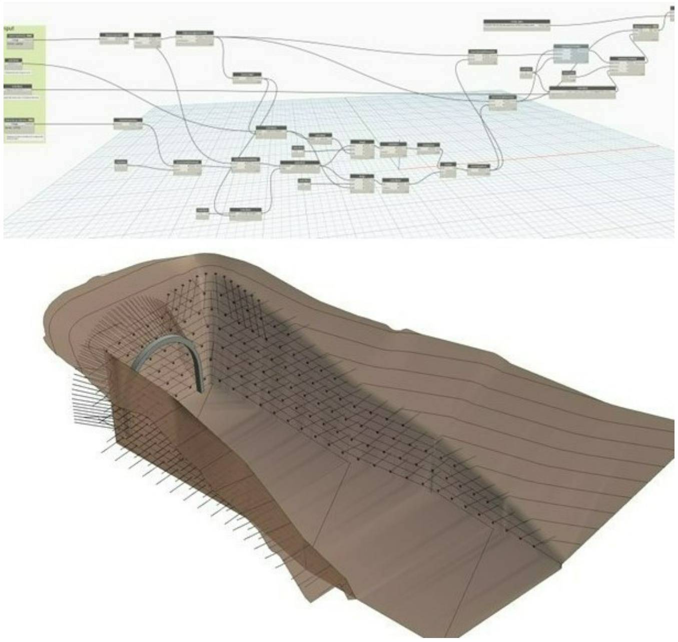
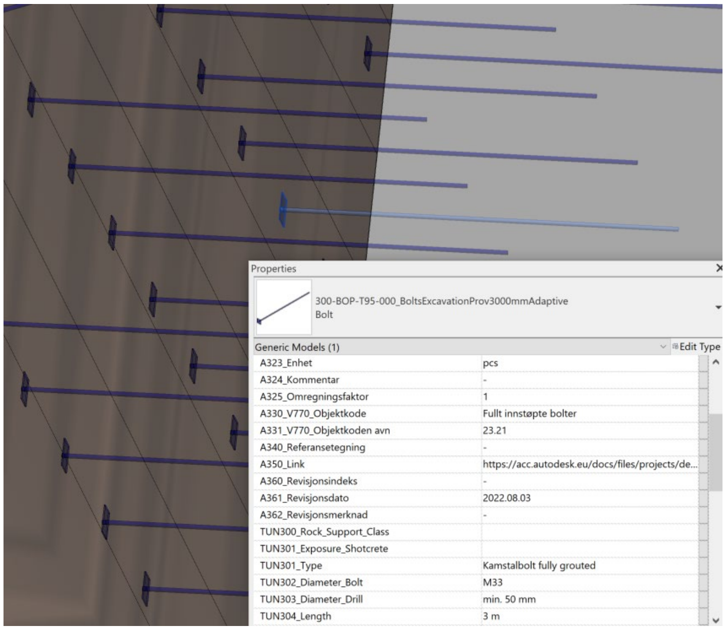


Fig. 5: The Dynamo script; automatic creation of the bolts' raster in the BIM model with Dynamo (Drotningsvik ramps, South portal).



Properties

300-BOP-T95-000_BoltsExcavationProv3000mmAdaptive
Bolt

Generic Models (1)

A323_Enhet	pcs
A324_Kommentar	-
A325_Omregningsfaktor	1
A330_V770_Objektkode	Fullt innstøpte bolter
A331_V770_Objektkoden avn	23.21
A340_Referansetegning	-
A350_Link	https://acc.autodesk.eu/docs/files/projects/de...
A360_Revisjonsindeks	-
A361_Revisjonsdato	2022.08.03
A362_Revisjonsmerknad	-
TUN300_Rock_Support_Class	
TUN301_Exposure_Shotcrete	
TUN301_Type	Kamstalbolt fully grouted
TUN302_Diameter_Bolt	M33
TUN303_Diameter_Drill	min. 50 mm
TUN304_Length	3 m

Fig. 6: Section view of the Drotningsvik ramps South portal, with the bolts raster and the parameters of one of the bolts.

3.5. Tunnel tubes modelling with BIM modelling plugins

The modelling of the tunnel tubes represents a further example of innovative parametric design applied to the BIM modelling of underground structures. The Revit plugin used for this task (Sofistik Infrastructure Modeler) enabled the creation of 3D structural models in which each structural component was modelled at the desired level of detail. Tunnel tubes were modelled using pre-processed geological data in combination with structural indications, according to the adopted excavation method ("Drill and Blast"). This led to the definition of a set of rock classes, and the associated rock support class with all the specific characteristics of the rock support layer (Fig. 7). The rock support characteristics for a given rock class were then nested inside a "family" through parameters controlling bolt placement, transversal spacing of the bolts and shotcrete thickness. The modelling of the tubes' rock support was done through the Sofistik plugin mentioned above, creating "instances" of families (i.e. bolts and shotcrete) along the road alignment, for each rock class chainage (Fig. 8).

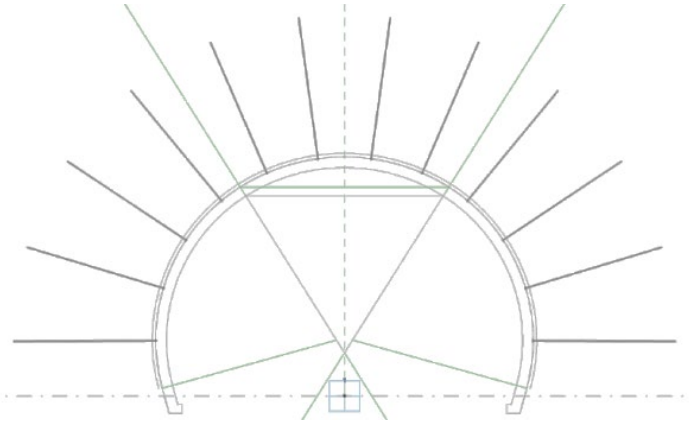


Fig. 7: Revit family of the tube's rock support (rock class "IVa").

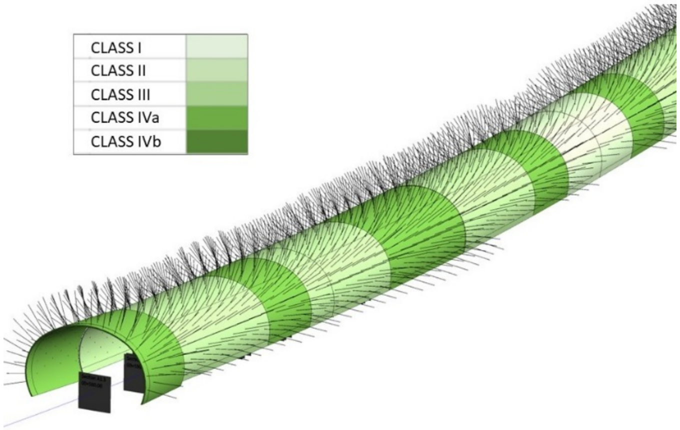


Fig. 8: Kolltveit tunnel: creation of the rock support component (shotcrete and bolts) for each rock class (in false colours).

3.6. Model coordination: from the Container Model to the Coordination Model

Once all the models were completed and parametrized, the creation of the Container Model was performed. This model contains all the objects of the structural discipline related to a certain project area (Fig. 9). The Container Model was then uploaded to the shared platform (CDE), where the Container Models of each discipline were merged to create the complete database of the project. This Coordination Model allowed for the final verification of all the clashes and issues between different disciplines (Fig. 10).

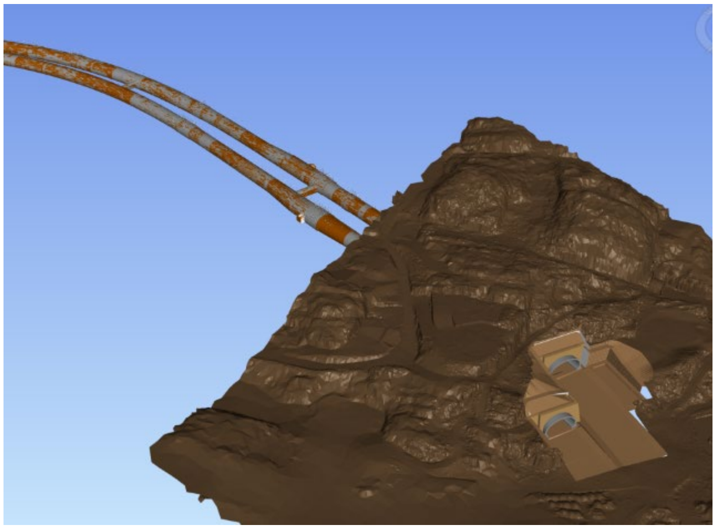


Fig. 9: View of a Container Model for the tunnel discipline (Kolltveit tunnel).

Fig. 10: View of the final Coordinated Model on the CDE (BIMCollab), seen from the interior of Kolltveit tunnel.

4. Conclusion

Some details concerning the BIM methodology adopted during the design phase of a complex civil/geotechnical infrastructure project were provided. The implementation of BIM for infrastructure projects has allowed significant improvements in several aspects of the design process, mainly: *i*) better communication and collaboration between design teams; *ii*) better understanding of the effective design choices and reduction of errors; *iii*) better handling of clashes and inconsistencies during the design phase; *iv*) more precise extraction of quantities from the models for each OBS in the Bill of Quantities. The BIM methodology also allowed a greater level of accuracy and completeness, describing describing in detail the Sotra Link Project and ensuring its manageability in each design phase.

Currently, the project has entered the Detail Design phase, and the modelling and delivery tasks are in line with the project scheduling. The project contract was awarded in September 2021 for a total value of 1.25 billion € and the design phase is expected to finish in 2023, while the infrastructure will be opened to traffic in 2027.

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