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BIM Use in the Infrastructural Field: The Case of the Extension of the Railway in the Underground Track of Catania, From the Central Station F.S. to the Airport

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ABSTRACT

BIM technologies provide tools and processes to effectively support the entire life of an infrastructure, from strategic planning to maintenance. As a consequence, infrastructure design processes currently make frequent use of BIM tools.

This paper describes the BIM oriented design of the underground railway extension in the metropolitan area of Catania.

The paper highlights the design process and the chosen BIM tools considering the boundary conditions characterizing the project, i.e. basic information missing in the final design project, need of coordination between different design disciplines and designer companies, and, finally, need for a flexible design approach able to adapt to changes occurring during design development.

INTRODUCTION

The underground railway extension in the metropolitan area of Catania is composed of two lots of approximately two km each, namely “Stesicoro-Aeroporto” and “Nesima –Misterbianco”.

Works to be realized are:

- Main tunnel: mechanized tunneling using a TBM-EPB machine, for the entire length of the lot;
- Underground stations: San Domenico, Vittorio Emanuele and Palestro, conventionally excavated as enlargement of the TBM tunnel after the partial demolition of precast segments;
- Ventilation and emergency shafts: connecting seven tunnel levels to road level on Stesicoro-Areaposto lot, six on Nesima-Misterbianco lot;
- Additional structures such as technical rooms and parking lot;
- Electric Substation at Monte Po' stop;
- Temporary works: TBM launching and arrival pit to be dismantled at the end of the works.

THE DESIGN APPROACH

The final design was conducted in a traditional way. The critical analysis of the project highlighted some critical issues due to insufficient topographic and geological data and investigations.

Only a small portion of previous data were reusable: the proposed design strategy to reduce construction risks maintaining expected schedule and costs can be summarized as follows:

- Geological survey integration and laboratory tests to reduce uncertainties and risks related to excavation;
- Execution of a detailed topographic surveys to identify potential interferences;
- Adoption of BIM oriented design to reduce potential omissions and other errors often present in complex designs with multiple contributors.

It should be noticed that the integration of geological and topographical investigations formed a new input for the design information model (BIM).

BIM PROCEDURES DEFINITION

Using a BIM approach requires a series of procedures that have to be defined in order to enhance the product final quality. Based on employer requirements, the final submission is to be provided using conventional CAD drawings. Consequently, a CAD manual was developed along with a BIM manual, though the difference between these manuals is merely formal.

The BIM Manual described all the standards and procedures to develop a high quality BIM model. This document is subdivided into chapters and comprises the following information:

- Goals of the BIM process;
- LOD (a LOD equal to a 300-350 was chosen, complying with AIA G202+213 standard BIM protocol; this LOD is suitable for an executive design);
- Team organization and coordination;
- BIM-Coordinator role;
- Technical instructions of design modeling, software to use and parameters to insert;
- Model and discipline coordination methodology to realize a geo-referenced model; containing all the necessary information;
- Templates to use in order to export 2D views from BIM model.

Document Management

All the design documents were stored on a cloud space in order to be synced and available to the team in a common document environment. Only the Project Manager and the BIM coordinator were granted “write” access to the entire repository, whereas the other members could save the drawings produced only on their own exchange folder. The drawings publishing process was automated via a Visual Basic code embedded (Macro) on the drawing list Excel file to ensure the correct compilation of title blocks.

Management of Topographical Data

Initial information were integrated with new detailed topographic survey output in two main phases:

- Congruence check between new and previous information;
- Realization of a high reliability digital terrain model.

Those activities were performed using Autodesk's software Civil 3D.

The following elements were represented in the model:

- The design tunnel layout;
- The temporary connection of the ending rail layout;
- Punctual design works: shafts, launch pit, stations enlargements;
- Technical map;
- Detailed survey near the punctual works with preexistences;
- Buildings with dimensions provided by the local Authority (online database), or by building condition assessments (where available).

Track alignment is represented by a bi-dimensional polyline linked to a bi-dimensional profile to obtain a 3D polyline. Tunnel typical cross-section (precast concrete segment) was modeled and extruded along the 3D polyline to get the entire tunnel geometry.

This workflow allowed to extract main tunnel CAD drawings and to add material related parameters to the typical section model, quantity take off was performed.

Geological Information Management

The great quantity of new geological data required a dedicated management system. Geological data were frequently accessed to extract information to be used in the drawings and reports.

The stratigraphy and on-site tests results were inserted into an Excel database connected to a software able to instantly deliver the information obtained from the boreholes and export them in CAD format.

This procedure allowed for avoiding transcription and communication error between geotechnical and geo-mechanical characterization and drafting. Furthermore, drawing and congruency checks frequency was highly reduced as they were performed only in the data input stage and not replicated at each design step.

Structural Modelling of current works: Equilibrium vents

Structural modelling was developed with Autodesk's Revit software, a parametric software allowing substantial savings in the design changes management during the design stage.

The design strategy defined at tender stage was based on the repetition of elements with similar characteristics in order to ease the management and maintenance operation during operational stage.

BIM process contributed to the high quality end product:

- Design timing led to model the works concurrently to the execution of geognostic surveys and extra topographic survey: new input data and changes were predicted;

- Works standardization limits non-value adding activities during construction and enhances management and maintenance during service and maintenance.

This solution allowed a gradual adjustment of the project based on the geotechnical knowledge of the area (sometimes with the need to modify the temporary support system) and ensure that all the individuals involved in the design activity were always up to date with the most recent information.

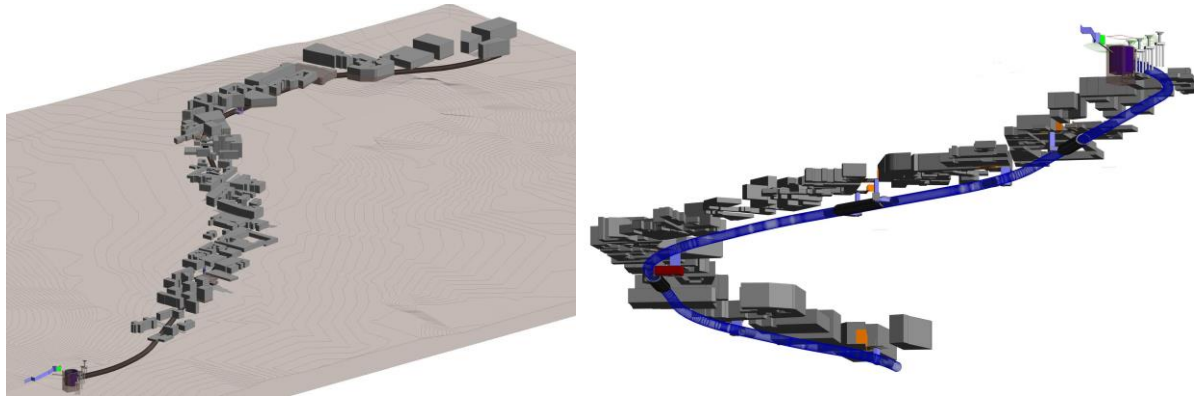


Figure 1. Views of the model's elements on technical paper

Structural Modelling: Stations Enlargements

The Stesicoro-Aeroporto contract included the construction of stations enlargements excluding distribution and access works.

The excavation stabilization phase and the final phase were modelled in Revit, modelling supports and cast-in-situ reinforced concrete lining.

The modeled elements were enriched with reference properties in order to perform WBS classification and cost definition based on the quantity takeoff.

Stations Functional Conception

The Executive Design, in line with the Final Design contents, takes into account the nature of the track, and in particular the tunnel cross-section, as well as the neighboring urban areas, and services and facilities served by the stations. In fact the track runs along the direction between Catania and Misterbianco, being coincident with the city's north ring road and in its close surroundings. In general, the design meets the needs of a metro rail in urban areas, specifically:

- concentrate access points at street level (stairs and elevators), with shelters and rest areas, even for modal interchange with other local public transport services;
- Stations will represent a space in which travelers will easily meet and evacuate, avoiding excessive canalization. Stations entrance, mezzanine, intermediate and platform levels alternate with open spaces, encouraging a perceptions variety which would facilitate access to platform and/or elevators to the street level.

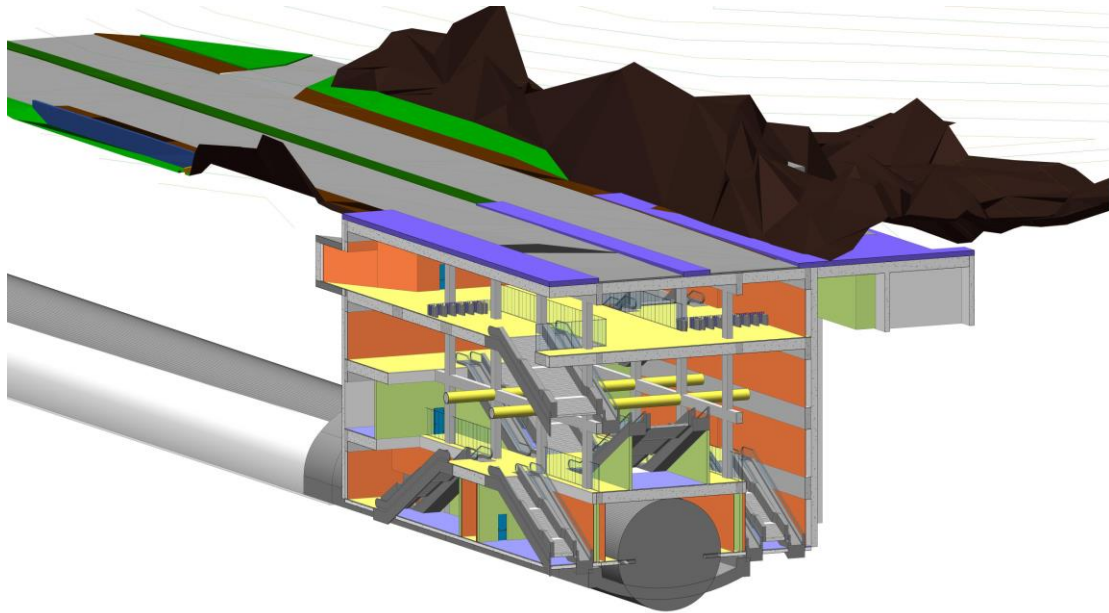


Figure 3. Fontana station

Structural Modeling of Mechanized Excavation Items

Three-dimensional modeling through BIM systems generally finds its natural scope of application in construction of buildings or similar structures, whether above ground or underground.

The modeling of the lining system of mechanized excavation is not as common as some aspects are beyond the normal use of structural BIM software.

More than one software tool was integrated to achieve the desired result. Initially, the universal ring geometry was designed by a spreadsheet defining:

- Geometry of segments;
- The definition of a series of cutting plans for the division of the ring into its constituent segments;
- Import this information, through Visual Basic code, into the Autodesk Inventor software, in which the physical division, through the use of defined cutting planes, was carried out;
- Geometry export of the blocks for their processing within Autodesk Revit;
- Congruence control with this information achieved with the information of track, extracted from Autodesk Civil 3D, through the use of a plug-in software, Dynamo, which allows the management of parametric data and elements, within the software, through links to external files (e.g., track alignment).

Reinforced bars were modelled by dedicated tools of Revit and the obtained tunnel ring were applied along the alignment by means of Dynamo routines. The rings are parametric and realistically oriented in space.

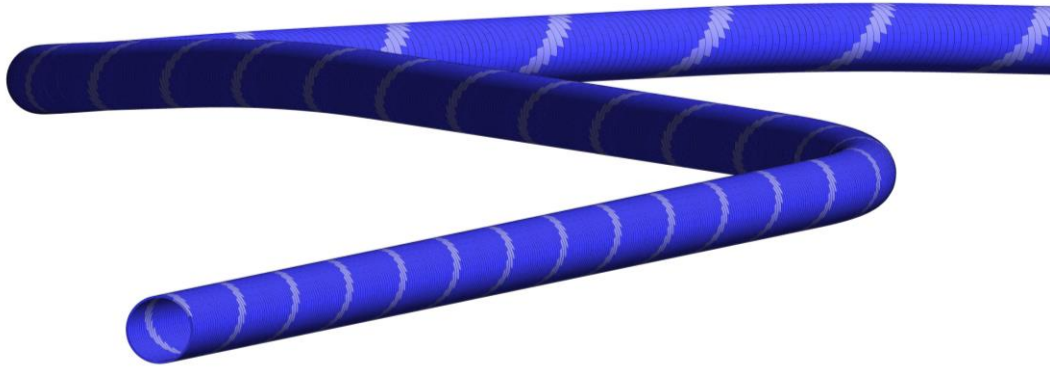


Figure 4. Generation of tunnel ring extrusion with software Dynamo

The heart of the production process is the Revit software. All elements' characteristics are analyzed in terms of reusability of data and of information completeness. As previously mentioned, the "BIM manual" sets the attributes that must be specified for each element, and which will provide the elements for quantity takeoff and estimate.

One of the most critical aspects in relation to the production of the segments is tied to the aspect of prefabrication, with particular reference to:

- Planarity of the contact surfaces between the segments;
- Realization of the rebar system and its installation within the formwork;
- Tolerance of construction and elements installation.

The realization of the model within the software Inventor allows to obtain solid representations of the individual segments with the certainty of flatness of the contact surfaces.

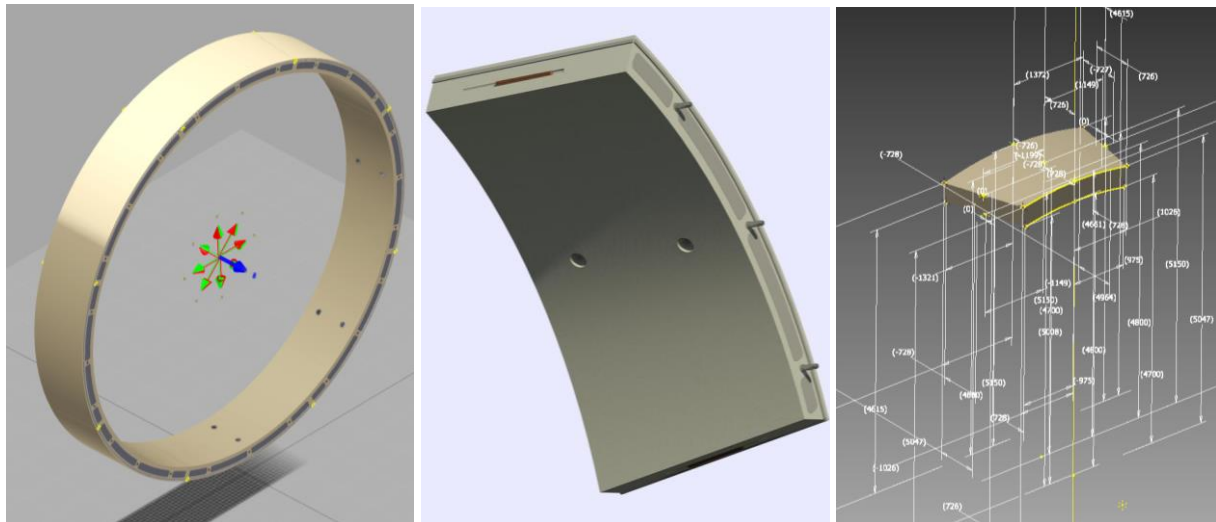


Figure 5. Ring geometry and TBM quoin modeled by software Inventor.

Import within the Revit software allows automatic modelling of rebars for each segment. In general, the geometry of metal reinforcements are very complex, and the use of the software allows for:

- Immediate check of the mutual interference between the various reinforcement rods;
- Immediate check of interference between rebars and the formwork elements of ashlar, which generally presents negatives for holes bi-block, bolts, erector, etc.
- Rebars summary table production, which is generally a time consuming task because of its complexity and importance.

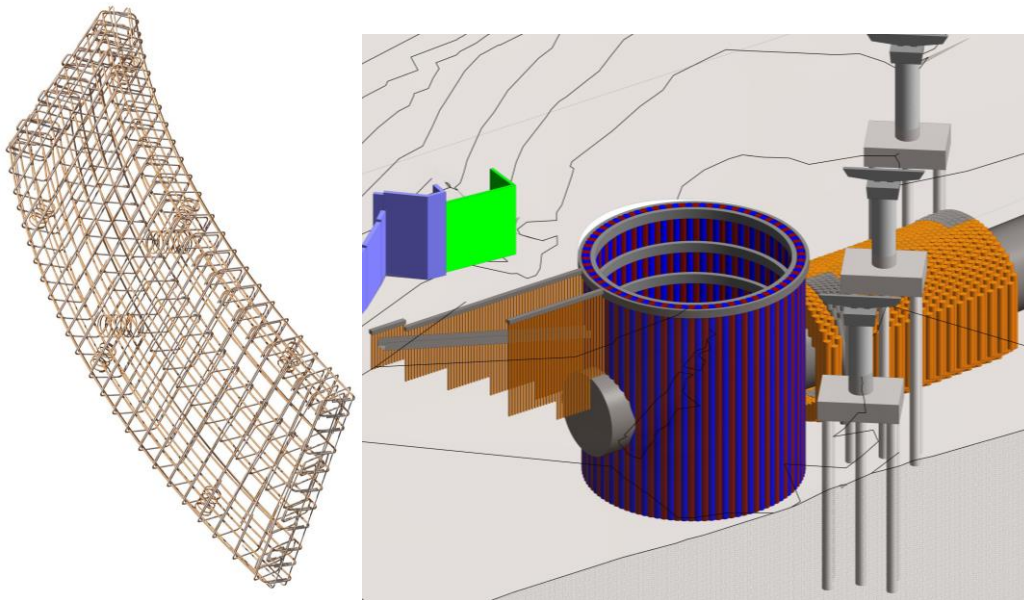


Figure 6. Revit precast segment rebars and launching pit in Stesticoro-Nesima model

TBM launching pit were directly designed within the Revit software.

Contrast elements (piles, micropiles and jet-grouting) were defined by specific families' parameters.

Each family was characterized by a set of attributes previously defined in the BIM manual in order to be able to manage the model information as well as the phase of quantity takeoff and estimates.

Models allowed to study the interference potential between the works on the project and the existing structures (viaduct with pile foundation) and the various works in the project, both structural and mechanical (e.g., Interference between debris belt and the structures).

CAD drawings were finally extracted from the models, in accordance with contract requirements, by means of templates. Templates were defined in the preparatory stage of the project according to the contents of BIM Manual.

Structural Calculations and Modeling

The use of BIM process is also used as part of the structural modeling. An analytical model can be exported from Revit to Robot software, other software (Dlubal, Scia, Sofistik, ecc.) or more simply, it is possible to export format acis / sat that can be read by several calculation software.

In both cases, the fundamental aspects are:

- Simplification of the modeling of the structure within the calculation software, with significant time saving;

- Respect of the consistency of the geometry of the works.

The overall BIM process is used to the advantage of the quality of the design and reliability of the obtained solutions.

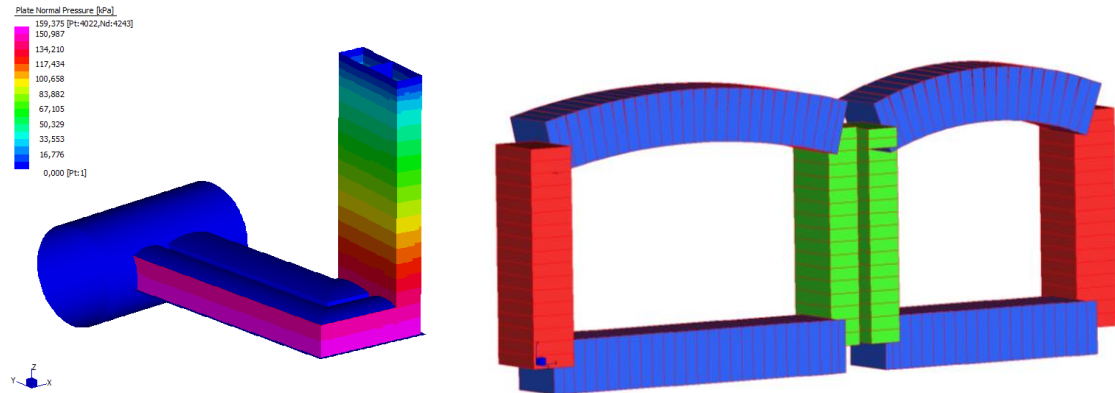


Figure 8. 3D FEM models of shafts. Geometry were extracted from Revit models.

From the point of view of geotechnical calculations, the market currently does not provide any software with direct connection to a BIM model type.

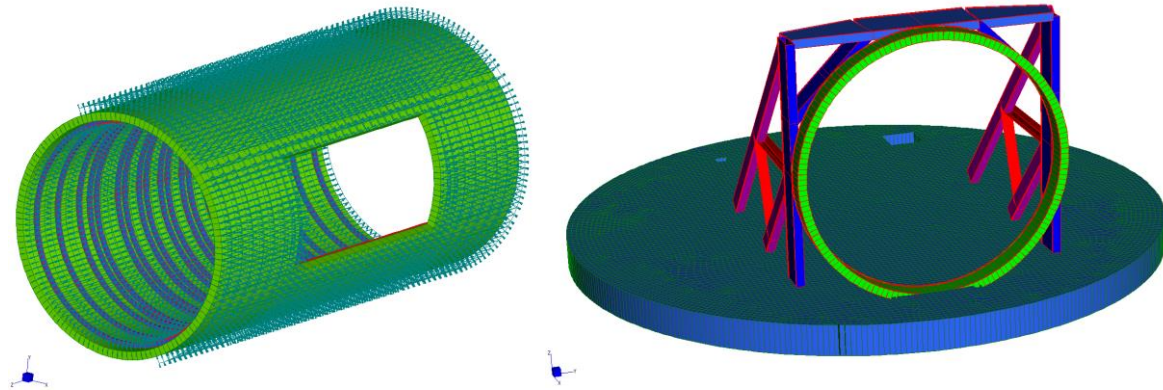


Figure 9. Fem models of shafts: details of shafts to main tunnel connection.

The use of the software MIDAS GTS has solved the most complicated conditions by importing the geometry in DXF format or acis / sat based on the Revit model.

The terrain can be imported directly through the export of model surfaces of Civil 3D, and through specific tools it is possible to cut the solid terrain with the aforementioned surface.

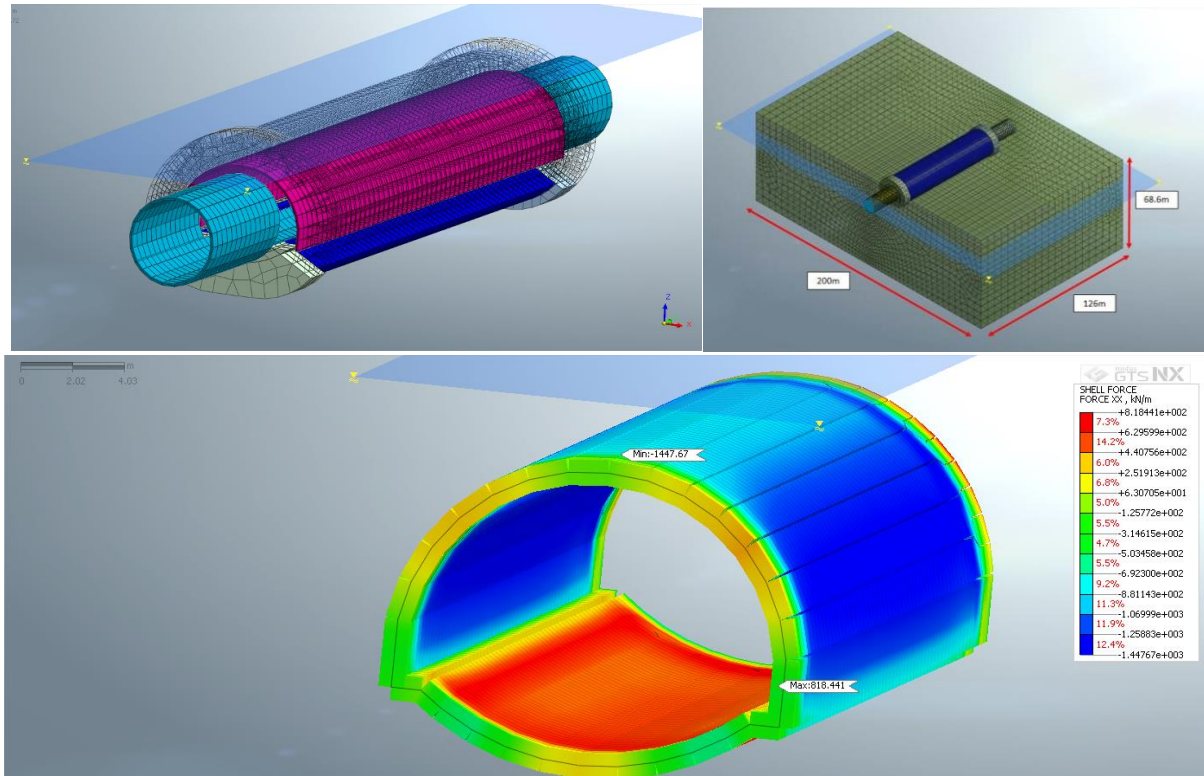


Figure 10. FEM 3D models of stations enlargements

Quantity Takeoff and Estimate

As previously reported, the BIM manual defined how to model the elements in order to obtain the quantity take off. Data extracted were bound to BoQ software and documents by means of WBS information in order to create a direct connection between design tools and quantity estimate tools.

CONCLUSIONS

This article describes the BIM process applied to design an underground infrastructure.

The use of the potential of BIM tools helped to implement models that were interfaced between all the major components of a multi-disciplinary infrastructure project:

- 3D modeling of all the major elements creating the infrastructure;
- direct interface between the 3D graphical models and the project of railway (alignments, profiles, sections)
- Parameterization of the main elements of the project, with the possibility to manage in an automated manner, changes to the geometric characteristics at an early stage
- Direct interface between the 3D graphical models and tools for structural and geotechnical calculation;
- Direct interface between the design and the tools of computing and accounting.