



BIM applications to underground projects: the example of the extension of Catania Railway

Paolo Cucino, Gabriele Eccher, Luca Schiavinato, Stefano Colombelli & Domenico Nave
SWS Engineering SpA, Trento, Italy
Guido Venturini
SWS Canada Ltd. Toronto, ON, Canada

ABSTRACT

BIM – Building Information Modelling is becoming the keystone in the Delivery Models of vertical and social infrastructures (hospitals, airports, skyscrapers, etc.). BIM permits to combine, manage and integrate any 3D project with its construction schedule (4D modeling) as well as with all the WBS of the work and all hit attributes.

BIM easily allows to generate a 5D models that permit to better manage budgets, cash flows and other essential key-factor parameters.

BIM capacity and experience in infrastructure works is rapidly improving and it has recently been defined as a mandatory requirement by several Authorities worldwide. The Engineering community considers that in the next 10 years the project management through BIM will become a worldwide standard.

Since 2013, SWS has decided to implement BIM methodology to all his underground projects. 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.

1 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 (about 4 km);
- 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: seven on Stesicoro-Aeroporto 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.

2 DESIGN ISSUES

The final design was conducted in a traditional way. The critical analysis of the project highlighted some issues due

to insufficient topographic and geological data and investigations. Only a small portion of previous data were reusable.

The detail design strategy was planned to reduce construction risks maintaining expected schedule and costs. Some of the key proposed actions were:

- 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 periodically evolving input for the design information model (BIM).

3 BIM PROCEDURES DEFINITION

Using a BIM approach requires a series of procedures that have to be defined in order to enhance the final product quality. Based on employer requirements, the final submission was 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, and comprises the following information:

- Goals of the BIM process;
- LOD (Level Of Detailing) chosen as 300-350 complying with AIA G202+213 standard BIM protocol;
- 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.

3.1 Management of Topographical Data

Initial information were integrated with new detailed topographic survey output in two main phases, using Autodesk's software Civil 3D:

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

The following elements were represented in the model:

- Tunnel layout;
- Layout of the existing railway line and its temporary connection with the works;
- Shafts, launching pit, stations enlargements;
- Technical map;
- Detailed topographical survey near critical areas;
- Buildings with dimensions provided by the local Authority (online database), or by direct building inspection (where available).

Track alignment is represented within the software 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 as a parametric cross-section and extruded along the 3D polyline to get the entire tunnel geometry.

This workflow allowed to extract main tunnel CAD drawings. Furthermore, cross-section models contained information about material types and allowed to perform overall quantity take off.

3.2 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 FEM models, design and drafting activities.

The stratigraphy and on-site tests results were stored 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 avoided transcription and communication error between geotechnical and geo-mechanical characterization and drafting. Furthermore, drawing consistency checks were highly reduced as they were performed only at data input entry and not replicated at each design step.

3.3 Structural Modelling of shafts

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 quality of the design:

- 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 stakeholders involved in the design activity were always up to date with the most recent information.

3.4 Structural Modelling of Stations Enlargements

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

First stage support and final lining were modelled in Revit, modelling supports and cast-in-situ reinforced concrete lining.

The modeled elements contained material properties and other relevant information required to perform WBS classification and cost definition based on the quantity takeoff.

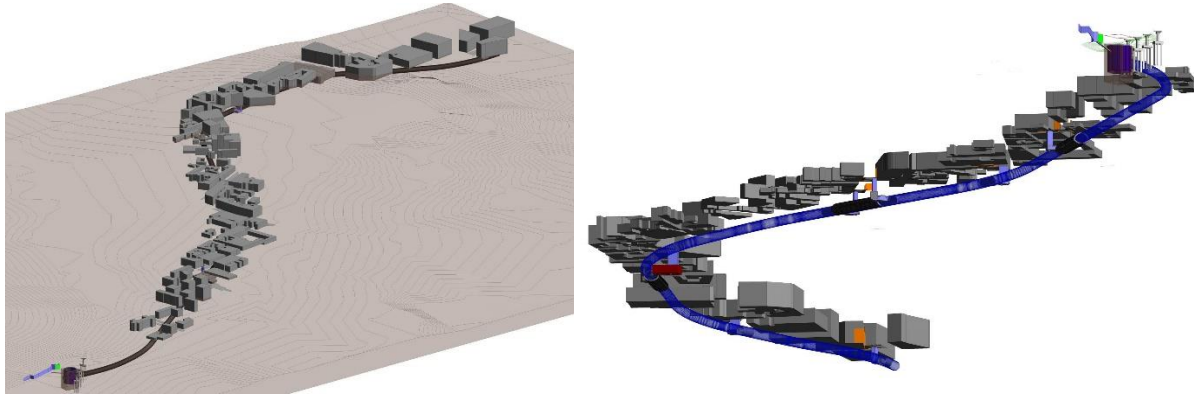


Figure 1. Views of the model's elements on technical chart

3.5 Stations Functional Conception

In general, the design meets the needs of a metro rail in urban areas:

- 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 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, encourage a perceptions variety which facilitates access to platform and/or elevators to the street level.

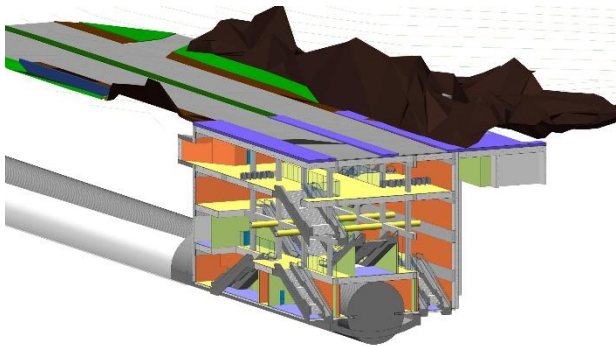


Figure 2. View of Fontana Station Architectural model

3.6 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 so common in structural BIM software.

More than one software tool was integrated to achieve the desired result. Initially, the universal ring geometry was designed strating from an excel spreadsheet defining:

- Geometry of segments;
- The definition of a series of cutting planes for the division of the ring into 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 in Autodesk Revit;
- Consistency control with this information achieved with the information of track, extracted from Autodesk Civil 3D, through the use of a plugin 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.

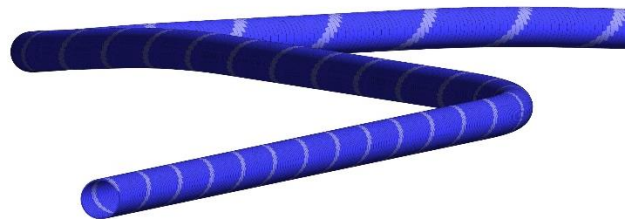


Figure 3. Generation of tunnel ring extrusion with software Dynamo

The heart of the production process is the Revit software. All elements' characteristics are analyzed in terms of reusability of data and 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 linked to prefabrication considerations:

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

The creation of the model within the software Inventor allowed to obtain a solid representations of the single segments ensuring spatial compatibility of the contact surfaces.

Import within the Revit software allows automatic modelling of rebars for each segment. In general, the geometry of reinforcement is complex, and the use of the software allowed for:

- Immediate check of the mutual interference between the various reinforcement bars;
- 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.

TBM launching pits 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 to manage the model information as well as the quantity takeoff.

Models allowed to study the clashes between the works 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 defined according to the contents of BIM Manual.

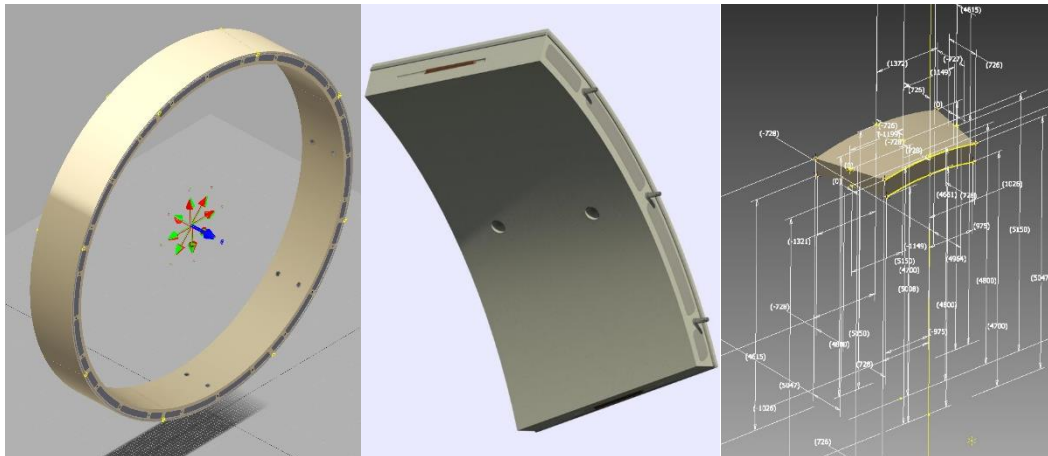


Figure 4. Ring geometry and TBM quoins modeled by software Inventor

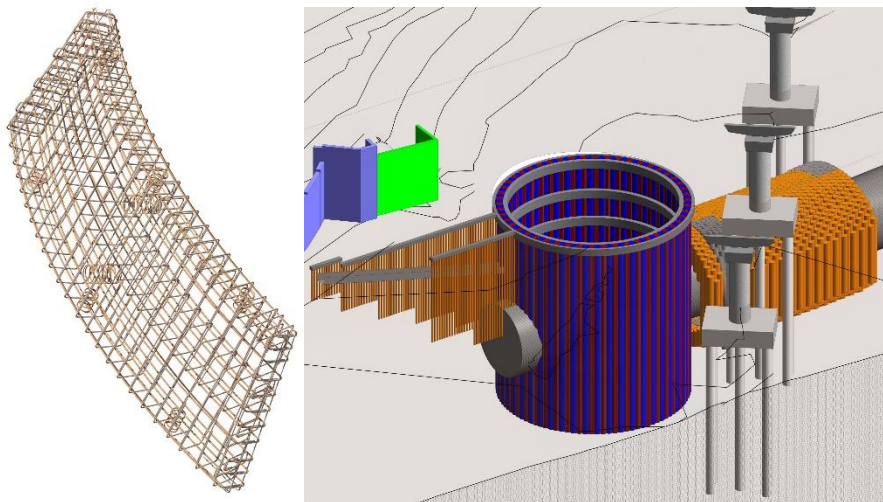


Figure 5. Revit precast segment rebars and launching pit in Stesicoro-Nesima model

3.7 Structural Calculations and Modeling

BIM models were also used as part of the structural modeling. An analytical model can be exported from Revit to Robot software or 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.

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

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

The terrain was imported as surfaces through Civil 3D, and through specific tools it is possible convert and adjust those surfaces in solid elements.

3.8 Quantity Takeoff and Estimate

As previously stated, 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.

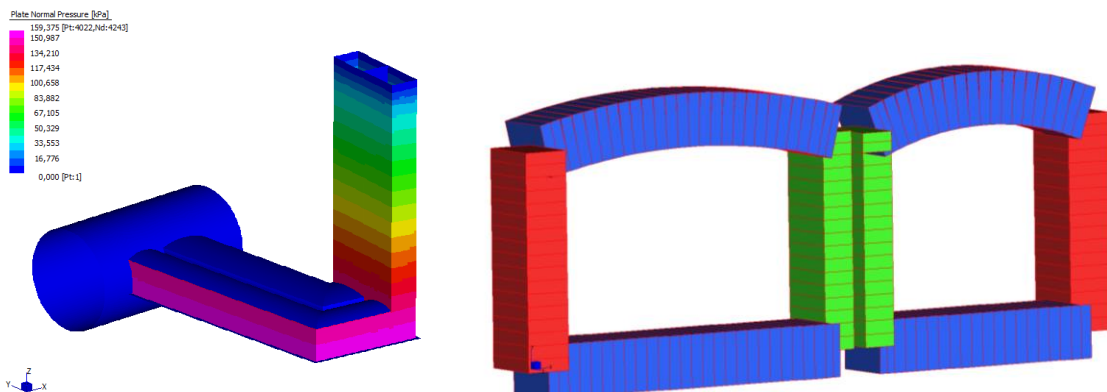


Figure 6. 3D FEM models of shafts. Geometry were extracted from Revit models

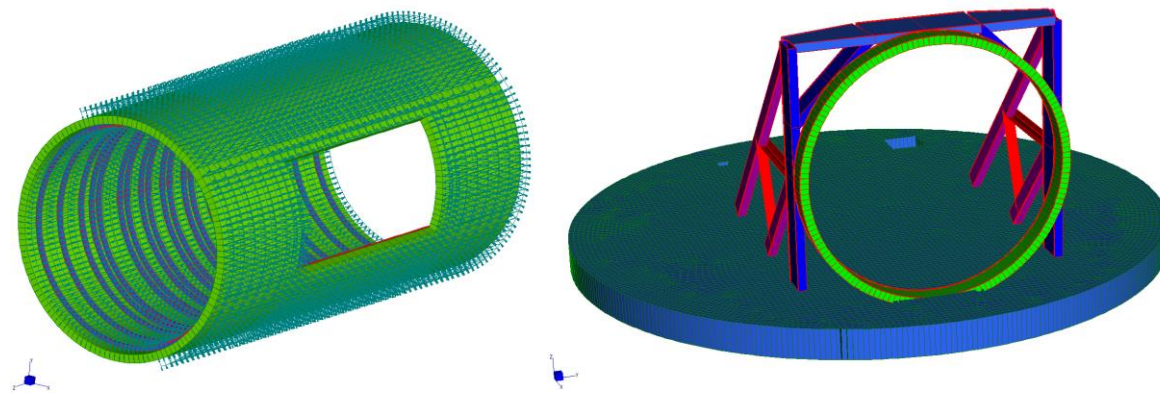


Figure 7. Fem models of shafts: details of shafts to main tunnel connection

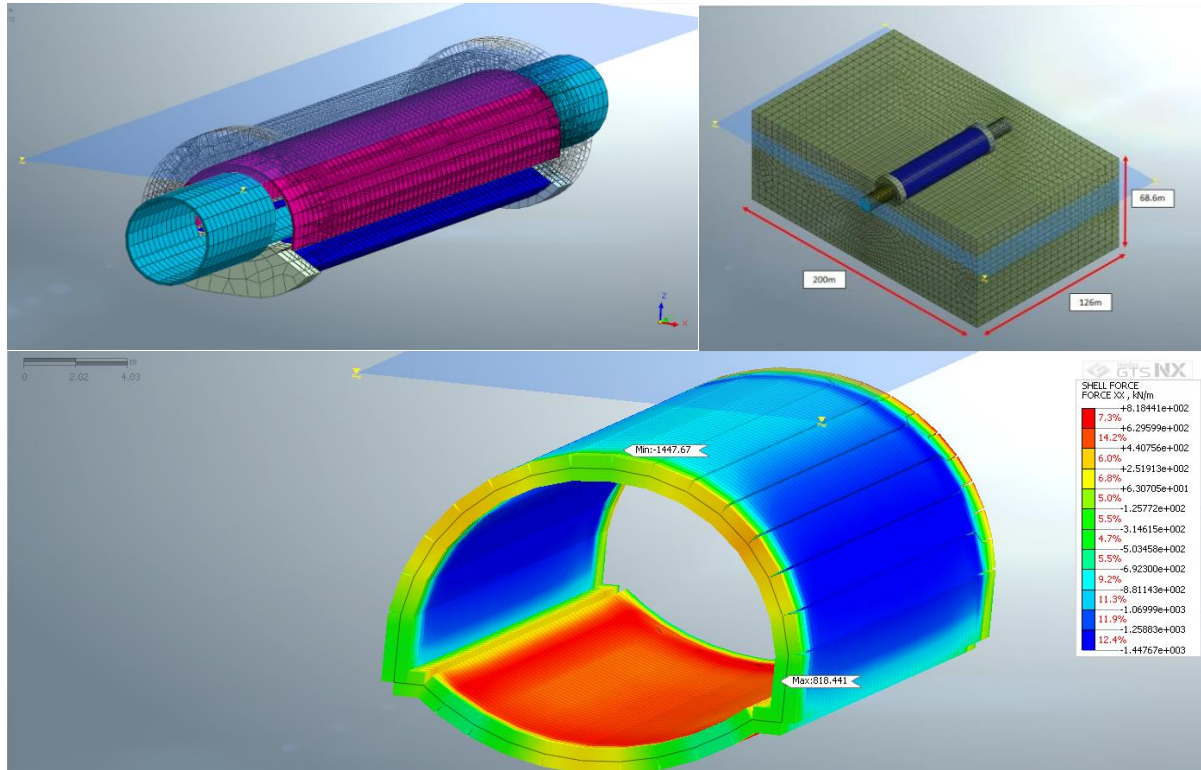


Figure 8. FEM 3D models of stations enlargements

4 CONCLUSIONS

The paper described the BIM process applied to design the underground infrastructure of the extension of Catania railway line.

The use of the potential of BIM tools helped to implement models that became a common interface 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 the 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.