Tunnelling 4.0: New technologies and automation

24 September 2019 – Buenos Aires, Argentina

BIM for the management of mechanized excavation data

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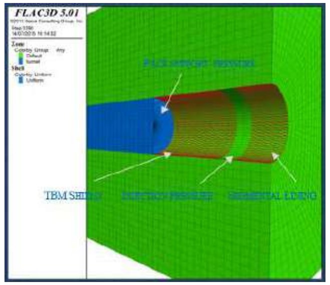
BIM and Mechanized tunneling
Lecture outline

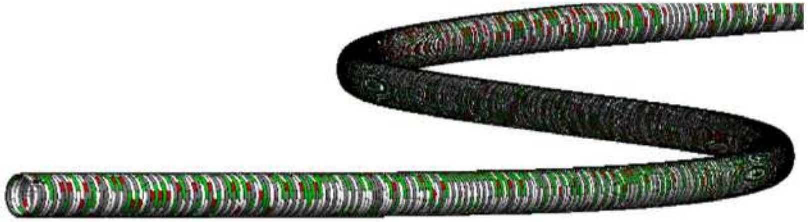
- **Introduction**
  - Dimensions of BIM in mechanized tunneling (from 3D to 6D)
  - Level of Details (LODs) in mechanized tunneling
  - BIM-based Tunnel Models using standards (IFC)
- **Tools & Techniques**
  - Revit, Dynamo, Phyton, Navisworks etc.
- **Examples of BIM application in Mechanized tunneling projects**
  - Along the Life-cycle of the project (Design, Production of Design, Construction, Maintenance)
  - For the different knowledge areas (Alignment, Geology, Precast of the segments, Advance of TBM etc.)
- **Conclusions**

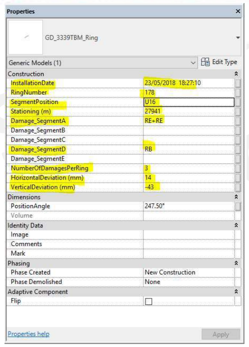
BIM and Mechanized Tunneling

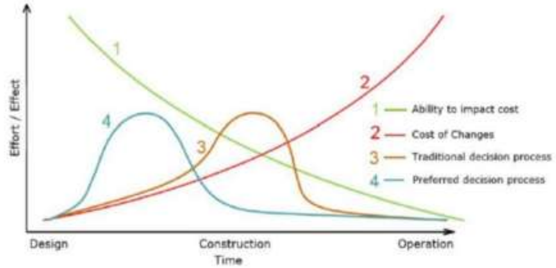
Mechanized tunneling includes many automatized processes and many repetitive synchronous activities and produces an amount of data. Mechanized tunneling is particularly suitable for the holistic parametric BIM approach



LINK models and information

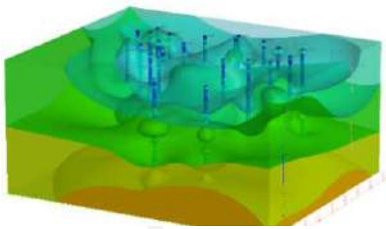






MacLeamy Curve.

3D

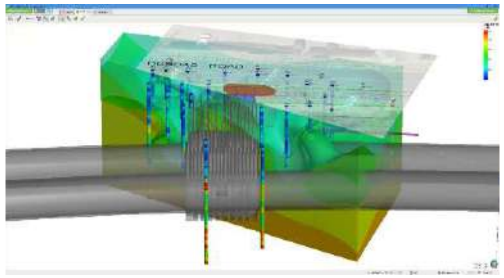


4D – Time / Construction Sequence
5D – Costs
6D – Project lifecycle information

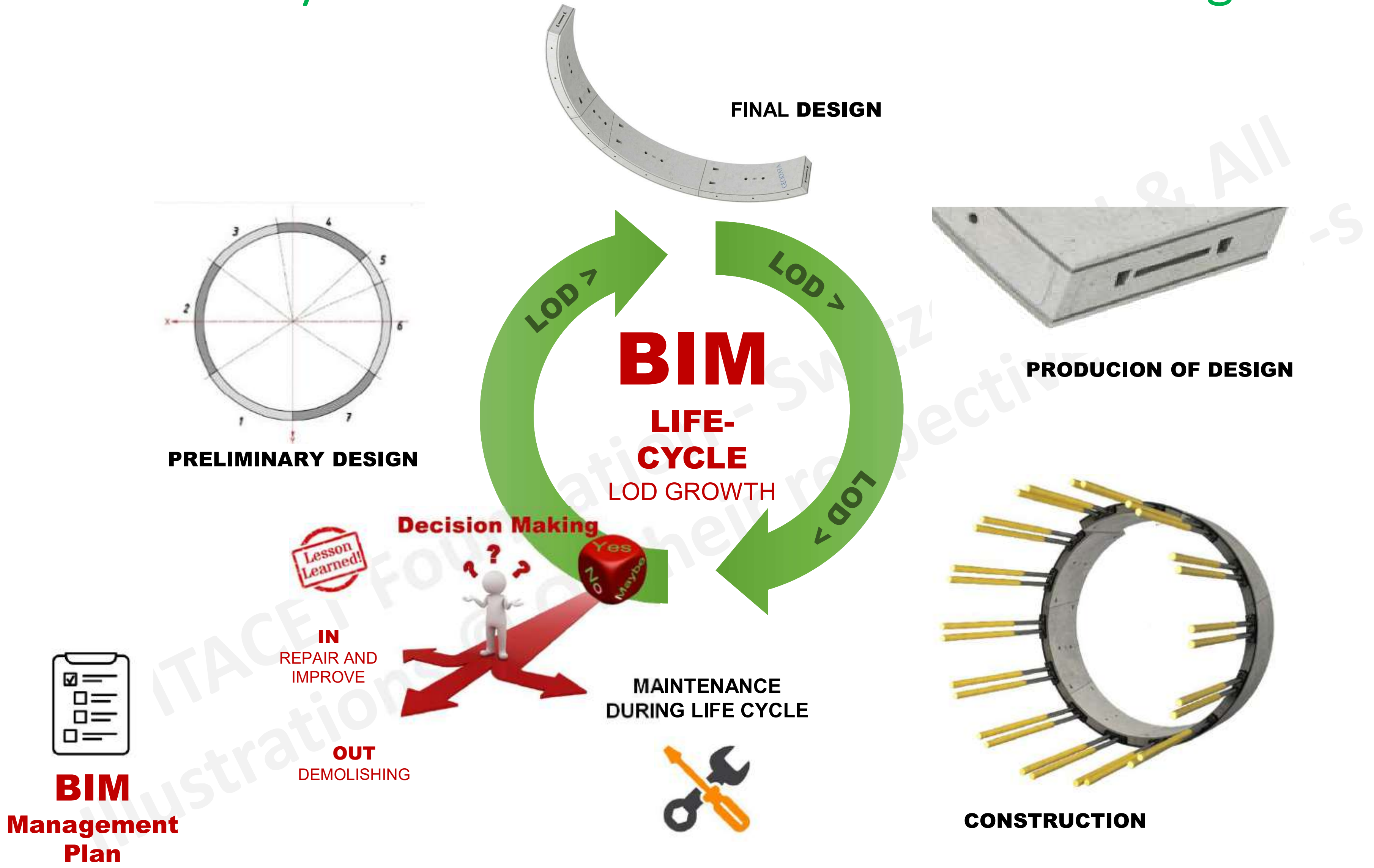
4D-5D-6D BIM i.e. integration of:

- **PAT** Process control during TBM advancement
- **Construction data** i.e. M&C data during the excavations
- **Damages of segments** along the alignment
- **Risk Register** along the alignment

nD

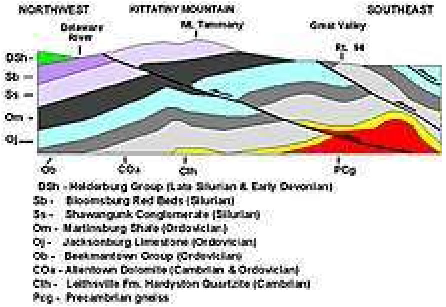


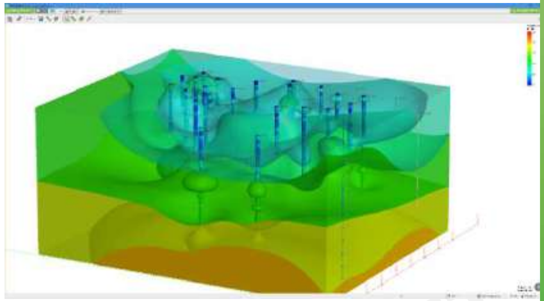
Life-cycle and LODs in Mechanized Tunneling

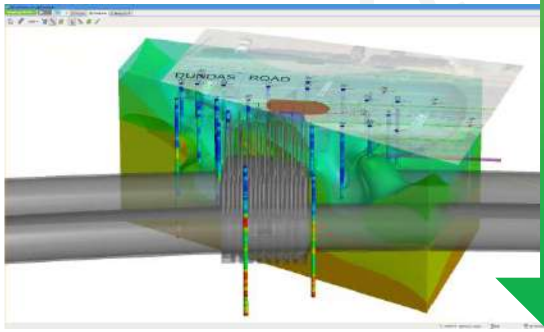


LODs in Mechanized Tunneling

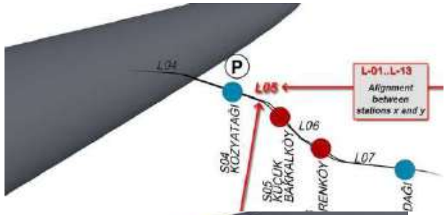
For each knowledge area there are different LODs

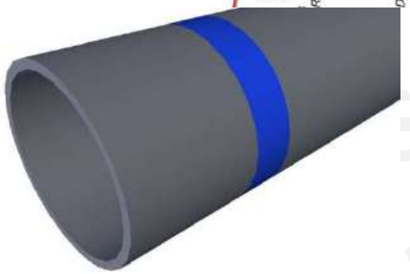


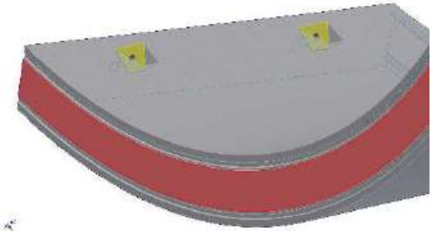




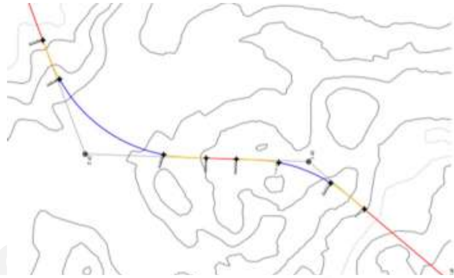
LODs Geology

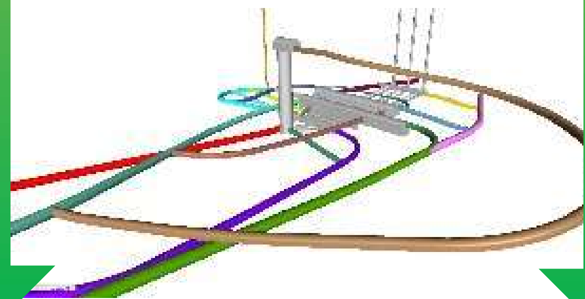






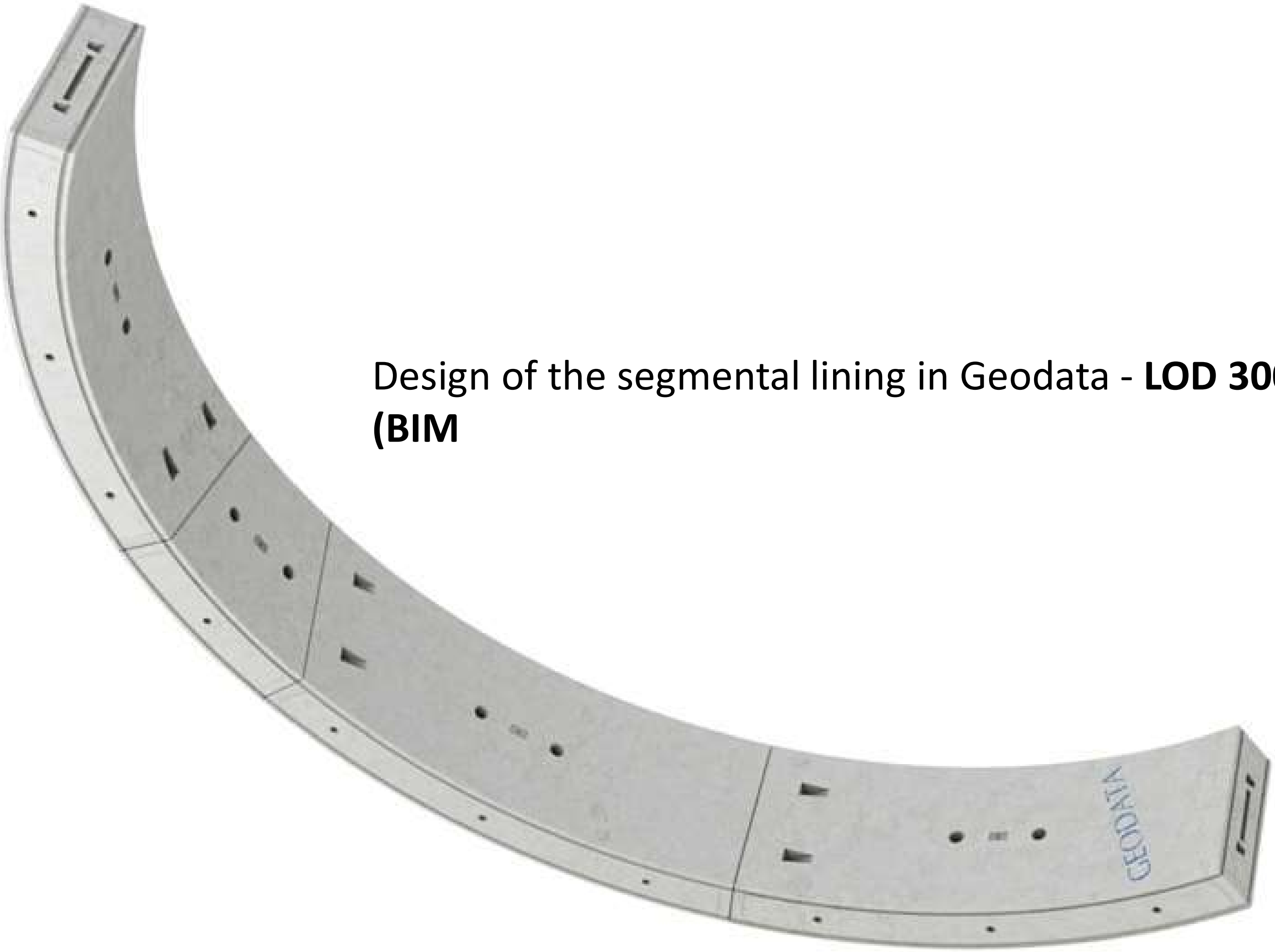
LODs Structures





LODs Aligment

LODs (Level of Details) in Mechanized Tunneling



Design of the segmental lining in Geodata - **LOD 300-400 (BIM**

LODs (Level of Details) in Mechanized Tunneling

BIM Management Plan

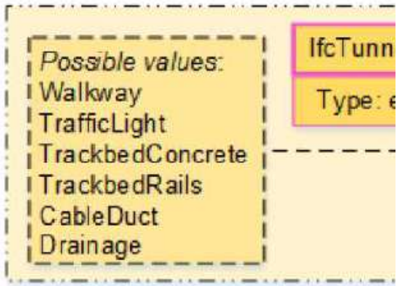
GEODATA
UNDERGROUND SOLUTIONS

Design elements	LOD200		LOD300		LOD350		LOD400		LOD500	
	Geometry	Information	Geometry	Information	Geometry	Information	Geometry	Information	Geometry	Information
Geometry										
General layout of the segment	X	X								
Type of segments	X	X								
Preliminary assumption of taper	X	X								
Shape	X	X								
Size	X	X								
Excavation phases (TBM and	X	X	X	X	X	X				
Design of the Segments			X	X	X	X				
Compoments										
Dowels (longitudinal connectors)					X	X	X	X		X
Bolts (trasversal connections)					X	X	X	X		X
Guiding Rod					X	X	X	X		X
Gasket					X	X	X	X		X
Steel Reinforcement or Wiremesh					X	X	X	X		X
Packers					X	X	X	X	X	X
Erector shear cone					X	X	X	X		X
Guidance rod groove					X	X	X	X		X
Service Bracket socket					X	X	X	X		X
Backfill grout					X	X	X	X		X
Machine Data										
Advance rate										X
Pressure cell and piezometer readings										X
Internal monitoring sections and deformation measurements										X
Additional analog data										
Properties of the support medium (density, filtrate water discharge and liquid limit)										X
Properties of the conditioning agent (EPB shield)										X
Composition and properties of the annular gap grout										X
Damage to the lining										X
Installation position of the rings										X
Shift protocols										X

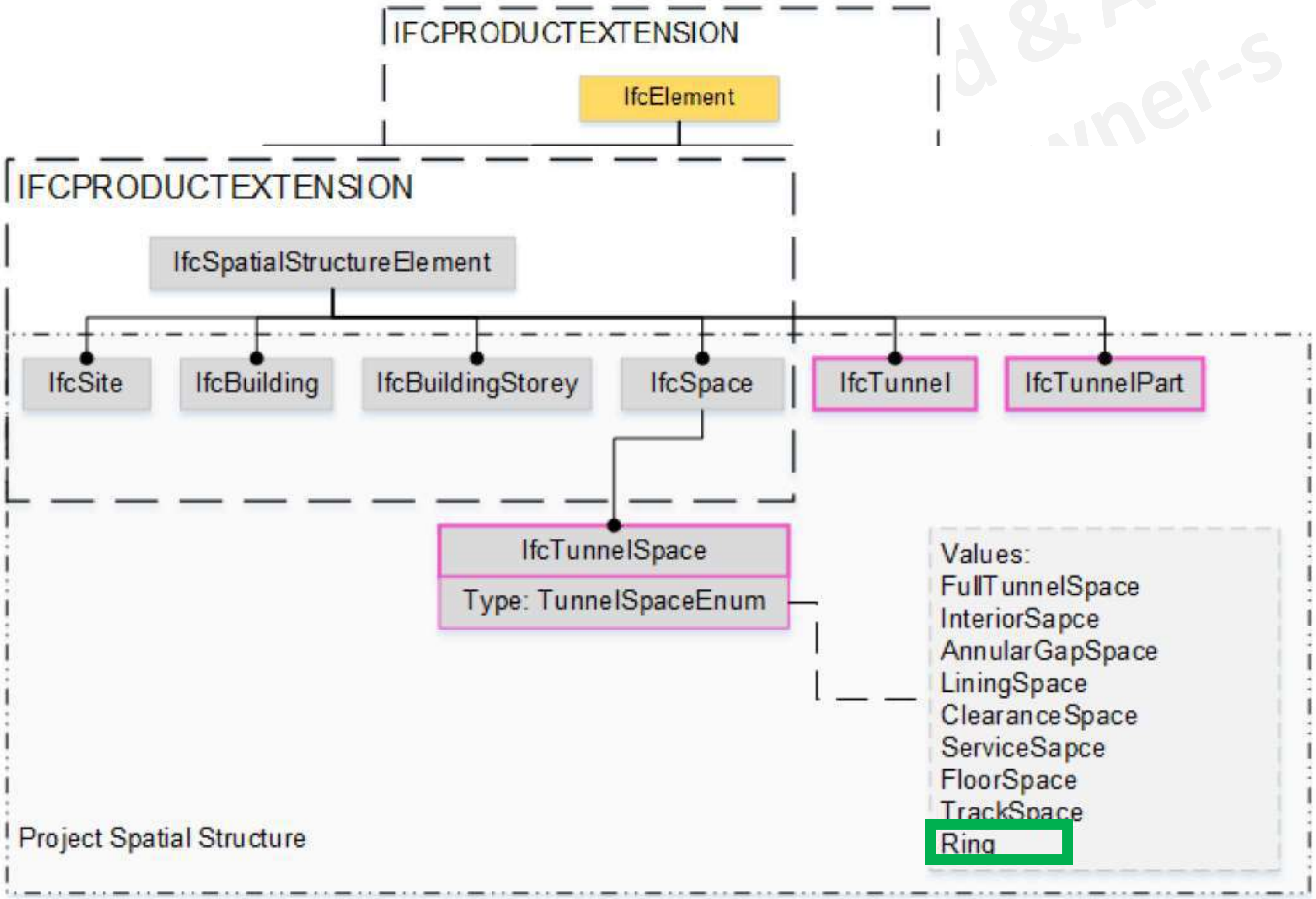
IFC for Mechanized Tunneling

BIM is Object Oriented

IFC (Industry Foundation Classes) *smartBuilding* for a uniform data exchange format toward IFC5



Projects funded by the German Rese
Universities of Bochum and Munich



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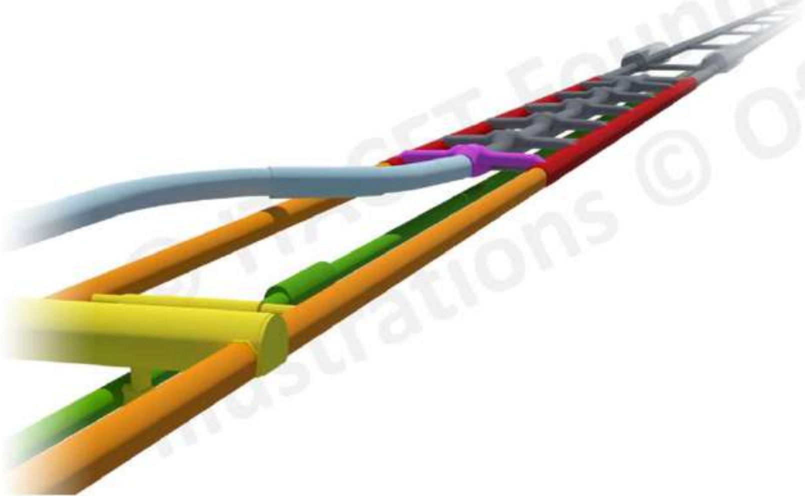
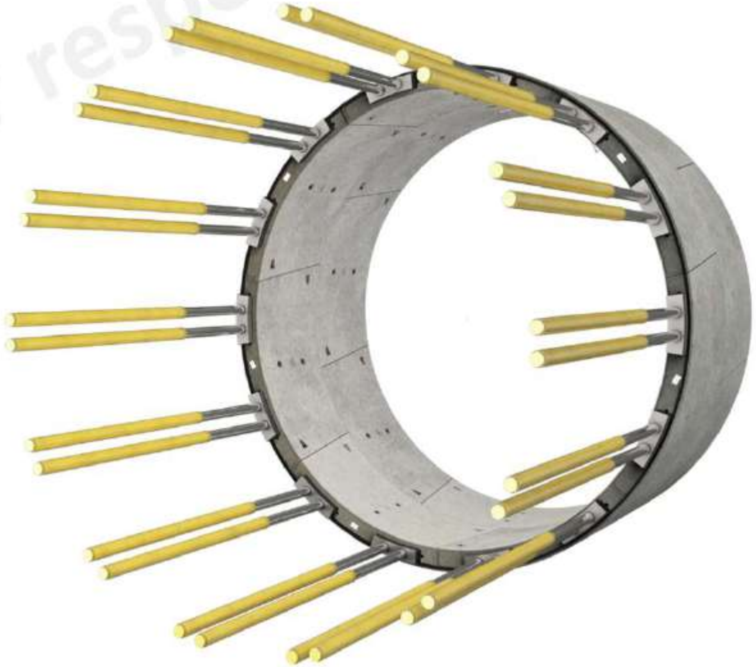
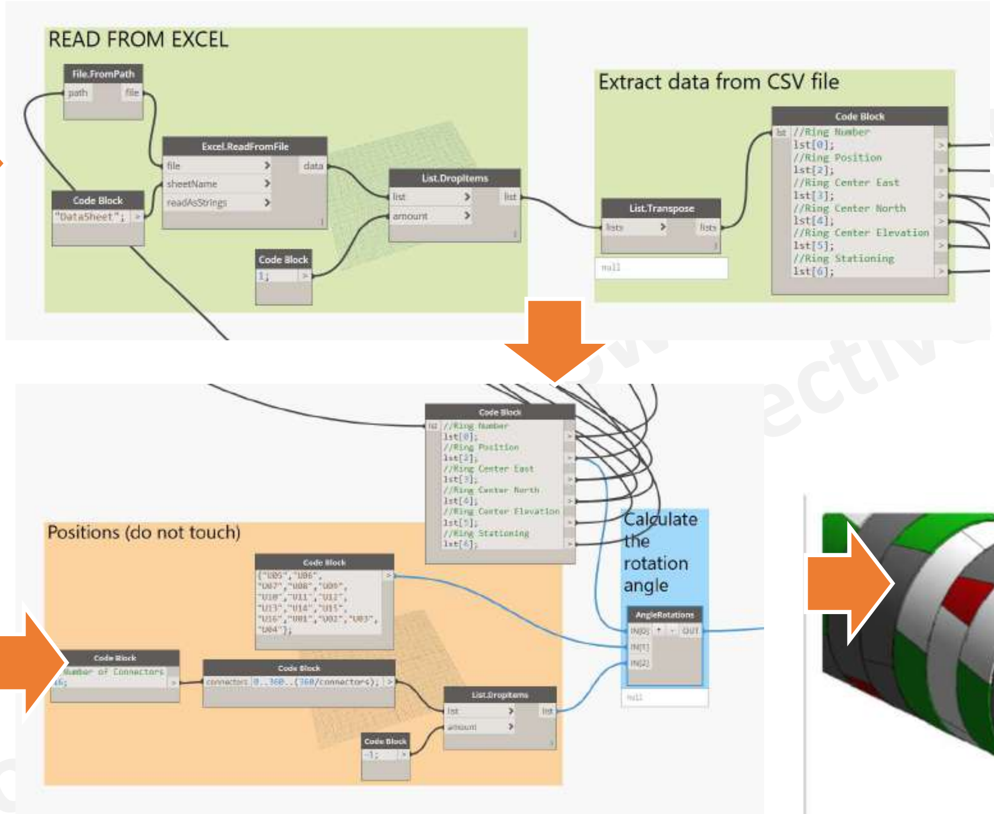
Tools for BIM

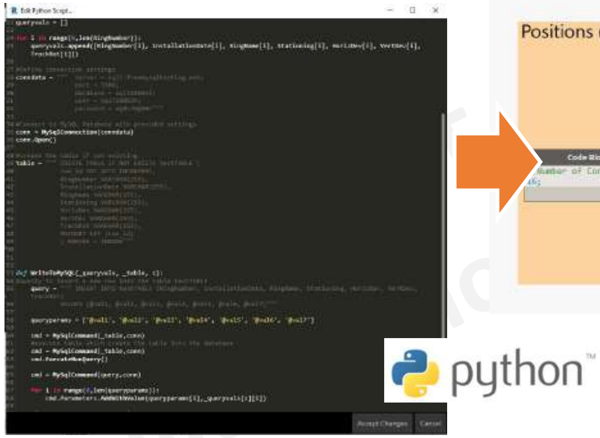
- **C3D and Revit:** software for BIM with tools to create intelligent 3D models which can be used to produce construction documentation
- **Dynamo** is an open-source, visual programming extension for Revit/C3D that allows to manipulate data, sculpt geometry, explore design options, automate processes, and **create links between multiple applications**
- **Python** is an interpreted, high-level, general-purpose **programming language**.
- **Navisworks** allows users **to open and combine 3D models,** navigate around them in real-time and review the model using a set of tools including comments, redlining, viewpoint, and measurements.

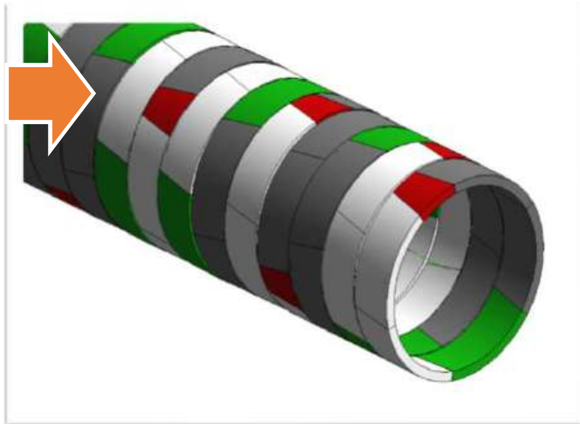




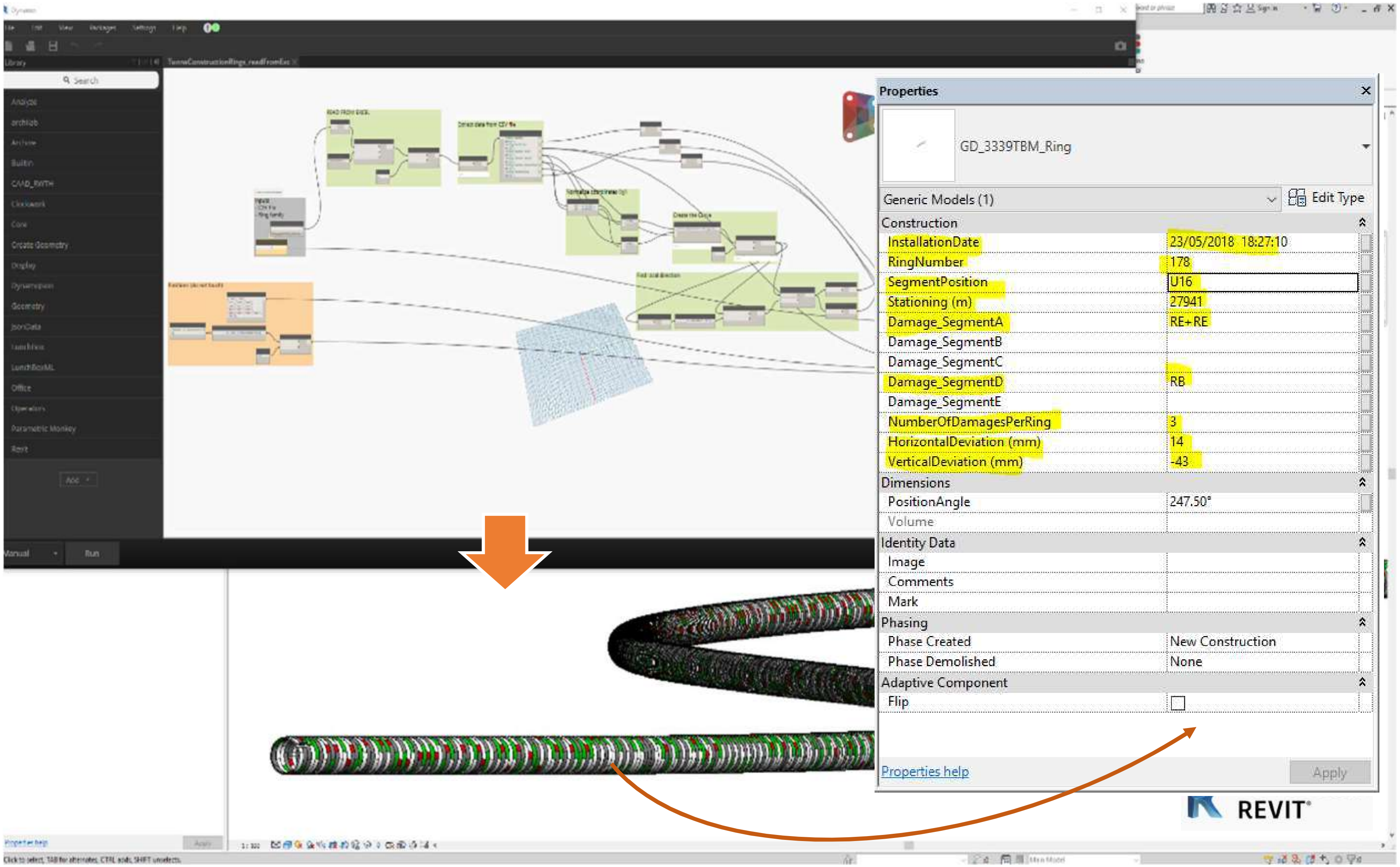
Tools for BIM





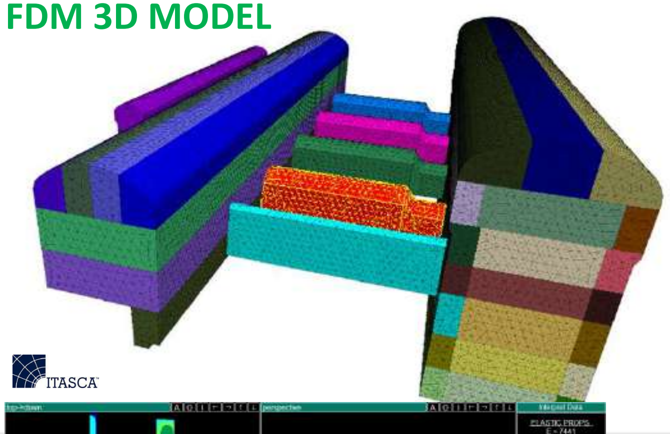


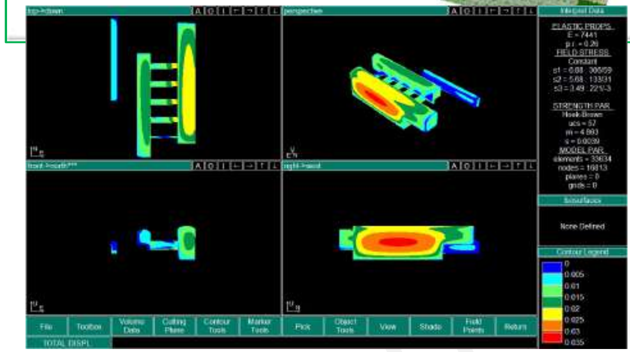
Tools for BIM



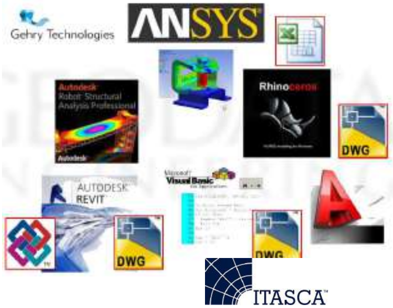
BIM and Numerical Simulations

FDM 3D MODEL

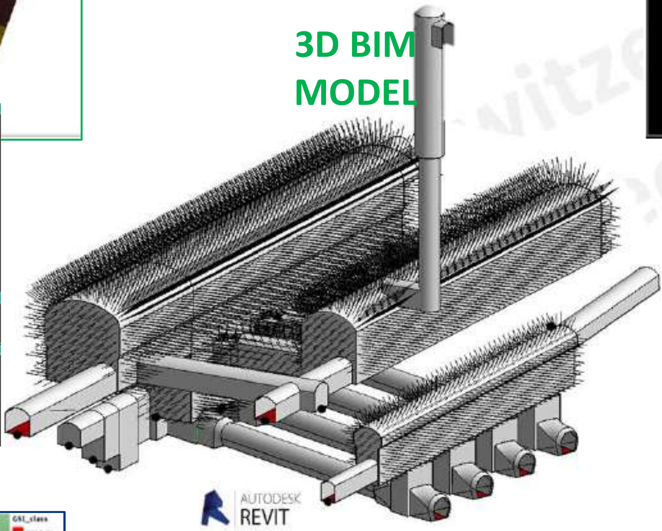


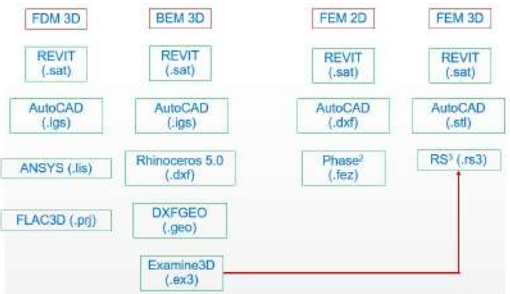


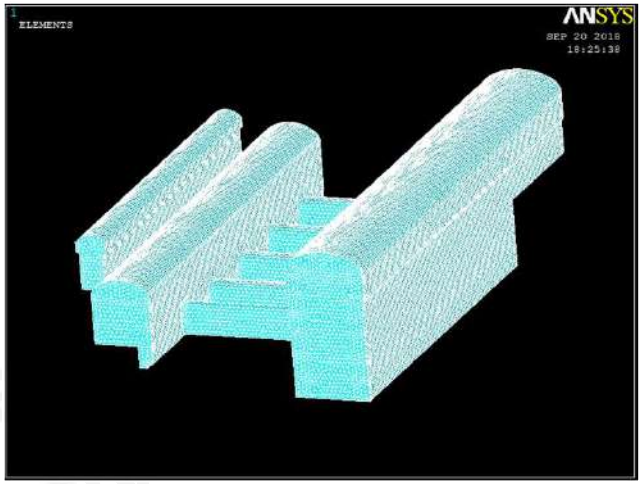
BEM 3D MODEL



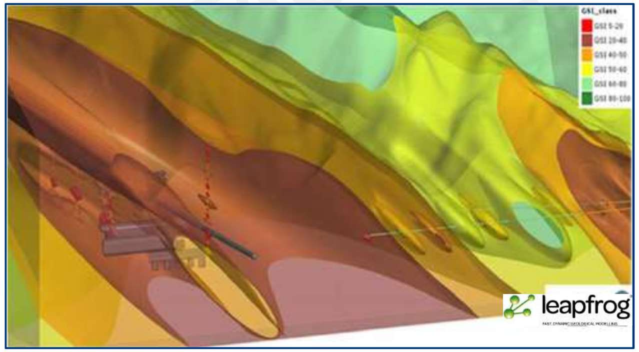
3D BIM MODEL



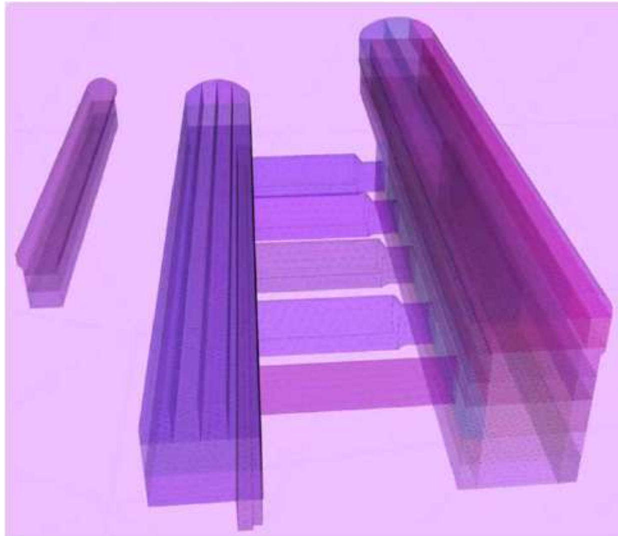




FEM 3D STRUCTURAL MODEL



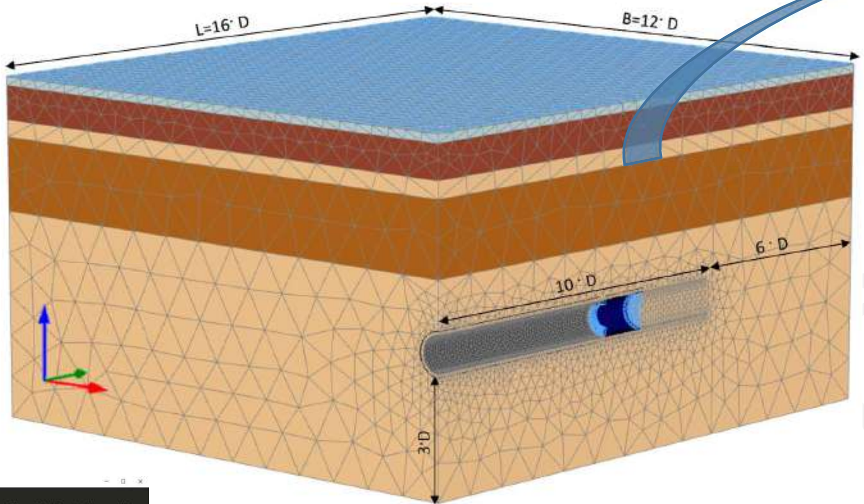
3D GEOLOGICAL MODEL

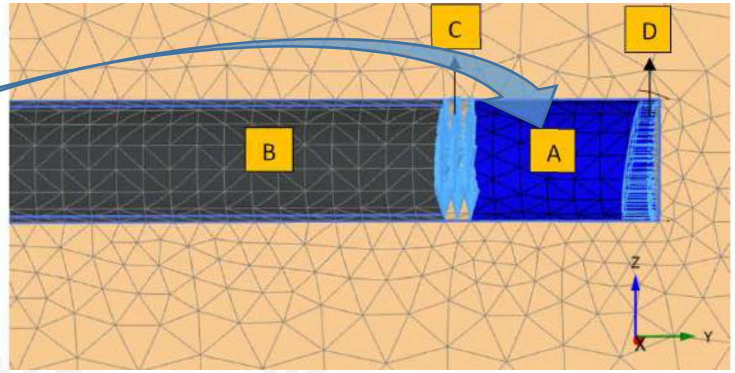


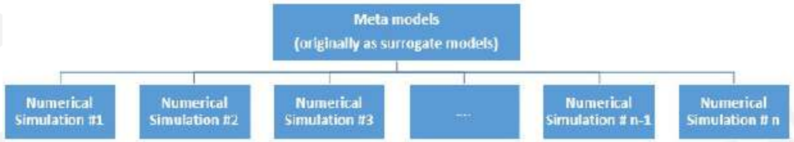
FDM 3D MODEL

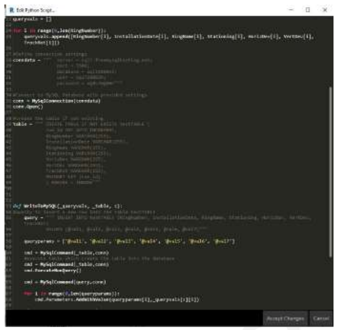
BIM and Numerical Simulations

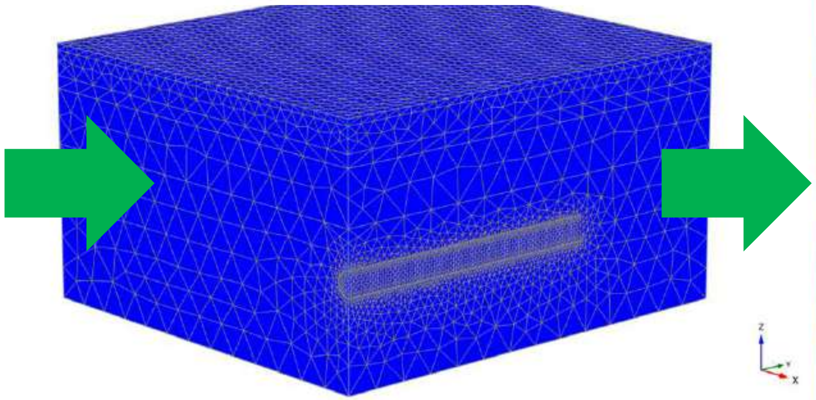
- ❑ Time-consuming modelling
- ❑ Decision-Making process
- ❑ Meta Models

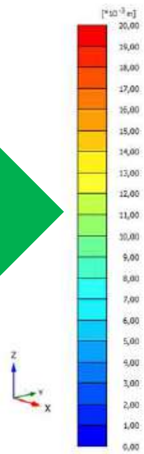


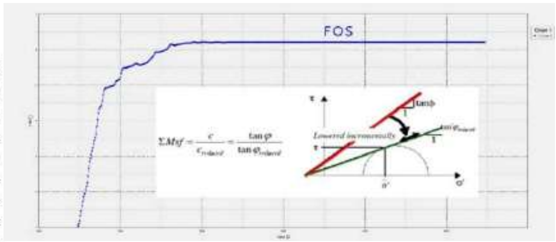




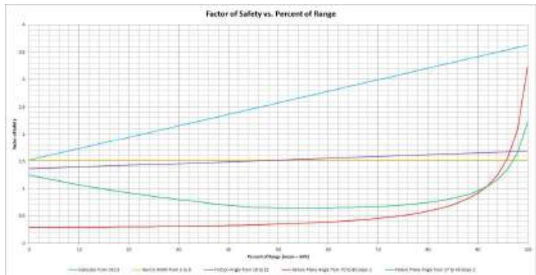








Factor of Safety (FoS)



PLAXIS

python

BIM and Numerical Simulations

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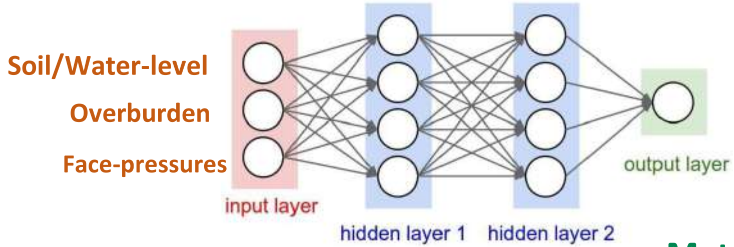
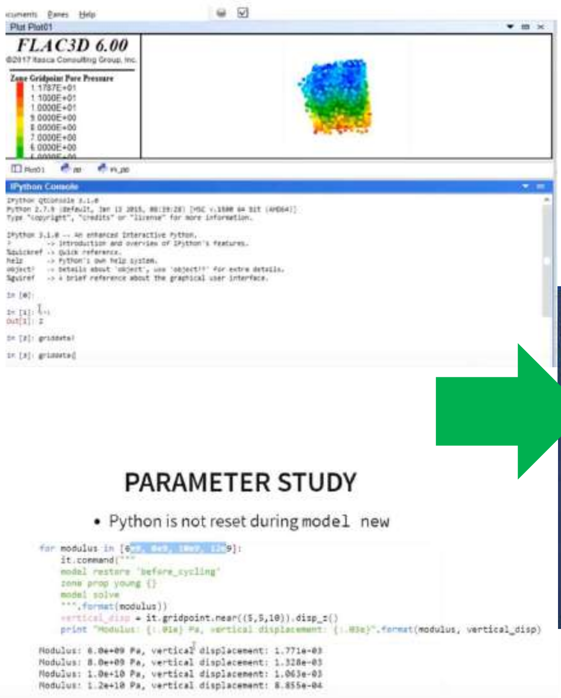
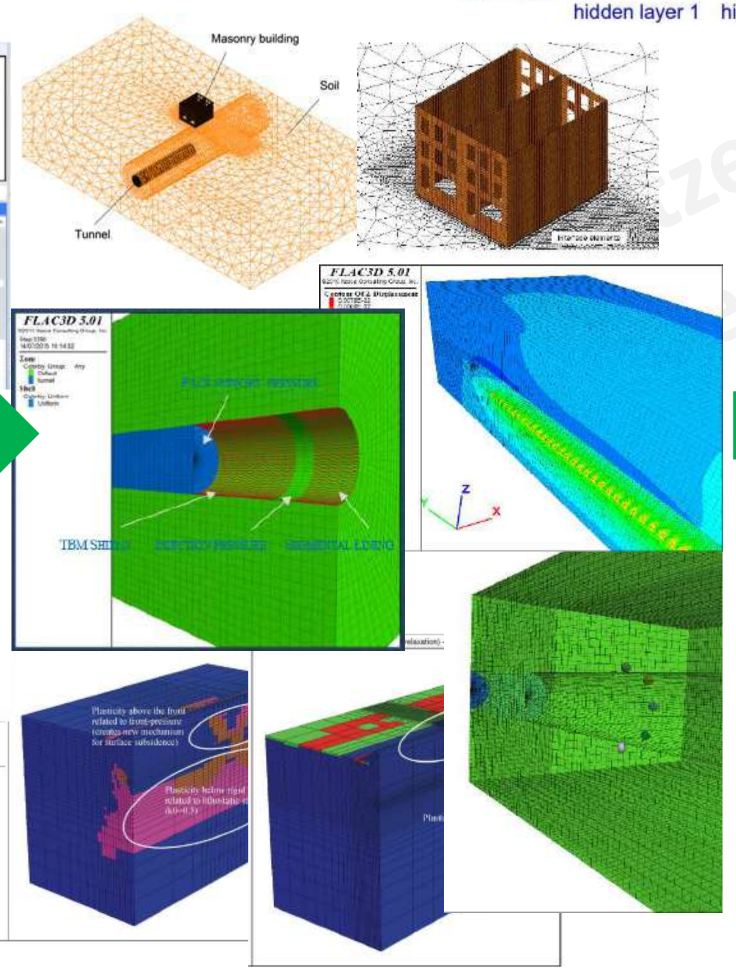
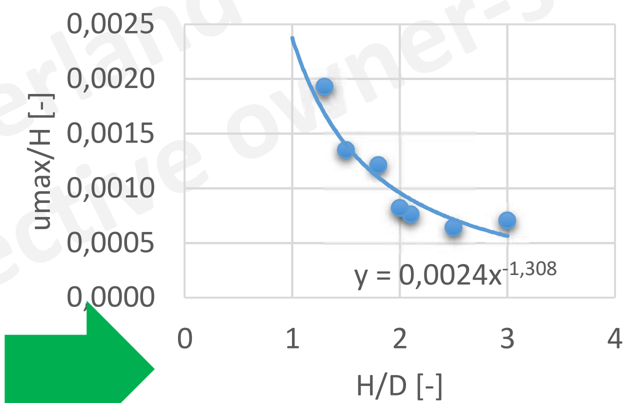
- ❑ Time-consuming modelling
- ❑ Meta Models



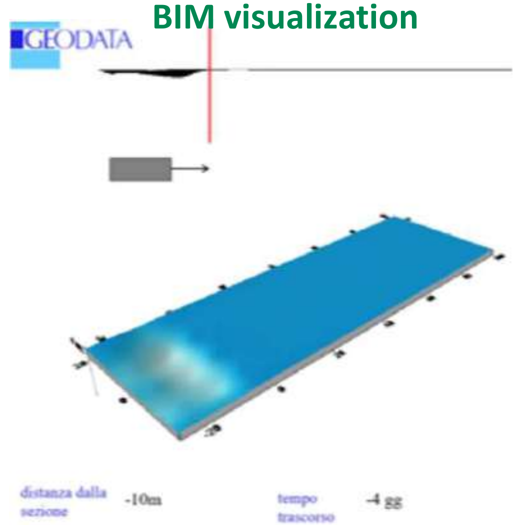




Meta-model - Correlations

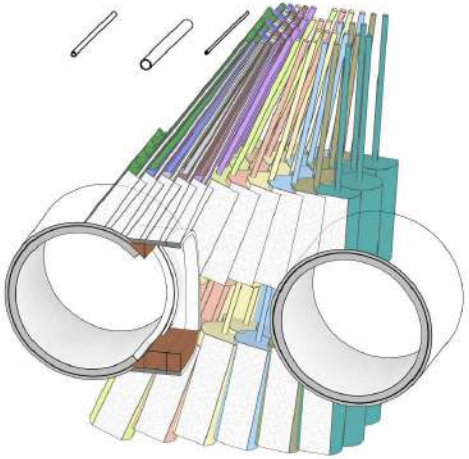


BIM visualization

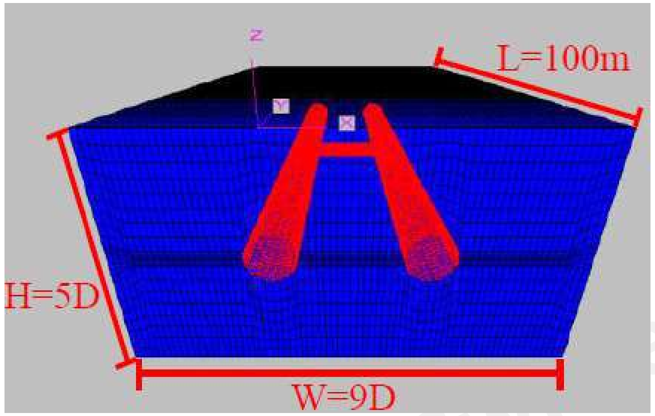


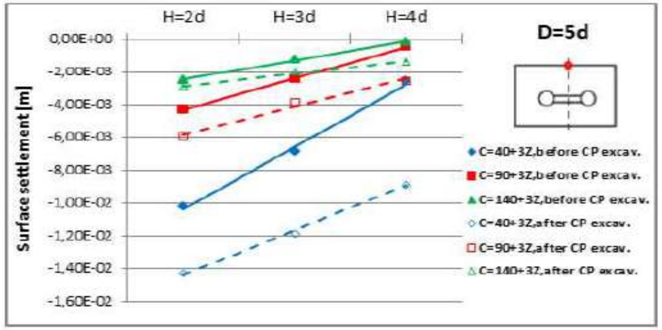
BIM and Numerical Simulations

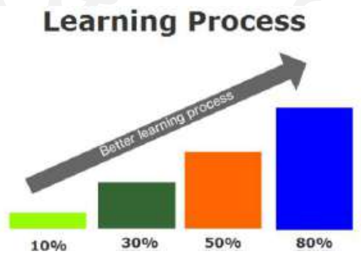
- Decision-Making process
- Time-consuming modelling
- Meta Models



BIM 3D model







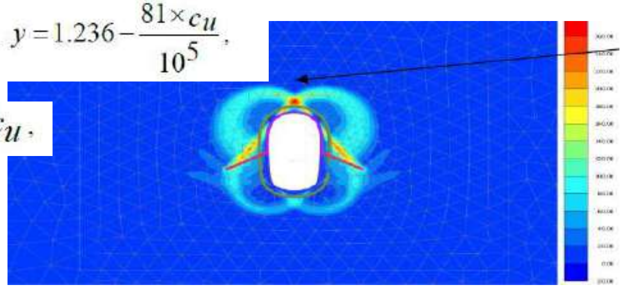
BIM

BIM tools

$$x = 1.380 - \frac{75 \times c_u}{10^5}, \quad y = 1.236 - \frac{81 \times c_u}{10^5},$$

$$\Delta = 2.81 - 0.02 c_u,$$

Meta-models Correlations



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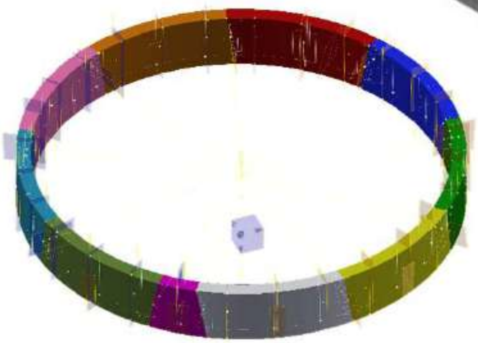
BIM and Mechanized tunneling: Project Life-cycle and Knowledge areas

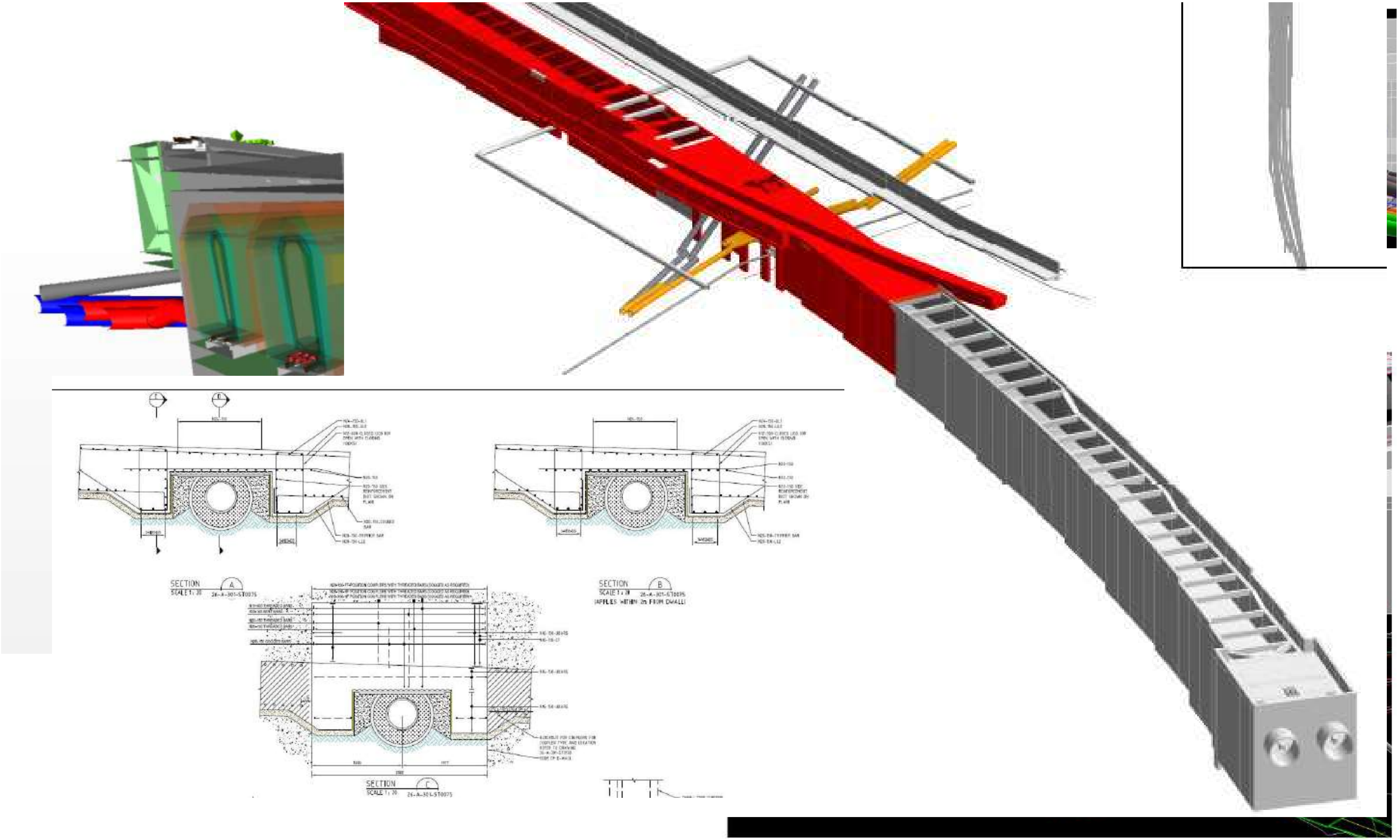
Design → Production of Design → Construction → Maintenance

- Clash detection (space-proofing and MEP components)
- Virtual construction for the study of the excavation sequence
- Variant studies and optimization of the alignment
- Justifiable assumptions, applied concept and design criteria
- Sensitivity calculations
- Probabilistic integrated calculations
- Risk-based study of various scenarios
- Structural design



Space-proofing and MEP

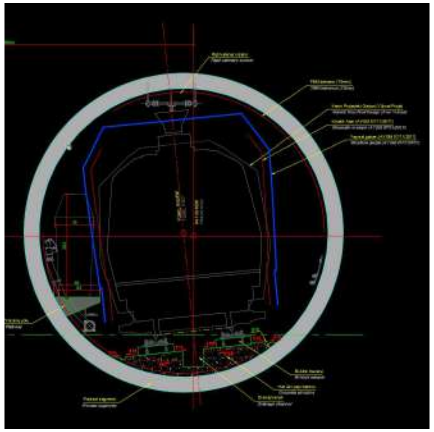
Clash detection - Virtual construction for the study of the excavation sequences

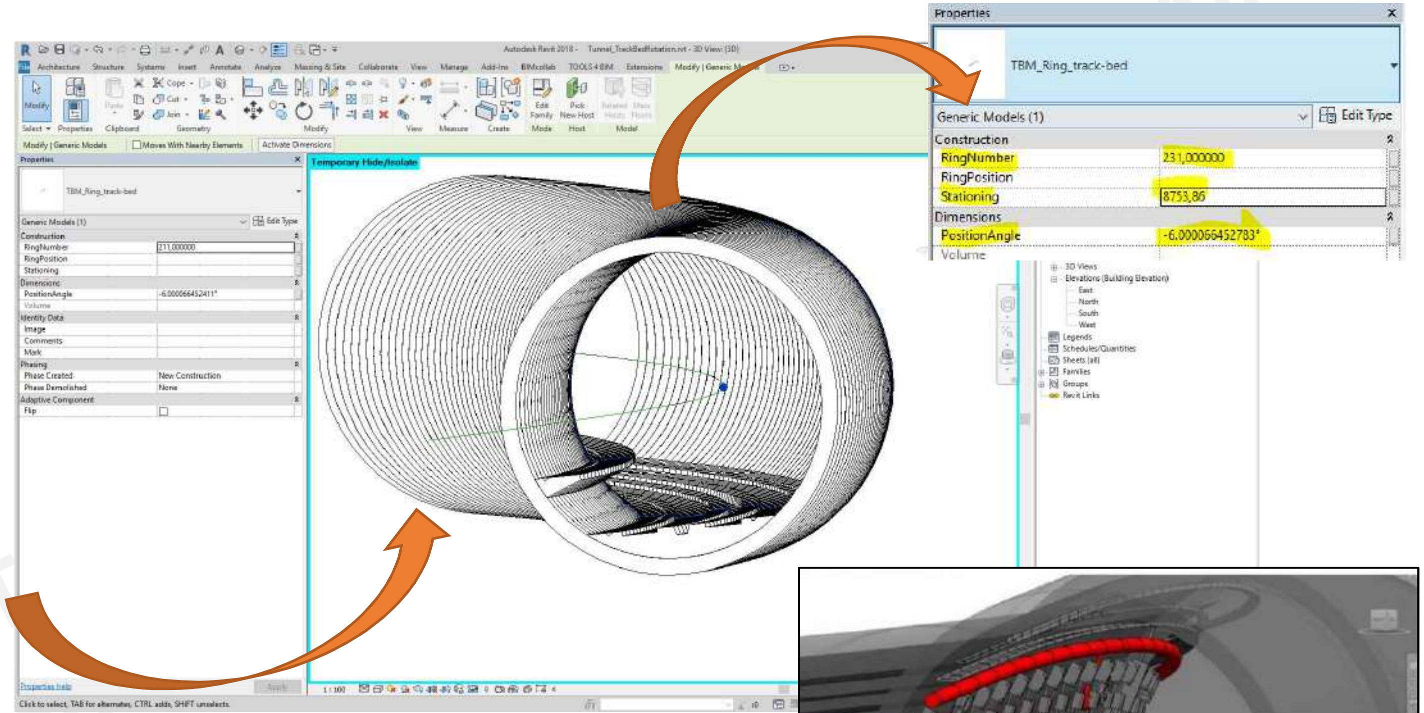


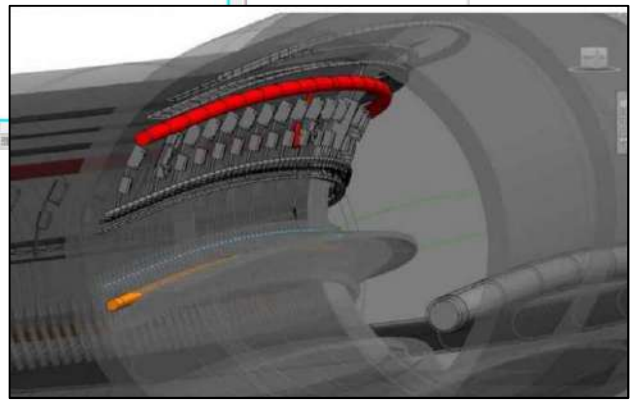
Alignment - Space-proofing – M.E.P.

Clash detection - Virtual construction for the study of the excavation sequences

BIM solution have been used to model the spaceproofing with the aim to evaluate the right position of trackbed, walkways and any other obstacles to be considered for MEP design.



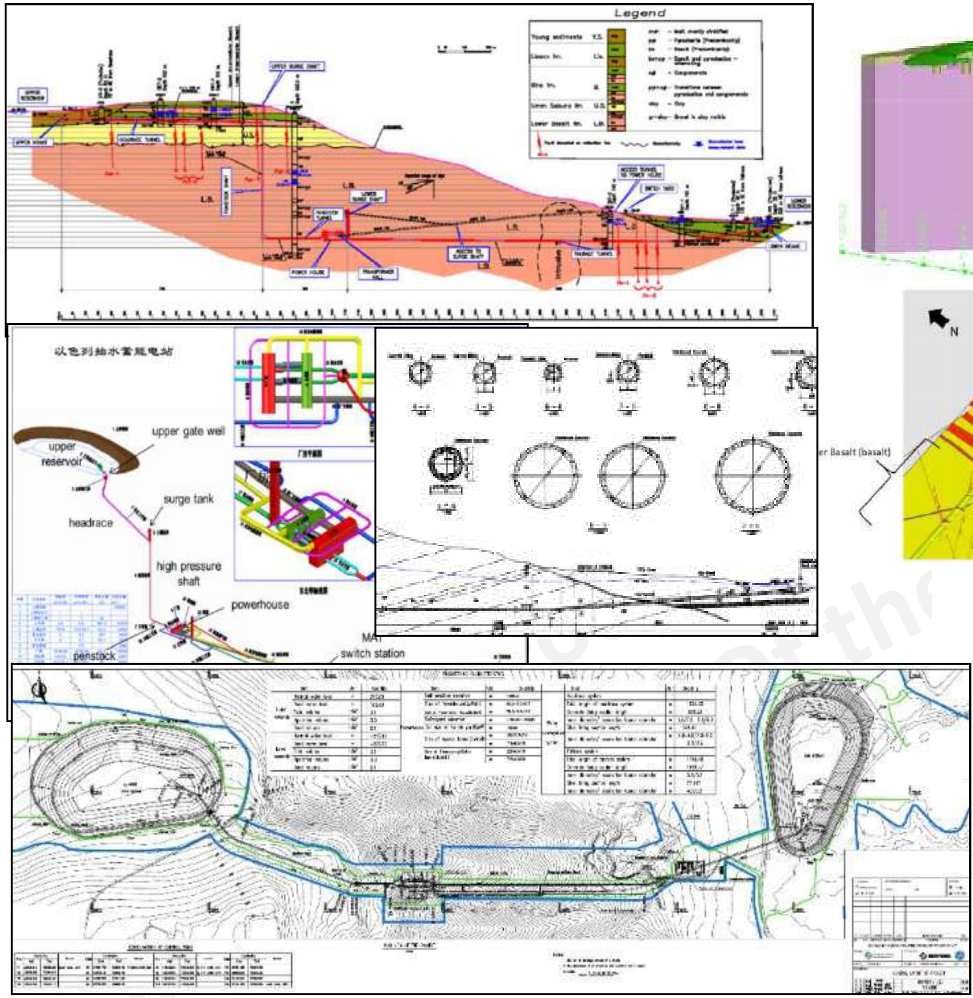




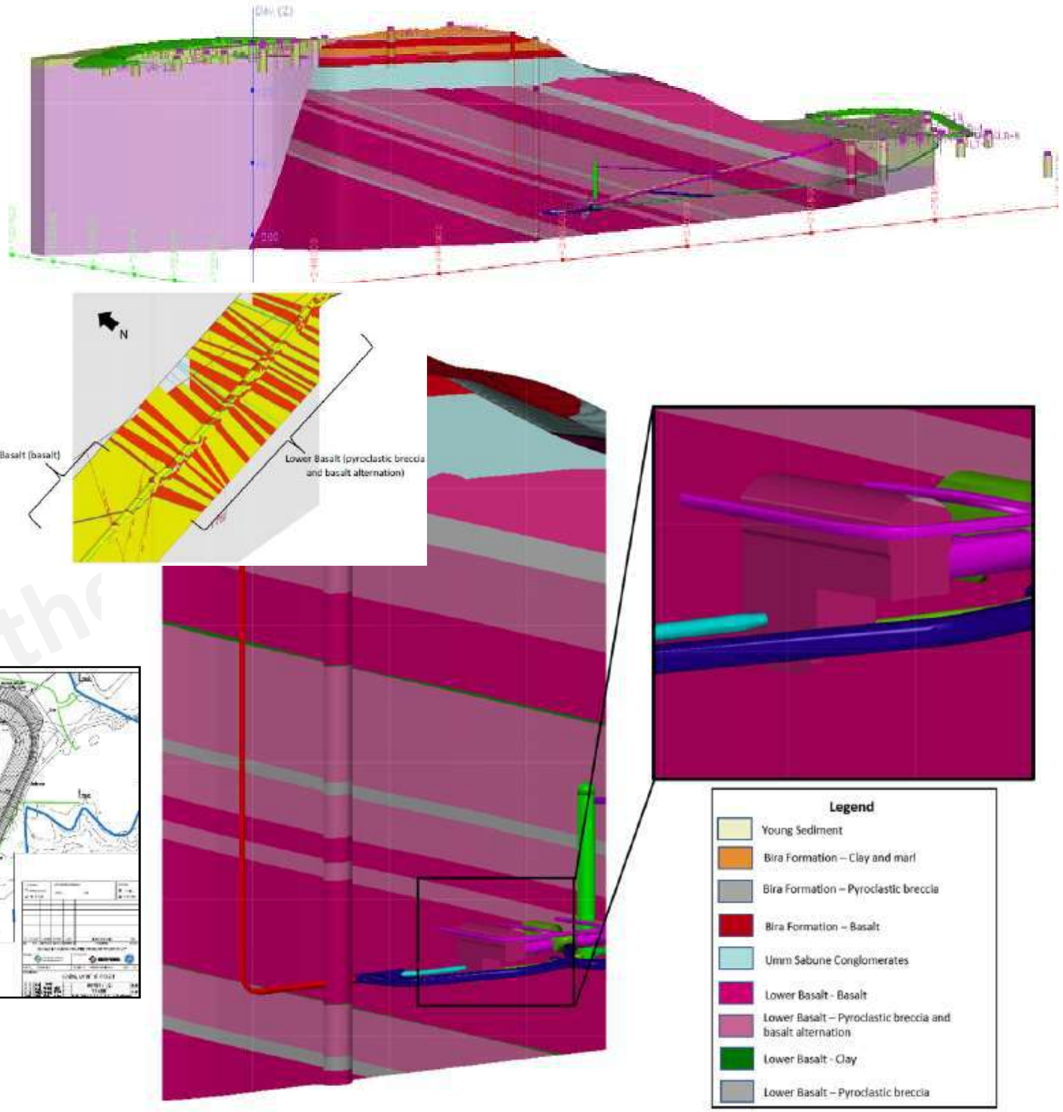
CLASH DETECTION: ALIGMENT AND MEP INSTALLATIONS

Geological assessment and design

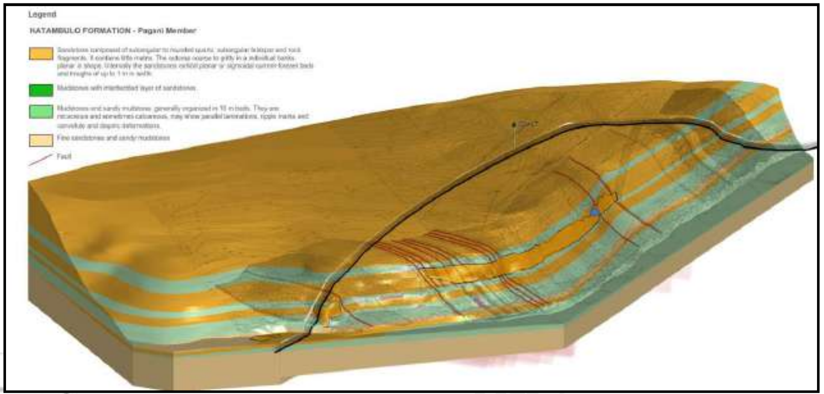
Without BIM



With BIM



Geological assessment and updating



Input data required (1)
- Topographic surface
- 3D layouts of works
- Existing geological maps and/or cross sections
- Structural data (mfaults, joints)

Input data required (2)
Lithological & geomechanical (i.e. RQD, GSI, RMR) database from boreholes

New input data:
- boreholes from GI
- lab and in-situ tests
- Geological & geostructural field surveys

Production of preliminary ground model via enhanced review of existing data

Use of preliminary ground model in GI design and specification

Processing and cross-checking GI results in production of refined 3D ground model

Production of derivatives from ground model e.g. synthetic cross sections

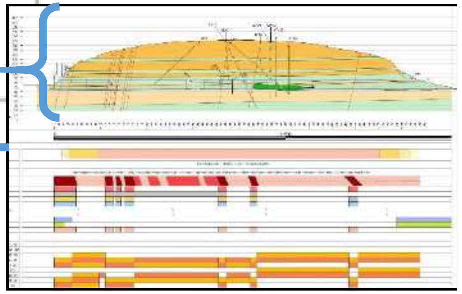
3D geotechnical model e.g. particle grading, shear strength, bulk density etc

Use of detailed ground model in design optimisation; examination of design in 3D geological environment

Integration of quantitative risk assessment and risk mitigation

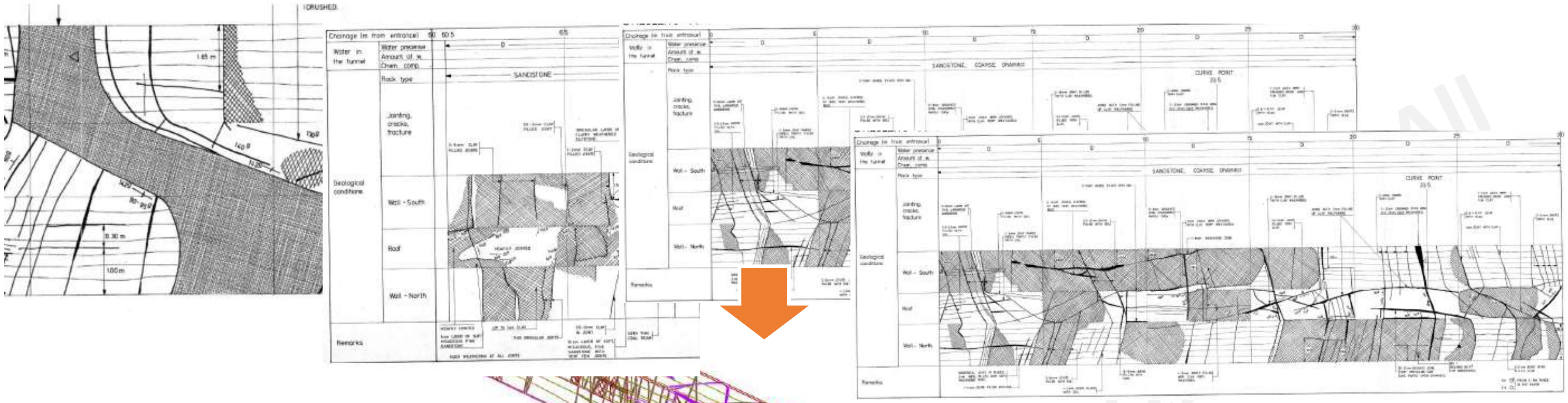
Integration of all data streams in accountable and traceable platform

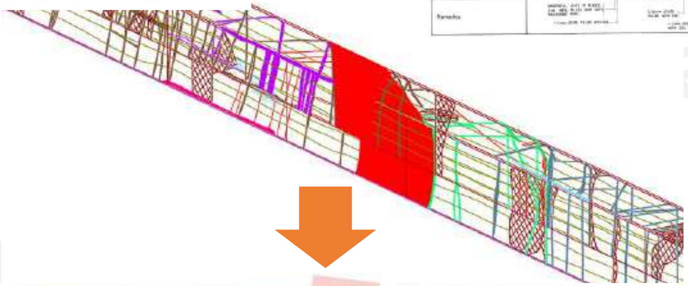
Project Hub; 3D Ground Model
Integrated, Iterative, Multidisciplinary, Traceable, Accountable

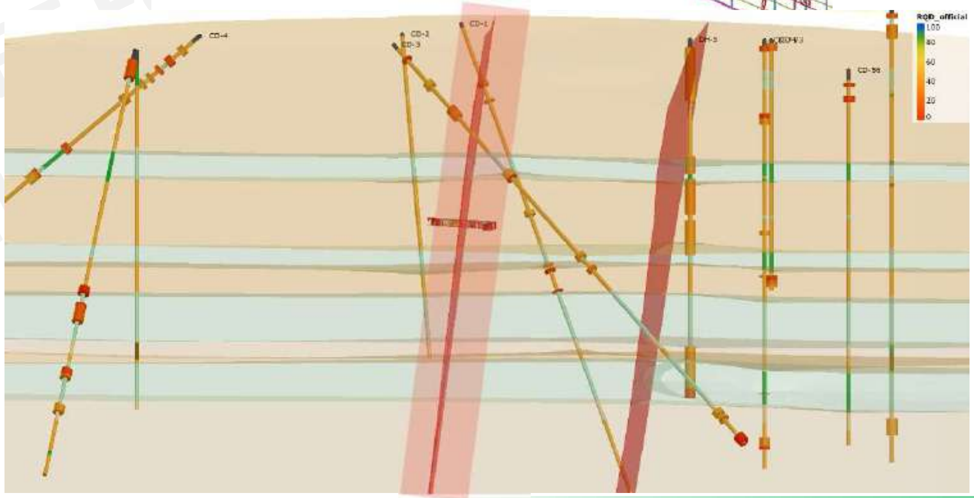


Geological assessment and design

from the input data to fault zone definition in the 3D model

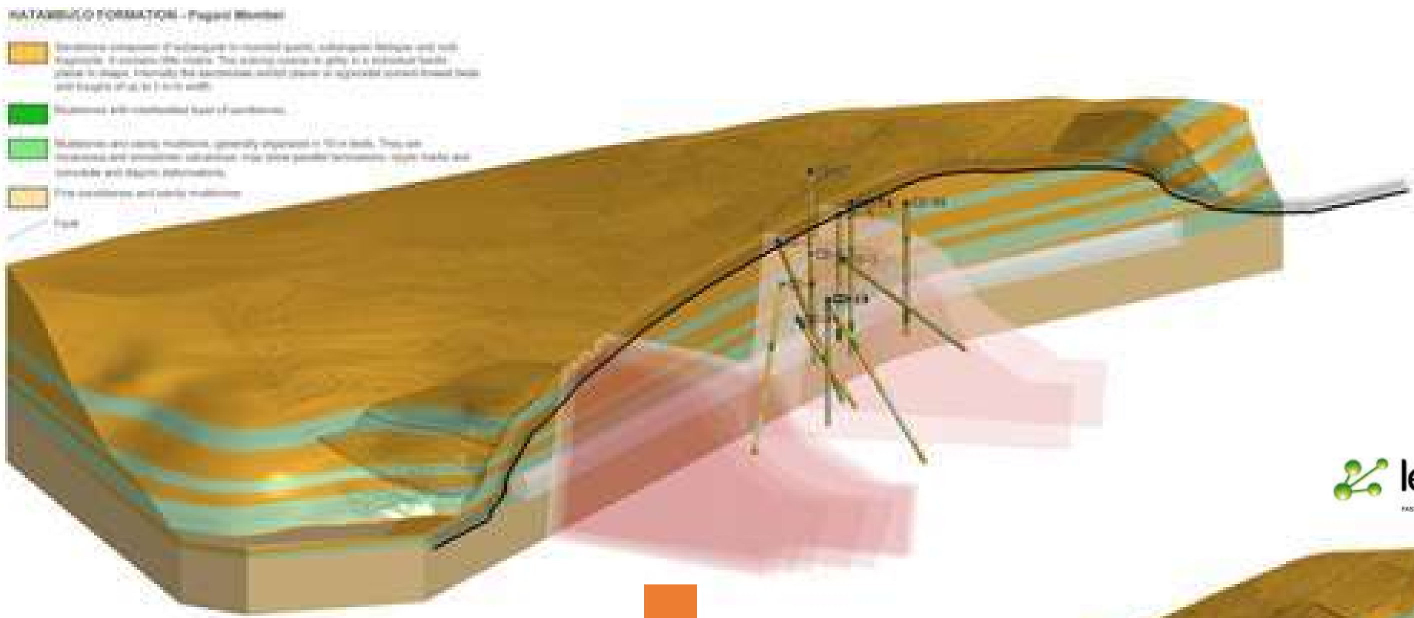




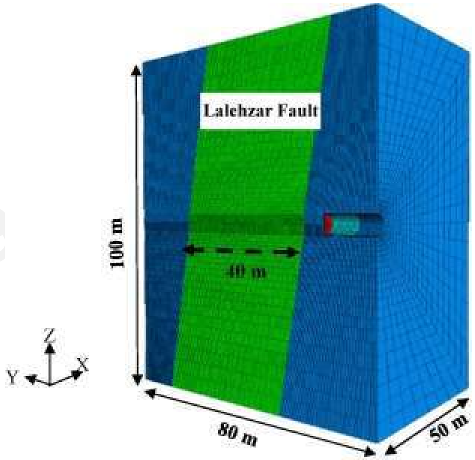


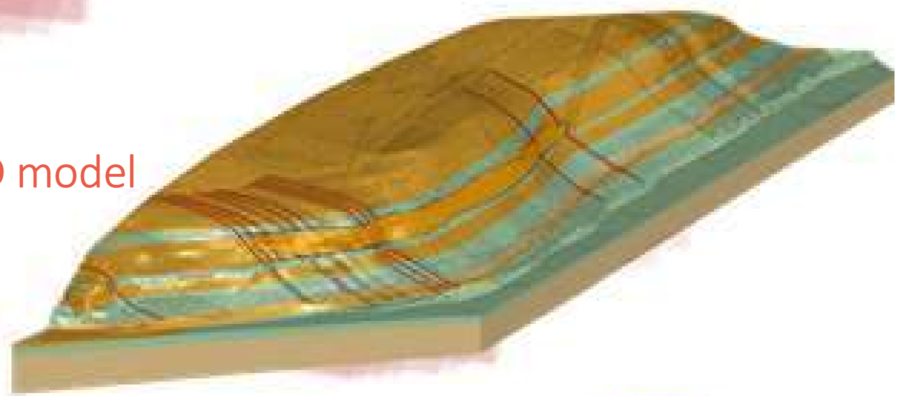
Definition of Fault zone in a 3D model

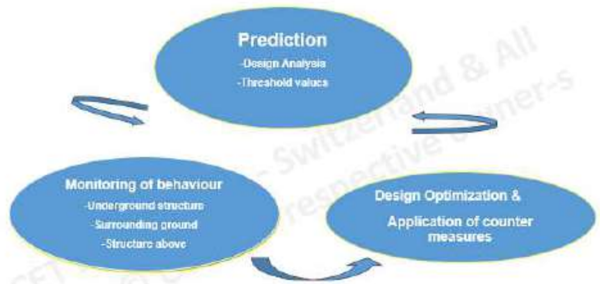
Geological assessment and design



Definition of **Fault zone** in a 3D model





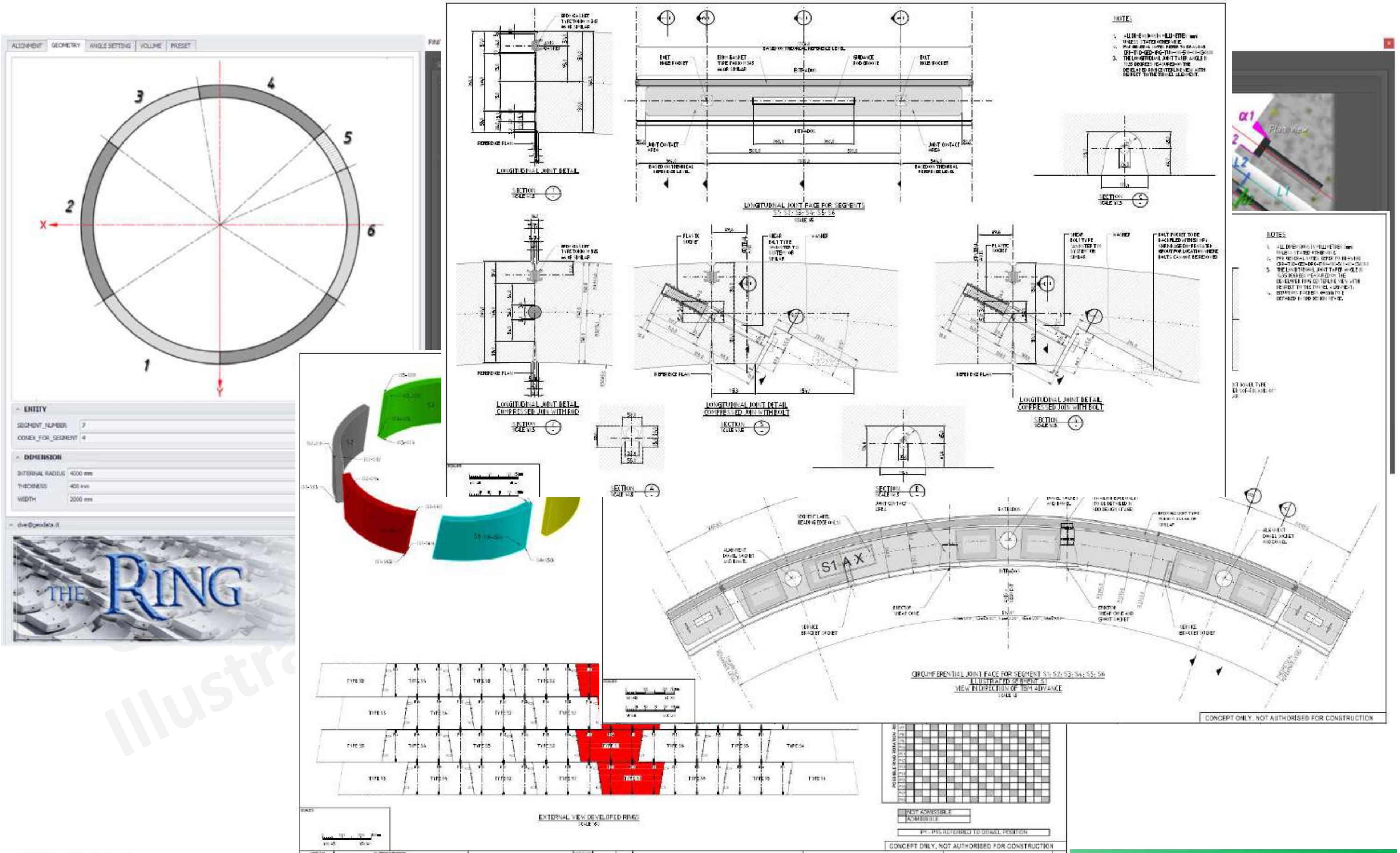


Design of Segmental Lining

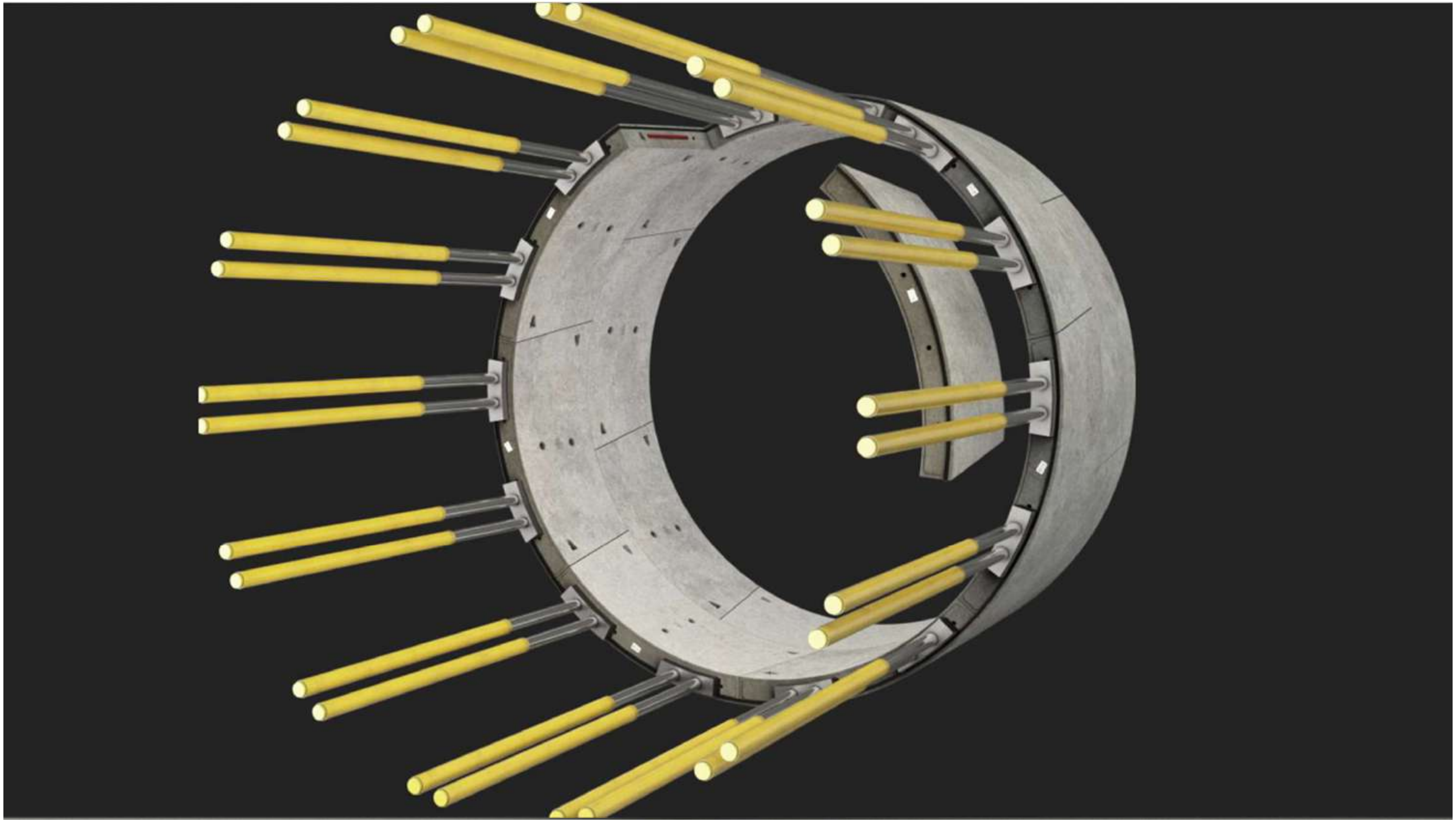
A software developed in Geodata for the design of the segmental lining covering all the LODs

Design of Segmental Lining

A software developed in Geodata for the design of the segmental lining covering all the LODs and shop-drawings for the precast

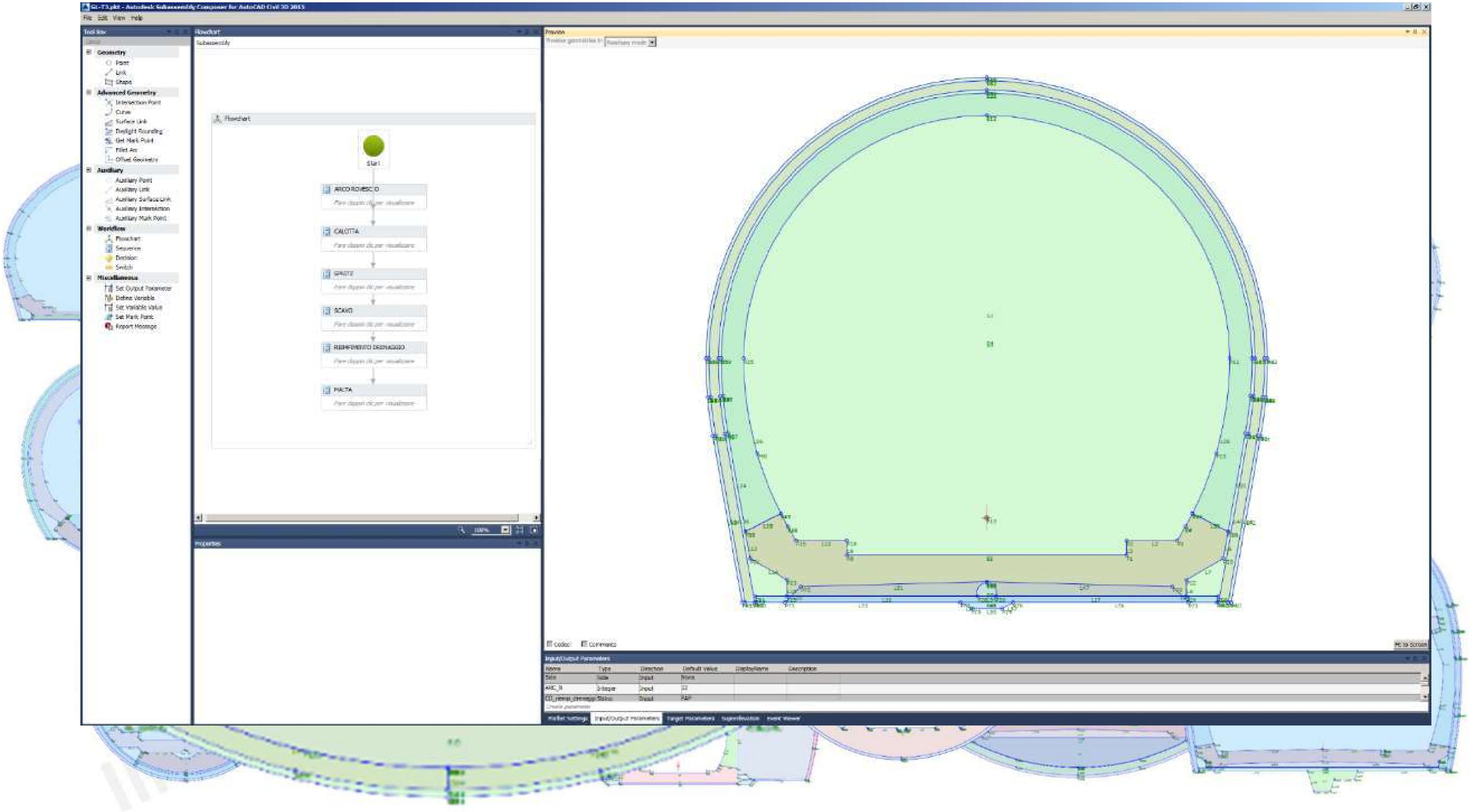


Design of Segmental Lining



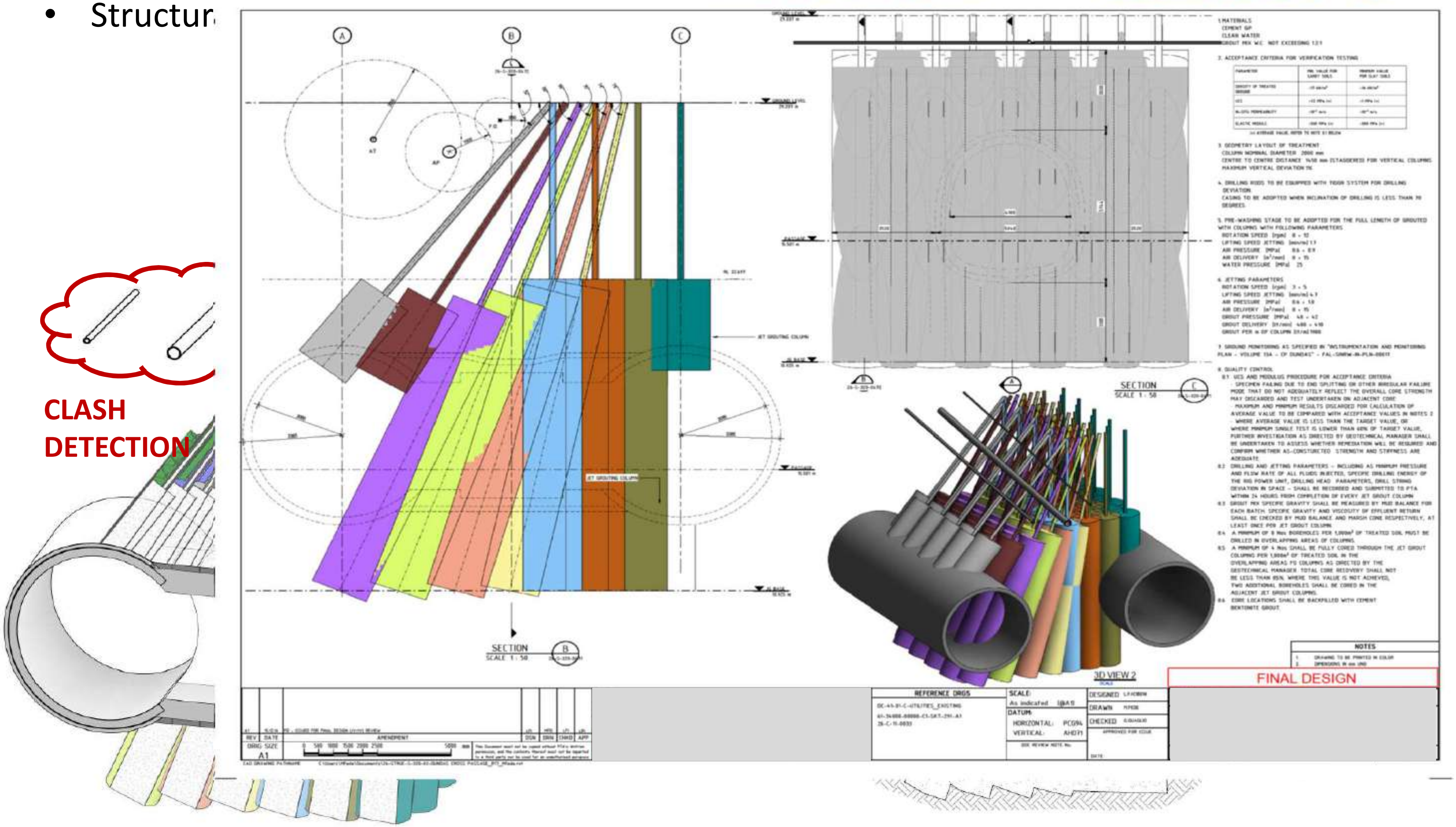
Design of Cross-passages and NATM sections

Parametric generation of complex geometries



Design of Cross-passages

- Functional design and MEP
- Clash detection
- Structur

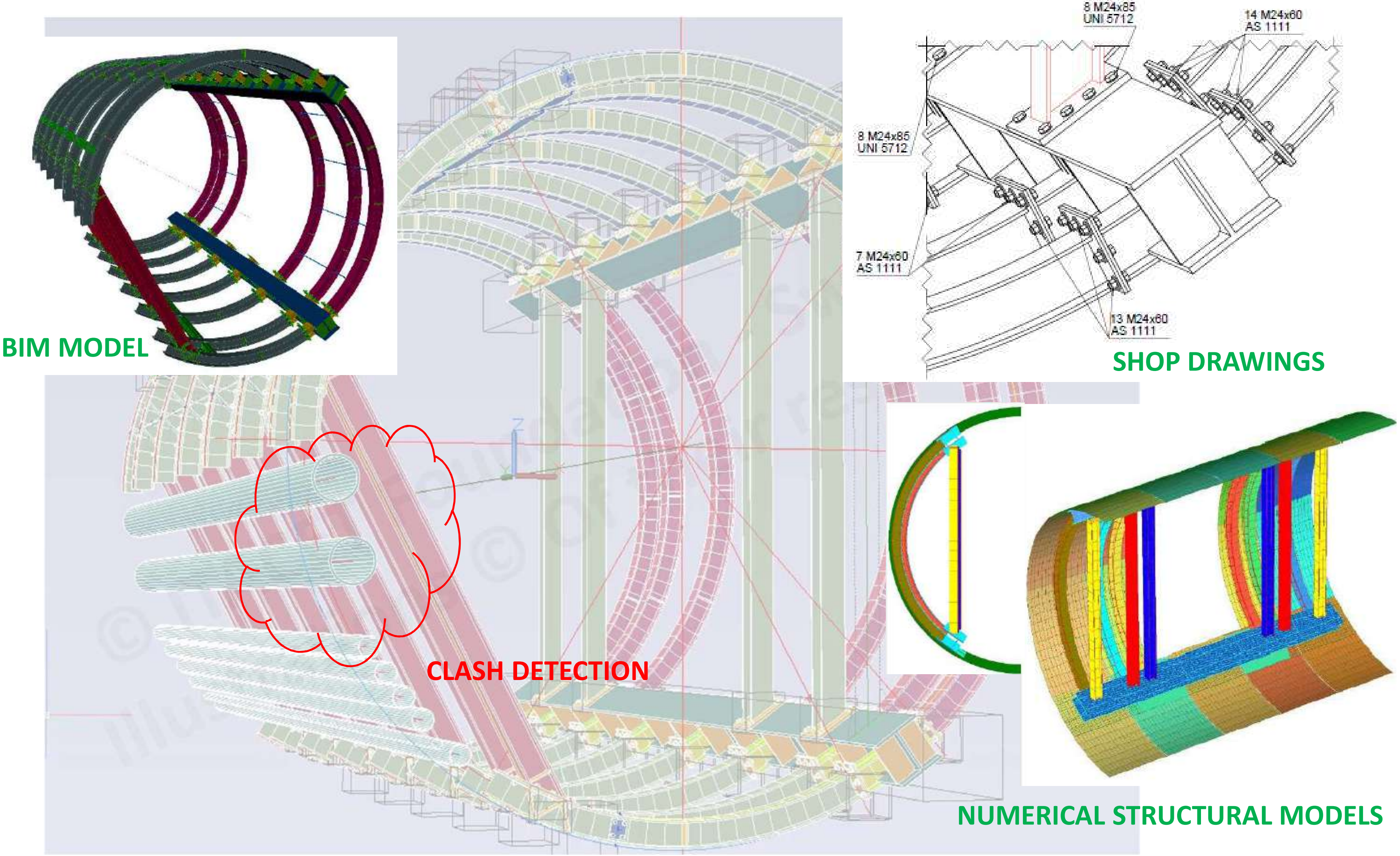


BIM MODEL

SHOP DRAWINGS

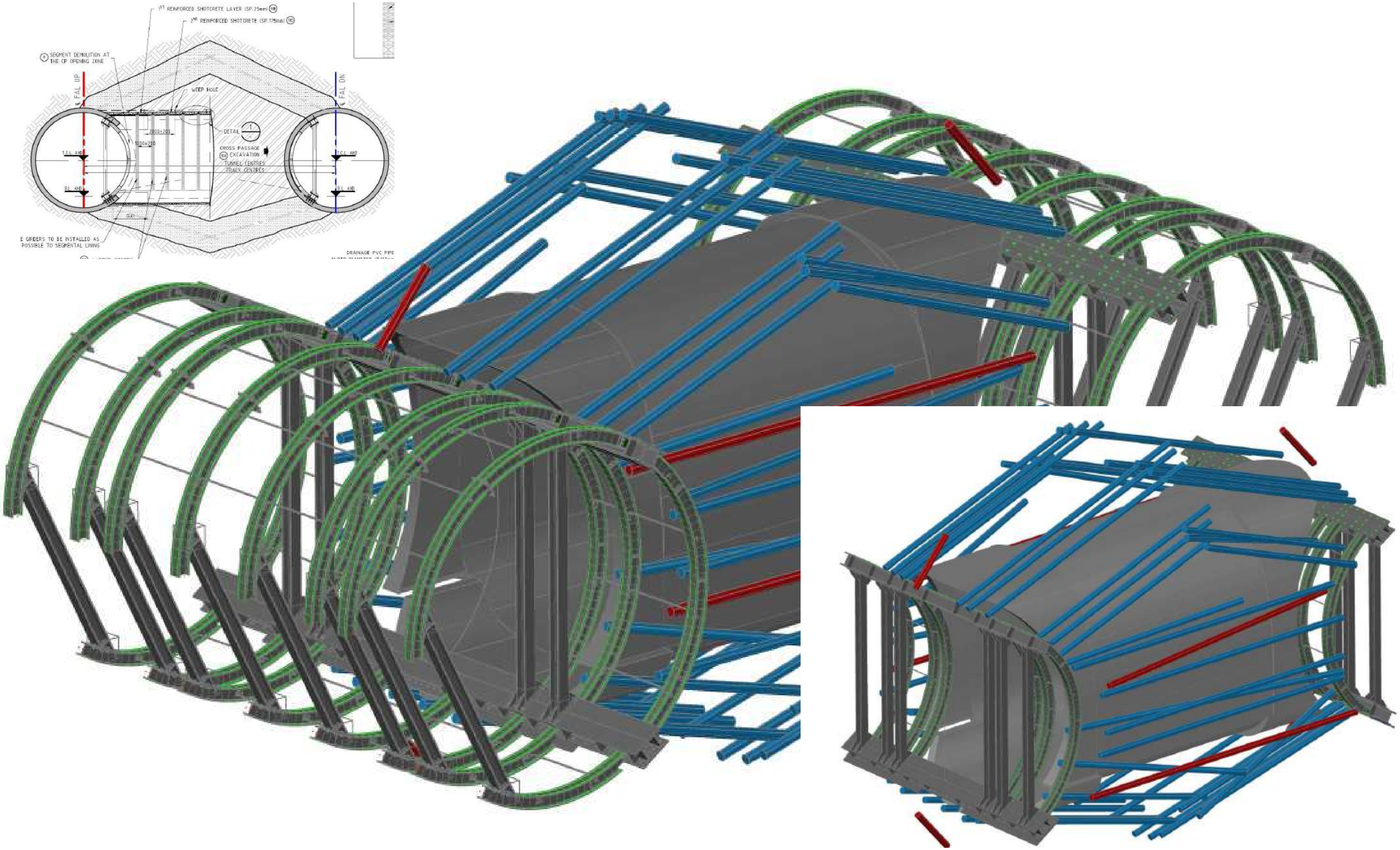
Design of Cross-passages

Design of temporary steel-frame and MEP services during construction



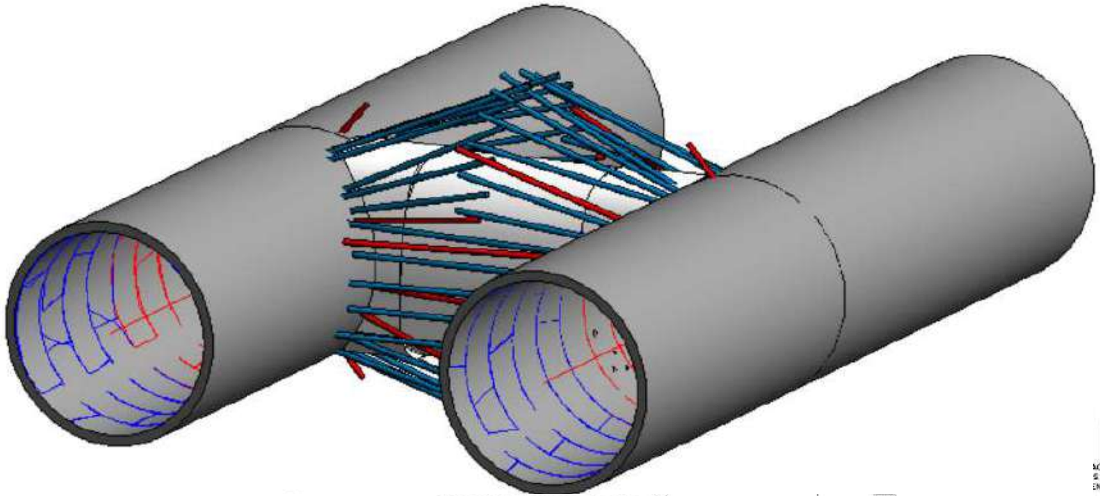
Design of Cross-passages

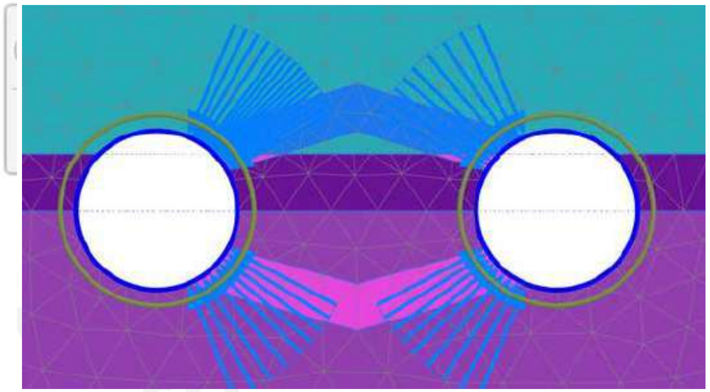
Clash detection for complex geometries: temporary steel-frame and ground-freezing support system

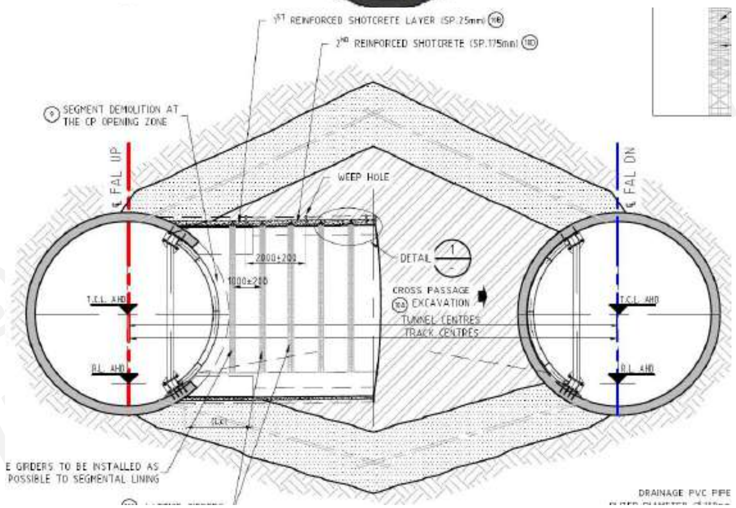


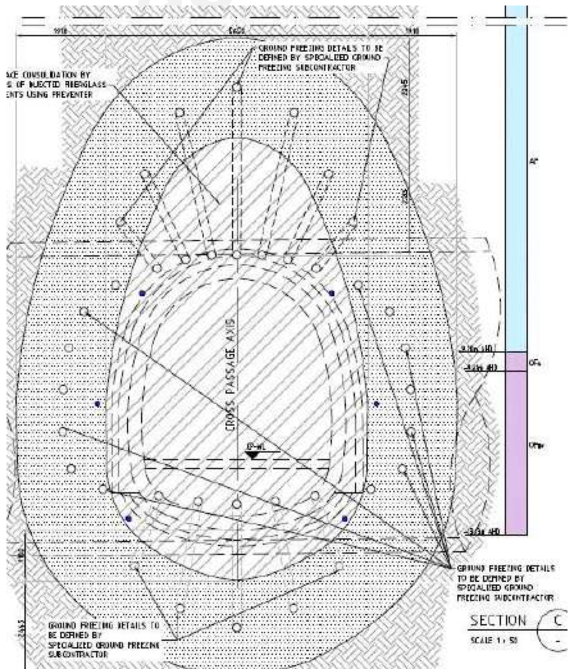
Design of Cross-passages

BIM model as an important input for the numerical computations and for the shop drawings

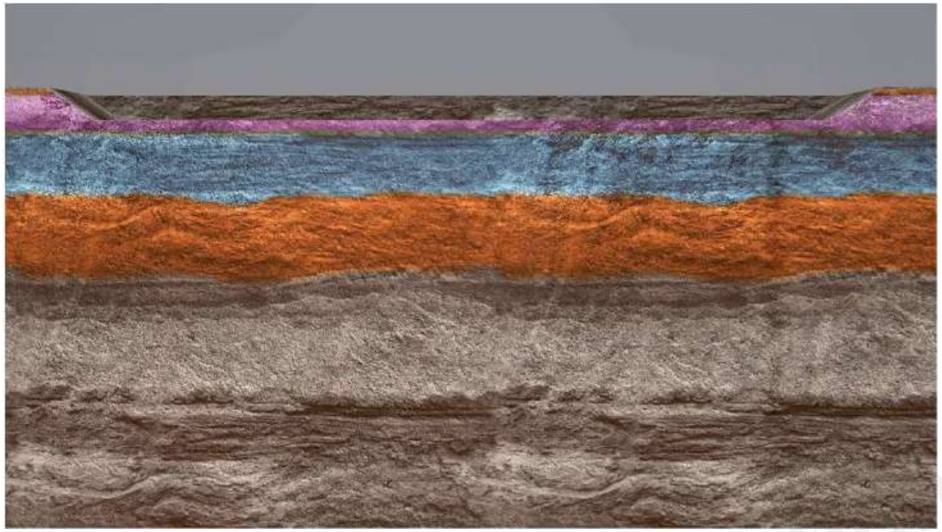




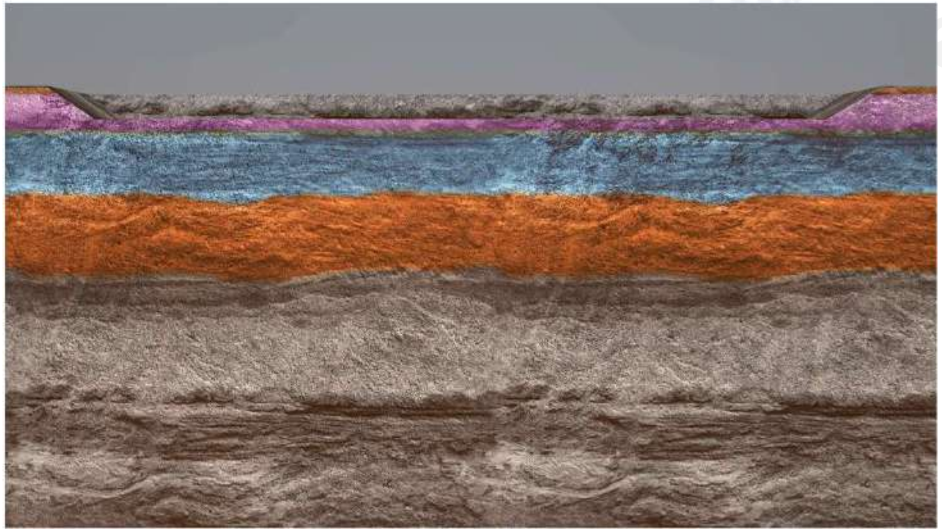




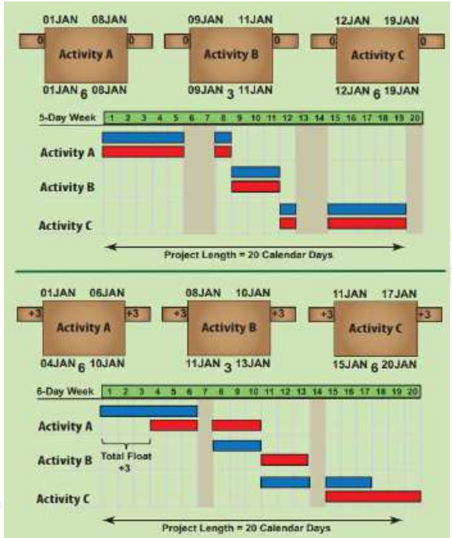
Project phasing simulations
Visual validation of two alternatives – 4D BIM

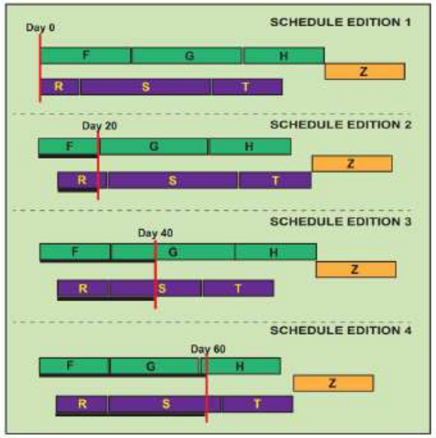


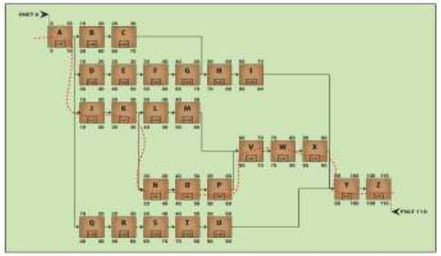
TBM **BEFORE** DEEP EXCAVATION (STATION/SHAFT)



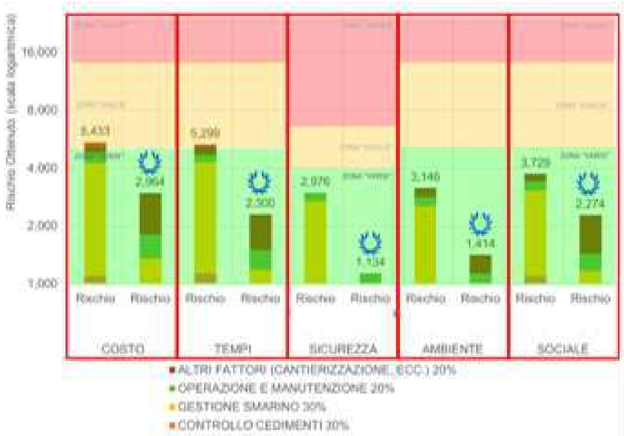
TBM **AFTER** DEEP EXCAVATION (STATION/SHAFT)





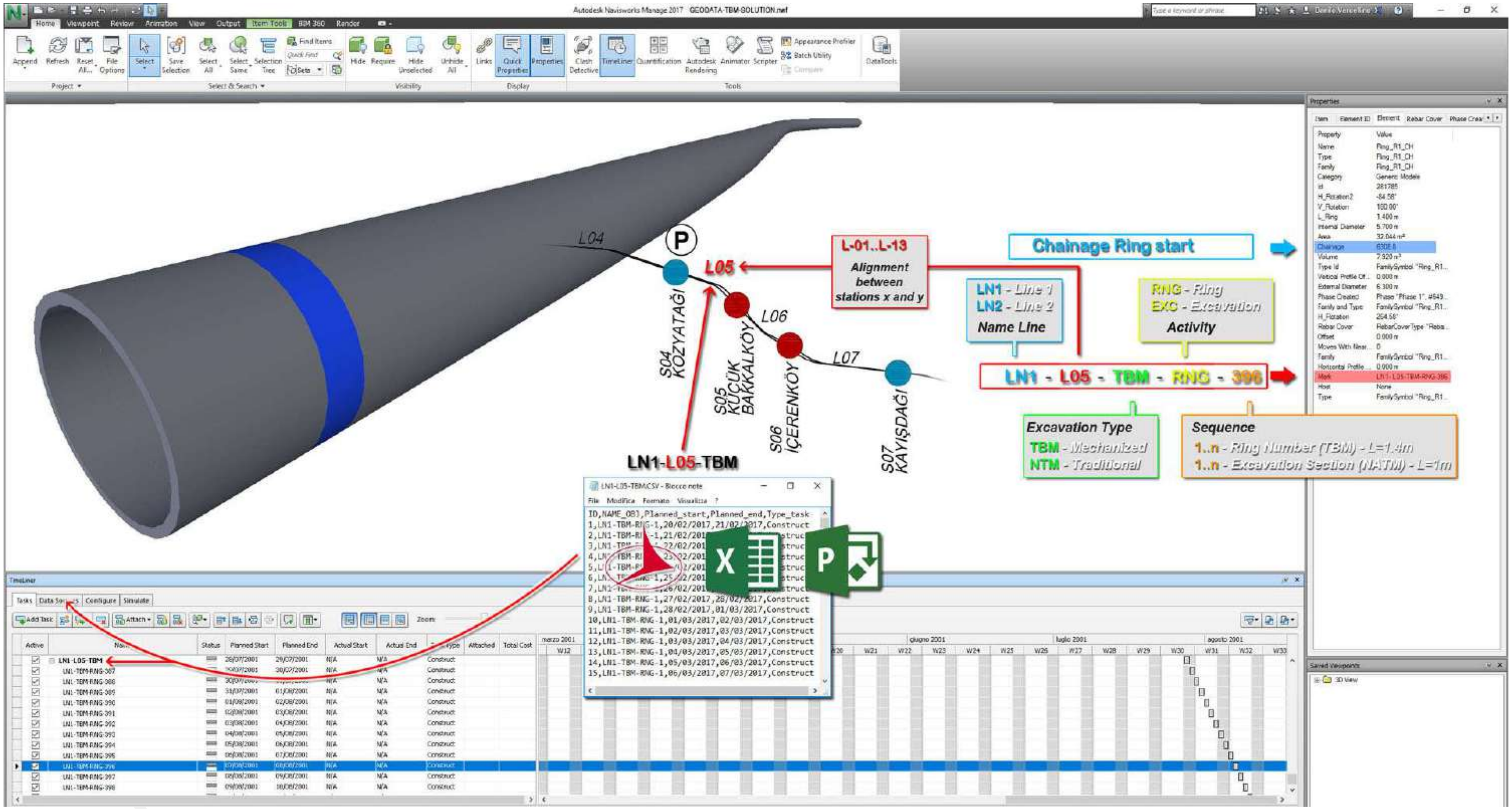


TIME MANAGEMENT
CPM



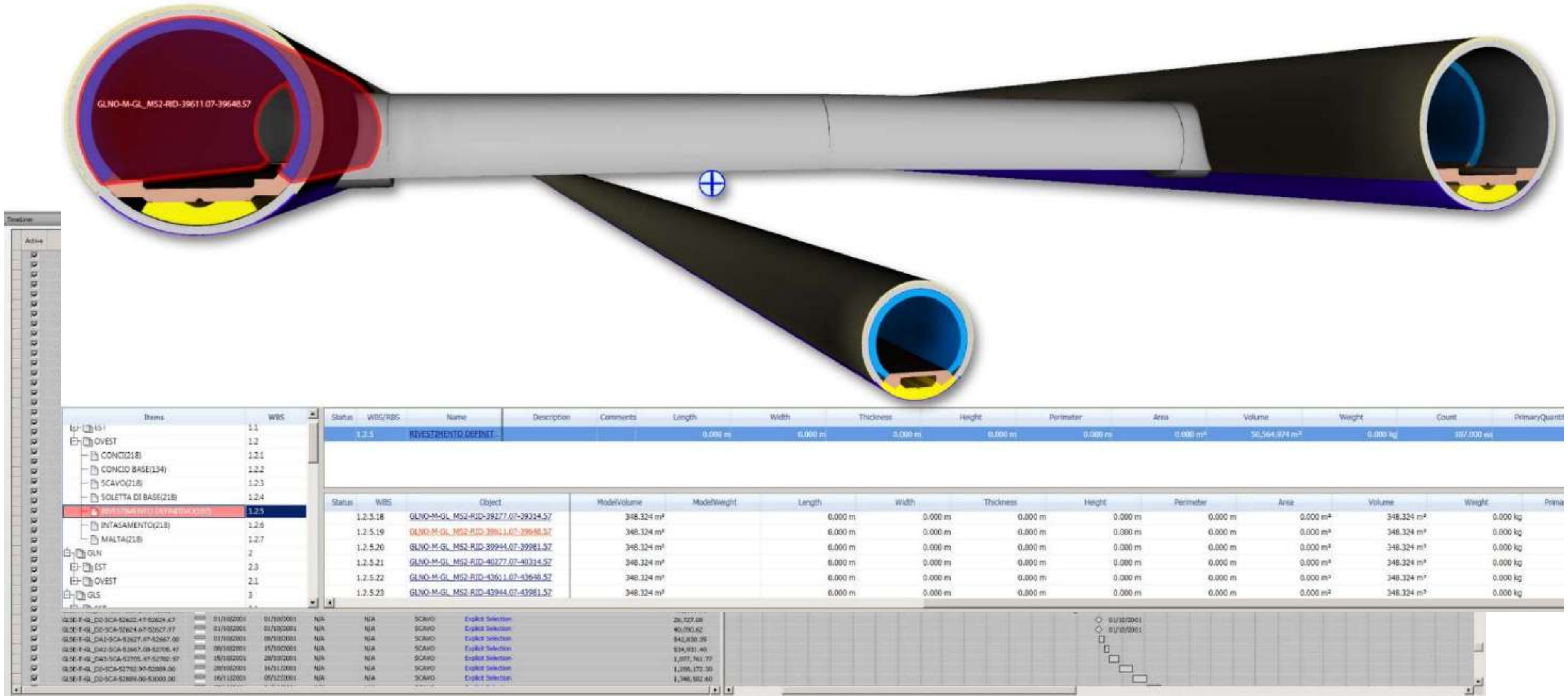
RISK ANALYSIS - MULTI-CRITERIA ANALYSES

Project phasing simulations



An example of 5D BIM (Time & Costs)

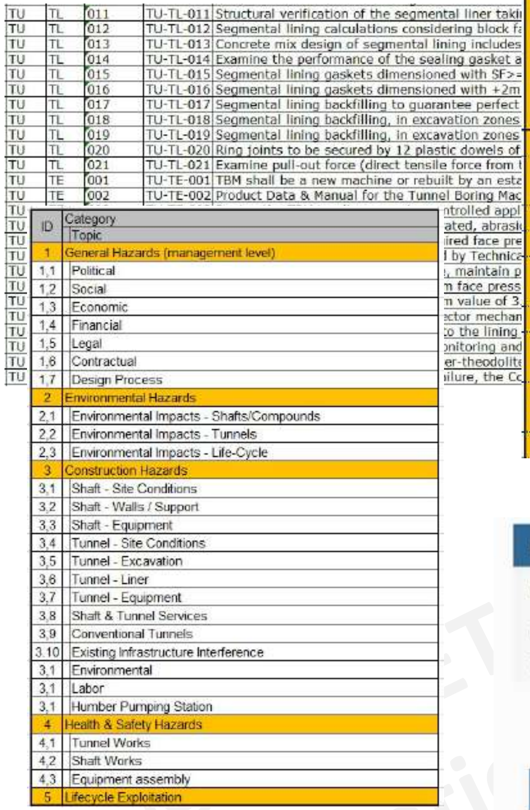
4D-5D BIM for Mechanized Tunneling
Project phasing simulation and evaluation of costs



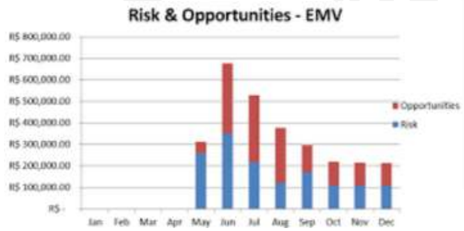
Time – Costs - WBS

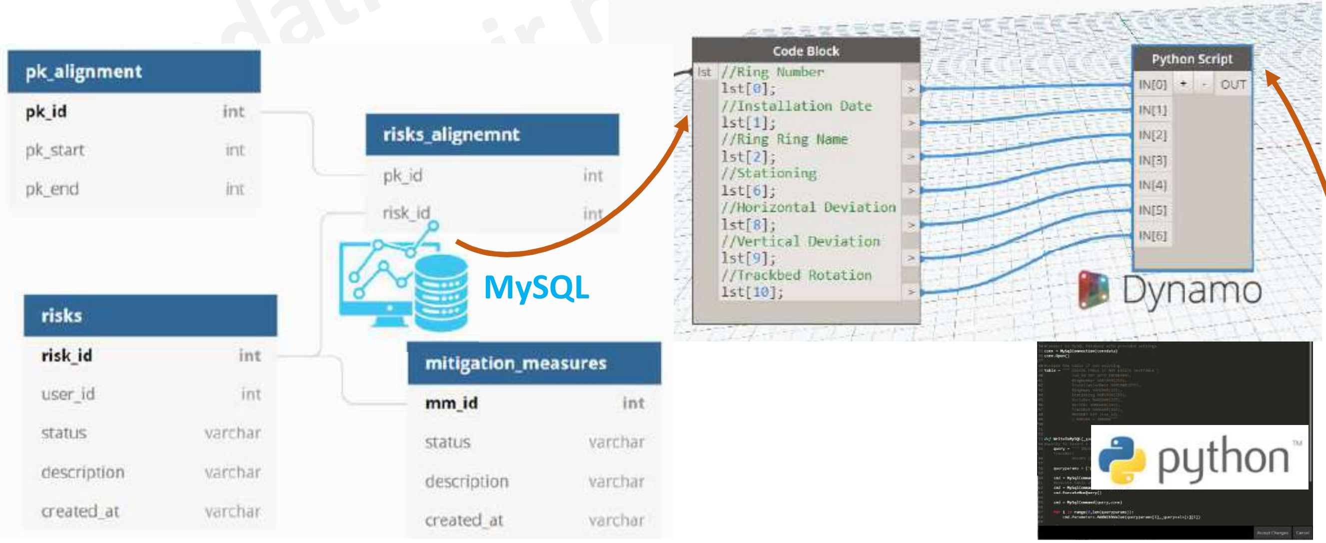
BIM and Risk Management

An Example of implementation of Risk Register along the alignment using MySQL, Dynamo and Python
EMV (Expected Monetary Value) for the decision making



Code				Hazard description	Initial Hazard & Risk Level (Evaluation)				
CATEGORY	Topic	Hazard	Location	I.D. / CATEGORY / Topic / Hazard / Location	Risk [R = PxI] Financial loss	Delays	Health & safety	Natural environment	Social
3	5	0		Tunnel - Excavation					
3	5	1		3.5.1 Excessive excavation - uncontrolled ground losses, leading to settlements or differen	10	10	15	10	15
3	5	2		3.5.2 Earth Pressure Balance - Lack of counter-pressure at the tunnel face, leading to settle	10	10	15	10	15
3	5	3		3.5.3 Void Filling - Improper grouting / backfilling, leading to settlements or differential sett	10	10	10	10	15
3	5	4		3.5.4 Ground conditioning - Inadequate ground conditioning	8	8	8	8	8
3	5	5		3.5.5 Frac-out from grouting - Excessive tail void grouting pressure, leading to surface heal	6	3	3	9	9
3	5	6		3.5.6 Frac-out from tunnelling - Fluid losses during tunnelling and/or interventions	8	8	4	12	12
3	5	7		3.5.7 TBM guidance - Lack of reliability of TBM guidance	6	6	3	3	6
3	5	8		3.5.8 Liner Installation - Inadequate segmental lining positioning	10	15	5	5	10

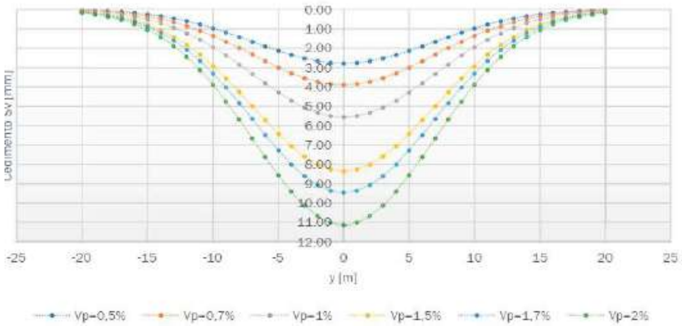


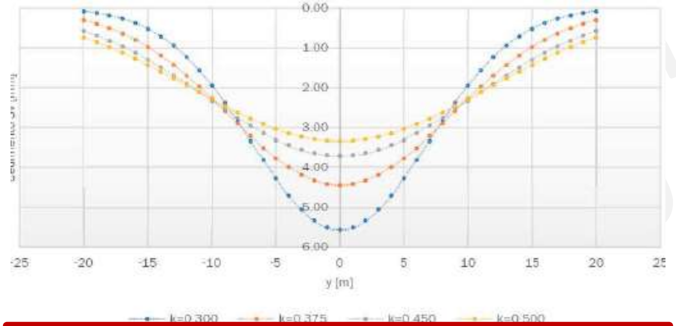


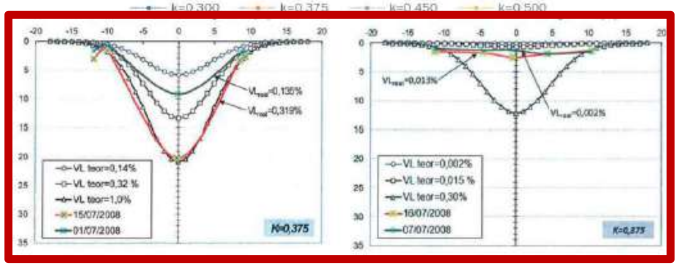
BIM and Risk Management

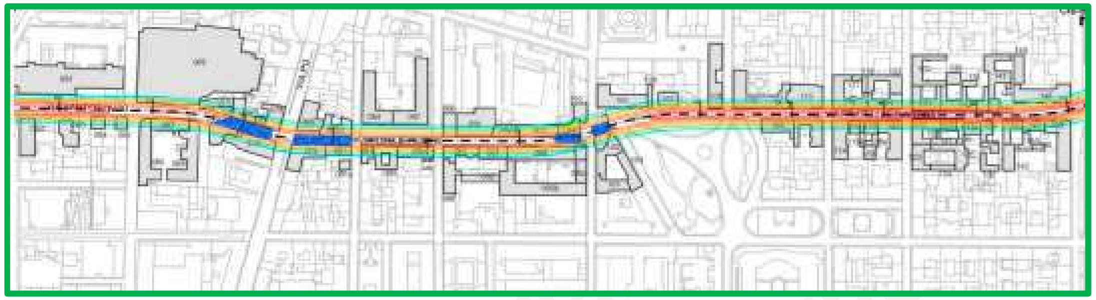
An Example of implementation of Building Risk Assessment (BRA)

Volume Loss
K-param

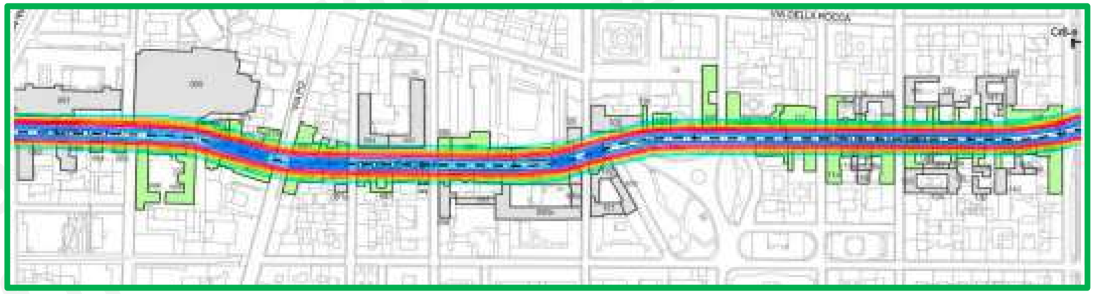




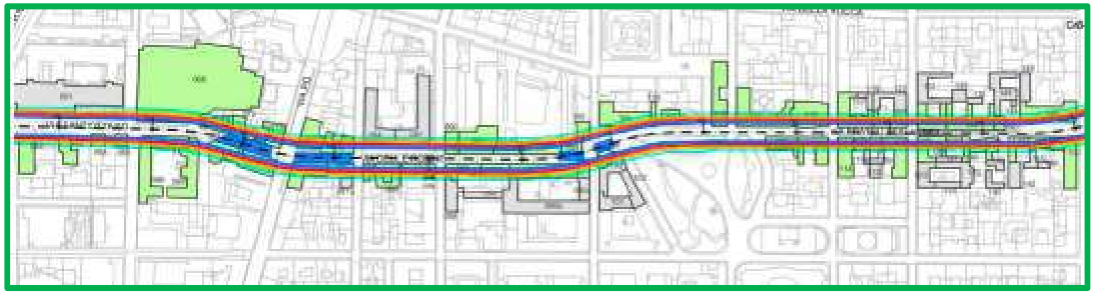




Volume Loss 0.5%



Volume Loss 1.0%



Volume Loss 1.5%

BIM and Mechanized tunneling: Project Life-cycle and Knowledge areas

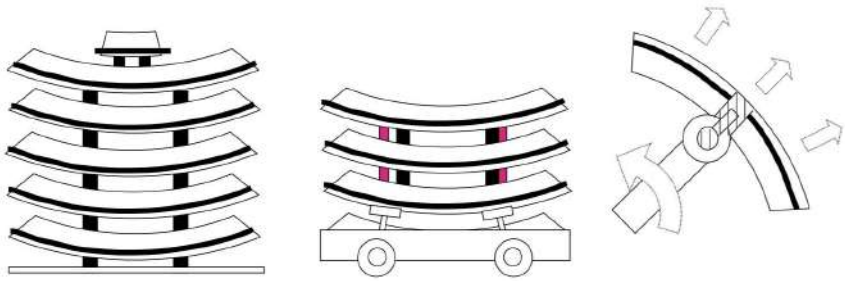
Design → **Production of Design** → Construction → Maintenance

- **Quality control**

Compliance with the requirements
Tests for the components and conformities
Tests for segments and conformities
Tests for Ground treatments

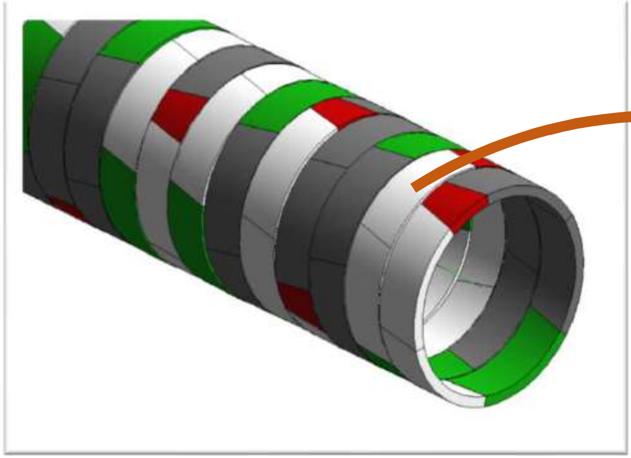
- **Traceability**

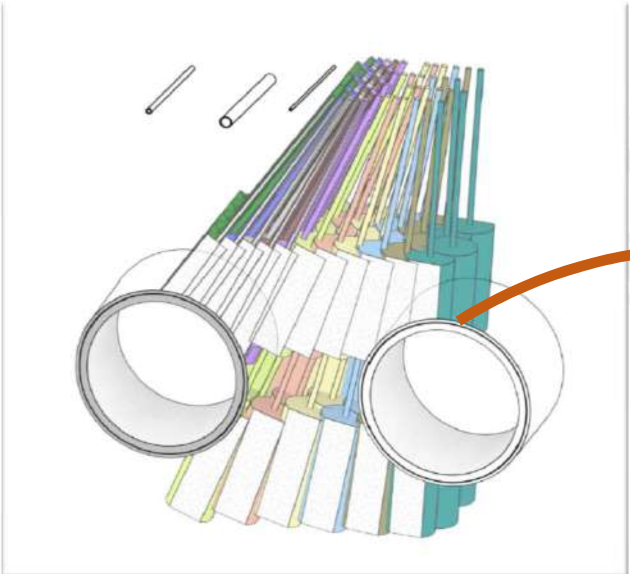
Complex process of Precast of segments
Data integration at any time



Production of Design

Documentation “start to end”





1. Records of information provided and exchanged between the Manufacturer, the Main Contractor and the Transport Company.
2. Roles and responsibilities during transportation.
3. Documents of segments inspections and acceptance for the delivery on site.
4. Documents of supervision during segments handling and transportation process.
5. Transport permits, notes and inspections check lists.
6. Eventual quality measures applied during handling and transportation of segments
7. Boreholes and laboratory test results for JG or other ground treatment
8. Document of conformity (workplace regulations)
9. Etc…

BIM

BIM and Mechanized tunneling: Project Life-cycle and Knowledge areas

Design → Production of Design → **Construction** → Maintenance

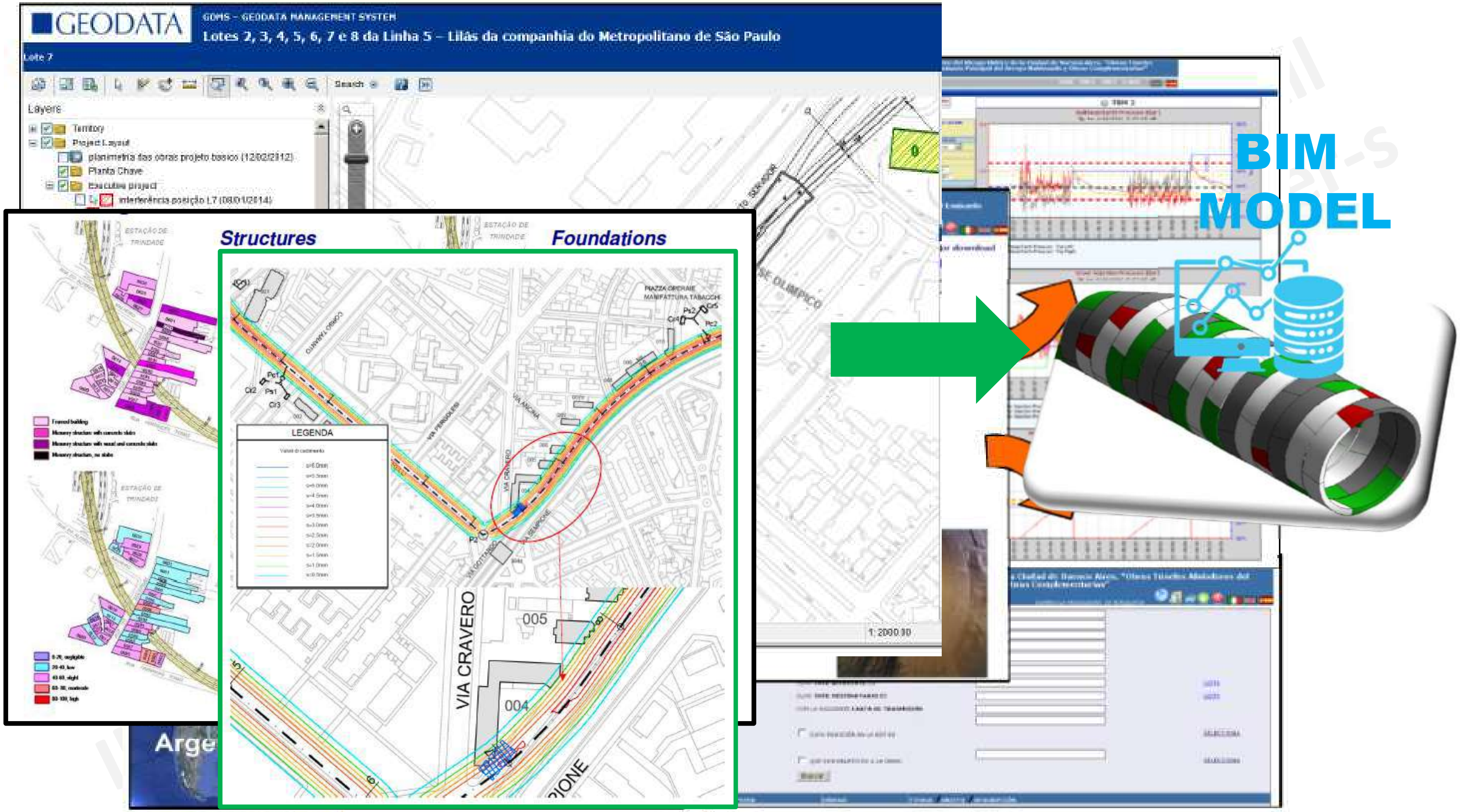
- **Management of a great amount of data Near Real-time (time and location)**

TBM data: Thrust, torque, penetration rate, face pressure, grout pressure, mucked materials weight, slurry properties, TBM KPI
Ground data: Piezometric level, deformation and displacements
Buildings data: Deformation and displacements

- **Monitoring and Control (M&C) with Data integration at any time**
- **Continuous comparison of the forecast and actual conditions, enabling corrections**
- **Risk and Issue Management**
- **Communication**
- **Web-based integration of software modules**

Construction stage

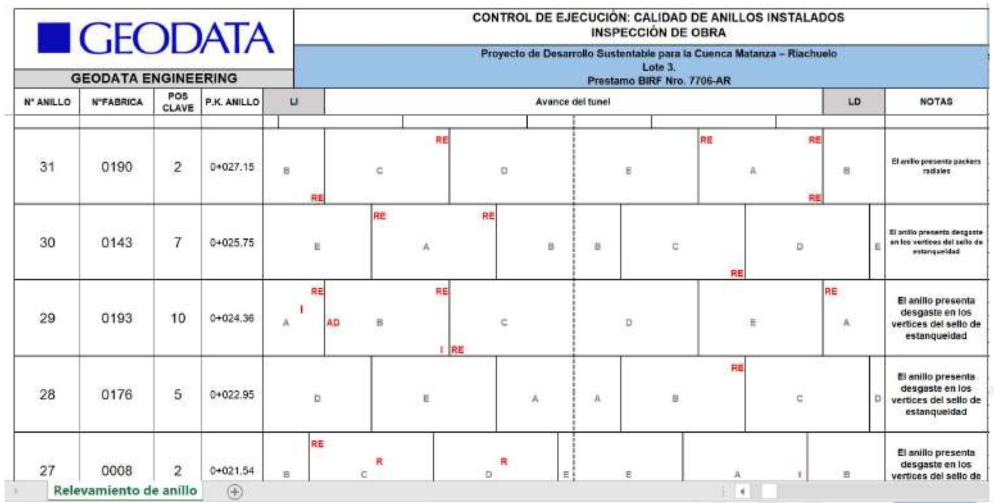
From DBMS to BIM to manage the amount of data during the excavation

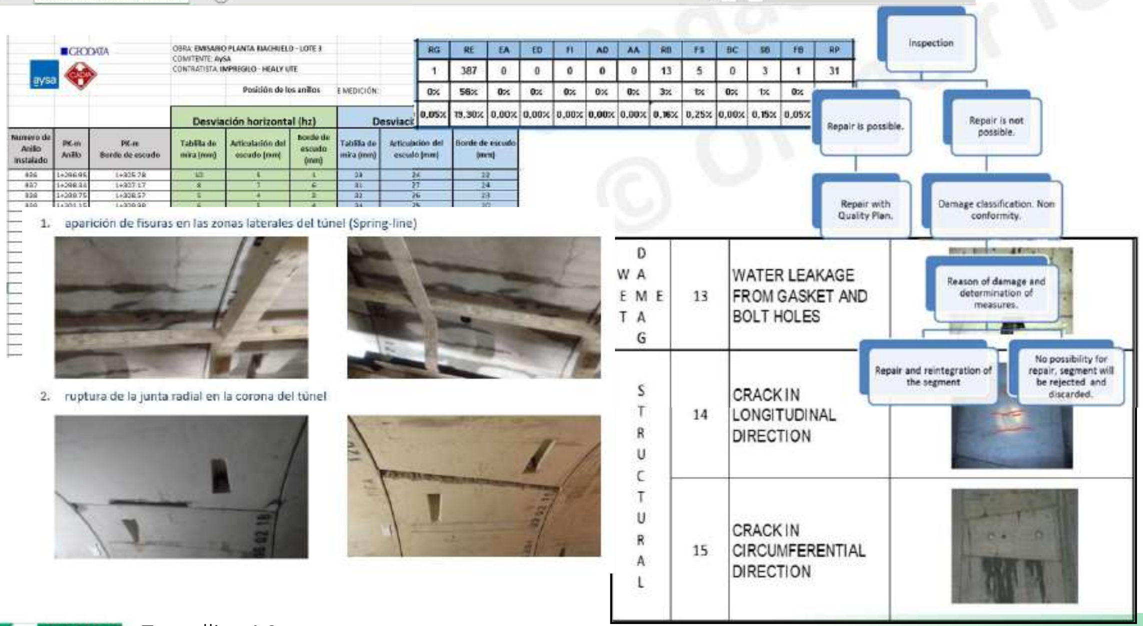


Construction stage

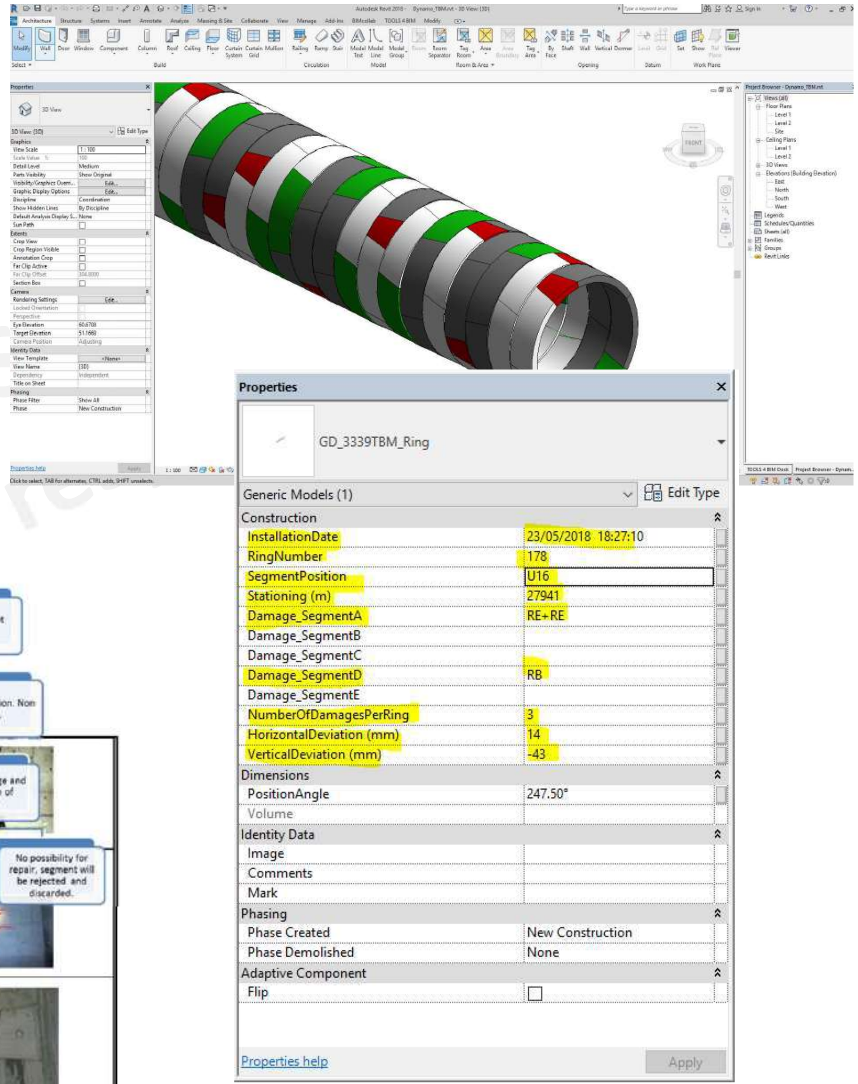
From DBMS to BIM to manage the amount of data during the excavation

Without BIM



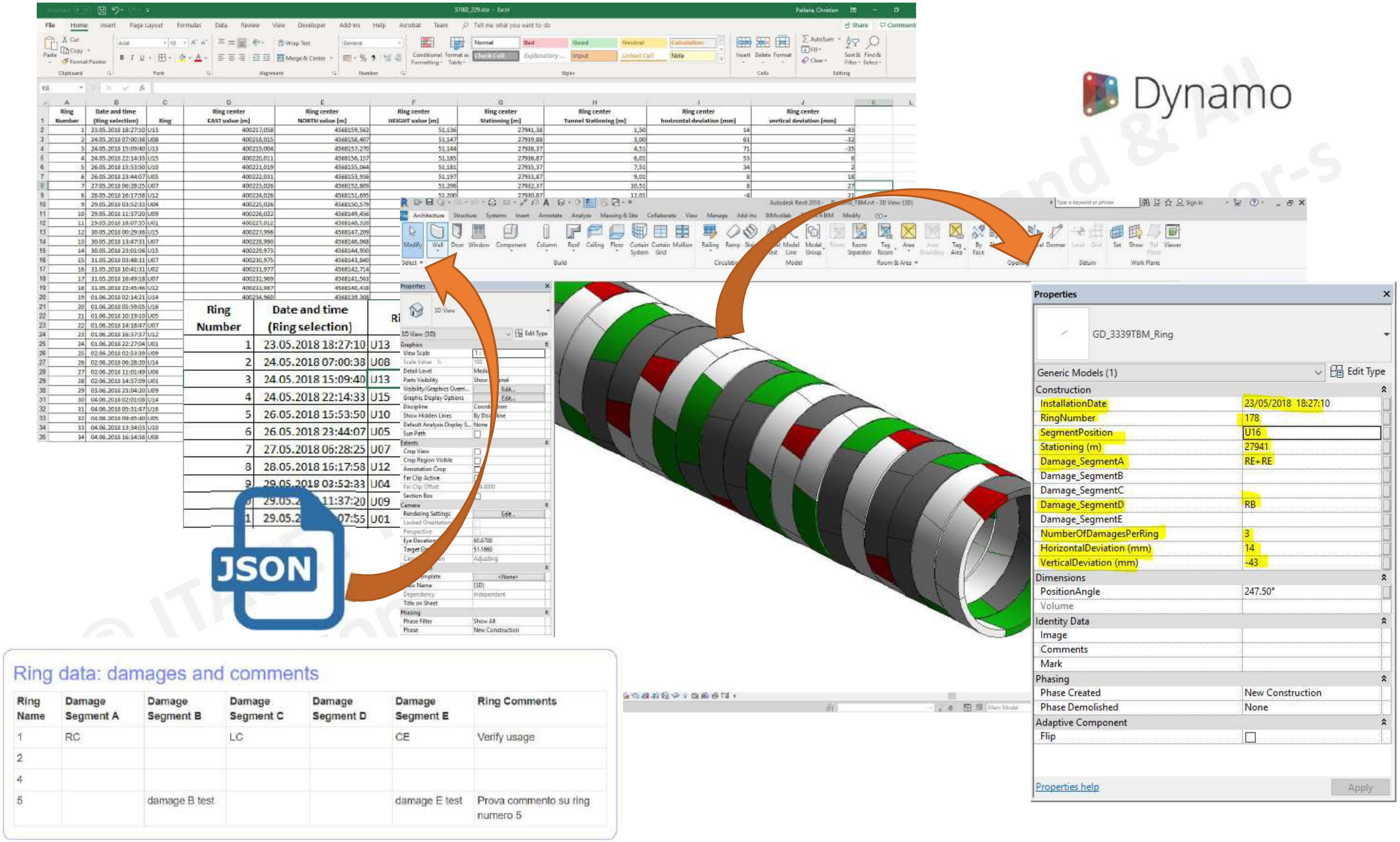


With BIM

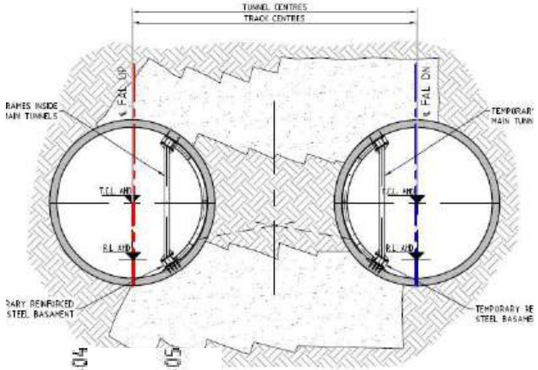


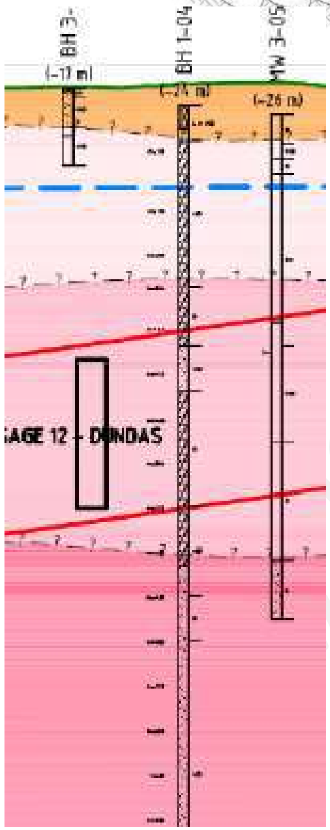
Construction stage

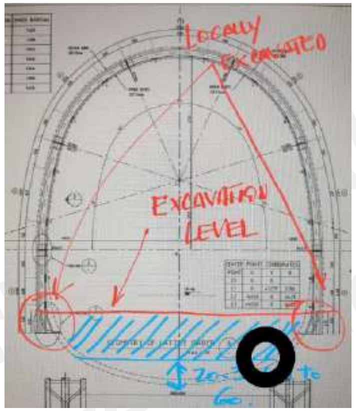
From DBMS to BIM to manage the amount of data during the excavation



Issue Management and back-analyses

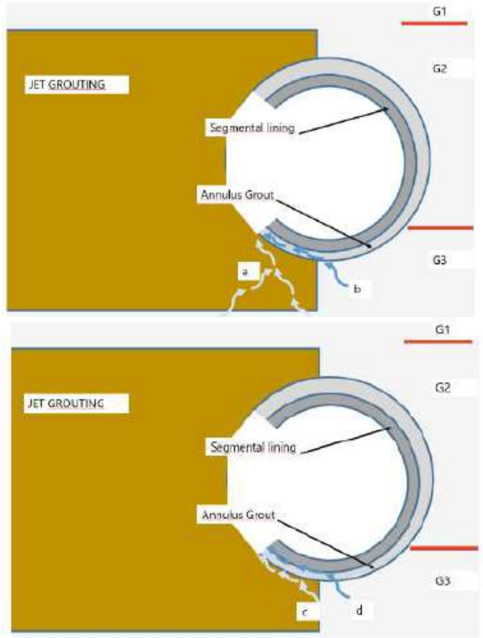




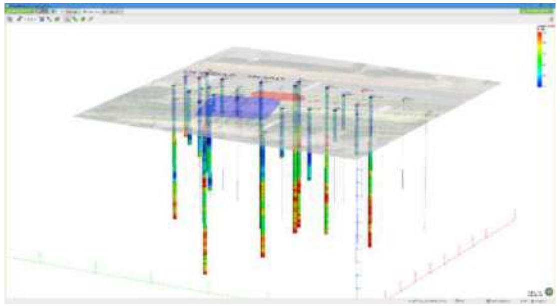


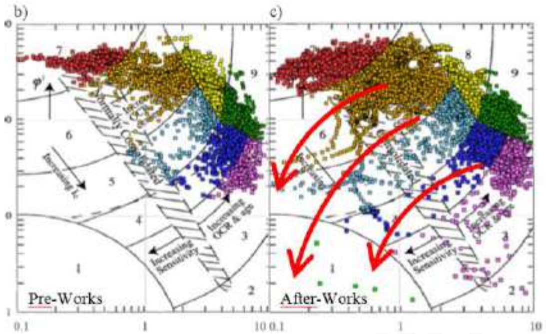
Issue Management – Potential Causes:

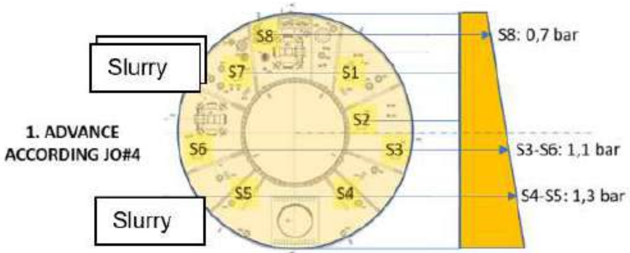
- **1. Mechanical strength of treated soil;**
- **2. Mechanical strength of annulus soil;**
- **3. Permeability of treated ground;**
- **4. Permeability of annulus grout;**
- **5. Effective complete treatment of soil with JG (no gaps between JG columns);**
- **6. Effective complete grouting of interface with annulus grout (no gaps between segments and annulus grout);**
- **7. Effective sealing, with grout, of interface between segmental lining and JG (sufficiently tight closure of interface).**

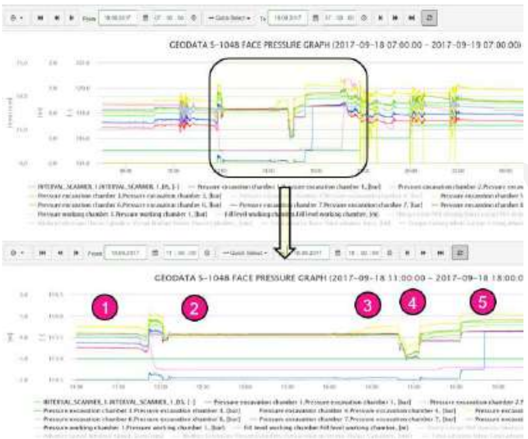


Issue Management and back-analyses

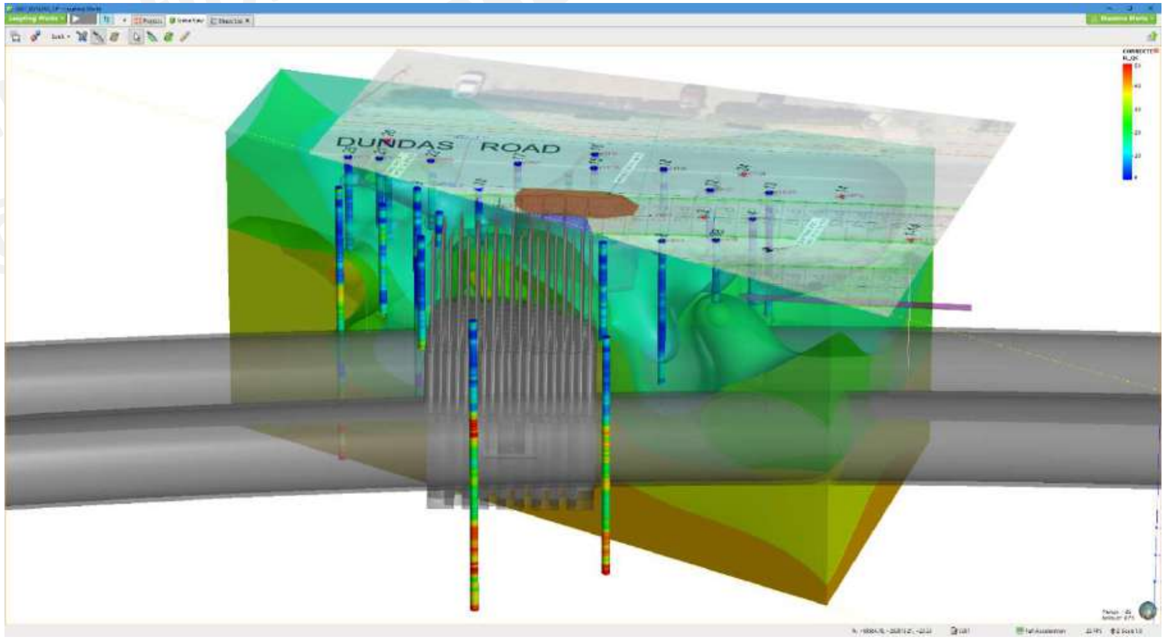




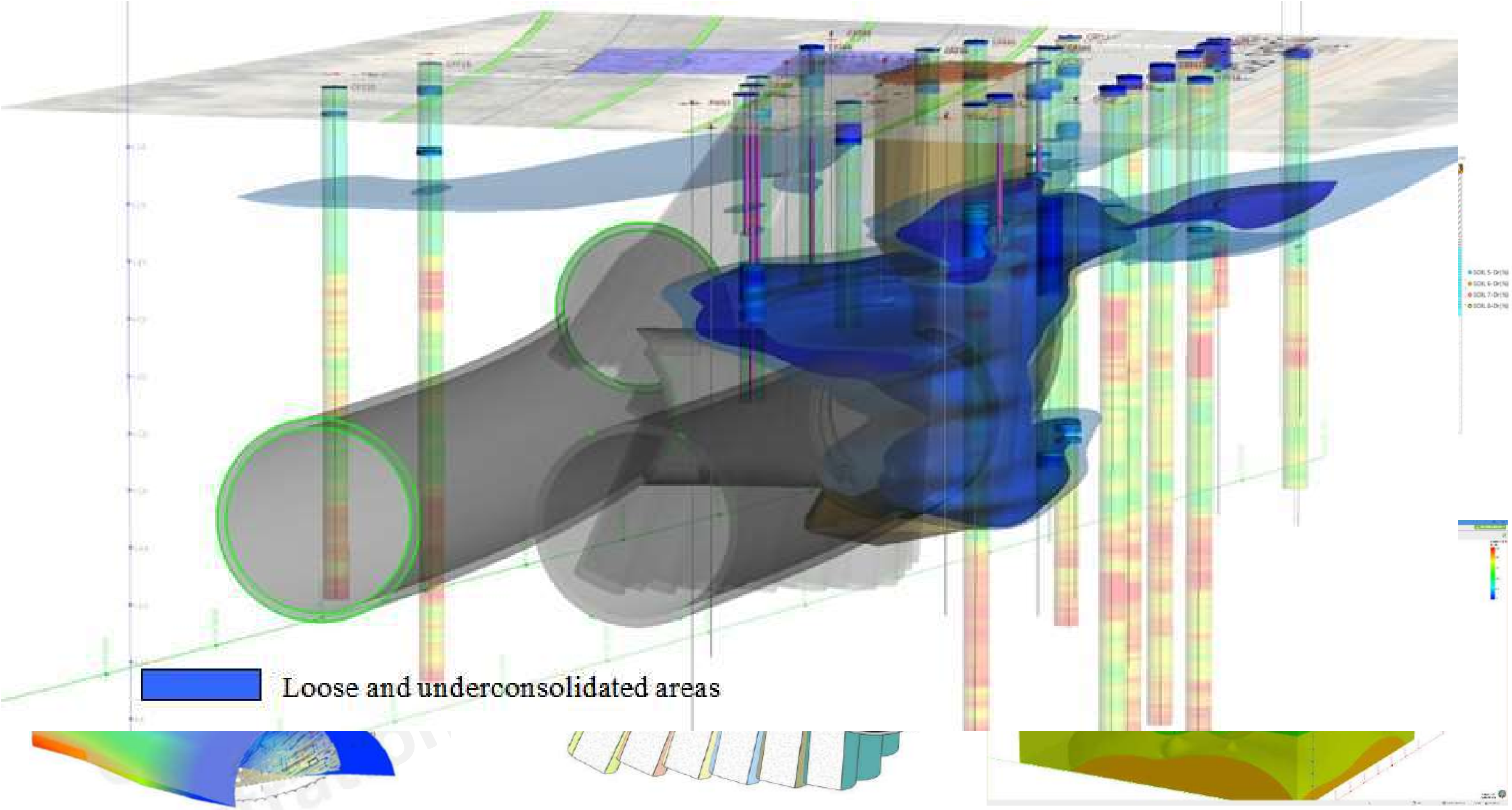




Updating of the model after the excavation of the two TBMs



Issue Management and back-analyses



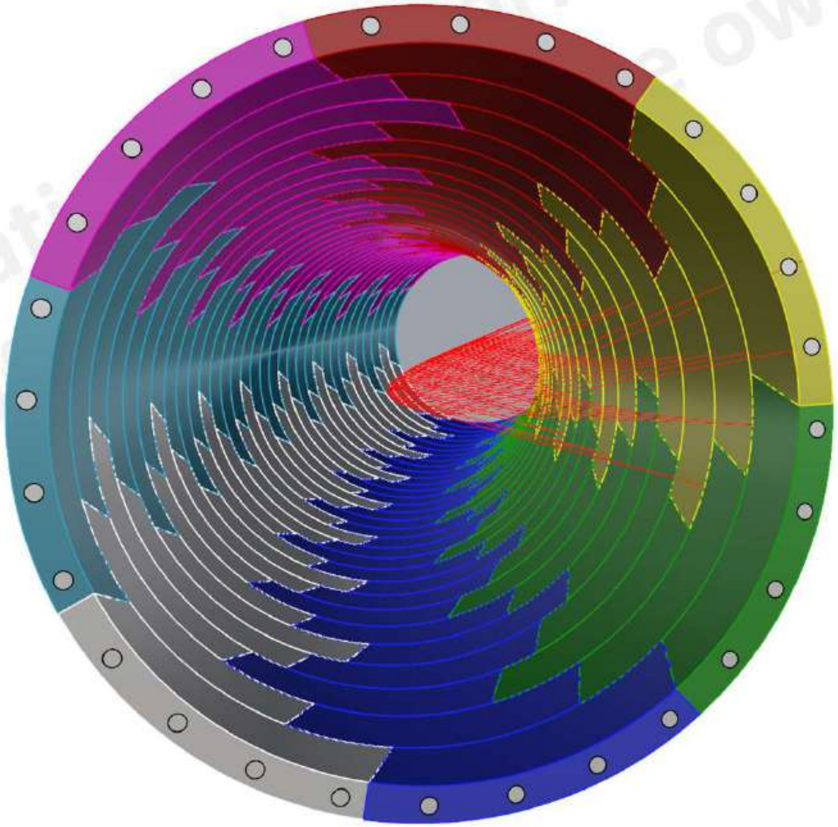
FDM/FEM Models

BIM Model

Geological Models

BIM and Mechanized tunneling: Project Life-cycle and Knowledge areas

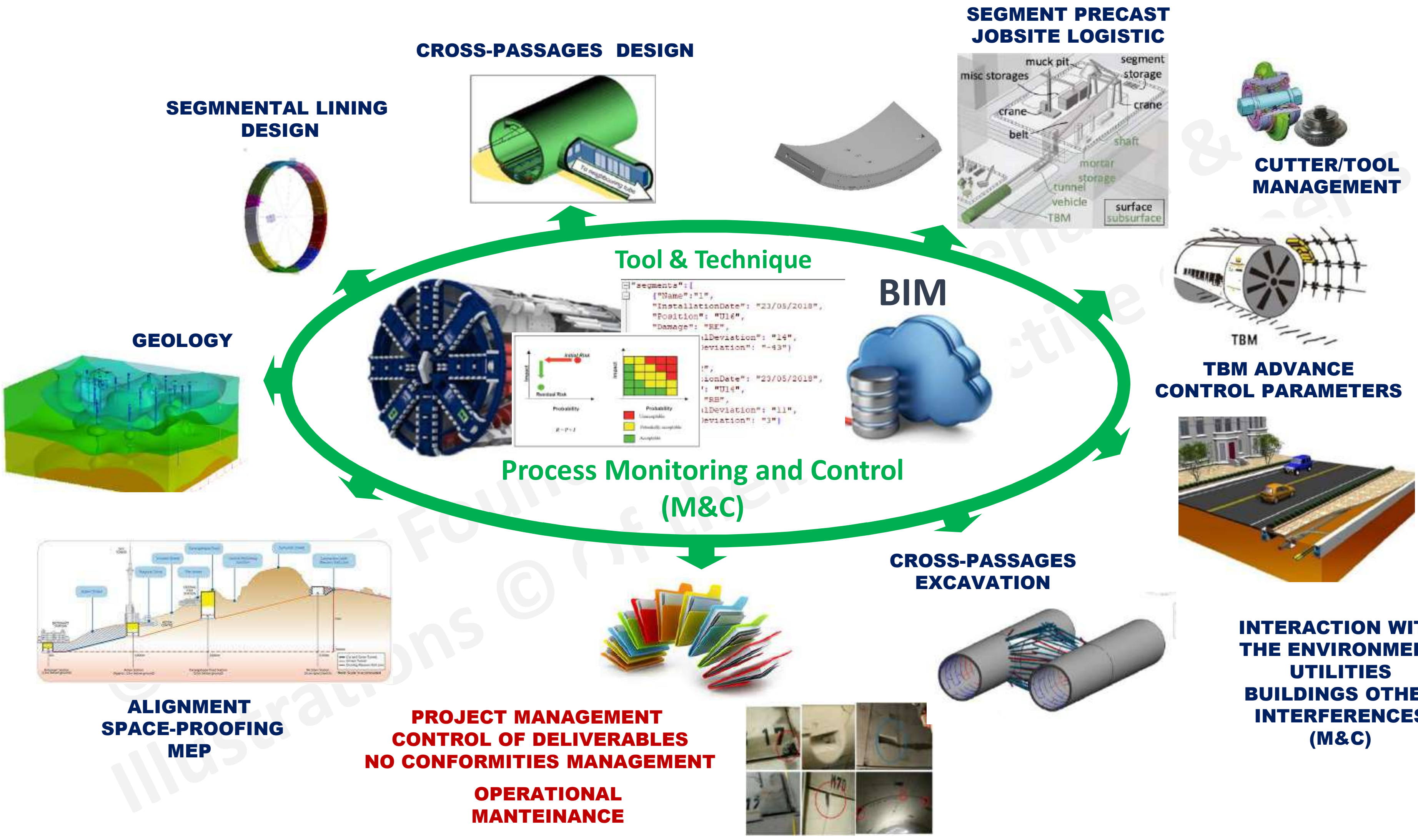
Design → Production of Design → Construction → **Maintenance**



Control of Project Deliverables
Management of No Conformities
Operational Maintenance
Reparations of damages
Juridical Claims

- **Traceability**
- **Quality Control**
- **Data management**

Traceability for Maintenance

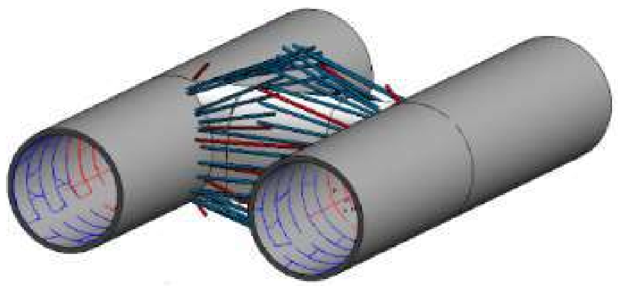


BIM and Mechanized tunneling
Lecture outline

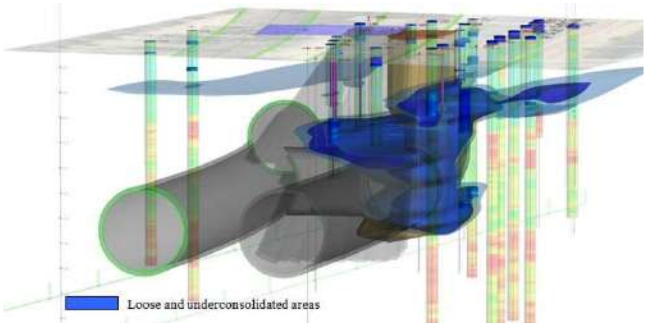
- **Introduction**
  - Dimensions of BIM in mechanized tunneling (from 3D to 6D)
  - Level of Details (LODs) in mechanized tunneling
  - BIM-based Tunnel Models using standards (IFC)
- **Tools & Techniques**
  - Revit, Dynamo, Phyton, Navisworks etc.
- **Examples of BIM application in Mechanized tunneling projects**
  - Along the Life-cycle of the project (Design, Production of Design, Construction, Maintenance)
  - For the different knowledge areas (Alignment, Geology, Precast of the segments, Advance of TBM etc.)
- **Conclusions**

BIM, an efficient response to meet the needs of modern tunneling

- BIM reduces human errors during **design** of the structural components (Universal ring, Alignment, Segments and connection system, Cross-passages and its components, Clash detection etc.)
- BIM is a driving force to the **requirement compliance** (Laws and regulations, Conditions)
- BIM helps on **construction management**: Scheduling TBM advancement - Logistics during precast, storage, transportation of segments
- BIM is a driving force to **streamline co-operation**, teamwork and better information management for the construction industry
- BIM increases **Quality** by controlling Time, Costs and SoW

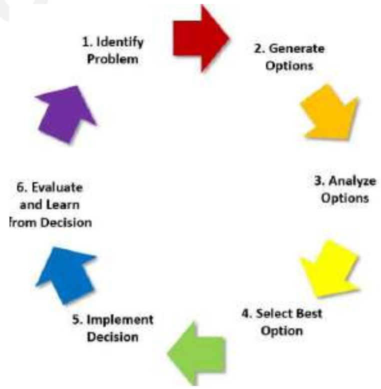


Triple Constraint of Project Management (PMI)

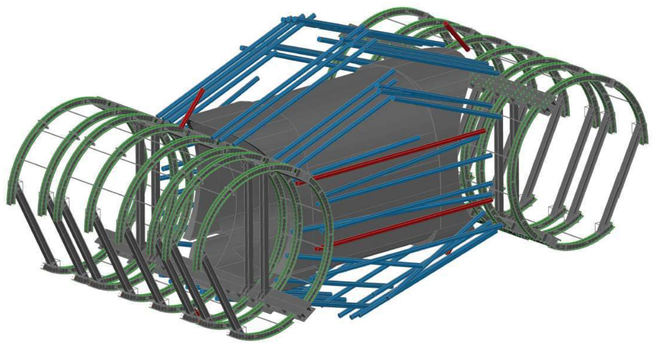


BIM, an efficient response to meet the needs of modern tunneling

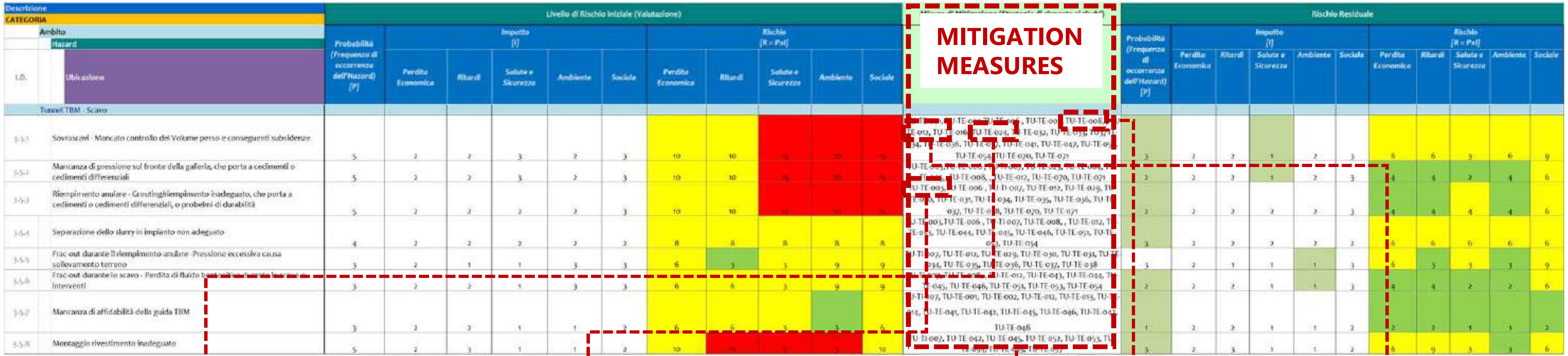
- BIM facilitates the **accessibility to a great amount of data** (control parameters, monitoring during the advance of the TBM, monitoring on the structures on the surface etc..) BIM can organizes the amount of data to use in the same project (prediction during the advance) or in other similar project (Big-data)
- BIM reduces human error during **construction** and allows **traceability** (causes of defects as damages on the segments)
- BIM facilitates **forecast during the construction** phases: communication between 3D geometrical modelling, efficient, numerical simulation and model adaptation based on measured data acquired during the boring process
- BIM is an important tool for the **Risk Analyses** and the **Issue management**: identifying and resolving issues in a project of Mechanized Tunneling (decision-making)



Project Management Principles (PMI)

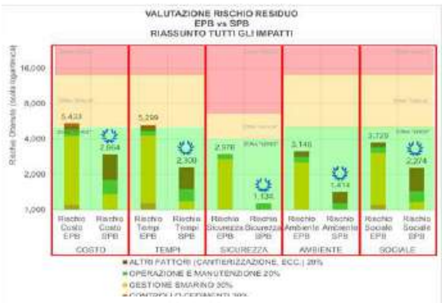


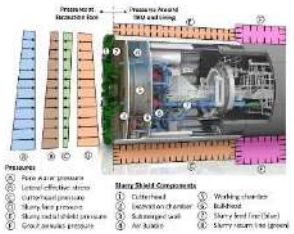
Conclusions



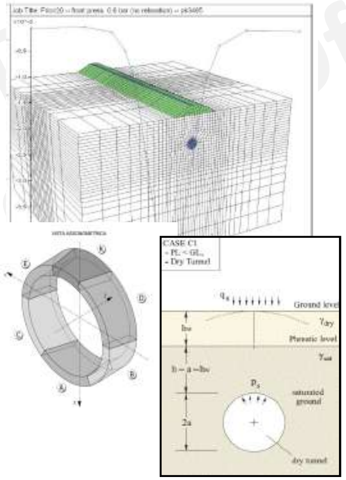
MITIGATION MEASURES

MULTI-CRITERIA ANALYSES



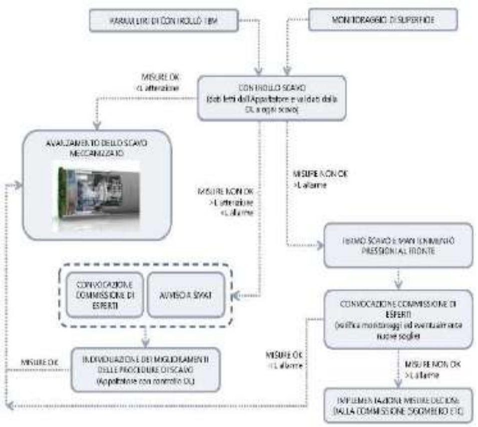


SENSITIVITY ANALYSES



BIM

MONITORING AND CONTROL PROCEDURES
PLAN OF ADVANCE OF TBM



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THANK YOU
FOR YOUR
KIND ATTENTION

Useful papers/books on this topic:

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Tunnelling 4.0: New technologies and automation

24 September 2019 – Buenos Aires, Argentina

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