



Tunnelling 4.0: New technologies and automation

24 September 2019 – Buenos Aires, Argentina

BIM for the management of
mechanized excavation data

Andrea Lavagno

Christian Pallaria



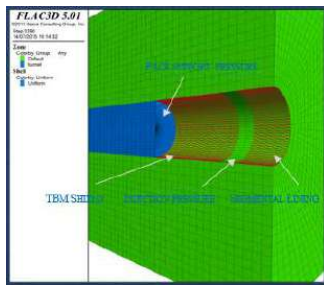
BIM and Mechanized tunneling

Lecture outline

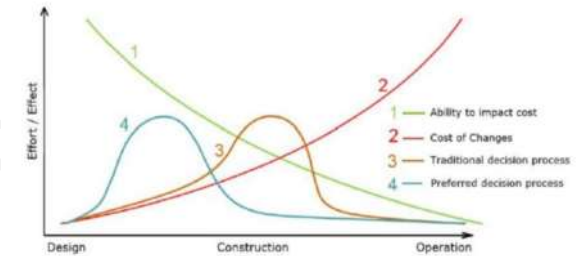
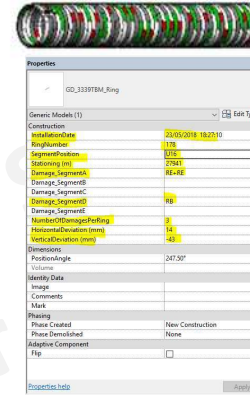
- **Introduction**
 - Dimensions of BIM in mechanized tunneling (from 3D to 6D)
 - Level of Details (LODs) in mechanized tunneling
 - BIM-based Tunnel Models using standards (IFC)
- **Tools & Techniques**
 - Revit, Dynamo, Python, Navisworks etc.
- **Examples of BIM application in Mechanized tunneling 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

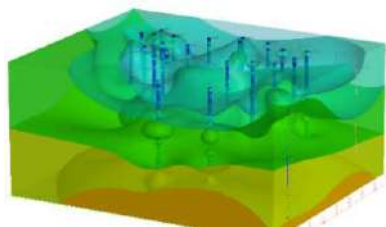
Mechanized tunneling includes many automatized processes and many repetitive synchronous activities and produces an amount of data. Mechanized tunneling is particularly suitable for the holistic parametric BIM approach



LINK models and information



3D



4D – Time / Construction Sequence

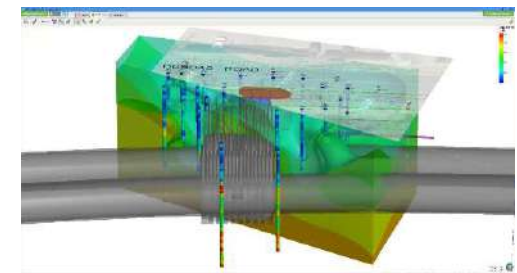
5D – Costs

6D – Project lifecycle information

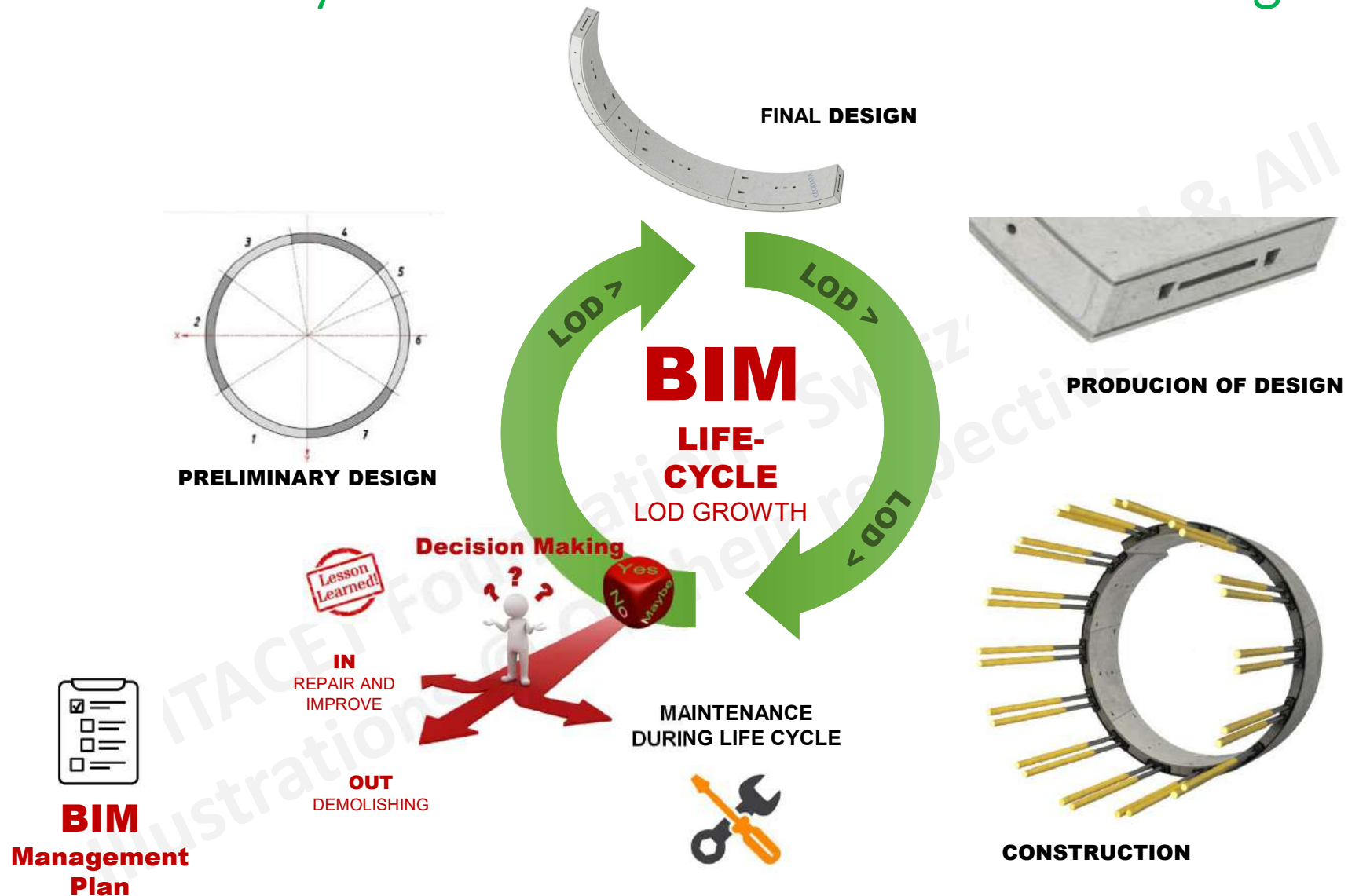
4D-5D-6D BIM i.e. integration of:

- **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

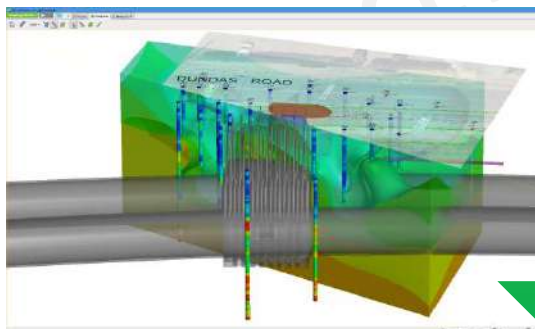
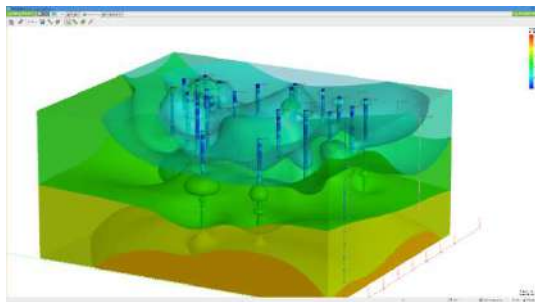
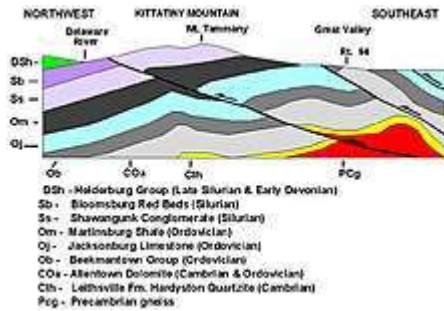


Life-cycle and LODs in Mechanized Tunneling

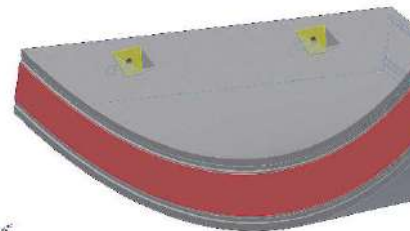
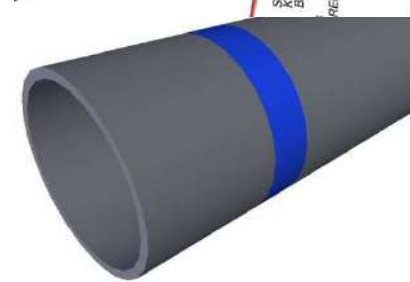
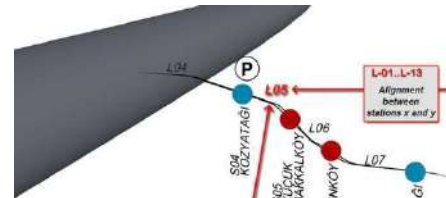


LODs in Mechanized Tunneling

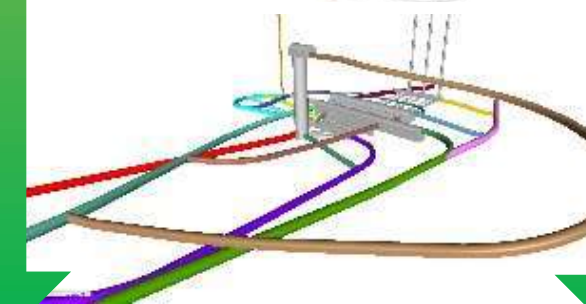
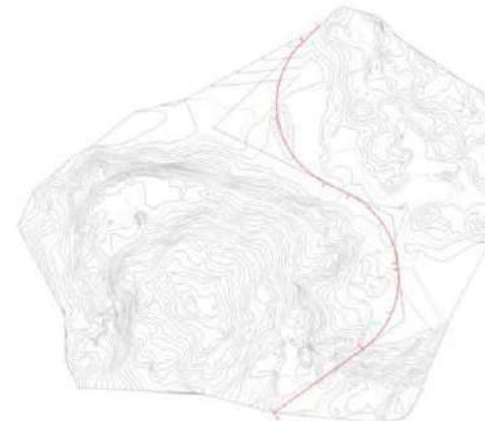
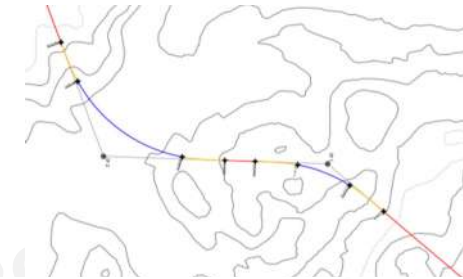
For each knowledge area there are different LODs



LODs Geology

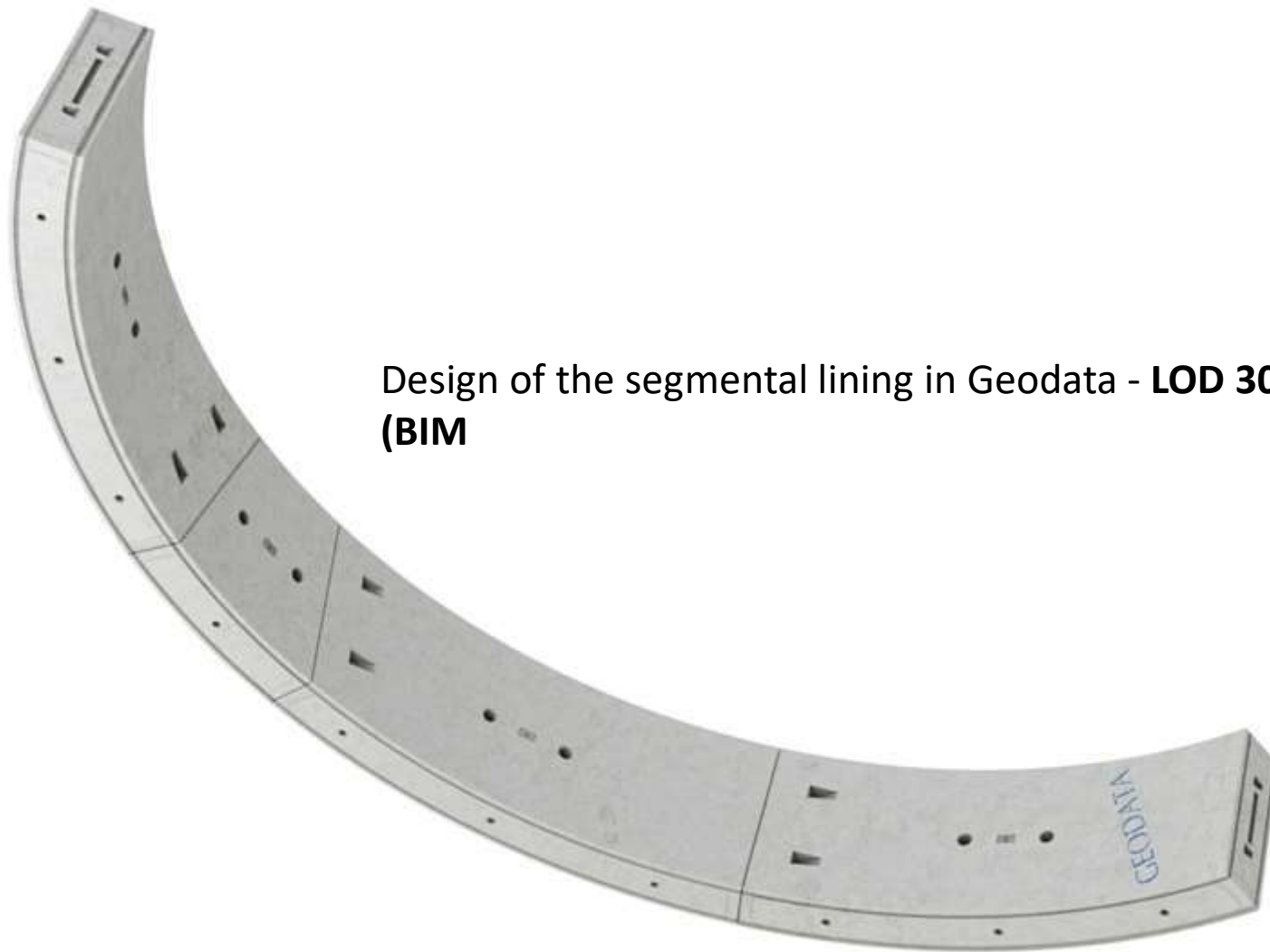


LODs Structures



LODs Alignment

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

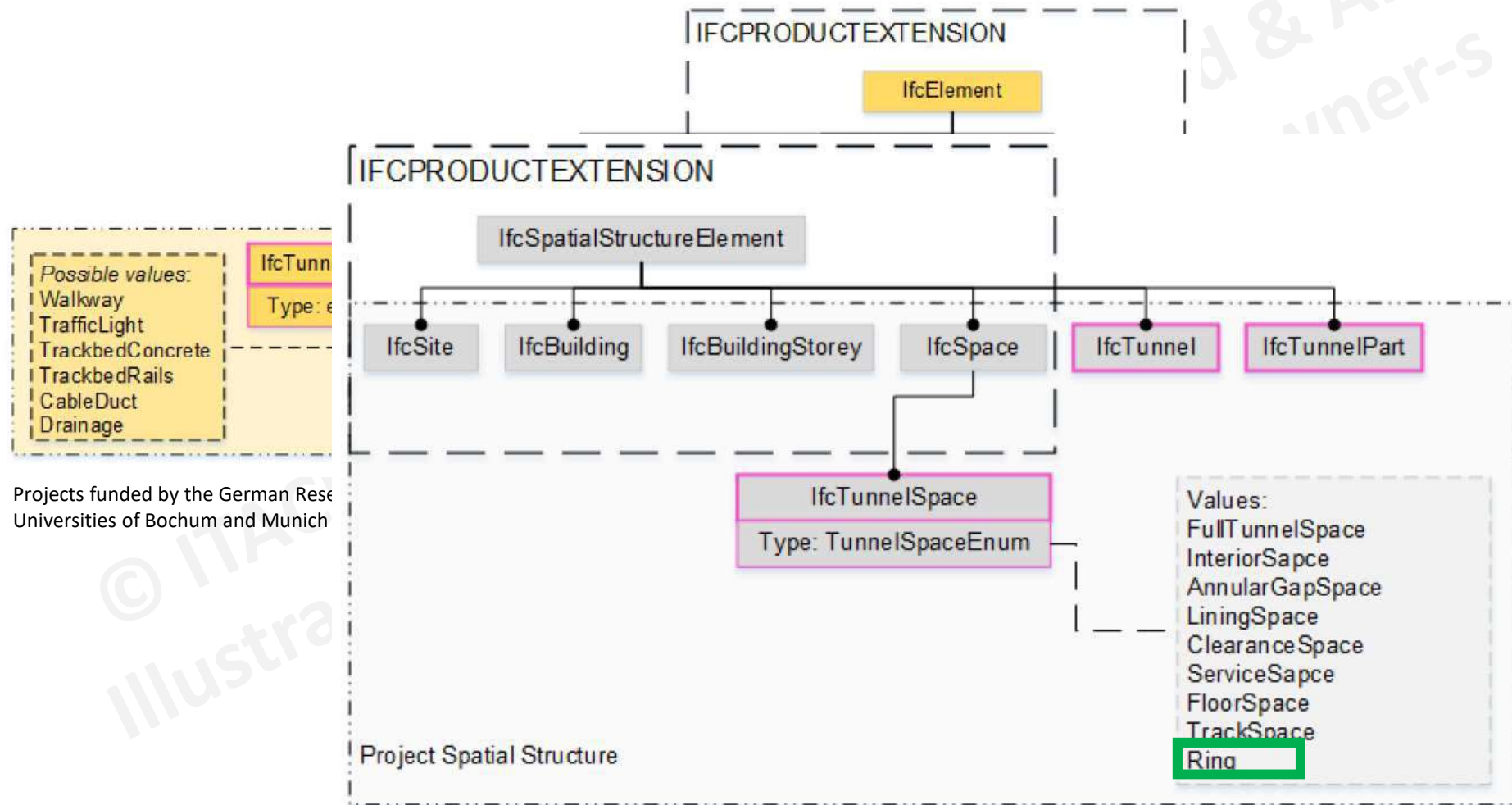
GEODATA UNDERGROUND SOLUTIONS										
Design elements	LOD200		LOD250		LOD350		LOD400		LOD500	
	Geometry	Information	Geometry	Information	Geometry	Information	Geometry	Information	Geometry	Information
Geometry										
General layout of the segment	X	X								
Type of segments	X	X								
Preliminary 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

GEODATA UNDERGROUND SOLUTIONS										
Design elements	LOD200		LOD300		LOD350		LOD400		LOD500	
	Geometry	Information	Geometry	Information	Geometry	Information	Geometry	Information	Geometry	Information
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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 reactions 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
Shifts or cracks										X

IFC for Mechanized Tunneling

BIM is Object Oriented

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



BIM and Mechanized tunneling

Lecture outline

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- **Tools & Techniques**

- Revit, Dynamo, Python, 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.)

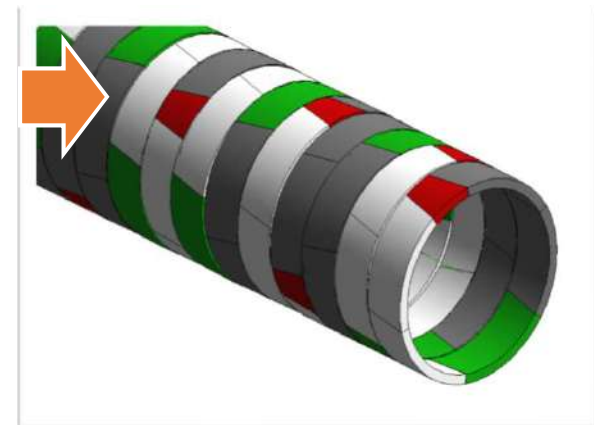
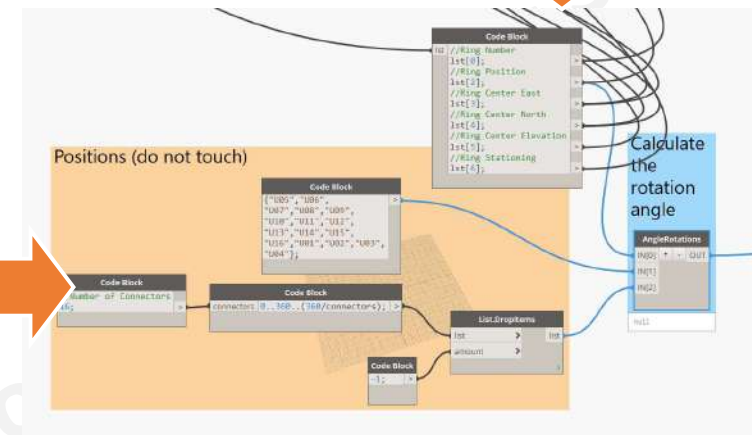
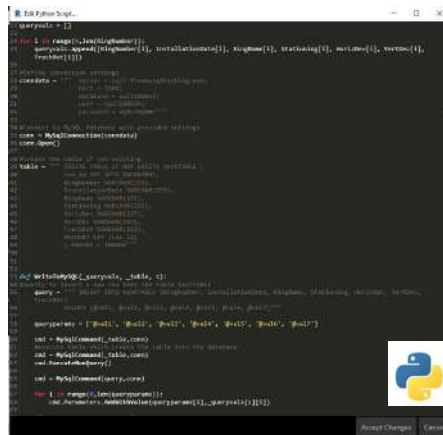
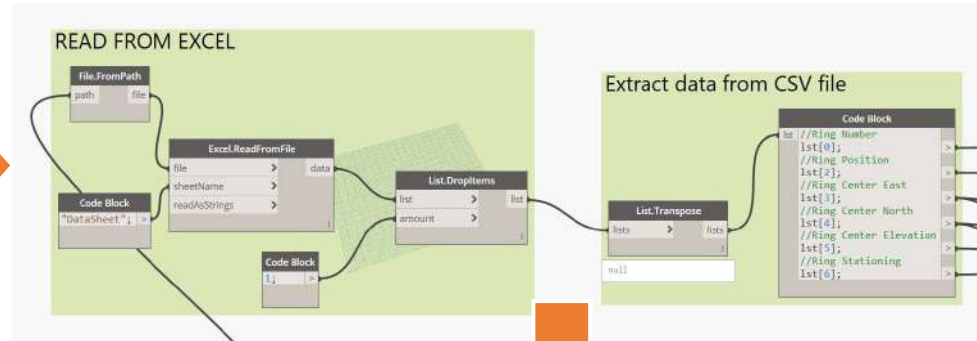
- **Conclusions**

Tools for BIM

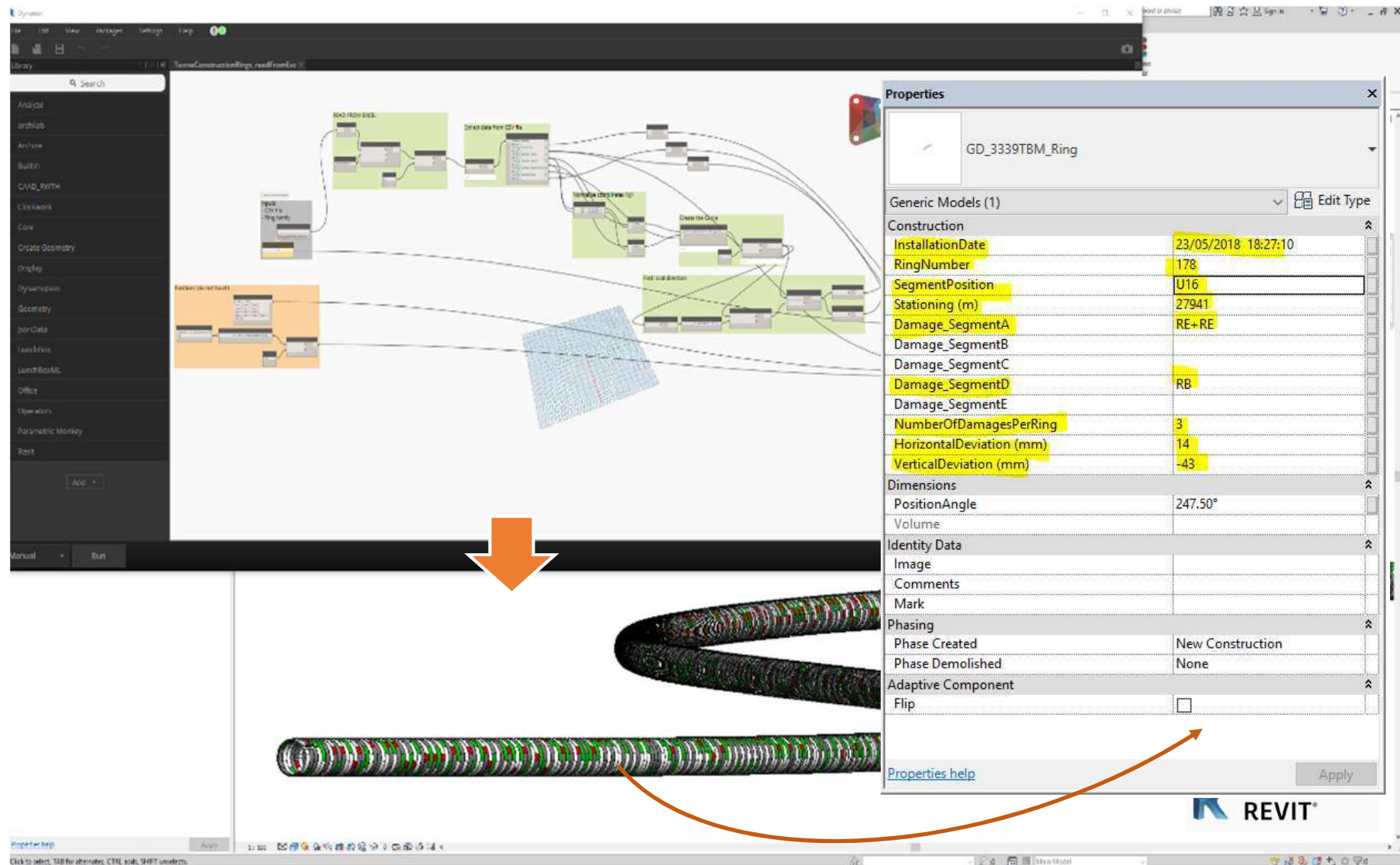
- **C3D and Revit:** software for BIM with tools to create intelligent 3D models which can be used to produce construction documentation
- **Dynamo** is an open-source, visual programming extension for Revit/C3D that allows to manipulate data, sculpt geometry, explore design options, automate processes, 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

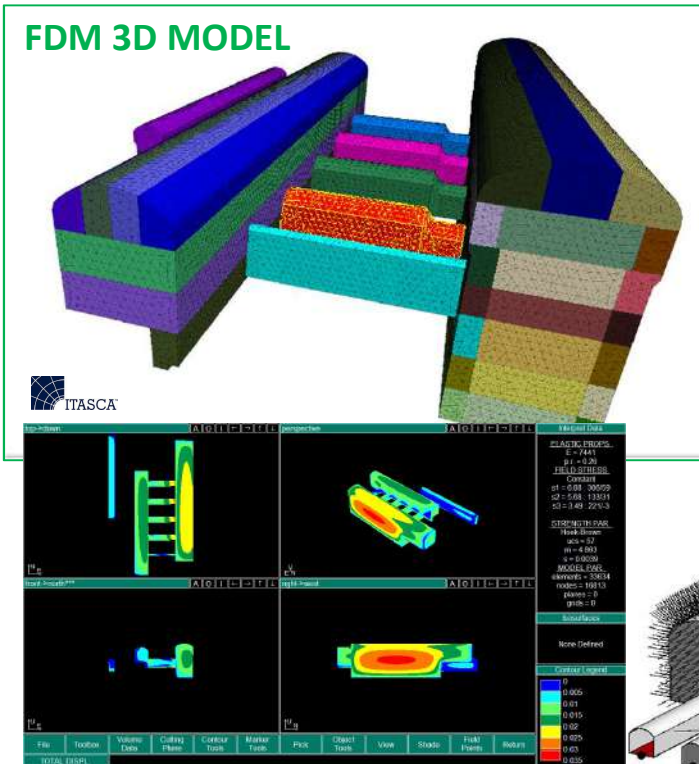


Tools for BIM

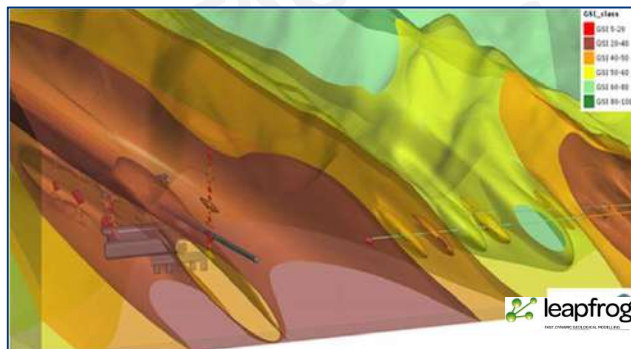


BIM and Numerical Simulations

FDM 3D MODEL



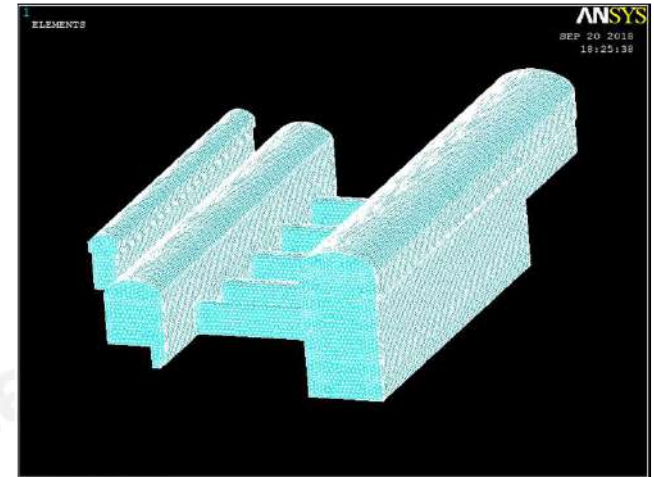
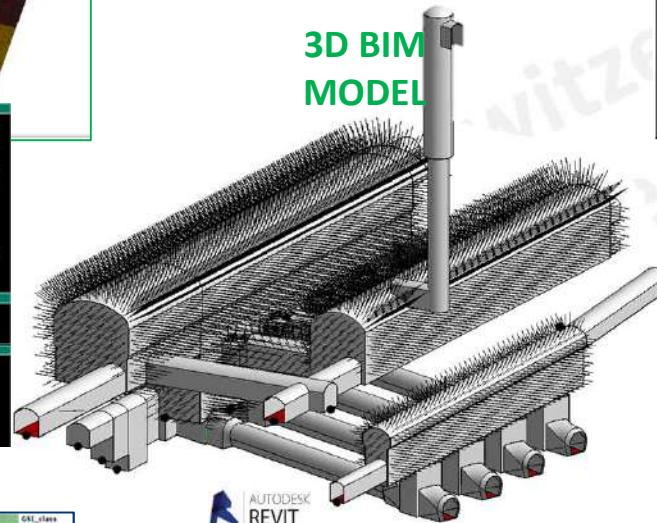
BEM 3D MODEL



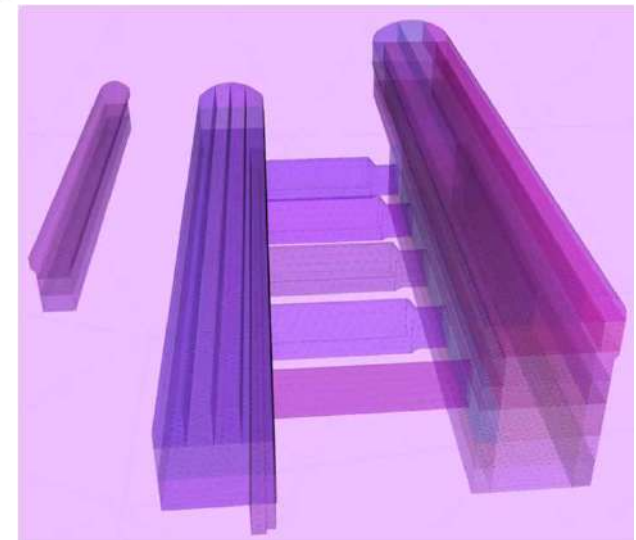
3D GEOLOGICAL MODEL



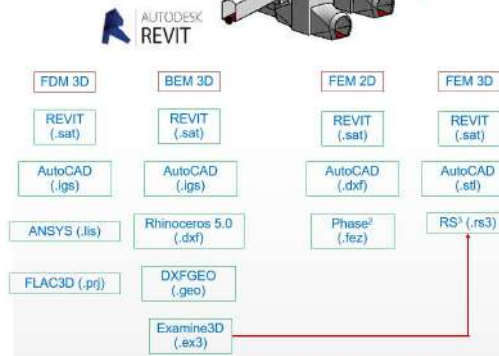
3D BIM MODEL



FEM 3D STRUCTURAL MODEL

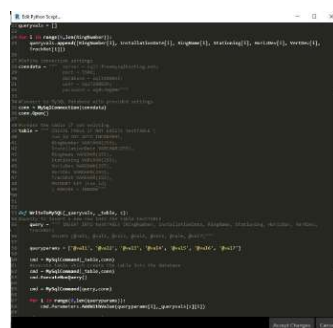
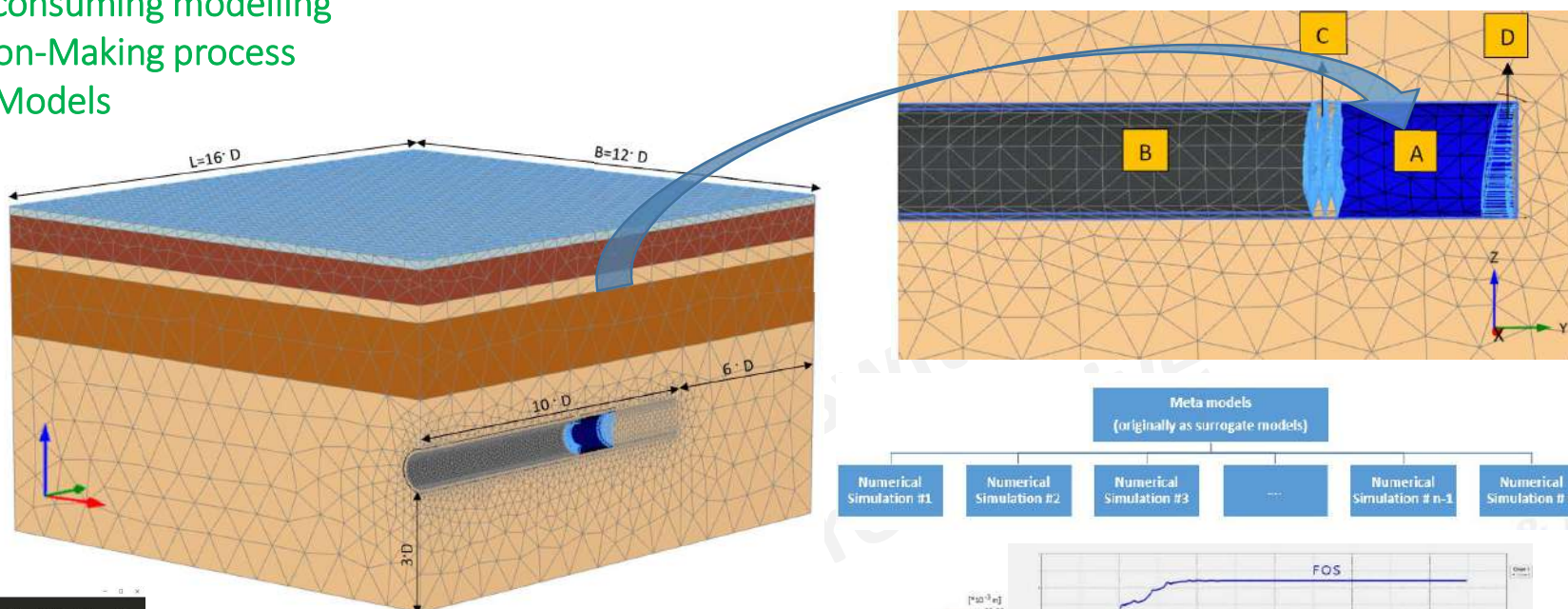


FDM 3D MODEL

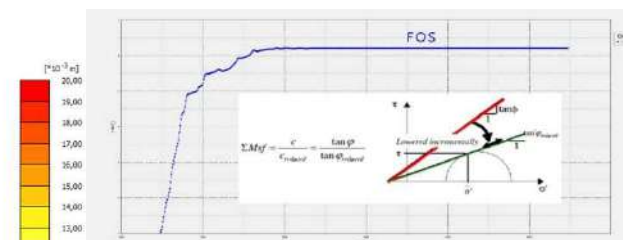
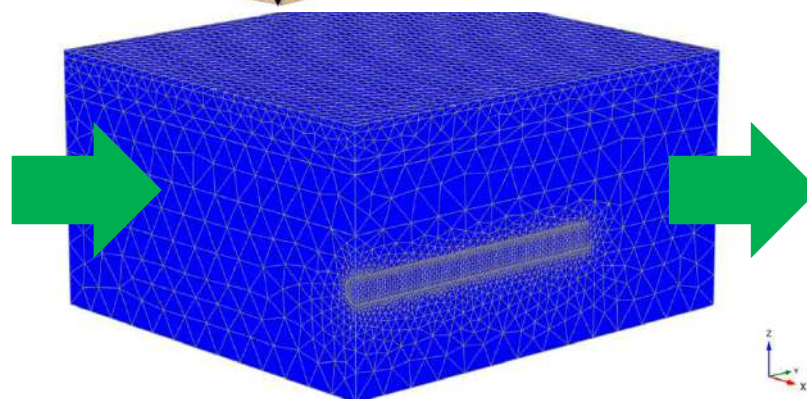


BIM and Numerical Simulations

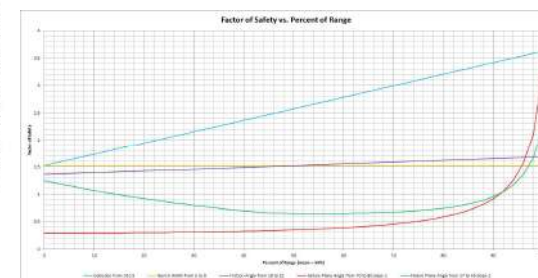
- ❑ Time-consuming modelling
- ❑ Decision-Making process
- ❑ Meta Models



PLAXIS

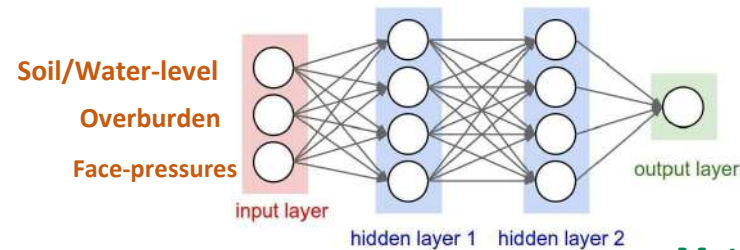
 python™

Factor of Safety (FoS)



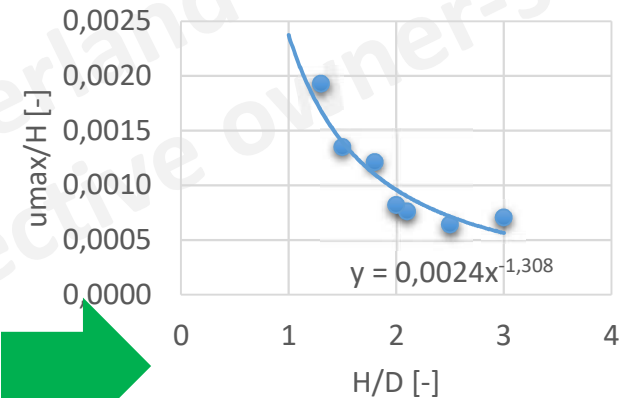
BIM and Numerical Simulations

- Decision-Making process
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- Meta Models

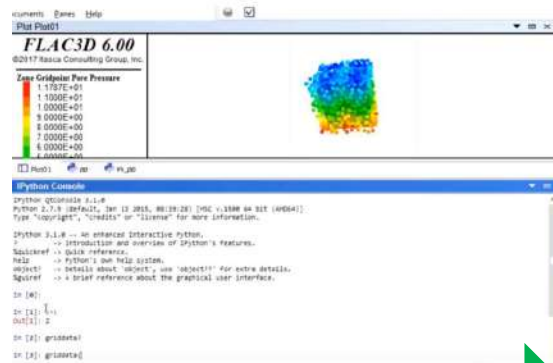
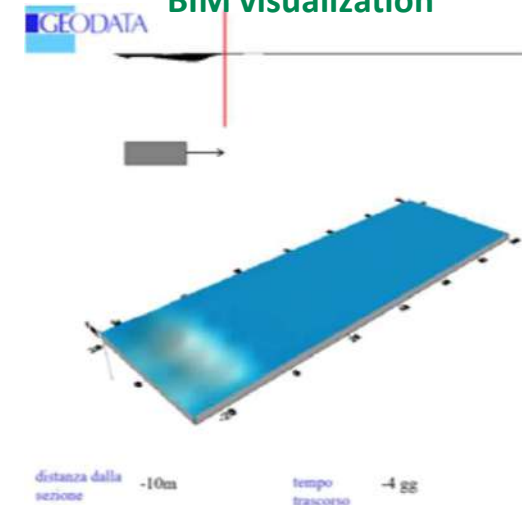


Settlements
Factor of Safety
Other factors

Meta-model - Correlations



BIM visualization

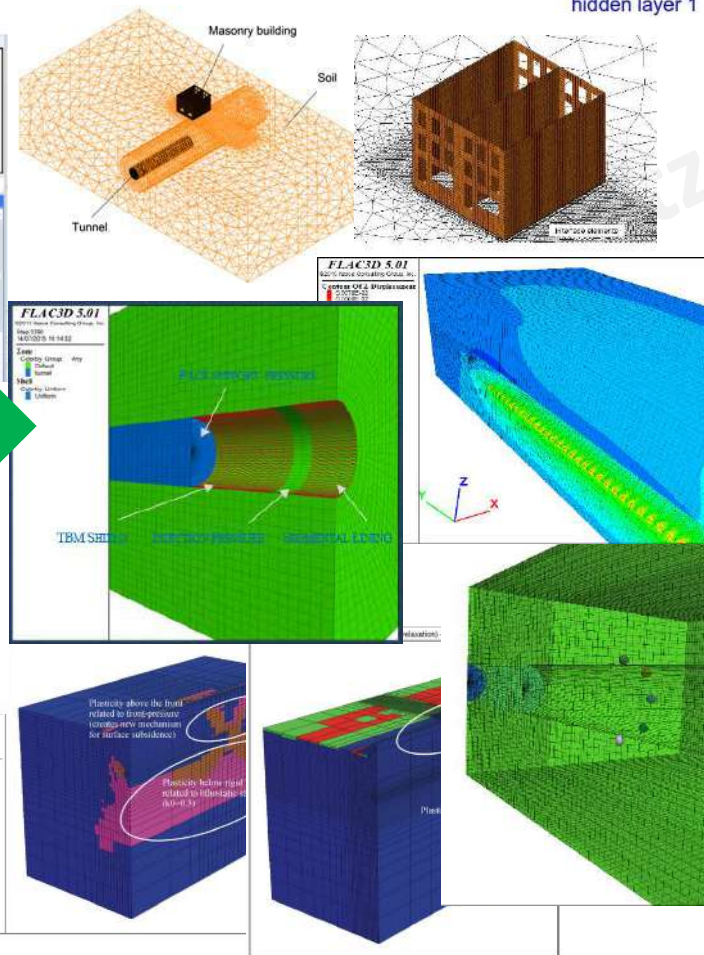


PARAMETER STUDY

- Python is not reset during model new

```
for modulus in [0.0, 0.05, 0.1, 0.2]:
    it.command("
model restore 'before_cycling'
zone group young {}
model solve
'''format(modulus)'''
vertical_disp = it.gridpoint.near(5,5,10).disp_z()
print 'Modulus: {} Pa, vertical displacement: {}'.format(modulus, vertical_disp)
```

Modulus: 0.0e+00 Pa, vertical displacement: 1.772e-03
Modulus: 0.0e+00 Pa, vertical displacement: 1.324e-03
Modulus: 1.0e+10 Pa, vertical displacement: 1.063e-03
Modulus: 1.2e+10 Pa, vertical displacement: 8.855e-04

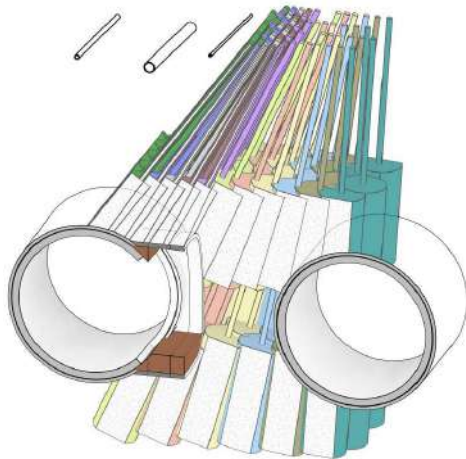


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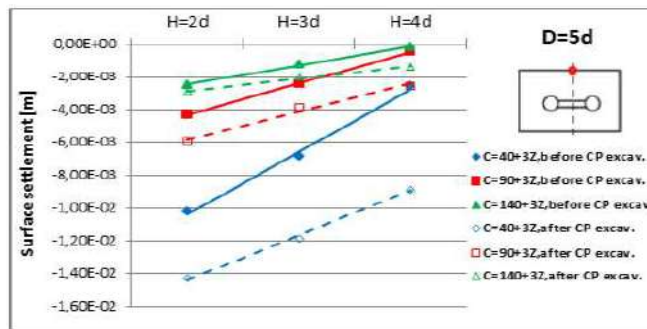
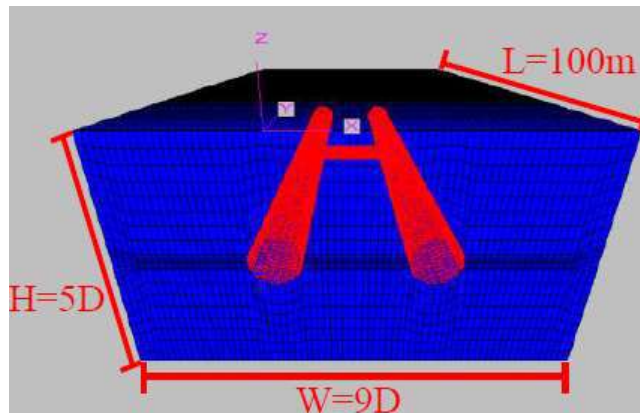
TOOLS & TECHNIQUES

BIM and Numerical Simulations

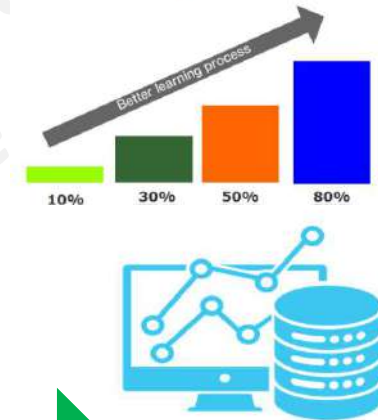
- Decision-Making process
- Time-consuming modelling
- Meta Models



BIM 3D model



Learning Process



BIM

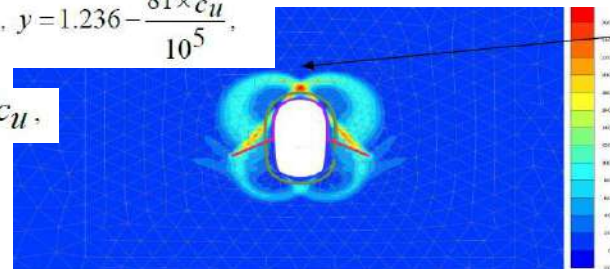


BIM tools

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

$$\Delta = 2.81 - 0.02 c_u$$

Meta-models
Correlations



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- **Tools & Techniques**

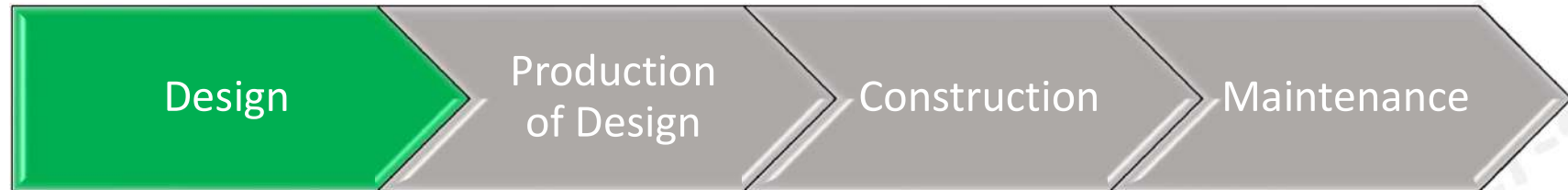
- Revit, Dynamo, Python, Navisworks etc.

- **Examples of BIM application in Mechanized tunneling projects**

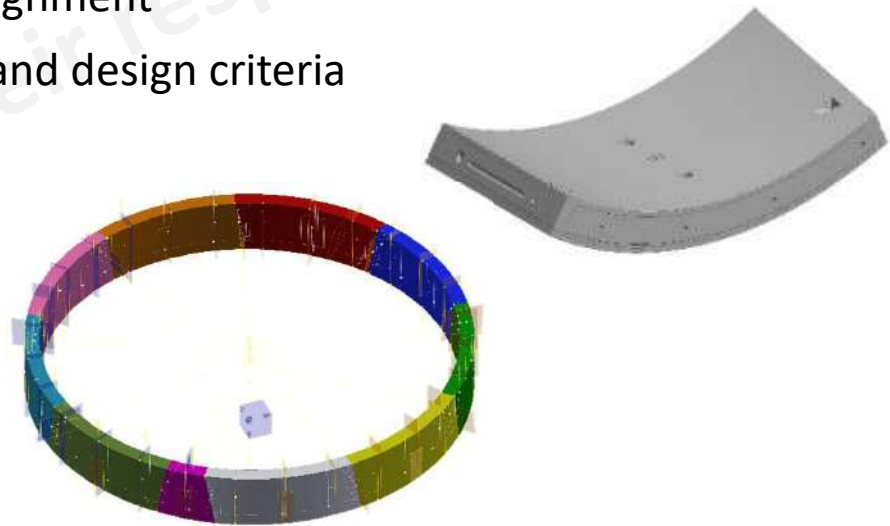
- Along the Life-cycle of the project (Design, Production of Design, Construction, Maintenance)
- For the different knowledge areas (Alignment, Geology, Precast of the segments, Advance of TBM etc.)

- **Conclusions**

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

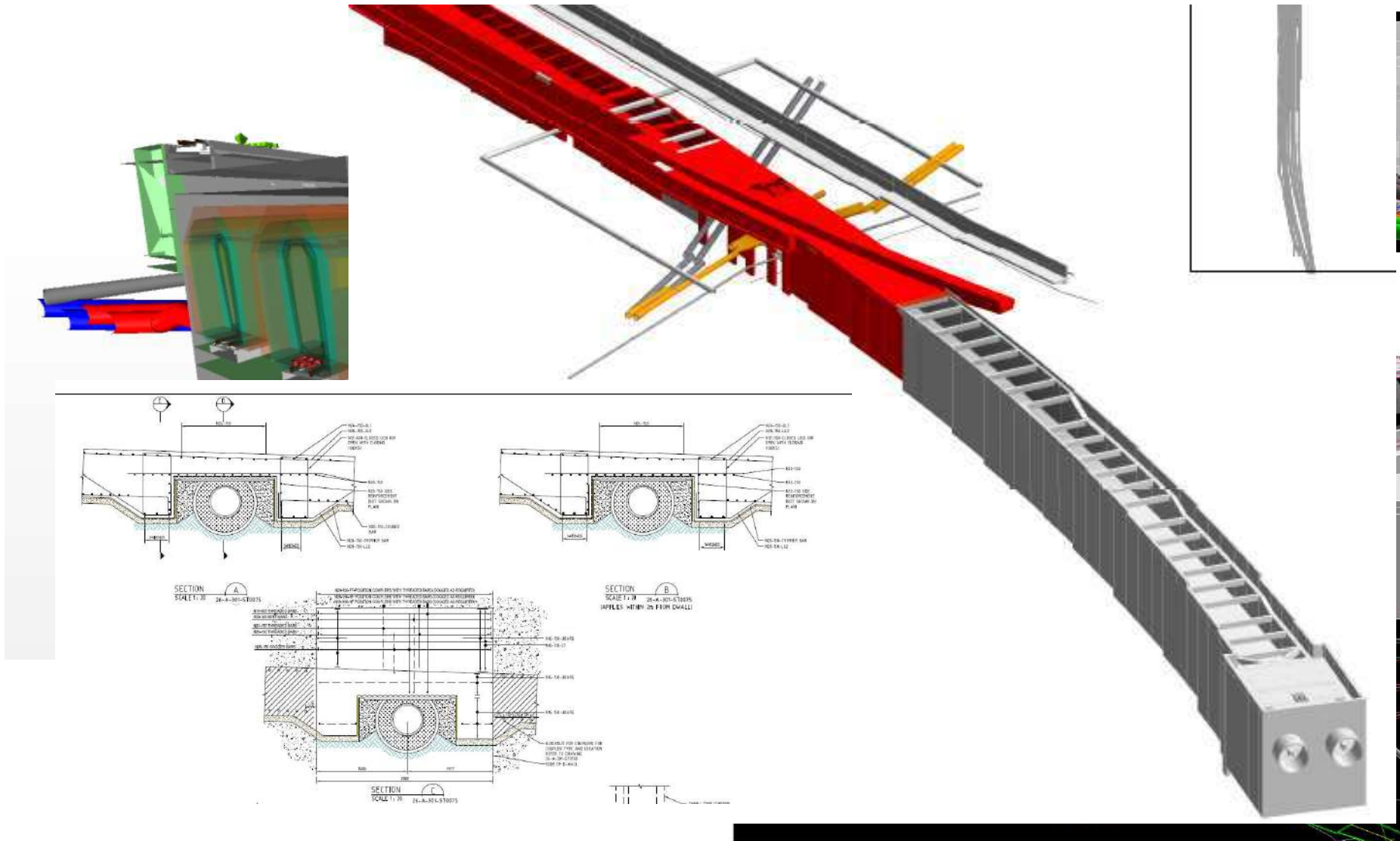


- Clash detection (space-proofing and MEP components)
- Virtual construction for the study of the excavation sequence
- Variant studies and optimization of the alignment
- Justifiable assumptions, applied concept and design criteria
- Sensitivity calculations
- Probabilistic integrated calculations
-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



Space-proofing and MEP

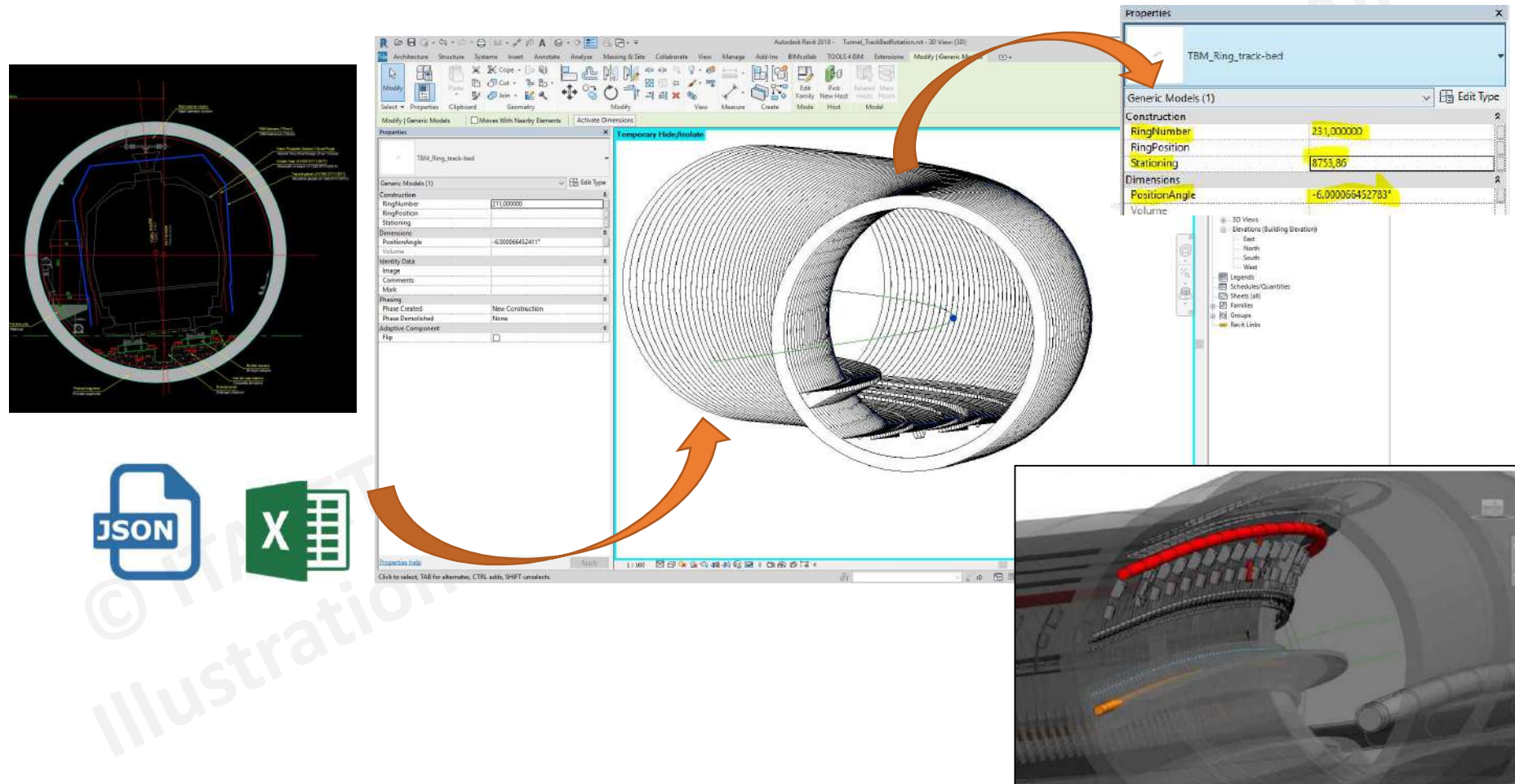
Clash detection - Virtual construction for the study of the excavation sequences



Alignment - Space-proofing – M.E.P.

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

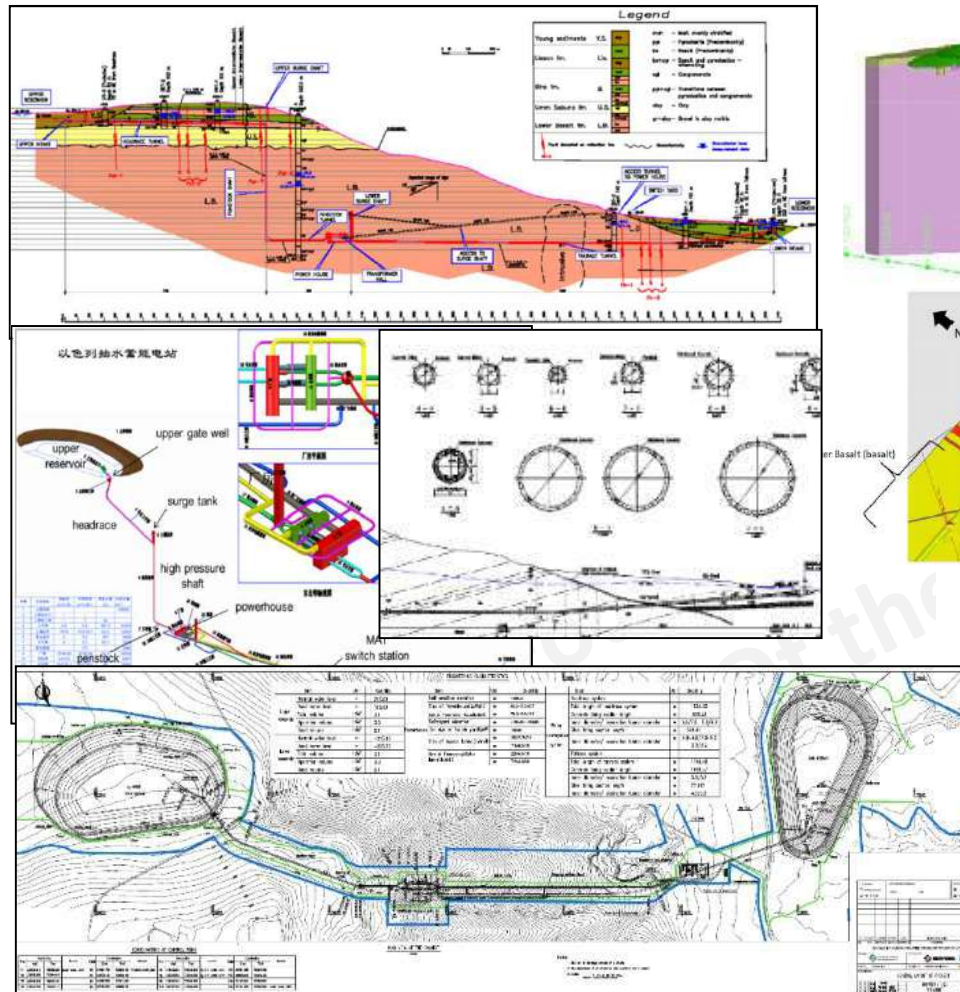
BIM solution have been used to model the spaceproofing with the aim to evaluate the right position of trackbed, walkways and any other obstacles to be considered for MEP design.



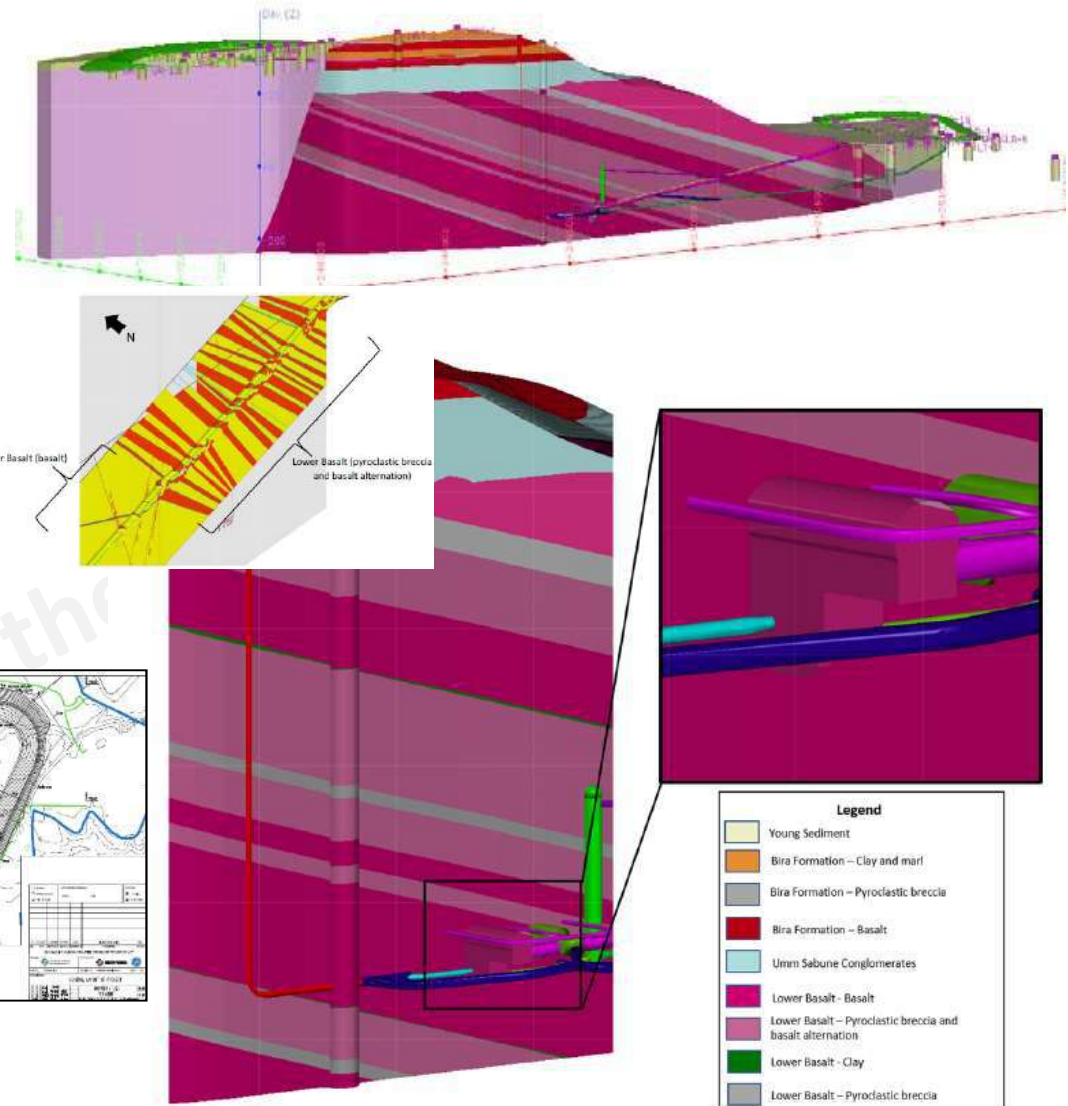
CLASH DETECTION: ALIGNMENT AND MEP INSTALLATIONS

Geological assessment and design

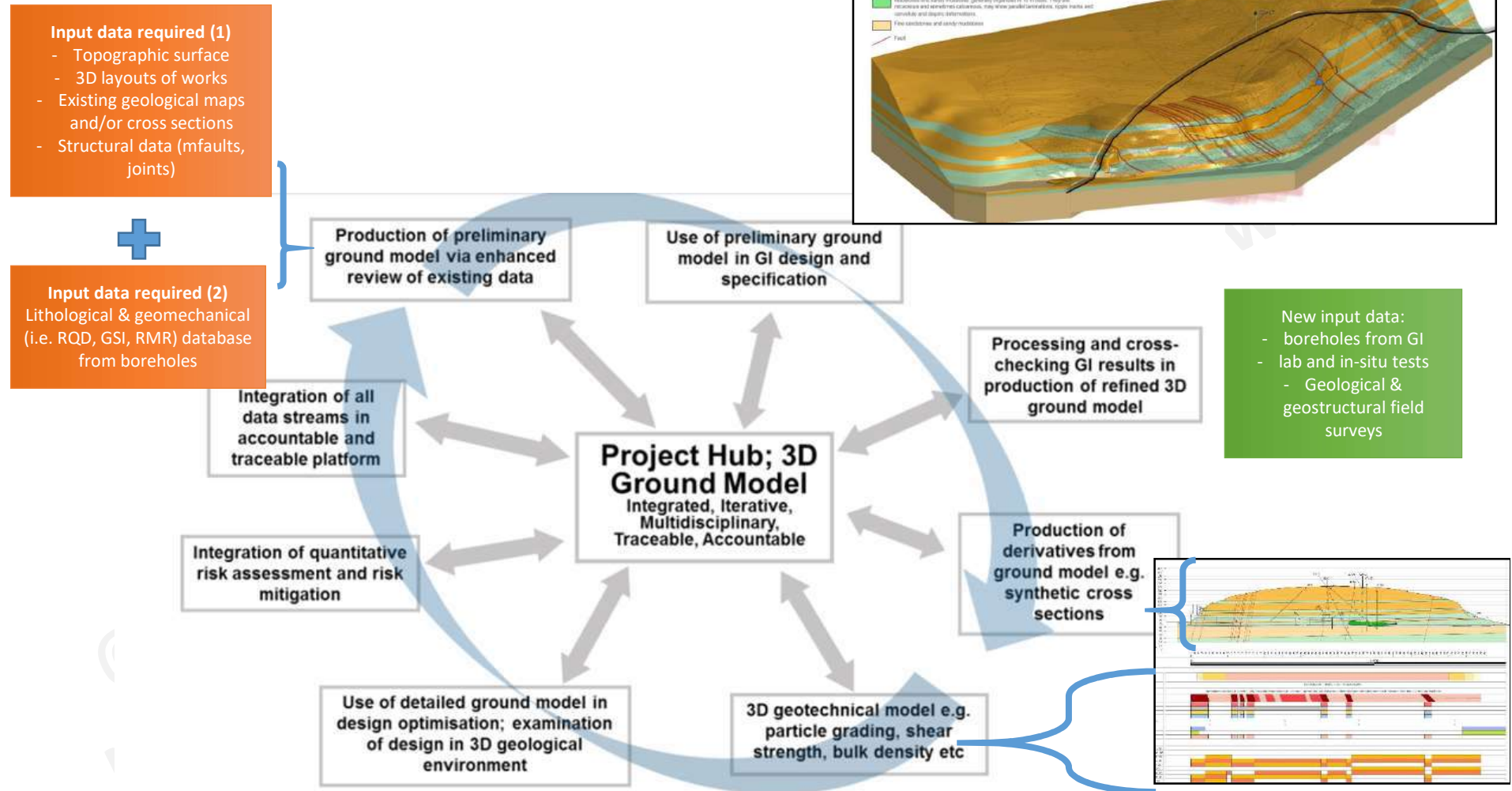
Without BIM



With BIM

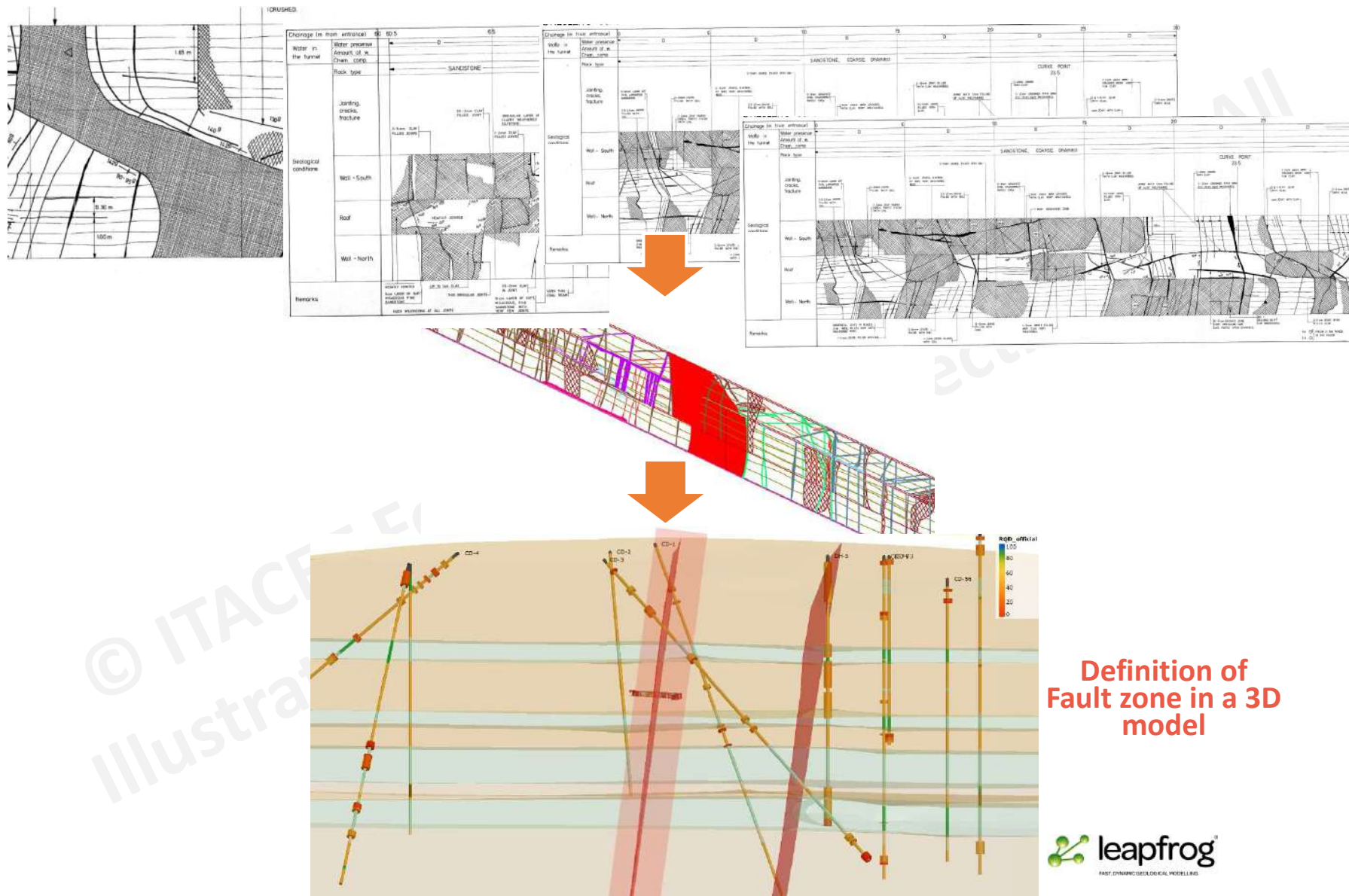


Geological assessment and updating



Geological assessment and design

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



Definition of
Fault zone in a 3D
model

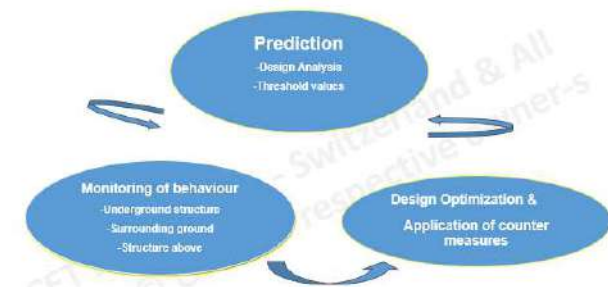
leapfrog
PART DYNAMIC GEOLOGICAL MODELLING

Abstract

- | | |
|---|--------|
|  | Yellow |
|  | Green |
|  | Blue |
|  | Orange |



A 3D block diagram illustrating a geological model. It shows a fold structure with a fault line. The model is colored in shades of brown, tan, and green, representing different geological units. The fault line is a prominent feature, showing a break in the rock layers. The diagram is labeled '3D model' in red text.



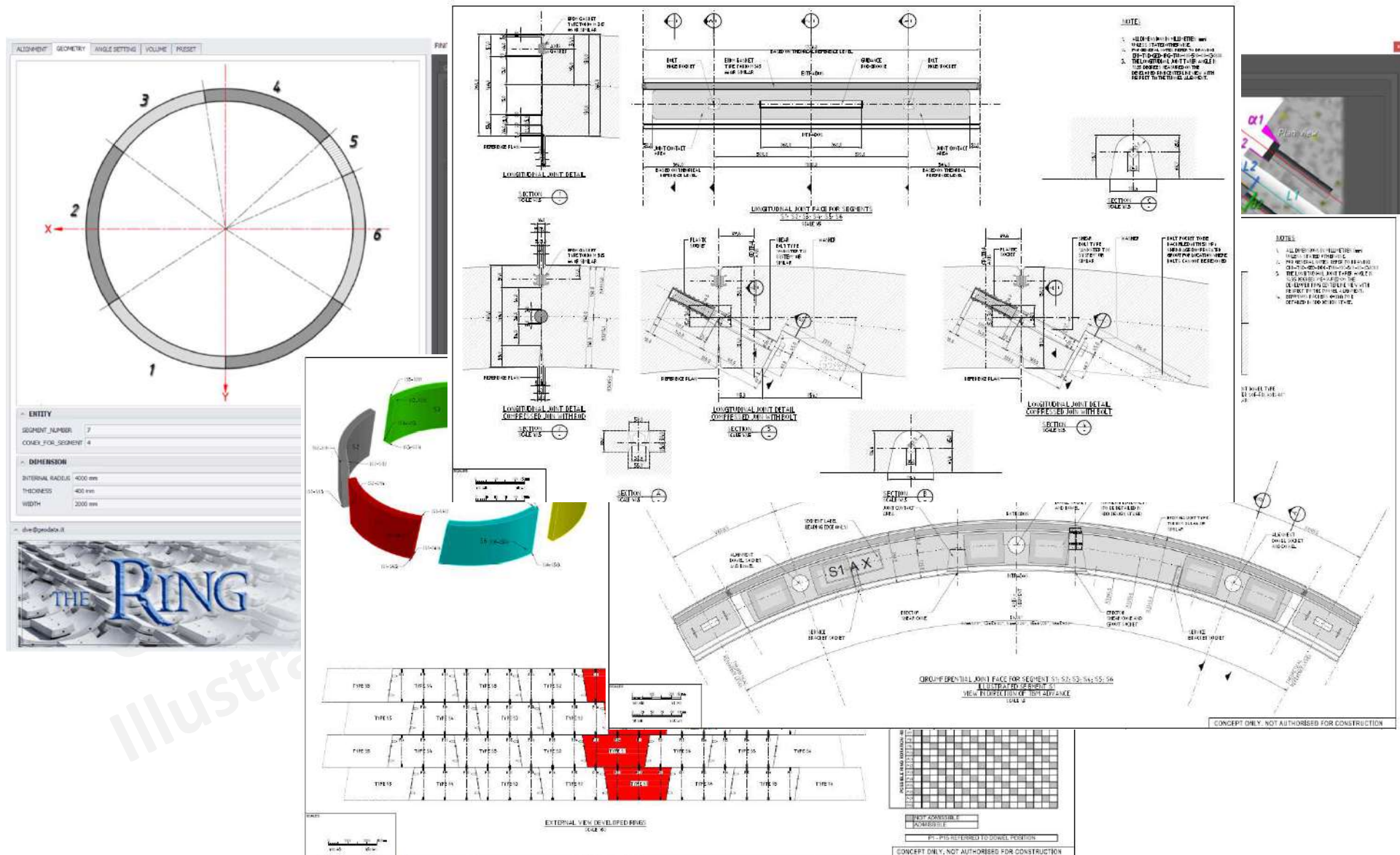
Design of Segmental Lining

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

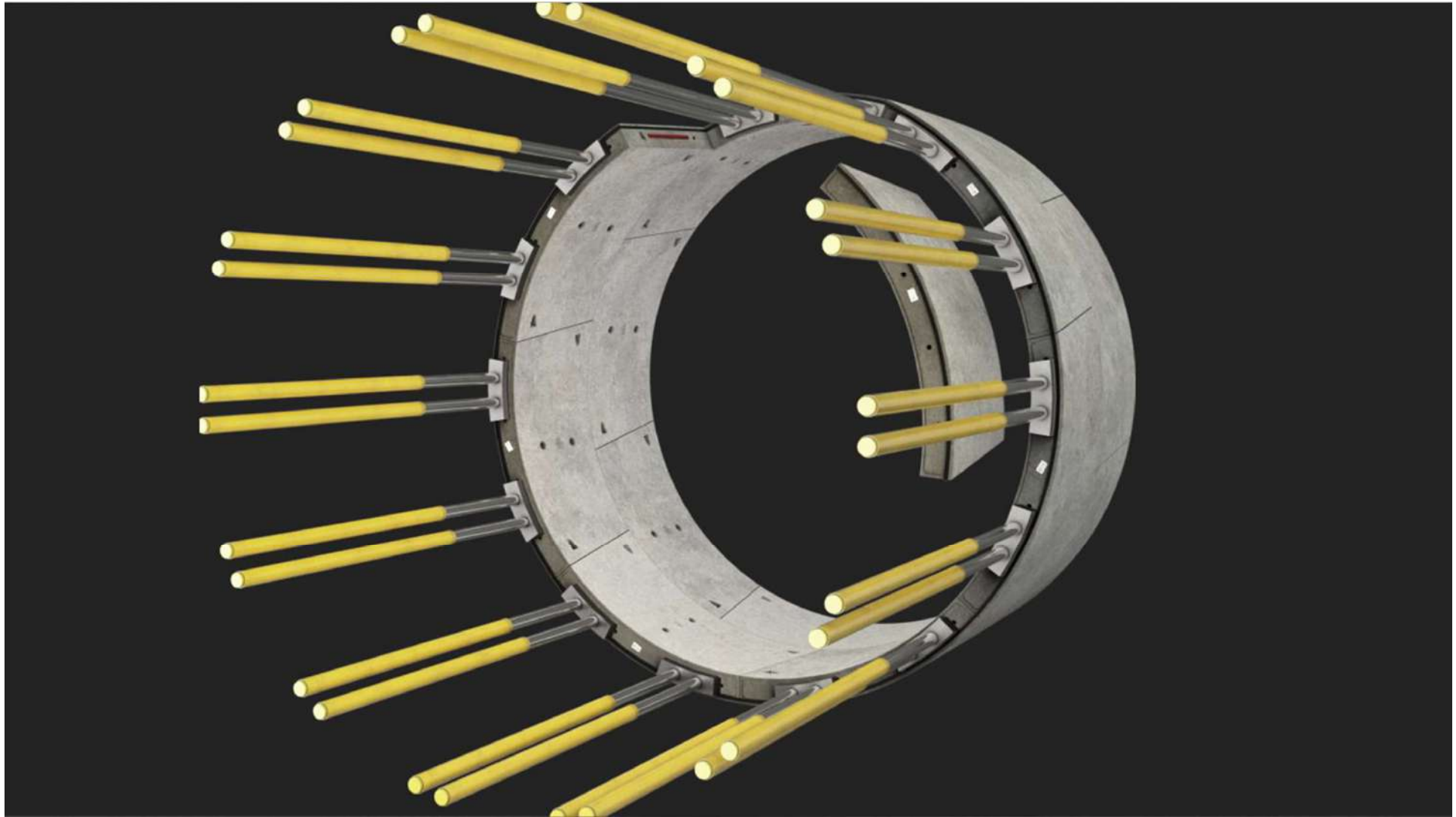


Design of Segmental Lining

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

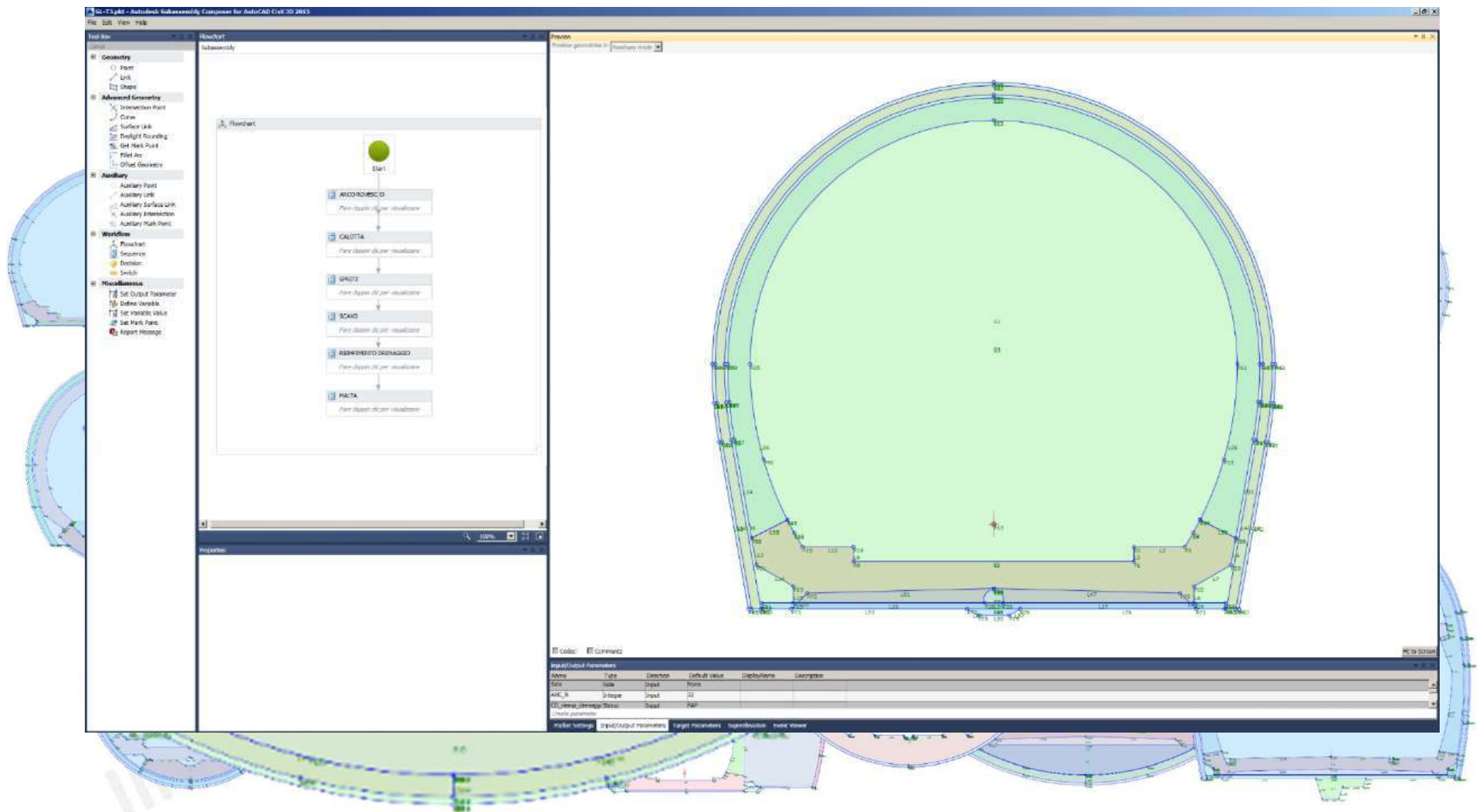


Design of Segmental Lining



Design of Cross-passages and NATM sections

Parametric generation of complex geometries

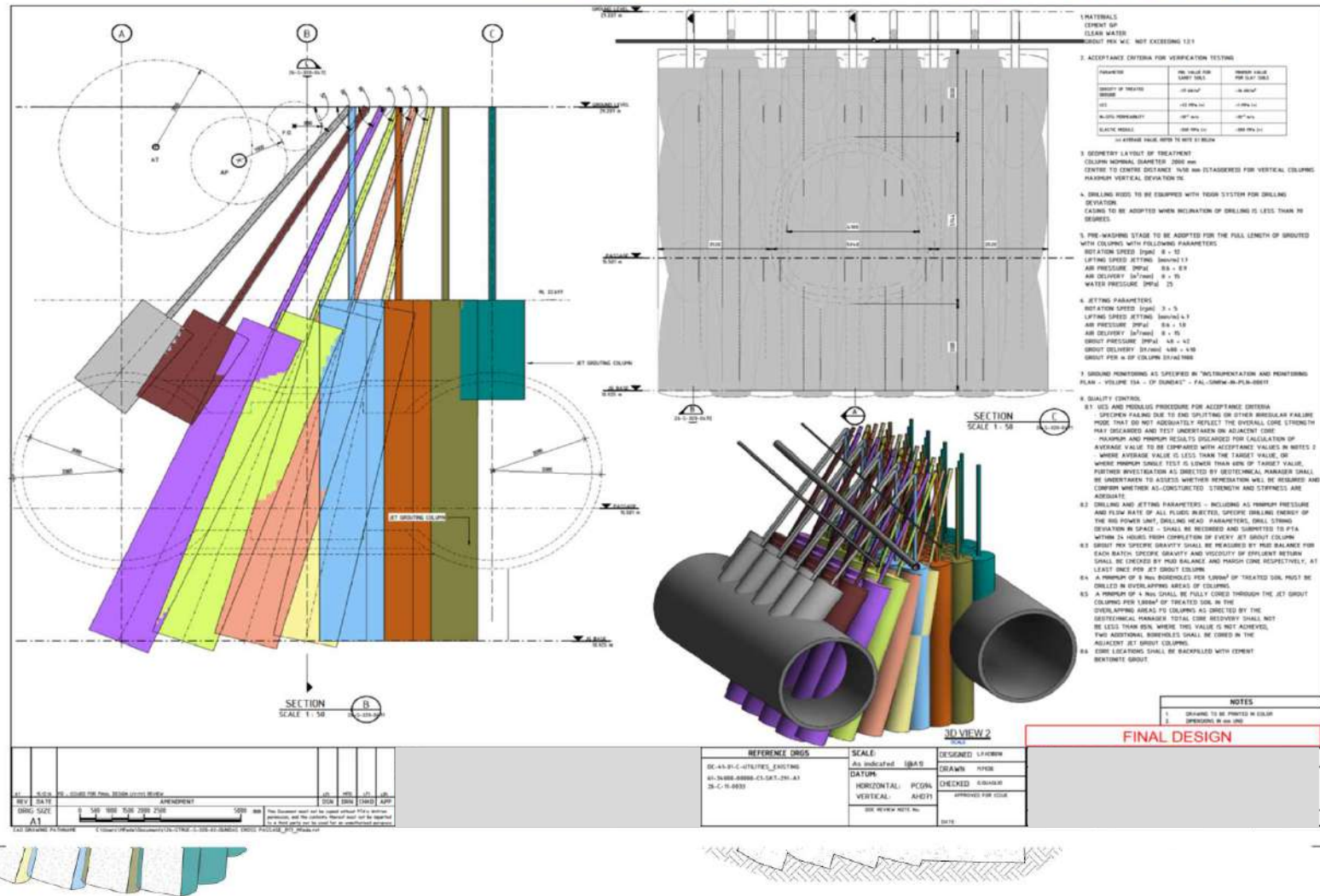
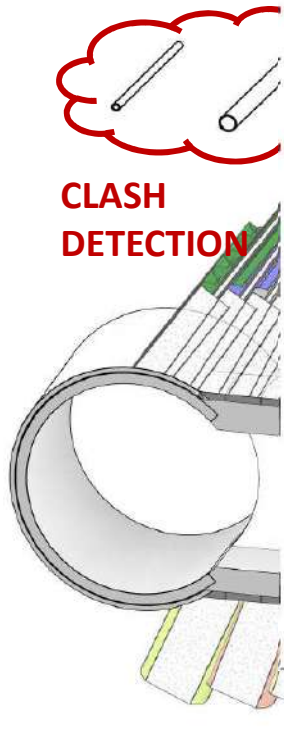


Design of Cross-passages

- Functional design and MEP
- Clash detection
- Structural



**CLASH
DETECTION**

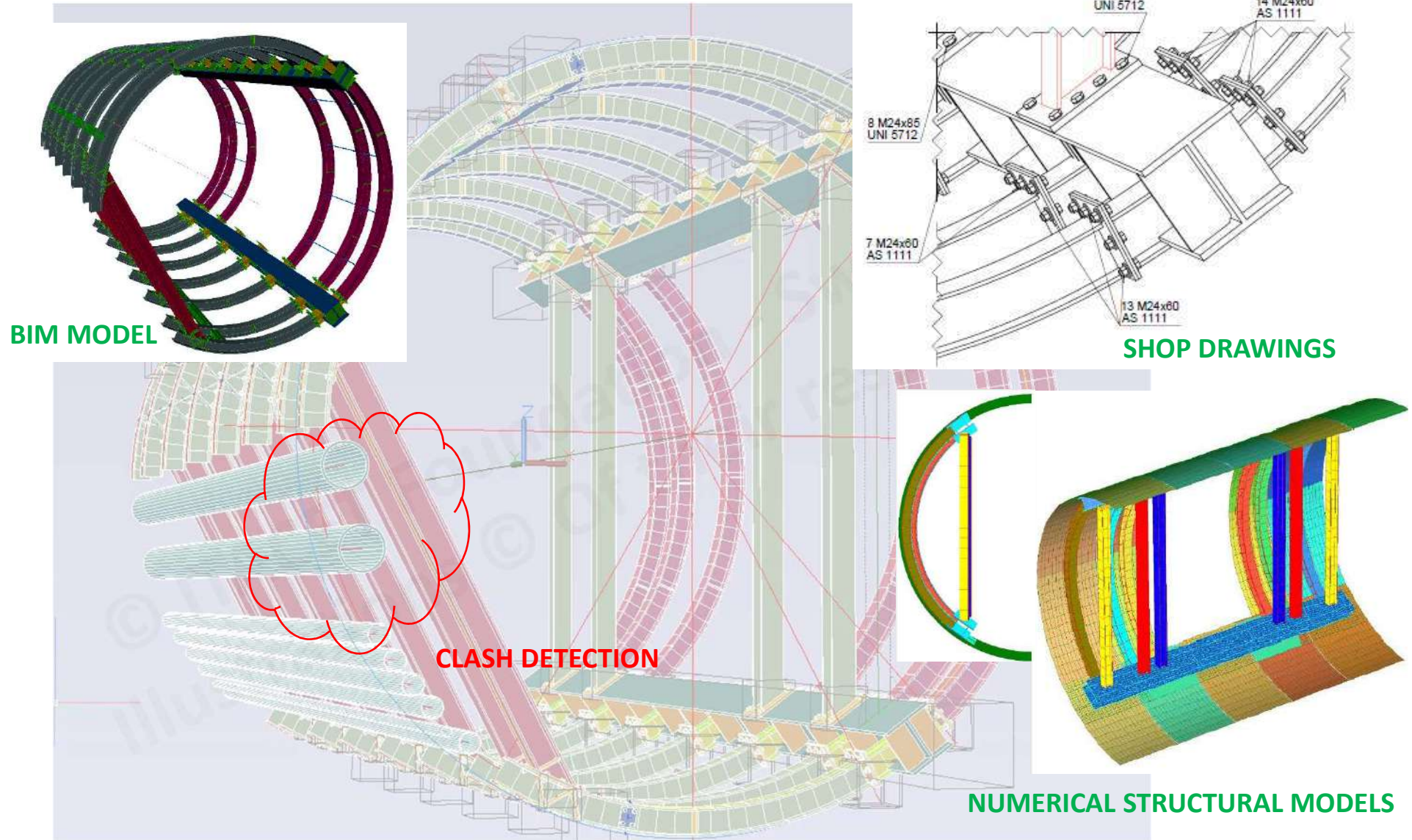


BIM MODEL

SHOP DRAWINGS

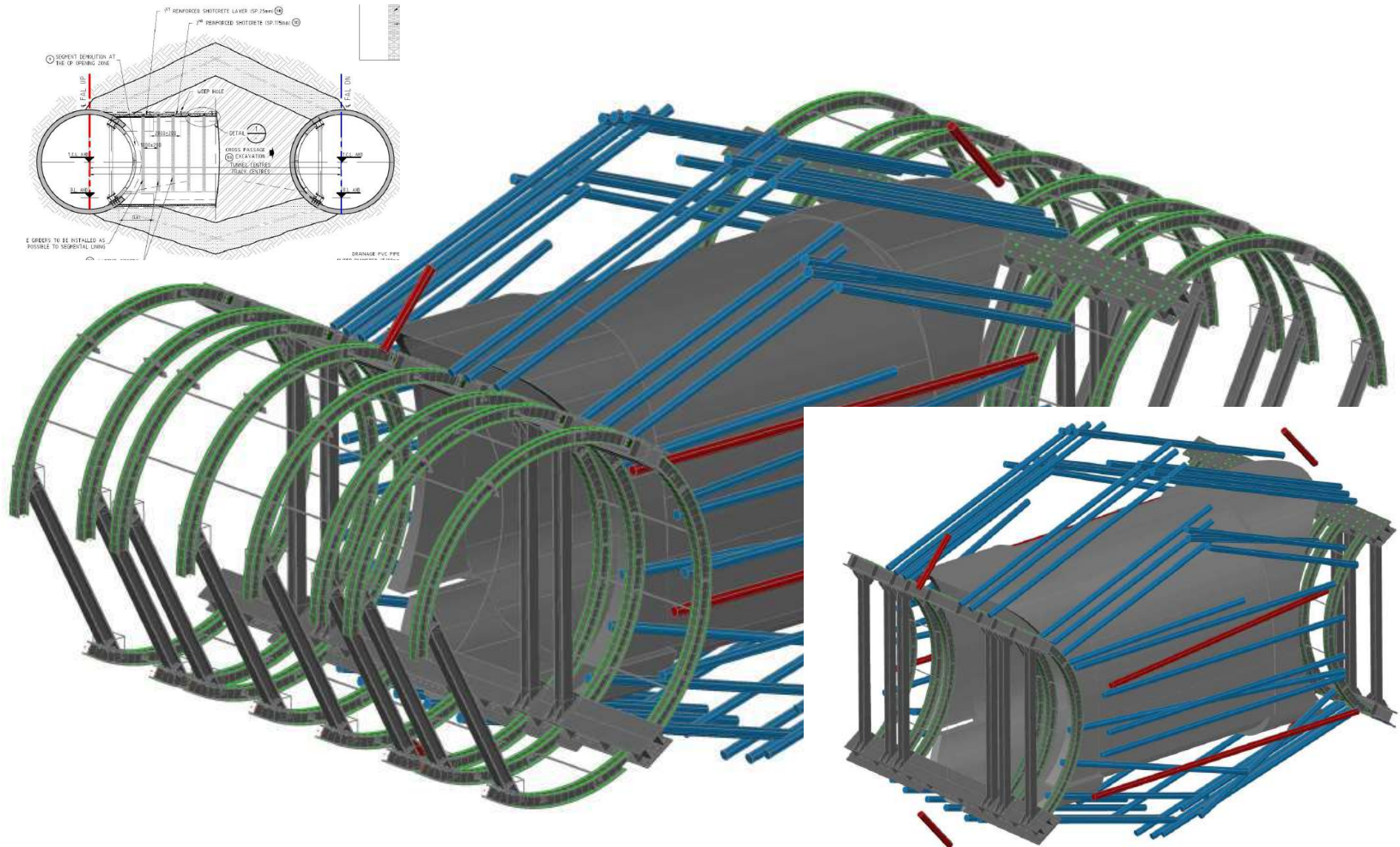
Design of Cross-passages

Design of temporary steel-frame and MEP services during construction

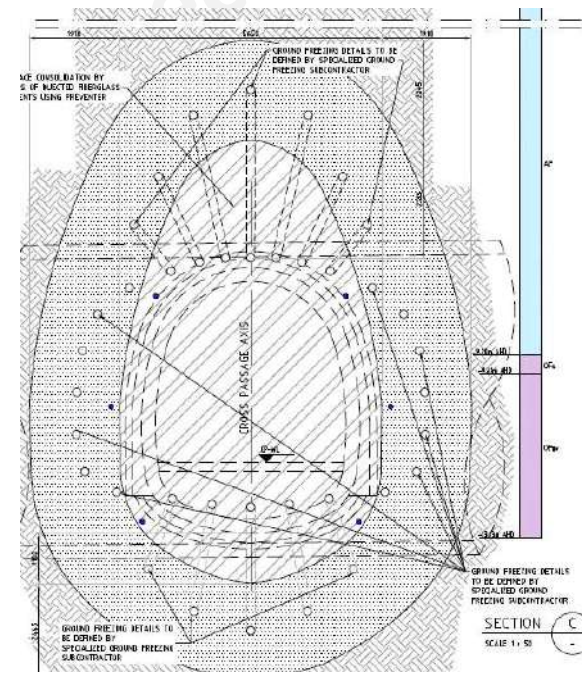
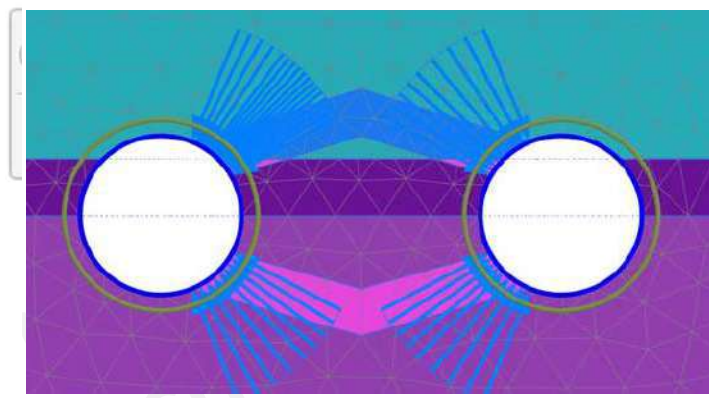


Design of Cross-passages

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

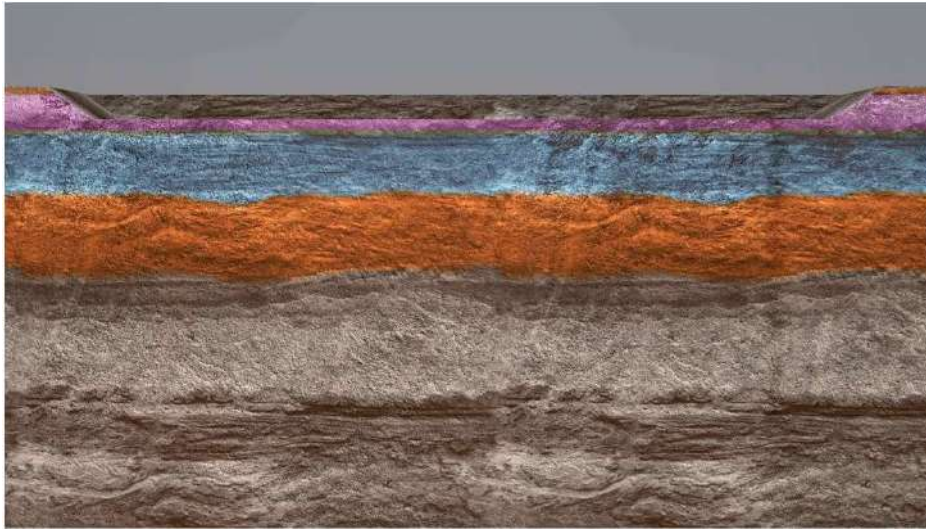


1

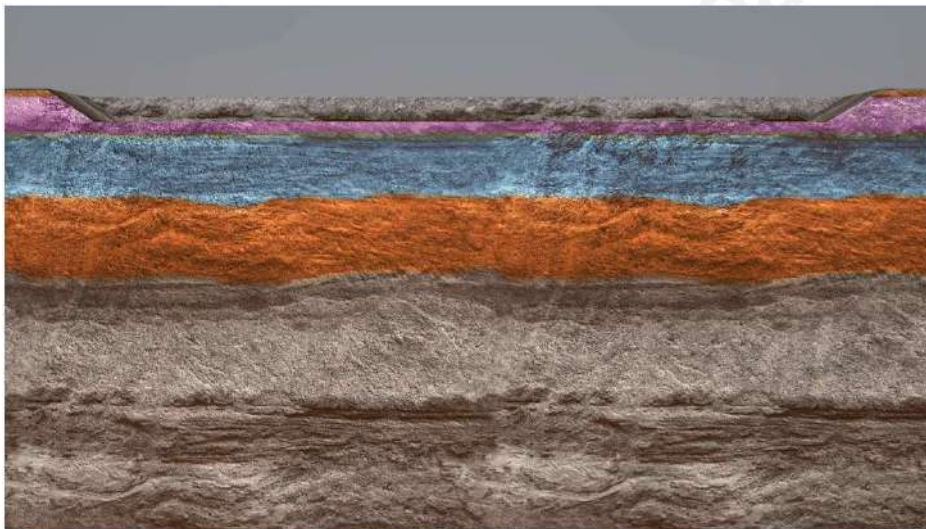


Project phasing simulations

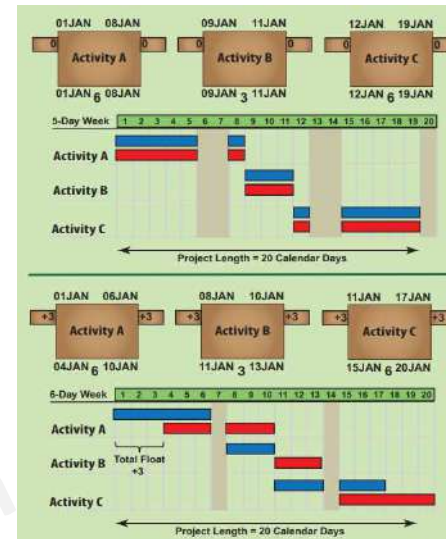
Visual validation of two alternatives – 4D BIM



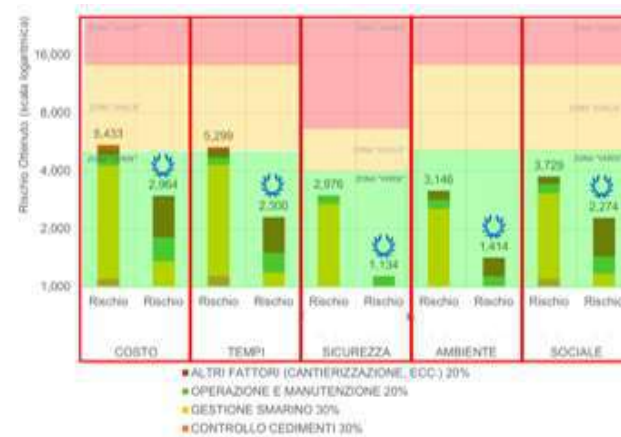
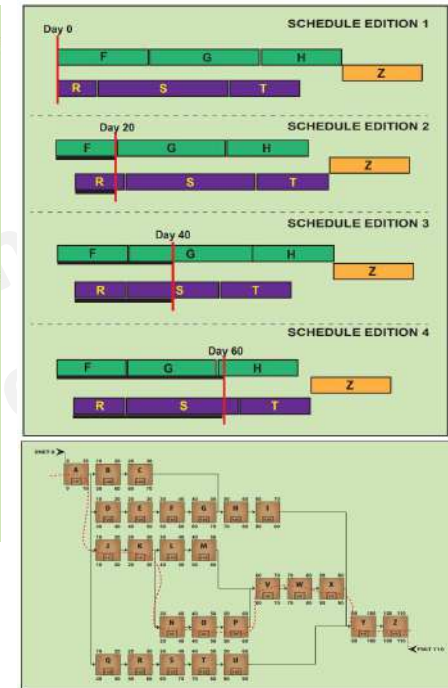
TBM **BEFORE** DEEP EXCAVATION (STATION/SHAFT)



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



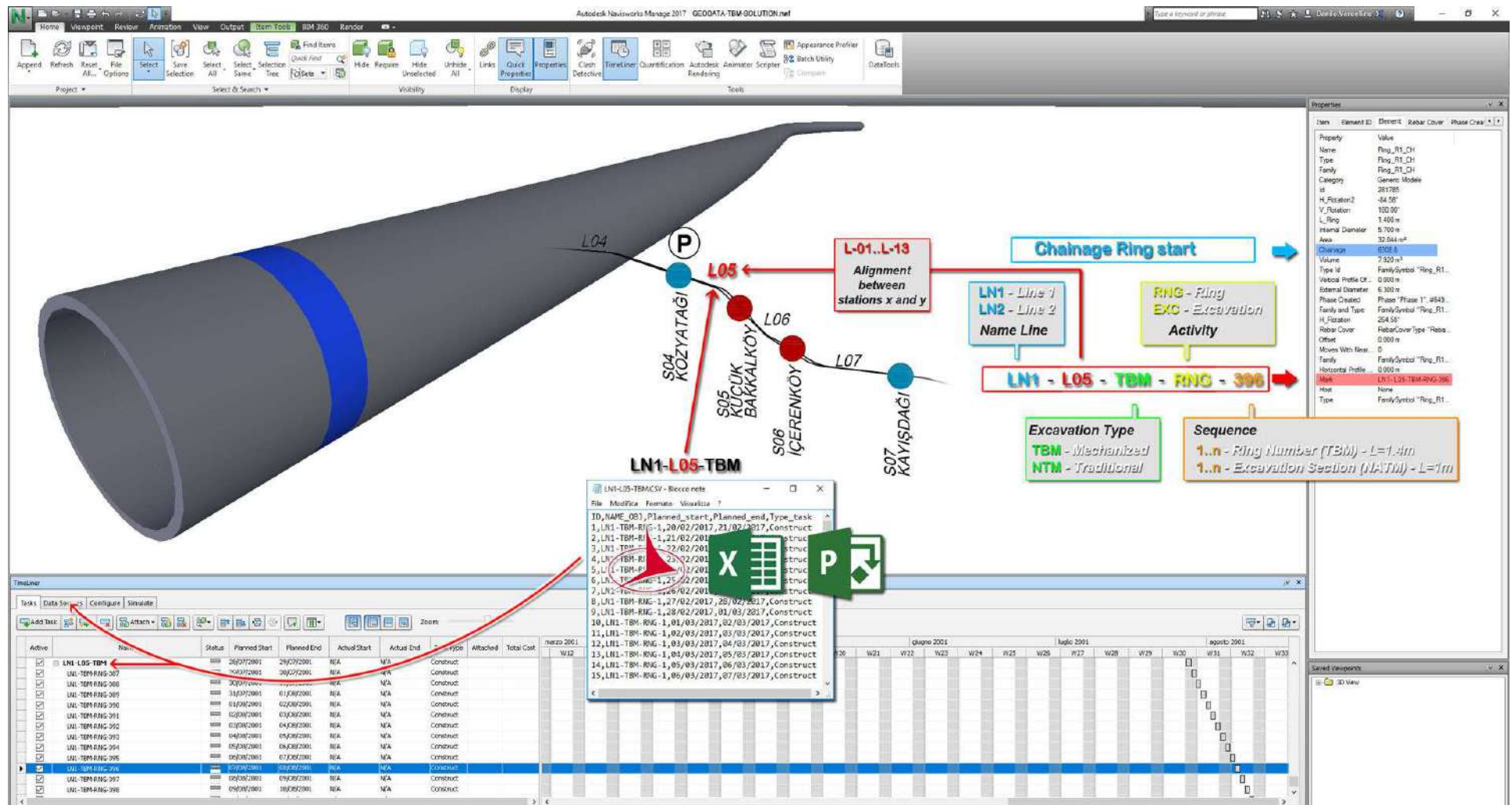
TIME MANAGEMENT
CPM



RISK ANALYSIS - MULTI-CRITERIA ANALYSES



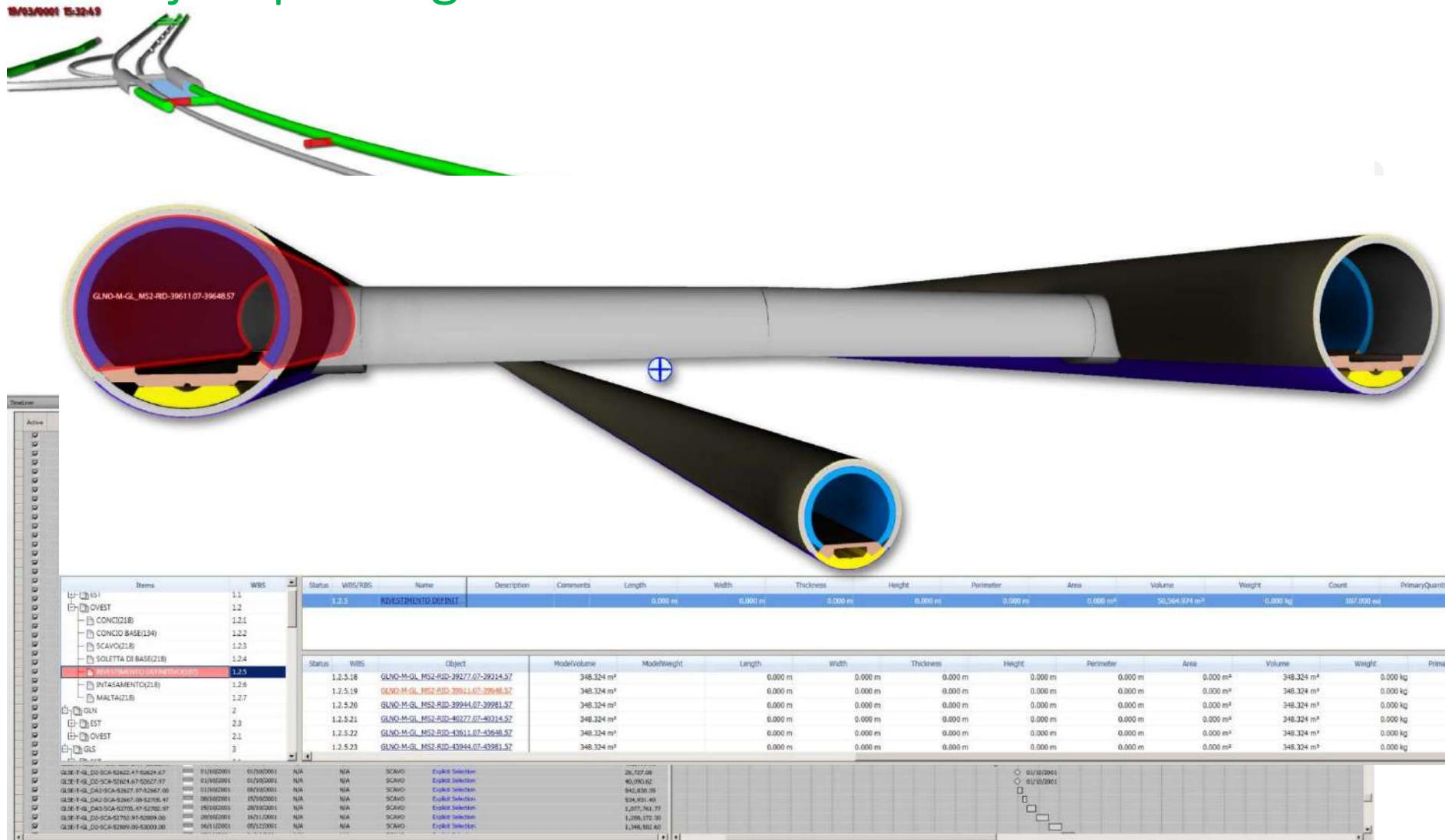
Project phasing simulations



An example of 5D BIM (Time & Costs)

4D-5D BIM for Mechanized Tunneling

Project phasing simulation and evaluation of costs



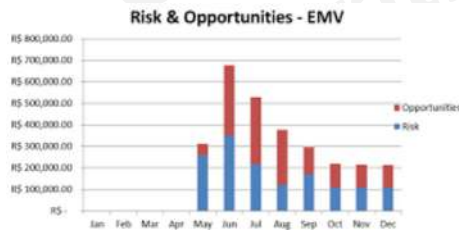
Time – Costs - WBS

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	CATEGORY		Risk [R = P x I]				
								Topic						
								Hazard						
						I.D.		Location		Financial loss	Delays	Health & safety	Natural environment	Social
TU	TL	011	TU-TL-011	Structural verification of the segmental liner taking into account the effect of the ground conditions	3	5	0	Tunnel - Excavation						
TU	TL	012	TU-TL-012	Segmental lining calculations considering block face pressure	3	5	2	3.5.2	Earth Pressure Balance - Lack of counter-pressure at the tunnel face, leading to settlements or differential settlements	10	10	15	10	15
TU	TL	013	TU-TL-013	Concrete mix design of segmental lining includes	3	5	3	3.5.3	Void Filling - Improper grouting / backfilling, leading to settlements or differential settlements	10	10	10	10	15
TU	TL	014	TU-TL-014	Examine the performance of the sealing gasket at the joint	3	5	4	3.5.4	Ground conditioning - Inadequate ground conditioning	8	8	8	8	8
TU	TL	015	TU-TL-015	Segmental lining gaskets dimensioned with SFS-2	3	5	5	3.5.5	Frac-out from grouting - Excessive tail void grouting pressure, leading to surface heave	6	3	3	9	9
TU	TL	016	TU-TL-016	Segmental lining gaskets dimensioned with +2m	3	5	6	3.5.6	Frac-out from tunnelling - Fluid losses during tunnelling and/or interventions	8	8	4	12	12
TU	TL	017	TU-TL-017	Segmental lining backfilling to guarantee perfect	3	5	7	3.5.7	TBM guidance - Lack of reliability of TBM guidance	6	6	3	3	6
TU	TL	018	TU-TL-018	Segmental lining backfilling, in excavation zones	3	5	8	3.5.8	Liner Installation - Inadequate segmental lining positioning	10	15	5	5	10
TU	TL	019	TU-TL-019	Segmental lining backfilling, in excavation zones	3	5	8	3.5.8	Liner Installation - Inadequate segmental lining positioning	10	15	5	5	10
TU	TL	020	TU-TL-020	Ring joints to be secured by 12 plastic dowels of	3	5	8	3.5.8	Liner Installation - Inadequate segmental lining positioning	10	15	5	5	10
TU	TE	001	TU-TE-001	Examine pull-out force (direct tensile force from	3	5	1	3.5.1	Excessive excavation - uncontrolled ground losses, leading to settlements or differential settlements	10	10	15	10	15
TU	TE	002	TU-TE-002	Product Data & Manual for the Tunnel Boring Machine	3	5	2	3.5.2	Earth Pressure Balance - Lack of counter-pressure at the tunnel face, leading to settlements or differential settlements	10	10	15	10	15
TU	TE	003	TU-TE-003	Controlled application of grout, abrasives and	3	5	3	3.5.3	Void Filling - Improper grouting / backfilling, leading to settlements or differential settlements	10	10	10	10	15
TU	TE	004	TU-TE-004	Controlled application of grout, abrasives and	3	5	4	3.5.4	Ground conditioning - Inadequate ground conditioning	8	8	8	8	8
TU	TE	005	TU-TE-005	Controlled application of grout, abrasives and	3	5	5	3.5.5	Frac-out from grouting - Excessive tail void grouting pressure, leading to surface heave	6	3	3	9	9
TU	TE	006	TU-TE-006	Controlled application of grout, abrasives and	3	5	6	3.5.6	Frac-out from tunnelling - Fluid losses during tunnelling and/or interventions	8	8	4	12	12
TU	TE	007	TU-TE-007	Controlled application of grout, abrasives and	3	5	7	3.5.7	TBM guidance - Lack of reliability of TBM guidance	6	6	3	3	6
TU	TE	008	TU-TE-008	Controlled application of grout, abrasives and	3	5	8	3.5.8	Liner Installation - Inadequate segmental lining positioning	10	15	5	5	10

ID	Category
1	General Hazards (management level)
1.1	Political
1.2	Social
1.3	Economic
1.4	Financial
1.5	Legal
1.6	Contractual
1.7	Design Process
2	Environmental Hazards
2.1	Environmental Impacts - Shafts/Compounds
2.2	Environmental Impacts - Tunnels
2.3	Environmental Impacts - Life-Cycle
3	Construction Hazards
3.1	Shaft - Site Conditions
3.2	Shaft - Walls / Support
3.3	Shaft - Equipment
3.4	Tunnel - Site Conditions
3.5	Tunnel - Excavation
3.6	Tunnel - Liner
3.7	Tunnel - Equipment
3.8	Shaft & Tunnel Services
3.9	Conventional Tunnels
3.10	Existing Infrastructure Interference
3.1	Environmental
3.1	Labor
3.1	Humber Pumping Station
4	Health & Safety Hazards
4.1	Tunnel Works
4.2	Shaft Works
4.3	Equipment assembly
5	Lifecycle Exploitation



pk_alignment	
pk_id	int
pk_start	int
pk_end	int

risks_alignemnt	
pk_id	int
risk_id	int

risks	
risk_id	int
user_id	int
status	varchar
description	varchar
created_at	varchar

mitigation_measures	
mm_id	int
status	varchar
description	varchar
created_at	varchar



MySQL

Code Block	
lst	//Ring Number
lst[0];	
lst[1];	//Installation Date
lst[2];	
lst[3];	//Ring Ring Name
lst[4];	
lst[5];	//Stationing
lst[6];	
lst[7];	//Horizontal Deviation
lst[8];	
lst[9];	//Vertical Deviation
lst[10];	
lst[11];	//Trackbed Rotation
lst[12];	

Python Script		
IN[0]	+	OUT
IN[1]		
IN[2]		
IN[3]		
IN[4]		
IN[5]		
IN[6]		

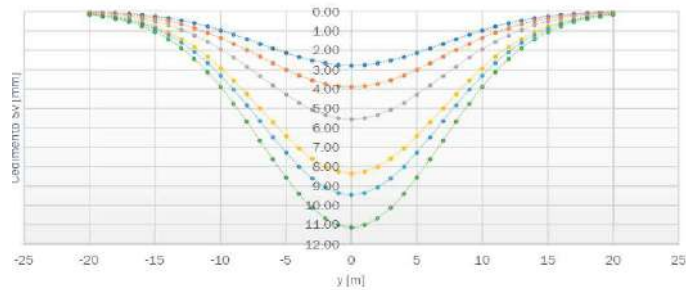
Dynamo



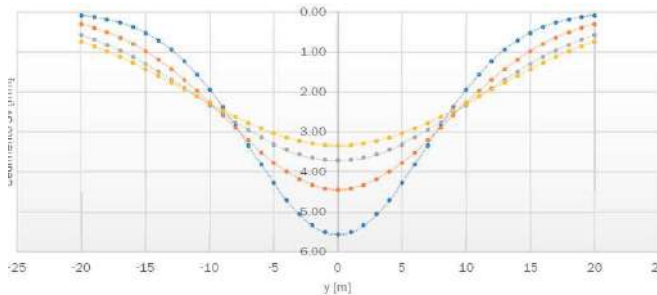
BIM and Risk Management

An Example of implementation of Building Risk Assessment (BRA)

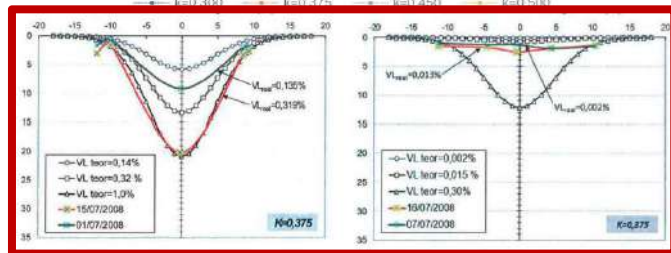
Volume Loss
K-param



Vp=0.5% Vp=0.7% Vp=1% Vp=1.5% Vp=1.7% Vp=2%



K=0.300 K=0.375 K=0.450 K=0.500



VL teor=0.14%
VL teor=0.32%
VL teor=1.0%
15/07/2008
01/07/2008

K=0.375

VL teor=0.002%
VL teor=0.015%
VL teor=0.30%
15/07/2008
01/07/2008

K=0.275



Volume Loss 0.5%

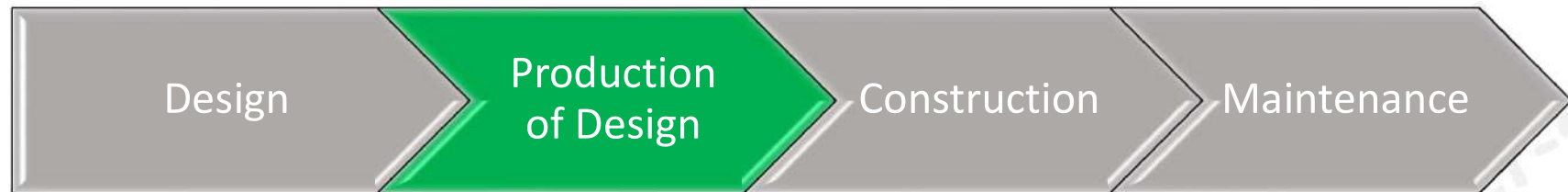


Volume Loss 1.0%



Volume Loss 1.5%

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



- **Quality control**

Compliance with the requirements

Tests for the components and conformities

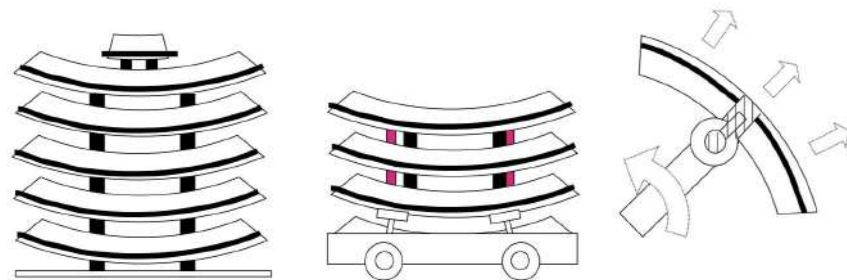
Tests for segments and conformities

Tests for Ground treatments

- **Traceability**

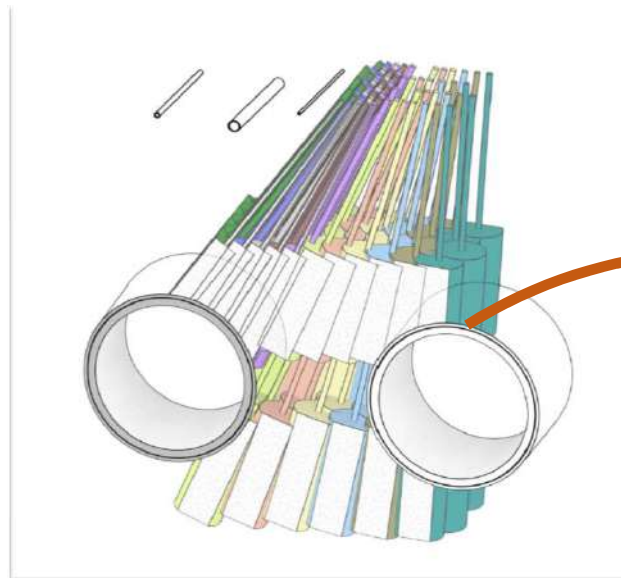
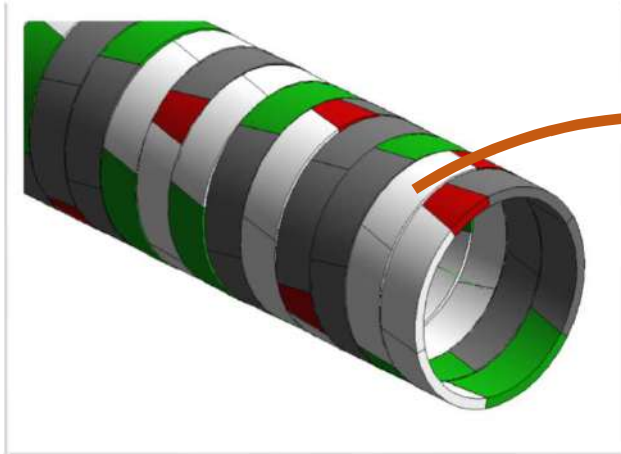
Complex process of Precast of segments

Data integration at any time



Production of Design

Documentation “start to end”

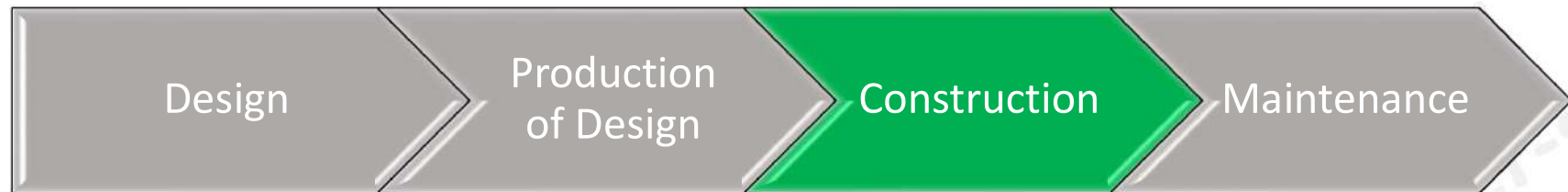


1. Records of information provided and exchanged between the Manufacturer, the Main Contractor and the Transport Company.
2. Roles and responsibilities during transportation.
3. Documents of segments inspections and acceptance for the delivery on site.
4. Documents of supervision during segments handling 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



- **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

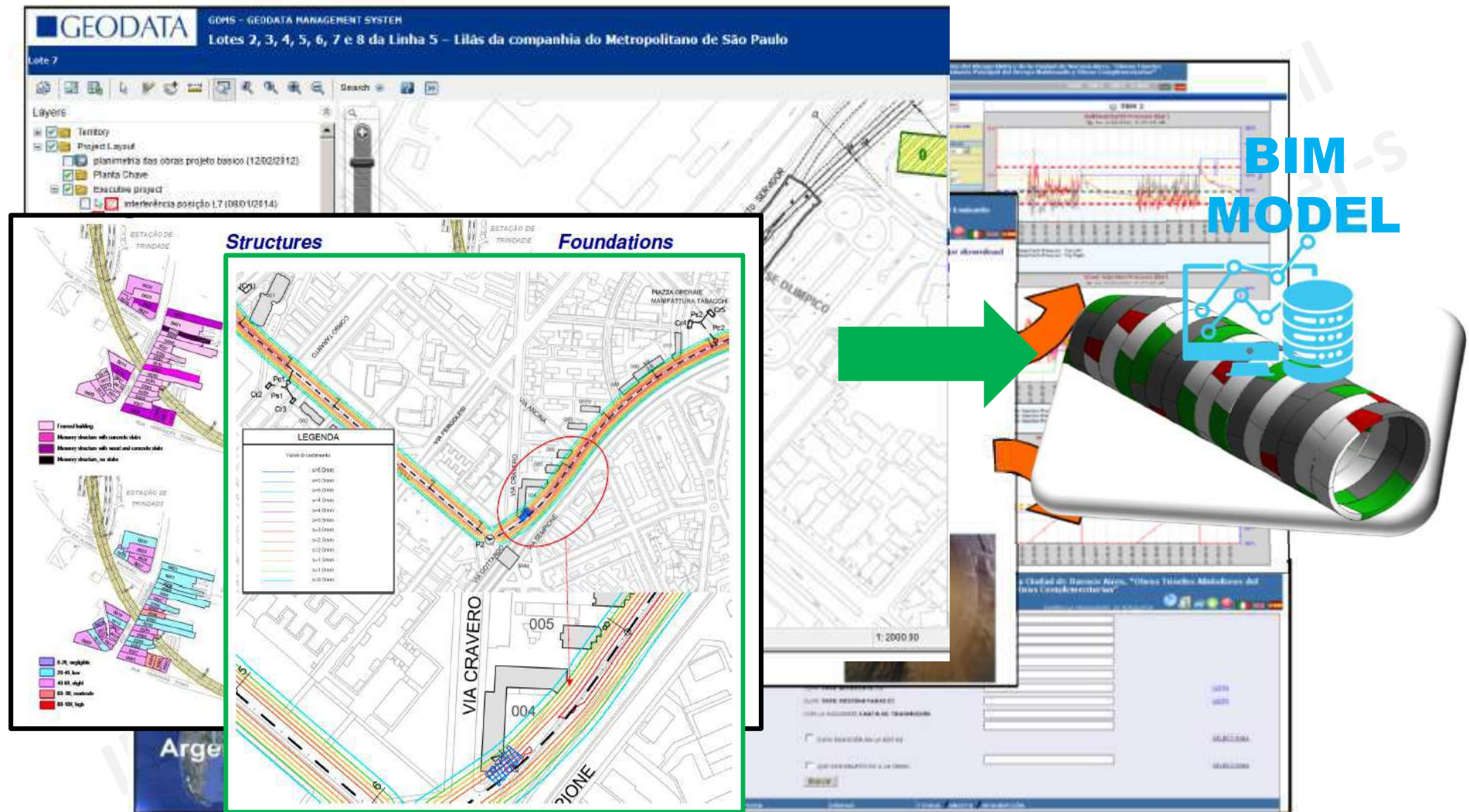
Buildings data: Deformation and displacements

- **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



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

Without BIM

GEODATA

GEODATA ENGINEERING

Proyecto de Desarrollo Sustentable para la Cuenca Matanza – Riachuelo

Lote 3.

Prestamo BIRF Nro. 7706-AR

Avance del tunnel

LD

NOTAS

N° ANILLO	N°FABRICA	POS CLAVE	P.K. ANILLO	LI	Avance del tunnel										LD	NOTAS	
31	0190	2	0+027.15	B	C	D	E	A	B						El anillo presenta pucker rotas		
30	0143	7	0+025.75	E	A	B	B	C	D	E						El anillo presenta desgaste en los vertices del sello de estanqueidad	
29	0193	10	0+024.36	A	B	C	D	E	A						El anillo presenta desgaste en los vertices del sello de estanqueidad		
28	0176	5	0+022.95	D	E	A	A	B	C	D						El anillo presenta desgaste en los vertices del sello de estanqueidad	
27	0008	2	0+021.54	B	C	D	E	E	A	I	B						El anillo presenta desgaste en los vertices del sello d

Relevamiento de anillo

 		OSIA ENAMOR PLANTAS BACHOHE - LOTE 1 CONTENIDO: Agua CONTRATISTA: IMPOSICIÓN - PEQUENAS			RIS RE EA 1 367 0			
IMPUESTO: 05 años EMISIÓN:					0% 580% 0%			
Desviación horizontal (hz)					Desviaci			
0.85% 19.30% 0.00%								
Numero de Acido instalado	PE en Acido	PE en Bordo de acedro	Tabilla de meta (mm)	Activación de acido (mm)	Acido de meta (mm)	Tabilla de meta (mm)	Activación de acido (mm)	Bordo de meta (mm)
836	1-206394	1-4035.76	33	1	1	33	36	33
837	1-206394	1-4035.77	4	1	1	4	33	24
838	1-206394	1-4038.77	5	4	2	32	76	20
839	1-206394	1-4038.78	5	4	2	32	76	20

- aparición de fisuras en las zonas laterales del túnel (Spring-line)

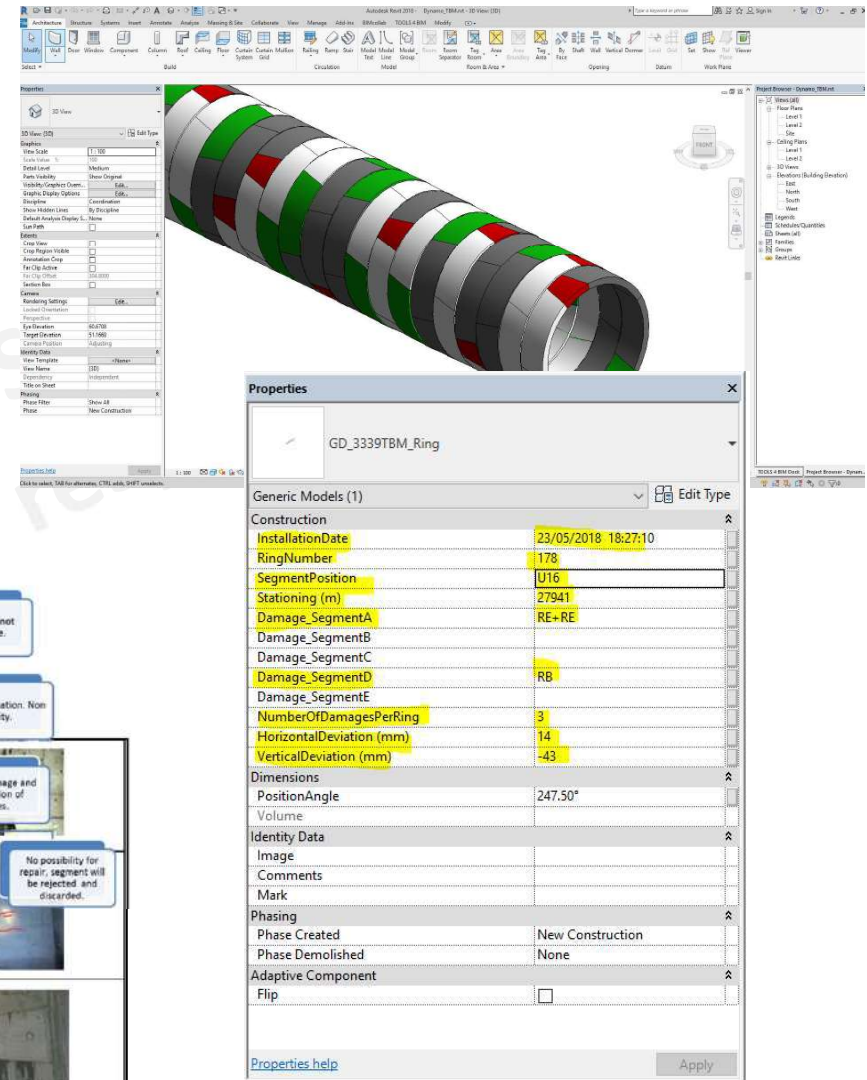


2. ruptura de la junta radial en la corona del túnel



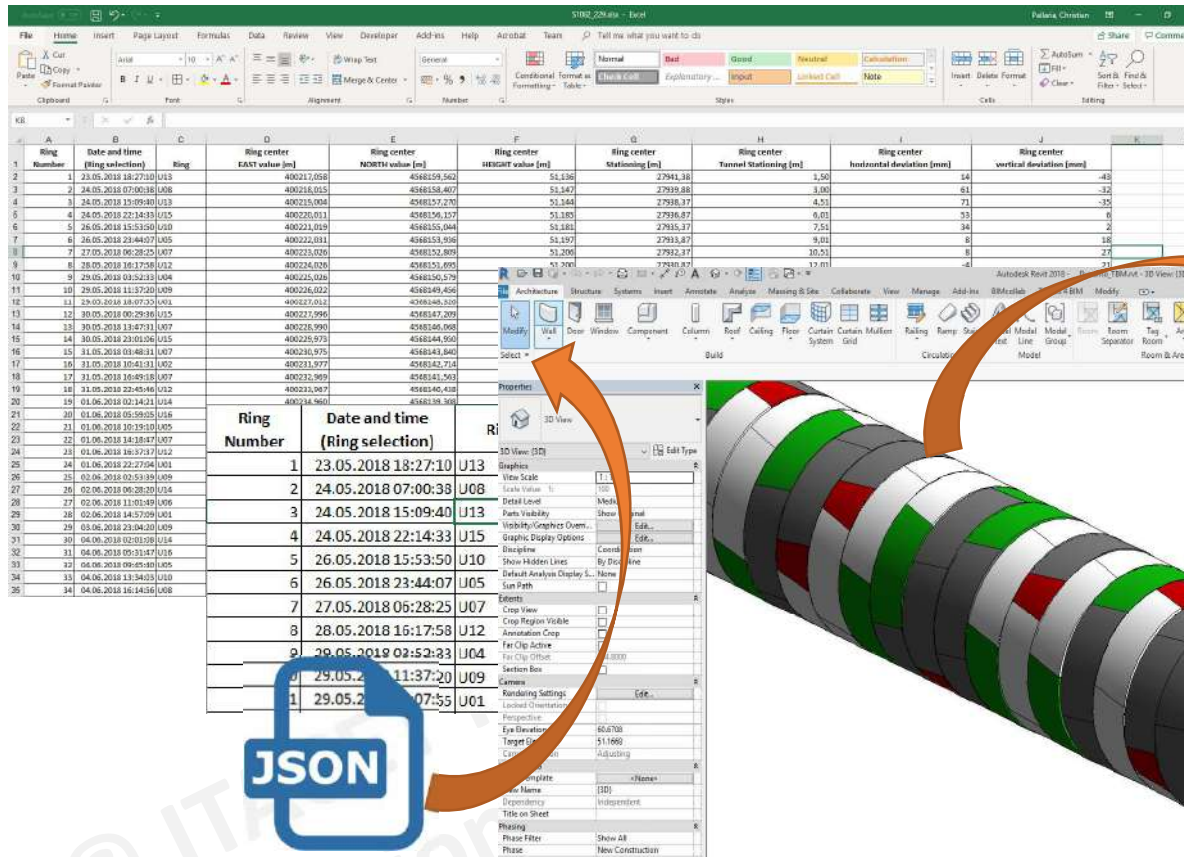
WATER TANK	13	WATER LEAKAGE FROM GASKET AND BOLT HOLES	 Reason of damage and determination of measures.
	14	CRACK IN LONGITUDINAL DIRECTION	 Repair and reintegration of the segment No possibility for repair, segment will be rejected and discarded.
STRUCTURAL	15	CRACK IN CIRCUMFERENTIAL DIRECTION	

With BIM



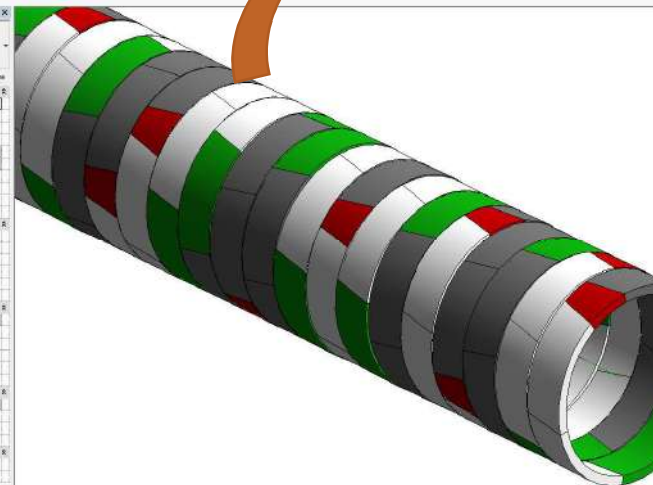
Construction stage

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



Ring Number	Date and time (Ring selection)	Ring selection	Ring center EAST value [m]	Ring center NORTH value [m]	Ring center HEIGHT value [m]	Ring center Stationing [m]	Tunnel Stationing [m]	Horizontal deviation [mm]	Vertical deviation [mm]
1	23.05.2018 18:27:10	U13	400217.058	4588159.562	51.136	27941.38	1.50	14	-43
2	24.05.2018 07:00:38	U08	400218.015	4588158.407	51.147	27939.88	3.00	61	-32
3	24.05.2018 13:09:20	U13	400215.004	4588157.770	51.144	27938.77	4.51	71	-35
4	24.05.2018 22:14:33	U15	400220.011	4588156.157	51.180	27936.87	6.01	53	8
5	26.05.2018 15:53:50	U10	400221.019	4588155.044	51.181	27935.37	7.51	34	2
6	26.05.2018 23:44:07	U05	400222.031	4588153.936	51.197	27933.87	9.01	8	18
7	27.05.2018 05:28:25	U07	400221.020	4588152.809	51.200	27932.37	10.51	8	27
8	28.05.2018 16:17:58	U12	400224.010	4588151.695	51.200	27930.87	12.01	8	31
9	29.05.2018 02:52:33	U04	400225.028	4588150.579	51.200	27929.37	13.51	8	35
10	29.05.2018 11:37:20	U09	400226.022	4588149.464	51.200	27927.87	15.01	8	39
11	29.05.2018 18:27:10	U13	400227.012	4588148.350	51.200	27926.37	16.51	8	43
12	30.05.2018 00:29:16	U15	400227.996	4588147.236	51.200	27924.87	18.01	8	47
13	30.05.2018 13:47:31	U07	400228.990	4588146.122	51.200	27923.37	19.51	8	51
14	30.05.2018 23:01:26	U15	400229.973	4588145.008	51.200	27921.87	21.01	8	55
15	31.05.2018 03:48:31	U07	400230.975	4588143.894	51.200	27920.37	22.51	8	59
16	31.05.2018 10:41:31	U07	400231.977	4588142.780	51.200	27918.87	24.01	8	63
17	31.05.2018 16:49:18	U07	400232.979	4588141.666	51.200	27917.37	25.51	8	67
18	31.05.2018 22:45:46	U12	400233.981	4588140.552	51.200	27915.87	27.01	8	71
19	01.06.2018 02:14:11	U14	400234.983	4588139.438	51.200	27914.37	28.51	8	75
20	01.06.2018 09:59:25	U16	400235.985	4588138.324	51.200	27912.87	30.01	8	79
21	01.06.2018 16:17:58	U12	400236.987	4588137.210	51.200	27911.37	31.51	8	83
22	01.06.2018 23:01:26	U15	400237.989	4588136.096	51.200	27909.87	33.01	8	87
23	02.06.2018 03:48:31	U07	400238.991	4588134.982	51.200	27908.37	34.51	8	91
24	02.06.2018 10:41:31	U07	400239.993	4588133.868	51.200	27906.87	36.01	8	95
25	02.06.2018 16:49:18	U07	400240.995	4588132.754	51.200	27905.37	37.51	8	99
26	02.06.2018 23:01:26	U15	400241.997	4588131.640	51.200	27903.87	39.01	8	103
27	03.06.2018 03:48:31	U07	400242.999	4588130.526	51.200	27902.37	40.51	8	107
28	03.06.2018 10:41:31	U07	400243.001	4588129.412	51.200	27900.87	42.01	8	111
29	03.06.2018 16:49:18	U07	400244.003	4588128.298	51.200	27899.37	43.51	8	115
30	03.06.2018 23:01:26	U15	400245.005	4588127.184	51.200	27897.87	45.01	8	119
31	04.06.2018 03:48:31	U07	400246.007	4588126.070	51.200	27896.37	46.51	8	123
32	04.06.2018 10:41:31	U07	400247.009	4588124.956	51.200	27894.87	48.01	8	127
33	04.06.2018 16:49:18	U07	400248.011	4588123.842	51.200	27893.37	49.51	8	131
34	04.06.2018 23:01:26	U15	400249.013	4588122.728	51.200	27891.87	51.01	8	135
35	04.06.2018 03:48:31	U07	400250.015	4588121.614	51.200	27890.37	52.51	8	139

Dynamo

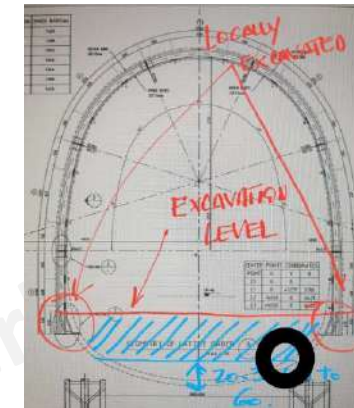
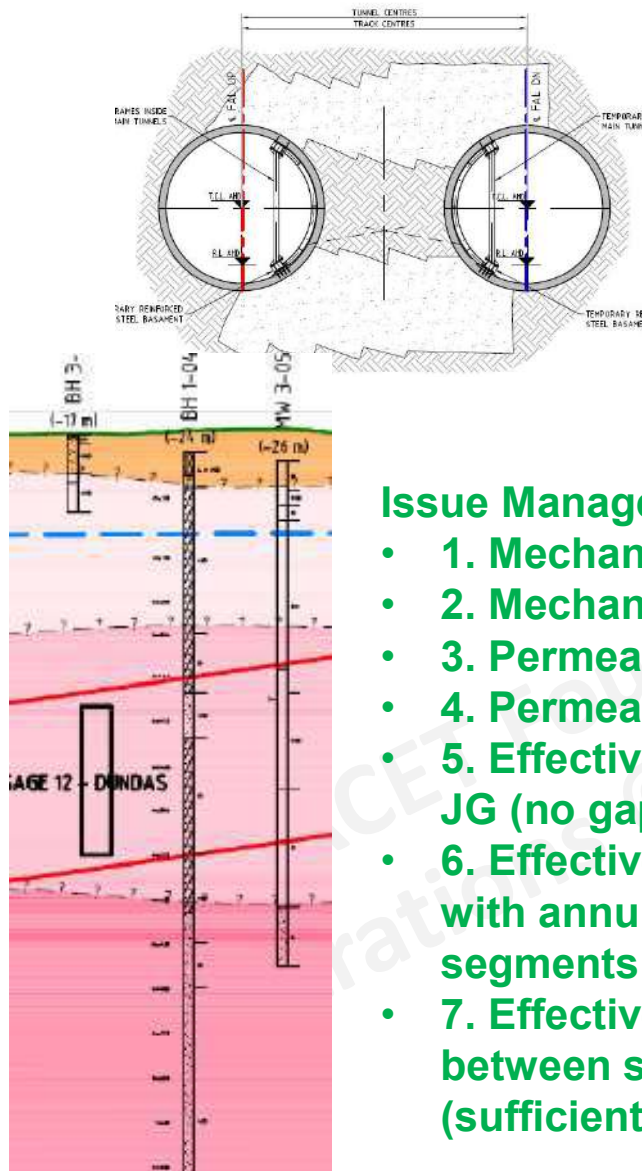


Properties	
GD_3339TBM_Ring	
Generic Models (1)	
Construction	
InstallationDate	23/05/2018 18:27:10
RingNumber	178
SegmentPosition	U16
Stationing (m)	27941
Damage_SegmentA	RE+RE
Damage_SegmentB	
Damage_SegmentC	
Damage_SegmentD	RB
Damage_SegmentE	
NumberOfDamagesPerRing	3
HorizontalDeviation (mm)	14
VerticalDeviation (mm)	-43
Dimensions	
PositionAngle	247.50°
Volume	
Identity Data	
Image	
Comments	
Mark	
Phasing	
Phase Created	New Construction
Phase Demolished	None
Adaptive Component	
Flip	☐

Ring data: damages and comments

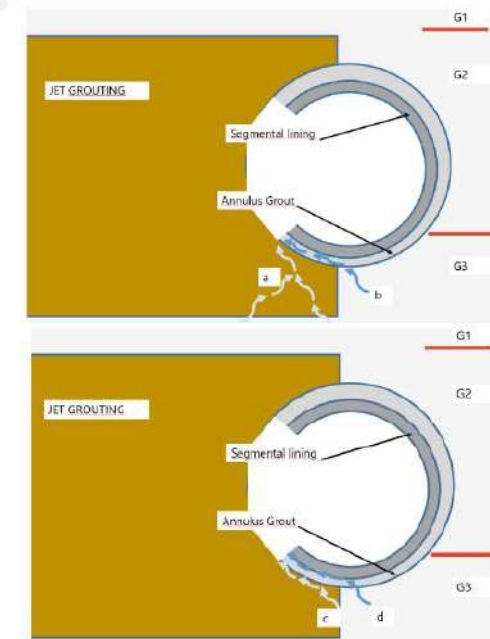
Ring Name	Damage Segment A	Damage Segment B	Damage Segment C	Damage Segment D	Damage Segment E	Ring Comments
1	RC		LC		CE	Verify usage
2						
4						
5		damage B test			damage E test	Prova commento su ring numero 5

Issue Management and back-analyses

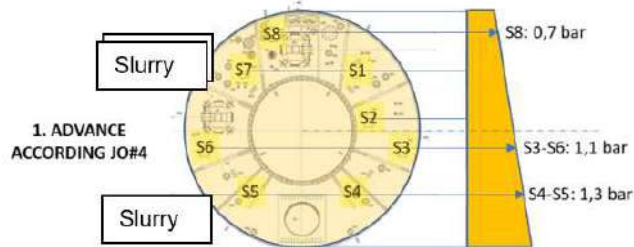
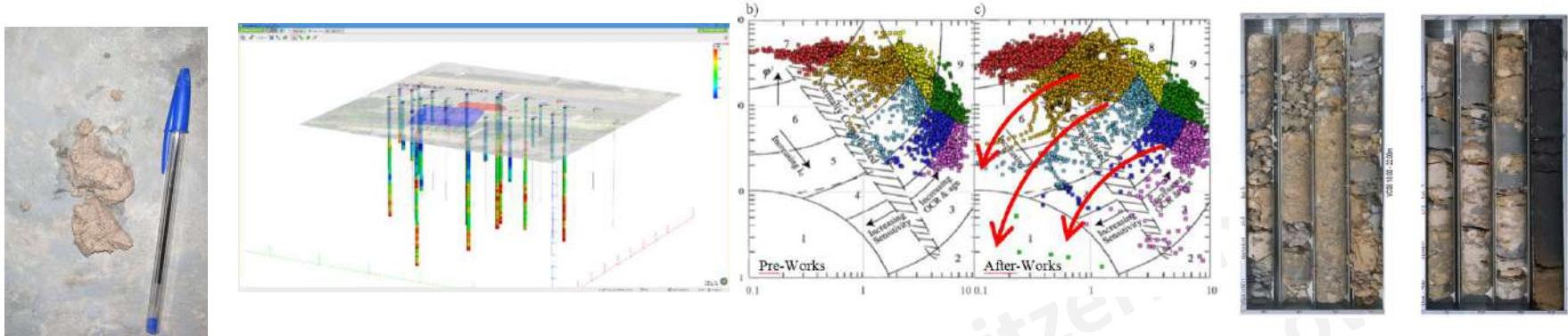


Issue Management – Potential Causes:

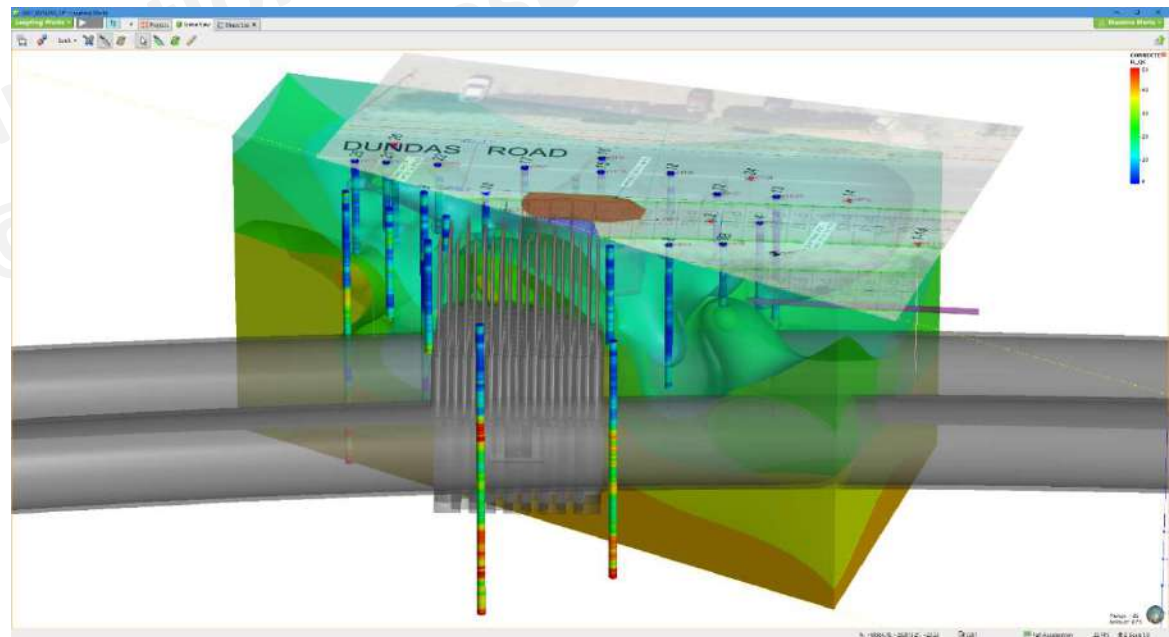
- 1. Mechanical strength of treated soil;
- 2. Mechanical strength of annulus soil;
- 3. Permeability of treated ground;
- 4. Permeability of annulus grout;
- 5. Effective complete treatment of soil with JG (no gaps between JG columns);
- 6. Effective complete grouting of interface with annulus grout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



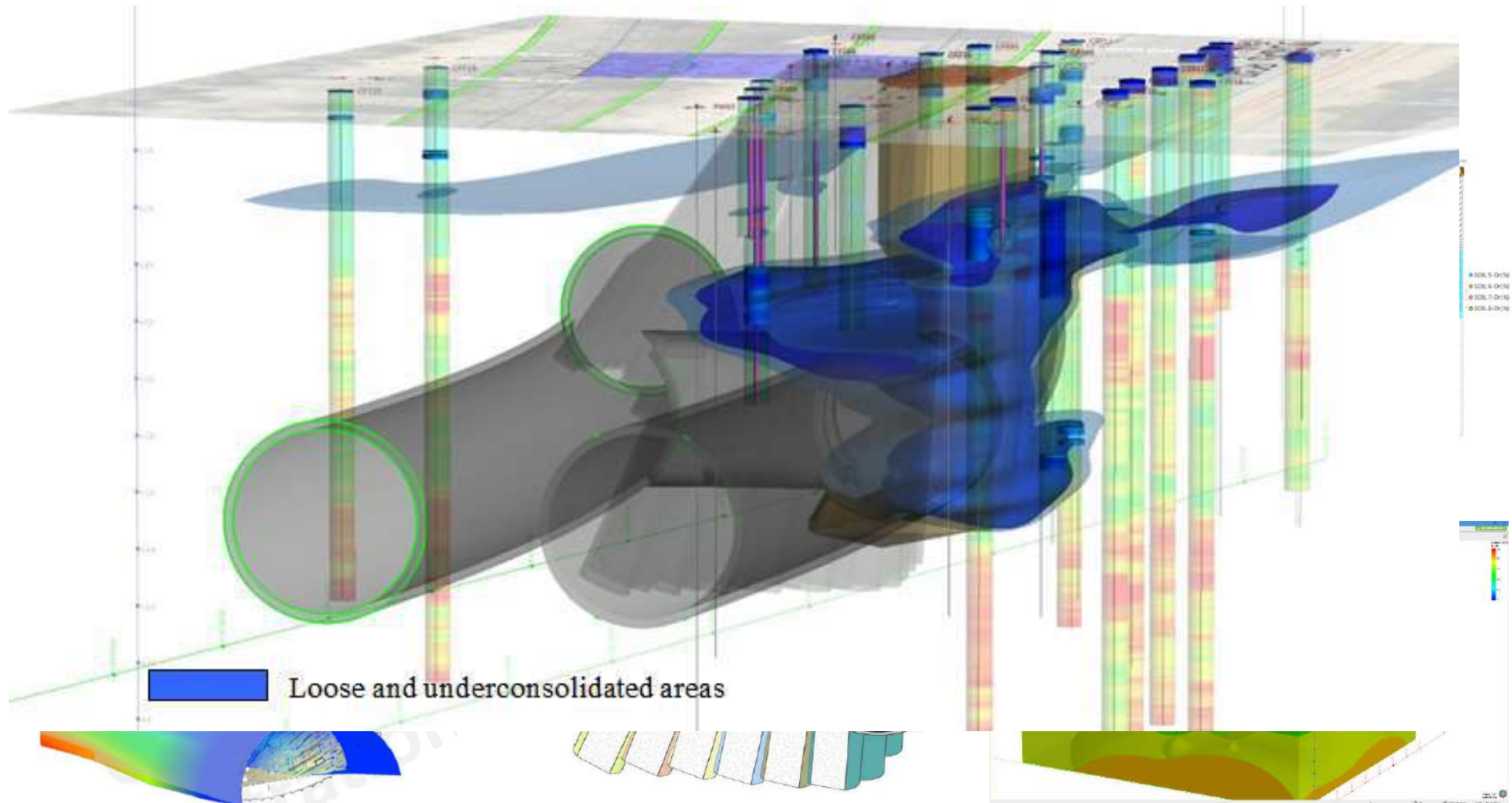
Issue Management and back-analyses



Updating of the model after the excavation of the two TBMs



Issue Management and back-analyses

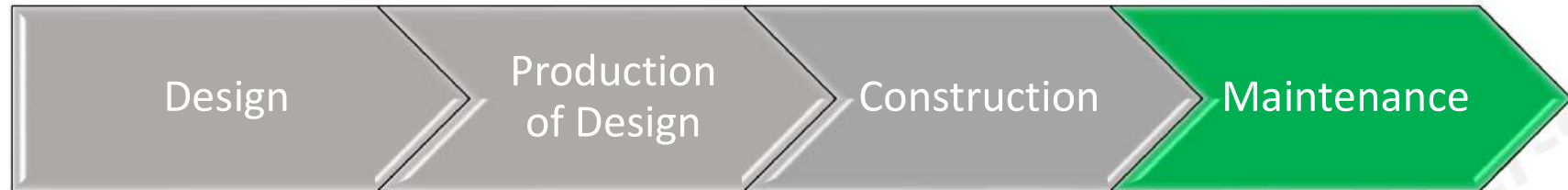


FDM/FEM Models

BIM Model

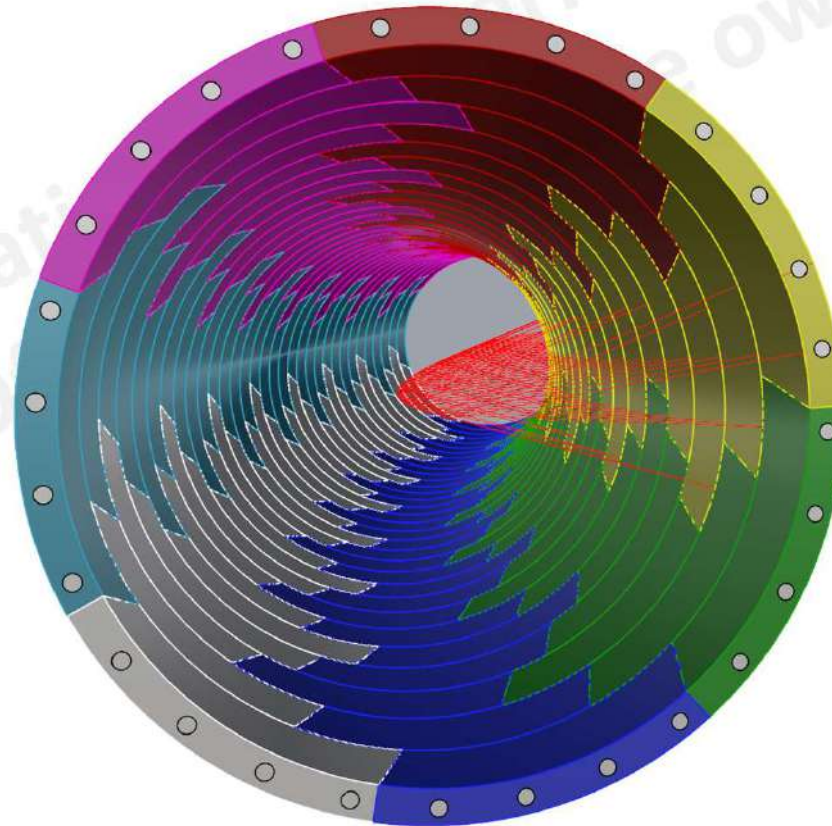
Geological Models

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



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

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



Traceability for Maintenance



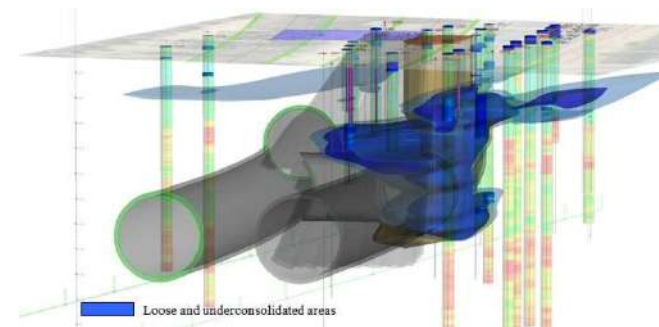
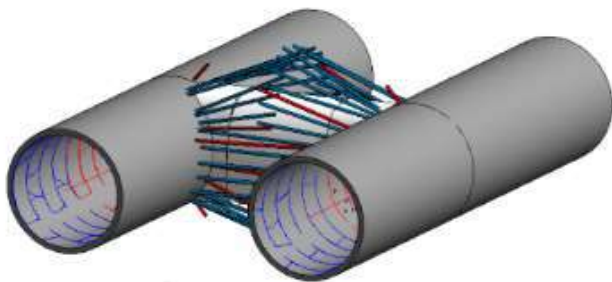
BIM and Mechanized tunneling

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, Python, 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

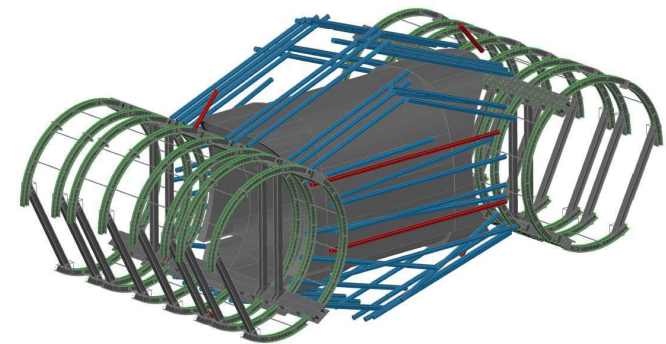
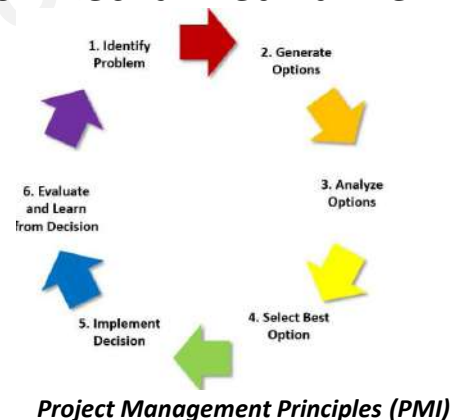
- BIM reduces human errors during **design** of the structural components (Universal ring, Alignment, Segments and connection system, Cross-passages and its components, Clash detection etc.)
- BIM is a driving force to the **requirement compliance** (Laws and regulations, Conditions)
- BIM helps on **construction 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

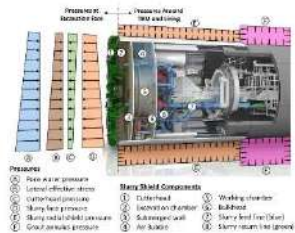
- BIM facilitates the **accessibility to a great amount of data** (control parameters, monitoring during the advance of the TBM, monitoring on the structures on the surface etc..) BIM can organize the amount of data to use in the same project (prediction during the advance) or in other similar project (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)



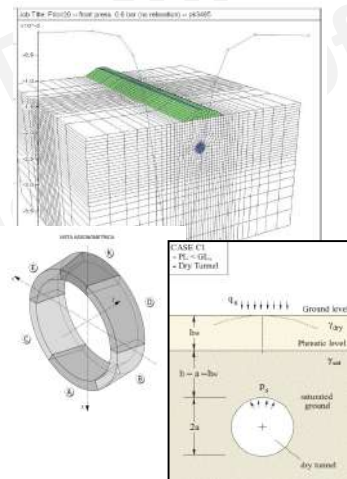
Conclusions

Descrizione		Livello di Rischio Iniziale (Valutazione)										Rischio Residuo												
CATEGORIA	Ambito Hazard	Probabilità (Frequenza di occorrenza dell'Hazard) [P]	Impatto [I]			Rischio [R = P x I]						Probabilità (Frequenza di occorrenza dell'Hazard) [P]	Impatto [I]			Rischio [R = P x I]								
			Pericolo Economica	Ritardi	Salute e Sicurezza	Ambiente	Società	Pericolo Economica	Ritardi	Salute e Sicurezza	Ambiente	Società		Pericolo Economica	Ritardi	Salute e Sicurezza	Ambiente	Società	Pericolo Economica	Ritardi	Salute e Sicurezza	Ambiente	Società	
1.0.	Ubicazione																							
	Tunnel TBM - Scavo																							
§.5.1	Sovranziel - Mancato controllo del Volume perso e conseguenti subsidenze.																							
§.5.2	Mancanza di pressione sul fronte della galleria, che porta a cedimenti o cedimenti differenziali	5	2	2	3	2	3	10	10					3	2	2	1	2	3	6	6	2	6	9
§.5.3	Riempiimento anulare - Gruotigliamento inadeguato, che porta a cedimenti o cedimenti differenziali, o problemi di durabilità	5	2	2	3	2	3	10	10					3	2	2	1	2	3	6	6	2	6	9
§.5.4	Separazione dello slurry in impianto non adeguato	4	2	2	2	2	2	8	8	8	8	8	8	3	2	2	2	2	3	6	6	2	6	9
§.5.5	Frac-out durante il riempimento anulare - Pressione eccessiva causa sollevamento terreno	3	2	1	1	3	3	6	3	3	9	9	9	3	2	1	1	3	3	6	3	3	3	9
§.5.6	Frac-out durante lo scavo - Perdita di fluido lubrificante e/o acqua - Interventi	3	2	2	1	3	3	6	6	3	9	9	9	3	2	2	1	3	3	6	3	3	3	9
§.5.7	Mancanza di affidabilità della guida TBM	3	2	2	1	1	2	6	6	3	6	3	6	3	2	2	1	1	2	6	2	1	1	2
§.5.8	Montaggio rivestimento inadeguato	5	2	3	1	1	2	10						3	2	3	1	1	2	6	9	3	3	6

MULTI-CRITERIA ANALYSES



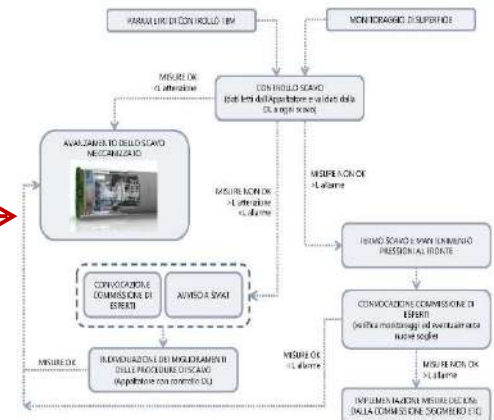
SENSITIVITY ANALYSES



BIM



MONITORING AND CONTROL PROCEDURES PLAN OF ADVANCE OF TBM



THANK YOU
FOR YOUR
KIND ATTENTION



Useful papers/books on this topic:

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-
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-
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Tunnelling 4.0: New technologies and automation

24 September 2019 – Buenos Aires, Argentina

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