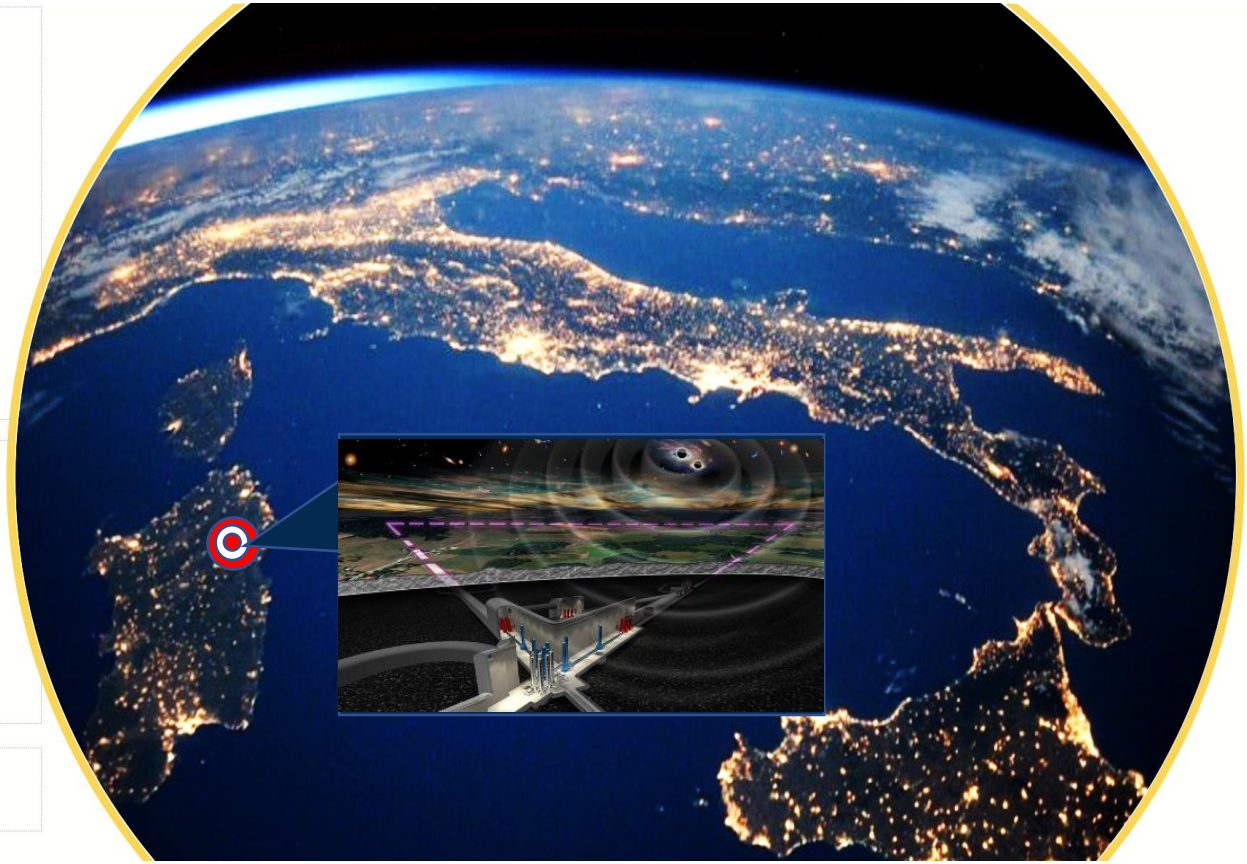
Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INFN

4th ET Annual Meeting,

Nov, 11-14, 2025, Opatjia, Croatia

Developing a Comprehensive Digital Framework for Sustainable ET Design: A Prototype for the Sardinia site

ETIC WP6 – Sustainable Design



M. Cagnizi, P. J. V. D'Aranno, F. Ferranti, M. Marzario, Q. Napoleoni, G. Sappa, F. Scipione, M. Marsella (DICEA, Sapienza, University of Rome); W. Wahbeh (FHNW)

ET Specificity and Challenges

Aspect	Specificity of ET	Critical Challenges
Infrastructure configurations	Two options: triangular (3 arms, 10 km) or L-shaped layout (15 km arms)	Selecting the optimal layout based on scientific, technical, and organizational constraints
Instrumentation	Xylophone setup: two interferometers per arm; low-frequency (cryogenic) + high-frequency (high-power lasers)	Managing the optimal positioning cryogenics, thermal stability, and vacuum systems
Optimal positioning	Location of tunnels and caverns within the site	Balancing geological suitability, construction feasibility, environmental constraints, and noise minimization
Scale & Engineering	Tens of kilometers of underground tunnels and ultra-high-vacuum systems	Excavation complexity, structural stability, and costs
Collaboration	Large-scale European project involving multiple countries	Governance, resource coordination, and long-term funding

Beyond isolated models — toward a methodological framework

Establish a flexible and evolving foundation for Digital Twin development

Progressive and federated integration of heterogeneous data

Involve multiple domains from spatial and engineering data sources that evolve progressively and asynchronously

Roadmap toward a full lifecycle twin

Define a roadmap for scalability and continuity evolving from design to operation

Flexible platform for sustainable ET development

Benefits of DDT

Unified Decision Environment

Integrates BIM, GIS, and simulations for consistent scenario evaluation

Early Risk Reduction

Identifies clashes, geotechnical risks, and system conflicts before construction

Cross-Disciplinary Coordination

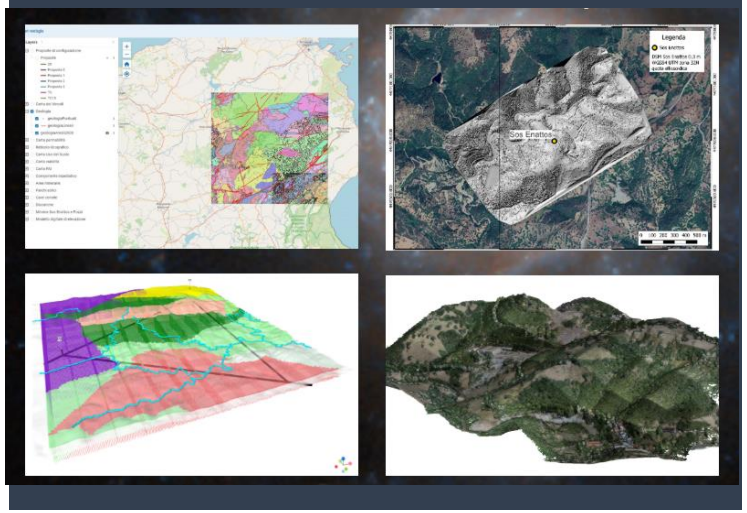
Structured collaboration across engineering, geology, and physics teams

Lifecycle Intelligence

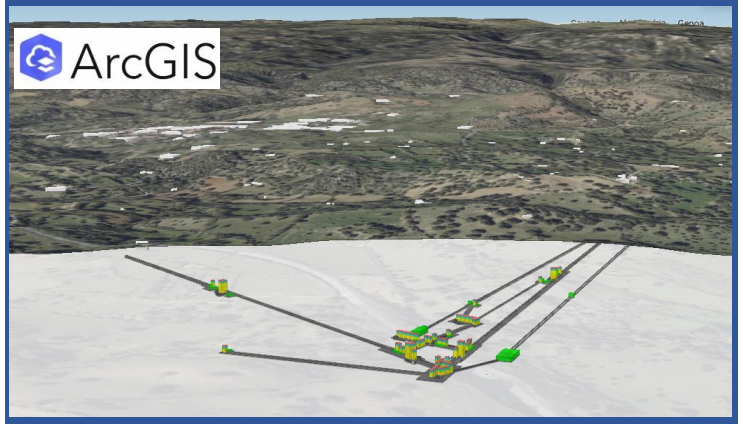
Foundation for construction → operation → predictive performance monitoring

Architecture Overview

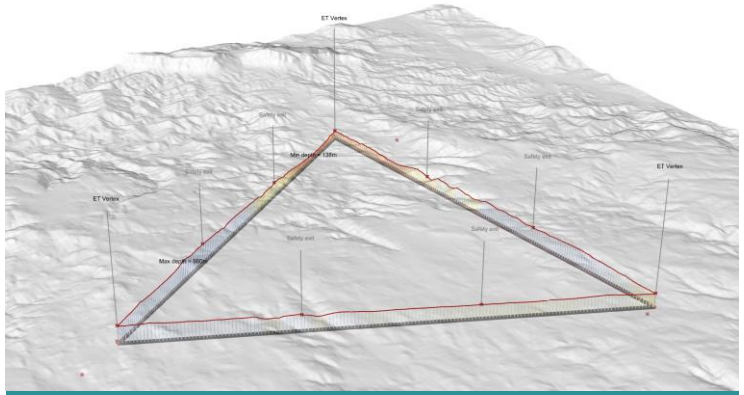
Data



Work Environments

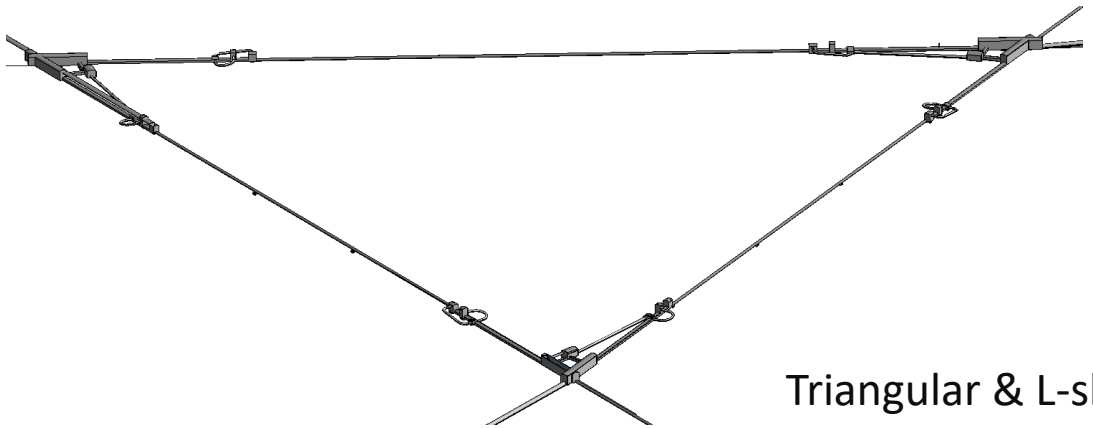


Analysis and simulation

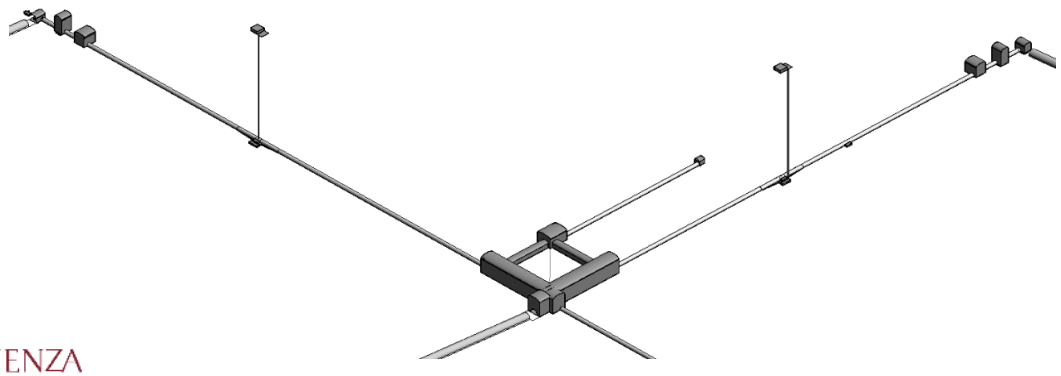


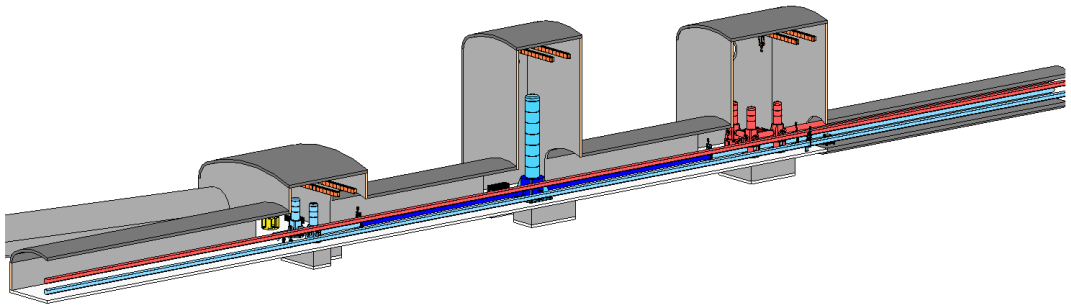
Data - BIM models (LOD ~100–200)

- Focus on main geometries
- Support early spatial reasoning



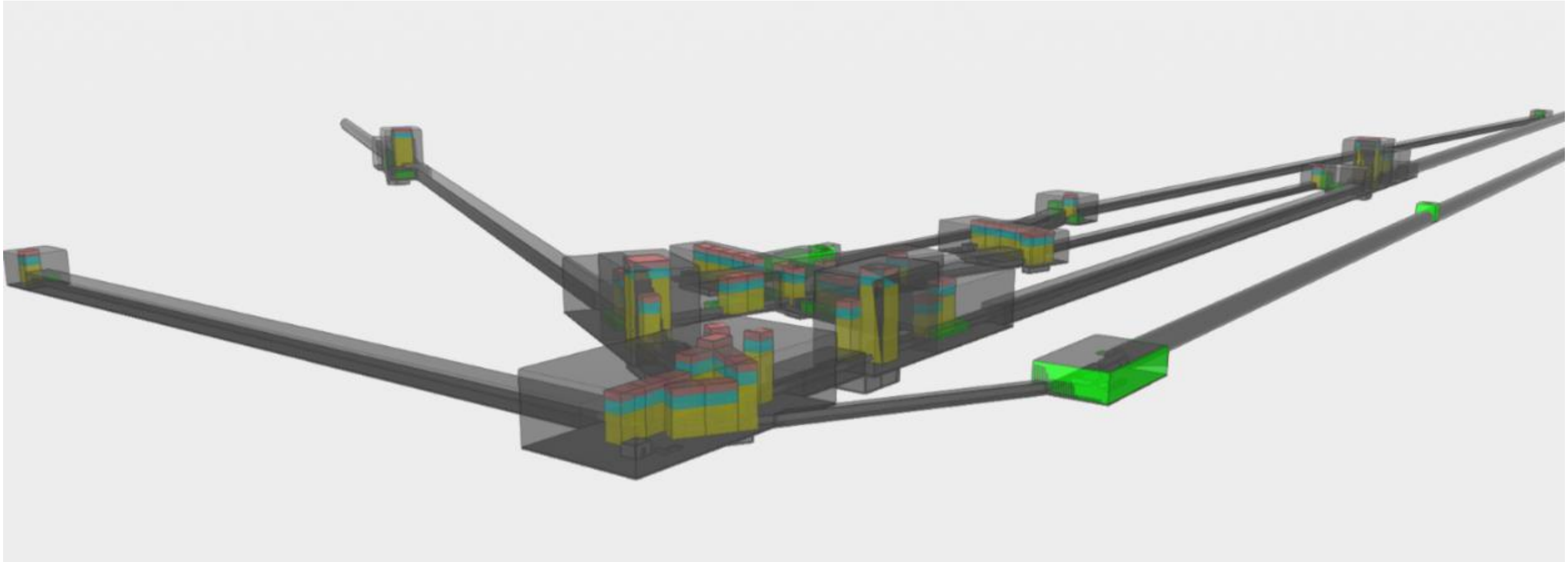
Triangular & L-shaped configurations





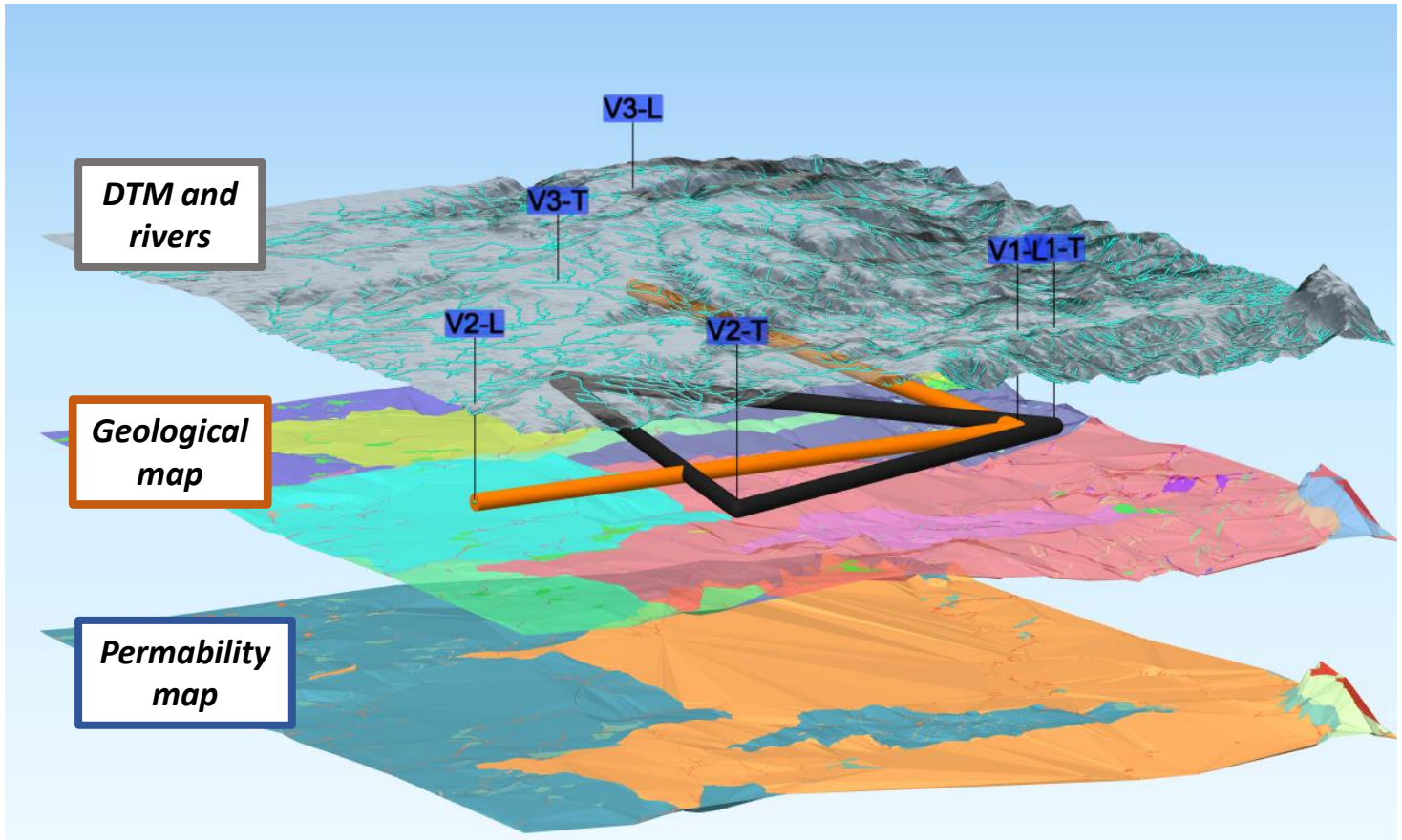
Tunnel & cavern volumes

Data - BIM models – Preliminary layout



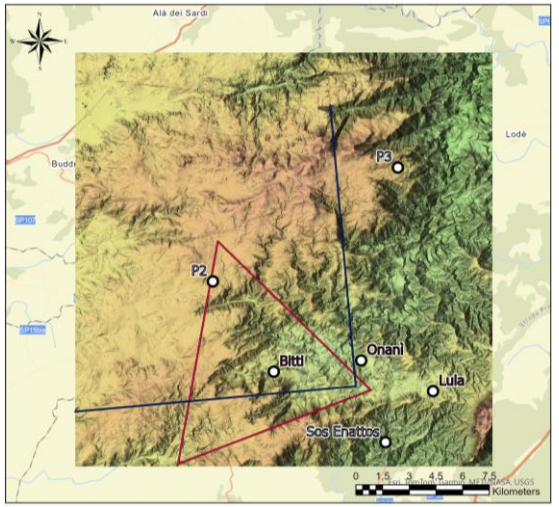
https://web.connect.trimble.com/projects/bgr1skWvm0U/viewer/3d/?modelId=QNb2MUCPiA8,ajUpeNC21Qk&=&origin=app21.connect.trimble.com&stoken=2WLZXPanBTpixPBDvoI6sH-zXipiZ4udqH5_sjqhgmuKdXt-S1nt7iNXV9Pk-0XZ)

Data – GIS layers

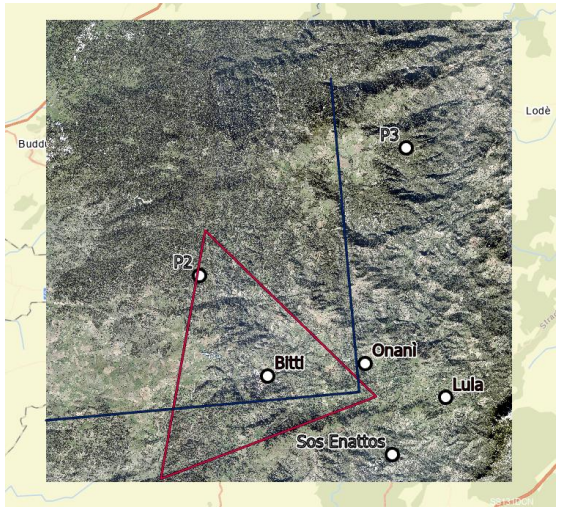


DIGITAL MAPS
institutional geoportals

DTM – Airborne Lidar Survey



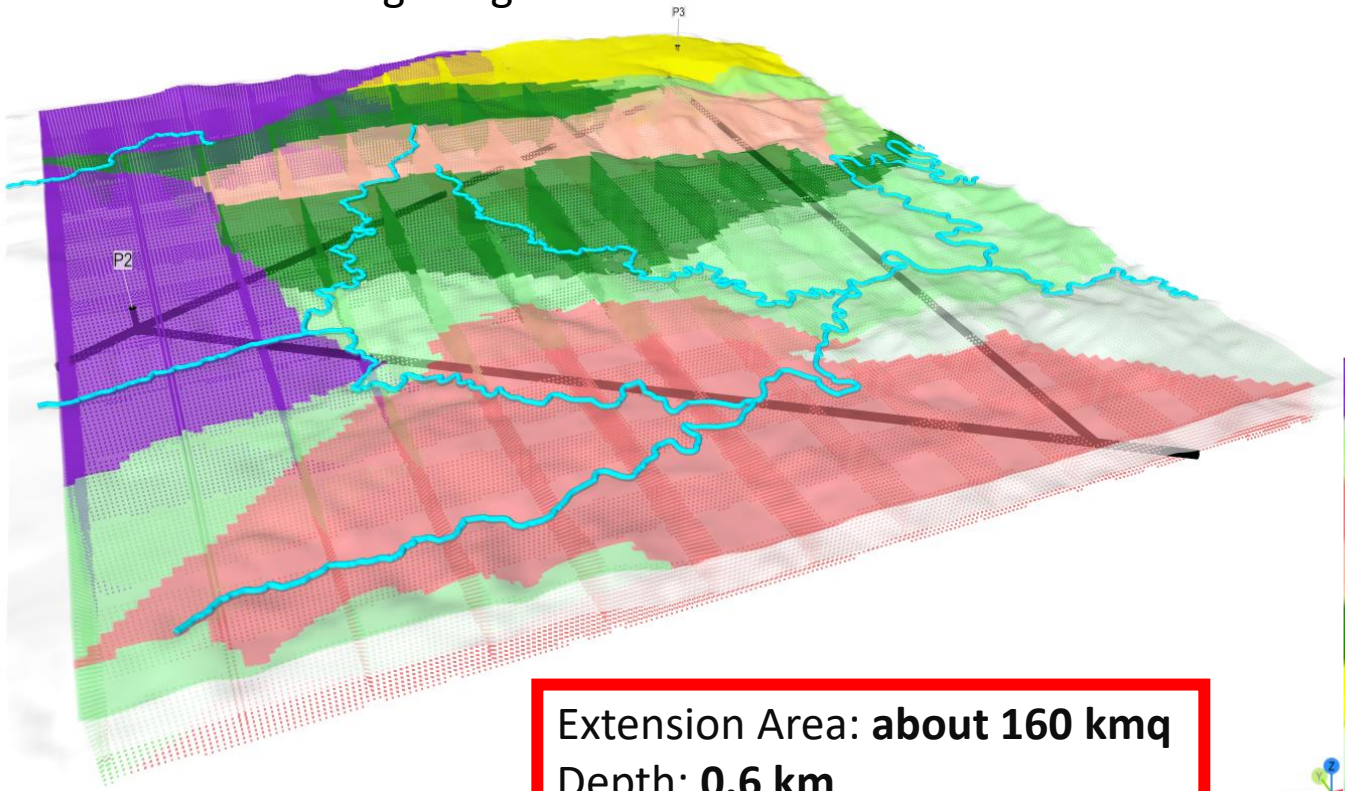
ORTHOPHOTO - Airborne survey



Robust basis for spatial and environmental analysis

Data - Geological Model V.1

- Based on available geological and geophysical data
- Main subsurface geological trends and associated rock volumes



Extension Area: **about 160 kmq**
Depth: **0.6 km**

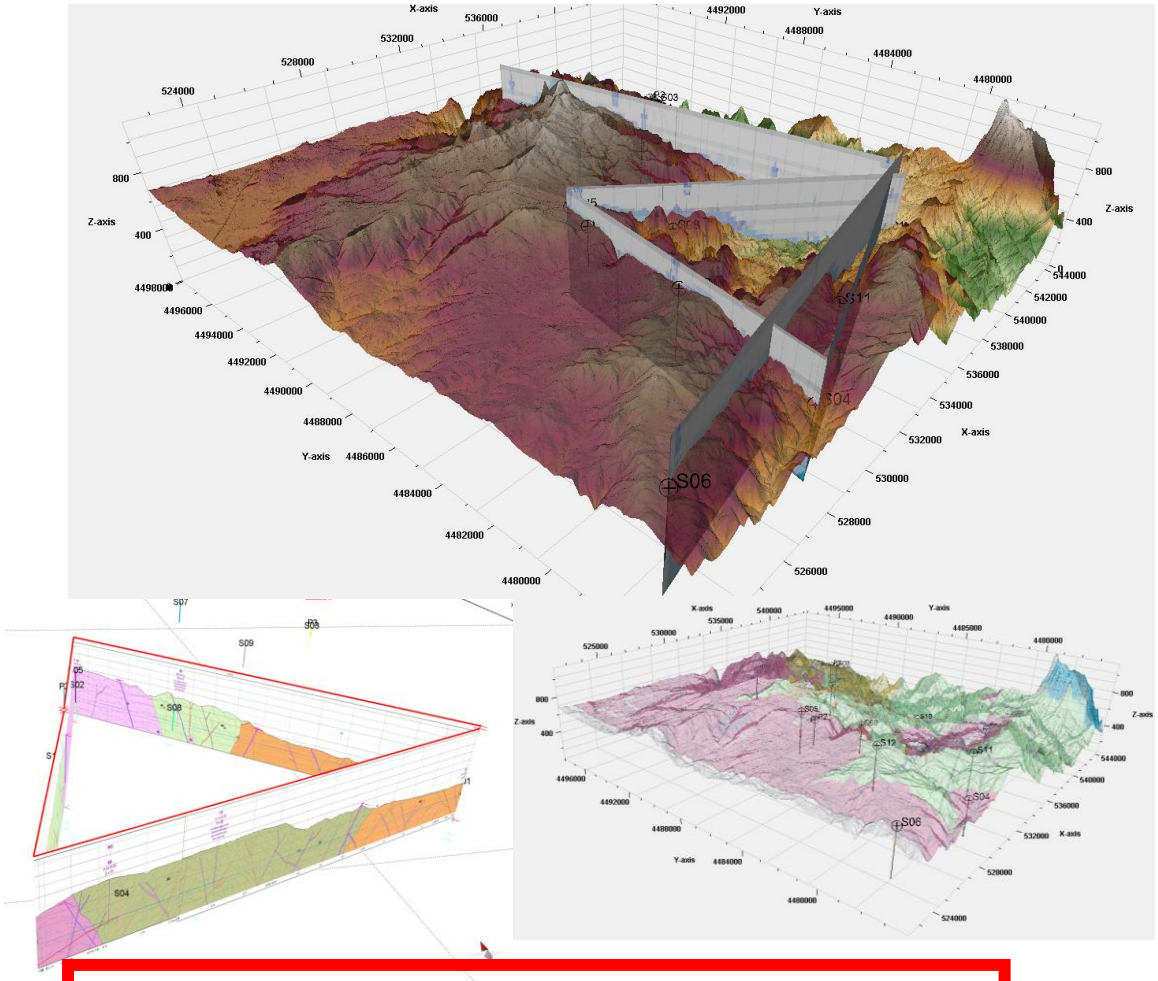
Objectives of the model

- Subsurface reconstruction (lithology, structures, hydrogeology)
- Integrated surface–subsurface understanding
- Geotechnical risk reduction & construction planning
- Scenario-based design for sustainable site development

Mixed grained Leucogranite (Permian)
MS0 - Oligoclase and gametmicaschist and paragneiss (pre-Cambrian/early Ordovician)
Onani-Bitti granodiorite (Permian)
OGA - Augengneiss (middle Ordovician)
MSS Staurolite and gamet paragneiss and micaschist (pre-Cambian/early Ordovician)
MAM - Mamone granodiorite orthogneiss (pre-Cambrian7early Ordovician)
MSA - albite and gamet micaschist and paragneiss (pre-Cambrian7aerly Ordovician)
OGG - Fine grained orthogneiss with mica (middle Ordovician)

Construction of a preliminary geological and geotechnical 3D model of the subsurface of the ET study area in Sardinia
L. Lipparini - 2022/2023

Data - Geological Model V.2 (to be finalized by the end 2025)



Extension Area: **about 450 kmq -** Depth: **1 km**

Geological data

Geological maps, field surveys, and sample analyses
Rock fracture studies for 3D model characterization

Geotechnical data

Boreholes (11 deep weels), coring results, and in-situ/laboratory geotechnical tests - 224 laboratory tests on undisturbed soil samples and more than 100 permeability, dilatometric and fracturing tests.

Geodetic and Geophysical data

LiDAR acquisitions (airborne & UAV)
Gravimetric, magnetometric, and seismic surveys

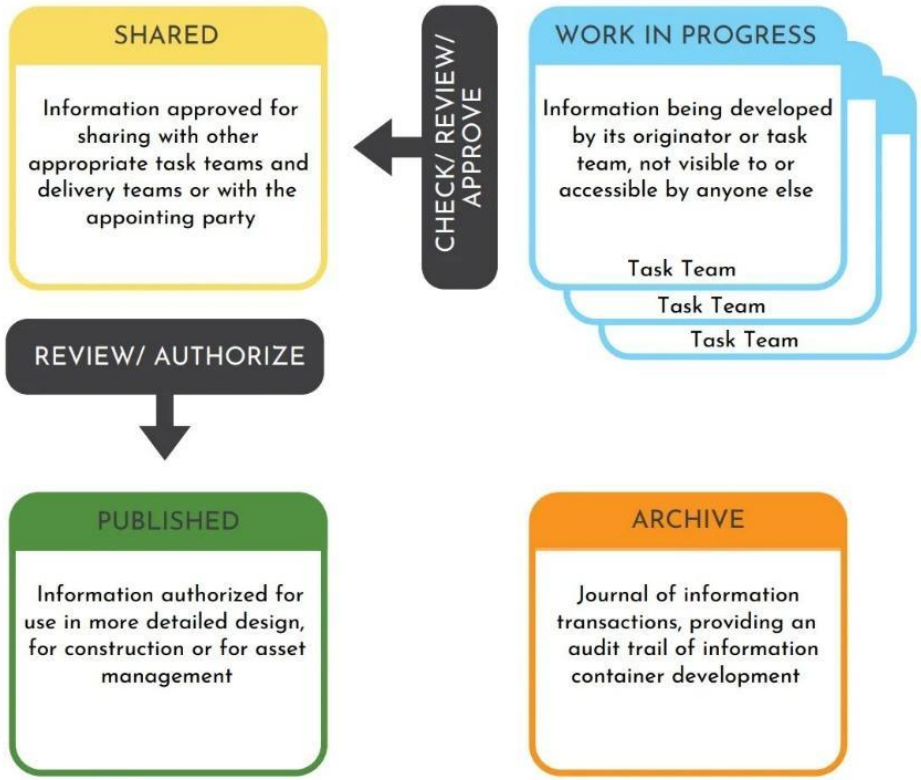
Hydrogeological data

Groundwater studies and hydrogeological models of the area
Reference material
Updated bibliography and technical documentation

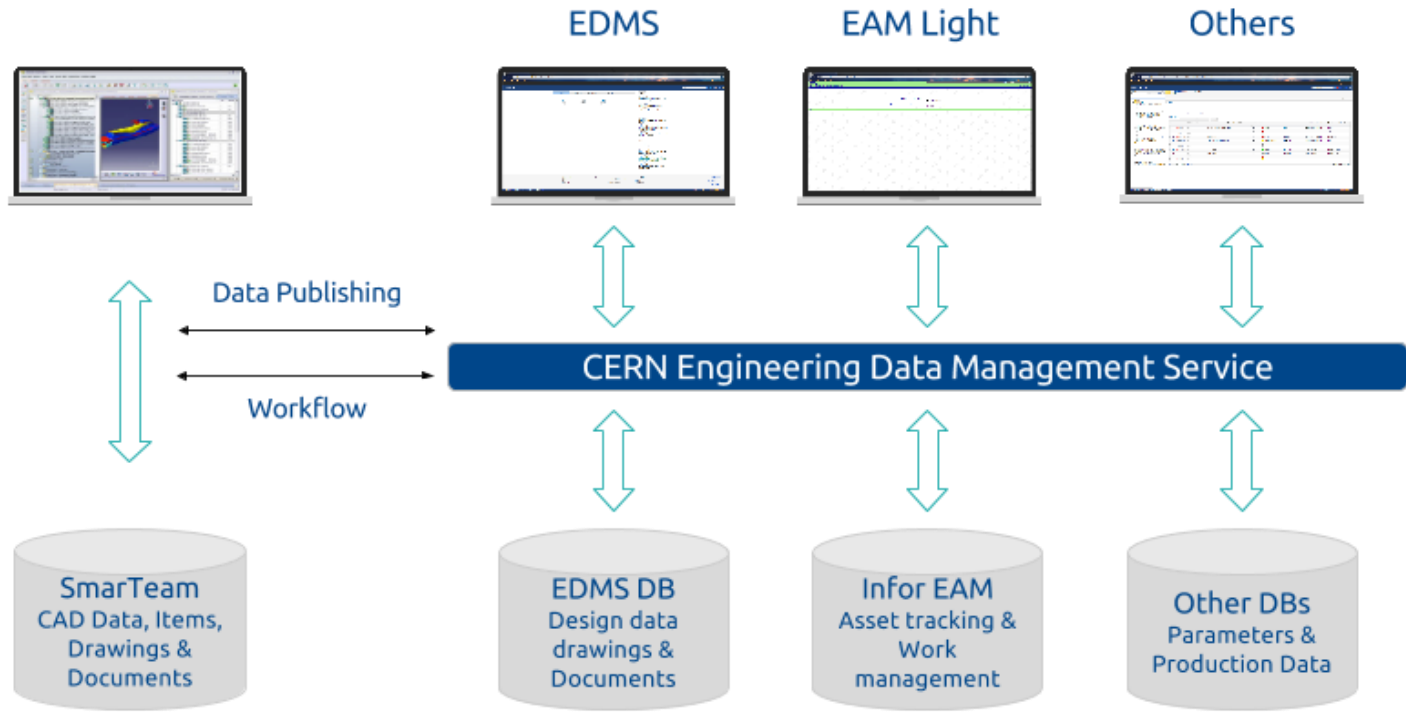
Work environments - BIM-GIS Integration Platform

Work environments - **CDE Platform**

Structured workspace where information is stored, versioned, validated, and shared across teams



ISO 19650 - Common Data Environment Workflow



CERN's EDMS System Overview

Analysis and Simulations – Rule-based Validation

- Early conflict detection across disciplines
- Verification of spatial and technical interfaces
- Design consistency before construction
- Alignment with complex-facility practice

Supports aggregated model review and 4D schedule-linked clash checks

Offers rule-based validation, openBIM support, and BCF issue tracking

Analysis and Simulations - **Optimisation using multi criterial analysis**

Optimization criteria inputs

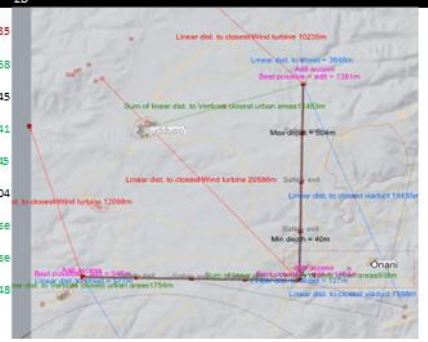
Criteria & optimising parameters

ID	Criteria	Aim	Optimisation	Constraints min	Constraints max	Weight
1	search limits					
1.1	Vertex V1 location X (East west)	Vertix 1 inside granit area		Bitti -1000	Bitti +8000	
1.2	Vertex V1 location Y (North south)	Vertix 1 inside granit area		Bitti -1000	Bitti +2000	
1.3	Vertex V1 Altitude			200	800	
1.4	Rotation (V1 as base point)			N(-10°)	N(+45°)	
2	SCIENTIFIC REQUIREMENTS					
2.1	No scientific requirments					
3	MORPHOLOGICAL AND TOPOGRAPHICAL CHARACTERISTICS					
3.1	Tunnel earth cover (Vertical)	Minimising the cover for the closest part of the tunnel to earth surface	Minimise dis.	40 M		7
3.2	Cavern earth cover (Vertical)	Minimising the cover for the closest vertix to earth surface	Minimise dis.	120 M		10
3.3	Cavern earth cover overall (Vertical)	Minimising the sum of vertical cover of the 3 Vertices	Minimise dis.			10
4	ENVIROMENTAL AND ADMINISTRATIVE COSTRAINTS					
4.1	Restricted areas	No 2D intersection	Avoid zone			
4.2	Existing roads	Close to the **vertices**	Minimise dis.			5
4.3	Viaducts	Min distance 3 km from vertices, try "The farer the better"	Maximise dis.	3		10
5	INSEDIATIVE AND ANTHOPIC INTERFERENCES					
5.1	Industrial Area Nuoro	Far from the **Vetices** (Out of GIS Radius)	Avoid zone	15 KM		10
5.2	Wind turbines Budduso'	Far from the **Vetices**	Maximise dis.	15 KM		10
5.3	Towns / populated zones	Close to the **vertices**	Minimise dis.			2
5.4	Industrial Area Sologo	Far from the **Vetices**	Maximise dis.			7
6	Geological Criteria					
6.1	Vertix 1 inside granit area					

Optimised positioning proposals

Results

Metrics	Location
Linear dist. to closest Wind turbine	10235
Linear dist. to closest viaduct	7558
Sum of linear dist. to Vertices closest urban areas	14145
Minimum depth of a vertix	141
Minimum depth from the terrain surface along the tunnel	45
Maximum depth from the terrain surface along the tunnel	504
Intersection with restricted areas?	False
Tunnel within 15km to Nuoro industrial zone?	False
Sum of the depth for all vertices	448

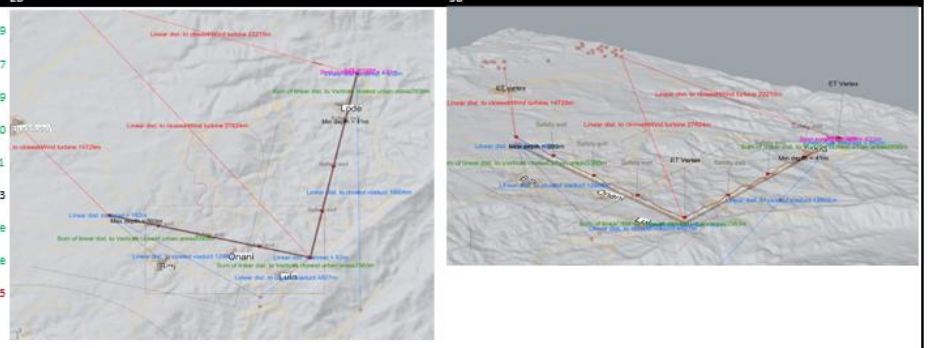


Criteria & optimising parameters

ID	Criteria	Aim	Optimisation	Constraints min	Constraints max	Weight
1	search limits					
1.1	Vertex V1 location X (East west)	Vertix 1 inside granit area		Bitti -1000	Bitti + 12000	
1.2	Vertex V1 location Y (North south)	Vertix 1 inside granit area		Bitti -2000	Bitti + 5000	
1.3	Vertex V1 Altitude			100	800	
1.4	Rotation (V1 as base point)			N(-45°)	N(+45°)	
2	SCIENTIFIC REQUIREMENTS					
2.1	No scientific requirments					
3	MORPHOLOGICAL AND TOPOGRAPHICAL CHARACTERISTICS					
3.1	Tunnel earth cover (Vertical)	Minimising the cover for the closest part of the tunnel to earth surface	Minimise dis.	40 M		7
3.2	Cavern earth cover (Vertical)	Minimising the cover for the closest vertix to earth surface	Minimise dis.	120 M		10
3.3	Cavern earth cover overall (Vertical)	Minimising the sum of vertical cover of the 3 Vertices	Minimise dis.			10
4	ENVIROMENTAL AND ADMINISTRATIVE COSTRAINTS					
4.1	Restricted areas	No 2D intersection	Avoid zone			
4.2	Existing roads	Close to the **vertices**	Minimise dis.			5
4.3	Viaducts	Min distance 3 km from vertices, try "The farer the better"	Maximise dis.			10
5	INSEDIATIVE AND ANTHOPIC INTERFERENCES					
5.1	Industrial Area Nuoro	Far from the **Vetices** (Out of GIS Radius)	Avoid zone	15 KM		10
5.2	Wind turbines Budduso'	Far from the **Vetices**	Maximise dis.	15 KM		10
5.3	Towns / populated zones	Close to the **vertices**	Minimise dis.			2
5.4	Industrial Area Sologo	Far from the **Vetices**	Maximise dis.			7
6	Geological Criteria					
6.1	Vertix 1 inside granit area					

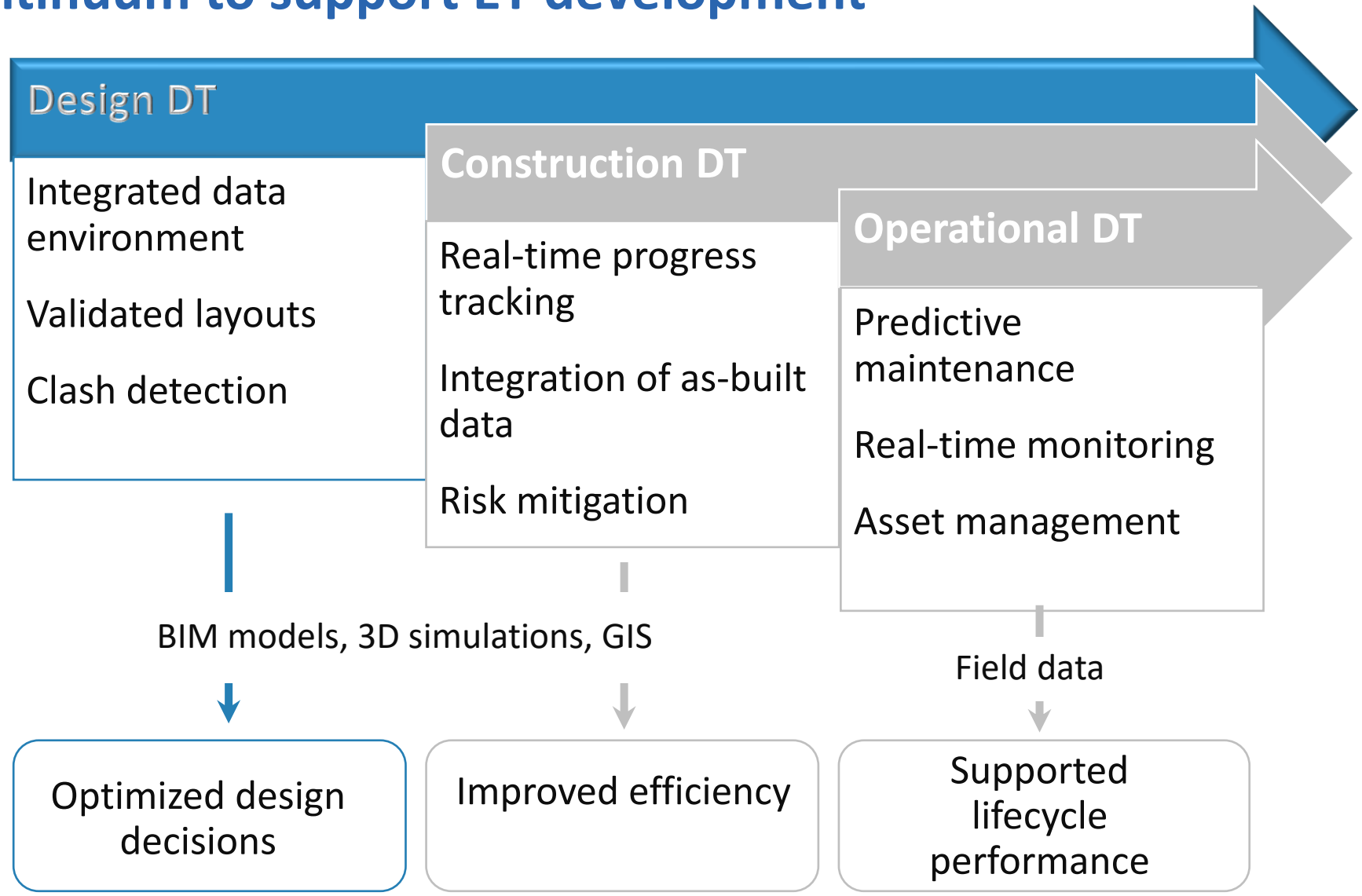
Results

Metrics	Location
Linear dist. to closest Wind turbine	14729
Linear dist. to closest viaduct	4827
Sum of linear dist. to Vertices closest urban areas	10759
Minimum depth of a vertix	140
Minimum depth from the terrain surface along the tunnel	41
Maximum depth from the terrain surface along the tunnel	593
Intersection with restricted areas?	False
Tunnel within 15km to Nuoro industrial zone?	False
Sum of the depth for all vertices	1105
V1 Out of Granit geological area	



Multicriteria Analysis Tool – W. Wahbeh 2022/2023

Digital continuum to support ET development



Finanziato dall'Unione europea NextGenerationEU

Piano Nazionale Ripresa e Resilienza
Missione 4 – Componente 2 – Investimento 3.1
Codice progetto: IR0000004

ET ITALY Einstein Telescope

ET – 3G Lab

ETIC
Einstein Telescope Infrastructure Consortium

Il laboratorio, dedicato alla ricerca avanzata nell'ambito dell'ingegneria civile e ambientale, sviluppa soluzioni progettuali ottimizzate e tecniche innovative per la realizzazione e gestione di opere civili."

INFN ROMA Istituto Nazionale di Fisica Nucleare Sezione di Roma
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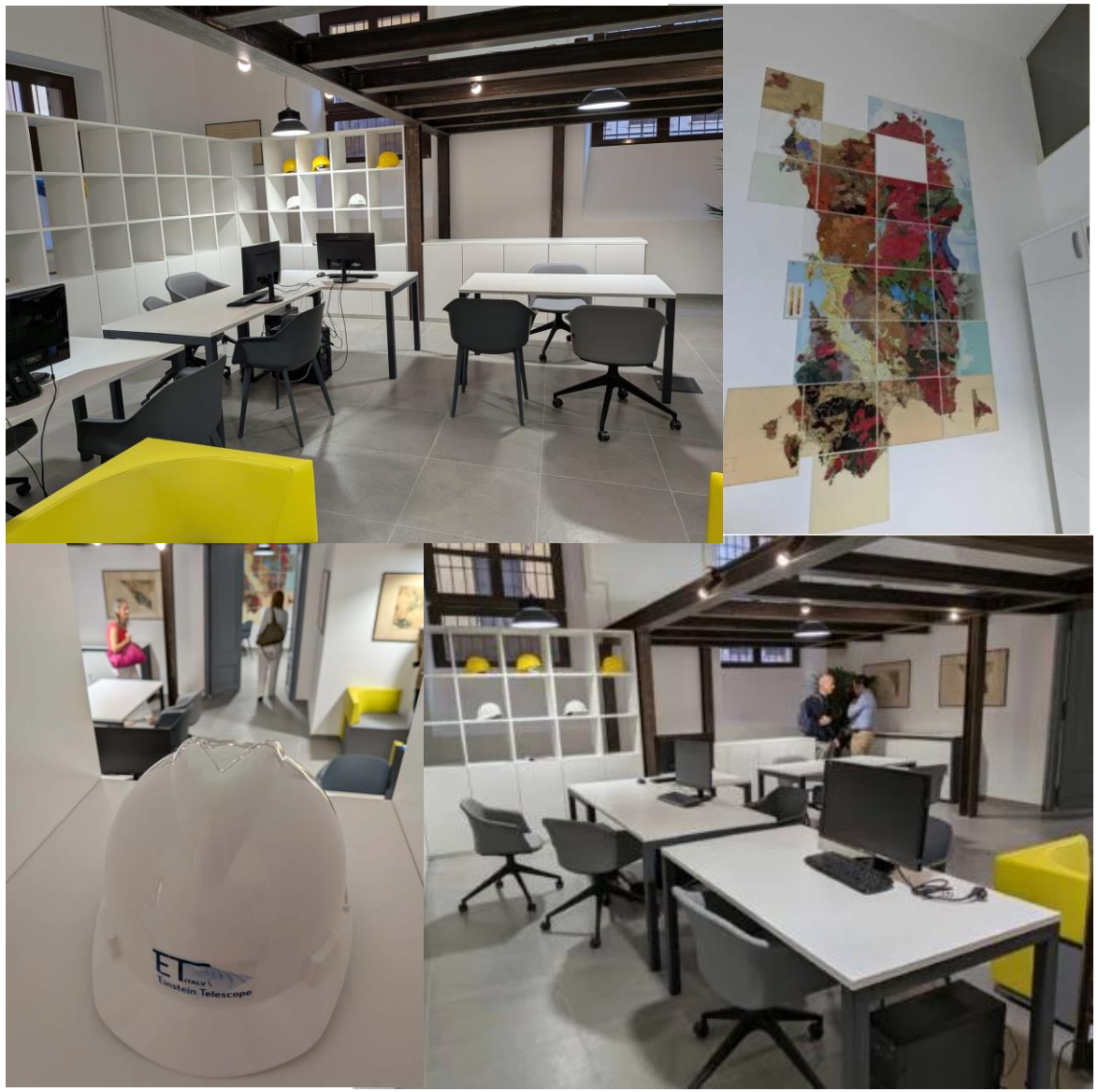

- Multidisciplinary laboratory focused on geomatics, geology, geotechnics, 3D modelling and digital workflows
- Support the design and construction phases of the ESFRI ET research infrastructure
- Cross-disciplinary collaboration (structures, aerospace, architecture) for joint research initiatives

Thank you for your attention