

# CIVIL AND ENVIRONMENTAL ENGINEERING

## InGeoLab Srl/DIATI - Digital Twin and OMA for the Integrated Monitoring of Infrastructures, Slopes and Natural Risks

<b>Funded By</b>	InGeoLab Srl [P.iva/CF:01209660073] Dipartimento DIATI
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<b>Context of the research activity</b>	<p>Development of an integrated methodology based on Digital Twin and Operational Modal Analysis (OMA) for continuous structural monitoring of critical infrastructures and detection of natural risks. Main applications include tunnels and natural or excavated slopes, aiming at early anomaly detection, predictive maintenance, and enhanced safety and resilience.</p>
	<p><b>Research Scope and Objectives</b></p> <p>This research project, developed in collaboration with the engineering firm Ingeolab S.r.l. (Aosta, Italy), focuses on the integration of Digital Twin technology and Operational Modal Analysis (OMA) for the advanced monitoring of civil infrastructures, with particular attention to tunnels and natural or excavated slopes in alpine and geotechnically complex environments.</p> <p>The collaboration with Ingeolab, a company with extensive experience in geotechnical and structural monitoring, provides a unique opportunity to bridge academic research with real-world engineering challenges. The project aims to design, implement, and validate a smart monitoring system capable of supporting decision-making processes in infrastructure management, risk mitigation, and maintenance planning.</p> <p><b>Research Context</b></p> <p>In mountainous regions such as the Aosta Valley, infrastructures like tunnels and slopes are exposed to a variety of stressors, including seismic activity, freeze-thaw cycles, hydrogeological instability, and anthropogenic impacts. Traditional monitoring systems often rely on periodic inspections or isolated sensor data, which may not provide sufficient resolution or timeliness to detect early signs of degradation or failure.</p> <p>The proposed research addresses this gap by developing a Digital Twin framework—a dynamic, data-driven virtual model of the physical asset—that is continuously updated through real-time sensor data and enriched by OMA techniques. This approach allows for the identification of changes in the</p>

dynamic behavior of structures, which can serve as early indicators of damage or instability.

## Objectives

### Objectives

The main objectives of the research are:

1. Development of a Digital Twin platform tailored for tunnels and slopes, integrating real-time data acquisition, numerical modeling, and visualization tools.
2. Implementation of OMA techniques to extract modal parameters (natural frequencies, damping ratios, mode shapes) from ambient vibrations, enabling non-invasive structural health assessment.
3. Integration of geotechnical and structural data, including displacement, acceleration, pore pressure, and environmental parameters, to provide a holistic view of infrastructure behavior.
4. Validation through field applications, leveraging Ingeolab's ongoing monitoring projects in the Aosta Valley to test and refine the methodology in real-world conditions.
5. Development of predictive maintenance strategies, using the Digital Twin to simulate future scenarios, assess risk levels, and support proactive interventions.
6. Knowledge transfer and scalability, ensuring that the developed tools and methodologies can be adapted to other types of infrastructures and geographical contexts.

### Expected Outcomes

The collaboration with Ingeolab will ensure that the research remains grounded in practical needs and engineering feasibility. Expected outcomes include:

- A prototype Digital Twin system for tunnel and slope monitoring;
- Improved understanding of the dynamic behavior of geotechnical structures;
- A set of guidelines for integrating OMA into infrastructure monitoring workflows;
- Scientific publications and technical reports;
- Contributions to the digital transformation of infrastructure management in mountainous regions.

This research aligns with broader goals of sustainable infrastructure, climate resilience, and digital innovation in civil engineering, and aims to contribute to safer and more efficient management of critical assets in challenging environments.

## Skills and competencies for the development of the activity

Background in civil or environmental engineering, with interest in monitoring tunnels, slopes and especially natural risks. Familiarity with sensors, data analysis, and digital models (Digital Twins) is also helpful, even if at small scales (e.g., laboratory testing of ultrasonic wave propagation velocity). Skills in MATLAB, Python and FE modelling are a plus. Ability to work in a team, write reports, and collaborate with the industry partner Ingeolab at their office in Aosta (AO) is essential.