Data Engineering for Tunnel Maintenance:
an IT approach to infrastructure management

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Abstract

The maintenance of existing transport infrastructure, particularly tunnels, faces increasing challenges related to ageing structures, fragmented data, and the need to ensure safety, efficiency, and sustainability. Traditional inspection and modelling processes are often manual, slow, and prone to information loss, limiting their effectiveness in long-term asset management. Digital transformation, supported by Building Information Modelling, provides a strategic opportunity to reorganise how information is collected, represented, and shared across the entire life cycle of infrastructure.

This doctoral research proposes an integrated framework that combines artificial intelligence, digital modelling, and immersive visualisation to improve how data are managed, interpreted, and made available to engineers. Artificial intelligence supports the processing and organisation of complex survey data by transforming raw information into structured knowledge. Digital modelling ensures that this knowledge is coherently represented, enabling the creation of consistent and interoperable models that accurately reflect the real condition of the infrastructure. To better link different Knowledge domains, tunnel maintenance ontologies are introduced as a semantic layer that connects heterogeneous data sources and provides a shared vocabulary. This semantic structure enhances data quality, transparency, and reuse across different platforms and professions.

Immersive technologies, including virtual and augmented reality, enhance the accessibility of these data, enabling engineers and inspectors to explore digital models interactively and obtain contextual information during virtual inspections. Beyond their technological value, these methods are conceived to integrate seamlessly into industrial workflows, demonstrating that innovation can be both operationally effective and organizationally sustainable.

Developed in close collaboration with the engineering company TECNE, the research shows how digital and semantic tools can support a proactive approach to maintenance, turning raw measurements into actionable knowledge. The proposed methodology strengthens communication between stakeholders, improves decision-making, and promotes the creation of a shared digital memory of infrastructure. Its scalability also opens promising perspectives for application in other sectors, such as cultural heritage or complex building environments, where data consistency and interpretability are essential for effective and sustainable management.