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

The Einstein Telescope (ET) research infrastructure is set to become the pioneering next-generation underground observatory for gravitational wave detection.
ET engineering design demands a multi-criteria approach to identify and address geological, geotechnical, environmental, and landscape challenges. To address these complexities, a Design Digital Twin (DDT) is being developed as a dynamic, data-driven platform that seamlessly integrates Building Information Modelling (BIM), GIS datasets, and multidisciplinary simulations. This comprehensive and federated system facilitates scenario analysis, optimizes tunnel alignment, and enhances cross-disciplinary coordination, while effectively mitigating risks and promoting sustainable design solutions in construction sites.
A crucial component of the DDT is the 3D surface and underground models integrated with the structural engineering models. To characterize the underground setting, stratigraphic, geotechnical, and hydrogeological investigations can support accurate subsurface characterization by defining engineering geological units with consistent lithological and mechanical properties. The integration of these datasets into the DDT ensures that geological uncertainty and geotechnical variability are explicitly addressed, improving risk evaluation and contributing to resilient and sustainable infrastructure planning.
As part of the initiatives launched under the ETIC PNNR project, the ET-3G Lab at Sapienza University of Rome—a research laboratory specializing in 3D engineering modeling—has developed a multidisciplinary framework. This innovative environment supports workflows and tools for ET Digital Twin (ET-DT) enrichment through the integration of GIS and BIM systems, combined with advanced computational multi-criteria analysis. These efforts will play a fundamental role in refining and validating methodologies embedded within the Digital Twin (DT) framework, thereby contributing to the advancement of research infrastructure development.
By anticipating the integration of increasingly accessible datasets into digital twin technologies, this study aims to showcase how comprehensive approaches can enhance ET's sustainable design while laying the groundwork for future Construction and Operational Twins.

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