

PhD position in Knowledge- and Data- driven Artificial intelligence for computational Civil and Environmental Engineering

Location: Université Paris-Saclay, France



Project description

The PhD candidate will be part of a team of 5 other PhD candidates and post-doctoral researchers to conduct research and develop efficient computational models of Civil Engineering assets in the framework of the project MINERVE.

The project MINERVE is about designing and developing numerical methods and tools for modeling the French rail infrastructure all over its life cycle. MINERVE is leading the ongoing transition towards designing, constructing, operating, maintaining, and decommissioning rail infrastructure assets in a way that is more efficient, more reliable, and with limited negative impact on the environment. MINERVE is improving the global performance of the national rail infrastructure by adapting it to the effects of climate change and by reducing its negative impacts on the planet while increasing its competitiveness.

The project MINERVE gathers 4 industrial partners (SNCF, RATP, Colas Rail, and Kayrros), 1 private research institute (IREX), and 1 academic institution (Université Paris-Saclay). It is financially supported by the French government in the framework of the Recovery Plan and of the Investing for the Future program.

PhD description

Title: Cognitive twins for railway infrastructure asset performance simulation through knowledge-driven artificial intelligence.

Keywords: artificial intelligence, knowledge representation and reasoning, semantics, cognitive digital twin, railway infrastructure lifecycle, data flow, knowledge graph, ontologies

Period: October 2022 – October 2025

Supervisors: Céline Hudelot, Pierre Jehel, Debra Laefer, Fernanda Marchiori

Context:

The development of digital twins is expected to significantly improve the monitoring of the performance of infrastructure assets [1, 2]. In the context of the MINERVE project, a digital twin of the French railway infrastructure is being developed. The tracks, bridges, tunnels, earthworks, retaining walls, coastal or river defenses all have specific mechanical and environmental features that need to be captured digitally. They are also designed and built according to specific fields of expertise and processes that depend on which physics and engineering sciences best describe

them, on which environmental conditions and hazards they are exposed to, on which techniques are adopted in their construction, and on how they will be used when in service.

In the MINERVE project, digital twins are developed to provide the infrastructures manager with the information they need to efficiently and continuously re-assess the performance of their assets during their design, construction, and operation phases. Therefore, the digital twins need to have access to various heterogeneous observation data (geospatial, mechanical, weather conditions, hazards, sensors...) along with simulation data (simulated features of the asset behavior in given conditions). Also, multidisciplinary expert knowledge needs to be integrated to achieve seamless cooperation between the design, construction, and operation phases.

Besides, more and more actors in the civil engineering sector are adopting new technologies to improve their productivity and manage the risks in their operations. With the development of computer vision, robotics, and high-performance simulation, the scope of the data and expert knowledge to be incorporated in the digital twin of a rail infrastructure asset is expected to significantly widen in the next few years.

In this context, this thesis aims at integrating semantic models into digital twins in order to better manage data, processes and services despite different types of heterogeneity and across the full lifecycle [9] but also to enhance them with cognitive and actionable capabilities (i.e. reasoning on facts and knowledge) for decision-support [3,4,5,6].

Objectives:

In the context of the simulation of the performance of railway infrastructure assets in their design and construction phases, the PhD candidate will have to:

1. Perform a detailed state-of-the-art of semantic-enhanced digital twins and related works [3,4,5,6].
2. Identify, map and characterize precisely the different domains, included their knowledge and data, involved in railway infrastructure life cycle (design, construction, operation and maintenance) as well as their interactions and perform an exhaustive state of the art of available semantic models (e.g. ontologies, knowledge graphs) in the literature [7,8,9,10]. This task will involve available data and knowledge but also data and knowledge likely to be available in the future.
3. Define with the MINERVE partners useful use-case scenarios involving all the functionalities of cognitive twins to characterize the needs of the MINERVE project but also to define evaluation and validation benchmarks.
 - a. Queries for life-cycle asset management with data and model-based approaches and involving cross-domain interoperability.
 - b. Queries involving reasoning and inferences (What? When? How? What if?) to deal with unforeseen scenarios.
 - c. Other semantic-oriented tasks and services.
4. Proposition, design, and evaluation of semantic models and tools to enrich the MINERVE digital twin platform.

References:

[1] S.A. Argyroudis, S.A. Mitoulis, E. Chatzi, J.W. Baker, I. Brilakis, K. Gkoumas, M. Vousdoukas, W. Hynes, S. Carluccio, O. Keou, D.M. Frangopol, I. Linkov (2022) Digital technologies can enhance global climate resilience of critical infrastructure, *Climate Risk Management*, <https://doi.org/10.1016/j.crm.2021.100387>

- [2] D. Delgado, Butler, Gibbons et al. (2017) Management of structural monitoring data of bridges using BIM. Proceedings of the Institution of Civil Engineers. Bridge Engineering: 170(BE3), 204-218, <http://dx.doi.org/10.1680/jbren.16.00013>
- [3] Kharlamov et al. (2018) Towards Semantically Enhanced Digital Twins – Big Data 2018.
- [4] Rozanec et al. (2021) Actionable Cognitive Twins for Decision Making in Manufacturing (<https://arxiv.org/abs/2103.12854>)
- [5] Zheng et al. (2021) The emergence of cognitive digital twin: vision, challenges and opportunities, *International Journal of Production Research*, 1-23
<https://doi.org/10.1080/00207543.2021.2014591>
- [6] Lu et al. (2020) Cognitive Twins for Supporting Decision-Makings of Internet of Things Systems. Proceedings of 5th International Conference on the Industry 4.0 Model for Advanced Manufacturing. Lecture Notes in Mechanical Engineering. Springer, Cham.
https://doi.org/10.1007/978-3-030-46212-3_7
- [7] Bischof et al. (2021) Rail Topology Ontology: A Rail Infrastructure Base Ontology – ISWC 2021
- [8] OntoRail - <https://ontorail.org/>
- [9] Shift2Rail - <https://rail-research.europa.eu/>
- [10] LinX4Rail Project - https://projects.shift2rail.org/s2r_ipx_n.aspx?p=LINX4RAIL

Conditions of Employment

3-year doctoral contract with a monthly gross salary of 2,100 EUR.

Included in the salary:

- participation of the employer to the public transportation costs
- social security
- retirement plan (for European citizens only)

Workplace

The PhD candidate will be appointed to the Laboratoire de Mécanique Paris-Saclay (LMPS) and to the Mathematics Interacting with Computer Science Laboratory (MICS) at Université Paris-Saclay.

- The LMPS (UMR 9026, Université Paris-Saclay / CentraleSupélec / ENS Paris-Saclay / CNRS) is dedicated to research on all aspects of solid mechanics (mechanics of materials and structures, civil engineering, fine experimentation, and efficient numerical modeling). The LMPS has about 220 members, including 110 PhD students and postdocs and 35 engineers, technicians and administrative staff on two sites of Paris-Saclay University: CentraleSupélec and ENS Paris-Saclay, both in Gif-sur-Yvette. The LMPS hosts four research teams. COMMET: Behaviour of Materials, Modeling, Experimentation and Theory; STAN: Science and Advanced Techniques in Computational Mechanics; MILA: Architected Materials; OMEIR: Structures, Materials, Environment: Interactions and Risks.
- Founded in the early 2000's, MICS is the research laboratory in Mathematics and Computer Science at CentraleSupélec. Research at MICS is concerned with the analysis and modelling of complex systems and data, whether they come from the industry, life or social sciences, financial markets, information technology or networks.

The PhD candidate will join both the OMEIR team of the LMPS laboratory and the LOGIMICS team of the MICS laboratory.

- The OMEIR team contributes to the energy, ecological, and digital transitions of all fields related to cities and infrastructures. It brings together the expertise of research groups specializing in construction and natural materials, the modeling of various physical phenomena (mechanical, thermal, hydric, chemical), advanced experimentation, natural risks, large-scale and advanced numerical simulations, and statistical learning.
- The LogiMICS team (Approches LOGIques pour la Modélisation, l'Interprétation des données et la Complexité des Systèmes) whose work concerns the definition of methods and computer tools based on rigorous modeling of the targeted domain using formal formalisms. Two main themes emerge : (1) the management, modeling and semantic interpretation of unstructured data, and (2° the use of formal methods to model, analyze, test, verify and validate systems.

The PhD candidate will complete his/her thesis in computer science, in the Interfaces Doctoral School of University Paris Saclay (<https://www.universite-paris-saclay.fr/ecoles-doctorales/interfaces>) , and in the SIS Graduate School: Sciences de l'Ingénierie et des Systèmes.

Your profile

Master degree in artificial intelligence with skills in

- Knowledge representation and reasoning
- Data and knowledge-driven AI

Experience with the following would be a plus:

- Numerical simulation, digital twins, civil engineering

or Master degree in civil engineering with skills and experience in artificial intelligence.

We are looking for highly motivated candidates who are self-driven, have excellent communication and writing skills (fluent spoken and written in English or French is mandatory), and enjoy working in an interactive environment with other PhD students, junior and senior researchers, and industrial and institutional partners.

How to apply?

We look forward to receiving your application with the following documents:

- Application letter explaining why you think you fit in the position
- Detailed CV and grade transcripts
- 1 or 2 recommendation letters

Please email your complete application to Pierre Jehel and Céline Hudelot:

- pierre.jehel@centralesupelec.fr
 - celine.hudelot@centralesupelec.fr
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