UMR CNRS 7635

Centre de Mise en Forme des Matériaux

PhD Position

Physics-Enhanced reduced-order digital twins for real-time prediction of soft tissue injury risk in prosthetic socket users

Keywords: PCA, dimensionality reduction, finite element modeling, hyperreduction

Supervision: Prof. David Ryckelynck, Prof. Yannick Tillier, Prof. Pierre-Yves Rohan

Partners of project: ENSAM

General context of the project:

Chronic wounds that fail to heal are currently considered to be among the most significant, unresolved, and costly medical burdens, affecting up to 2% of the global population, with costs exceeding those associated with more publicly recognized diseases like skin cancer. Pressure ulcers (PUs) and diabetic foot ulcers (DFUs) constitute the largest share of these non-healing wounds.

While smart textiles capable of monitoring impedance, pressure, temperature, and humidity have been developed to detect early signs of tissue damage, they seldom address the mechanobiological conditions required for tissue health or leverage the full potential of digital twins. The TWIN-IT project (PEPR Santé Numérique, 2024–2028) addresses this challenge by developing personalized multiscale digital twins that explicitly integrate the biological and mechanical processes driving soft tissue injury. The project is structured around five scientific work packages forming a progressive chain (Figure 1).
This PhD position is at the heart of WP4 (Simplification and Validation of the Multiscale Model for Real-Time Applications), serving as a critical bridge between scientific rigor and clinical usability. The high-fidelity models developed in WP3 — multiphase poromechanical models coupling tissue deformation, interstitial fluid flow, oxygen transport, and inflammation — are by nature computationally intensive, requiring hours to days of simulation time. To be of any clinical value, these models must be dramatically accelerated while preserving their predictive accuracy at the patient level.
The proposed PhD will focus on developing a hybrid reduced-order digital twin - combining physics-based model reduction (ROM-nets, dictionary-based dimensionality reduction) with machine learning, to enable real-time prediction of tissue injury risk directly from sensor data collected by sensors in instrumented prosthetic sockets (WP5). This work builds on a strong methodological foundation developed at CEMEF, including dictionary-based ROM-nets already validated for subdermal strain prediction in sitting postures, and extends it to the more complex, multiscale, and patient-specific context of TWIN-IT.

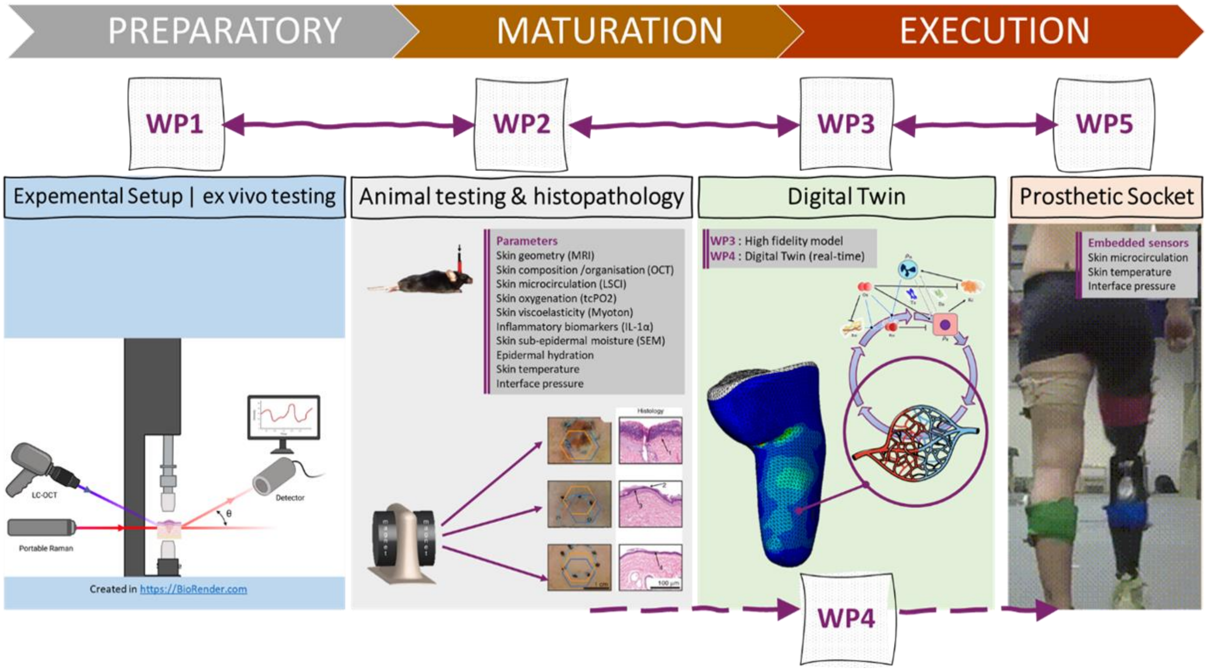

Figure 1 Work packages of TWIN-IT project. The PhD focuses on model order reduction for real time application of digital twining. It belongs to WP4.

PhD objectives:

The core objective of this PhD is to transition from high-fidelity, computationally intensive multiscale finite element models to low-fidelity, real-time digital twins. By integrating physics-based equations with machine learning, this research aims to create scalable models that maintain high predictive accuracy for clinical deployment. This task builds on strong prior work, including real-time strain localization using dictionary-based ROM-nets (Rohan et al., 2023) developed by an expert in reduced-order modeling and expert in biomechanical modeling. The main contribution of this PhD is the reduced order modeling of patient specific multiscale models. A Hybrid computational Workflow will be developed to merge physics-based equations and machine learning for real-time predictions. The dictionary involved in a ROM-net is composed of local PCA (Principal component analyses) related to groups of similar patients, where the similarity criteria aim to facilitate dimensionality reduction of biomechanical data. The reduced digital twin will be implemented onto a demonstrative platform: A functional prototype of the digital twin showcasing clinical utility. A real-Time evaluation against Embedded Sensor Data will be performed on a functional prototype: The digital twin will be developed based on the scientific data collected in TWIN-IT and evaluated against partial data collected from embedded sensors that will be collected by the functional prototype. Goal-oriented error estimators and AI techniques will be employed to enhance computational efficiency and manage prediction uncertainties. The dimensionality reduction of mechanical data will be supplemented by a dimensionality reduction of the geometrical data related to the patient morphology (Ferhat et al., 2026). The latter reduction will be performed using a spectral shape analysis (ShapeDNA) of specific patient meshes.

Upon successful validation, the research will extend to the design of prosthetic sockets, specifically testing the feasibility of real-time monitoring for transfemoral amputees. Clinically, this work aims to identify and monitor mechanical factors that contribute to soft tissue lesions and pain, thereby supporting the development of preventive strategies and personalized patient care.

References:

(Rohan et al., 2023) Rohan, P.-Y., Fougeron, N., Keenan, B., Pillet, H., Laporte, S., Osipov, N., Ryckelynck, D., 2023. Real-time numerical prediction of strain localization using dictionary-based ROM-nets for sitting-acquired deep tissue injury prevention, in: Reduced Order Models for the Biomechanics of Living Organs. Elsevier, pp. 385–402.

https://doi.org/10.1016/B978-0-32-389967-3.00027-5
(Ferhat et al., 2026) Ferhat, A., Proudhon, H., Remacha, C., Ryckelynck D, 2026. Functional maps regularization for high quality mesh morphing applied to shape registration in computed tomography. *Engineering with Computers* **42**, 10. https://doi.org/10.1007/s00366-025-02243-8

Candidate profile:

We are looking for a highly motivated researcher with a **strong background in computational mechanics**. The ideal candidate should possess the following qualifications:

- **Core competencies**: **Strong skills in finite element simulation** and a background in **statistics or machine learning**, particularly regarding biomechanical solid models.
- **Preferred experience**: Prior experience in finite element modeling and the analysis of multiscale data will be highly valued.
- **Soft Skills & Mindset**: The candidate must demonstrate independence, scientific rigor, and a genuine curiosity regarding the development of thermomechanical digital twins..

Key point of the subject:

Innovative monitoring of pressure ulcers risks using scientific machine learning.

Overview of CEMEF and of your future research team:

You will join **CEMEF**, the largest research center of **Mines Paris – PSL** associated with the **CNRS**. For over fifty years, CEMEF has conducted cutting-edge research in **mechanics, materials, numerical simulation, and artificial intelligence**, in close collaboration with industry and academic partners. The doctoral project will be supervised by scientists from the CSM (Computational Solid Mechanics) research team, whose work focuses on computational mechanics and biomechanics. You will operate within a highly international and multidisciplinary environment of around **170 people**, including approximately **75 PhD candidates**.

<table>
<tr><td>Type de contrat</td><td>CDD</td><td rowspan="6">Online application
on the dedicated platform
Application deadline :
30/06/2026</td></tr>
<tr><td>Working time</td><td>Full time</td></tr>
<tr><td>Duration</td><td>3 years</td></tr>
<tr><td>Salary</td><td>27 kEur (before tax)</td></tr>
<tr><td>Location</td><td>CEMEF Mines Paris 1 rue Claude Daunesse 06904 Sophia Antipolis, France</td></tr>
<tr><td>Starting date</td><td>Oct. 1st, 26</td></tr>
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