Merging the physical and virtual worlds through digital twins. Application to mechanical equipment to optimize design, monitoring and maintenance.

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Outline

- About Cetim
- Digital twin: introduction & context
- Digital twin: some use cases
- Conclusion

French Technical Center for Mechanical Industries

Dedicated to fostering an industry that is more autonomous, optimistic, and sustainable

The technical hub for 17 professional sectors

- 1100 employees
- €180 million in revenue
- 65% of activities in collective projects and R&D
- 6000 members (companies)
- An international company

Connecting research with small and medium-sized enterprises (RTO).

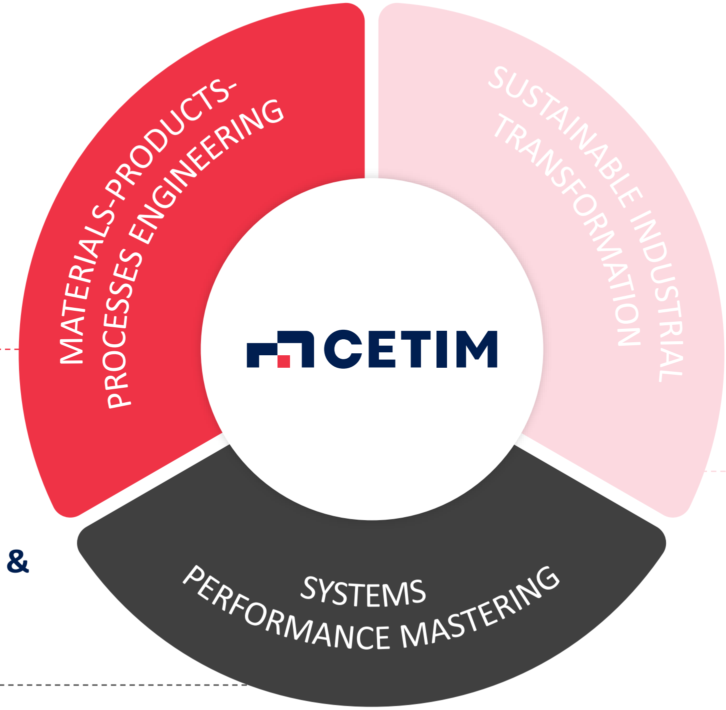
In 2025: >65 PhDs & Post-doctorates, >380 scientific and technical publications.

Our fields of expertise

UNIQUE R&D CAPABILITIES AND MULTI-DISCIPLINARY COMPETENCIES

- Metallic, Polymer, Composite, Glass & Ceramic Materials
- Surfaces engineering
- Advanced Manufacturing Processes
  - Casting, Forge, Hot & Cold Metallurgy
  - Additive Manufacturing
  - Special Machining
  - TP Composites
- Multi-Materials Assembly

- Products, Components & Equipment Performance (Fatigue, Power transmission, EMC, NVH, Sealing)
  - Design & Dimensioning optimization
  - Characterization & Qualification by digital & multiphysical Testing Engineering
  - Durability, Optimization of the lifespan

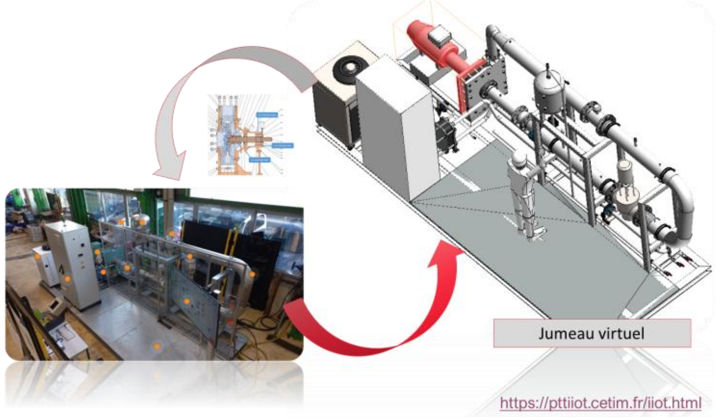


- Operational excellence & Industry 4.0
  - Automated production controls
  - Digitisation of processes
  - Quality control & Metrology of the future
- Decarbonization, environmental & energy transition
  - Eco-efficient plant (energy, water, waste, etc.)
  - Low-impact products/systems
- Risk management and systems integrity
  - Advanced NDT
  - SHM & monitoring
  - 3D scanning & reverse engineering

TRAINING & SKILLS MANAGEMENT	FAILURE ANALYSIS AND EXPERTISE	CONSULTING SERVICES FOR INDUSTRIAL TRANSFORMATION

Digital twin: what are we talking about ?

«A Digital Twin is more than a 3D digital representation or virtual model of a system.
It's a living virtual clone of a physical system, requiring the existence of a physical twin and communication with the object it copies.»

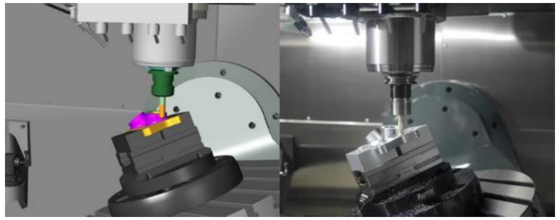


- The French Alliance « Industry of the Future », gave in 2023 the following definition:

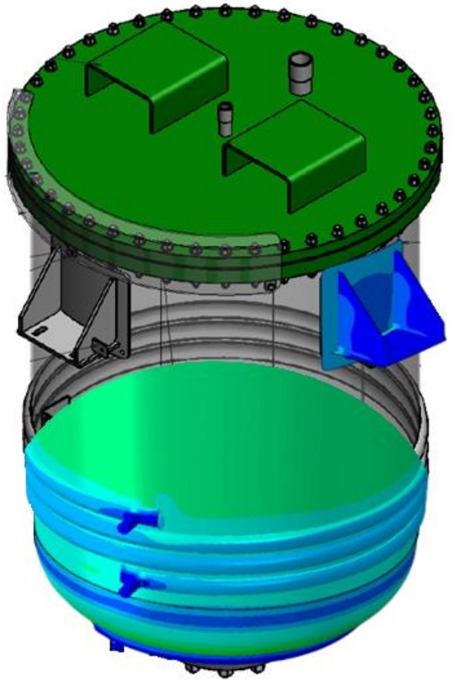
« A Digital Twin is an **organized set of digital models** representing a **real-world entity** designed to **address specific issues and uses** ,

The Digital Twin is **updated in relation to reality**, with **a frequency** and **precision** adapted to its issues and uses ,

The Digital Twin is equipped with **advanced operating tools,** including the ability to understand, analyze, predict, optimize **the operation and management of the real entity**. »



Example collaborative digital twin project. Application to pressure vessels.



CETIM CARNOT

IMT Nord Europe
École Mines-Télécom
IMT-Université de Lille

Région Hauts-de-France

stcn Chaudronnerie Tuyauterie acier & inox

Industrial context

- Pressure vessels are used in many industrial sectors for production, storage and transportation of products

- Usually operate in severe conditions and present high risk for operators, equipment and environment

- Design, manufacture and operation of pressure vessels are strictly regulated by laws and building codes

- Classical maintenance strategies

Preventive

Curative

→ Need for predictive maintenance strategies

Digital twins are emerging as an effective solution

Real time - Distance - informations

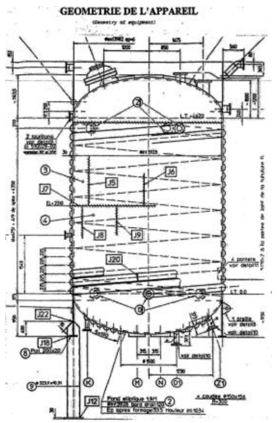
Decision making

Optimize planning interventions

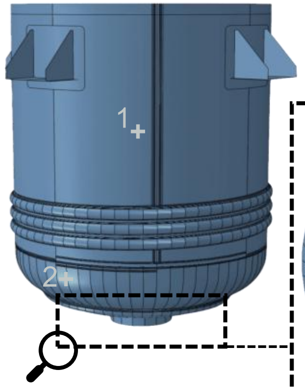
Reduce cost and risk

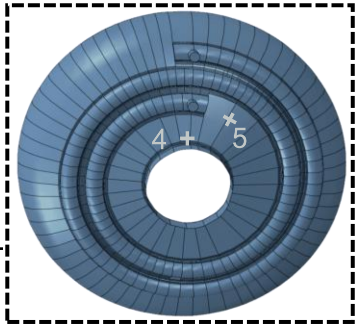
Pressure vessel use case : the physical system

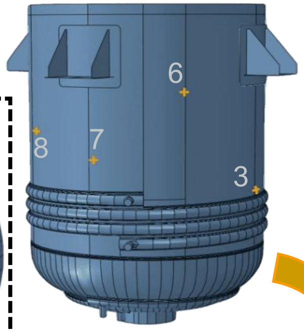
A reduced model of a polymerization reactor



Designed, fabricated, inspected, instrumented (strains, pressure, temperature, acoustic emission) and fatigue tested under cyclic pressure

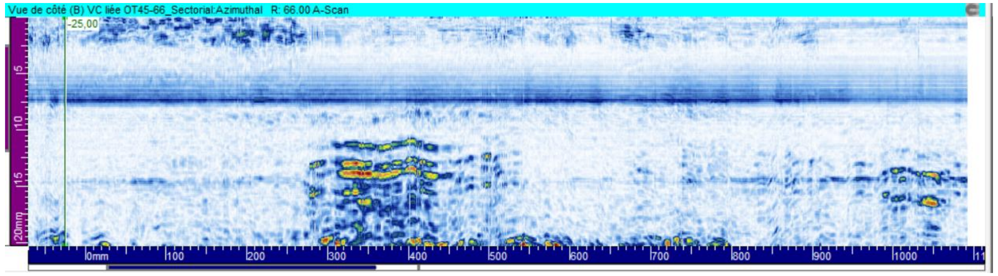






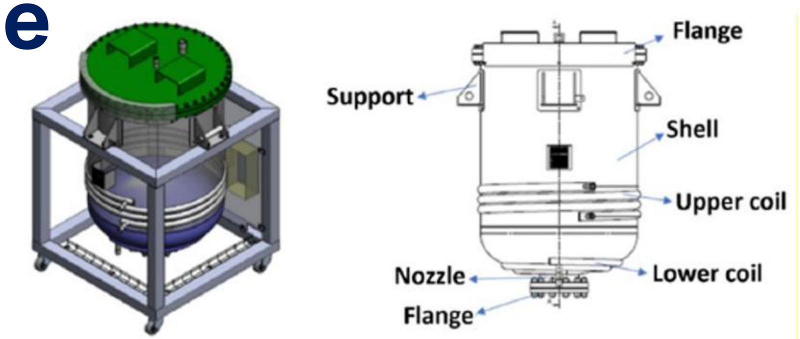
Strain gauges are placed based on :

- ➢ Preliminary results from FE analysis
- ➢ Expert feedback
- ➢ In critical and nominal zones of the structure to measure local responses, calibrate and validate the model
- ➢ Ultrasonic inspection of welded areas



Sample defect detection

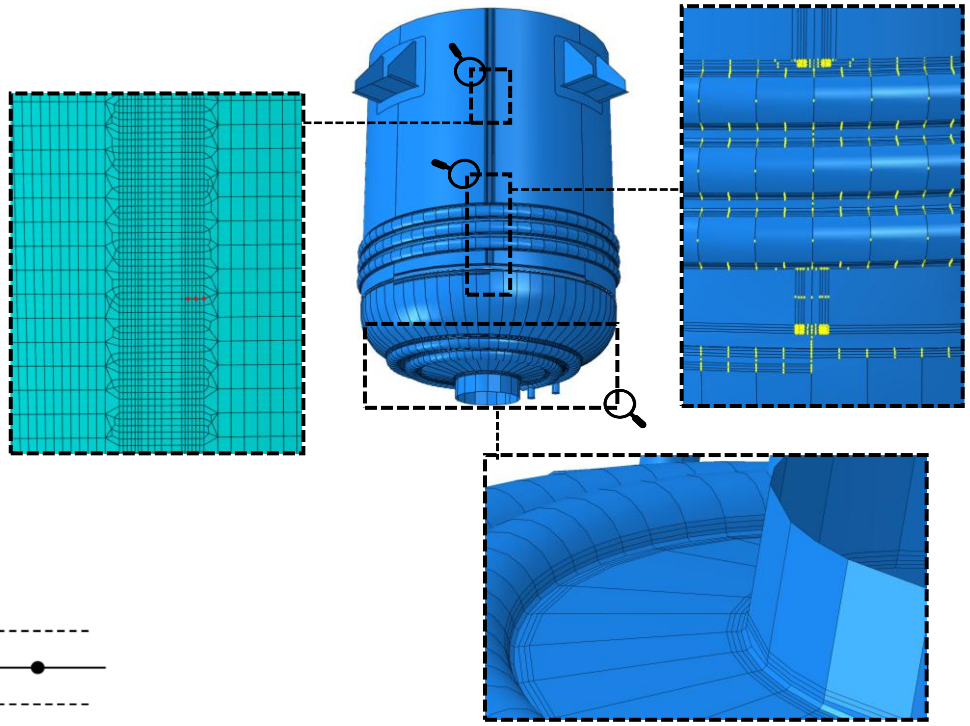
Pressure vessel use case: the virtual clone

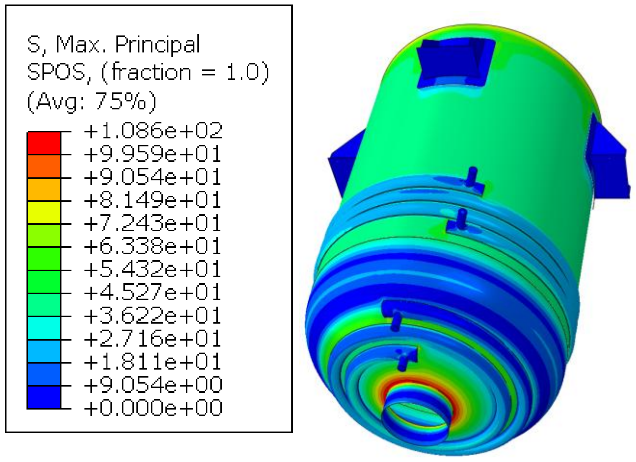


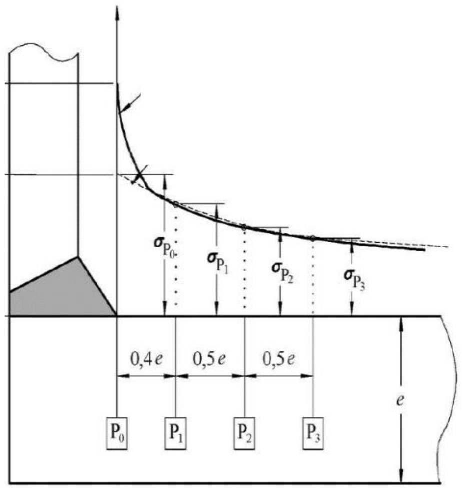
- ❖ Dimensions : height = 1,8m, diameter = 1,1m
- ❖ Operating conditions :
  - Cyclic pressure of the water in the shell : 0 →5,3 Bar
  - Cyclic pressure of the water in the coils : 0 →3,8 Bar
- ❖ Numerical modeling taking into account gravity, fixed support and hydrostatic pressure
- ❖ Weld modeling and post-processing
  - Corner weld modeled with an additional element
  - Hot spot method (international institute of welding recommendations)
- ❖ Model calibrated with strain gage measurements (error <9%)

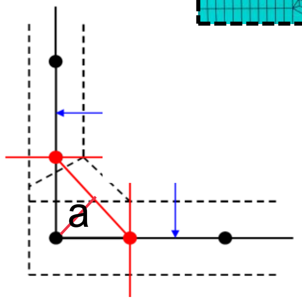
Material	P265GH
Young's modulus	201000 MPa
Yield strength	265 MPa
Ultimate tensile strength	460 MPa

EN 10028-2-2009 Steel Flat Non-Alloy Alloy Elevated Temp Prop



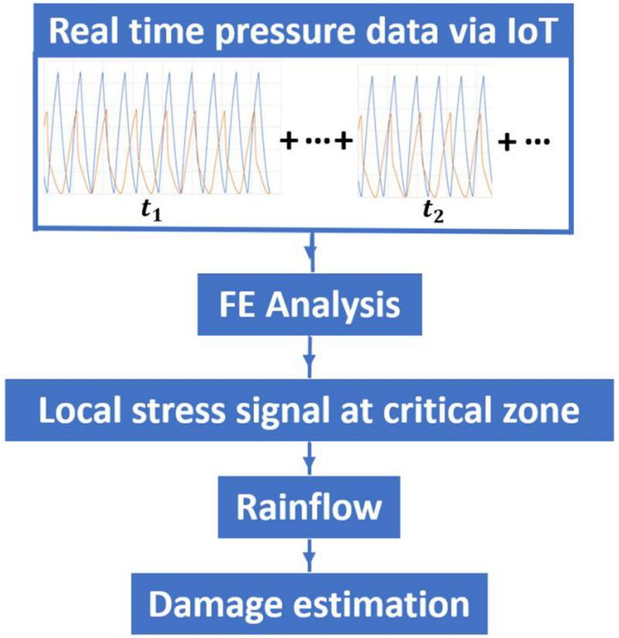


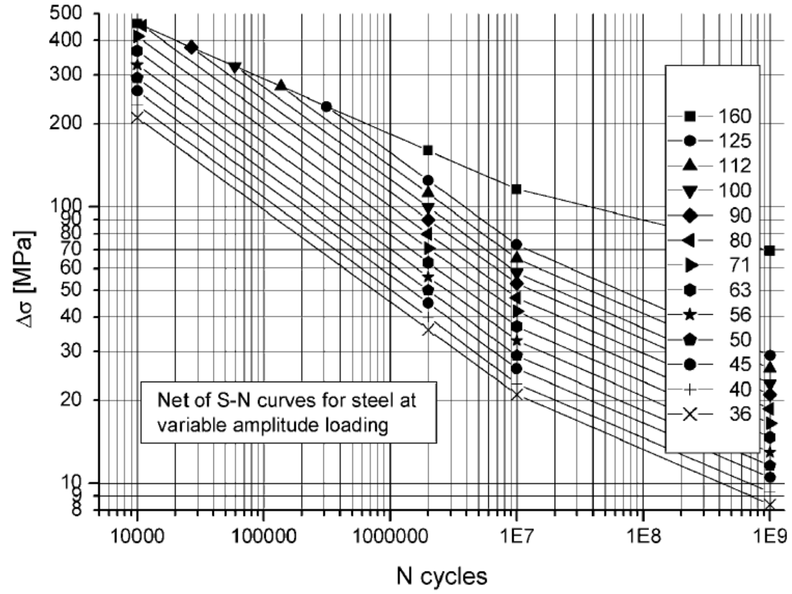




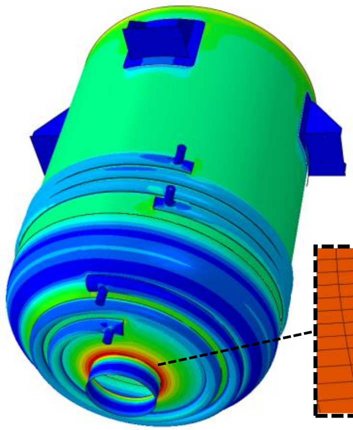
Fatigue damage calculation

- ✓ Damage calculation based on Stress Life curve according to IIW
- ✓ Maintain the concept of reactivity

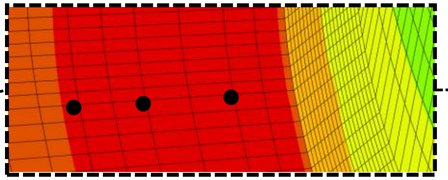




FAT
71



Resulting hot spot stress range in the critical location of **109 MPa**



550000 cycles

Damage calculated and linearly incremented on a daily basis. This value is then reported on a dashboard and information regularly transmitted to an operator.

Software chain used:
Solidworks, Abaqus, DesignLife, GlyphWorks

Conclusion on the pressure vessel use case

A digital twin of a pressure vessel has been successfully developed to monitor and optimize maintenance of the equipment.

The steps involved are:

- Design & manufacture of the physical equipment,
- Optimized deployment of sensors for a smart, connected device,
- Testing under representative loads,
- Development of a representative virtual model,
- Construction of the digital twin by hybridization of physical/data models.

Digital twin appears as a reliable way to monitor operation, evaluate resistance and safety in real service conditions, and finally to capitalize on data to optimize the design of new products.

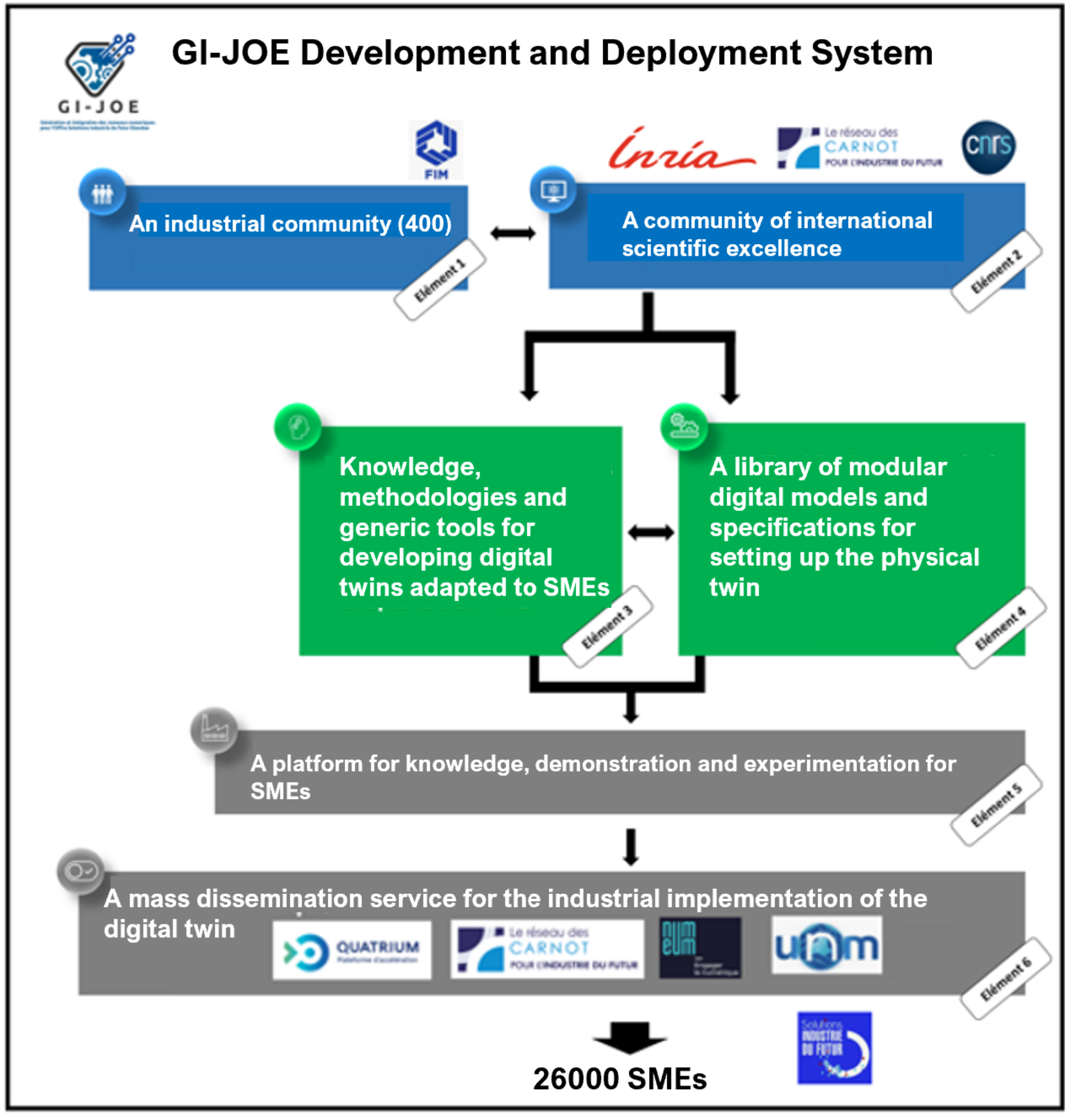
Future work will concentrate on data driven models and optimal sensors placement.

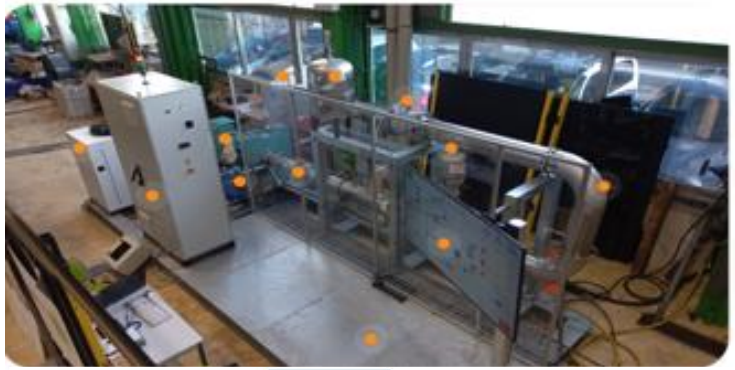
For the industrial partner in this project, an SME in pressure vessels fabrication, the digital twin technology represents an opportunity for activity diversification and business development

Digital Twin for Predicting Progressive Damage in Operating Pressure Vessels. Procedia Structural Integrity, https://doi.org/10.1016/j.prostr.2024.03.030
Digital Twin for Real-time Pressure Vessels Fatigue Life Prediction. Advances in Mechanical Engineering, https://doi.org/10.1177/16878132251327666

More digital twins use cases

A strategic Digital Twins project dedicated to a wide range of mechanical equipment





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industrial future
and planet-friendly