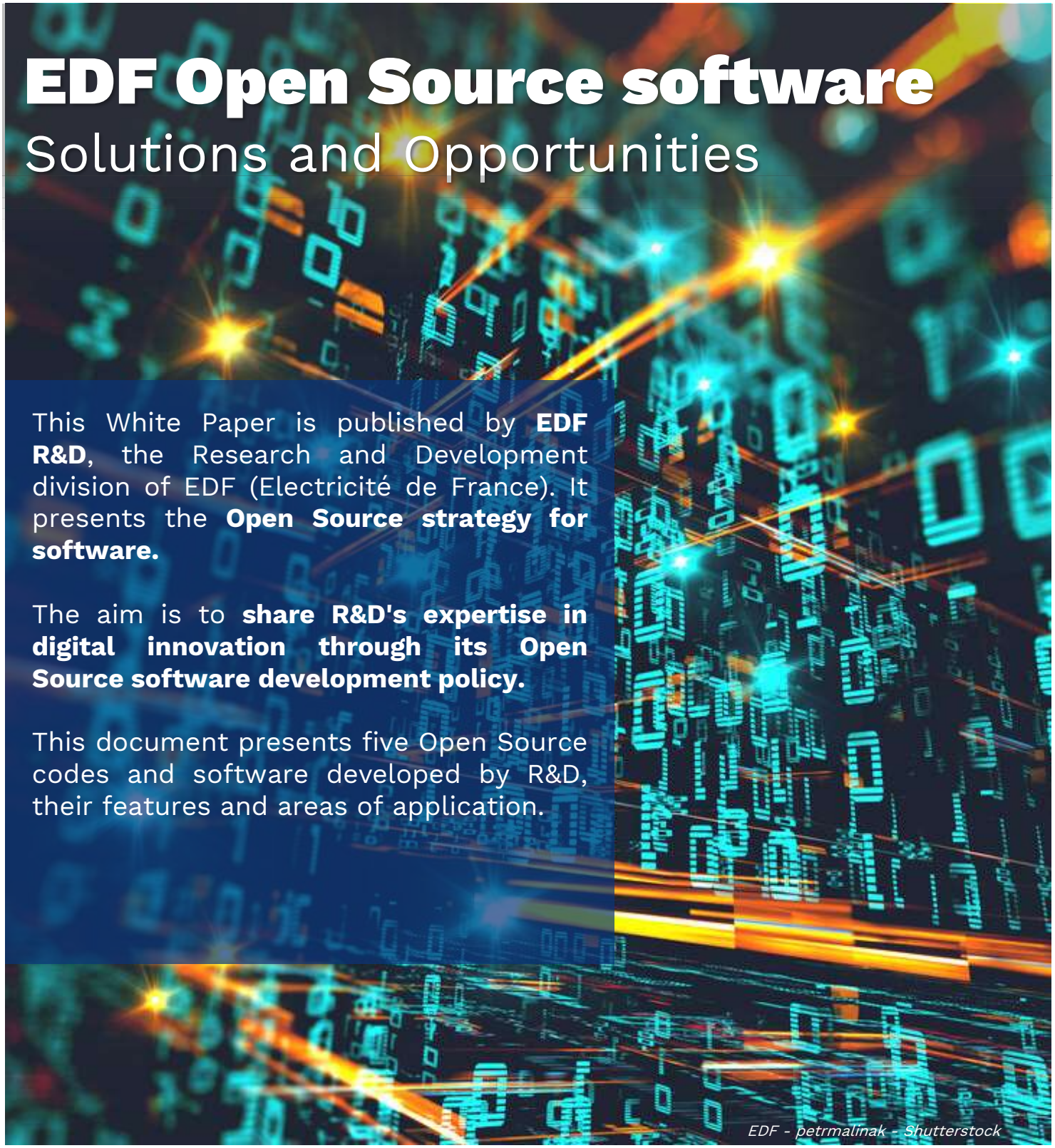
R&D WHITE PAPER

EDF Open Source software

Solutions and Opportunities



This White Paper is published by **EDF R&D**, the Research and Development division of EDF (Electricité de France). It presents the **Open Source strategy for software.**

The aim is to **share R&D's expertise in digital innovation through its Open Source software development policy.**

This document presents five Open Source codes and software developed by R&D, their features and areas of application.

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Open Source numerical simulation codes

Context, issues and strategy

EDF R&D's computing power places it among the world's leading industrial research centres. The Open Source codes and software developed by EDF R&D are used in many industrial sectors.

For example, in the mechanical sector, **Code_Aster** is used by the automotive industry to simulate engine cooling and improve energy efficiency. Another example: **Code TELEMAC** is used in the construction sector to model hydraulic flows around bridges and dams, guaranteeing their stability and durability. **Code OpenTURNS** is used in the aerospace industry to assess the reliability of critical components and systems, and to optimise the design of space vehicles and aircraft.

It is worth noting that a code such as **Code_Saturne** is now one of the most parallelized in its category. We should also mention that the new HPC version of **Code_Aster** now makes effective use of parallel computers, particularly for justifying the earthquake resistance of structures, with study possibilities that were not achievable a few years ago in structural mechanics.

In a world where collaboration and knowledge sharing have become essential to meeting technological challenges, EDF R&D is a pioneer in digital innovation. Through its policy of developing Open Source software, EDF R&D is a major player in the field of digital simulation.

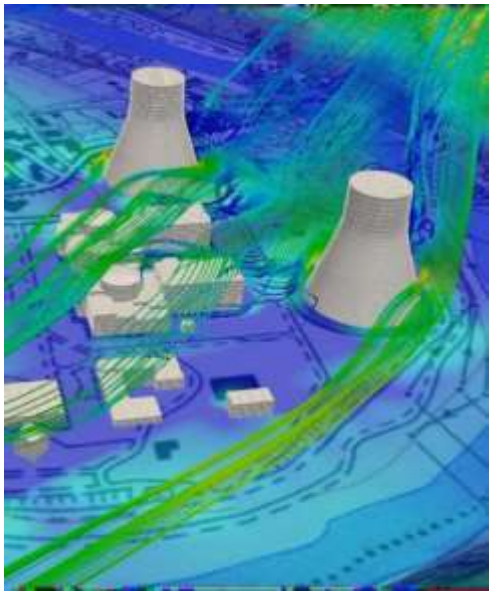
For over 20 years, EDF R&D's Open Source policy has enabled it to share its codes with a constantly expanding academic and industrial community. Codes such as Code_Saturne, Code_Aster and Télémac-Mascaret are now recognised in their respective communities as state-of-the-art codes designed for massive parallelism.

EDF R&D ensures total transparency and is recognised by a large scientific community. Users have full access to the software source code, which fosters confidence in the results obtained and enables rigorous validation of the models. The publication of software source codes allows the scientific community to verify and validate the performance of the software, thus reinforcing its credibility and reliability.

The increase in the number of users and their feedback on error detection, model validation limits, benchmarks, etc., facilitates the continuous improvement of the codes. EDF R&D controls the use of the codes and their development, which offers great flexibility. Codes are continuously developed in line with identified industrial needs. Controlling the development and use of the codes means that we can capitalise on the simulation and modelling know-how accumulated over several decades, as close as possible to the state of the art.

EDF R&D's Open Source codes strengthen European sovereignty in terms of digital tools. They provide autonomous, secure software solutions that are independent of commercial suppliers.

EDF's Open Source codes offer transparency, flexibility and collaboration in the field of digital simulation. By adopting an open and collaborative approach, EDF is actively helping to shape the future of computer simulation and engineering, while consolidating its position in the global market.



Open Source numerical simulation codes

Context, issues and strategy

In economic terms, the development and dissemination of EDF's Open Source codes will stimulate innovation and the competitiveness of national industry. For example, in 2023, the average cost of acquiring proprietary digital simulation software is significantly expensive, whereas the use of EDF's Open Source codes will significantly reduce these costs, thereby promoting the development of businesses and the national economy.

High-Performance Computing (HPC) continues to forge ahead, constantly offering new computing power to open up new opportunities for studies that were previously unattainable. These include the development of research methodologies, the democratisation of probabilistic approaches and parametric computing, in all fields of study. 3D field physics codes make extensive use of this new computing power to improve the quality of studies, to go down to spatial scales that are more representative of the physical phenomena observed, and to study a diversity of scenarios as a function of multiple parameters.

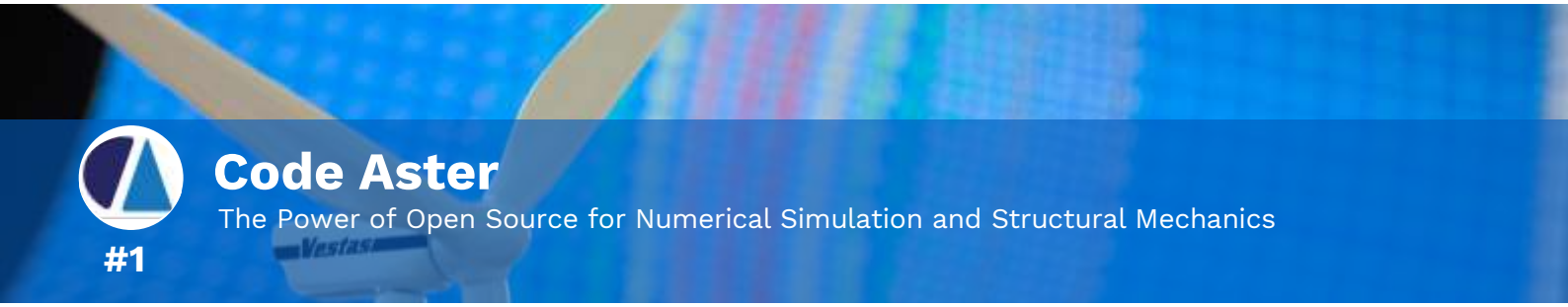
Other significant advances have been made in recent years, having a major impact on simulation strategies. Ever more powerful solutions are based on the ever-increasing computing power of supercomputers, offering new study possibilities. Innovative Augmented Reality (AR) and Virtual Reality (VR) technologies are making it easier to understand complex physical phenomena, while the widespread use of the Cloud is leading to new ways of designing simulation infrastructures.

Numerical simulation is very much affected by these new technologies, which offer new opportunities, such as coupling simulation and artificial intelligence to increase the productivity of studies, or coupling simulation and experimentation in real time, in particular through the development of digital twins.

Seismic study / CNPE de CRUAS *(DT), code_aster simulation*

2021: 34 days for a complete calculation

2022: 7 minutes of calculation



Code Aster

The Power of Open Source for Numerical Simulation and Structural Mechanics

#1

Technical features and functions

Code_aster is an Open Source software package developed by EDF R&D for general-purpose numerical simulation of solid mechanics. It addresses complex engineering problems in sectors such as civil engineering, aeronautics, automotive and energy, including nuclear power. Its quality and reliability, validated by nuclear industry standards, ensure accurate modelling and analysis of structures and materials under various stresses. With its modular, scalable architecture, Code_aster offers a complete suite of tools for modelling, analysing and optimising mechanical structures, and solving thermo-mechanical problems.

Developed by simulation experts at EDF R&D, Code_aster is recognised for its **reliability** and **accuracy** in modelling the most complex physical behaviours. It has been validated by more than 4,000 tests, half of them using external references.

This gives it **exceptional flexibility** and enables it to be adapted to a variety of use cases, from simple linear problems to complex non-linear simulations. The integration of Code_aster with Salome in Salome_meca provides a modular platform dedicated to modelling, numerical analysis and post-processing. It facilitates the automatic processing of data from Code_aster simulations. What's more, thanks to its enhanced python interface, Code_aster can be easily coupled with all types of engineering tools.

As open software, Code_aster relies on accessibility, feedback and exchanges with the international scientific community to maintain its state-of-the-art status.

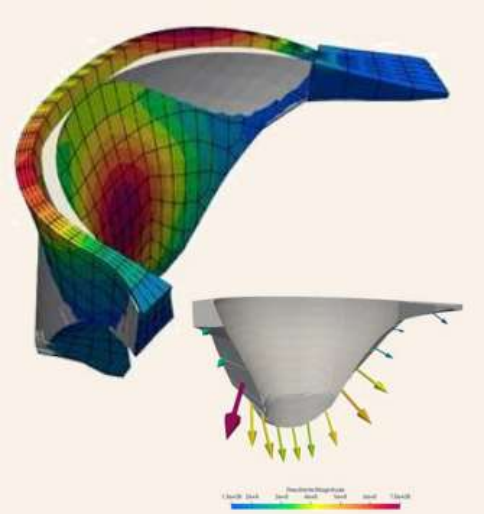
Code_aster is particularly rich in behaviour laws, finite elements and load types. It offers an exhaustive suite of functionalities adapted to a variety of simulation needs, from structural analysis to thermal analysis, as well as other engineering specialities. This versatility guarantees a complete solution for any simulation requirement.

Code_aster in figures

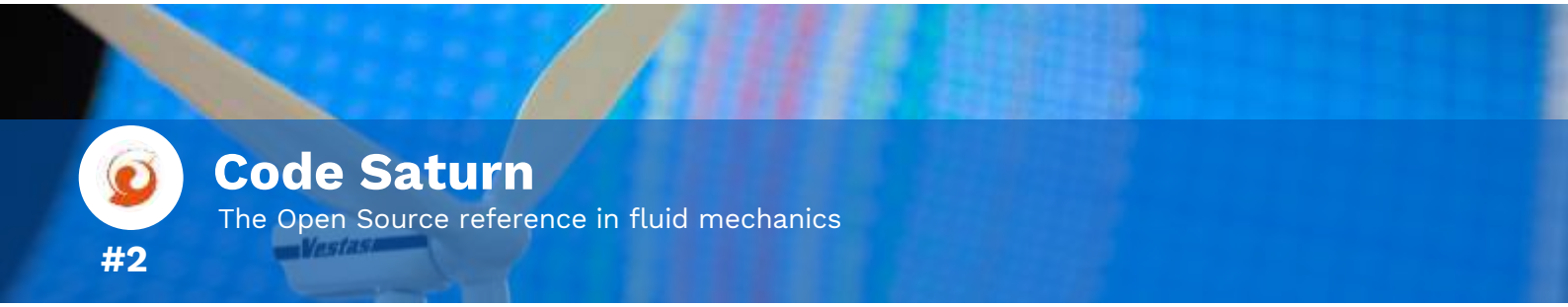
- **Over 35 years' expertise** in structural mechanics
- **More than 4,200 test cases** for verification, as well as validation studies covering various fields of mechanics.
- **More than 2940 publications**

Fields of application

Types of application	Types of analysis
• Non-linear static strength of equipment • Static strength and ageing of structures • Earthquake resistance of structures • Earthquake resistance of equipment • Fatigue and breakage of metal components • Geomechanics • Periodic structures • Metallurgy, forming, • Welding, additive manufacturing processes • Vibration analysis, rotating machines	• Thermal calculation, thermo-hydration or metallurgy • Modal, spectral or linear dynamic calculation • Non-linear static mechanical and thermo-mechanical calculations • Linear static analysis • Non-linear dynamic calculation • Thermo-hydro-mechanical calculation • Fracture calculation, fatigue and limit analysis



Study of the earthquake resistance of a dam with modelling of fluid-structure interaction and absorbing boundaries on the foundations.



Code Saturn

The Open Source reference in fluid mechanics

#2

Technical features and functions

Code_saturne, developed by EDF R&D for over 20 years, is an Open Source fluid mechanics simulation software package designed for detailed analysis of fluid or gaseous flows, heat transfer and chemical reactions.

With its **neptune_cfd** extension for simulating two-phase flows, it enables precise modelling of fluid movements by solving the Navier-Stokes equations on a fine scale. It is based on the finite volume method, which divides space into small volumes, making it easy to accurately monitor velocity, pressure, temperature and chemical composition at any time and at any point.

Code_saturne is used in the nuclear industry to ensure that power plants operate correctly, in aeraulics to simulate air quality, and in other sectors such as defence, aeronautics, shipbuilding and port infrastructures.

Code_saturne is **accessible** to all users through its graphical interface, and facilitates advanced uses thanks to the ability to write specific user routines. Its **versatility** enables it to handle a wide range of fluid mechanics problems, including turbulent and incompressible flows, as well as multiphysics phenomena.
What's more, Code_saturne **is highly parallelized** to take full advantage of the performance of modern supercomputers (with tests carried out on tens of thousands of cores and billions of cells).

Code_saturne integrates easily into workflows with other simulation tools and CAD systems, in particular with the SALOME_cfd platform. This collaboration enables consistent and efficient modelling, simulation and data analysis.
Its development is supported by a rigorous verification and validation process carried out on a daily basis, guaranteeing its reliability.

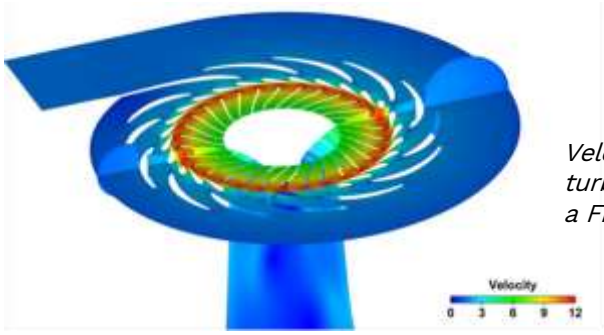
Code_saturne in figures

- **More than 500 engineers** and researchers use it
- **More than 1,000** executions tested every day
- **More than 246 scientific publications.**

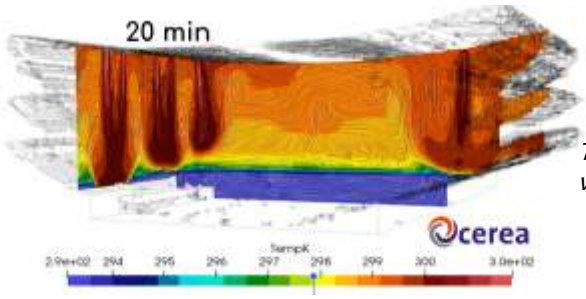
Fields of application

Code_Saturne contains numerous turbulence models, both with the Reynolds Averaged Approach (RANS) and Large Scale Simulation (LES). It also includes various modules for modelling a wide range of physics, such as:

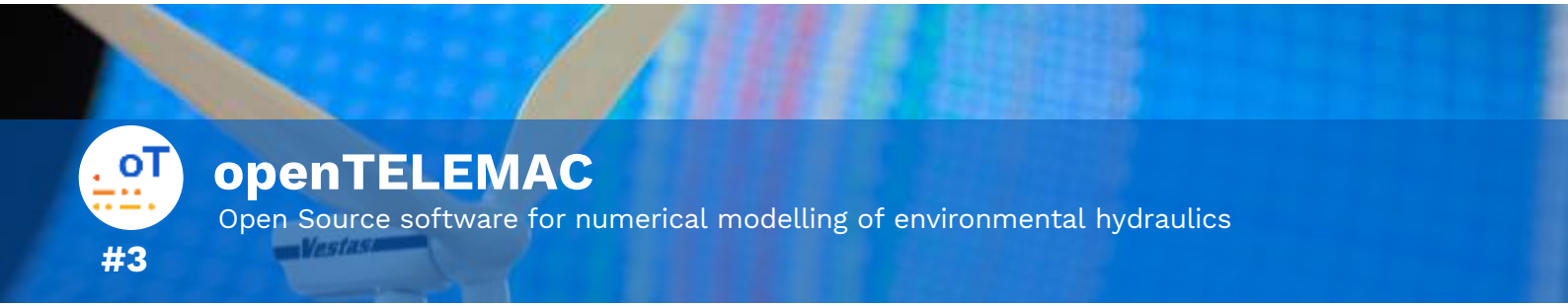
- Homogeneous or stratified flows
- Atmospheric flows
- Underground flow
- Fires (combustion, radiation)
- Interface monitoring (ALE and VoF methods)
- Particle tracking (Lagrangian)
- Electric arcs



Velocity field in a turbomachine calculation for a Francis99 turbine.



Temperature field in a ventilated sports stadium.



openTELEMAC

Open Source software for numerical modelling of environmental hydraulics

#3

Technical features and functions

The TELEMAC system has been developed by EDF R&D in **collaboration with French, European and international partners** for over thirty-five years. It is a suite of coupled and parallelized scientific calculation codes for modelling free-surface environmental hydraulics. The system includes 1D, 2D and 3D, Eulerian and Lagrangian models for predicting a wide range of phenomena related to water flow in the natural environment: free-surface hydrodynamics, wave transformation, sediment transport, water quality and ice formation. This modelling can be applied to reservoirs, rivers, lakes, seas and oceans. The main features of this software are, on the one hand, the choice of a spatial discretization based on the finite element method, which is suitable for unstructured meshes (the choice of the finite volume method is also available in 2D) and, on the other hand, parallelization by domain decomposition, which enables high performance on calculation clusters.

openTELEMAC **specialises in hydrodynamics and environmental modelling.** It is recognised for its ability to carry out accurate, high-quality simulations. It is particularly effective for modelling complex, coupled physical processes such as the dynamics of underwater dunes, the evolution of coastlines under the action of waves and currents, the study of the impact of climate change, thermal and salt stratification, and interactions with civil infrastructures and hydraulic structures.

The software can be easily **integrated with other** modelling **tools and software**, enabling a more comprehensive and integrated approach to environmental and hydraulic modelling. In addition, openTELEMAC is compatible with Linux and Windows, making it easy to integrate into various development environments and computer systems, including embedded systems and digital twins.

Given its open source nature, openTELEMAC **is flexible**, **transparent** and supported by an international community of experts who contribute to its ongoing development.

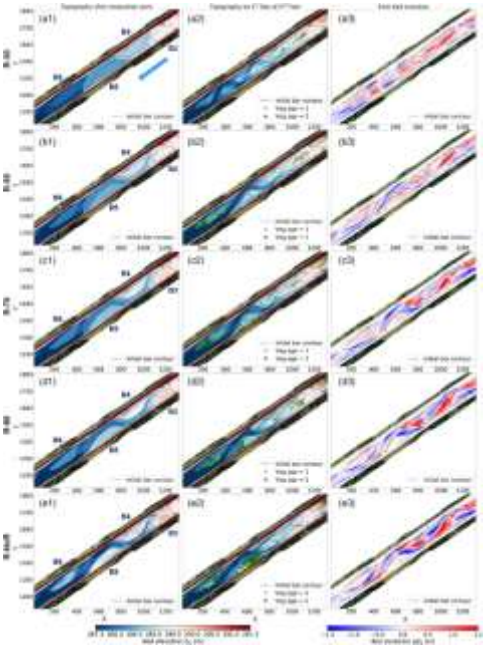
openTELEMAC in figures

- Open Source since 2010
- **Over 2,600** registered **users**
- Bringing together **1D, 2D and 3D**, Eulerian and Lagrangian codes
- A **consortium of 9 partners**: ARTELIA, BAW, CEREMA, CERFACS, ENPC, HR Wallingford, IMDC, STFC and EDF

Areas of application

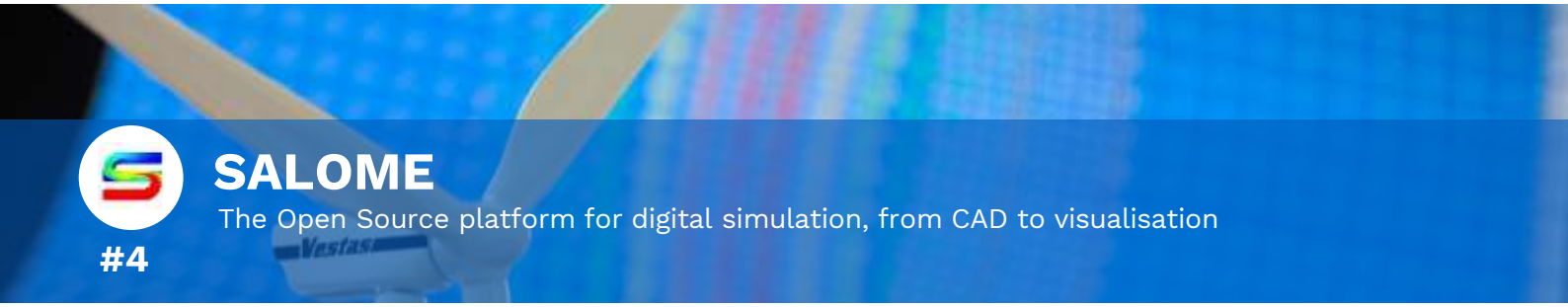
openTELEMAC covers a wide range of applications such as:

- Design of offshore, port and coastal structures
- Impact studies for dredging or rehabilitation works
- Environmental impact studies of thermal and saline discharges and pollutants
- Studies of flooding, overflows, surges, dam failures, and the impact and operation of hydraulic structures
- Studies of the impact of climate change on rivers and coastlines, on the management of reservoirs and other infrastructures



Interactions between hydrodynamics, sediment transport and plant processes in the Isère River (France):

Initial bed elevation after restoration work, final bed elevation and vegetation distribution.
According to Li et al (2023).



SALOME

The Open Source platform for digital simulation, from CAD to visualisation

#4

Technical features and functions

SALOME is an Open Source platform dedicated to numerical simulation, designed to facilitate every stage of a study: from the creation of the CAD model and mesh to post-processing and the visualisation of results, including the chaining of calculation schemes.

The application offers a wide range of functions, including an advanced parametric CAD modeller, a module for generating and editing meshes with numerous algorithms, a calculation supervisor, and several data analysis and processing tools including data assimilation, parameter calibration for calculating uncertainties and field manipulation.

SALOME stands out as an Open Source platform, allowing state-of-the-art libraries to be selected and the most up-to-date versions to be integrated. This approach ensures maximum accessibility and flexibility for the customisation and collaborative development of numerical simulations.

SALOME offers a wide range of functions, including a powerful parametric CAD modeller, a mesh generation and editing module with numerous algorithms, a calculation supervisor and a host of data analysis and processing tools.

SALOME is easily **extensible** and allows calculation codes to be integrated and linked to the pre- and post-processing tools provided by the platform. Several disciplinary platforms are available, such as salome_meca (with code_aster), salome_cfd (with code_saturne) and SALOME-HYDRO (with TELEMAC-MASCARET).

Thanks to **the interoperability** between its modules, SALOME stands out for its ability to provide high value-added services. This platform offers **customisable** functionalities, designed to adapt precisely to the unique needs of different physical applications.

SALOME in figures

- **Over 150,000 downloads** per year
- **Over 5,000** verification **tests**
- **Over 120,000 visitors** a year

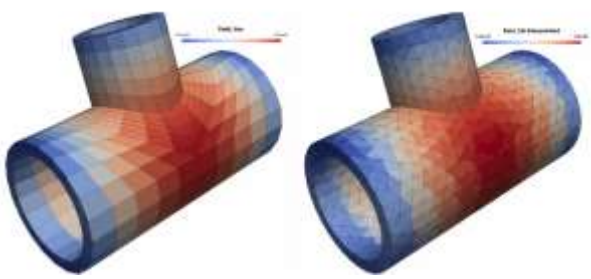
Examples of practical applications

SALOME MECA: With code_aster for seismic analysis, from the study of porous media to acoustics, via fatigue and stochastic dynamics.

SALOME CFD: With code_saturne for the analysis of 2D, 2D-axisymmetric or 3D flows, whether permanent or transient. The flows analysed can be laminar or turbulent, incompressible or slightly compressible, isothermal or not, and can include the transport of a scalar.

SALOME Hydro: with openTELEMAC to carry out free-surface hydraulic studies.

Example of post-processing a simulation of a reactor building in salome_cfd



Example of a 3D field projection from a source mesh to a target mesh

openTURNS

Open Source software for modelling uncertainty

#5

Technical features and functions

openTURNS is an Open Source software package that can be used to model uncertainties, propagate them through a calculation code and prioritise their impact on an output variable. It is based on the Uncertainty Processing Methodology developed by EDF R&D and enhanced by our partners since 2000.

openTURNS offers services of varying complexity, enabling all stages of uncertainty processing to be carried out:

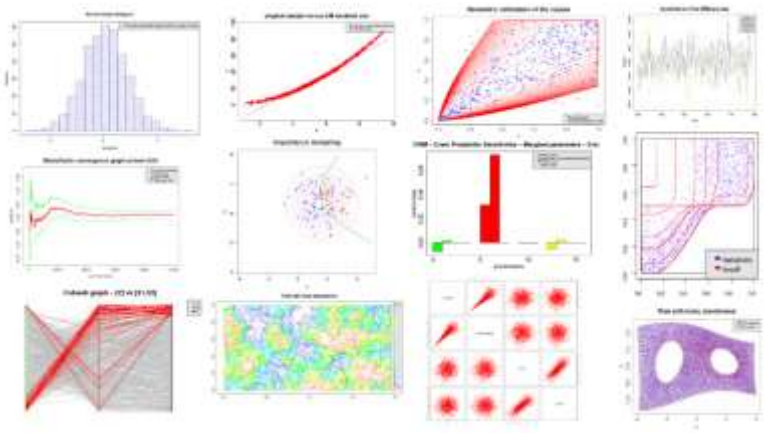
- The probabilistic modelling of a vector is based on a multivariate distribution whose dependency structure is a copula. A mechanism for composing distributions increases the modelling capabilities of the tool, particularly for handling large dimensions. penTURNS can also be used to model processes and fields (Gaussian processes, ARMA, etc.). Multivariate laws and processes can be constructed from data using a wide range of statistical processing functions (parametric and non-parametric adjustments, goodness-of-fit tests, data visualisation graphs, etc.).
- The propagation of uncertainties is ensured by dedicated algorithms, based on massive simulation (Monte Carlo methods and variance reduction methods), optimisation or integration methods, or analytical calculation whenever possible (using the algebra of functions of order 2).
- Prioritisation is quantified by a number of indices specific to propagation algorithms (Sobol indices, FORM indices, etc.).
- The calculation code can be replaced by a meta-model built using deterministic techniques (regression, etc.) or probabilistic techniques (chaos polynomials, kriging, etc.).

The flexibility of openTURNS means it can be coupled with any calculation code, written in any language and of any complexity (Python, C, C++, FORTRAN or any other language).

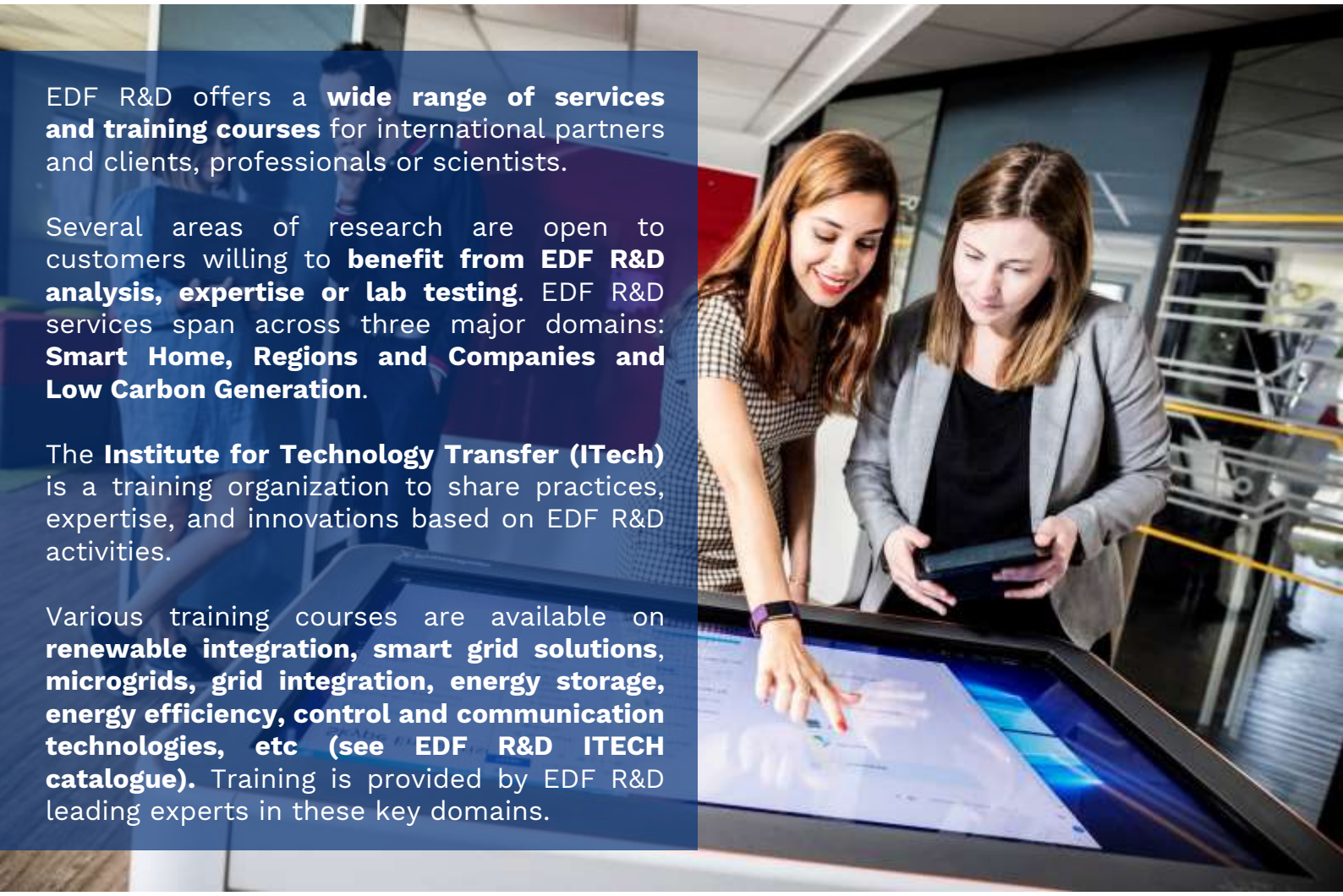
Some industrial applications

OpenTURNS covers a wide range of applications such as:

- Estimation of defect detection probability curves for non-destructive testing process qualification
- Calibration/validation of building heating models
- Modelling by inversion of the Strickler coefficient
- Estimate of flood quantile at each point on the watercourse



OpenTURNS in graphics



EDF R&D offers a **wide range of services and training courses** for international partners and clients, professionals or scientists.

Several areas of research are open to customers willing to **benefit from EDF R&D analysis, expertise or lab testing**. EDF R&D services span across three major domains: **Smart Home, Regions and Companies and Low Carbon Generation**.

The **Institute for Technology Transfer (ITech)** is a training organization to share practices, expertise, and innovations based on EDF R&D activities.

Various training courses are available on **renewable integration, smart grid solutions, microgrids, grid integration, energy storage, energy efficiency, control and communication technologies, etc (see EDF R&D ITECH catalogue).** Training is provided by EDF R&D leading experts in these key domains.

EDF R&D BROCHURE OF SERVICES

Consult the interactive document by clicking on the picture opposite

EDF R&D ITECH CATALOGUE OF TRAINING COURSES

Consult the interactive document by clicking on the picture opposite

EDF R&D: DARE TO LOOK TOWARDS THE FUTURE AND INNOVATE AT PRESENT

EDF R&D carries out **research for all EDF Group entities**, helping them improve performance and prepare the future integrating innovative technologies and solutions.

EDF R&D has **three Labs in France, six abroad** (China, Germany, Italy, Singapore, UK, USA) and a **R&D representative office in Brussels**.

OUR 4 SCIENTIFIC PRIORITIES

1. **DECARBONISING OUR CUSTOMERS' USES THANKS TO ELECTRICITY**
2. **STRENGTHENING THE PERFORMANCE OF OUR GENERATION ASSETS**
3. **INVENTING TOMORROW'S ENERGY SYSTEMS**
4. **ACCELERATING DIGITAL TRANSFORMATION**

EDF Lab's facilities in Saclay, one of EDF R&D research centres.

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