Digital Twin platform for integrated design of tokamak components – case studies on EU DEMO divertor and ITER divertor

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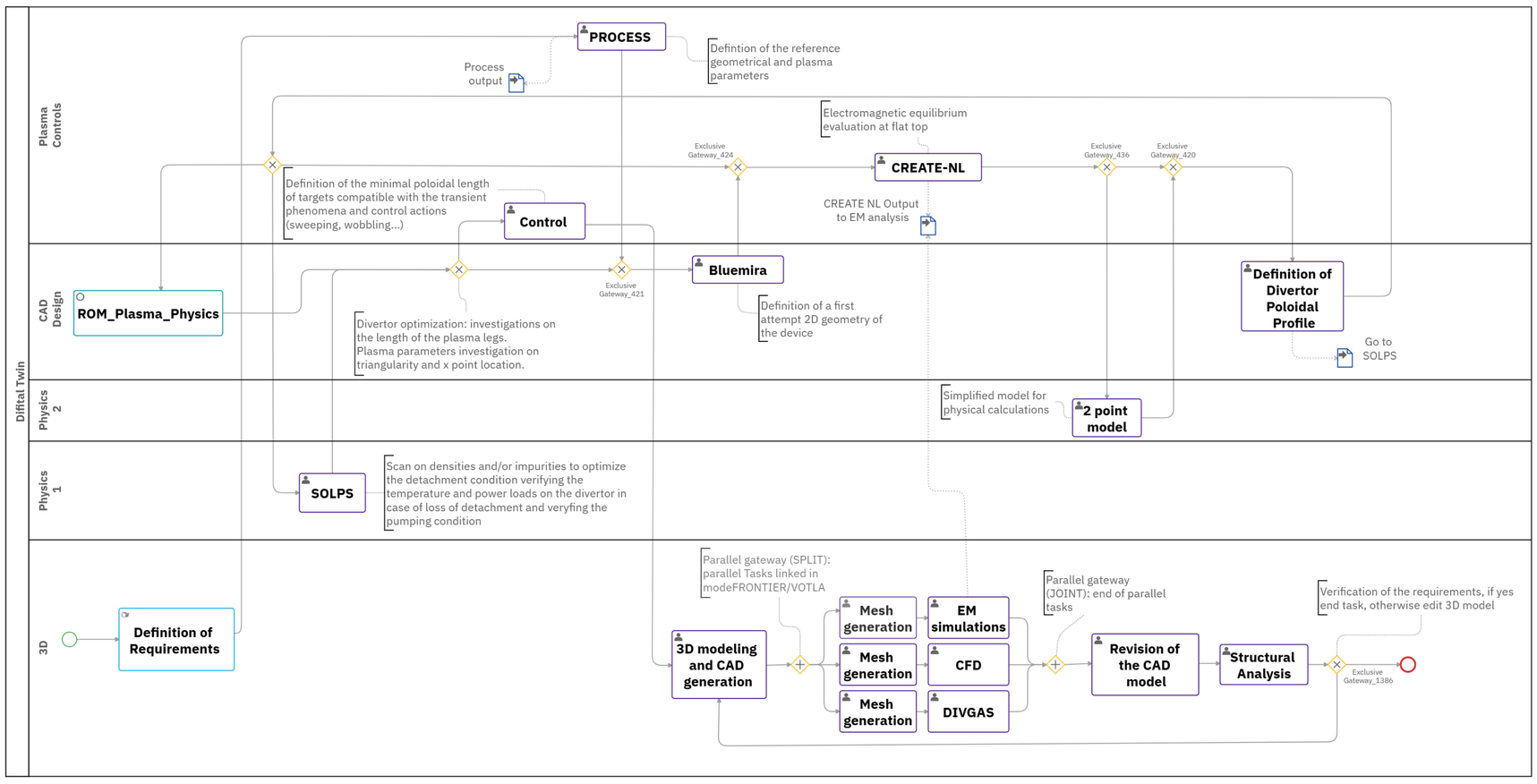


Digital twin:

- **Means:** A virtual representation of a system that faithfully reflects a real object across its full lifecycle, continuously updated in real time and enhanced by simulations, automated learning, and reasoning techniques to optimize design, development, and operation.

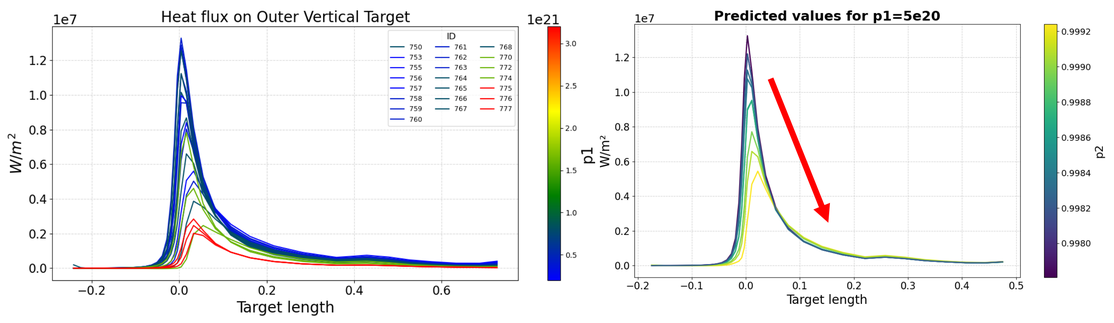
- **Needs:** A digital twin model aims to maintain a close connection between the **real system** and its **virtual counterpart** by integrating and correlating data obtained from both environments. Consequently, a platform capable of supporting simulation sharing, data management, and results visualization is essential. In this context, VOLTA, a Simulation Process and Data Management platform, also provides a dedicated tool for developing BPMN (Business Process Model and Notation) models to track the product lifecycle and the various tasks required to achieve the final product, thereby simplifying process visualization and data exchange.

VOLTA

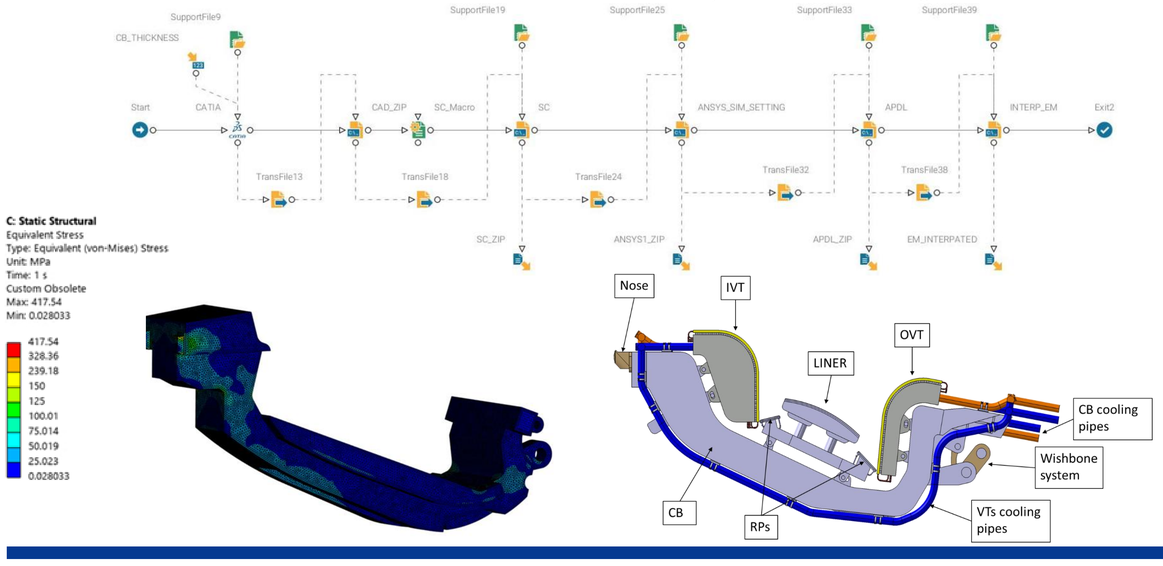
Previous activity 2025:

The activity of the year 2025 considered the EU-DEMO divertor geometry for the development of an infrastructure to manage a “Digital Twin”. In particular, the activities were focused on:

- **Development of a BPMN model:** it graphically summarizes all the sequential operations required for the development of a divertor. The activity is contained within a pool and divided into lanes, which represent the different work teams involved. Within the lanes, the tasks assigned to each team are reported. In this way, the activities are tracked sequentially, as well as the data flow.
- **Generation and Discretization of 2D Geometries for divertor and FW:** An automated workflow was developed to generate and discretize different divertor and first wall geometries, which are then prepared for transfer to the plasma physics group for evaluation.
- **Integration of an ITER-SOLPS Database for the Training of Reduced Order Models (ROMs) Using modeFRONTIER:** the feasibility of integrating an ITER-SOLPS database within modeFRONTIER has been demonstrated to train ROMs using the proprietary romBOX node for the prediction of heat flux under different combinations of two main parameters (the same as those varied in the database).

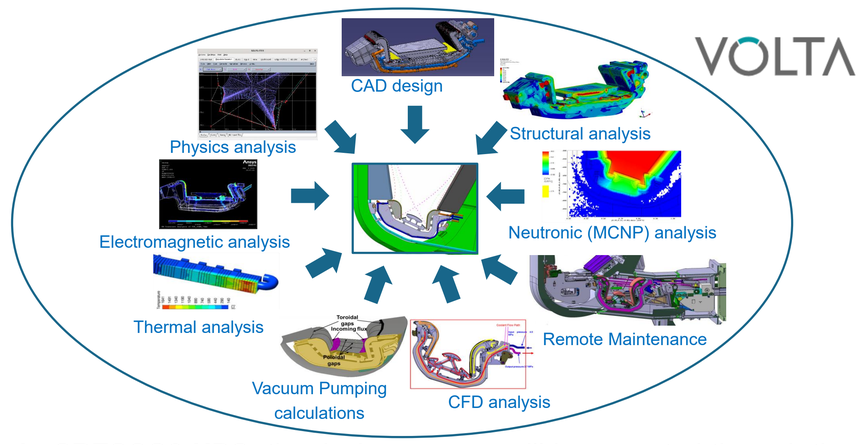


- **Automated Workflow for Structural Analysis Using modeFRONTIER**: an automated workflow has been developed for the generation of different 3D geometries of the Cassette Body of the EU-DEMO divertor. The workflow includes the export of the structural mesh, the interpolation of the EM loads onto the new discretization, and the structural analysis of the resulting model.



Next activity 2026-2027:

- **Complete the integrated Physics/Engineering Simulation Framework started in 2025:**
  - **Developing the physics** area and **improving the engineering** loop areas by means of **Electro-Magnetic**, **Thermo-Hydraulic** and **Vacuum calculations** for **multi-objective optimization**, managed by VOLTA/ModeFrontier, following the BPMN diagram. With such framework, applicable to all main fusion devices’ sub-systems, we would develop and **consolidate a simulation framework** which overcomes main issues experienced in the design process of complex system, like the timely and correct execution of design tasks, the collaboration among different areas and physics domains, the integration of different analysis and data exchange among them (like EM and Thermal loads to structural assessment), the optimization against competing requirements and design needs.



- **Integration in CRESCO8 HPC:** the design process will be executed through the CRESCO system, providing the entire design team with access to the VOLTA platform and enabling calculations on HPC resources.

- **Develop a Digital Twin Environment for the ITER Divertor:** the framework crated in 2025 will be applied to the ITER divertor, with the objective of developing a divertor digital twin environment capable of integrating the input from synthetic diagnostics (e.g.: neutron yield) for the calculation of heat flux on divertor. For this purpose, the possibility of integrating the IMAS database in the framework will be investigated with the advantage of collaboration with IO experts within the IO Science division. The digital twin environment for the ITER divertor will be generated by developing a technical interface between IMAS and VOLTA, to properly access all the relevant data affecting the divertor operation, obtained by SOLPS and ASTRA calculations and by synthetic diagnostic measurements, that include also the bonus of measurement uncertainty.
  - These data will be used to calculate relevant parameters affecting the divertor operation, like *heat* fluxes, *neutron* fluxes and *neutral* pressure in the divertor area.
  - The database on physics calculation will be used to train ROMs.
  - The capabilities of the visualization tools of VOLTA for the simulation results will be investigated.

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