VIVID-DTE - Verification-oriented Interactive Visualisation and Decision support for the Digital Twin Environment

Advanced Interactive Visual Analytics Tools for EUROfusion Digital Twin Environment (DTE)

Leon Kos, Matic Brank, Leon Bogdanović, and Stefan Costea

University of Ljubljana, Mech. Eng., Aškerčeva 6. SI-1000 Ljubljana, Slovenia, leon.kos@lecad.fs.uni-lj.si

EUROfusion research increasingly depends on high-fidelity modelling of plasma physics, materials, and power plant systems. As the Digital Twin Environment (DTE) evolves, researchers and operators must interpret growing volumes of complex simulation and experimental data. Current reliance on static figures and offline post-processing limits situational awareness and slows model validation and verification (V&V). This project develops next-generation visualisation tools that turn data into interactive, intuitive, and actionable insight.

Introduction

3D scientific visualization in HPC environments is a topic that ranges from post-processing (on dedicated visualization clusters) to in-situ code instrumentation. Often, 3D visualization is based on multi-layered data access frameworks that need custom plugins to be developed for specific codes. Interfacing fusion codes in EUROfusion Code Development for Integrated Modelling is based on IMAS IDS standardized data structures that describe various physical aspects of fusion experiments and are designed to be suitable for use with simulation codes and experimental data. Integration with IMAS thus brings a common data model to integrated simulations that allows direct comparison with experiment, use of experimental data as an input or mixed approaches.

Motivation

Existing workflows create bottlenecks for V&V and data interpretation. The project addresses this by delivering interactive, real-time visual representations of simulation outputs, supporting data assimilation, improving cross-disciplinary collaboration, and enabling multi-user exploration and annotation.

Approach, Novelty & Inovation

The work combines geometry-aware pre-/post-processing (SMITER/SALOME) with interactive multi-resolution 3D and time-dependent visualisation, synthetic–experimental data overlays, and a drag-and-drop workflow designer. A persistent multi-scale communication layer based on the IMAS data model enables visualisation tools to operate in situ within simulation workflows. Users can build reusable dashboards and analysis workflows without coding, stored as portable study files or linked to IMAS/UDA services. This shifts analysis from static post-processing to integrated, real-time visual analytics, shortening V&V cycles and enabling operator-in-the-loop decision support.

Impact

The tools will accelerate model convergence, improve detection of off-normal conditions, enhance system-level understanding, and support knowledge transfer through shareable, reproducible visual workflows. The modular framework is designed for uptake across DTE activities, TSVVs, and related EUROfusion projects.

Aims & Objectives

Build user-centred visualisation stack for DTE supporting rapid V&V and decision support.

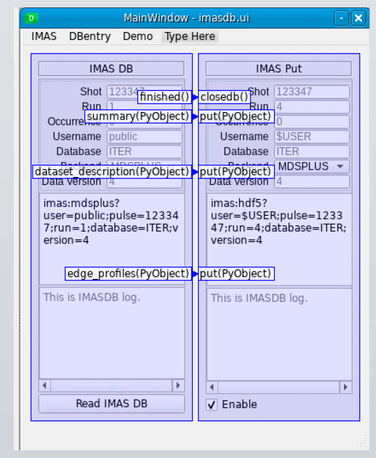
O1. Unified visual analytics (Muscle3-linked 3D/temporal + IMAS-ParaView)
O2. PySide6/QtDesigner no-code workflow interface
O3. Operator decision-support dashboards
O4. Robust V&V toolchain with overlays & provenance
O5. FAIR/IMAS-aligned interoperability

System Architecture

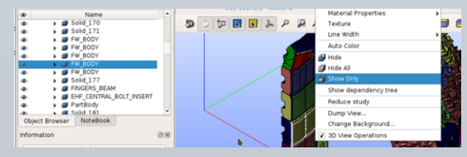
Develop IMAS-aligned adapters for SMITER/SALOME, plant models, diagnostics, and experimental data, supporting multiple formats (HDF5, NetCDF, EQDSK) and study-level storage with provenance. Implement in-situ and GPU-accelerated processing, interactive 3D visualisation, and operator dashboards for KPIs, alerts, and scenario replay, all accessible through a no-code workflow/UI framework.

Core Visual Analytics Methods

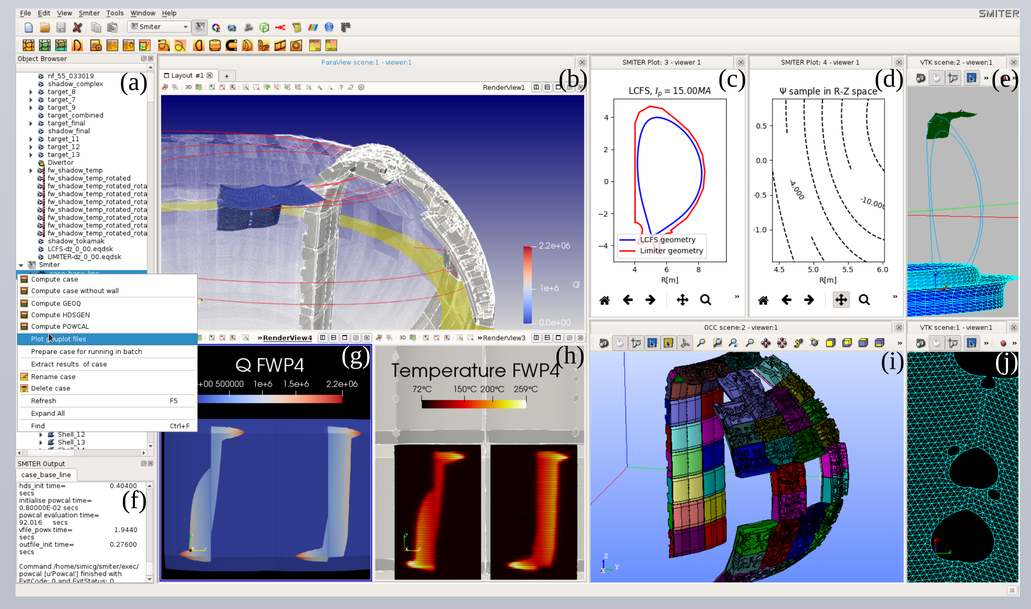
Enable linked-view analytics, cross-filtering, uncertainty-aware rendering, and synthetic–experimental overlays with automated alignment. Ensure high performance for large datasets, human-centred design, and reproducibility through study-level storage of configurations, data sources, and derived results.



(a) IMAS Database integration with signal-slot processing using Qt Designer and custom widgets.

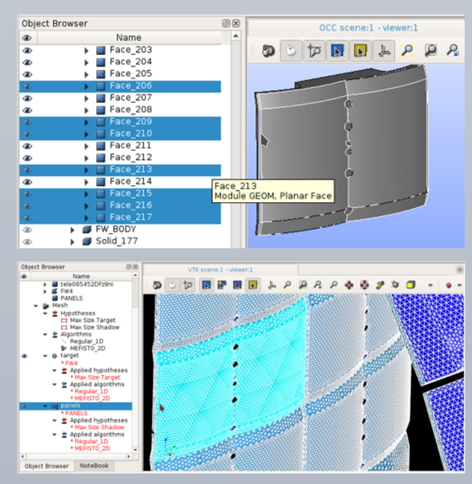


(b) CAD integration (CSG and parametric) for defeaturing

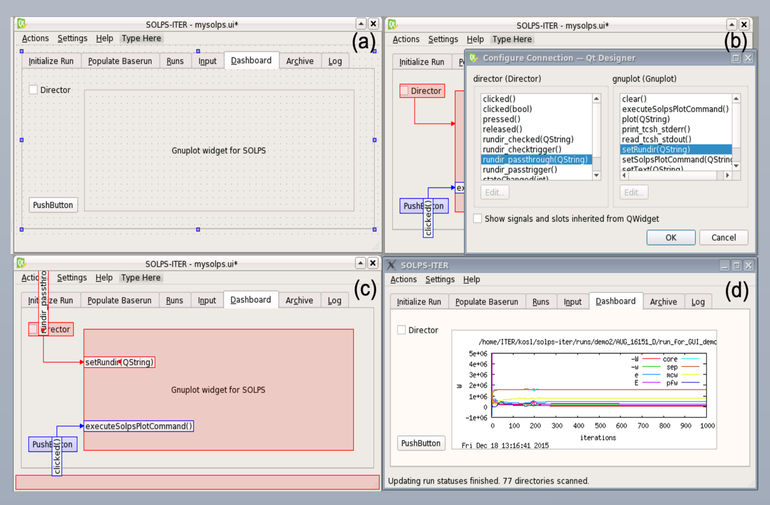


SMITER & SALOME Integration

Support direct ingestion and export of SMITER study files while preserving cases and parameters, and enable geometry-aware visualisation on CAD/mesh data. Provide both batch and interactive execution with persistent study files for seamless visualisation during and after simulations.

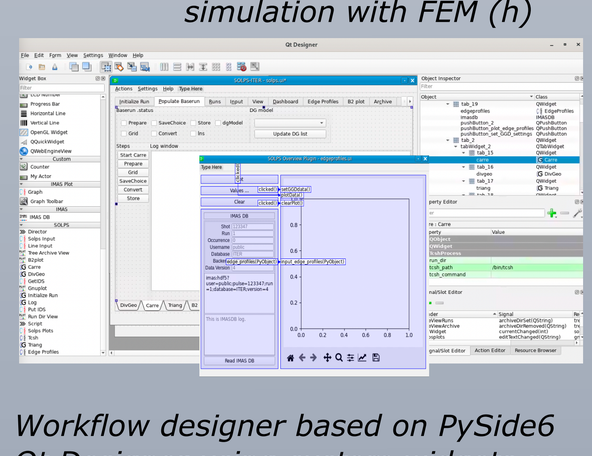


(i) Meshing panels for heat flux (g) and temperature simulation with FEM (h)



Workflow Designer Environment

Deliver a drag-and-drop workflow interface with modular widgets for data access, analytics, visualisation, and export, supporting signal/slot execution. Ensure full reproducibility of dashboards and workflows via saved UI/XML study definitions.



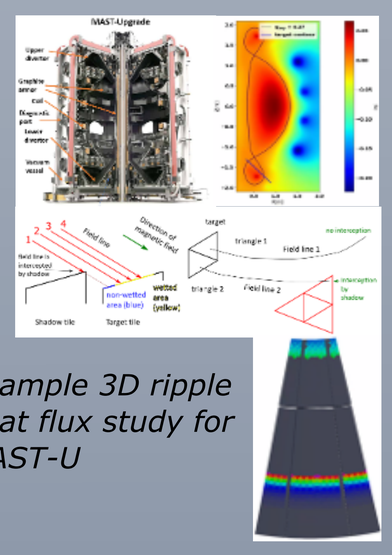
Workflow designer based on PySide6 Qt Designer using custom widgets as IMAS actors. No coding of workflow!

Digital Twin Integration

Enable tight feedback loops between data, models, and operators, providing configurable geometry-aware overlays and KPIs to support situational awareness in the DTE.

Exploitation, Maintenance & Dissemination

Deploy the framework within DTE infrastructure with integration guidance, establish maintainability practices including CI and documentation.



Example 3D ripple heat flux study for MAST-U

Engineering design and supercomputing laboratory

University of Ljubljana Faculty of Mechanical Engineering

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