

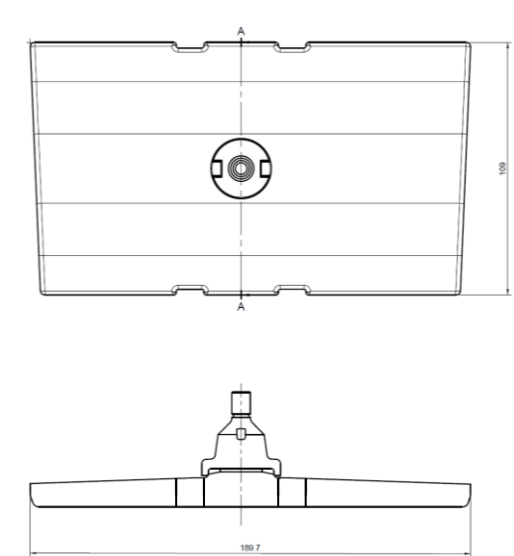
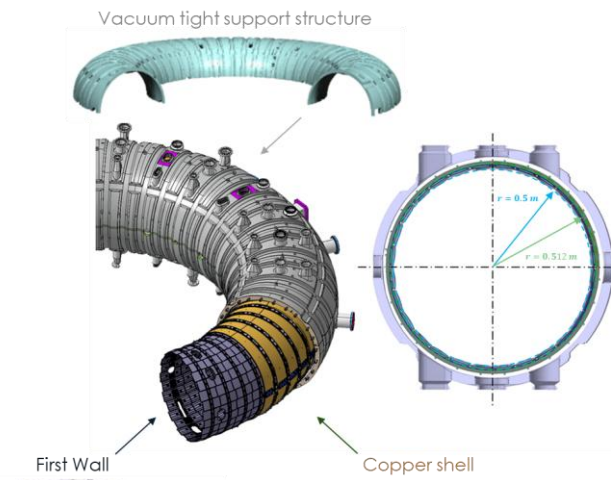
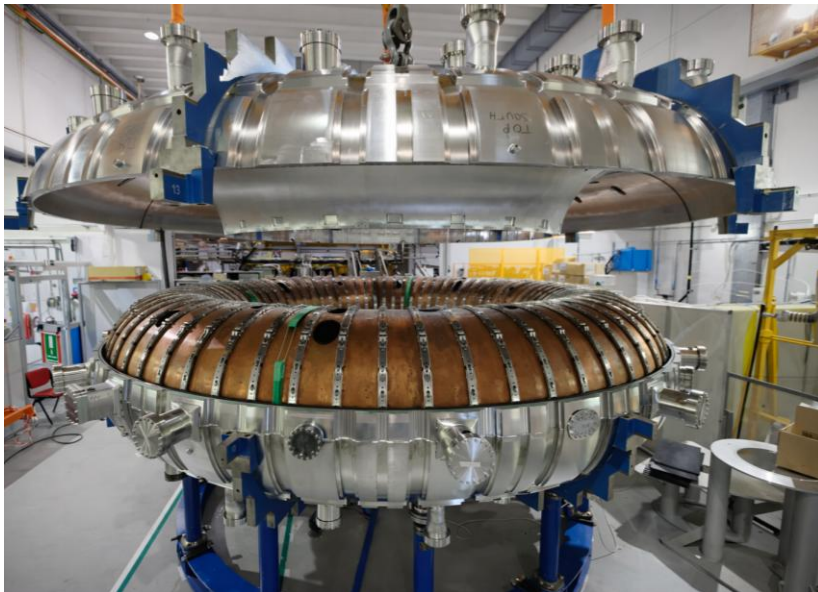
Remote Handling in Fusion Reactors: the RFX-mod2 Challenge

RTDA

Giuseppe Andrea Fontanelli

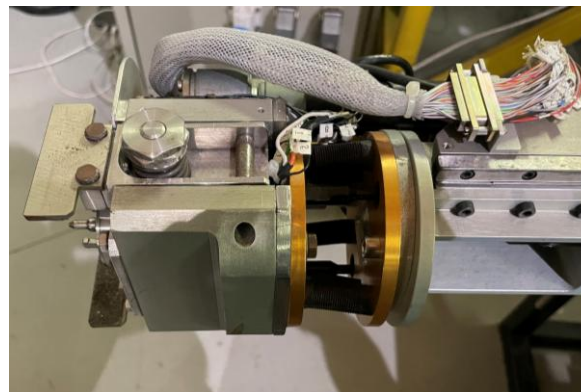
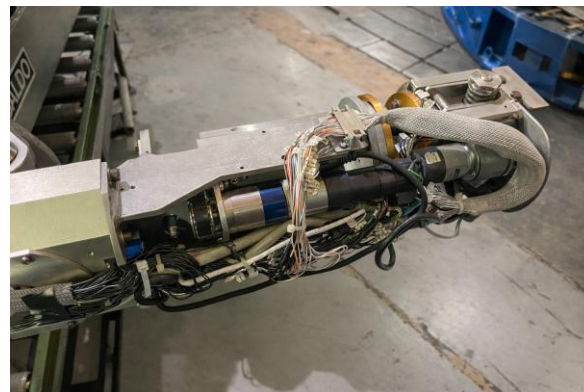
The RFX-mod2 fusion reactor

- RFX-mod2: requires periodic first-wall maintenance (graphite tile replacement)
- Internal access limited to **150 mm circular ports** — direct human intervention not feasible
- Tile engagement/disengagement requires ≥ 150 N axial force with millimetre-level positioning accuracy
- Operations demand a **high-dexterity**, remotely operated manipulator capable of operating through port constraints
- A dedicated training facility is essential to qualify operators and validate procedures before live interventions on the machine



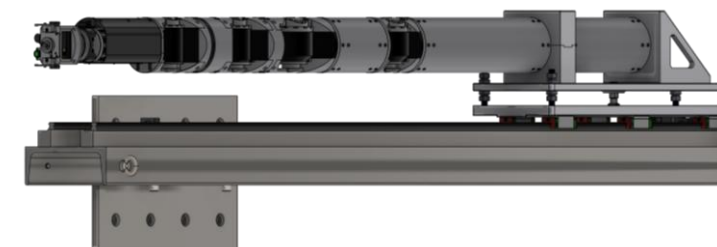
Existing manipulator: Identified Limitations

- Existing manipulator designed in the 1980s for a previous reactor configuration
- **Mechanical backlash** in joints reduces the positioning accuracy
- Complex, wiring harness due to **external power and control electronics** reflects in poor maintainability
- Not redundant **6-DOF** kinematics does not permit reconfiguration to reduce joints torque
- **Complex conical gears** transmission mechanism
- **Reduced stiffness for the joint 5** and required **counterweight**
- Mock-up not representative of the updated first-wall geometry

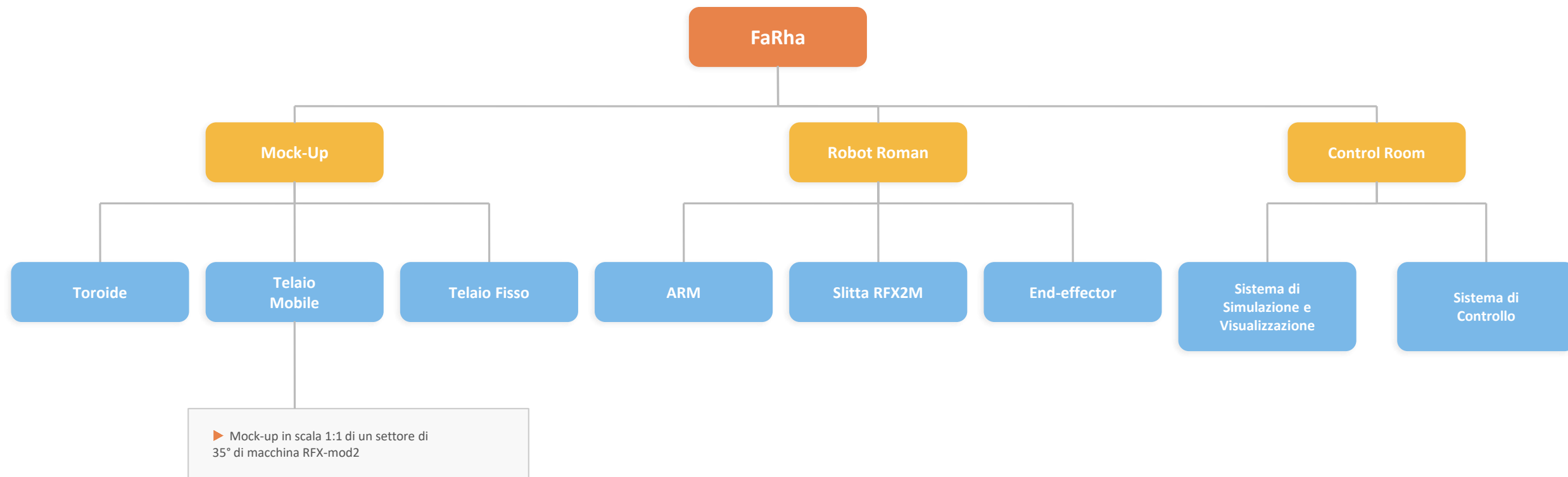


New Manipulator Design: Key Engineering Solutions

- **Integrated actuators** — transition from separate motor, gearbox, encoder and bevel transmission assemblies to compact units integrating motor, harmonic drive reducer, and power/control electronics
- **48 V power bus + EtherCAT daisy-chain** — simplified wiring architecture replacing the complex legacy harness;
- **7-DOF redundant kinematics** — additional degree of freedom improves dexterity in confined tokamak geometry and enables null-space posture optimisation
- **Revised joint 5/6 axis sequence** — swapped rotation axes provide a stiffer joint 6, reducing mechanical compliance at the wrist compared to the existing design;
- **Lightweight aluminium structure** — tube-and-connector frame reduces arm mass while maintaining structural stiffness
- **2D/3D vision in end-effector** — integrated vision sensors for tile localisation and alignment during manipulation task;
- **Improved calibration system** — dedicated calibration mechanism accounts for all 3D rigid-body displacements between the arm base and the access port
- Use of a **backdrivable** joint solution for all joints except J5 to allow a manual extraction of the arm in case of **failure**



FaRha Training Facility: System Architecture



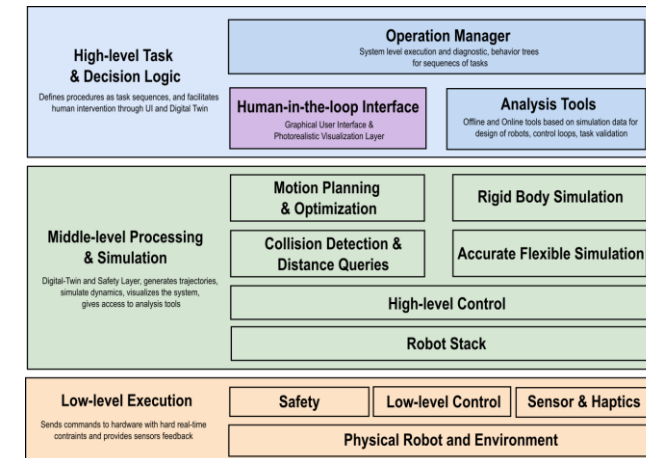
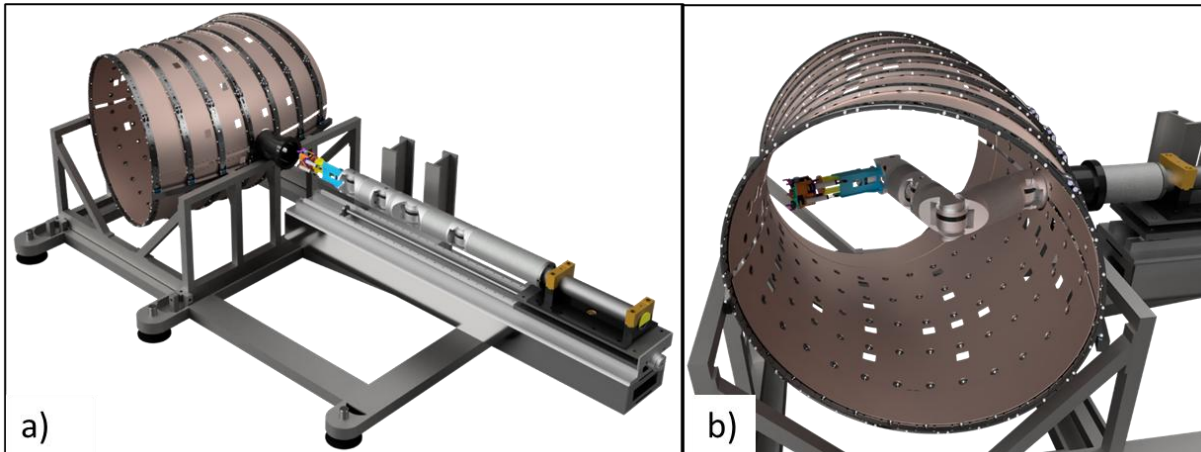
Conceptual Design: Mechanics and Control Room Software

Mechanical design (PhD Salvatore Fusco)

- 7-DOF kinematic architecture with redundancy for tile removal dexterity
- Joints design, actuators selection, end-effector layout and slide integration
- Requirements-driven design feeding into Sophia High Tech specifications

Control Room software (PhD Alessandro Sofia)

- Motion simulation & path planning
- Digital twin for offline trajectory verification including flexibility at joints and link side
- Virtual reality environment for immersive operator training
- Teleoperation with supervisory control



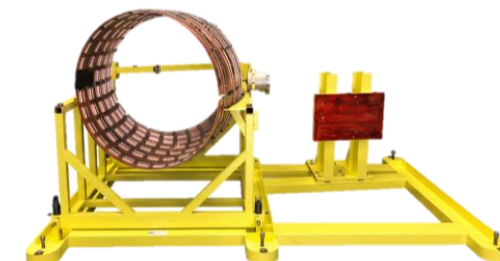
Executive Design: Industrial Partners

- Technical specifications developed internally from project requirements
- Continuous technical supervision throughout executive design phase

Mechanical & electrical executive design, manufacturing of the ROMAN manipulators

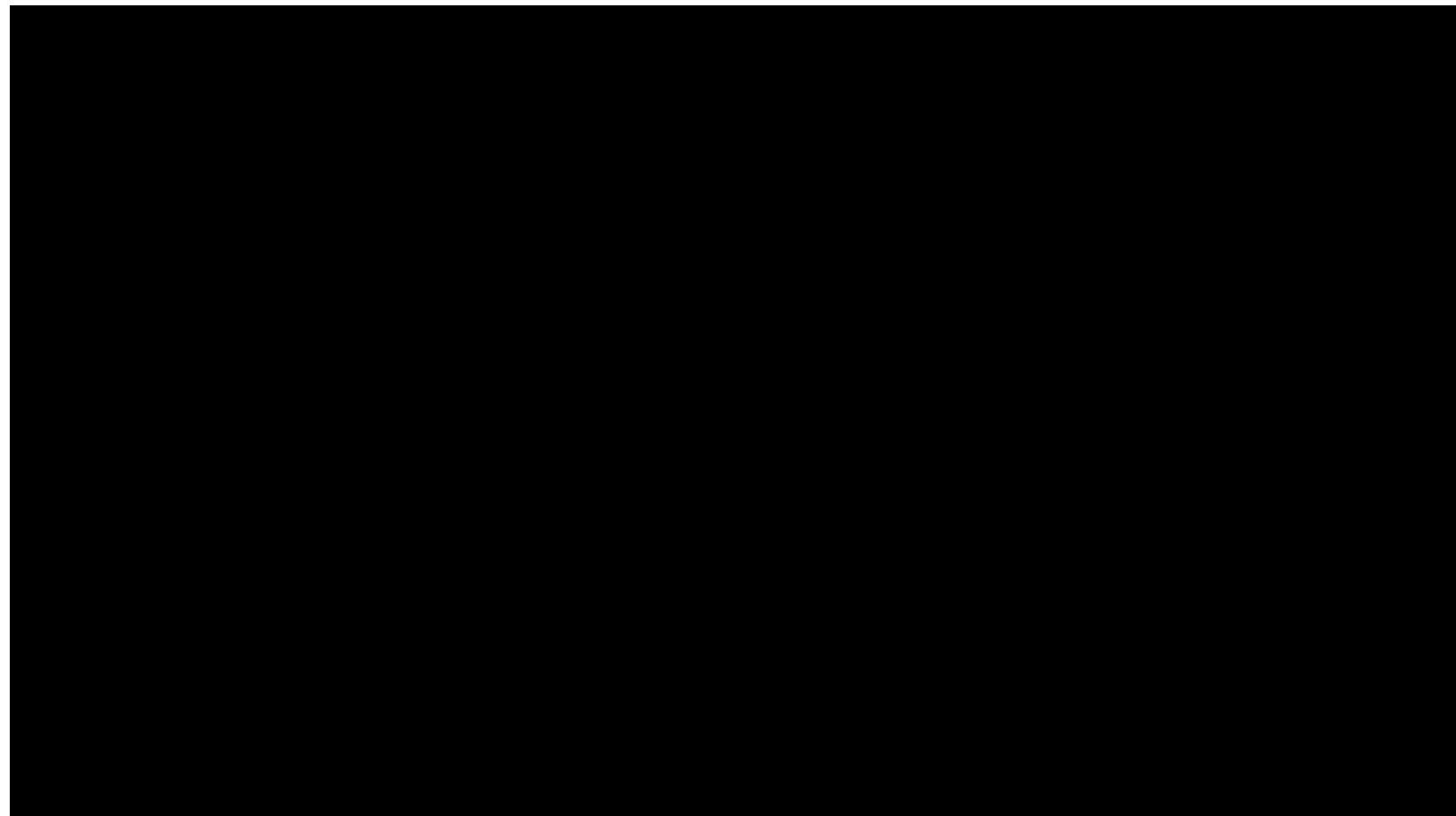


Structural executive design, precision machining of the Mock-up



First Results and System Validation

- ROMAN manipulator manufactured and functionally tested
- 7-DOF kinematics verified
- Control room integration validated in preliminary trials

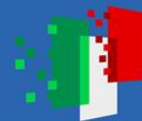




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Nefertari

Thank You!



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