

1) Why the INCOSE Foundation/ Stevens Ph.D. Award should be given to me

My doctoral research is based on the hypothesis that integrating Concurrent Engineering (CE), Model-Based System Engineering (MBSE), Data-Driven (DD) approaches and Design for Testability (DfT), into a unified framework can significantly improve the efficiency, reliability, and sustainability of complex space systems design and development through the product full life-cycle. By embedding testability principles directly in the loop, system architectures can be validated earlier, risks reduced and verification streamlined across all lifecycle phases.

Approach: My research adopts a multi-layered and iterative approach, designed to progressively integrate CE, MBSE, DD, and DfT into a harmonized framework. This approach is not only theoretical but is validated through academic case studies [1][2][3] and will be tested in an operational environment in the Concurrent Design Facility (CDF) at ESA ESTEC center, as part of Open Space Innovation Platform (OSIP) visiting research project [4] starting from October 2025.

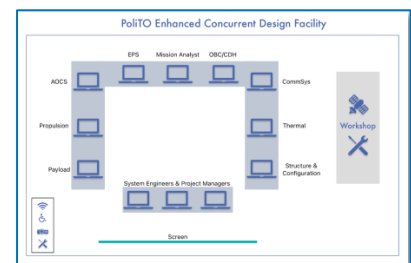
The methodology is articulated in four complementary pillars:

(1) **Database-driven Knowledge Management**, including the development of a relational Space Mission and Systems Database, covering missions, systems, subsystems and components, implemented in MySQL [3]. The database ensures design traceability, reuse and consistency, serving as a repository with dual usage (top-down and bottom-up access) supporting feasibility studies, subsystem sizing and component selection based on validated data.

(2) **Concurrent Model-Based System Engineering**, to extend the MBSE application into concurrent facilities, both internally in the PoliTo CubeSat Concurrent Design Facility [1][2][3] and in the ESA ESTEC CDF [4]. This ensures that system models are created and iterated in real time by multidisciplinary teams. The framework emphasizes (i) the *early identification of design conflicts*, thanks to parametric models and real-time feedback loops; (ii) *continuous refinement of system budgets and analysis* across disciplines to maintain coherence; (iii) *collaborative trade-offs*, where decisions are made transparently and supported by quantitative analysis; (iv) *integration of dynamic simulation environments*, so each design choice and operation strategy is tested against realistic mission scenarios. Coupling of tools – Capella/SysML (for MBSE), COMET (for CE), Valispace (for DD), Matlab and Python – is performed through semantic mediation to ensure interoperability and continuity [5].

(3) **Design for Testability in the loop**, means embedding testability as a first-class design driver, not as a downstream activity. Each iteration of the product development incorporates observability, controllability, and verification pathways in the trade-off process, ensuring the system is not only functional but also testable both in the lab and in orbit. This is performed through (i) systematic integration of *Verification & Validation* (V&V) activities in the CE-MBSE, thanks to a set of procedures and best practices, and the explicit allocation of testability requirements at mission, system, and subsystem level; (ii) development of an *add-on* module, currently under development, which integrates DfT metrics into CE-MBSE workflow compatible with the general framework toolchain and future standards.

(4) **Validation through Case Study and Institutional Collaboration**, as the framework is being validated through academic and research case studies and will be industrially validated in ESA during my OSIP. This ensures that the methodology is tested in a state-of-the-art operational environment, with feedback from ESA experts, and that its outcomes are aligned with European efforts in digitalization and MBSE adoption.



The expected outcome of my PhD is therefore the definition of a scalable and reusable CE-MBSE-DfT framework supported by validated tools, open-source modules, and best practices. This framework will enable faster and more reliable mission design and system development and operation, ensure verification-aware digital continuity across all lifecycle phases, and contribute to the evolution of system engineering standards, through direct validation at ESA CDF and dissemination in academic and professional communities. In this instance, I am uniquely positioned to deliver this vision thanks to my combined experience as a past *ESA Graduate Trainee* (2022-2023), a *PhD researcher* (2023-now) at Politecnico di Torino and the recipient of an *ESA OSIP Visiting Research grant* that will validate the methodology directly at ESTEC CDF.

2) What my research will contribute to Systems Engineering and Integration

My research contributes to the scientific foundations of systems engineering by formalizing a harmonized CE-MBSE-DfT framework that integrates data-driven decision-making and verification loops directly into the concurrent workflow.

The novelty specifically lies in two main critical aspects.

On one hand, the explicit integration of MBSE and Concurrent Engineering disclose the full potential of both methodologies, as they are highly complementary. CE accelerates early-phase design by fostering multidisciplinary collaboration and rapid iteration, while MBSE ensures digital continuity, traceability, and formal requirements management. When combined, they enable a seamless design process that is simultaneously fast, rigorous, and resilient across the lifecycle. However, this integration is not straightforward and, if we focus on how MBSE is currently often implemented, this is not fully implemented at its full capacity with dynamic modeling. By integrating dynamic simulation with the modeling capacity and philosophy of MBSE, it transforms into a **decision-support and validation**, not just a representational framework, especially when coupled with Concurrent Engineering.

On the other hand, current methodologies often separate design from verification, creating a gap between early-phase feasibility studies and subsequent testing and validation. My work bridges this gap by incorporating testability metrics as design drivers from the earliest phases. This establishes a theoretical foundation for “verification-aware system design.”

In addition, two additional key improvements boost the novelty of this work.

Firstly, by developing a relational *Space Missions and Systems Database* [3], the research demonstrates how structured knowledge management can support design traceability, mission-to-component alignment, and systematic reuse of data. This provides a contribution to the integration of databases and system models within system engineering.

Additionally, the research builds on *knowledge transfer*, in particular from unmanned space systems (main field of expertise) to human spaceflight design [6], including space stations, habitats and crew modules, as this is critical to advance safe and efficient space exploration. The structured CE-MBSE methodology usually applied to satellite programs, when transferred and adapted to human-centered design, enables the systematic capture, reuse and tailoring of design knowledge, processes, and verification techniques. In this context, the human is considered as the payload, deriving requirements and constraints in a way similar to payload-driven system design. MBSE supports this process by enabling early validation of human-system interaction and modelling operational scenarios. At the same time, CE promotes real-time interdisciplinary collaboration, ensuring that human-centered requirements are integrated from the earliest stage of the design.

Therefore, my research supports the advancement of the body of knowledge in the system engineering and integration domain by embedding testability into concurrent model-based system engineering and by demonstrating the value of database-driven, simulation-integrated MBSE. I aim to advance the state of

Serena Campioli 2026 INCOSE Foundation/ Stevens Doctoral Award application

practice by delivering validated tools, as well as workflows and best practices tested both in academia and ESA's operational environments. This vision is realized following the Open Source philosophy: the first released of the framework is available in a GitHub repository entitled MOSAiC – *Modeling & Simulation Architecture for integrated Complex systems* [7], a Python-based framework that bridges (as of now) Capella system models with GMAT simulations, enabling automated data extraction, scenario simulation, and result visualization for space system architectures. By making the tool publicly available, I ensure accessibility to both expert practitioners and students, lowering barriers to entry and fostering reproducibility. I strongly believe in the importance of promoting transparent, reusable and community-driven science. Open-Source tools such as MOSAiC can accelerate the dissemination of CE-MBSE best practices, support cross-institutional collaboration, and provide a common ground where academia, industry, and agencies can converge to co-develop the next generation of systems engineering frameworks.

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