

Expériences et défis scientifiques des jumeaux numériques

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Agility and safety in the development of complex software-intensive systems

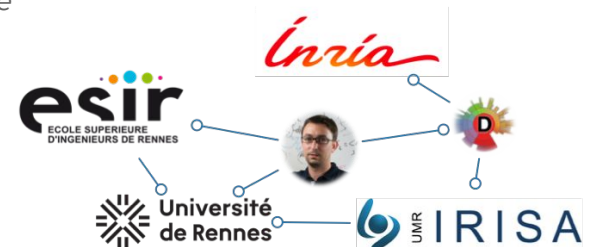
Research interest in Software and Systems Engineering, incl.: Model-Driven Engineering, Software Language Engineering, Domain-Specific Languages, Software-Product Lines, Software Validation & Verification, Resilience Engineering, Scientific Computing, Sustainable Digitalization, ICT for Sustainability.

Application domains: (smart) cyber-physical systems (transport, defense), internet of things (telecommunication, cities/farming, industry 5.0) and environmental sciences (climate change, sustainability).

Editor-in-Chief of the Journal on Software and Systems Modeling (SoSyM), Spring Nature
Editor for the JOT (former Deputy Editor-in-Chief) and SQL Journals
Steering Committee member of the MODELS, SLE and ICT4S conferences

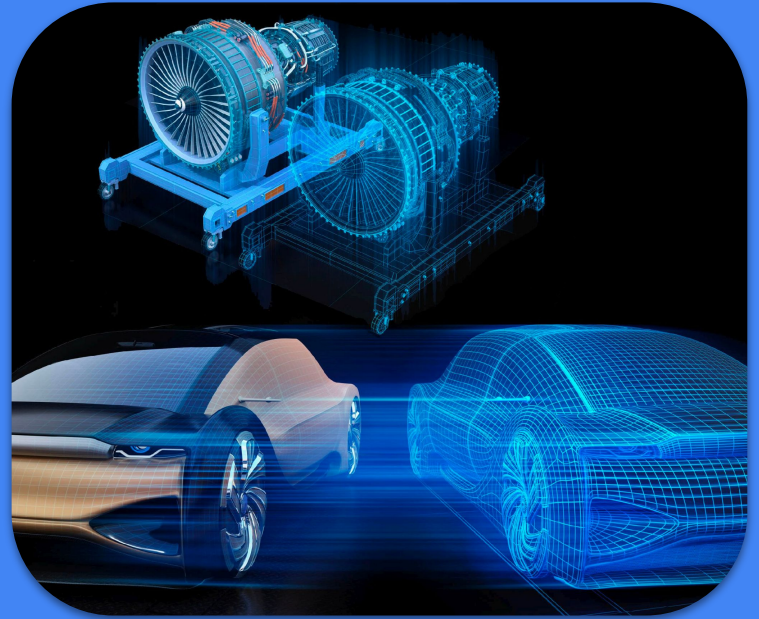
Chief Science Advisor at TwiinIT
Scientific Advisor in Software and Systems Engineering
Collaborations with Airbus, Safran, Thales, Orange, CEA, DGA, Obeo, Akka...

Working group and open-source project leader at the Eclipse Foundation



Digital Twins

C'est quoi ?



A Simple Truth about Digital Twins

A digital twin represents a system

Is it **always one**?
Can there be many?

Digitalization entails abstraction: how much can we abstract?

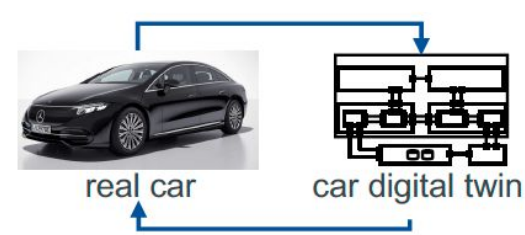
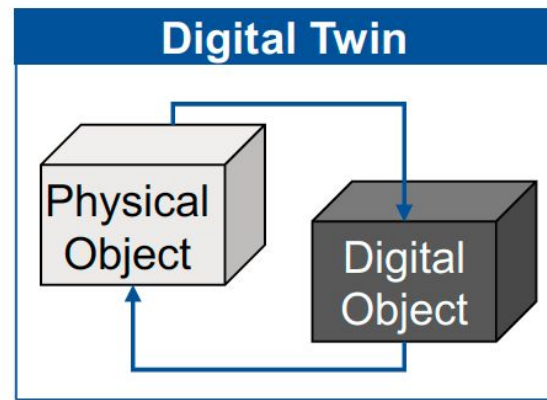
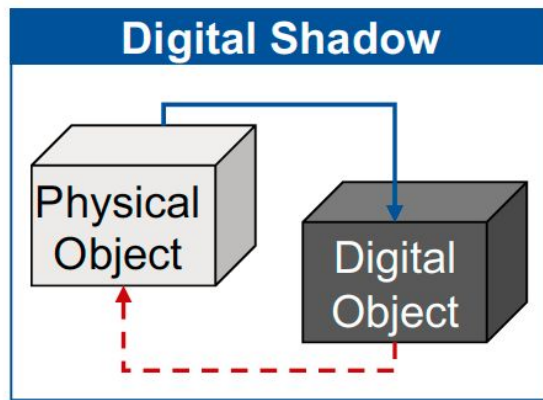
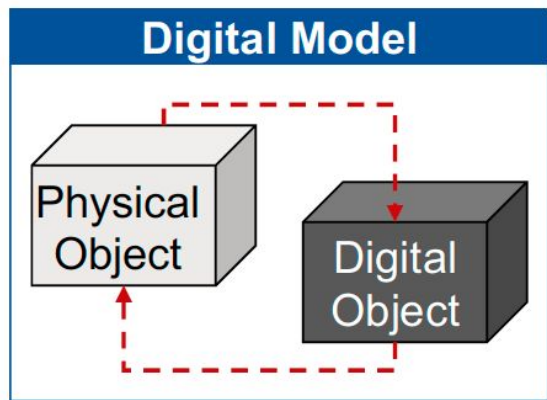
What does it mean to be a **twin**?

Is this the only **purpose**?

A **single one**? Many? Systems-of-systems? Does the system need to exist already?

Does it need to be a CPS? **Process twins**? **person twins**?

DT: A Characterization Based on Data Flows



- - - -> Manual Data Flow

————> Automated Data Flow

DT: “Une Définition de l’AIF”

- Collectif d’industriels et d’académiques réunis autour du Jumeau Numérique
- ~1 réunion par mois depuis fin 2020
- Copilotage
 - Olivier SCART Olivier.SCART@3ds.com
 - Ariane PIEL Ariane.PIEL@cea.fr
- Publication :
« Le Jumeau Numérique, levier majeur de la transformation digitale de l’industrie »
Définition, cartographie de cas d’usage, et création de valeur

1 Un Jumeau Numérique est un **ensemble organisé de modèles numériques** représentant une **entité du monde réel** pour **répondre à des problématiques et des usages spécifiques.**

2 Le Jumeau Numérique est **mis à jour par rapport au réel,** à une **fréquence** et une **précision** adaptées à ses problématiques et à ses usages.

3 Le Jumeau Numérique est doté d’**outils d’exploitation avancés** permettant notamment de :



comprendre



analyser



prédire

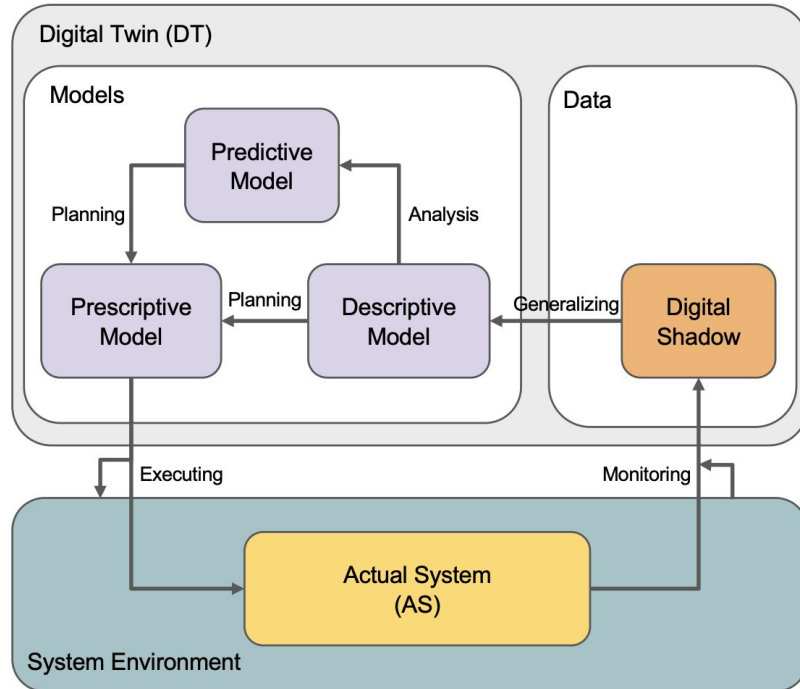


optimiser

le fonctionnement et le pilotage de l’entité réelle.

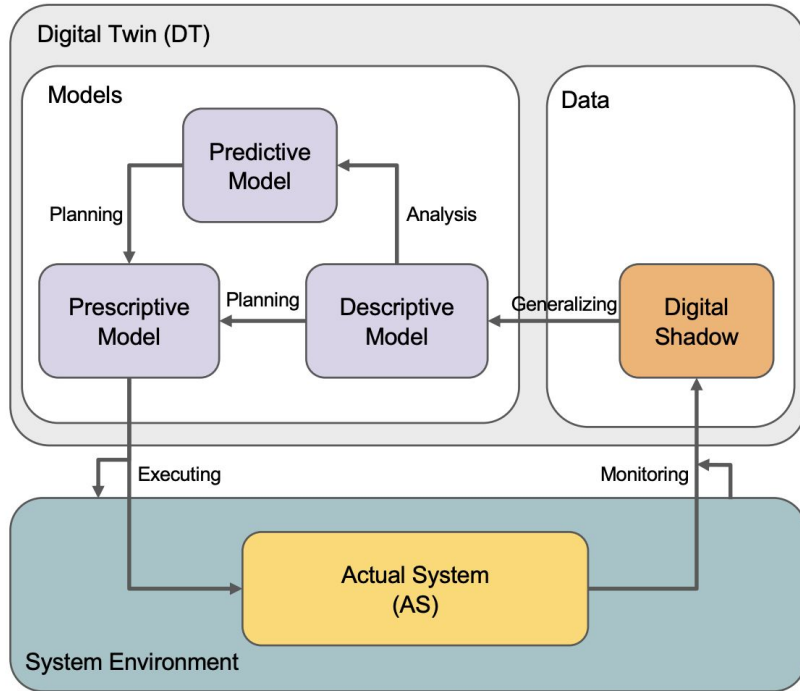


Model-Driven Digital Twin Engineering

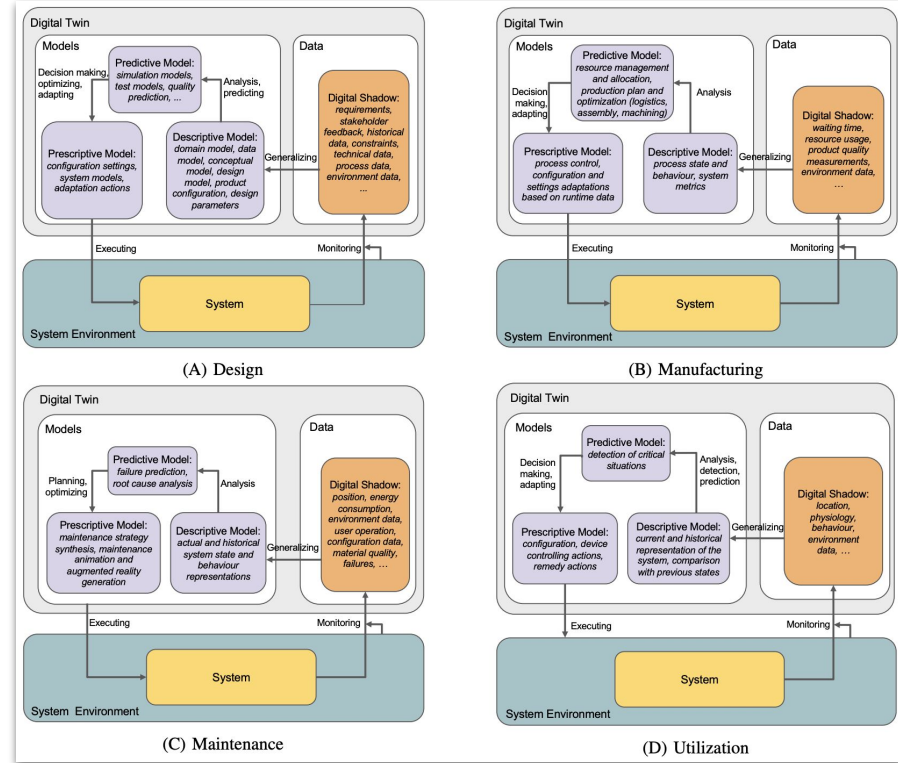


Conceptualizing Digital Twins. Romina Eramo, Francis Bordeleau, Benoit Combemale, et al.. IEEE Software, March-April 2022, pp. 39-46, vol. 39.

Model-Driven Digital Twin Engineering



Conceptualizing Digital Twins. Romina Eramo, Francis Bordeleau, Benoit Combemale, et al.. IEEE Software, March-April 2022, pp. 39-46, vol. 39.



Model-Driven Digital Twin Engineering

Approach:

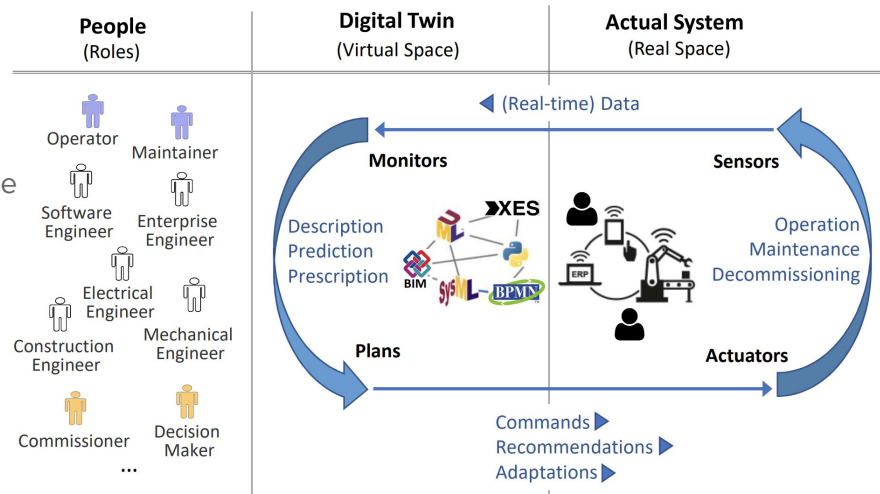
- Modeling continuum across the supply and value chain
- model transformation chain from design models to models@runtime

Opportunities:

- Systematically managing heterogeneous models
- Bi-directional synchronization with the actual system
- Collaborative development throughout the system life-cycle

Modeling challenges:

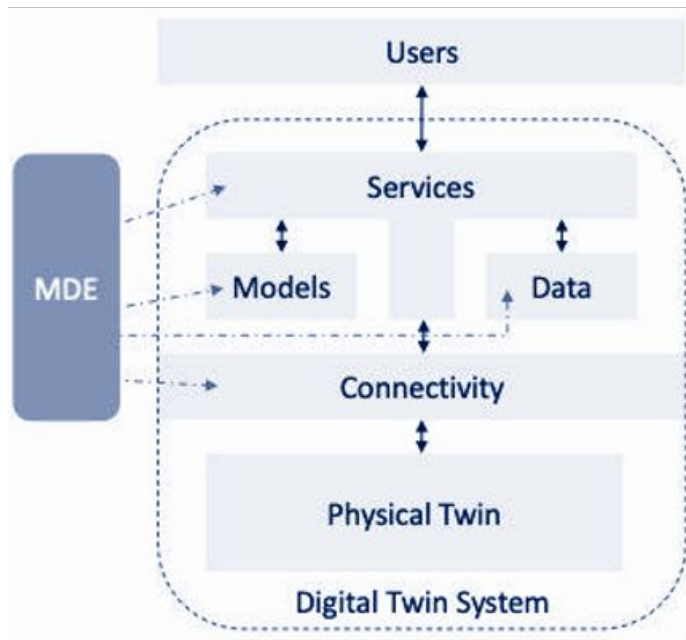
- Modeling Languages for Digital Twins
- Architectural Framework for Digital Twins
- Openness and Sustainability
- Uncertainty
- Design Space Exploration
- Inconsistency Management
- Model evolution and coevolution
- Models AND Data



**Towards Model-Driven Digital Twin Engineering:
Current Opportunities and Future Challenges.**

Francis Bordeleau, Benoit Combemale, Romina Eramo, et al.. ICSMM 2020.

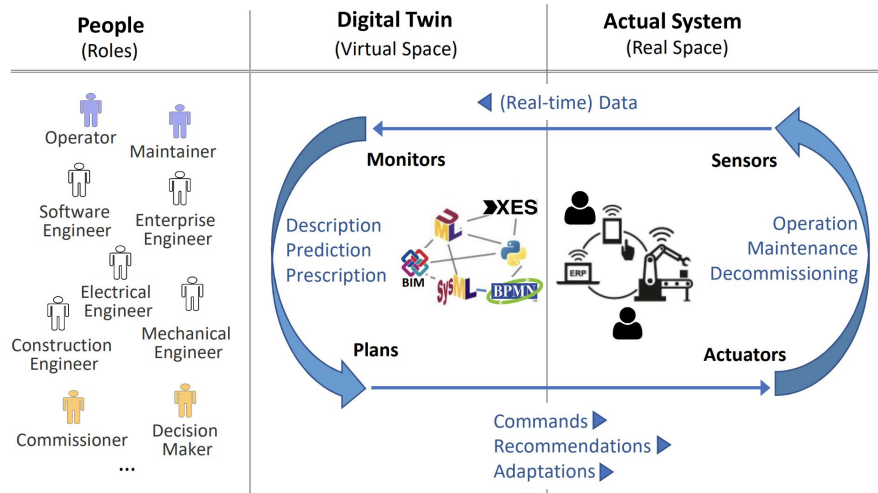
Model-Driven Digital Twin Engineering



Model-Driven Engineering of Digital Twins.

Dagstuhl Seminar #22362, 2022.

<https://www.dagstuhl.de/22362>

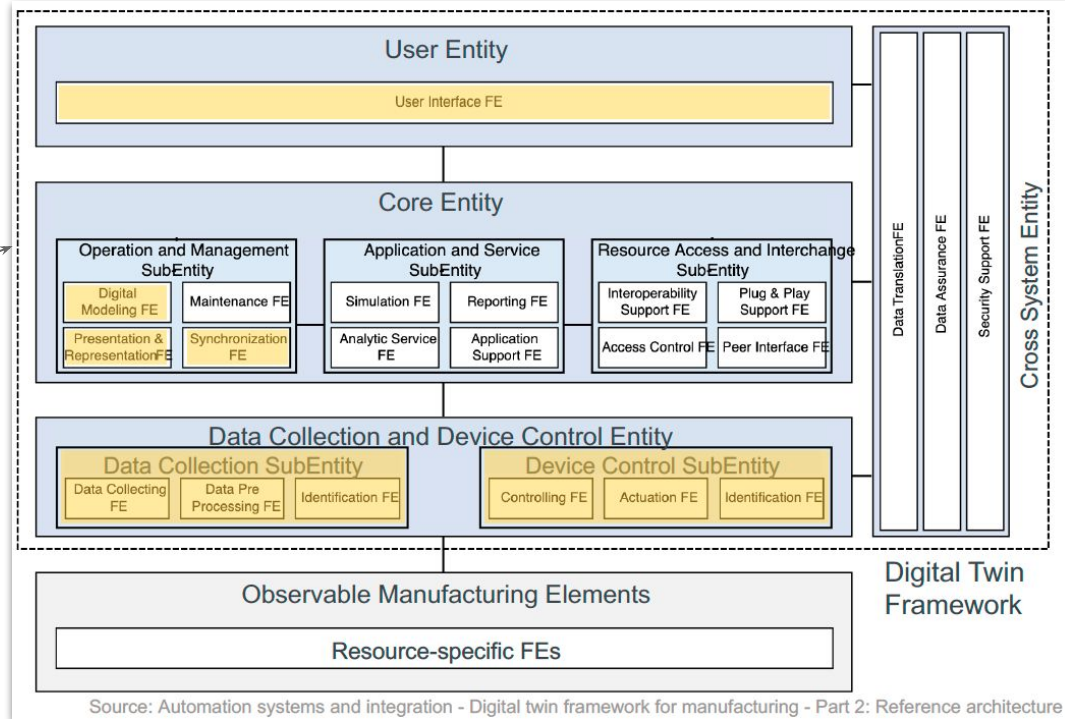


Towards Model-Driven Digital Twin Engineering: Current Opportunities and Future Challenges.

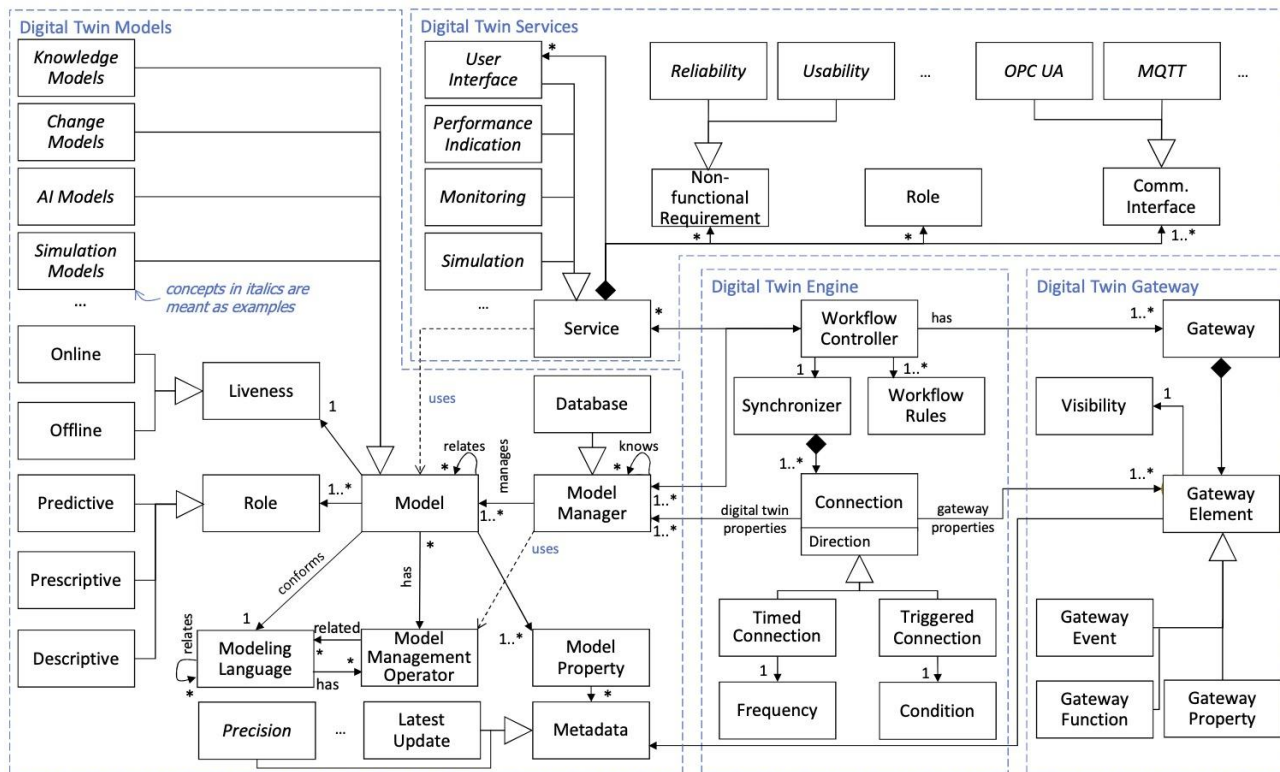
Francis Bordeleau, Benoit Combemale, Romina Eramo, et al.. ICSMM 2020.

DT Framework for Manufacturing (ISO 23247)

- Published in 2021
- Part 1: Overview & general principles
- Part 2: Reference architecture
- Part 3: Digital representation of manufacturing elements
- Part 4: Information exchange



Towards an unifying conceptual model...



A Conceptual Model for Composable Digital Twins. WIP.

Take-away message

“A digital twin is a software system using data, models, and services to purposefully represent and manipulate its original CPS.”

(borrowed from A. Wortmann)

Digital Twins

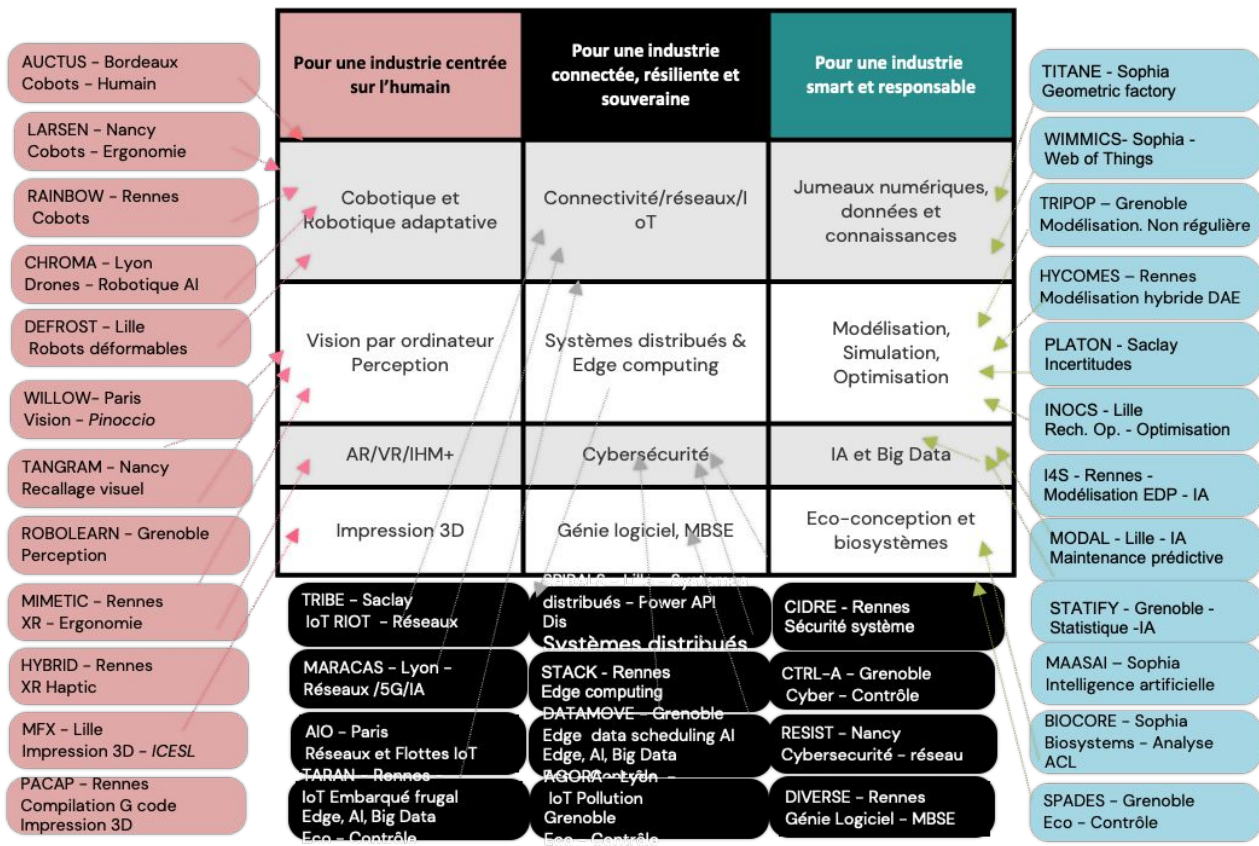
Panorama 360 @ Inria



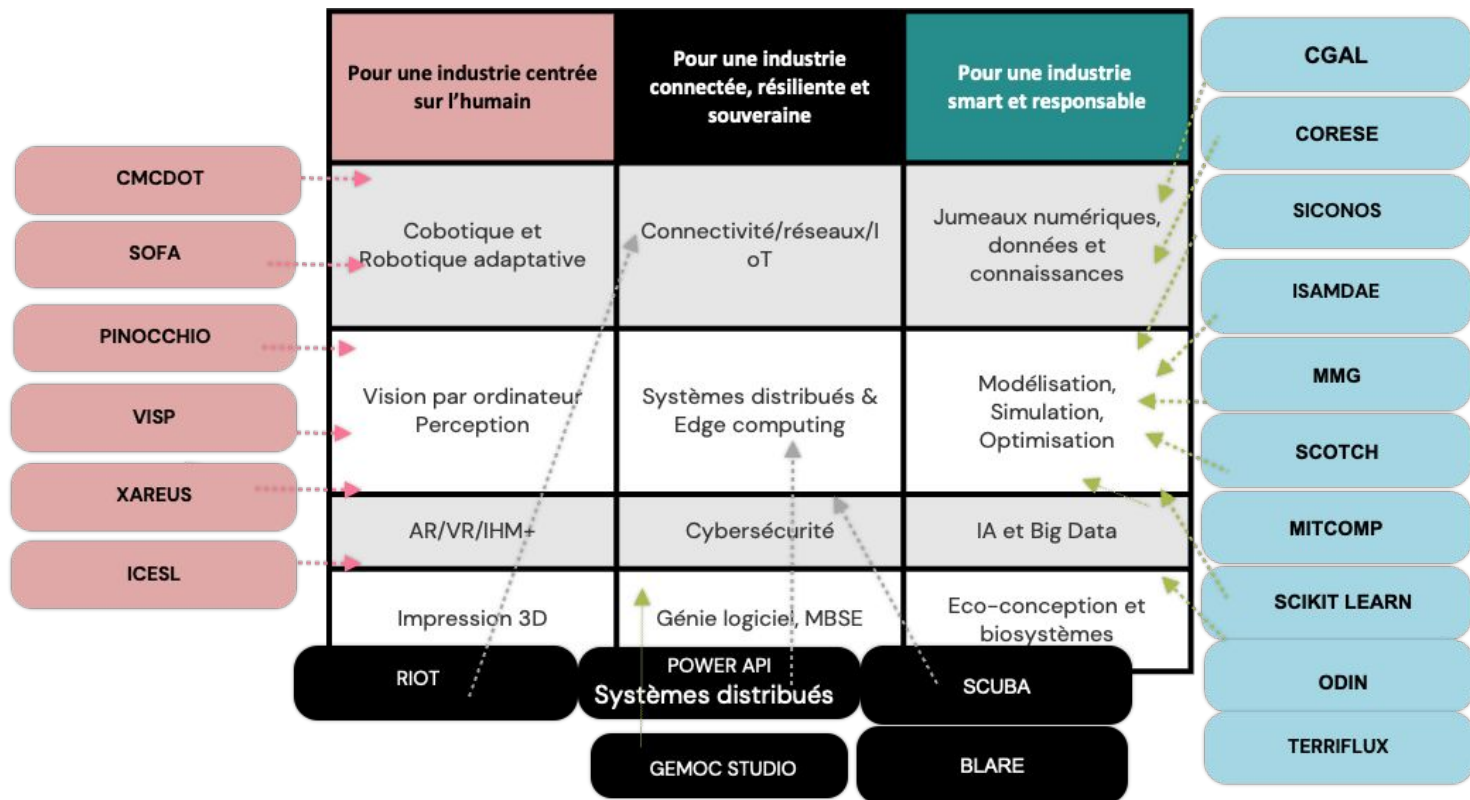
Research on Digital Twins @ Inria

Pour une industrie centrée sur l'humain	Pour une industrie connectée, résiliente et souveraine	Pour une industrie smart et responsable
Automatisation & Production 21	Systèmes distribués 17	Chaîne numérique & IA 35
<i>Recherches sur la collaboration robot-humain, l'assistance, la flexibilité, la personnalisation de la production et des services.</i>	<i>Recherches sur les enjeux de résilience, de sécurité et de souveraineté de l'Infrastructure distribuée, support de l'I5.0.</i>	<i>Recherches sur les jumeaux numériques, la modélisation, la simulation et l'IA, l'optimisation, l'impact environnemental</i>
Cobotique et robotique adaptative 9	Connectivité/réseaux/IoT 7	Jumeaux numériques, données et connaissances 7
Vision par ordinateur Perception 4	Systèmes distribués & Edge computing, Green IT 5	Modélisation, Simulation, Optimisation
AR/VR/interfaces augmentées 5	Cybersécurité 3	IA et Big Data 8
Impression 3D et hyper-personnalisation 3	Génie logiciel, MBSE 2	Eco-conception et biosystèmes 3

Research on Digital Twins @ Inria



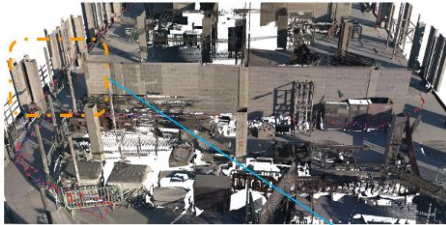
Research on Digital Twins @ Inria



BIM2TWIN: DT for Construction



What is all about?

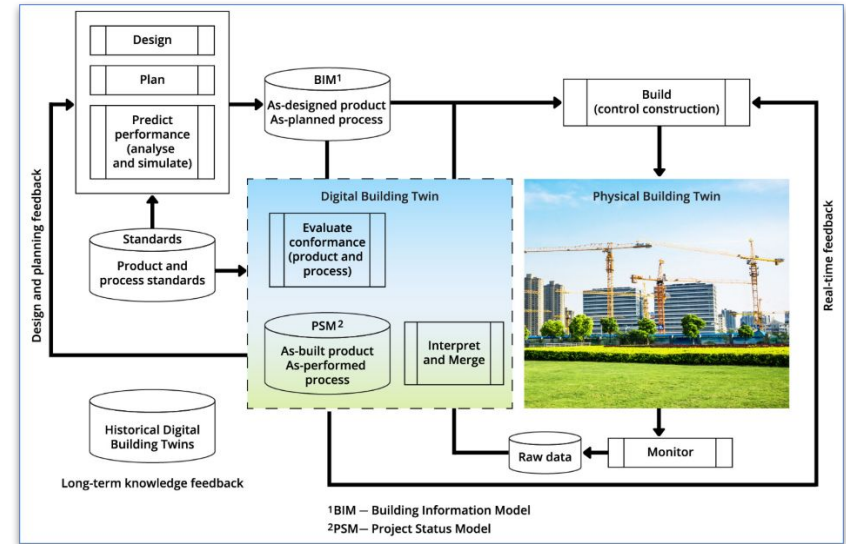


Construction site at the first month of scanning

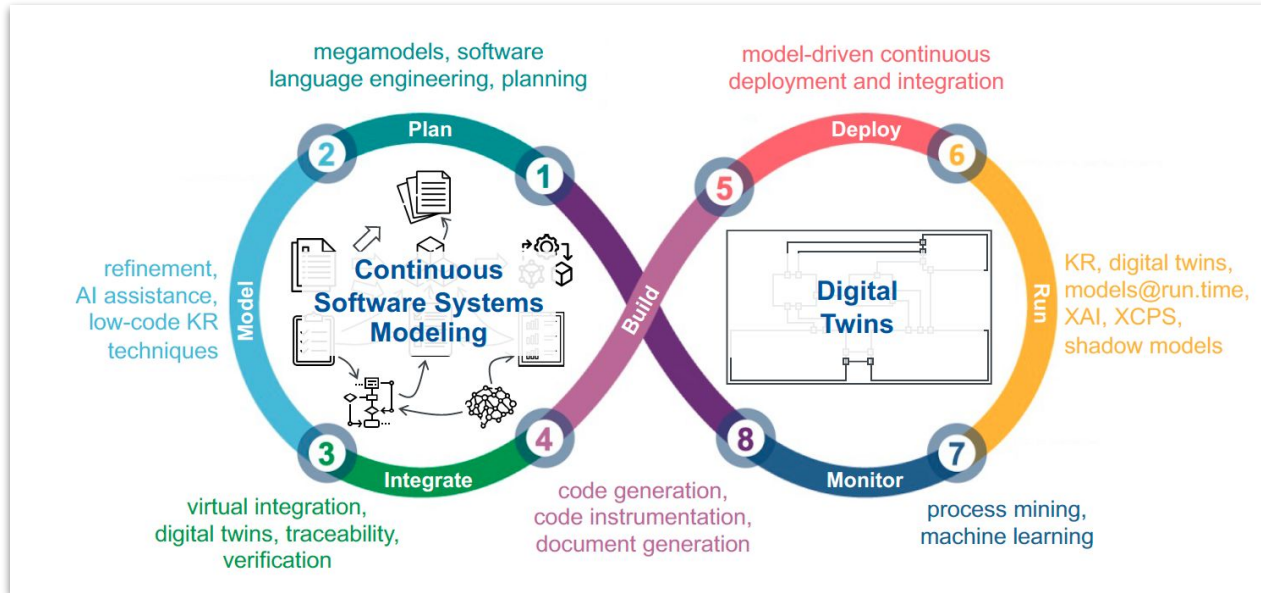


The same site a couple of weeks later

The wall was not finished during month zero, but finished in the course of the four next months. Was it constructed up to the norms and on time?



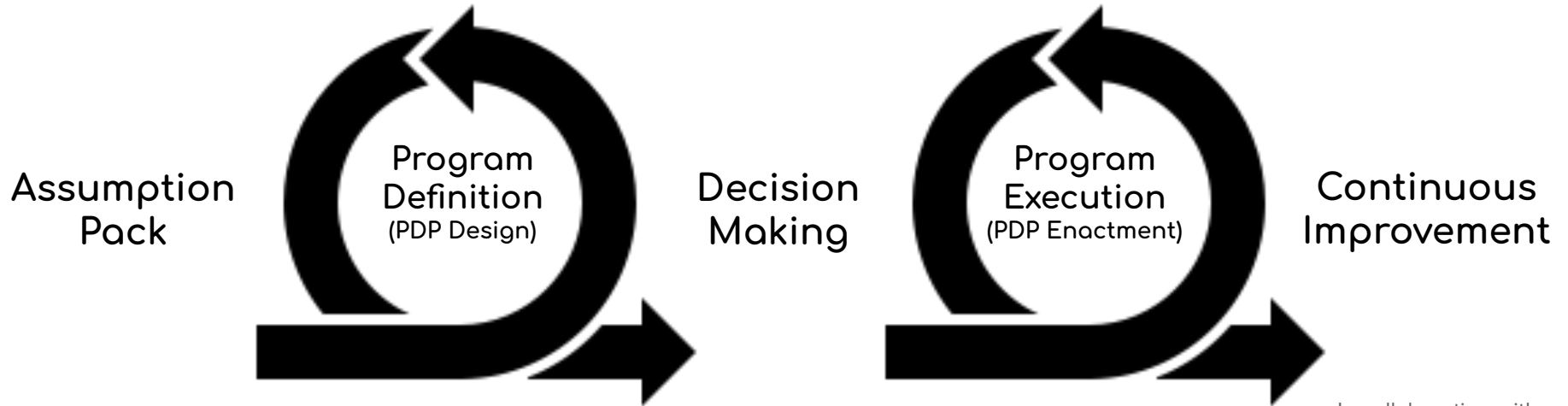
Model-Based DevOps for CPS (MBDO)



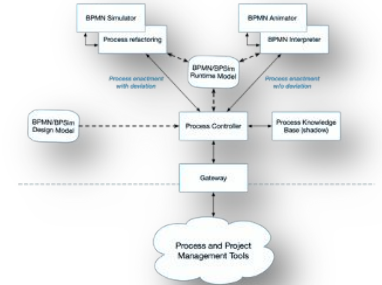
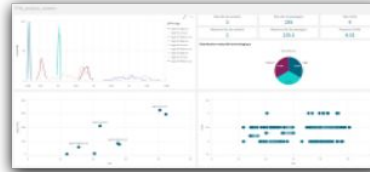
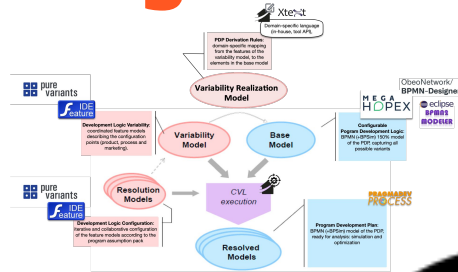
OneWay: The Case Of Avionics Program Development Plan

Model-based approach

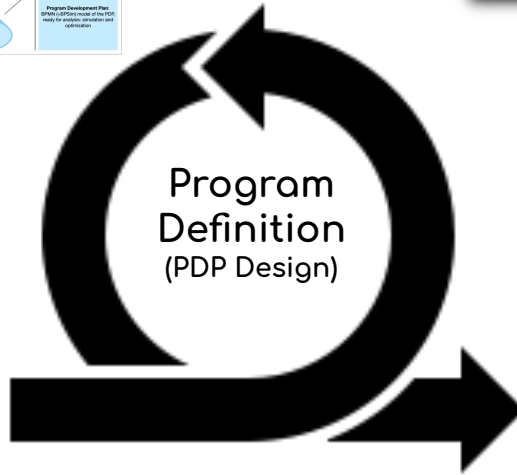
from PDP instantiation, to PDP exploration, optimization and digital twin



OneWay: The Case Of Avionics Program Development Plan

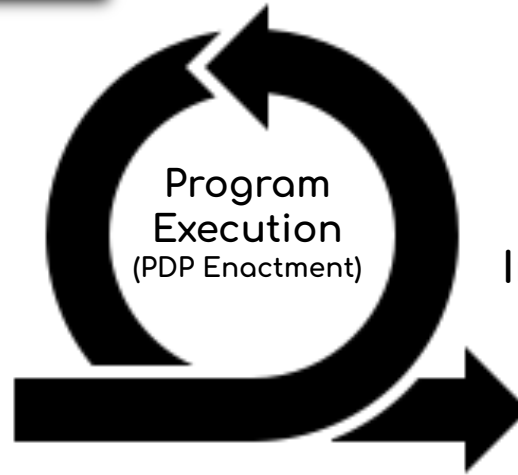


Assumption Pack



Program Definition
(PDP Design)

Decision Making



Program Execution
(PDP Enactment)

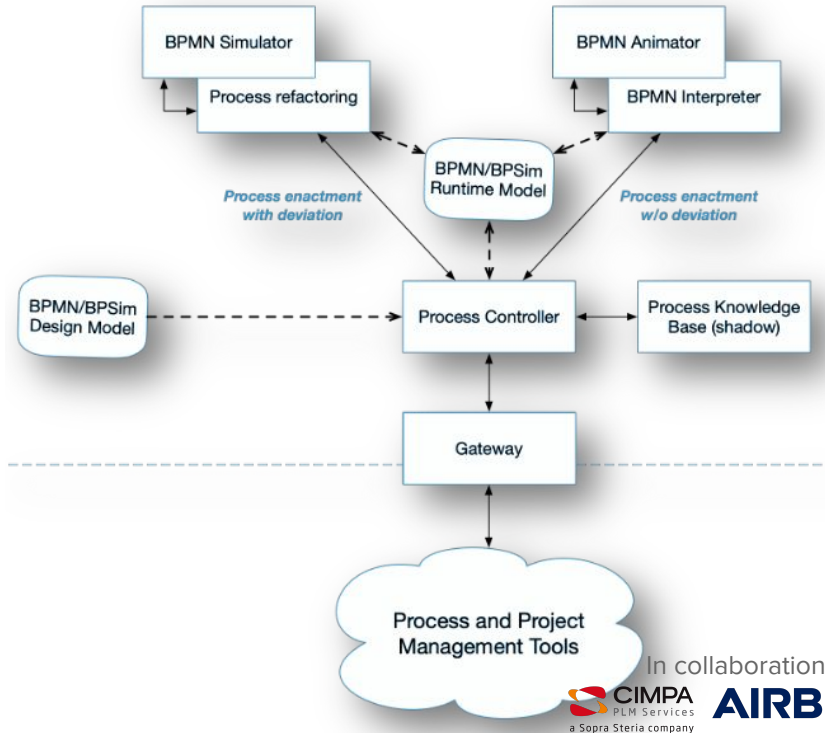
Continuous Improvement

OneWay: The Case Of Avionics Program Development Plan

- Monitoring via process enactment with the interpreter
- Capitalization through the shadow
- Refactoring (automatic optimization or manual refactoring) of the prescriptive part of the model (i.e. the future)
- Impact analysis with the simulator

Perspectives:

- Deviation management
- Automatic optimization
- Process Knowledge Base Optimization
- Cockpit definition



In collaboration with

OneWay: The Case Of Avionics Program Development Plan

The screenshot displays a BPMN modeling environment. The central canvas shows a process diagram titled "MinimalParalleGateway". The process starts with a start event, followed by a parallel gateway (PGW1) that splits into two parallel paths: one leading to task T1 and another to task T2. Both T1 and T2 lead to a second parallel gateway (PGW2), which then leads to task T3. Task T3 leads to another parallel gateway (PGW3) that splits into two paths: one leading to task T2' and another leading to a "GeneratePGW_L4" event. Both T2' and "GeneratePGW_L4" lead to a final end event. The diagram includes various parameters such as "TimeParameters.waitTime: 10" and "TimeParameters.processingTime: 20".

The right sidebar shows a "Problems" panel with one item: "Sequencing deviation on task T3". The bottom status bar contains a "Digital Twin Status" window with the following data:

Status	Event	Timestamp
✓	Start Process	Sun Jun 23 10:23:20 CET 1974
✓	START T1	Wed Jul 03 01:00:00 CET 1974
✓	START T2	Wed Jul 03 01:00:00 CET 1974
✓	END T1	Tue Jul 23 01:00:00 CET 1974

Below the log, the "Controller Status" section indicates a "Correcting deviation on START T3 (Fri Aug 02 01:00:00 CET 1974)" with the reason: "Task cannot be executed at this time". The "Worst simulated lead time: 60 | 95th percentile lead time: 60" is also displayed.

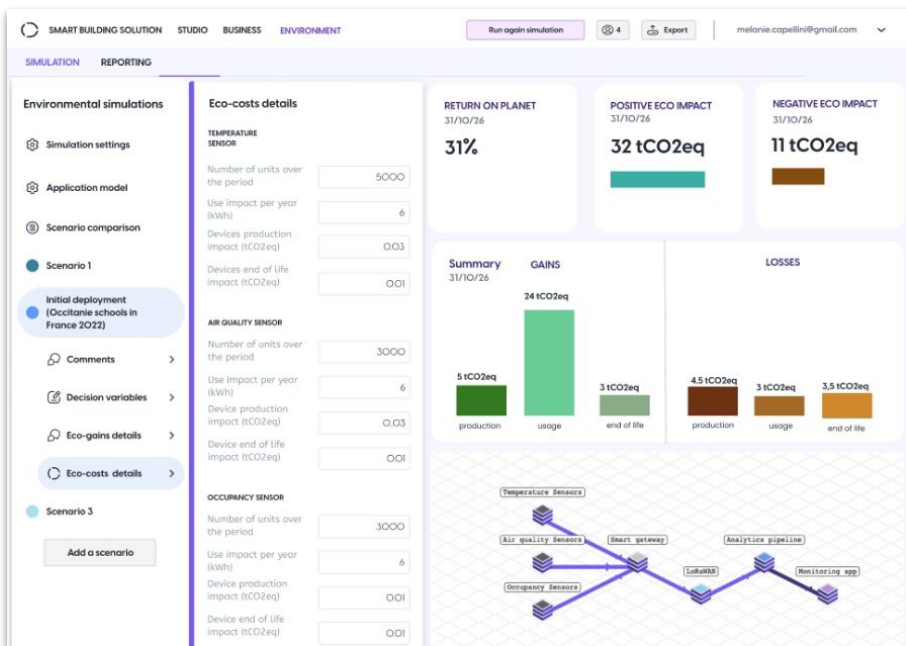
STACKEO: DT for IoT

STACKEO

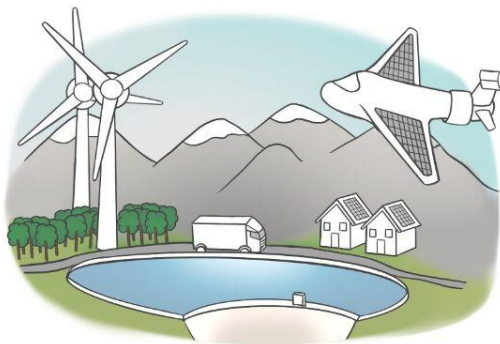
Dimensionnement et analyse économique, environnementale de la chaîne du capteur au Cloud

Travaux en partenariat Inria avec le LIP et Stackeo sur le jumeau numérique d'un système IoT autour de la plate-forme Stackilab.

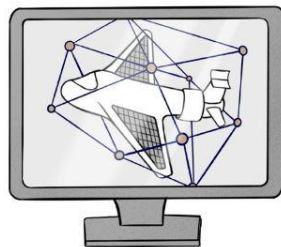
- Langage et outils de modélisation des systèmes IoT
- Aide à la configuration des réseaux
- Simulation d'impact économique et d'impact environnemental
- Connection avec les systèmes de gestion de device pour l'observabilité et la reconfiguration



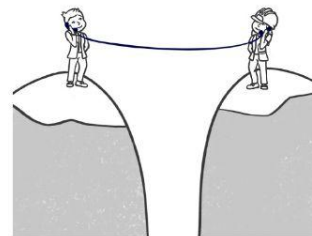
Nowadays products are gaining in **complexity**, operated in **various environments** with increasing interactions and **multiple** use cases.



Our multi-field adaptive modeling technology offers you an **innovative digital representation** of your product



Comprehensive view from design to maintenance



Efficient collaboration between expertise fields



Efforts focused in the right place

Our digital twin solution is made of **open-source** modules **compatible** with your existing tools.



Quicker and smarter design



Reduced operating costs



Assessed maintenance costs

Developed by a **highly skilled team** led by :



Dr. Guy DE SPIEGELEER, CEO
guy.de-spiegeleer@twiinit.com
 Aerospace design, system engineering



Eng. Adrien DELSALLE, CTO
adrien.delsalle@twiinit.com
 Computer science & modeling

Scientifics advisors from *Inria*



Prof. Benoit COMBEMALE
 CSA
 Systems eng., Open Source Software



Prof. Olivier BARAIS
 CTA
 Web dev., DevOps



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Digital Twins

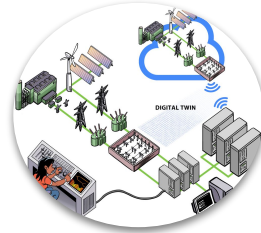
Looking Ahead?



(some) Open challenges



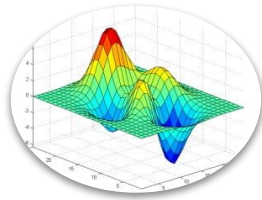
- software engineering, MBSE
- collaborative modeling
- interoperability and composability



- Distributed systems
- Cloud-, Edge-computing, HPC
- Internet of Things



- great opportunities for saving resources, balanced with massive resource consumption
- human value-driven systems engineering



- numerical analysis
- multi-physics simulation

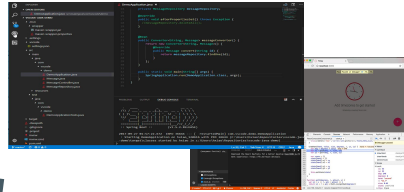
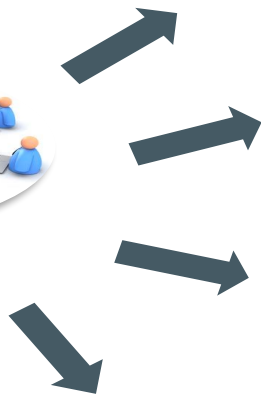


- predictive modeling
- resilience engineering
- explainable AI

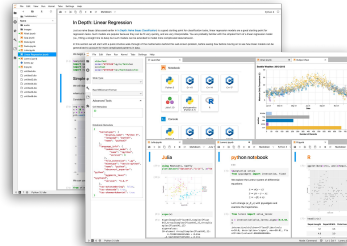
Virtual Lab



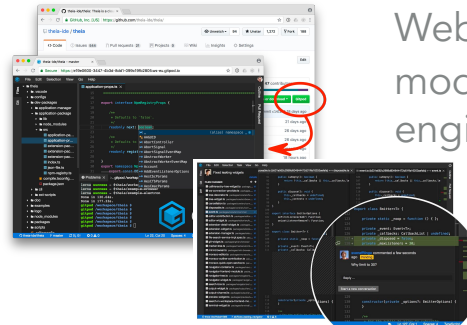
Socio-technical
coordination



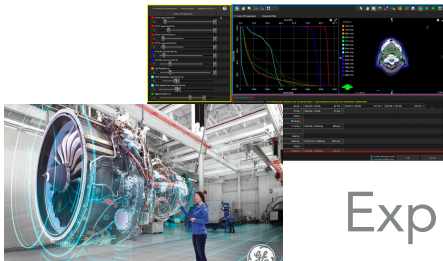
Lightweight, modular, customizable,
distributed and self-adaptable scientific
and engineering platforms...



Polyglot, literate
modeling and programming



Web-based, Collaborative
modeling, modeling flow, social
engineering



Exploratory and live programming, digital twin

ENGINEERING DIGITAL TWINS - ONLINE SEMINAR SERIES



SHARING KNOWLEDGE

Providing a platform to share experiences, challenges, and novel research



BUILDING A COMMUNITY

Bringing together people from academia and industry to discuss the applications and engineering of digital twins



ESTABLISHING RESEARCH GOALS

Building a common understanding and vocabulary and defining research agendas for the future

STEERING COMMITTEE



ORGANISING COMMITTEE



MDE OF DIGITAL TWINS - Workshop @ MODELS

3rd International Workshop on Model-Driven Engineering of Digital Twins

ModDIT'23

co-located with **MODELS 2023**

[About](#) | [Program](#) | [Call](#) | [Dates](#) | [Committees](#)

About the Workshop

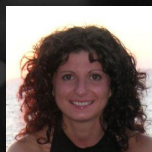
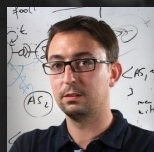
Digital twin (DT) is a concept that is gaining growing attention in many disciplines to support engineering, monitoring, controlling, and optimizing cyber-physical systems (CPSs) and beyond. It refers to the ability to clone an actual system into a virtual counterpart, that reflects all the important properties and characteristics of the original system within a specific application context. While the benefits of DT have been demonstrated in many contexts, their development, maintenance, and evolution, yield major challenges. Part of these needs to be addressed from a Model-Driven Engineering (MDE) perspective. ModDIT'23 aims at bringing together researchers and practitioners on DTs to shape the future of systematically designing, engineering, evolving, maintaining, and evaluating DTs across different disciplines.

Topics

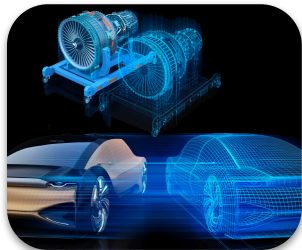
Topics of interest include, but are not restricted to:

- Modelling concepts and languages, methods, and tools for developing digital twins
- Digital twins for DevOps
- Quality assurance for and evaluation of digital twins
- Deployment and operation of digital twins
- Model consistency, management, and evolution of engineering models
- Architectural patterns for digital twins
- Digital twins for continual learning and continuous improvement
- Combining models and data in digital twins
- Digital twins for dynamic (re)configuration and optimization
- Case studies, experience reports, comparisons

ORGANISING COMMITTEE



En résumé...



Jumeaux numériques

- ▶ Point de vue donnée / modèle et architectural
- ▶ Continuum entre la conception, l'opérationnalisation, l'évolution, la maintenance...



Jumeaux numériques à Inria

- ▶ centrée humain
- ▶ connecté, résiliente et souveraine
- ▶ responsable



Encore des verrous scientifiques

- ▶ Ingénierie des jumeaux numériques
 - composabilité et complémentarité des modèles
 - interopérabilité et composabilité des jumeaux numériques
 - environnement numérique continu (conception ∞ operations)
- ▶ Gateways pour systèmes physiques (IoT, Cloud/Edge, HPC, etc.)
- ▶ ...

Expériences et défis des jumeaux numériques

Au coeur des technologies numériques de l'industrie du futur, le Jumeau Numérique, occupe une place centrale, au carrefour des systèmes IoT, de l'analyse de données, de l'IA, de la modélisation et de la simulation, de l'optimisation et de l'automatisation. Les jumeaux numériques font appel à la représentation des données et des modèles, à la manipulation de graphes de connaissances, à la visualisation et à l'algorithmique 3D, à l'acquisition, la préparation et la manipulation de données issues de capteurs et à la consolidation de modèles et de connaissances hétérogènes, à la modélisation et la simulation numériques, à l'intelligence artificielle et à la décision distribuée. Les jumeaux numériques sont des systèmes complexes, à l'interface et synchronisés avec le monde physique. Ils stockent des volumes de données massifs et proposent des interfaces et des services de haut niveau. Plusieurs équipes d'Inria poursuivent des travaux originaux dans le domaine du jumeau numérique aussi bien au niveau de leur conceptualisation, de l'architecture, la représentation des connaissances, le couplage de modèles, la représentation 3D, la modélisation hybride avec des applications dans l'industrie, dans le bâtiment, en télécommunication ou en santé. Dans cet exposé, nous introduisons le concept de jumeau numérique, puis nous dressons successivement une cartographie des équipes Inria travaillant sur le sujet général du jumeau numérique, et présentons des exemples concrets de projets et de startups. Enfin, nous développons quelques questions et enjeux scientifiques vis à vis des verrous actuels pour la mise en oeuvre d'un jumeau numérique.