MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

2022 MELISSA CONFERENCE
8-9-10 NOVEMBER 2022

esa
European Space Agency

CREATING A CIRCULAR FUTURE

Specification process of a simulation platform for the MELiSSA project

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Master Thesis

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MELiSSA MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

2022 MELiSSA Conference

09/11/2022

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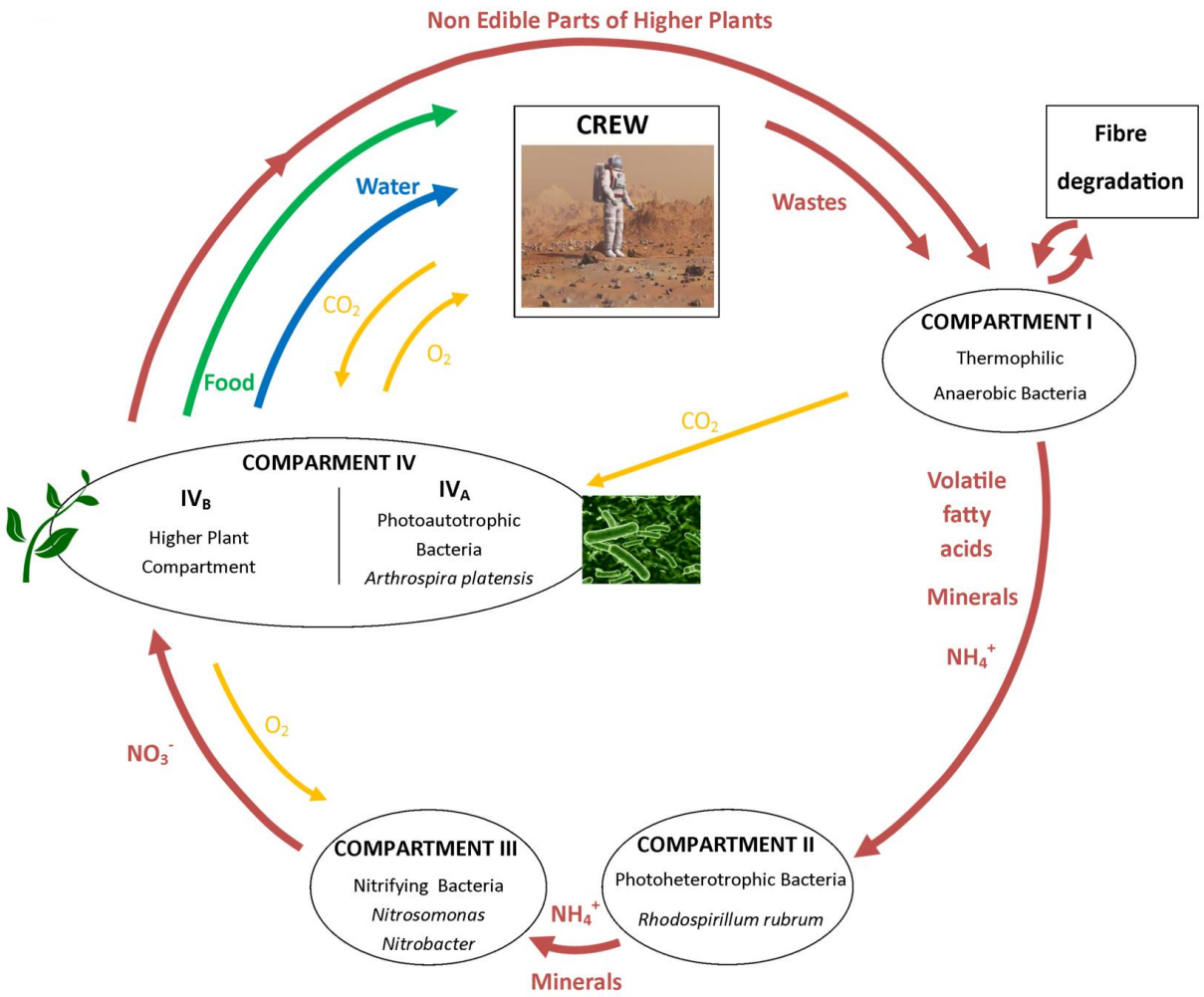
Specification process of a simulation platform for the MELiSSA project

1. **Context** : Why MELiSSA needs a simulation platform ?
   - Existing work & Simulations needs
2. **Audit :** What are the needs and challenges ?
   - Interviews & Audit synthesis
3. **Literature review :** What can we learn from similar projects ?
   - LSS & Digital Tools for LSS
4. **Gaps, proposals and perspectives :** How can we improve the simulation specification process ?
   - Simulation Request and Architecture
5. **Synthesis & Conclusion**
   - Contributions & Next Steps

Context : Why MELiSSA needs a simulation platform ?



Extremely **complex closed loop** system,
with many stakeholders

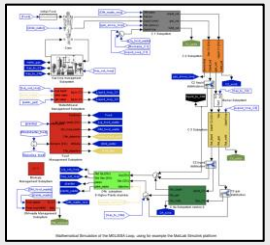
To better understand MELiSSA **performances**,
especially in terms of **circularity,**
we need a **global simulation platform.**

How can we specify this platform and extend it for all terrestrial systems in a circular economy perspective?

Context : Why MELiSSA needs a simulation platform ?

WHAT ALREADY EXISTS

Separate simulation models for each “Brick” with few interconnection between them and **different tools** (*Simulink, ProSim…*) Mainly **static**, no **control** laws



ENGINSOFT

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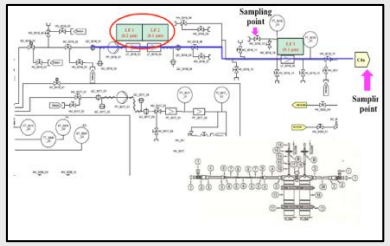

ALiSSE (*Advanced life support system evaluator*) SHERPA ENGINEERING

Collects data from the simulation models, add **control laws** and output **7 metrics**. Very **specific** to MELiSSA, **complex to use** and does not cover the **entire** loop

ESA’S NEED

A dynamic simulator of the **entire MELiSSA Loop** :

- Compare diverse architectures /scenarios by computing their **circularity performance** (*Flows and Process*)
- Identify **limiting chemical components** (*What & When*) and the biological evolution
- **Flexible** : experts can add, remove and edit bricks
- **Unique** and interesting for **every actors**
- Standard Platform able to adapt to **any circular economy systems,** including **terrestrial applications**

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Audit : What are the needs and challenges ?

Interviews with 5 experts from different fields

CHRISTOPHE LASSEUR
Head of MELiSSA

CHLOÉ AUDAS
ECLSS Engineer

PHILIPPE FIANI
ALiSSE expert

LAURENT POUGHON

CLAUDE-GILLES DUSSAP
Chemical engineering experts

Knowledge & Needs regarding
the Simulation Platform

Formalised with a **PowerPoint Mapping on 3 layers**
(Operational Analysis, Overall Architecture, Scenario)

Stakeholders and Needs Mapping

Operational Analysis (Simplified)

CUSTOMERS / Users

PROVIDERS / Developers

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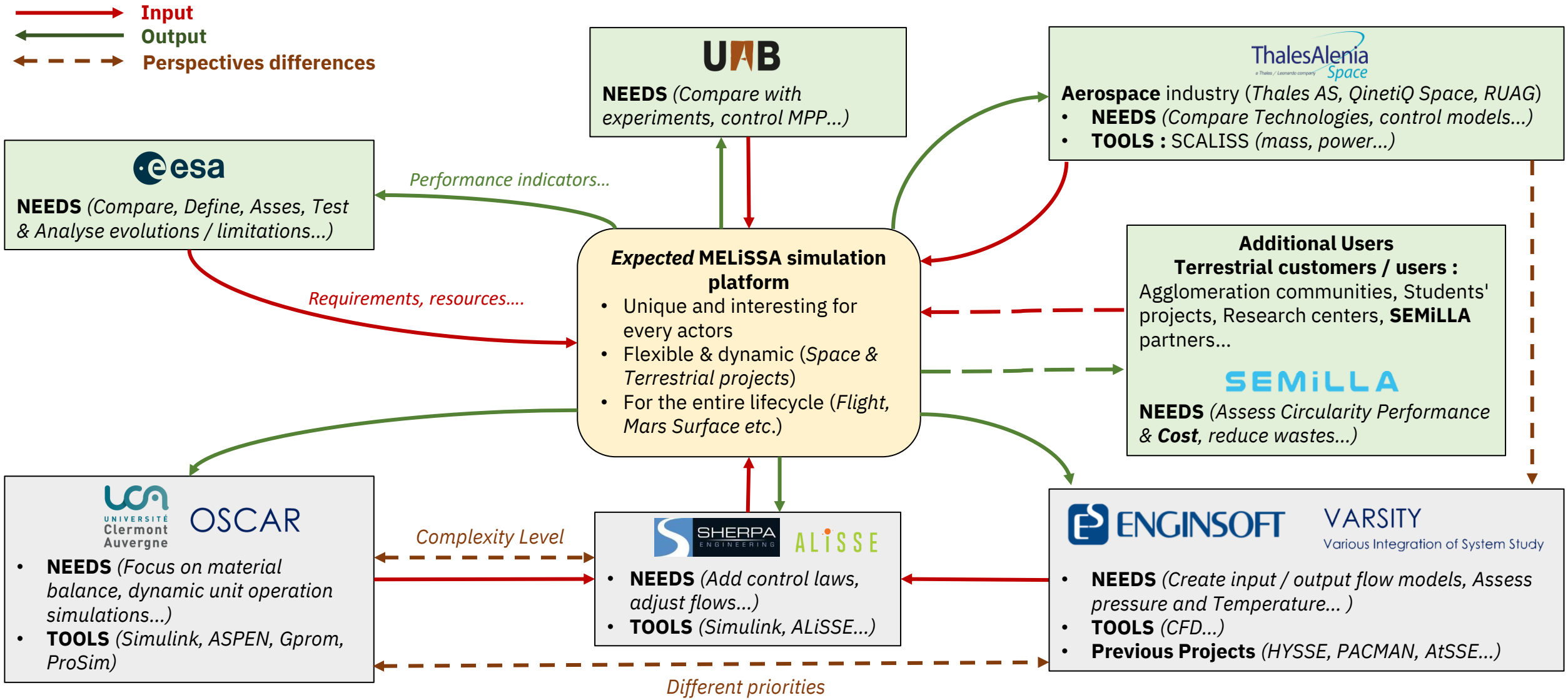

Detailed mapping available on request

Stakeholders and Needs Mapping

Overall architecture of the simulation platform (Simplified)

Scenarios Definition — HCI

Users

esa

ThalesAlenia Space

Goals

- system architects
- technological designers

impacts

Inputs

– Environment
– **Mission assumptions**
– Crew induced metabolic loads
– Crew time allocation
– System power requirements
– Logistics hypothesis

impacts

SHERPA ENGINEERING

DECISION SYSTEM : ALiSSE Global evaluation Level (**OSCAR's** Brain Level)

*Run a **mission scenario,** System decomposition into **requirements** ,System **evaluation** and **comparison***

VARSITY ALISSE

Coordination, Configuration

Metrics

SHERPA ENGINEERING

INFORMATION SYSTEM : ALiSSE Resource level (**OSCAR's** Brain Level)

Energy, Matter & Flow Management

ALISSE

Dealing with request and configurations

Reference model

- **Interactions** & **Flow** management
- **Thermal** and **electrical** energy management
- Resources Calculation

Control of the global loop

Currently not existing for the global dynamic loop

Metrics calculation

Control variable calculation

Models **calibration**

control

connection

OPERATION SYSTEM Technological level – based on **OSCAR** 6 layers - *Physical, Chemical, Thermal, Process modelling* :

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Chemical & Process models

STATIC Matlab Simulink models with manual links

Metabolic flow calculation tool

STATIC **process simulators tool** (ASPEN, Gprom, ProSim)

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Kinetic transfer aspect ENGINSOFT

what is limiting & what is the main actor :

DYNAMIC Matlab Simulink **material balance models**

DYNAMIC CFD models

Potential incompatibility in a common platform / different interests

Physical & Thermal Model

ENGINSOFT

Input / Output flow models

Static CFD models

- Temperature
- Pression
- Piping & Pneumatic

Example : Simulation process

Sequence Diagram (8 steps)

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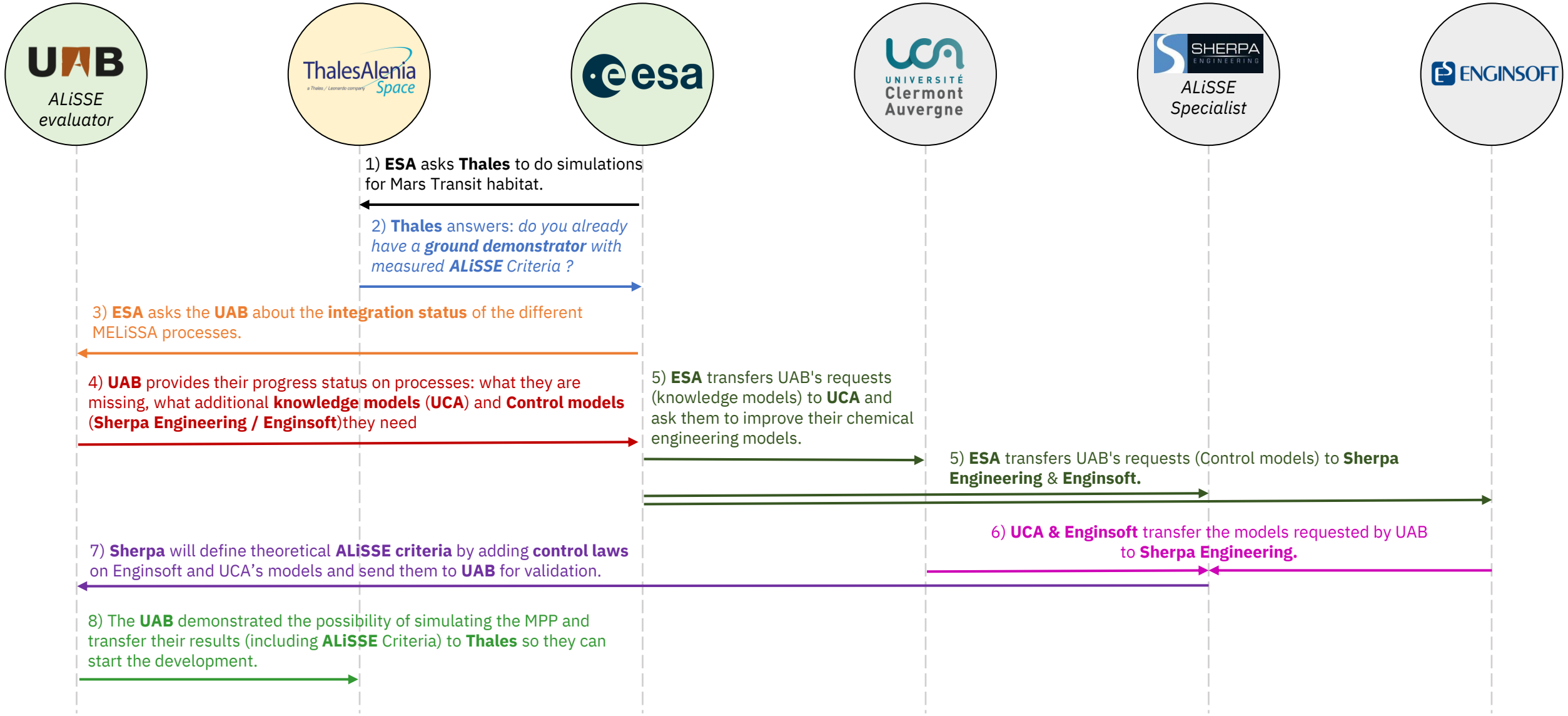
CUSTOMERS / Users | **PROVIDERS / Developers** | **MIXED**



Audit Synthesis : What are the needs and challenges ?

Several projects and tools already exist:

- Building on **previous** work
- **Integrate** existing tools at the right level in the future platform

OSCAR ALISSE VARSITY Various Integration of System Study

Multiple diverse stakeholders:

- Different **interests** and **objectives** (*Trade-off between precision / flexibility / useability*)
- **Various** domains and expertise (*Chemical engineering / Systems Engineering/ Control / CFD / LSS*)
- Specific Methods and **Tools**

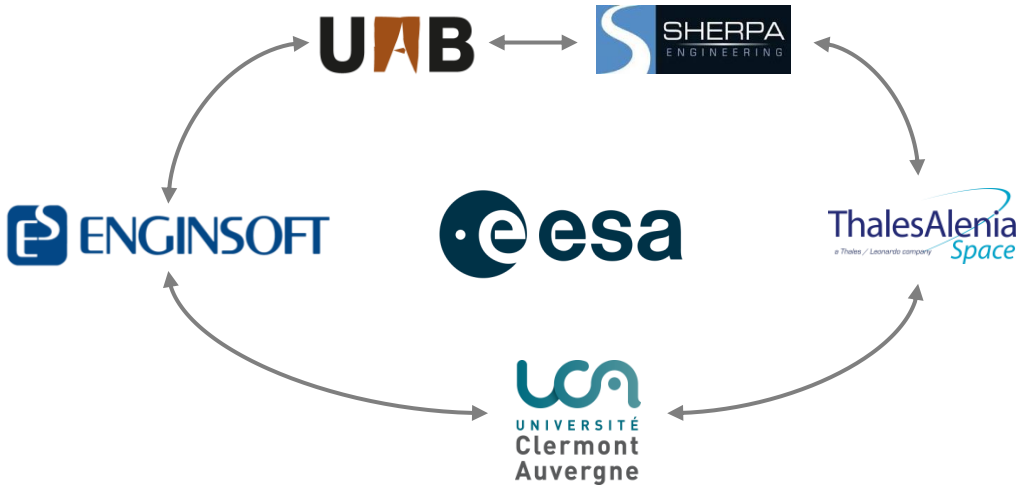
MATLAB & SIMULINK aspentech ProSim

Technical Challenges:

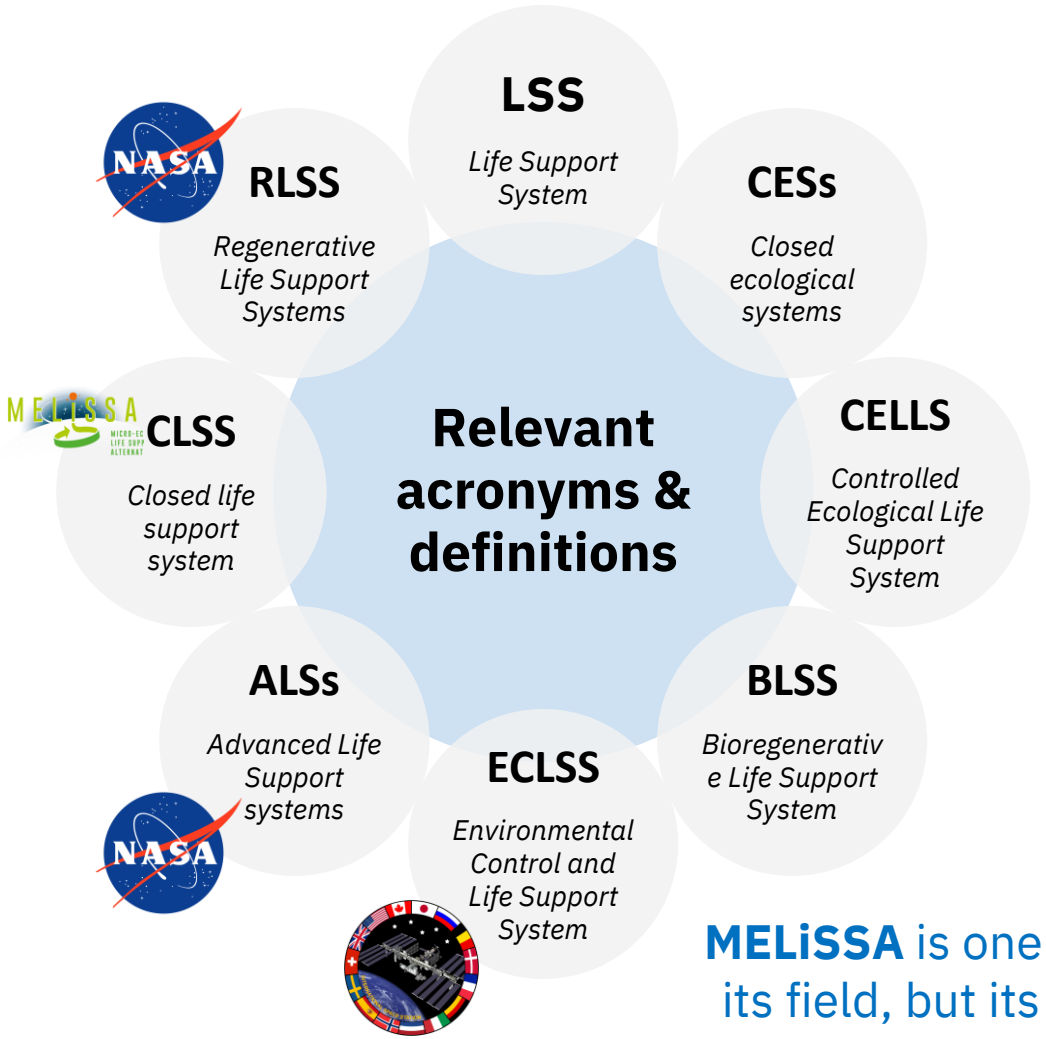
- **Interface** between the tools
- Dynamic closed loop : huge **stability** issues
- Adaptable to any **circular economy systems**, including terrestrial applications
- No similar commercial tool available

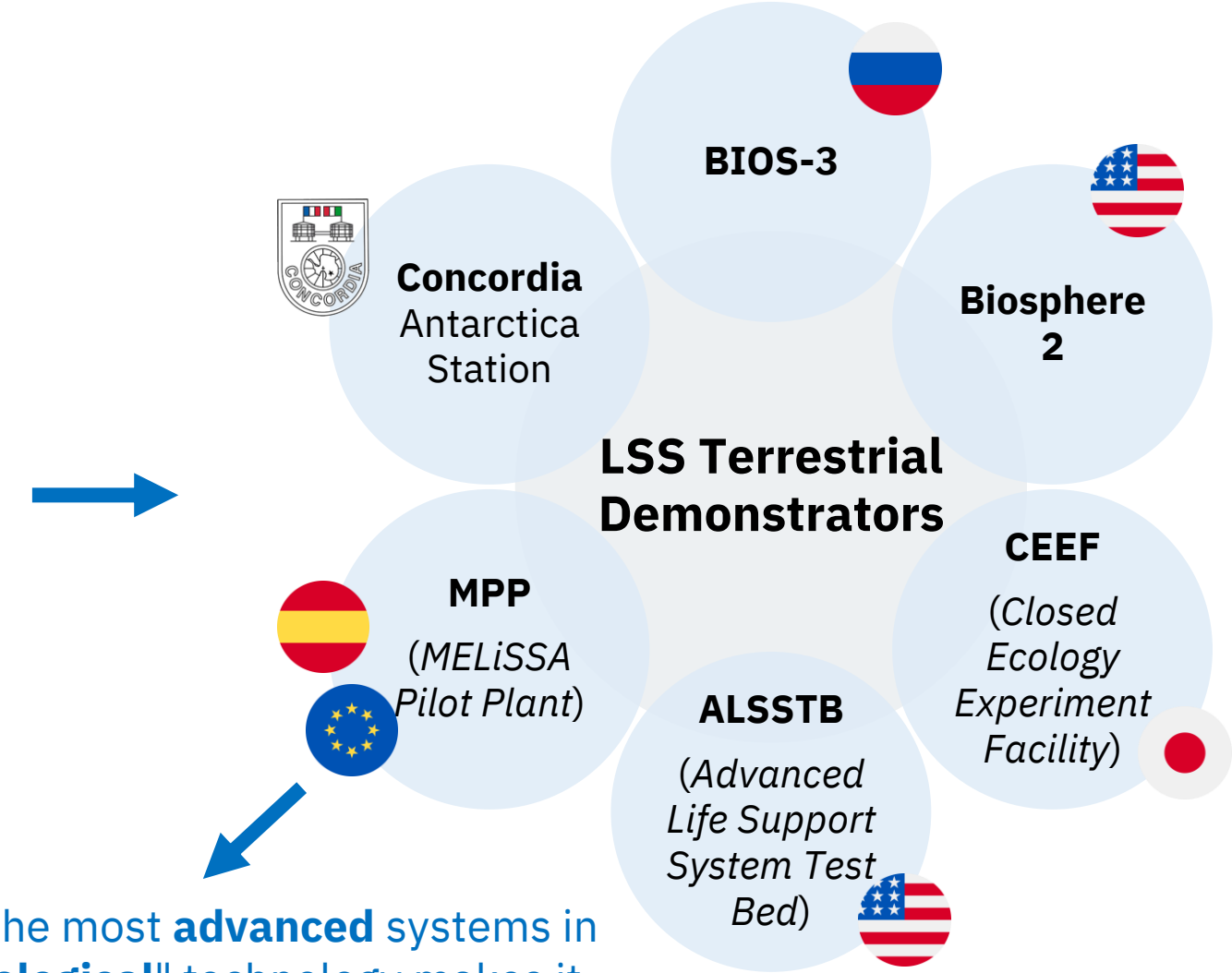
Human challenges:

- Involve every stakeholders
- Data Sharing



Literature review : What can we learn from similar projects ?





MELiSSA is one of the most **advanced** systems in its field, but its "**biological**" technology makes it **very complex to simulate**

Definitions & References available on request

Literature review : What can we learn from similar projects ?

Most advanced tools
But not enough to meet ESA's need

Simulation Tools for LSS

(Description, Software, In/Outputs & Limits)

Legacy Projects

- G-189A
- CASE/A
- BioSim
- EcoSimPro

ALSSAT

- **Excel**, VBA
- Mass, Power, Volume

ELISSA

- **Labview**
- **ESM** : Equivalent System Mass
- +Open Source Library
- -Poor Algae Models

ALiSSE

- Interface with **Simulink**
- +**Multicriteria**: Mass, Power, Crew Time, Risk, Reliability, Sustainability
- -Long simulation times, not user friendly

SCALISS

- **Java**
- Mass, Power consumption

V-HAB

- **Matlab**
- +**Multicriteria**: Stability, Controllability, Crew time
- +Modular structure
- -Poor Algae & Crew module compared to UCA

Detailled Inputs, Ouputs, Limits & References available on request

Literature review : Synthesis & Gap

Many LSS simulation platforms projects have failed in the past

- **Long-term programs** ≠ PhD projects
- **Technical complexity** of assembling numerous simulation models : diverse **methods and tools.**
- **Divergent expectations** and priorities between stakeholders.
- **Data sharing :** some actors may feel dispossessed of their work (*NASA Houston ELISSA example*).
- **Poor consideration of stakeholders' needs** during the specification phase: lack of interest at the end.

It is crucial to involve all stakeholders from the needs definition phase

- **Research gap** in the field of **simulations specification and architecture**
- The **improvement** of existing **methods** can prevent MELiSSA from undergoing the same failures as similar projects
- **Similar gap** addressed by **IRT SystemX** (*J.-P. Brunet et al., 2020; Sohier et al., 2019, 2021*)

Gap : How to formalize simulation needs while ensuring traceability?

“Simulation Request” Process

Henri SOHIER

Mouadh YAGOUBI

1. Simulation **scope** & level of **detail** *(What part ?)*
2. **Objective**
3. **Quality, cost, and delivery** *(fast or accurate?)*
4. **Test scenarios** of the simulation
5. Data for simulation **calibration and validation**
6. Verification and validation **(V&V)** of the simulation

Results & Benefits

- ✔ Developed **software tools** to demonstrate their methods
- ✔ Linked **system architecture** (*MBSE*) with numerical simulations
- ✔ **Formalizes** the **exchanges** and requests between system and simulation architects
- ✔ Limits the **loss** of information and improve V&V
- ✔ Leverages **past** simulations

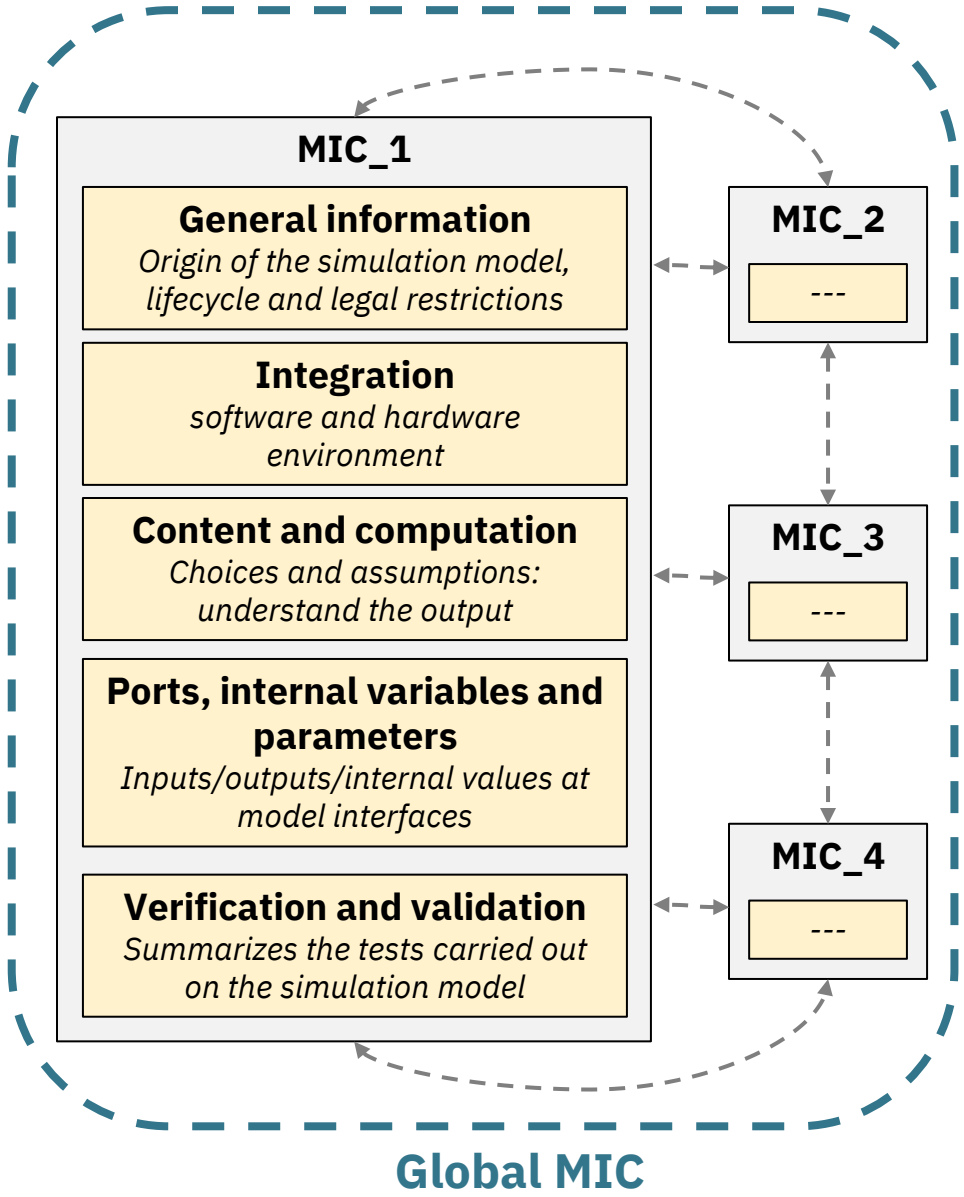
Gap : How to Support Simulation architecture ?

MIC : Model Identity Card *(Göknur et al., 2015)*

RENAULT System× SET Level

An Open-Source collaborative standard

- Simplify simulation models **specification**, **sharing** and **reusing**
- Standardized **interfaces** definition
- List **key information** for characterizing simulation models with an **XML format** (*software tool*)
- Helps to assemble **multi-disciplinary, multi-actors & multi-domain** simulation models
- Improve **traceability** with system requirements



Gap : How can we improve the simulation specification process ?

2 Different processes

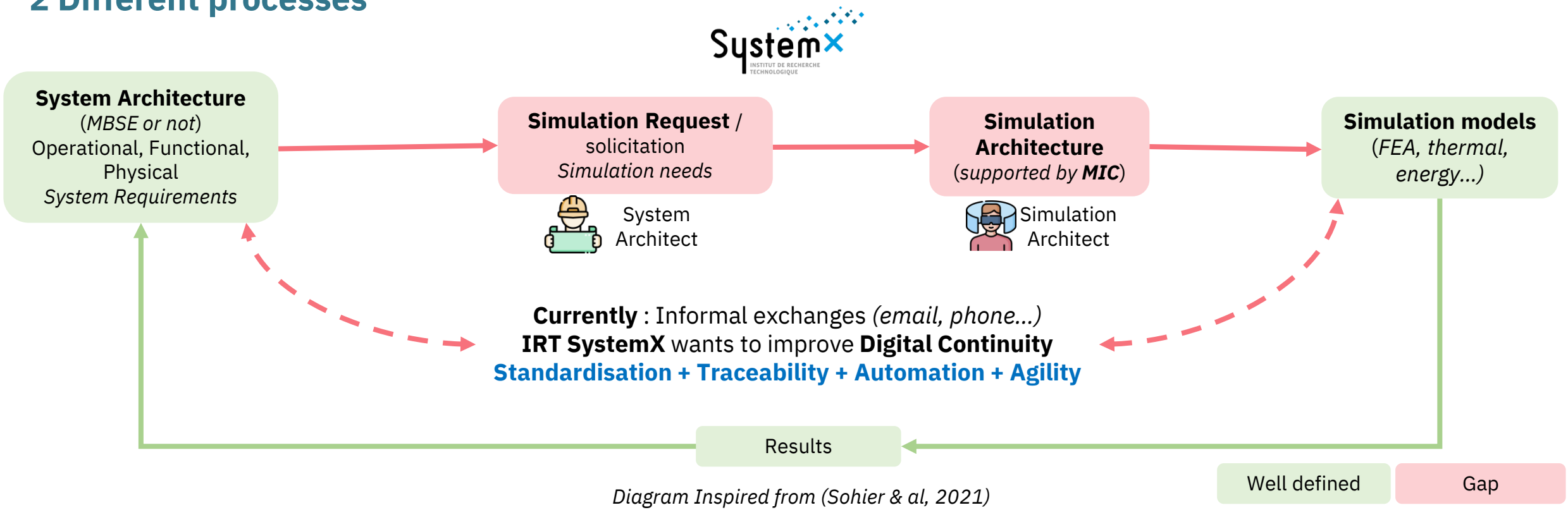


Diagram Inspired from (Sohier & al, 2021)

Credible Simulation Process (Heinkel, 2021)

A method for the high-level project manager

Overview of an optimal sequential process for developing a simulation (*roles, resources*)

Proposal : Comparison of Simulation Specification Methods

Credible Simulation Process (2021)

- ✓ Useful for the **manager** to have an overview of an optimal sequential process
- ✓ Identify **Roles, expertise, inputs, outputs** required at each step

BUT

- ! Very **generic** / conceptual
- ! Requires **experience** to apply it

Simulation Request Process (2021)

- ✓ **Detailed** steps
- ✓ Strong **traceability** with system requirements, architecture and simulation needs
- ✓ **Software** Tooling

BUT

- ! Depends on custom **tools**
- ! Requires **highly detailed** System Architecture (***MBSE** preferred*)

MIC : Model Identity Card (2020)

- ✓ **Standardization** of simulation architecture
- ✓ Improves **connectivity** between models (*interface definition through XML*)

BUT

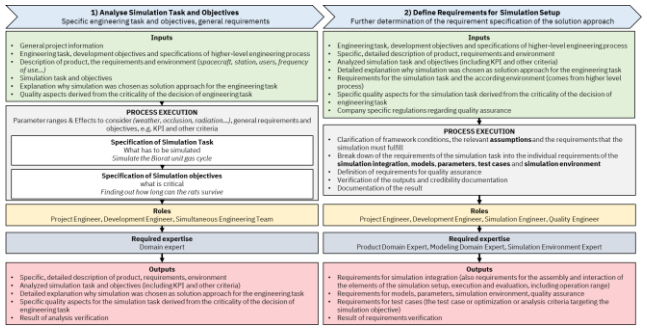
- ! Requires a strong simulation **expertise**
- ! Must be filled in by the simulation architect in a **dedicated tool**

Difficult to apply fully in our academic context, but relevant for MELiSSA

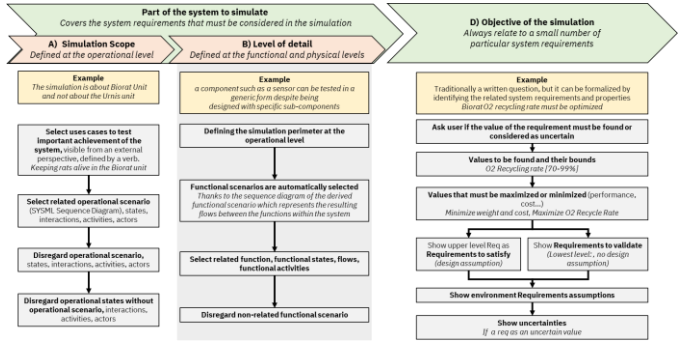
Proposal : Creation of Simplified PowerPoint Templates

Summarizes documents and interviews in a few slides (overview)

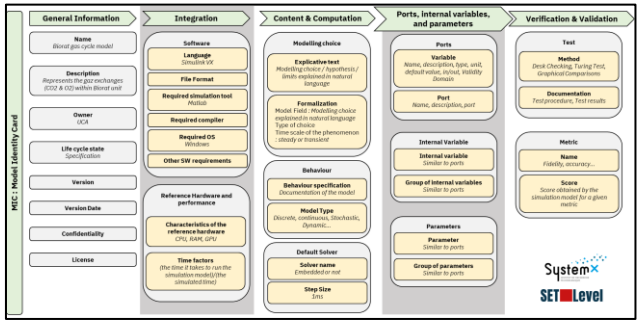
Credible Simulation Process



Simulation Request Process



MIC : Model Identity Card



Benefits

- ✔ Applicable to any complex systems: including **MELiSSA** and **Circular Economy**
- ✔ Allow stakeholders to **compare** methods and **adapt** them to their needs
- ✔ **Optimize** collaboration, needs & simulation architecture definition : **“Top Down”** approach
- ✔ Move Towards : **standardization, connectivity, traceability, and digital continuity**

Perspectives

- ❗ **Customize** the templates for **Circular Economy features** (*budget*) and **indicators**
- ❗ Application of the methods by the **experts**
- ❗ BUT : the simulation platform remains **technically very complex** (*dynamic closed loop*)
- ❗ This methodological support is only part of the answer

Synthesis & Conclusion

Proposals to ESA and stakeholders

State of the art

- Existing LSS/simulation tools
- Criticalities & challenges

Mapping of the industrial audit

- Interviews synthesis
- 3 layers: support communication and decision making
- Gap identification

Comparison of 3 methods/tools to help specify the simulation platform and architecture

- Advantages/Limits
- Templates proposal
- Perspectives

Next Steps

Improve industrial audit

- Interview additional stakeholders (*MPP, THALES, EnginSoft, Circular Economy…*)
- Update the Mapping

Select with experts which methods could be applied

- Work with **SETLevel** & **IRT SystemX** to **adapt their methods** to the project (*Supported by the templates*)
- Implement **Circular Economy** aspects
- Keep in mind the **technical limitations**

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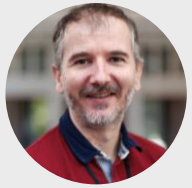

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