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Paper #132

Applying Model-Based Systems Engineering Methods to a Novel Shared Systems Simulation Methodology

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www.incose.org/symp2022

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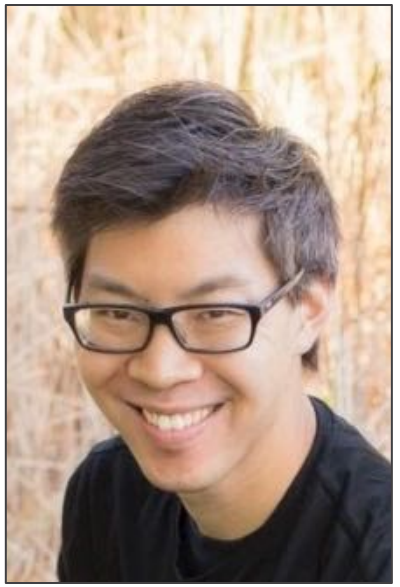

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Jeremy Ross

Michael J. Vinarcik

Agenda

- Shift to Model-Based Systems Engineering
- Problem Statement
- Model-Based Architecture Development
- Shared Systems Simulation Coupling
- Architecture Trade Study Example
- Interface and Complexity Challenges

Traditional Systems Engineering

- Document-centric
- Isolated, disjointed views
- Ineffective for cross-functional collaboration

Slide adapted from M. Vinarcik, 2022
Supercruise: Model-Based Systems Engineering and Digital Engineering in 2022 [1]

Traditional Systems Engineering

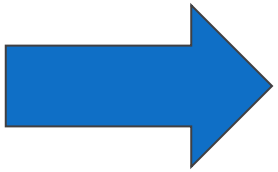
- Document-centric
- Isolated, disjointed views
- Ineffective for cross-functional collaboration

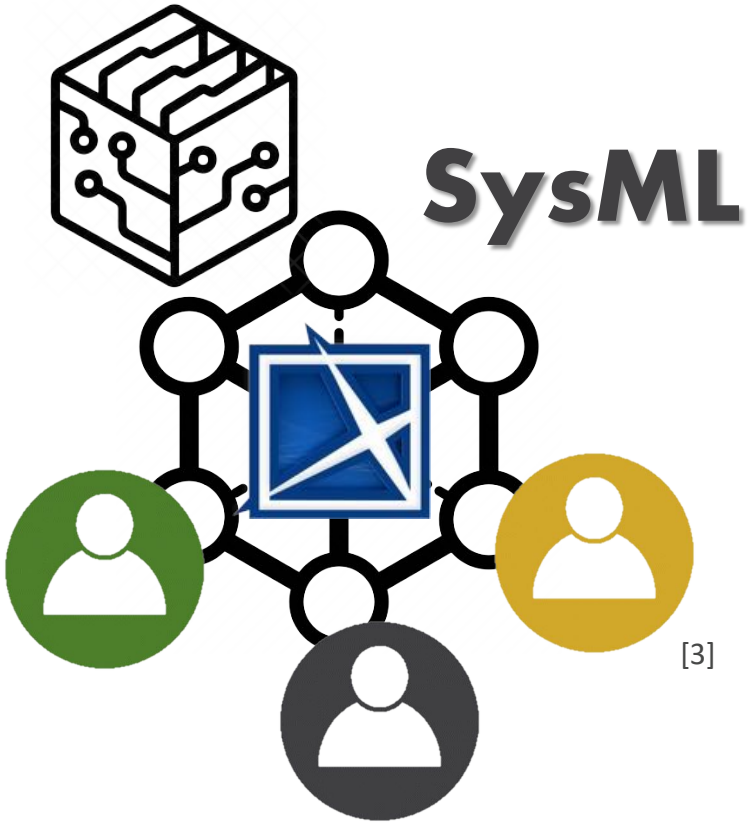
- Integrated system models viewed as **secondary and descriptive only.**
  (Weilkiens, et al. 2016) [2]

Slide adapted from M. Vinarcik, 2022
Supercruise: Model-Based Systems Engineering and Digital Engineering in 2022 [1]

The Shift to Model-Based Systems Engineering

Document Based

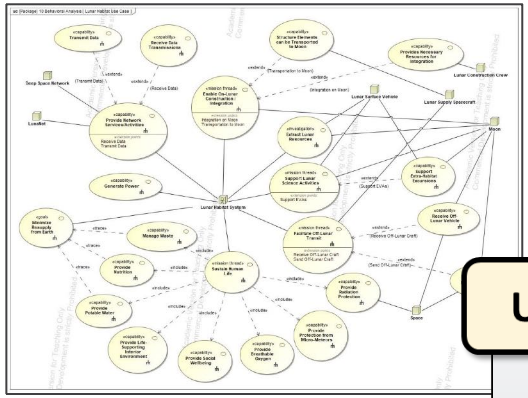


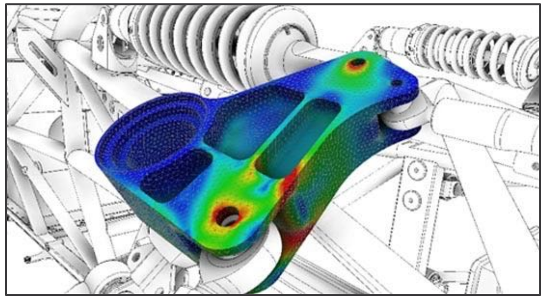


[3]

Shared Common Model

Up-Front Architecting → Detailed Systems Engineering





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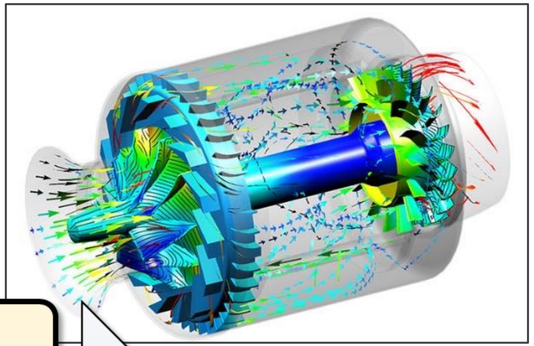

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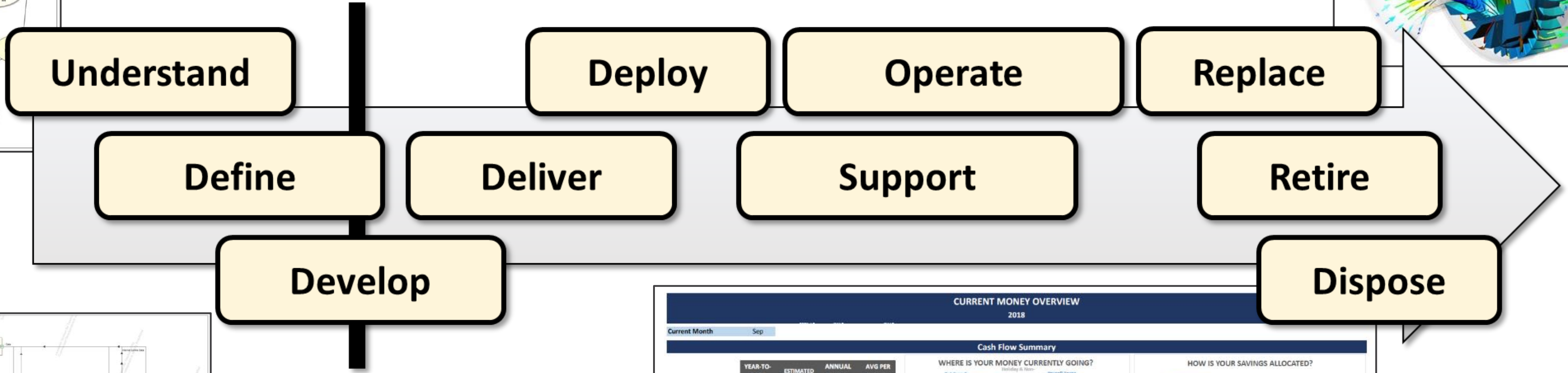
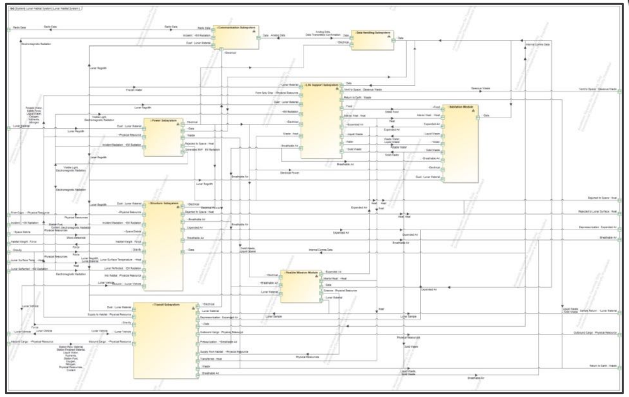
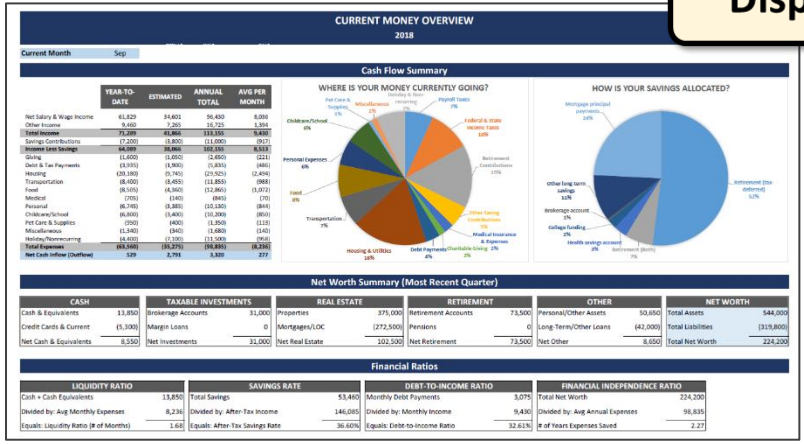






[6]

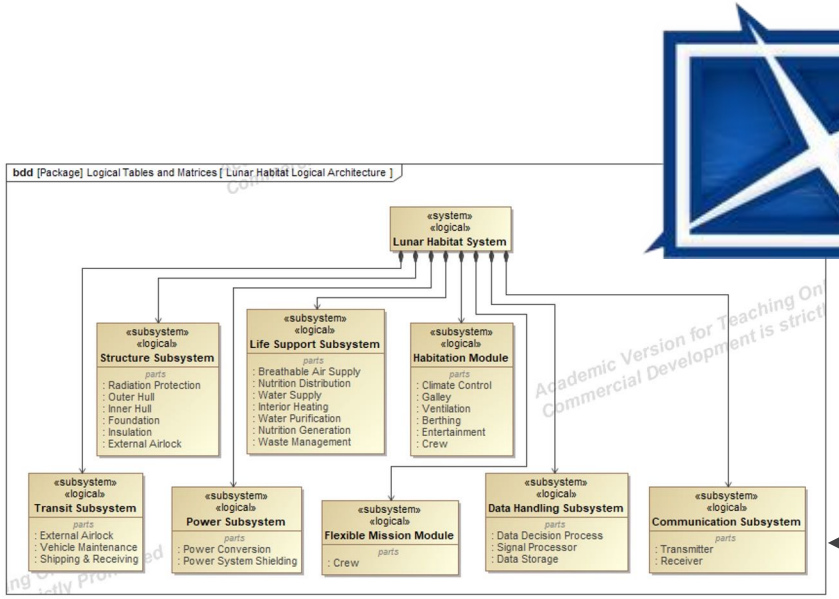
Executable System Models

- ▶ Descriptive system model → executable simulation
- ▼ Ineffective toolchains
- ▼ Significant descriptive model rework

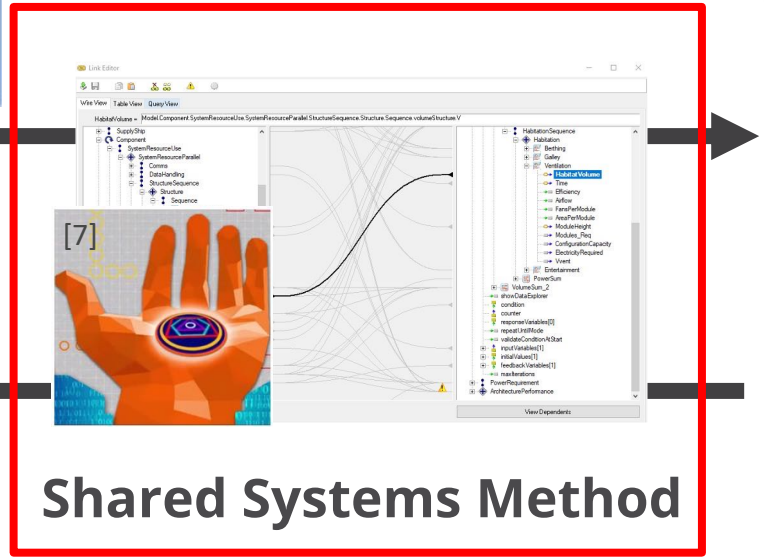
Problem Statement

- How can the rigor and precision of a model-based approach be extended from the system definition space into the **system simulation and analysis domain?**

Solution: The *Shared Systems Simulation Methodology*

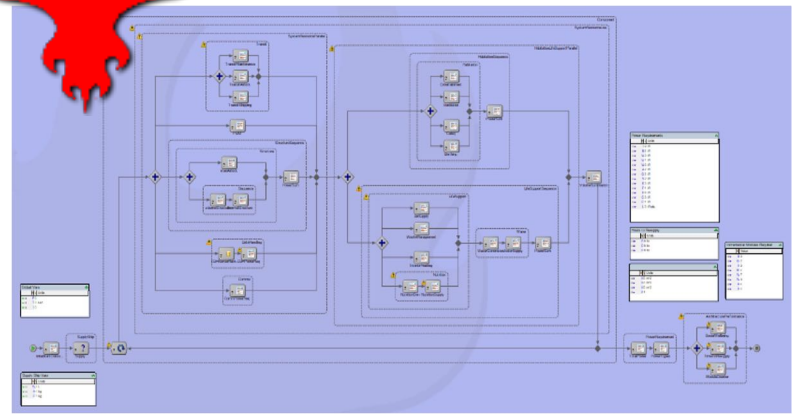


Model-Based Architecture



Shared Systems Method

[7]



Systems Simulation

System of Interest

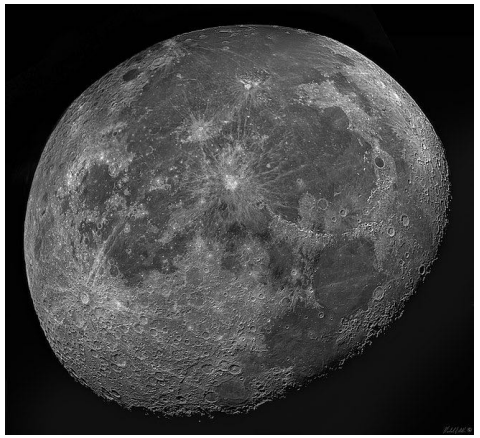
Technical Complexity

Stakeholder Interest

Engineering Novelty

“We choose to go to the moon” – John F. Kennedy

Technical Complexity

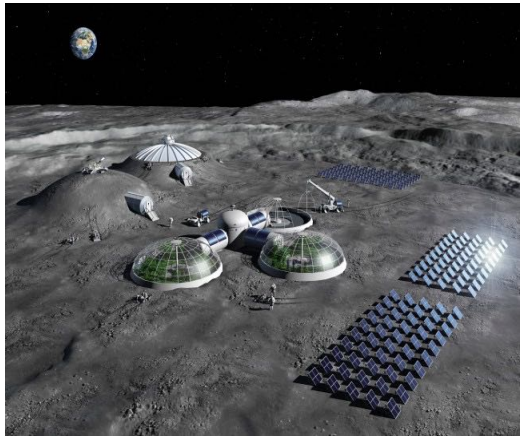


[8]

Stakeholder Interest

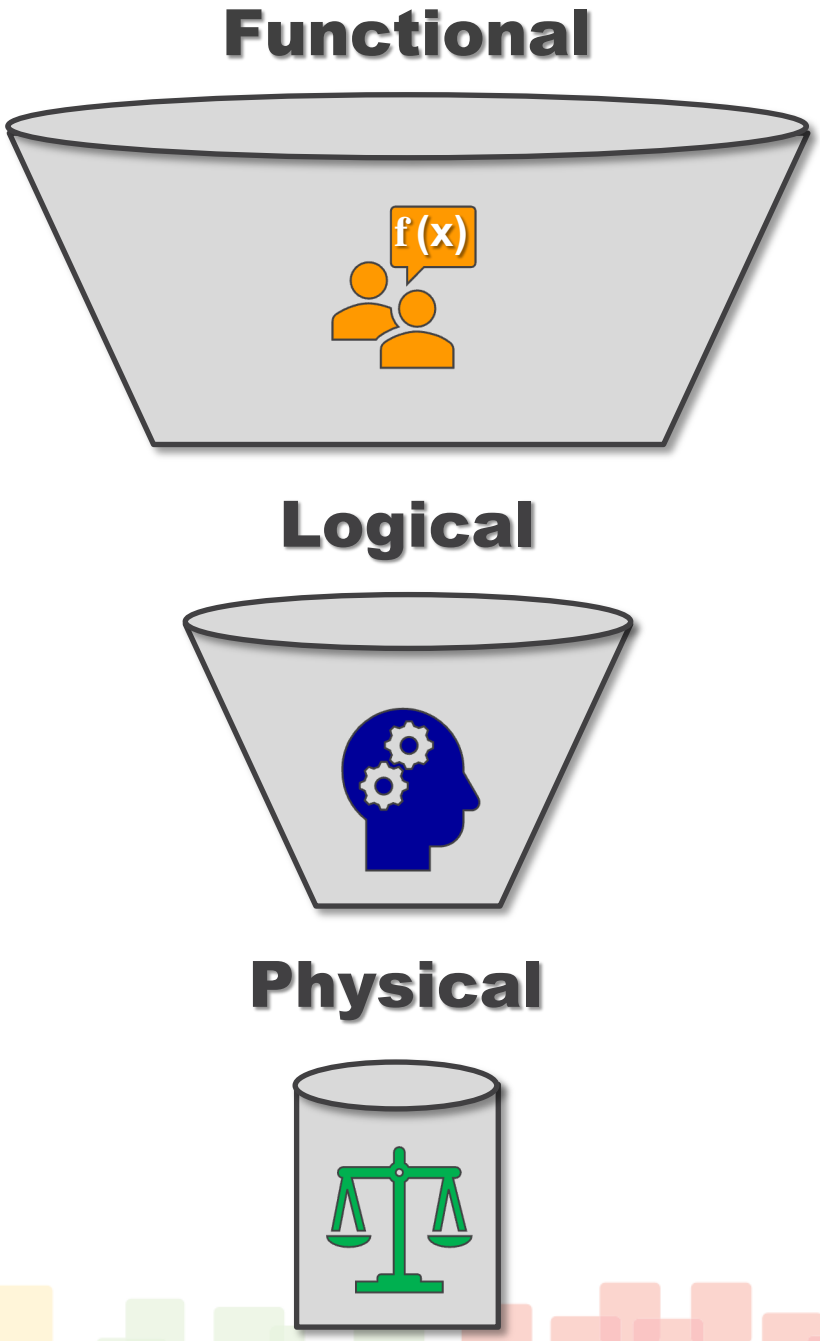
[9]

Engineering Novelty



[10]

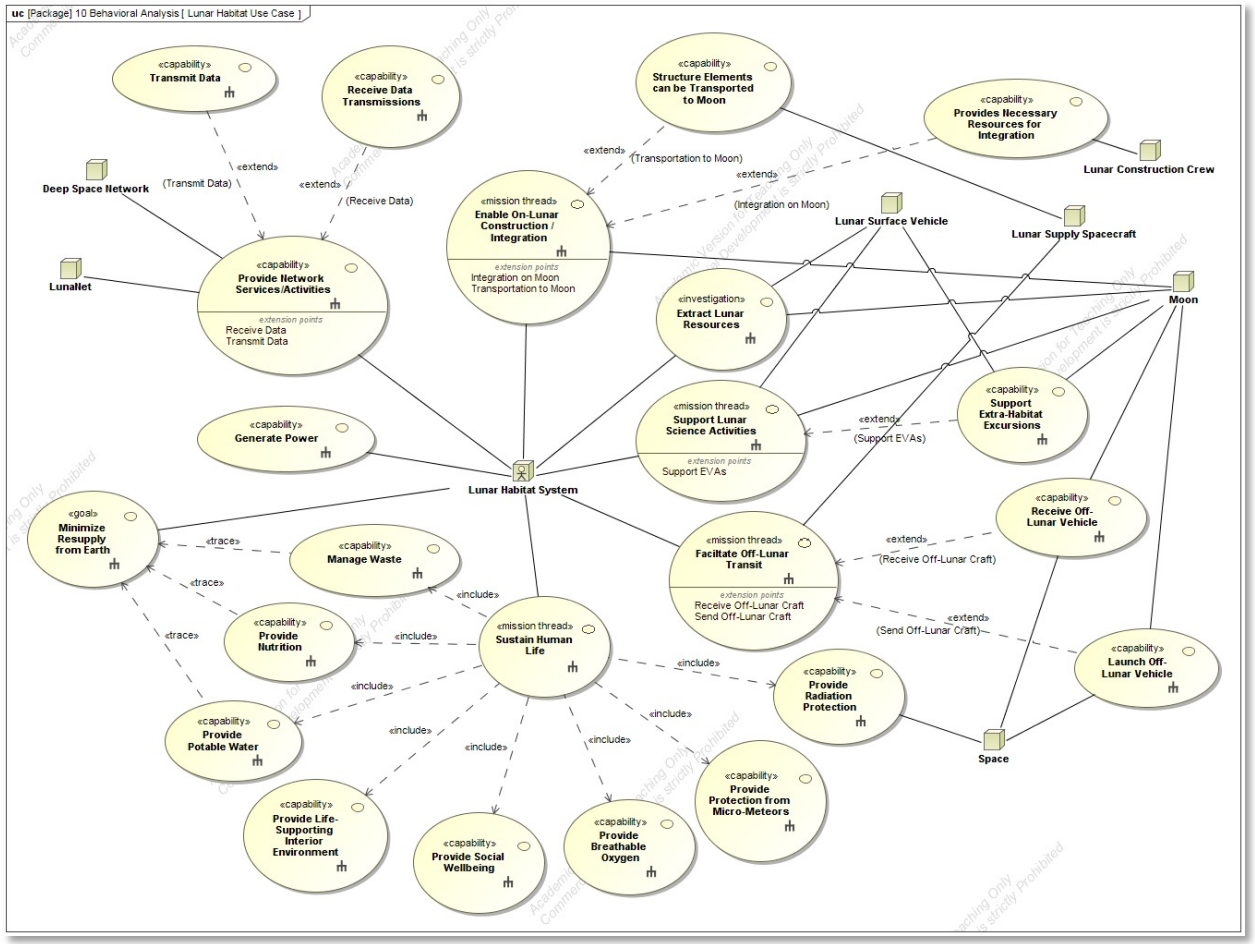
The Three Phases of Architecture Decomposition

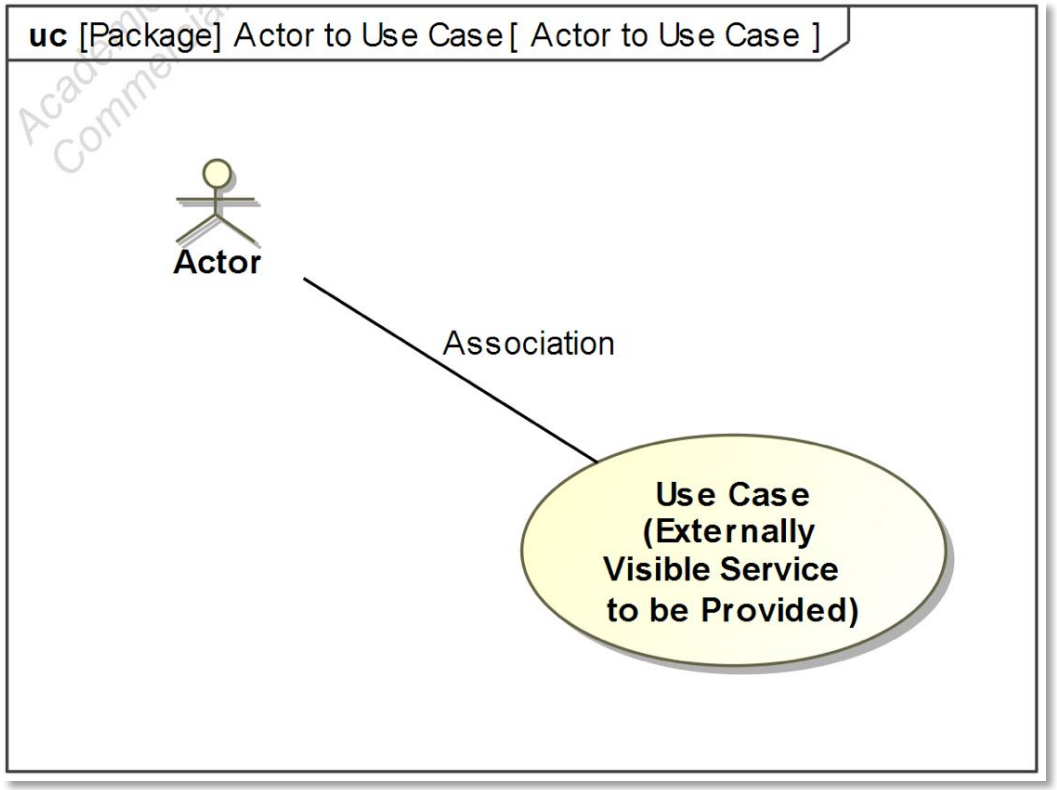


Functional Decomposition

«requirement»
Requirement
Id = "0"
Text = "Sample Requirement"

, **Use Case** , and **Actor** definition.





Functional Decomposition

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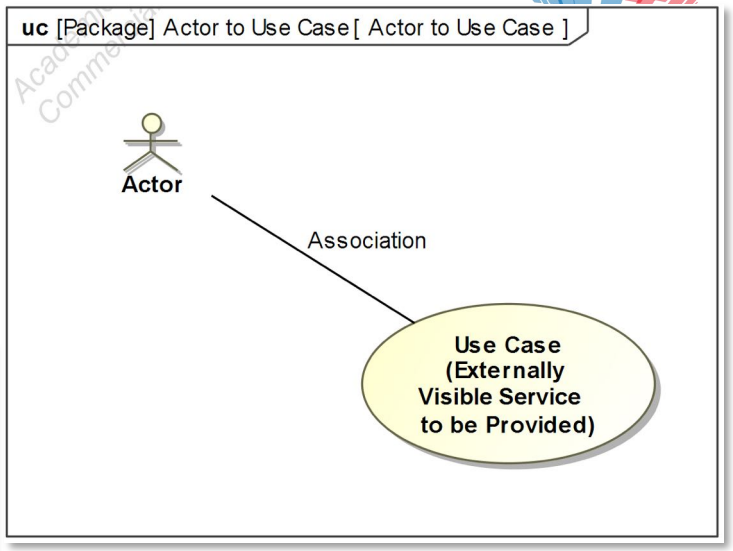
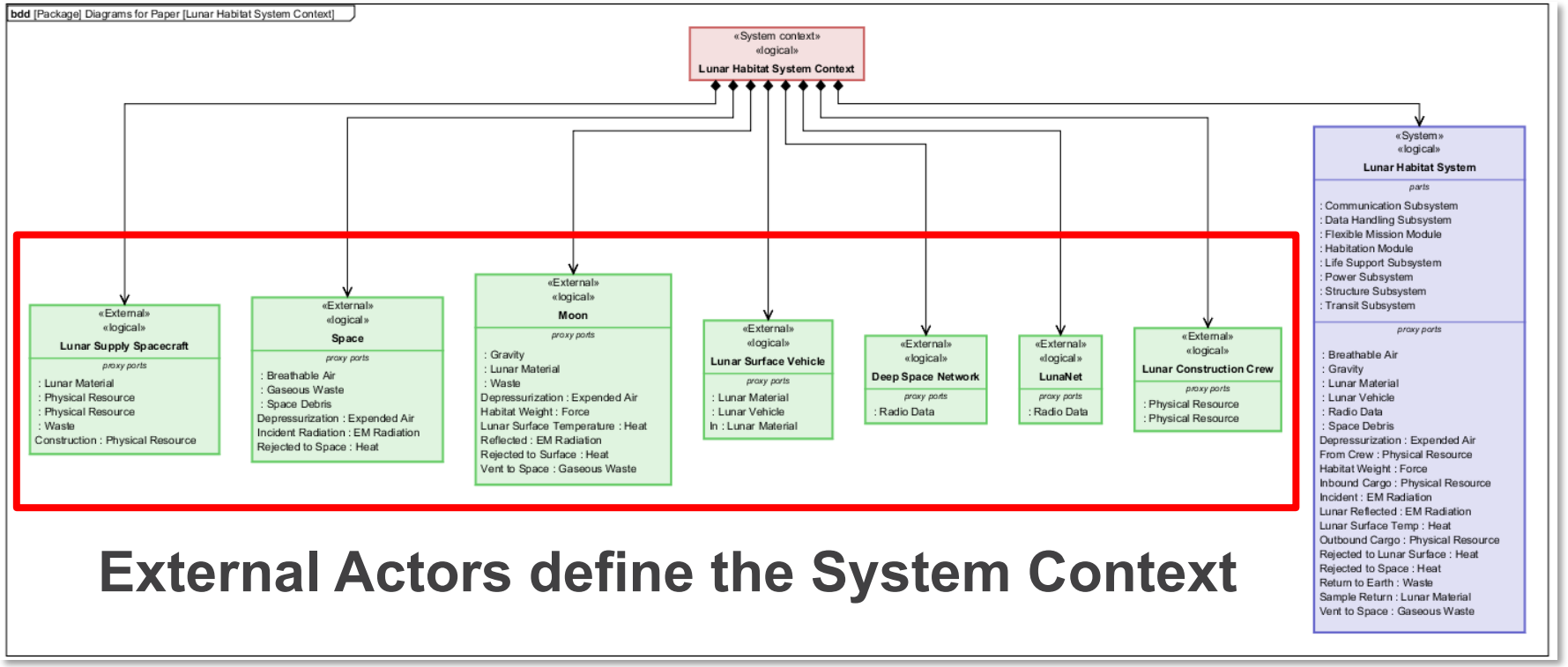
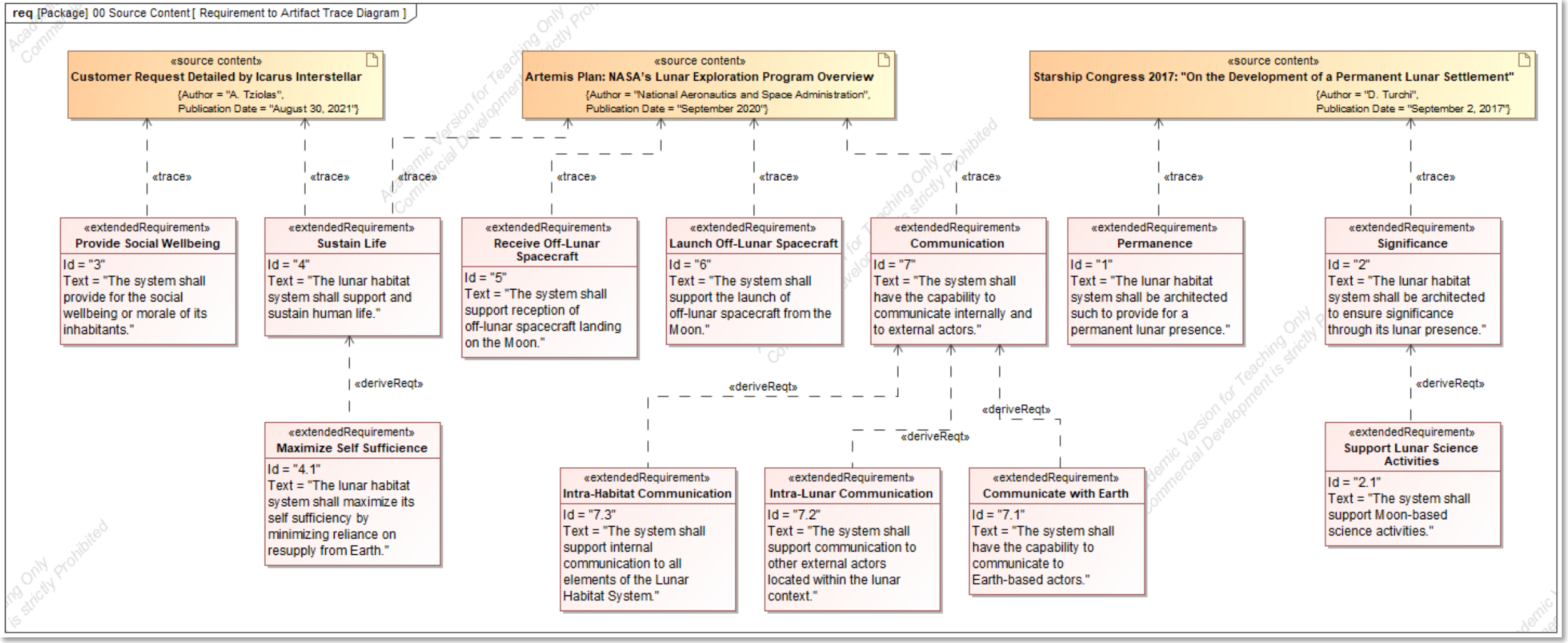


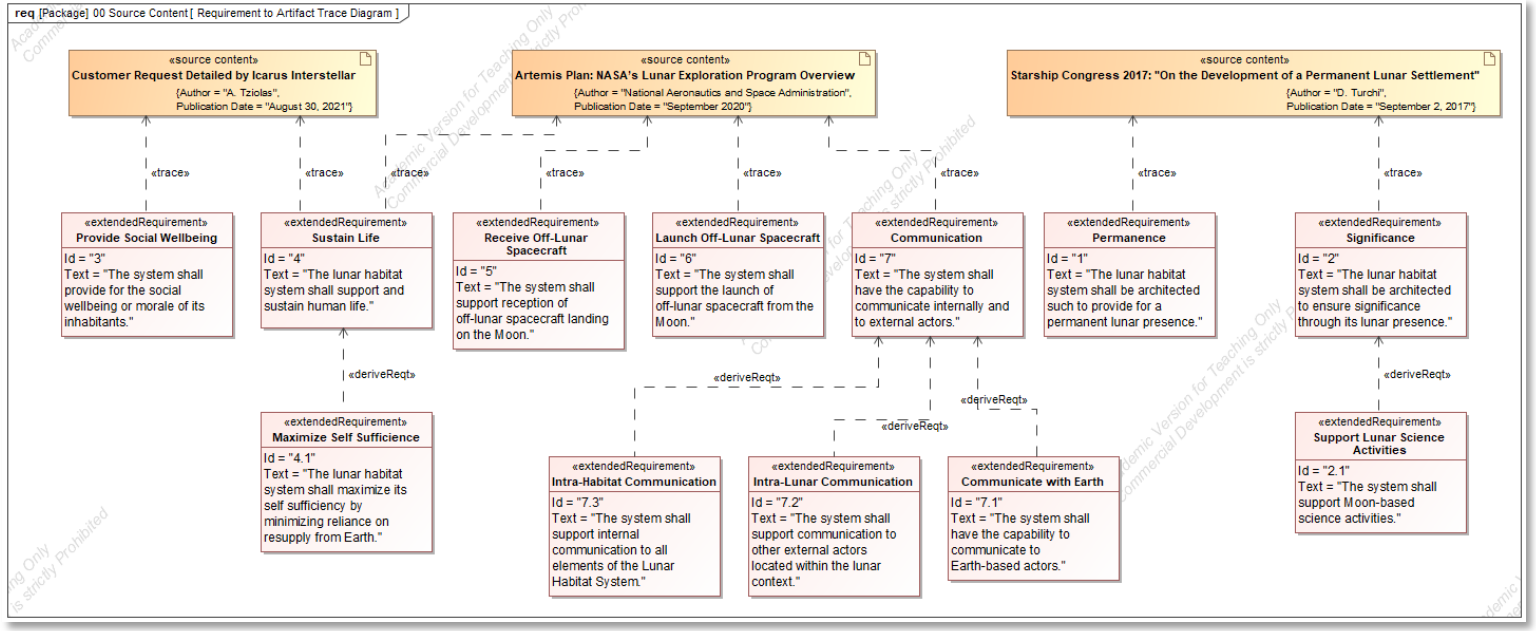


External Actors define the System Context

Functional Decomposition



Functional Decomposition



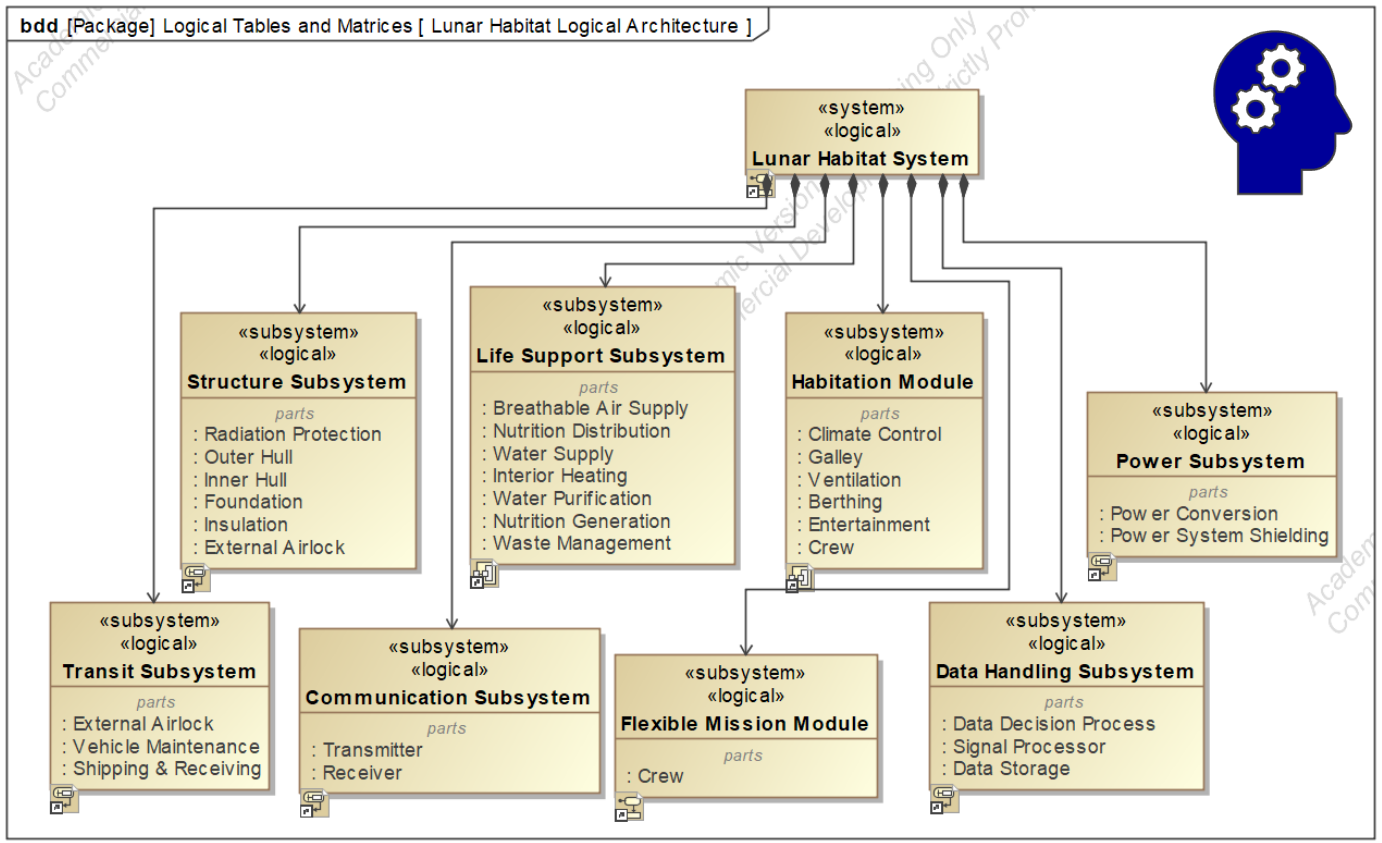
Legend

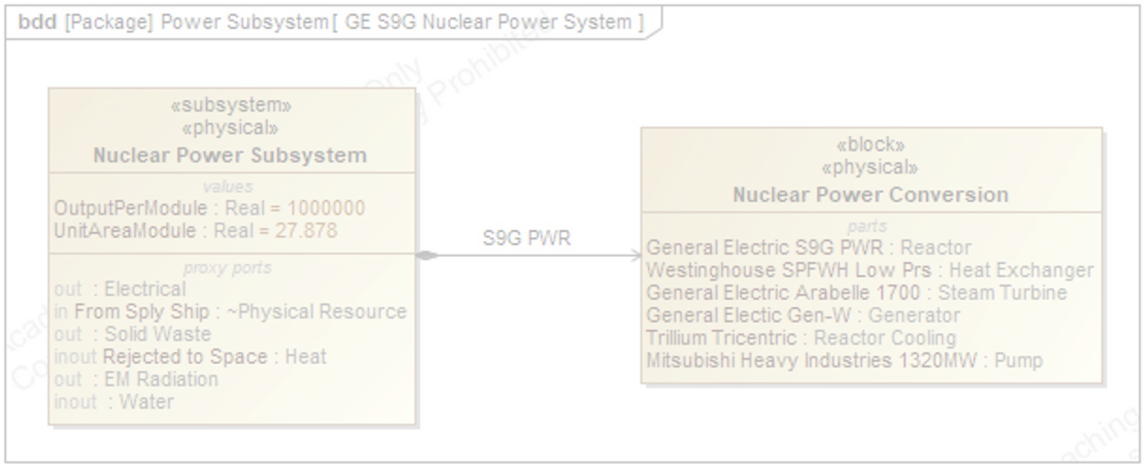
↗ Trace

	1 Permanence	2 Significance	2.1 Support Lunar Science Activities	3 Provide Social Wellbeing	4 Sustain Life	4.1 Maximize Self Sufficience	5 Receive Off-Lunar Spacecraft	6 Launch Off-Lunar Spacecraft	7 Communication	7.1 Communicate with Earth	7.2 Intra-Lunar Communication	7.3 Intra-Habitat Communication
Enable On-Lunar Construction / Integration					↗							
Extract Lunar Resources		↗										
Facilitate Off-Lunar Transit								↗				
Generate Power	↗				↗	↗						
Launch Off-Lunar Vehicle								↗				
Manage Waste	↗				↗							
Minimize Resupply from Earth						↗						
Provide Breathable Oxygen	↗				↗	↗						
Provide Life-Supporting Interior Environment	↗				↗	↗						
Provide Network Services/Activities				↗					↗	↗	↗	↗
Provide Nutrition	↗				↗	↗						
Provide Potable Water	↗				↗	↗						
Provide Protection from Micro-Meteors	↗				↗							
Provide Radiation Protection	↗				↗							
Provide Social Wellbeing									↗	↗		
Provides Necessary Resources for Integration					↗							
Receive Data Transmissions									↗	↗	↗	↗
Receive Off-Lunar Vehicle							↗					
Structure Elements can be Transported to Moon					↗							
Support Extra-Habitat Excursions		↗	↗								↗	
Support Lunar Science Activities		↗	↗									
Sustain Human Life	↗	↗			↗							
Transmit Data									↗	↗	↗	↗

Logical and Physical Decompositions

Logical Architecture: generic representation of system elements, defined in terms of functions they provide

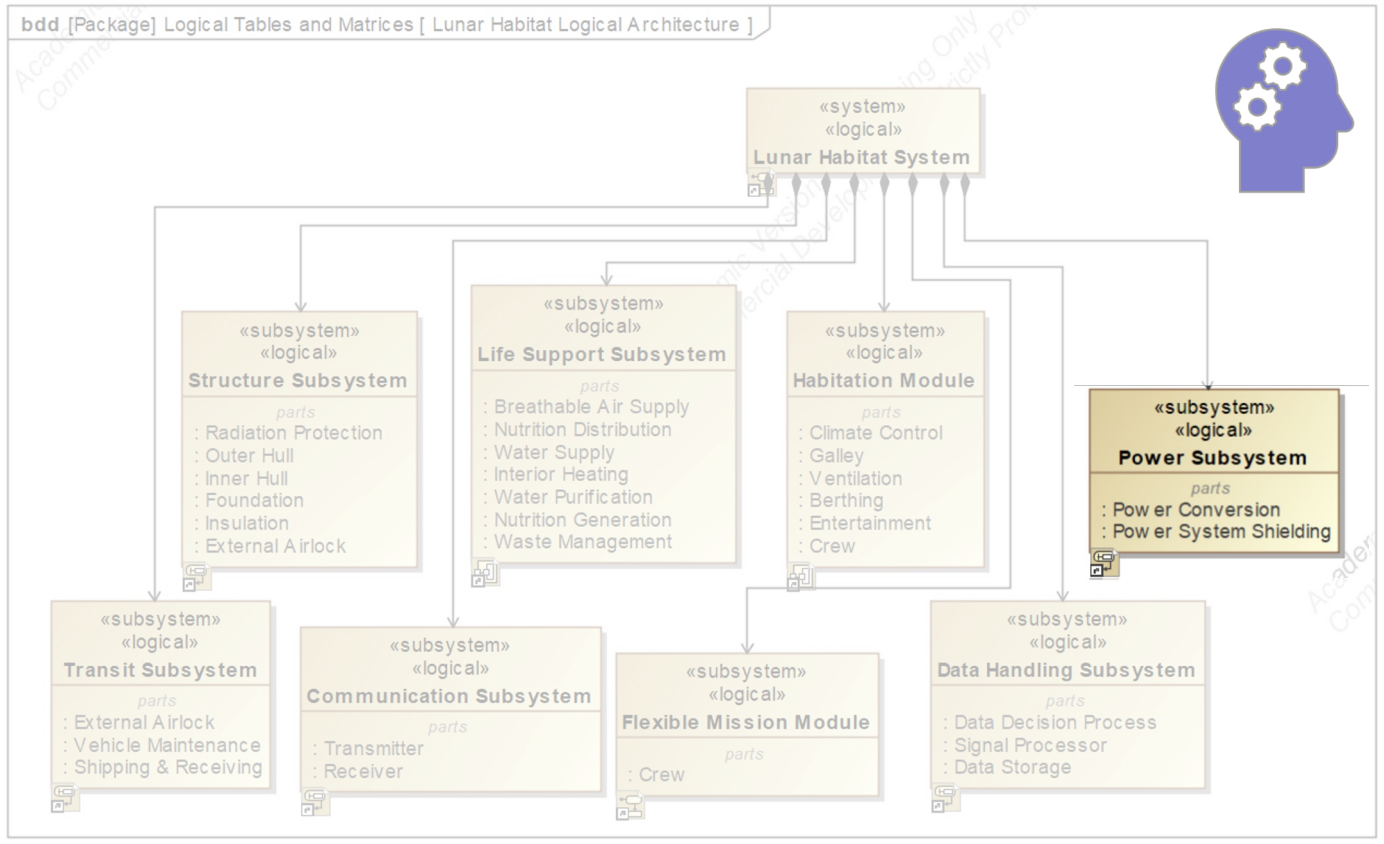


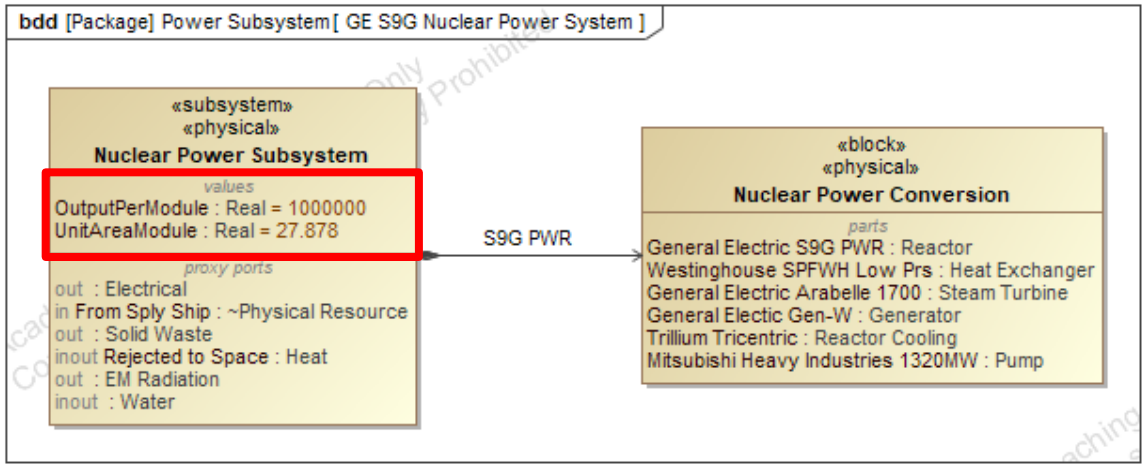


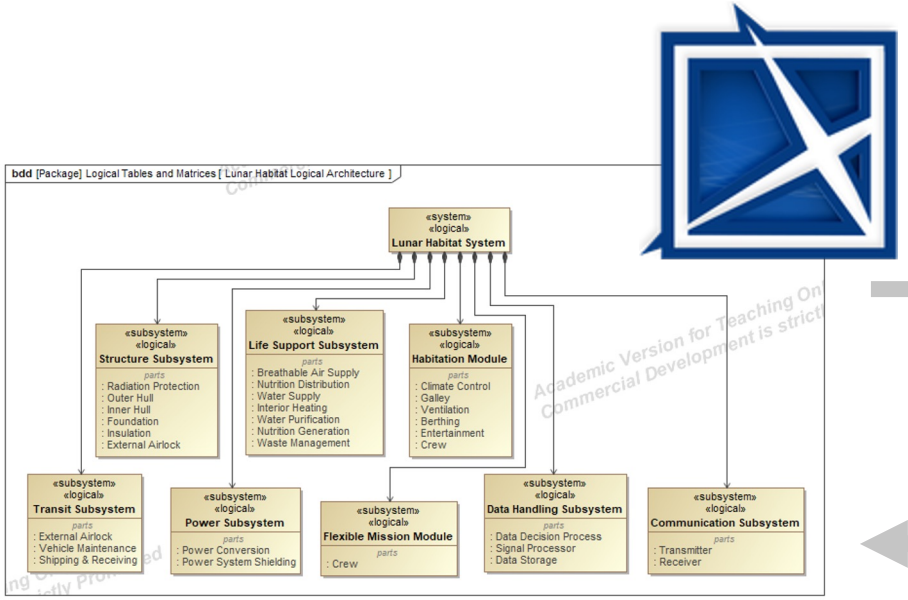
Logical and Physical Decompositions

Logical Architecture: generic representation of system elements, defined in terms of functions they provide

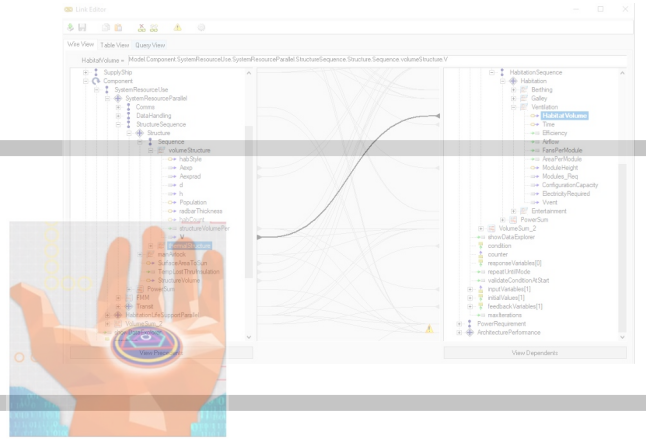
Physical Architecture: unique, specific instantiations of system elements

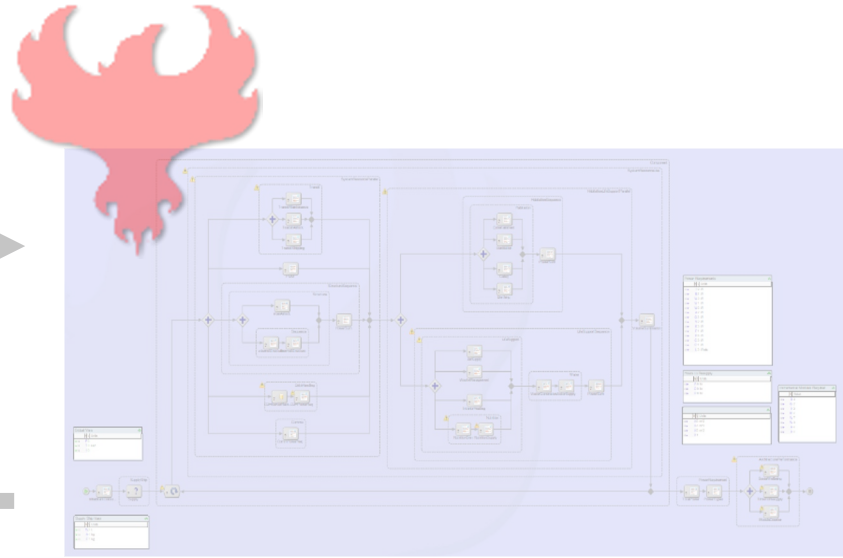




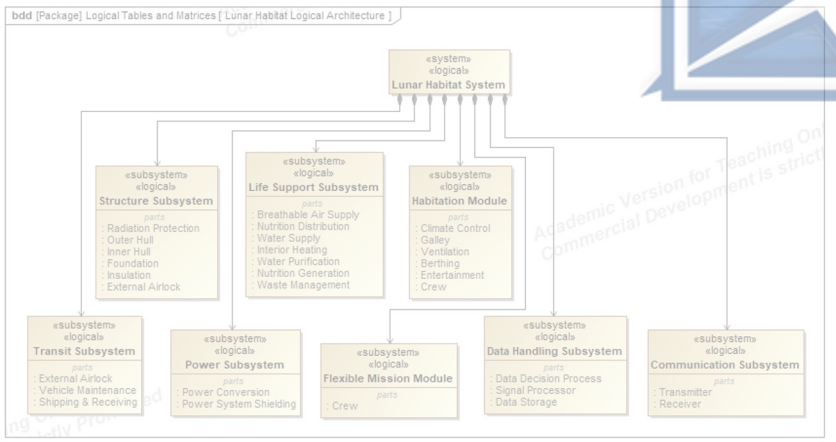


Model-Based Architecture

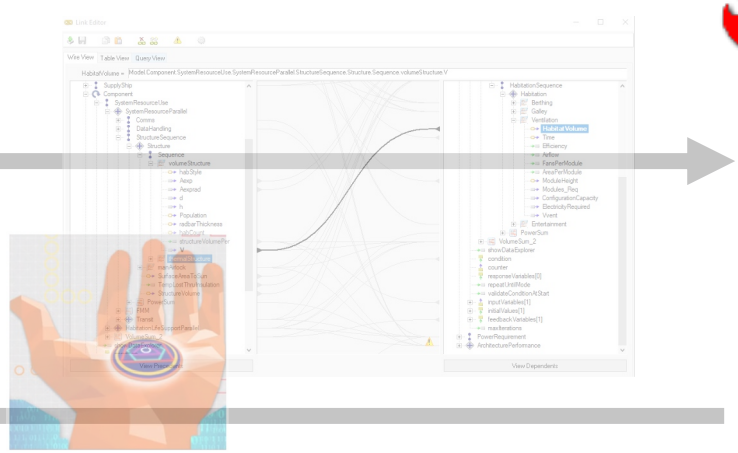


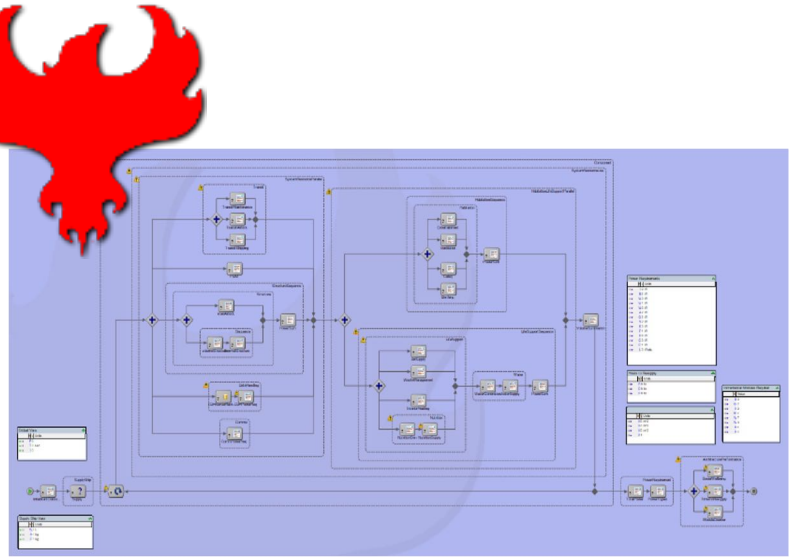


Systems Simulation



Model-Based Architecture



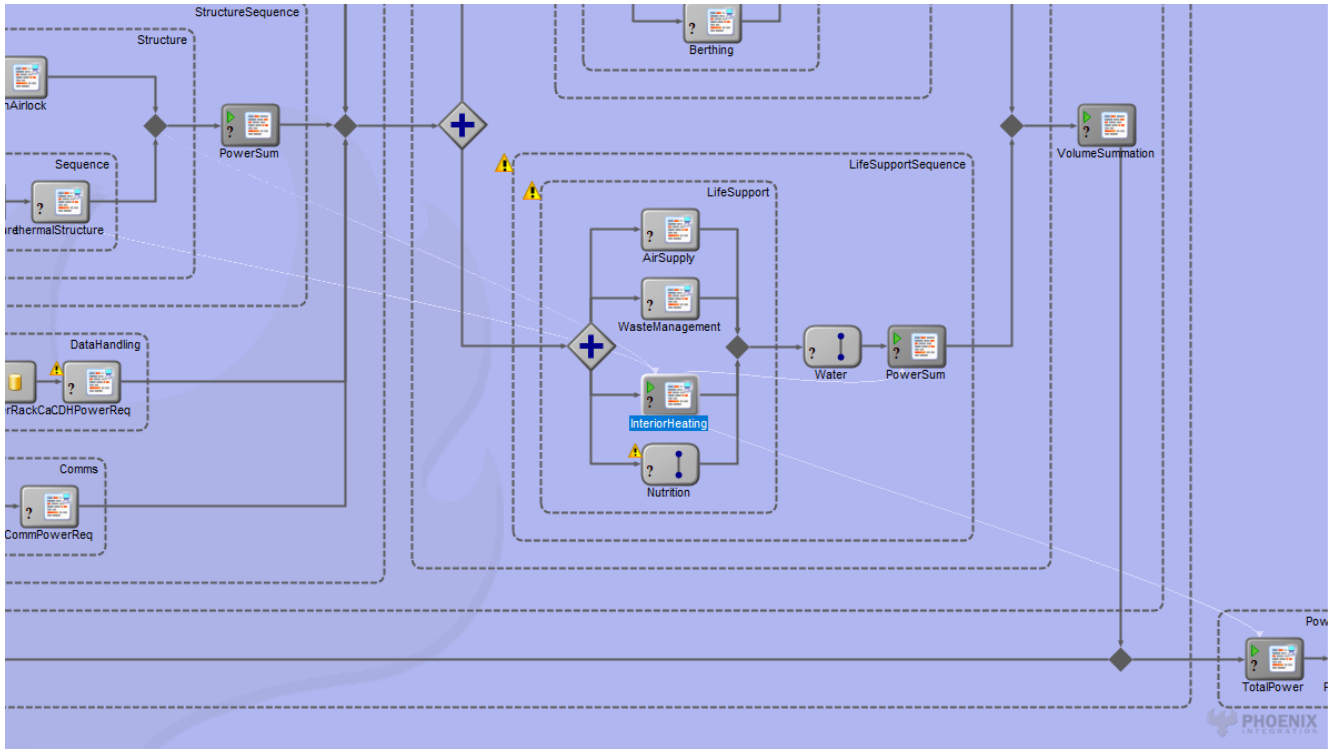


Systems Simulation

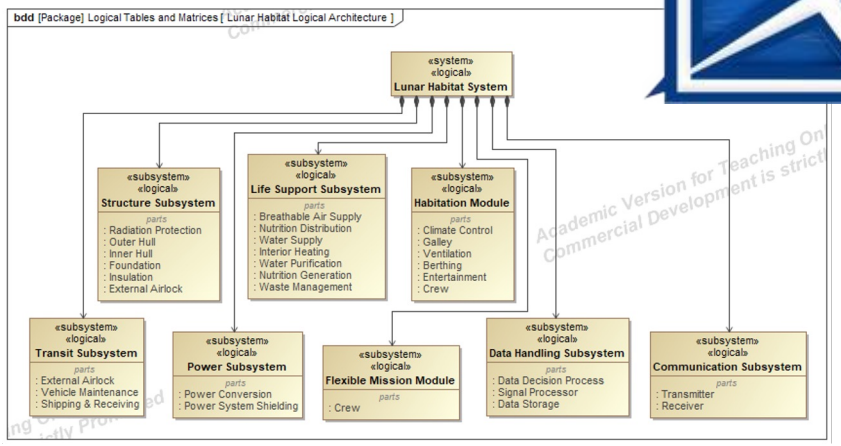
Shared Systems Simulation Development

- Defined system behaviors using detailed system simulations
- Sequenced and integrated simulation elements via a simulation workflow

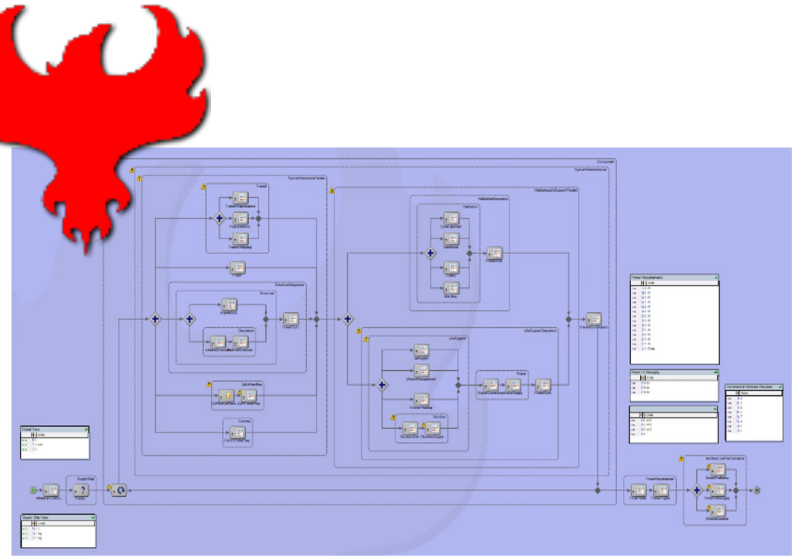
Phoenix® Integration
An Ansys Company
[6]



Shared Systems Simulation Coupling

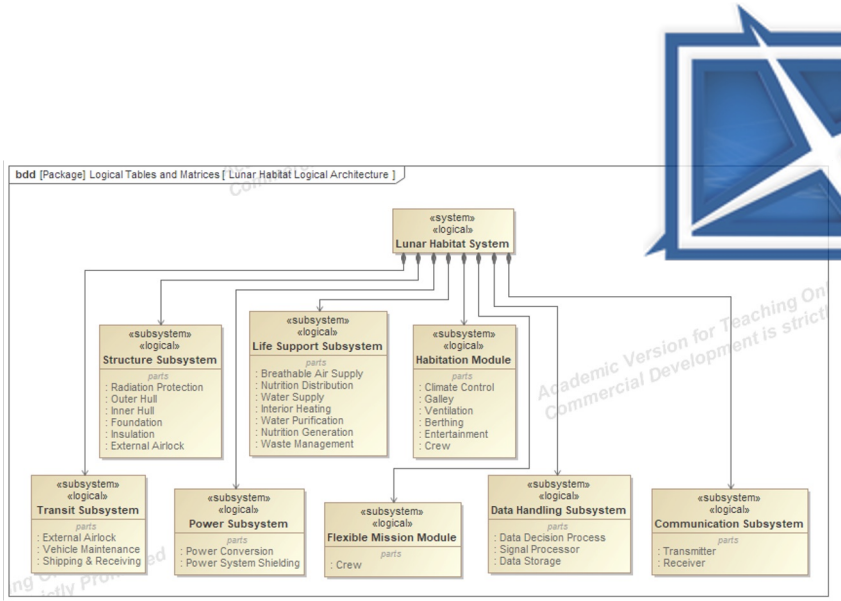


Model-Based Architecture

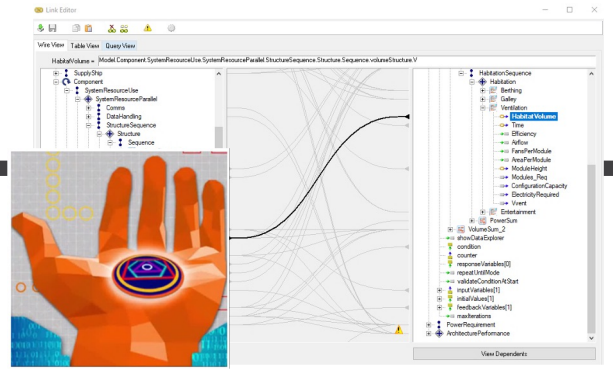


Systems Simulation

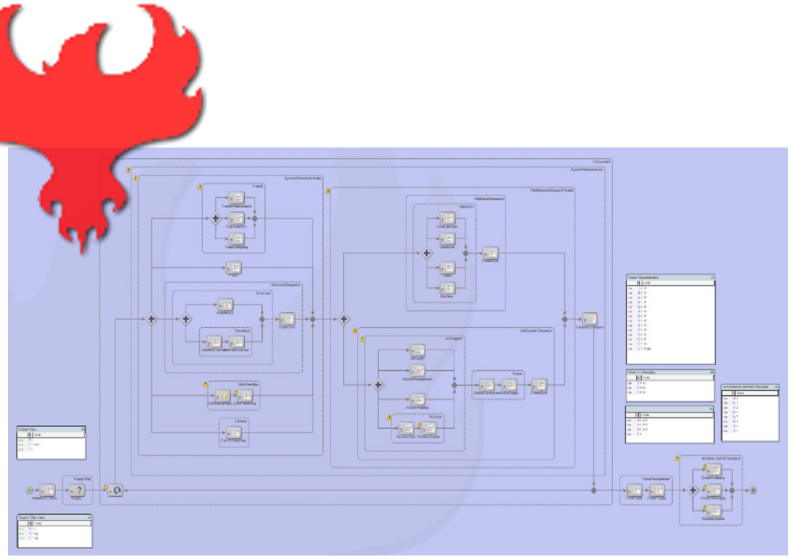
Shared Systems Simulation Coupling



Model-Based Architecture



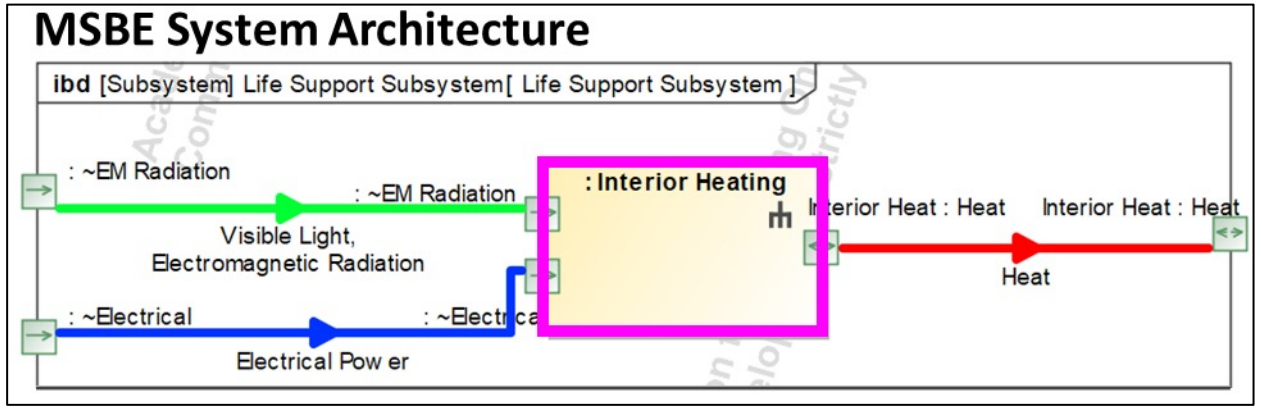
MBSE Connector Interface

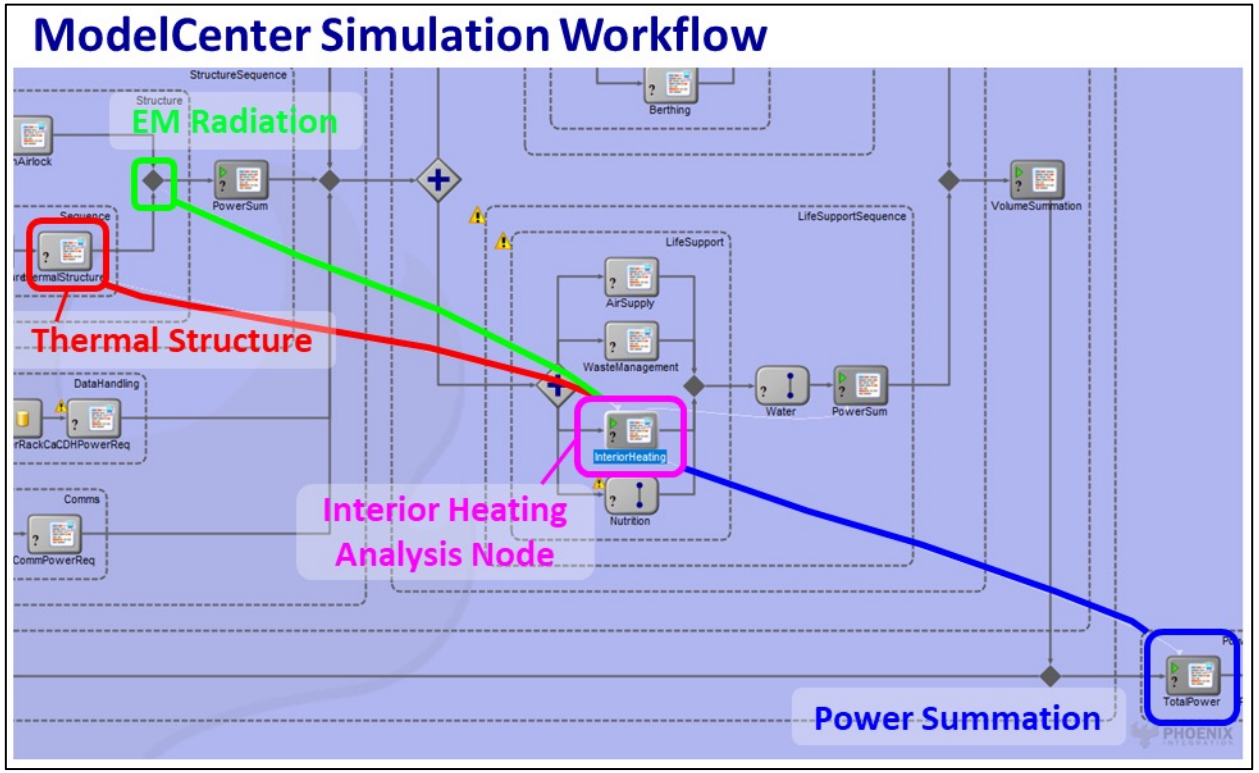


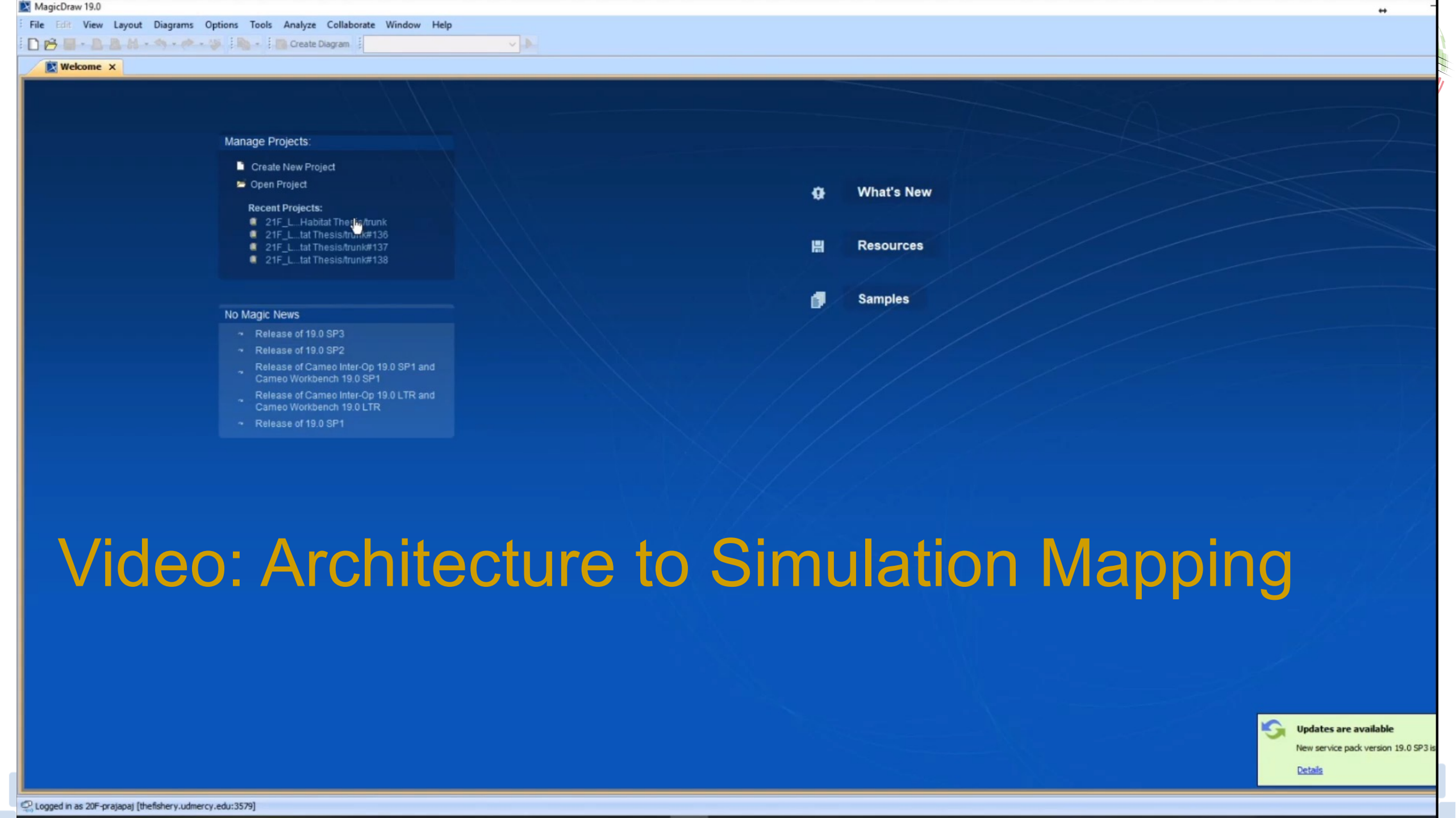
Systems Simulation

Shared Systems Simulation Coupling

- Coupled the simulation to the model-based architecture

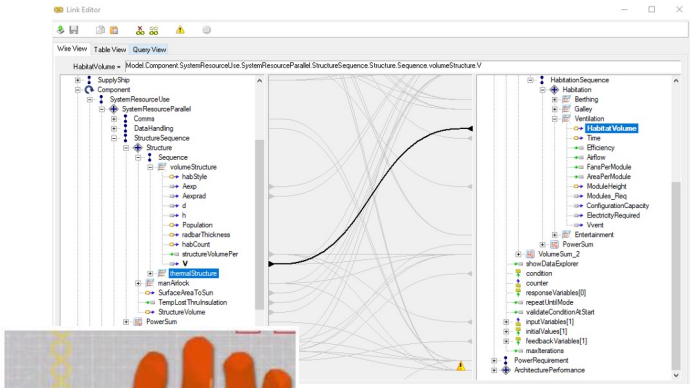




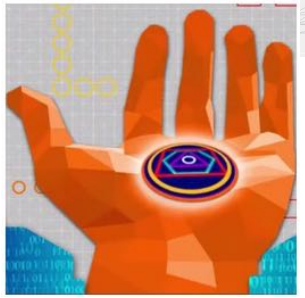


Video: Architecture to Simulation Mapping

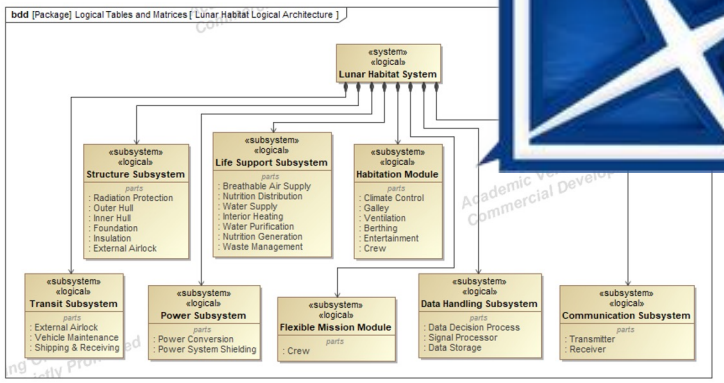
Shared Systems Simulation Coupling

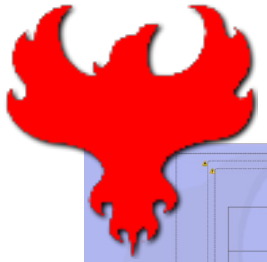


MBSE Connector

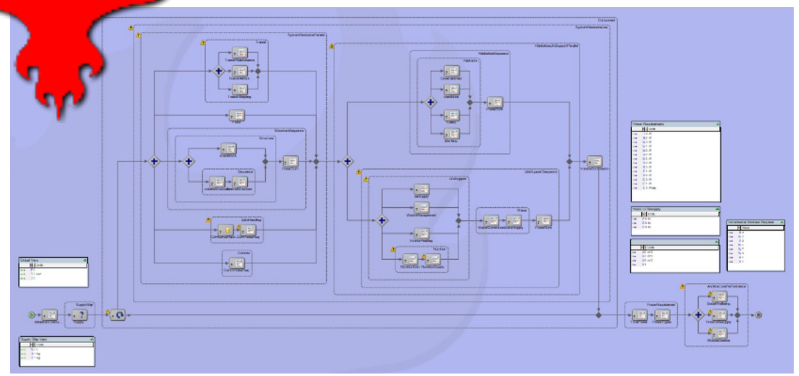


MagicDraw





ModelCenter



Agenda

- ✓ Shift to Model-Based Systems Engineering
- ✓ Problem Statement
- ✓ Model-Based Architecture Development
- ✓ Shared Systems Simulation Coupling
- ► Architecture Trade Study Example
- ► Interface and Complexity Challenges

Agenda

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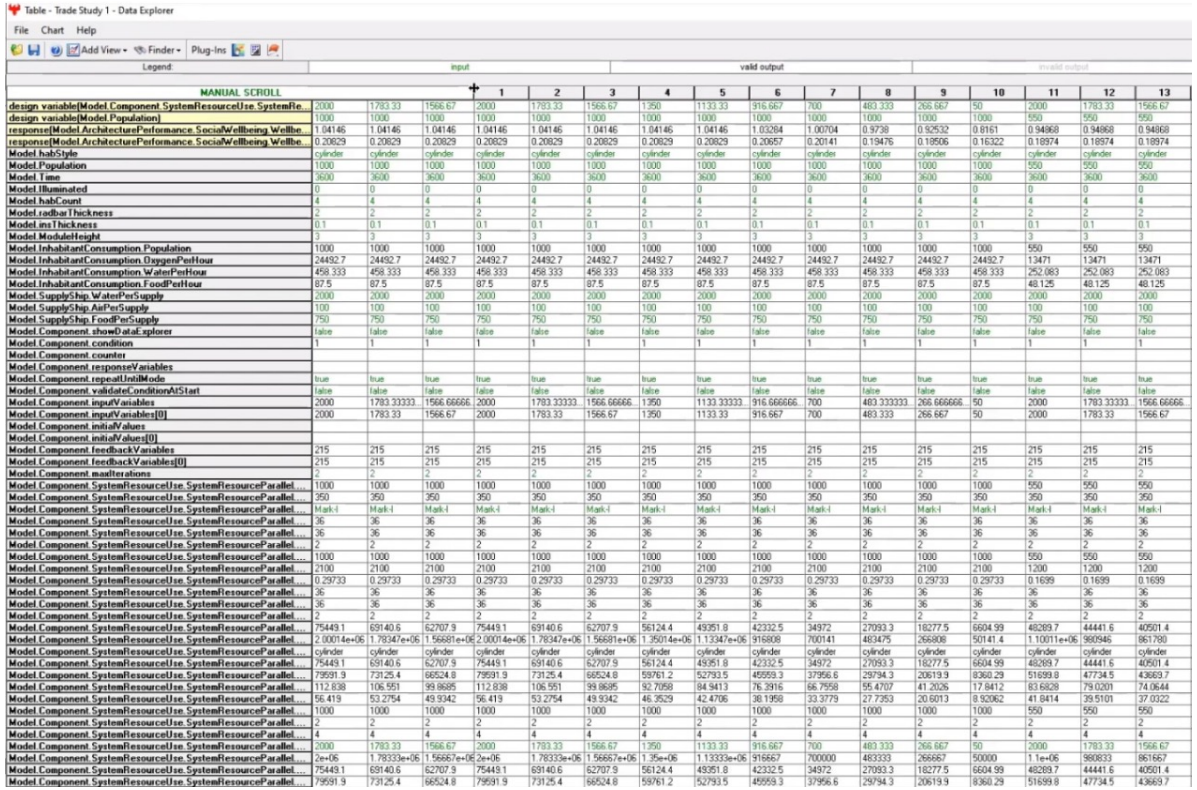
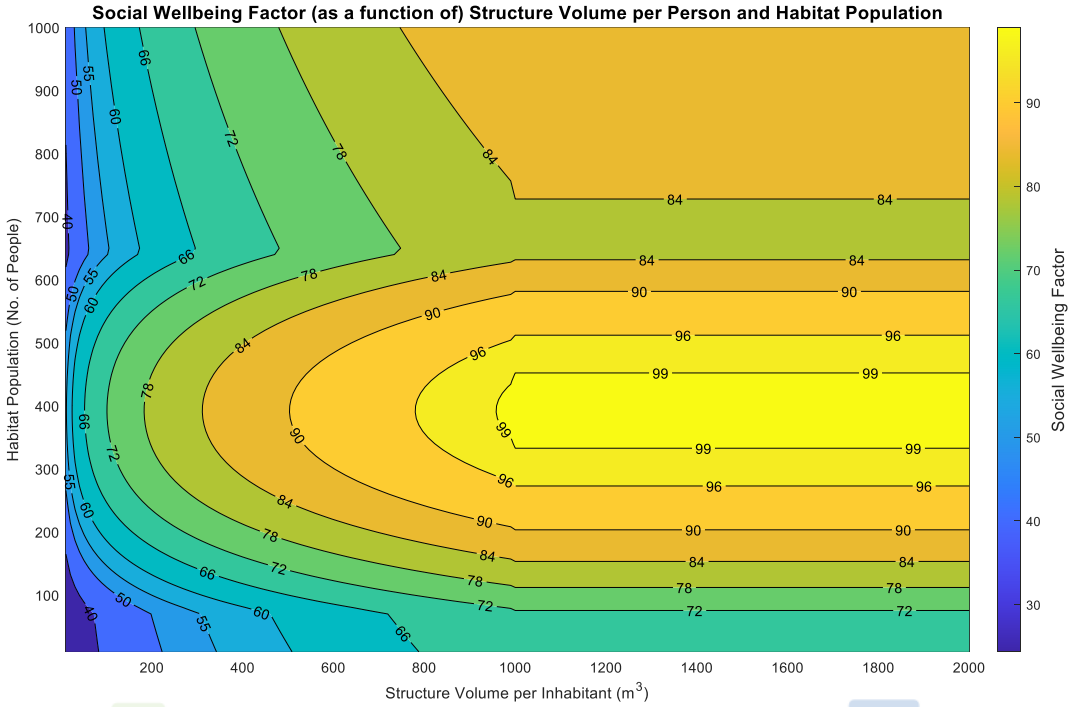
- ✓ Shared Systems Simulation Coupling
- ► **Architecture Trade Study Example**
- ► Interface and Complexity Challenges

Architecture Trade Studies

- Coupled system simulation enabled trade studies to characterize system behavior and guide decision-making



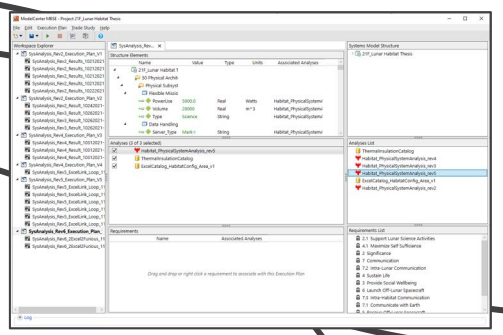


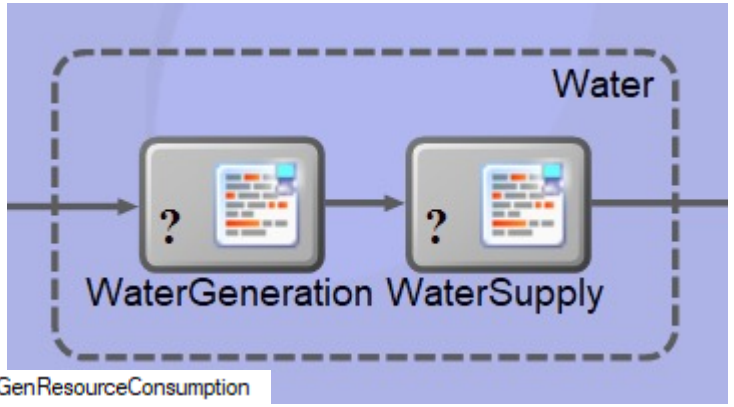
Design Configuration #1: Passive Filtration

«block»
«physical»
Water Generation

values
NumModules : Real = 4.0
PowerEfficiency : Real = 20.0
GenerationCapacity : Real = 20.0
Area : Real = 250.0
ModulesRequired : Real

MBSE Connector





WaterGenResourceConsumption
GeneratedWater
GeneratedWaterPerModule
WaterGenModules_Act
Time
PowerEff
AreaPerModule
ModuleHeight
ElectricityRequired
Vwatergen_Act
GenerationCap

«block»
«physical»
Water Generation

values
NumModules : Real = 4.0
PowerEfficiency : Real = 120.0
GenerationCapacity : Real = 20.0
Area : Real = 50.0
ModulesRequired : Real

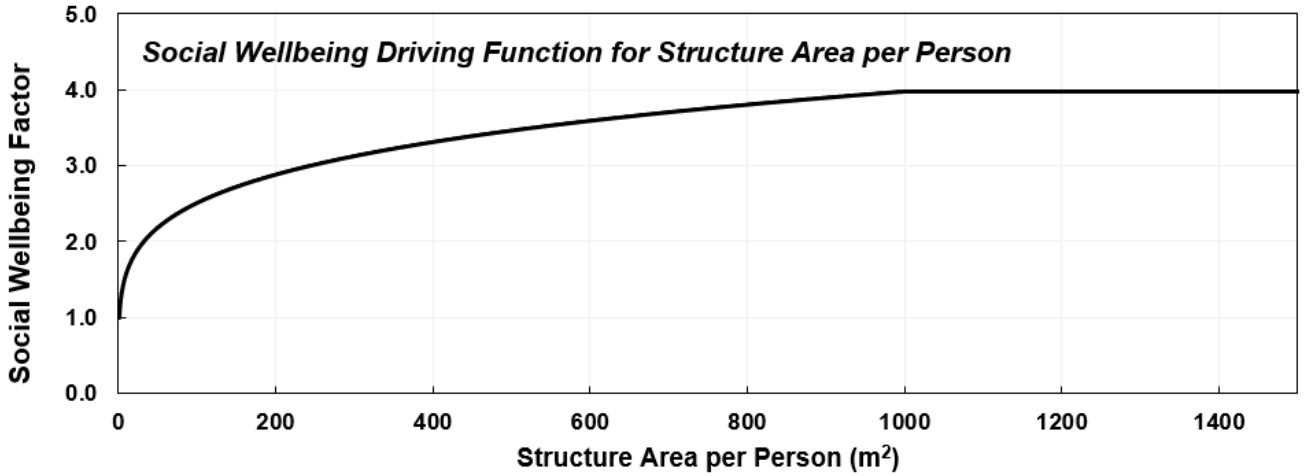
Design Configuration #2: Active Chemical Filtering

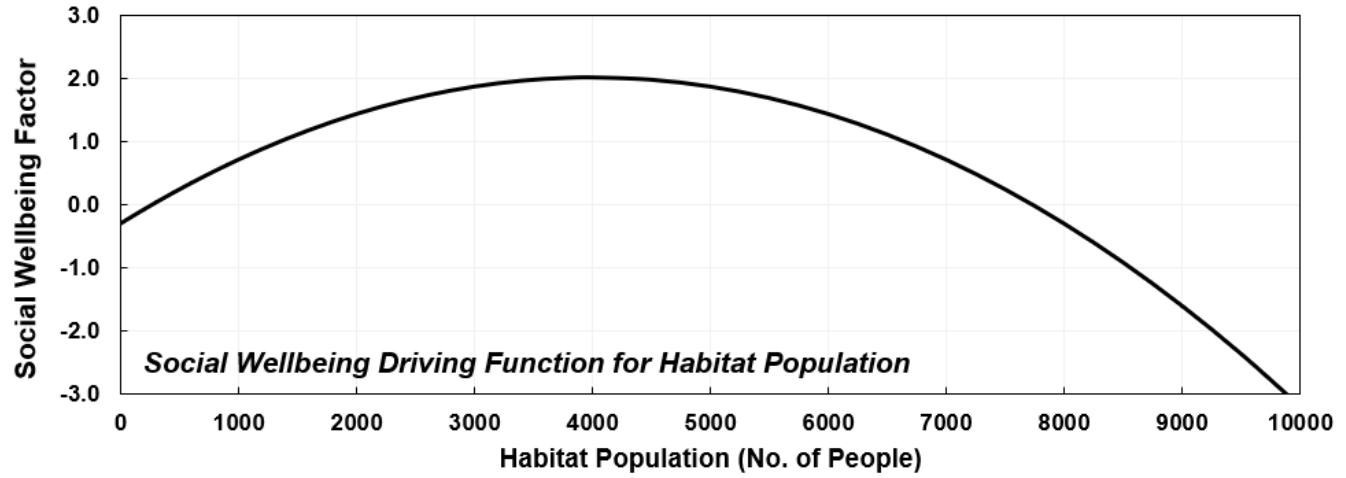
«block»
«physical»
Active Chemical Filtering : Water Generation

Area = 50.0
GenerationCapacity = 20.0
ModulesRequired = 4.0
NumModules = 4.0
PowerEfficiency = 120.0

Example Trade Study: Social Wellbeing

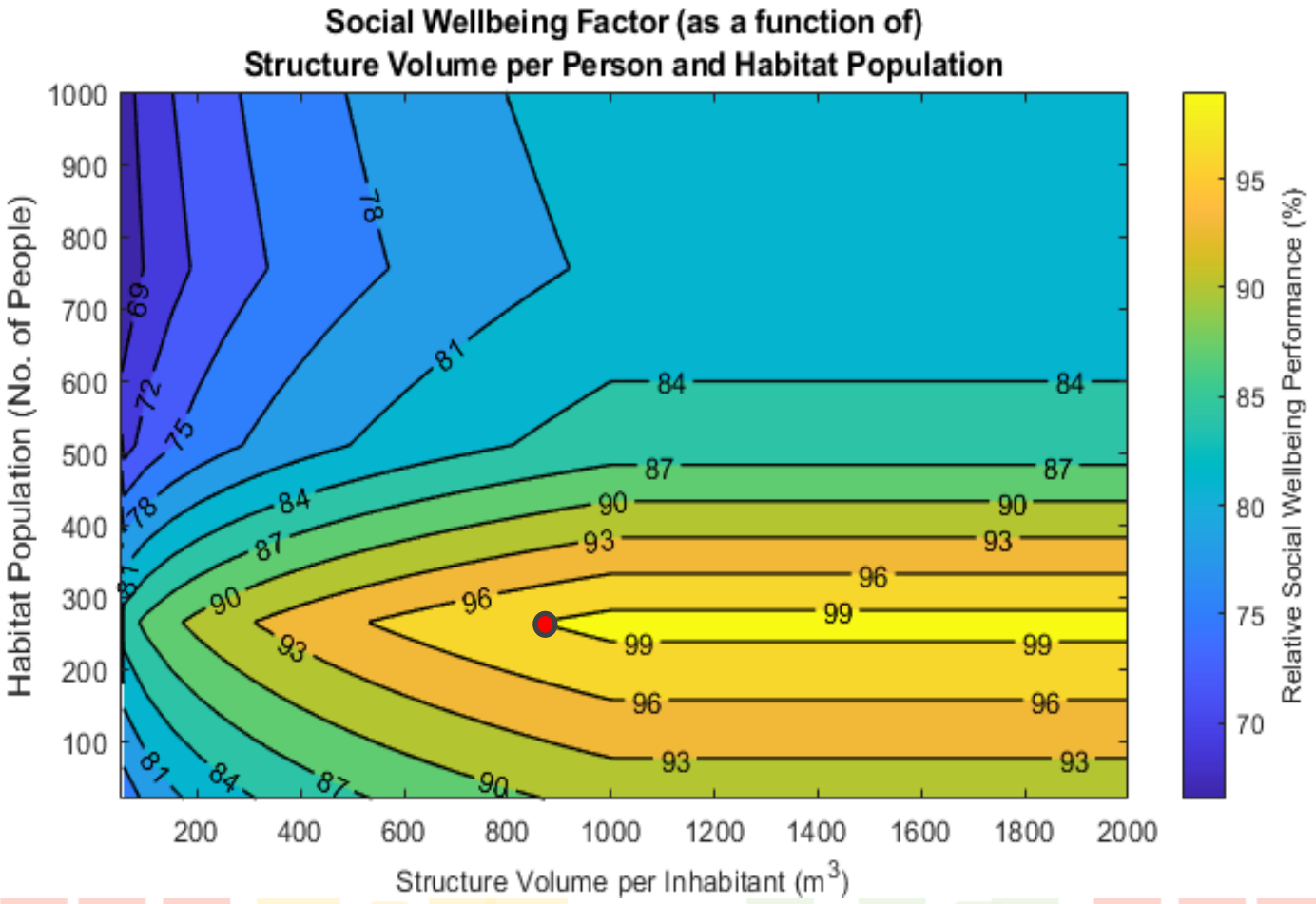
- Social considerations = sustained architecture success
- *Social Wellbeing Factor* enables qualitative analysis in the shared system model





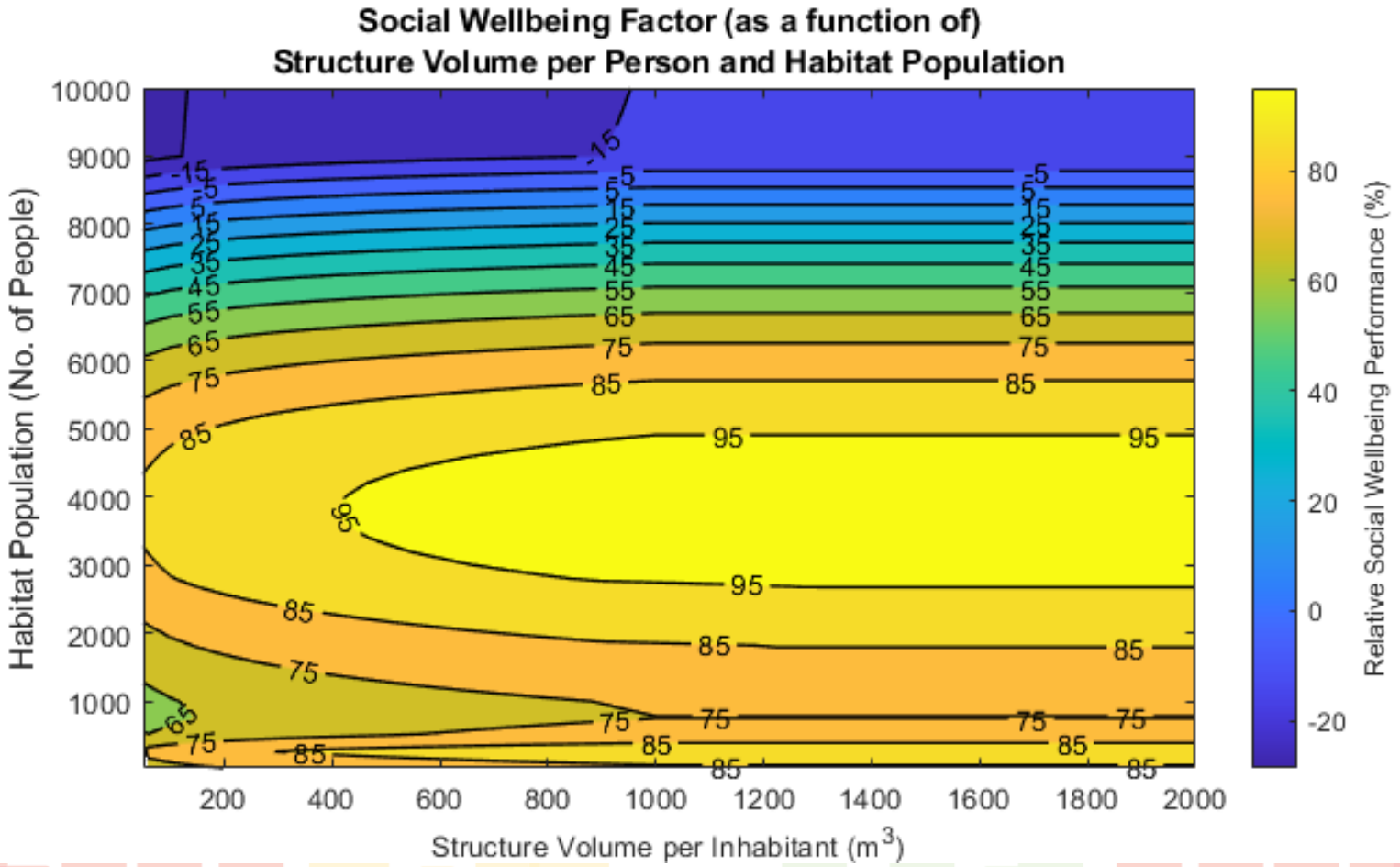
Example Trade Study: Social Wellbeing

- Architecture decisions influence down-stream system response
- Identify sociological emergent behavior



Example Trade Study: Social Wellbeing

- Studies can predict both present and future behavior
- Methods supports analysis of the “soft” aspects of complex socio-technical systems

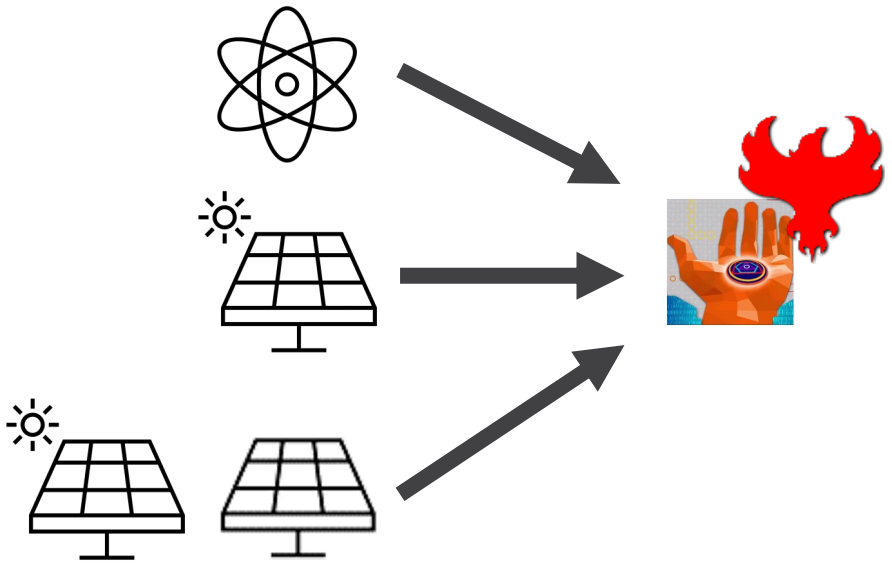


Advantages and Successes

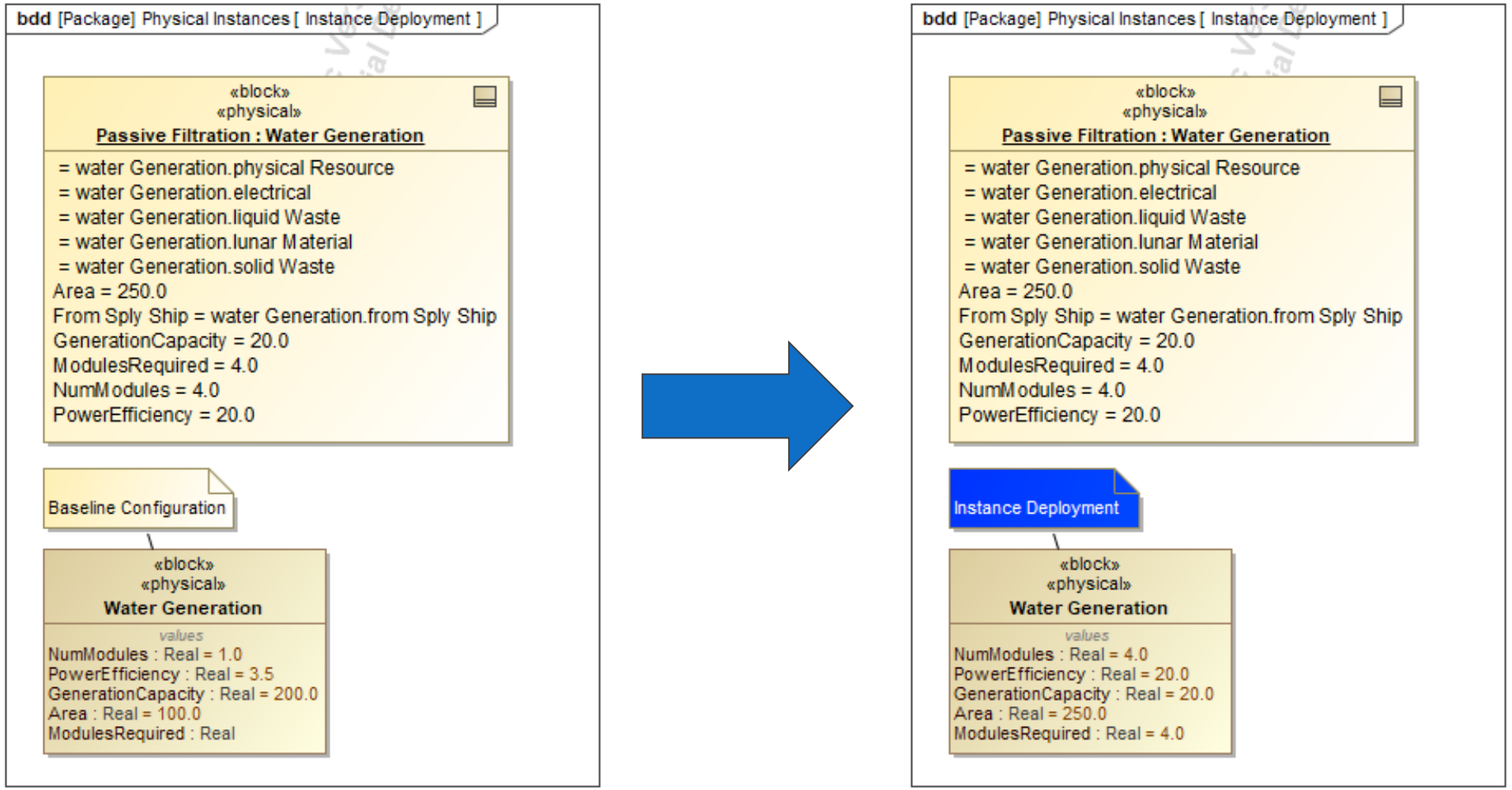
- ✓ Leveraged the Shared Systems Model
- ✓ Created a flexible, rigorous, robust, and efficient simulation
- ✓ Identified emergent system behaviors

Challenges

- System simulation DOEs require multiple physical architecture configurations

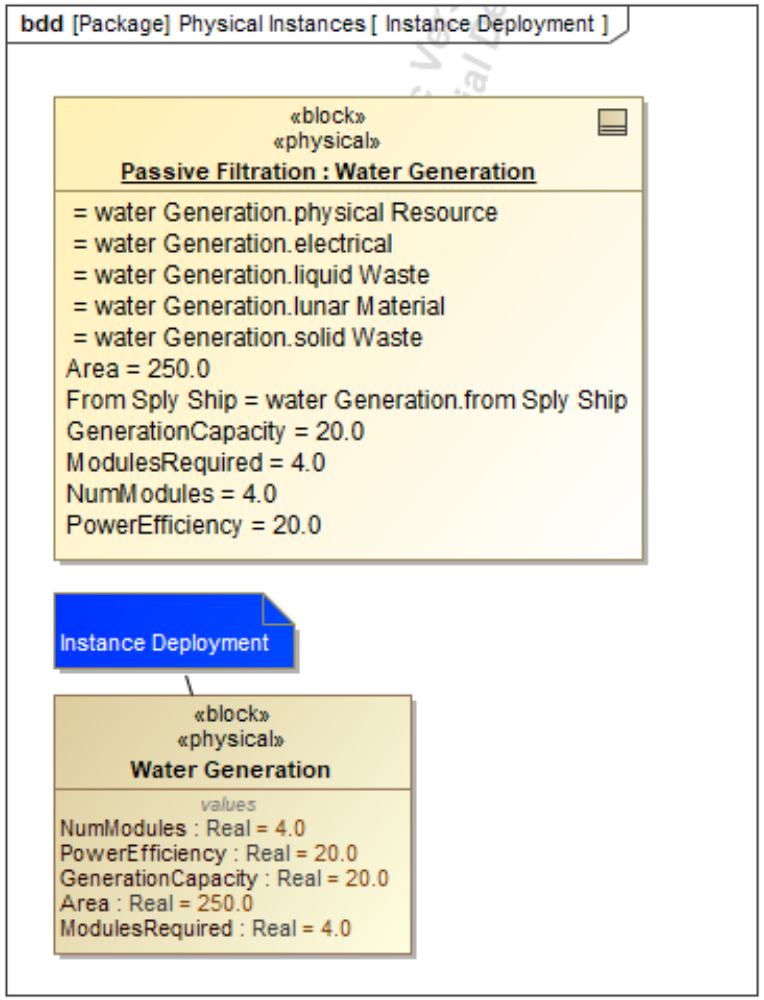


Instance Management

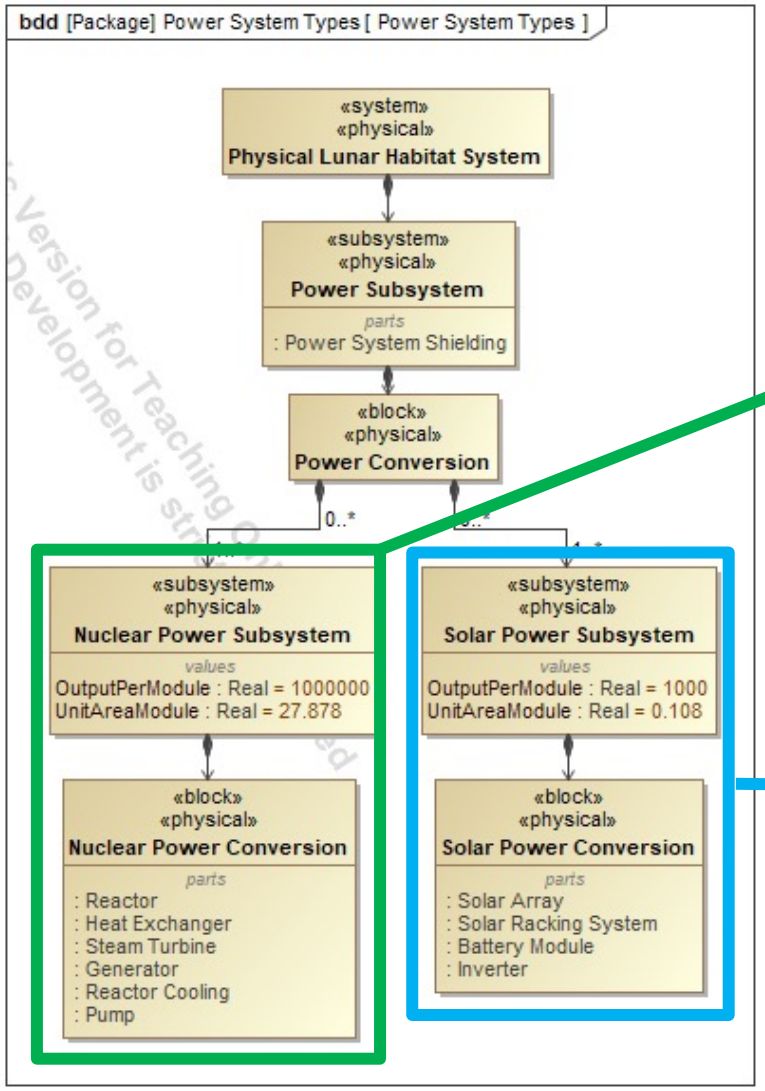


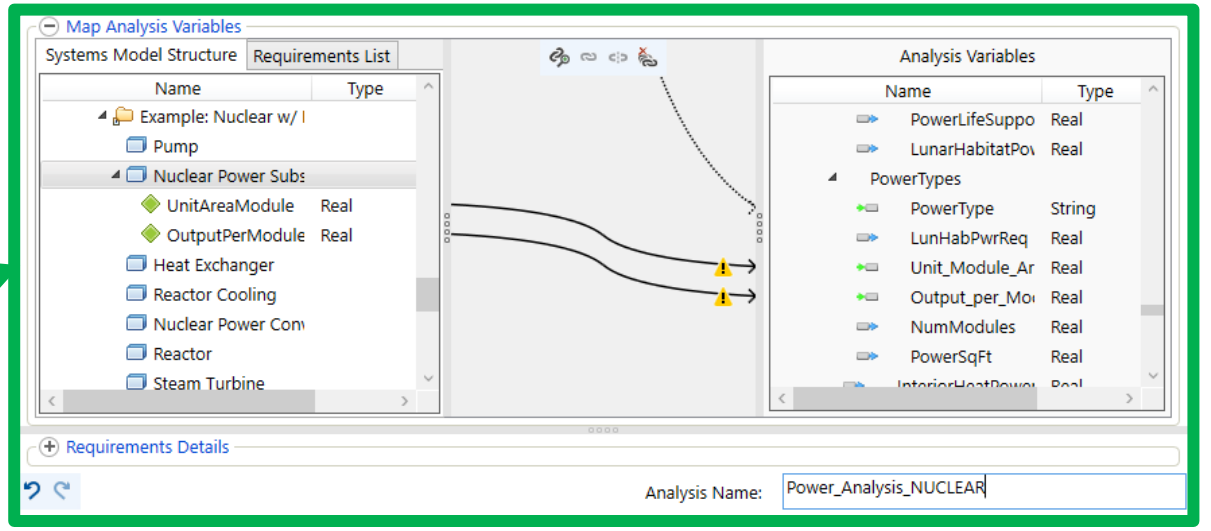
Instance Management

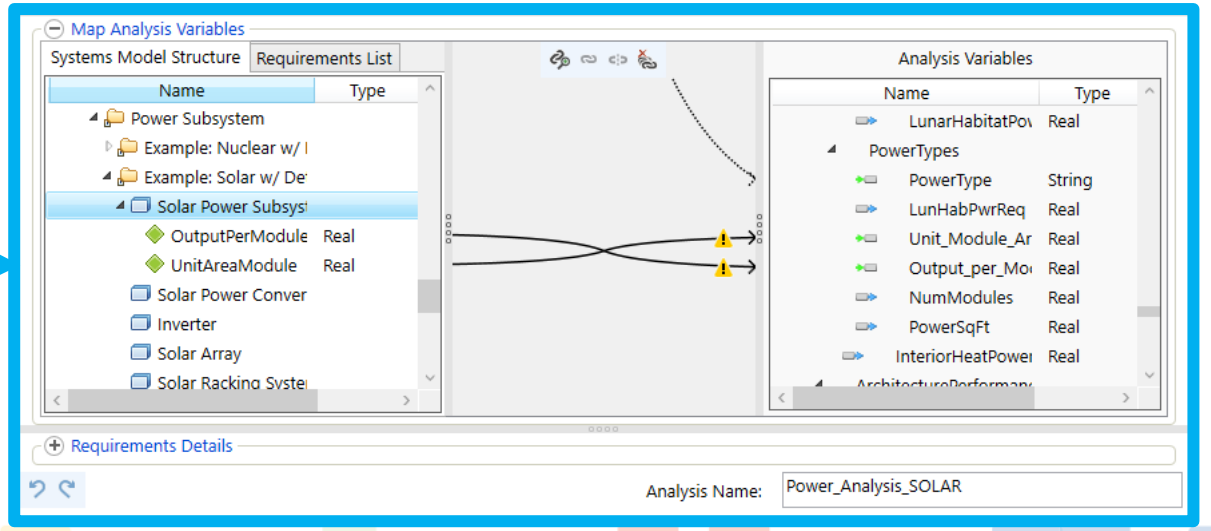
- Modeler-in-the-loop intensive
- Document-centric
- Inefficient and fragile



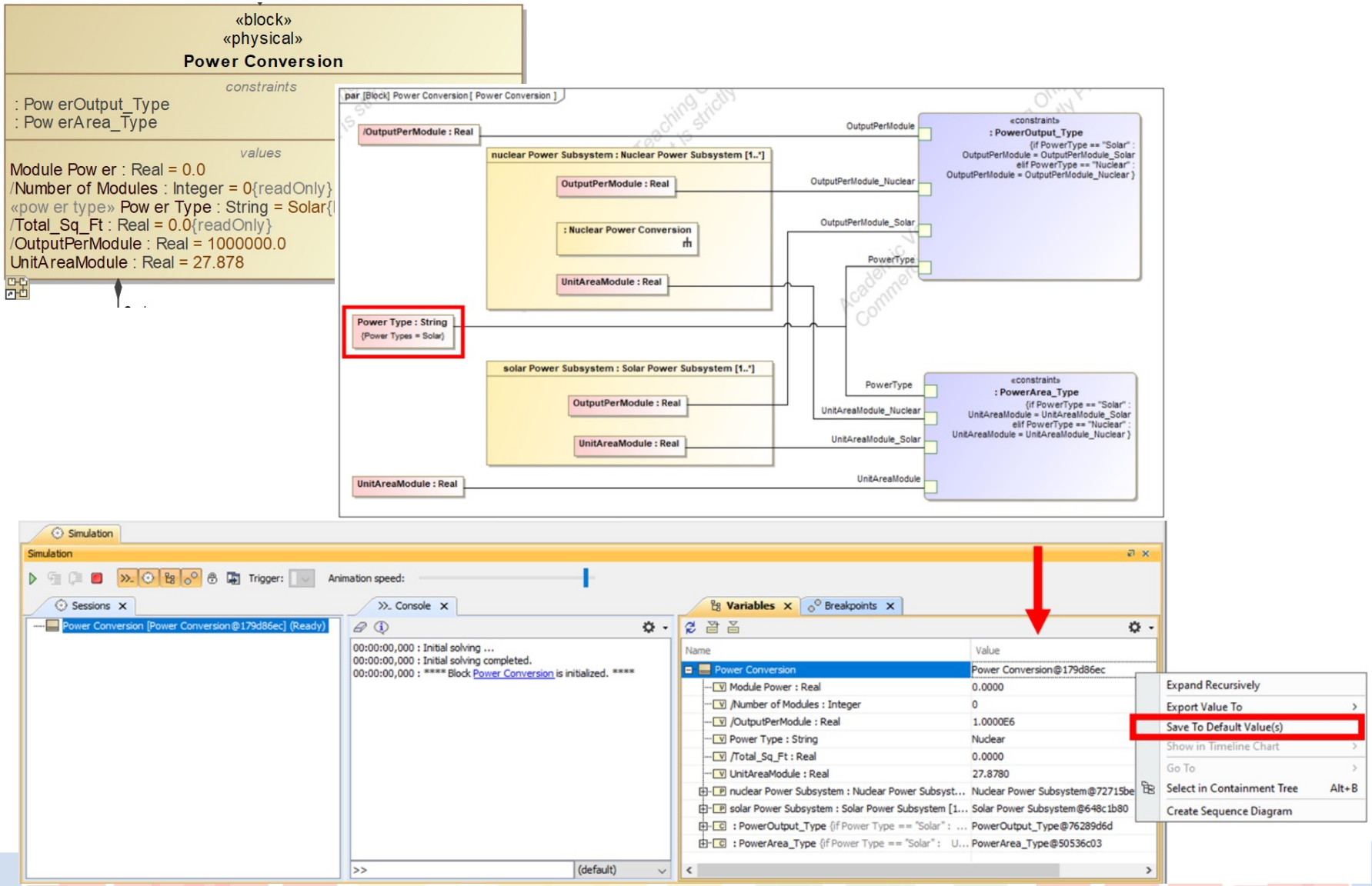
Parallel Physical Trees







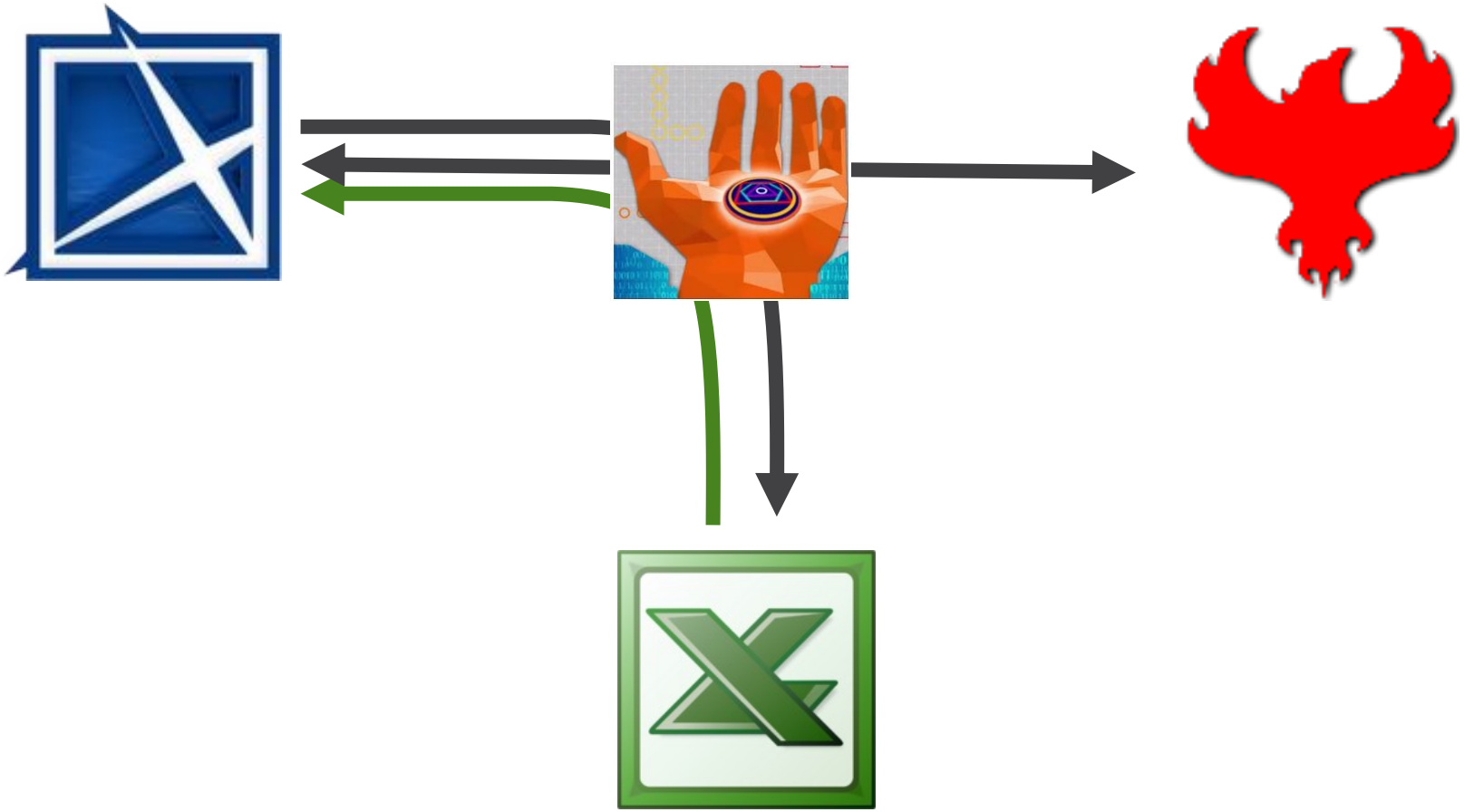
Parametric Definition



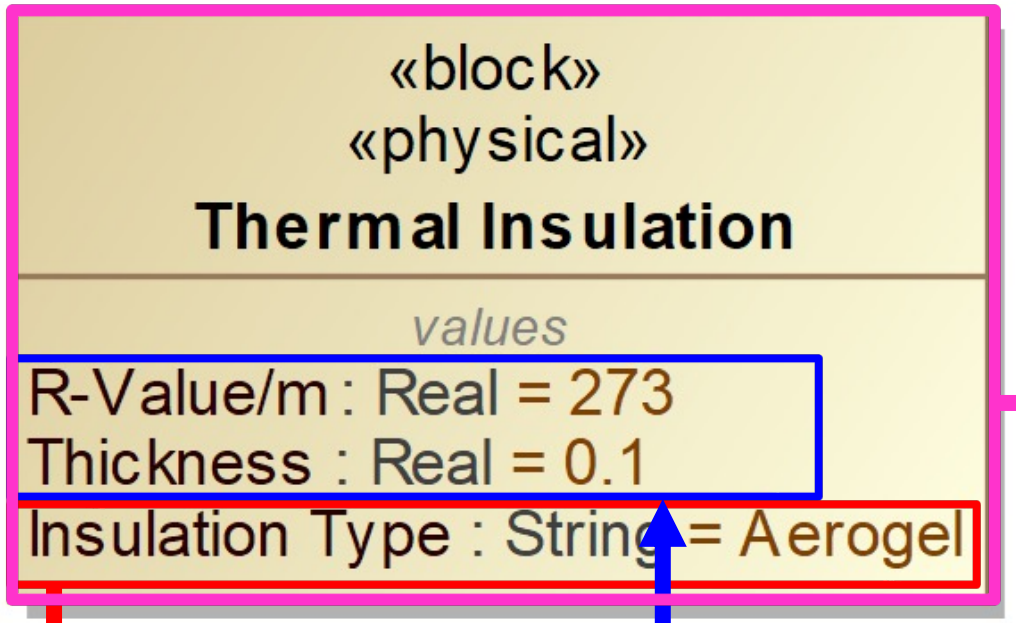
Coupled Design Catalog

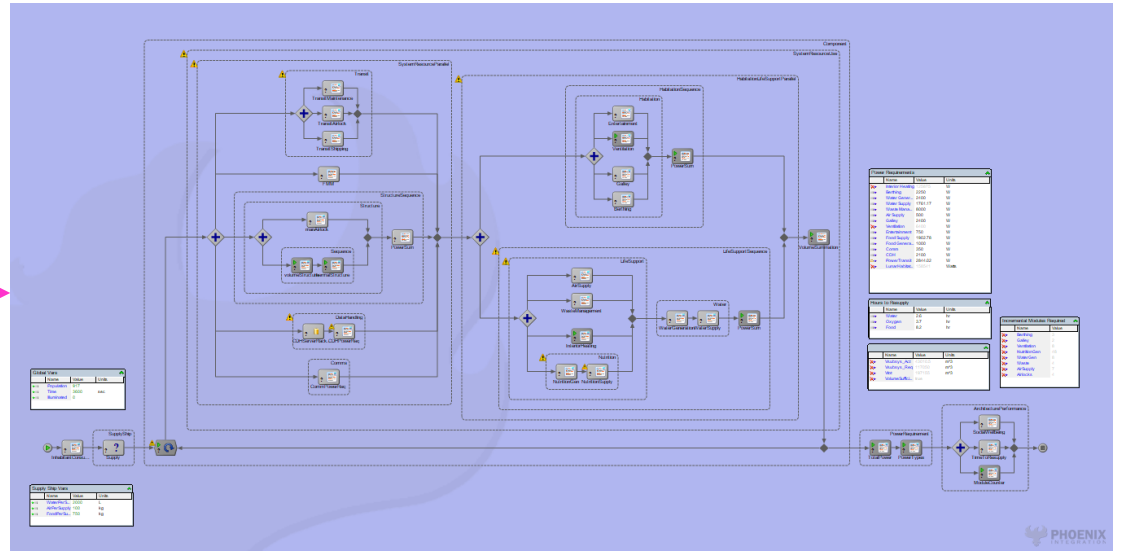
Design Catalog: ModelCenter Excel-based element that stores design detail in a tabular form

Coupled Design Catalog



Coupled Design Catalog





Insulation Type	R_Value	Thickness
Aerogel	273	0.1
Silica Aerogel	390	0.1
Glass Bead Aerogel	780	0.1

Coupled Design Catalog

- No requirement of duplicate physical trees or bespoke parametric equations
- DOE support
- Architecture as authoritative source of truth
- Minimal architecture modification for executability

Conclusions

The Shared Systems Simulation Methodology:

- Translates MBSE rigor to the detailed engineering phase.
- Maintains the model-based architecture as the A.S.O.T.
- Supports expansive system characterization via simulations.
- Requires novel solutions to emergent issues such as multiple physical architecture configuration requirements.

Further Reading

University of Detroit Mercy Masters Thesis:

Applying Model-Based Systems Engineering (MBSE) Methods to a Novel Shared Systems Simulation Methodology [11]

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Advisor: Professor Michael J. Vinarcik, ESEP-Acq, FESD

32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

www.incose.org/symp2022

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