Teaching Systems Design to ISE Students

LEON MCGINNIS
PROFESSOR EMERITUS
STEWART SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING
GEORGIA TECH

This talk will describe where I am today in my 20+ year journey to understand how to teach design of "IE" systems like material handling systems, warehouses, distribution systems, factories, supply chains, healthcare systems and more.

The journey has two motivating observations:

1. "generate alternatives" IS the design problem, while "choose the best" is simply an analysis problem
2. All other engineering disciplines treat design much more formally than we have traditionally in ISE.

What are the challenges?

1. Most students have virtually zero tacit knowledge about "IE systems"
   - Expecting them to be able to generate design alternatives using tacit domain knowledge is going to be frustrating for them and you
2. We don't teach a design methodology, or a systematic way to go about identifying design options
   - But we do teach a lot of analysis methodology, so students naturally want to bring this analysis methodology into their design experience
3. Other engineering disciplines seem to have a lot of computational design tools, and we don't
   - But we do have a very powerful set of computational tools to support analysis

Challenge 1: Lack of Domain Knowledge

- Fewer and fewer students arrive with any "real" experience
- There was a time when we had a number of domain-specific courses
- We no longer have the luxury of "teaching" a domain
- Where you find strong engineering design, you invariably find a ***domain-specific language***, or DSL
- Is there an analysis-agnostic but domain-specific language applicable to "IE systems"?

Response: Discrete-Event Logistic Systems (DELS)

- Claim: a very large portion of "IE Systems" can be described and understood using four foundational concepts:
  - ***Product***: that which the system produces, either a good or a service, and is realized as discrete units of flow movin through the system
  - ***Process:*** a type of activity that transforms units of flow in some way, changing properties, (dis)assembling, moving, storing, measuring
  - ***Resource***: discrete asset (or labor) unit that is capable of executing a well-defined set of process types
  - ***Operational control***: how the system mediates between competing claims that products put on resources

A DELS is:

A network of resources through which flow units pass and are transformed by processes executed by the resources and authorized by tasks issued by an operational controller.

Products

- Objects with ***properties***
- Can contain other products as ***parts***
- Have a natural ***graph structure***
- Examples:
  - Assemblies: parent-child relationships; Bill-of-Materials
  - Order, order lines
  - Patient
  - Shipment

Process

- Transformation with inputs and outputs:
  - Products
  - "Messages"
- Can contain other processes
- Product inputs are transformed in some way
- Message inputs can invoke sub-processes
- Are naturally expressed as ***activity networks***
- Examples

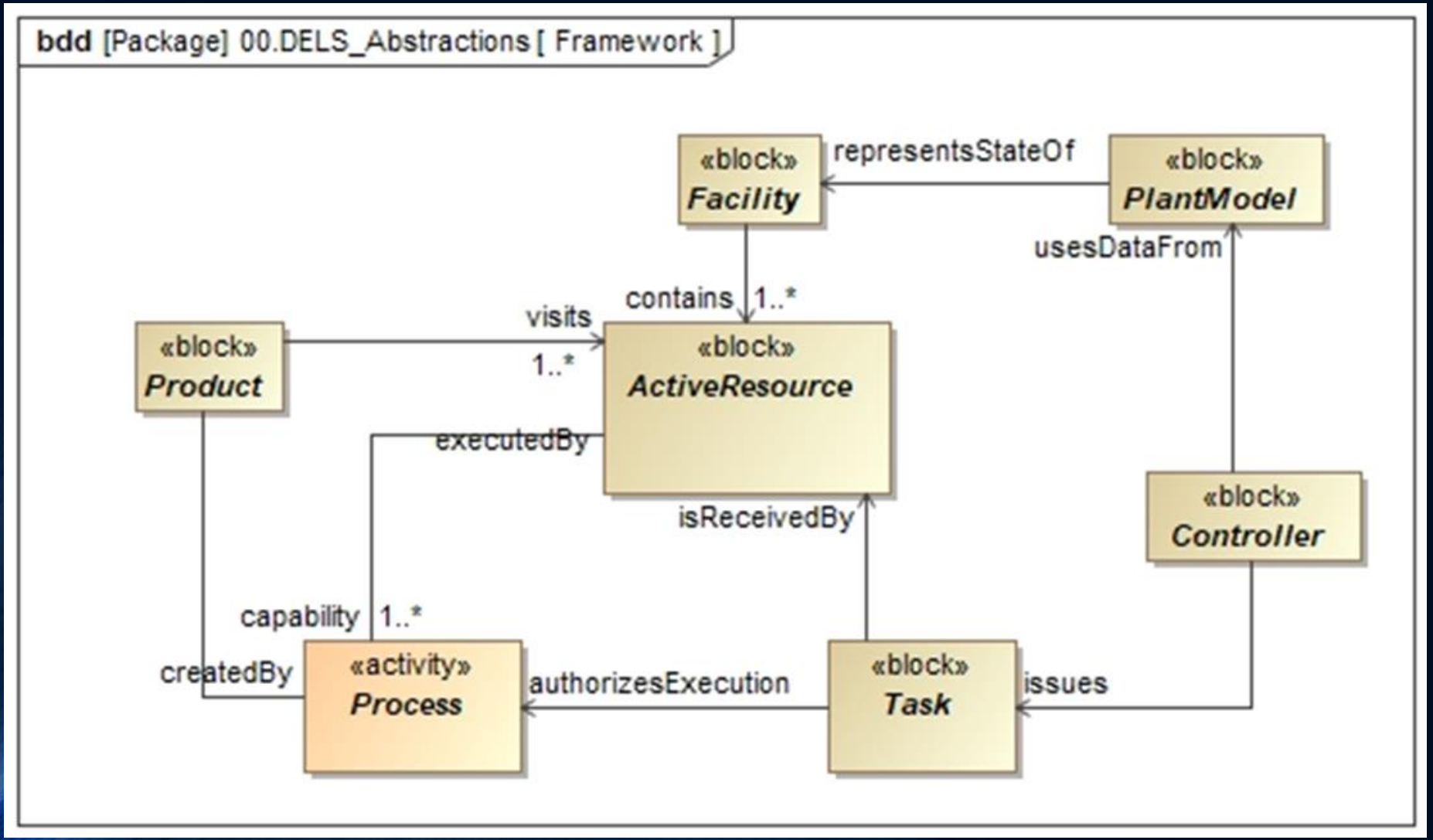
Resource

- Object with properties
  - ***Values***
  - ***Operations*** (process capabilities)
- Can contain other resources
- Examples:
  - People with skills
  - Machines and tools of all sorts
  - Space

Operational Control

- Decision-making to ***manage the flow*** of product among resources in a well-defined control domain
- Five fundamental operational control decisions
  - Admission, assignment, sequencing, resource configuration, next process
- Generic ***functional architecture***
- Natural representation as ***state machine***

Object-oriented Conceptual Framework



Challenge 2: Lack of Design Methodology

- Teachable and repeatable set of steps
- Applicable to any DELS
- Accessible to senior-level ISE undergraduate student

Response: RFLP

- ***Requirements***: what the system must be able to do to meet stakeholder expectations
- ***Functional*** analysis: How the system requirements will be met
- ***Logical*** architecture: How functions are realized and organized
- ***Physical*** design: physical realization of the logical architecture

My experience teaching RFLP

- Students grasp the R and F pretty easily, especially with some examples
- The L part is harder, but presents opportunities to teach domain-specific content, like order-picking methods or cell design options
- P is often out-of-scope, simply because of time in a one semester course; obviously requires domain knowledge

Challenge 3: Lack of computational support

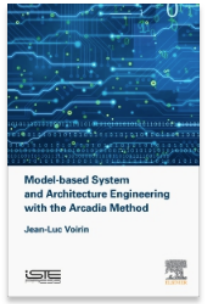
All of these are analysis tools, they don't generate alternatives!

Response

- For years, I tried to use SysML tools—specifically NoMagic's MagicDraw—because it has all the capabilities to create DELS models based on the product, process, resource, control framework
- But it was just too hard to manage the evolution of models through the RFLP method
- Then I discovered **Capella**, an Eclipse-based implementation of the Arcadia method, that implements RFLP
  - Free
  - Pretty large development community (mostly in Europe)

Capella™

Implements



Model-based System and Architecture Engineering with the Arcadia Method

1st Edition - November 22, 2017 • Author: Jean-Luc Voirin

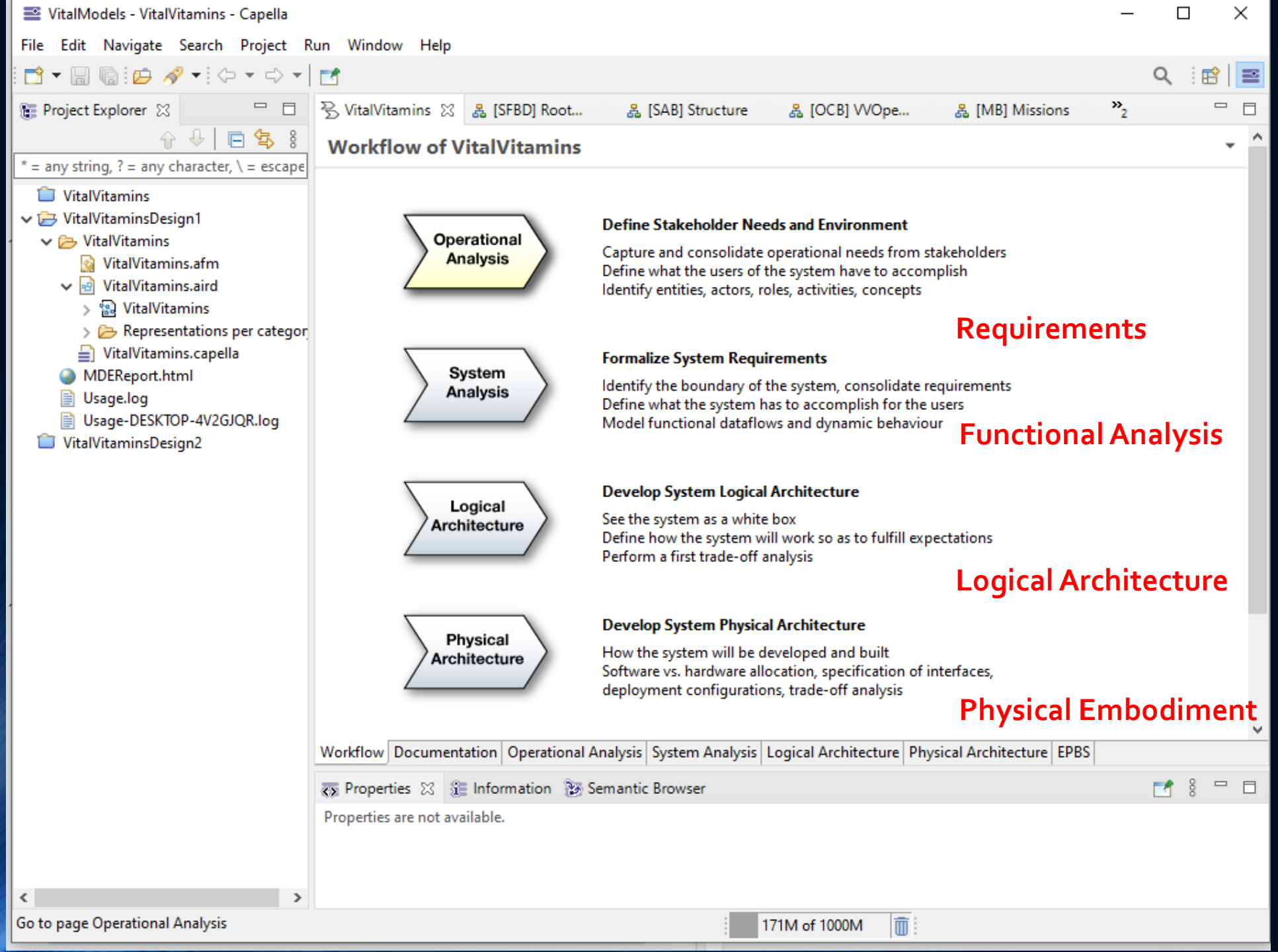
Language: English • Hardback ISBN: 9781785481697

eBook ISBN: 9780081017944

Based On

ECLIPSE™ FOUNDATION

Fair bit of excellent content available on-line that explains Capella and how to use it. Warning; most of it is in the context of "product" systems.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[MB] Missions
Workflow of VitalVitamins
Operational Analysis
Define Stakeholder Needs and Environment
Capture and consolidate operational needs from stakeholders
Define what the users of the system have to accomplish
Identify entities, actors, roles, activities, concepts
Requirements
System Analysis
Formalize System Requirements
Identify the boundary of the system, consolidate requirements
Define what the system has to accomplish for the users
Model functional dataflows and dynamic behaviour
Functional Analysis
Logical Architecture
Develop System Logical Architecture
See the system as a white box
Define how the system will work so as to fulfill expectations
Perform a first trade-off analysis
Logical Architecture
Physical Architecture
Develop System Physical Architecture
How the system will be developed and built
Software vs. hardware allocation, specification of interfaces,
deployment configurations, trade-off analysis
Physical Embodiment
Workflow
Documentation
Operational Analysis
System Analysis
Logical Architecture
Physical Architecture
EPBS
Properties
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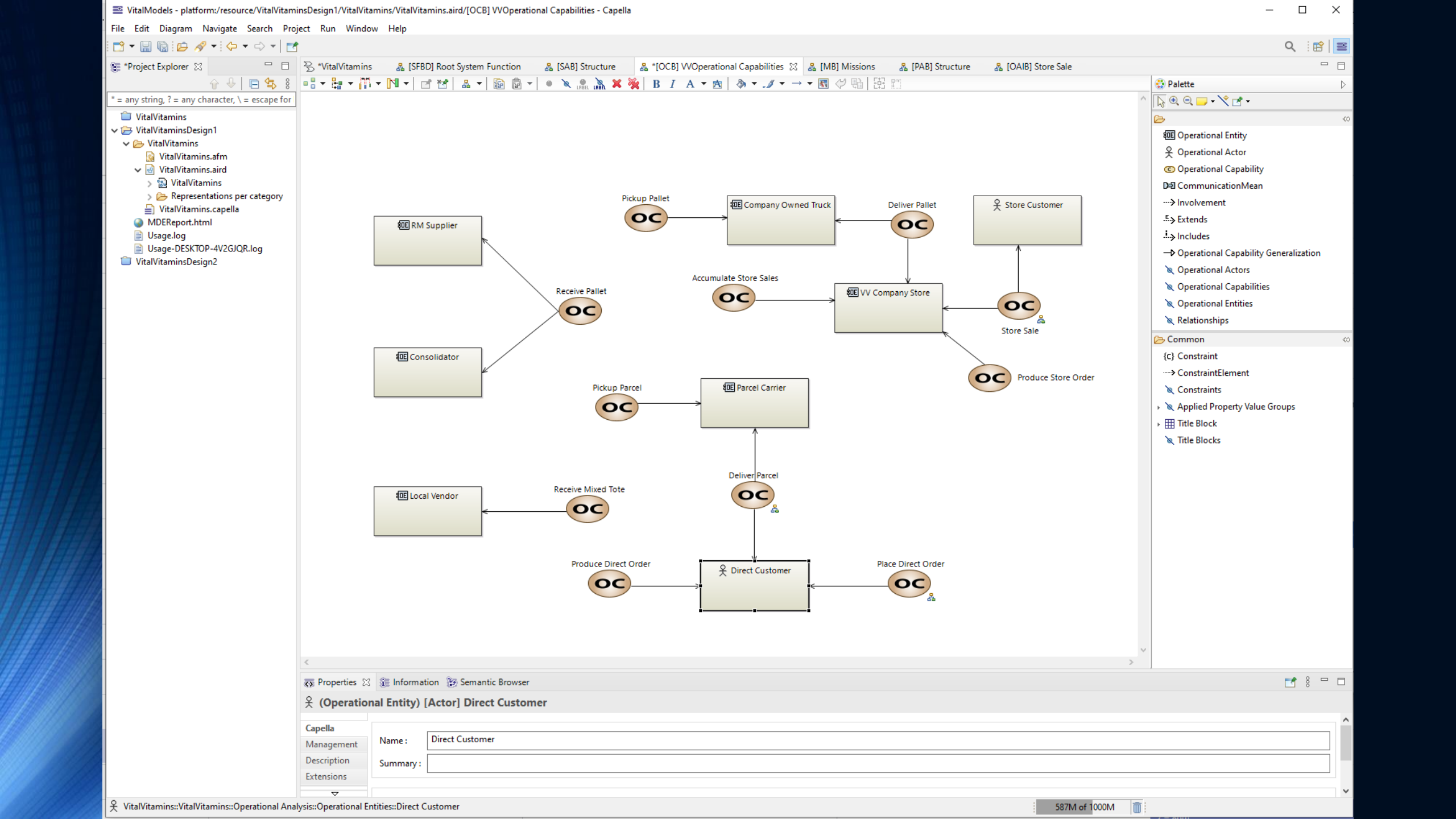
171M of 1000M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Deliver Pallet
Store Customer
RM Supplier
Receive Pallet
Accumulate Store Sales
VV Company Store
Store Sale
Consolidator
Produce Store Order
Pickup Parcel
Parcel Carrier
Deliver Parcel
Local Vendor
Receive Mixed Tote
Produce Direct Order
Direct Customer
Place Direct Order
Palette
Operational Entity
Operational Actor
Operational Capability
CommunicationMean
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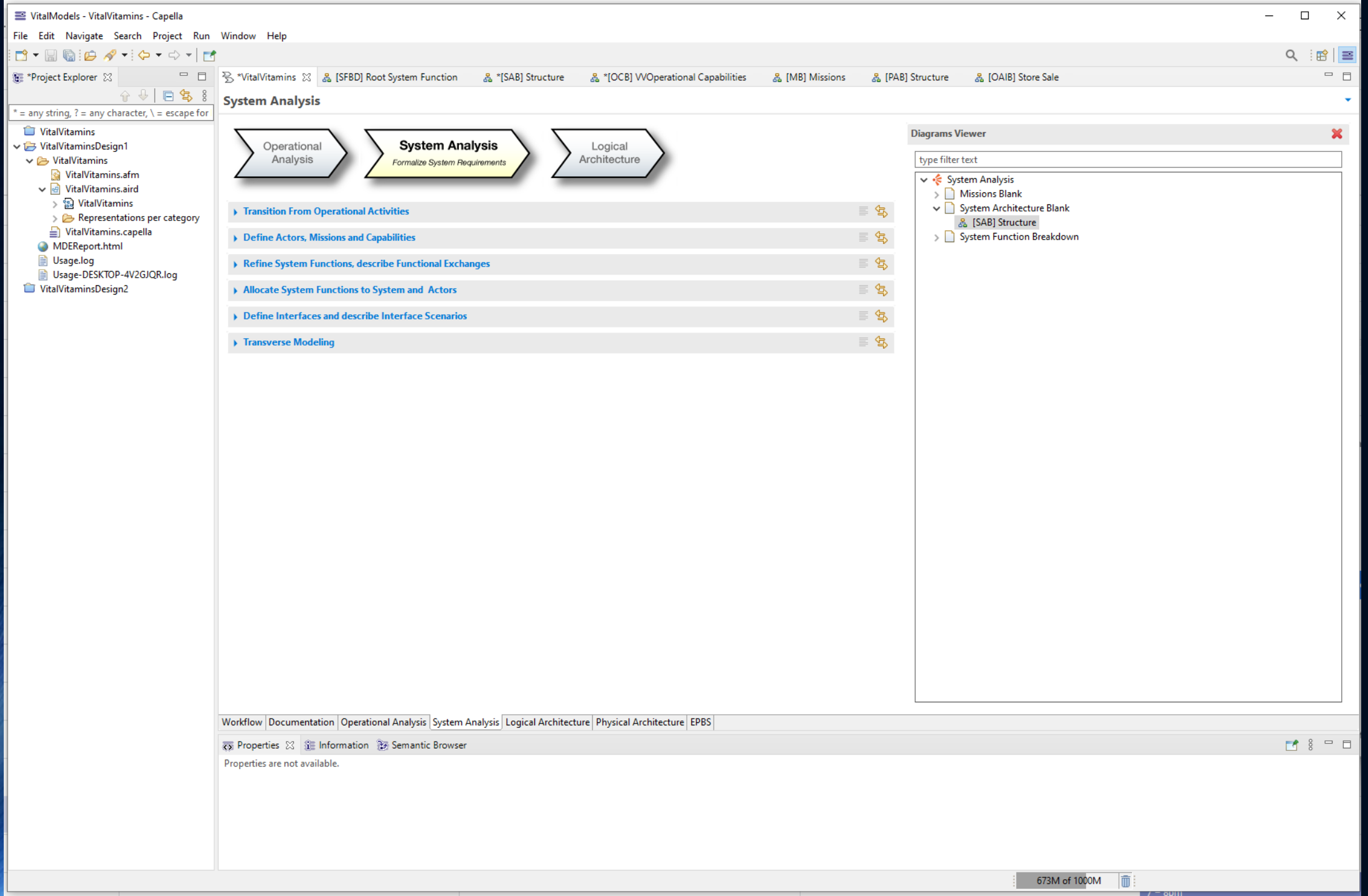
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System Analysis
Operational Analysis
System Analysis
Formalize System Requirements
Logical Architecture
Transition From Operational Activities
Define Actors, Missions and Capabilities
Refine System Functions, describe Functional Exchanges
Allocate System Functions to System and Actors
Define Interfaces and describe Interface Scenarios
Transverse Modeling
Diagrams Viewer
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System Analysis
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[SAB] Structure
System Function Breakdown
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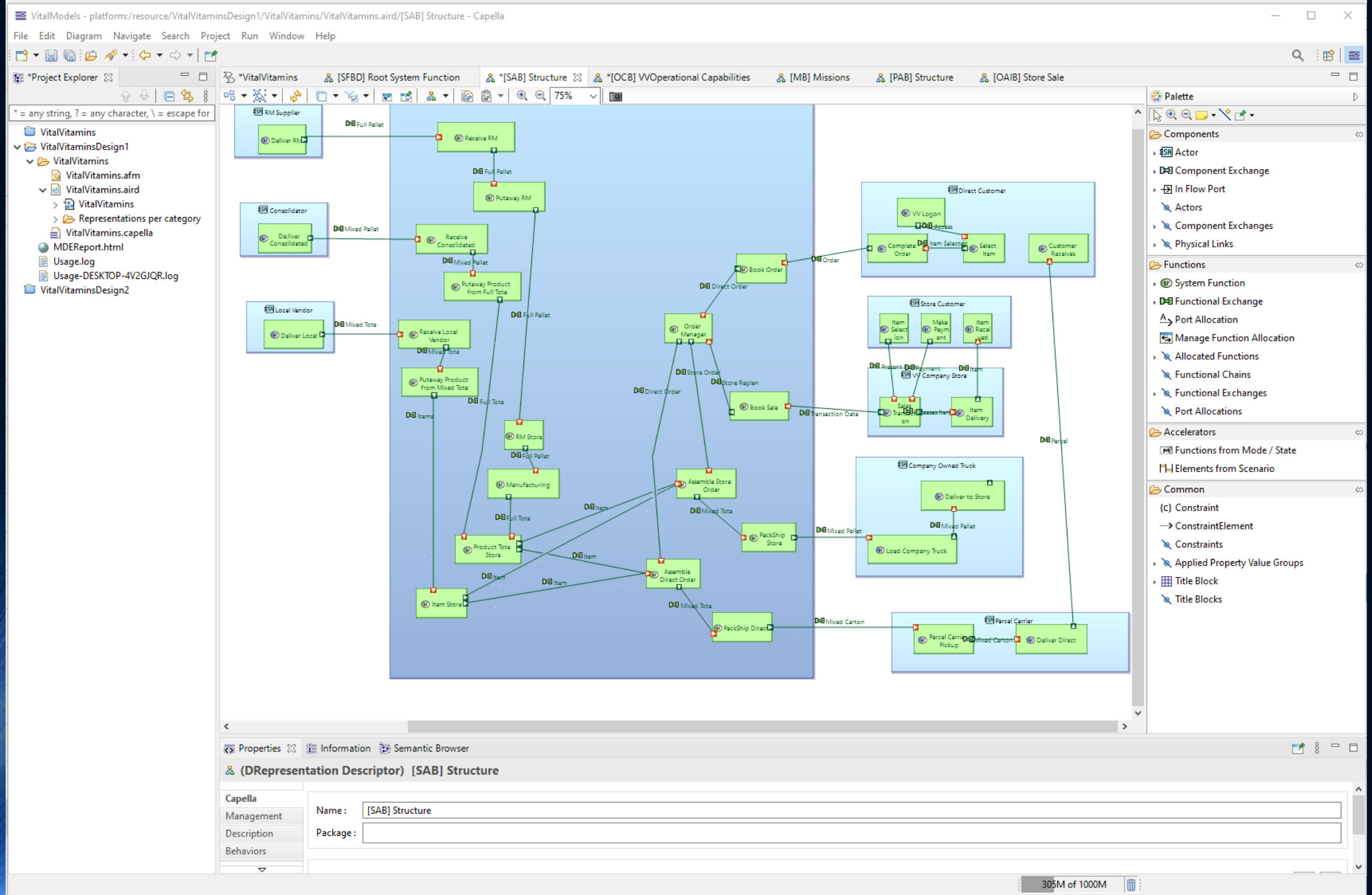
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Deliver RM
Full Pallet
Receive RM
Putaway RM
Consolidator
Deliver Consolidated
Mixed Pallet
Receive Consolidated
Putaway Product from Full Tote
Local Vendor
Deliver Local
Mixed Tote
Receive Local Vendor
Putaway Product from Mixed Tote
Full Tote
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Manufacturing
Product Tote Store
Item Store
Book Order
Order Manager
Direct Order
Store Order
Store Replen
Book Sale
Assemble Store Order
Assemble Direct Order
PackShip Store
PackShip Direct
Item
Direct Customer
VV Logon
Access
Complete Order
Item Selected
Select Item
Customer Receives
Order
Store Customer
Item Selection
Make Payment
Item Received
Present Payment
VV Company Store
Sales Transaction
Item Delivery
Transaction Data
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Parcel Carrier Pickup
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Manage Function Allocation
Allocated Functions
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Functional Exchanges
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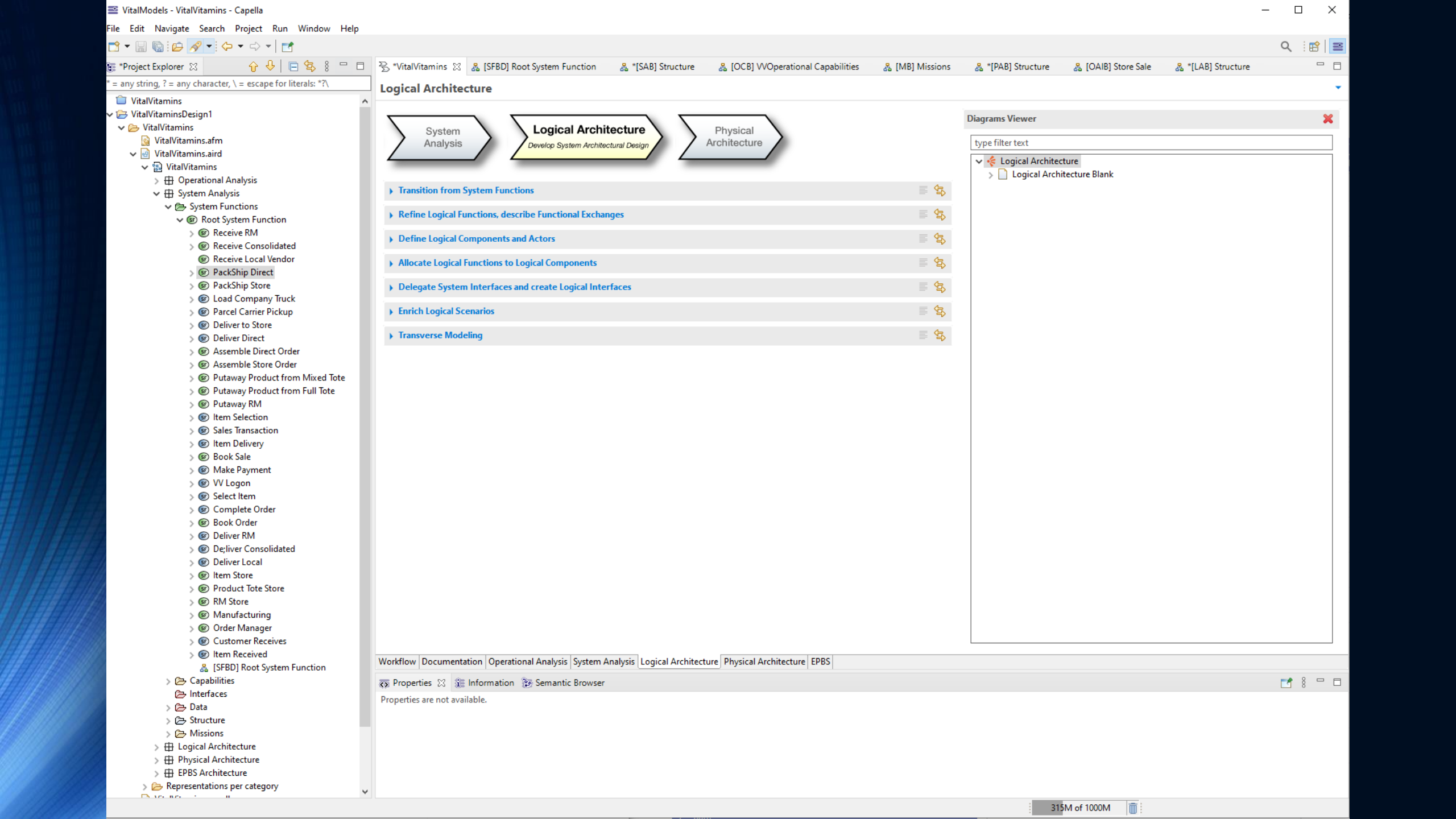
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Receive Consolidated
Receive Local Vendor
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PackShip Store
Load Company Truck
Parcel Carrier Pickup
Deliver to Store
Deliver Direct
Assemble Direct Order
Assemble Store Order
Putaway Product from Mixed Tote
Putaway Product from Full Tote
Putaway RM
Item Selection
Sales Transaction
Item Delivery
Book Sale
Make Payment
VV Logon
Select Item
Complete Order
Book Order
Deliver RM
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Product Tote Store
RM Store
Manufacturing
Order Manager
Customer Receives
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[MB] Missions
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Logical Architecture
System Analysis
Logical Architecture
Develop System Architectural Design
Physical Architecture
Transition from System Functions
Refine Logical Functions, describe Functional Exchanges
Define Logical Components and Actors
Allocate Logical Functions to Logical Components
Delegate System Interfaces and create Logical Interfaces
Enrich Logical Scenarios
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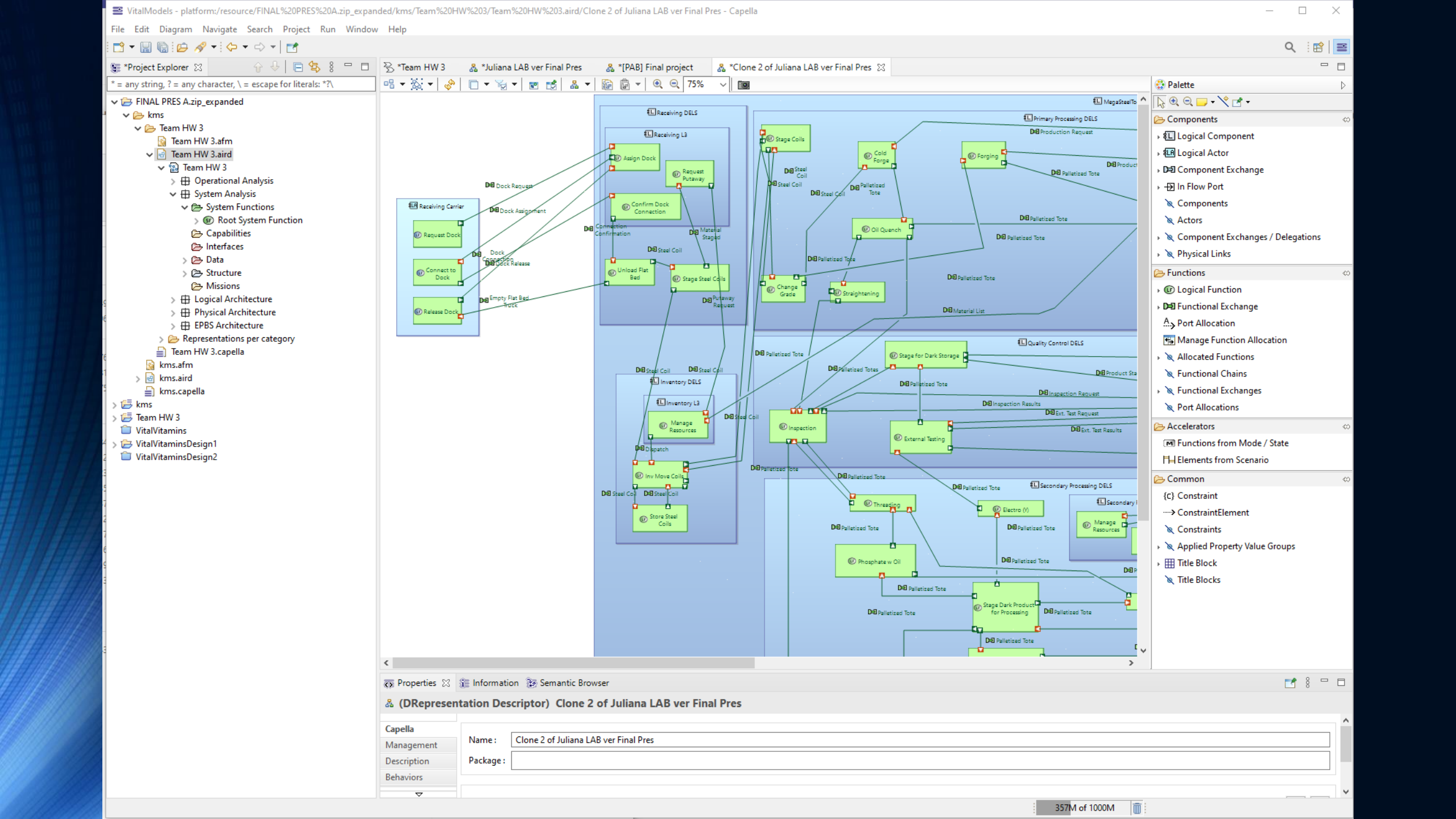
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Receiving DELS
Receiving L3
Assign Dock
Request Putaway
Confirm Dock Connection
Receiving Carrier
Request Dock
Connect to Dock
Release Dock
Unload Flat Bed
Stage Steel Coils
Dock Request
Dock Assignment
Dock Release
Empty Flat Bed Truck
Inventory DELS
Inventory L3
Manage Resources
Dispatch
Inv Move Coils
Store Steel Coils
Primary Processing DELS
Stage Coils
Cold Forge
Forging
Oil Quench
Straightening
Change Grade
Quality Control DELS
Stage for Dark Storage
Inspection
External Testing
Secondary Processing DELS
Threading
Electro (Y)
Phosphate w Oil
Stage Dark Product for Processing
Palette
Components
Logical Component
Logical Actor
Component Exchange
In Flow Port
Components
Actors
Component Exchanges / Delegations
Physical Links
Functions
Logical Function
Functional Exchange
Port Allocation
Manage Function Allocation
Allocated Functions
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Functional Exchanges
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VitalModels - VitalVitamins - Capella

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      - System Analysis
        - System Functions
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            - Receive RM
            - Receive Consolidated
            - Receive Local Vendor
            - PackShip Direct
            - PackShip Store
            - Load Company Truck
            - Parcel Carrier Pickup
            - Deliver to Store
            - Deliver Direct
            - Assemble Direct Order
            - Assemble Store Order
            - Putaway Product from Mixed Tote
            - Putaway Product from Full Tote
            - Putaway RM
            - Item Selection
            - Sales Transaction
            - Item Delivery
            - Book Sale
            - Make Payment
            - VV Logon
            - Select Item
            - Complete Order
            - Book Order
            - Deliver RM
            - De;liver Consolidated
            - Deliver Local
            - Item Store
            - Product Tote Store
            - RM Store
            - Manufacturing
            - Order Manager
            - Customer Receives
            - Item Received
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        - Interfaces
        - Data
        - Structure
        - Missions
      - Logical Architecture
      - Physical Architecture
      - EPBS Architecture
    - Representations per category

*VitalVitamins | [SFBD] Root System Function | *[SAB] Structure | [OCB] VVOperational Capabilities | [MB] Missions | *[PAB] Structure | [OAIB] Store Sale | *[LAB] Structure

Physical Architecture

Logical Architecture → **Physical Architecture** *Develop System Architectural Design* → EPBS

- Transition from Logical Functions
- Refine Physical Functions, describe Functional Exchanges
- Define Physical Components and Actors, Manage deployments
- Allocate Physical Functions to Physical Components
- Delegate Logical Interfaces and create Physical Interfaces
- Enrich Physical Scenarios
- Transverse Modeling

Diagrams Viewer

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- Physical Architecture
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Workflow | Documentation | Operational Analysis | System Analysis | Logical Architecture | Physical Architecture | EPBS

Properties | Information | Semantic Browser

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50%

Palette

- Node Components
  - Node PC
  - Physical Actor
  - Physical Link
  - Physical Port
  - Component Port Allocation
  - Manage Node PCs Deployment
  - Node PCs
- Behaviour Components
  - Deploy Behavior PC
  - Component Exchange
  - In Flow Port
  - Manage Behavior PCs Deployment
  - Behavior PCs
  - Deployed PCs
  - Component Exchanges / Delegations
- Functions
  - Physical Function
  - Functional Exchange
  - Port Allocation
  - Manage Function Allocation
  - Allocated Functions
  - Functional Chains
  - Functional Exchanges
- Accelerators
  - Functions from Mode / State
  - Elements from Scenario
- Common
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  - ConstraintElement
  - Constraints
  - Applied Property Value Groups
  - Title Block
  - Title Blocks

Properties | Information | Semantic Browser

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Capella

Management

Description

Behaviors

Name : [PAB] Final project

Package :

Team HW 3::Team HW 3::Physical Architecture::Structure::[PAB] Final project (Synchronized)

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Teaching System Design

- DSL: product, process, resource, operational control
- Design methodology: RFLP
- Computational support: Capella
- Case studies: CICMHE Design Competition cases
  - Original case
  - Rewritten using DSL structure
- Course notes

Invitation

Your turn