MANAGING COMPLEXITY IN HIGH-TECH SYSTEMS

Research at ESI

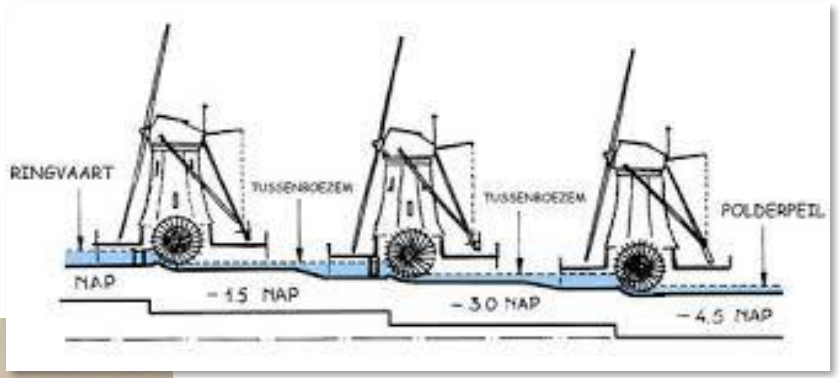
Wouter Leibbrandt
Science and operations director

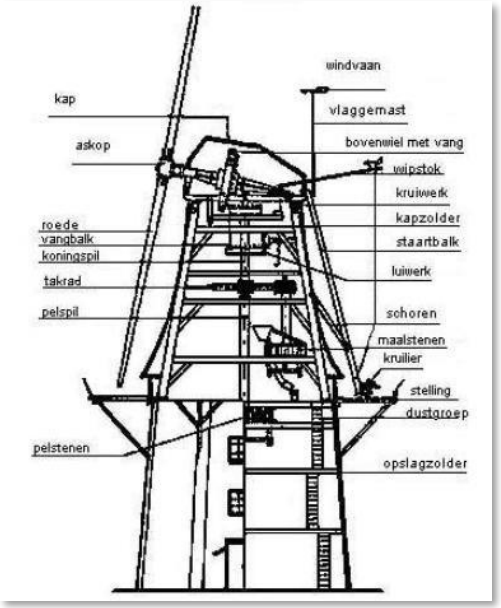
7 November 2018

An initiative of industry, academia and TNO

ESI

Engineering of complex systems has been done for ages
E.g in the Netherlands





Some complex systems today (from The Netherlands)

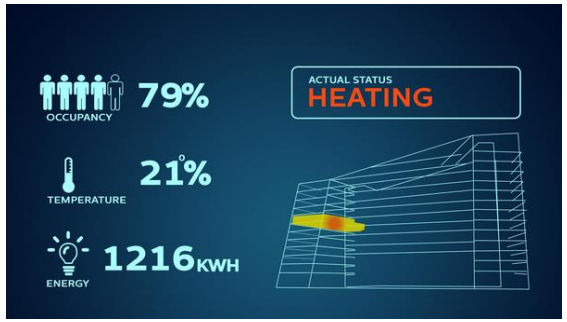
Semiconductor manufacturing equipment

Medical systems

Agricultural robots

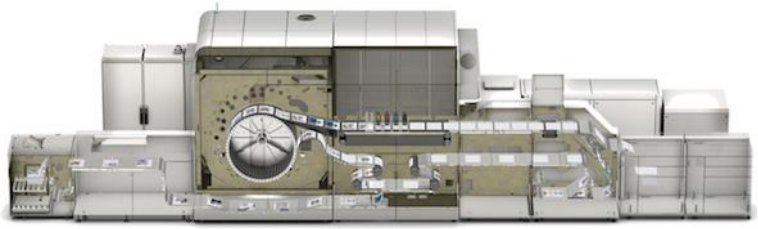
Combat management systems

Electron microscopes



Building control

Robotized warehousing

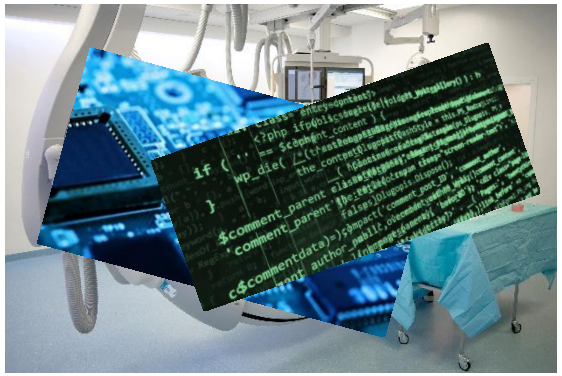


Industrial printers

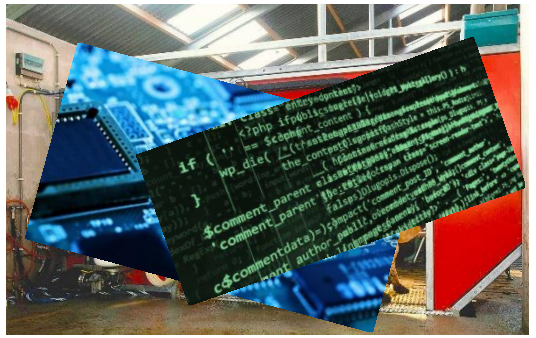
Automotive

Some complex systems today (from The Netherlands)

Semiconductor manufacturing equipment

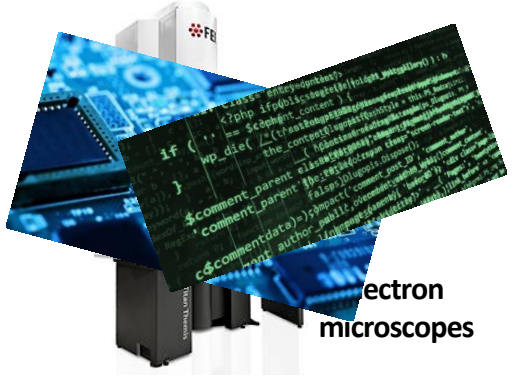


Medical systems



Agricultural robots

Combat management systems



ectron microscopes

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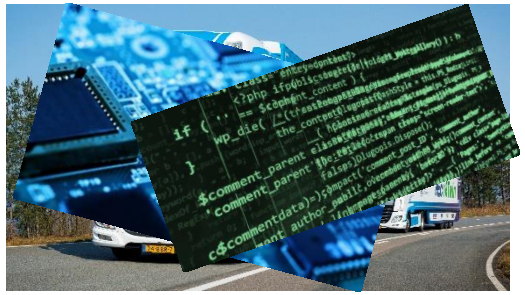
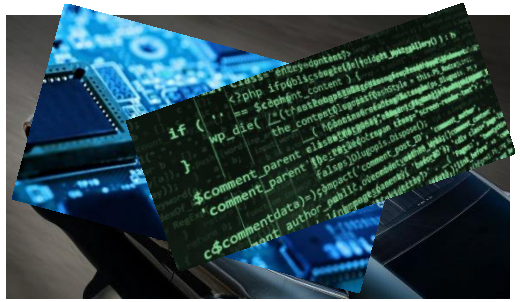




Automotive

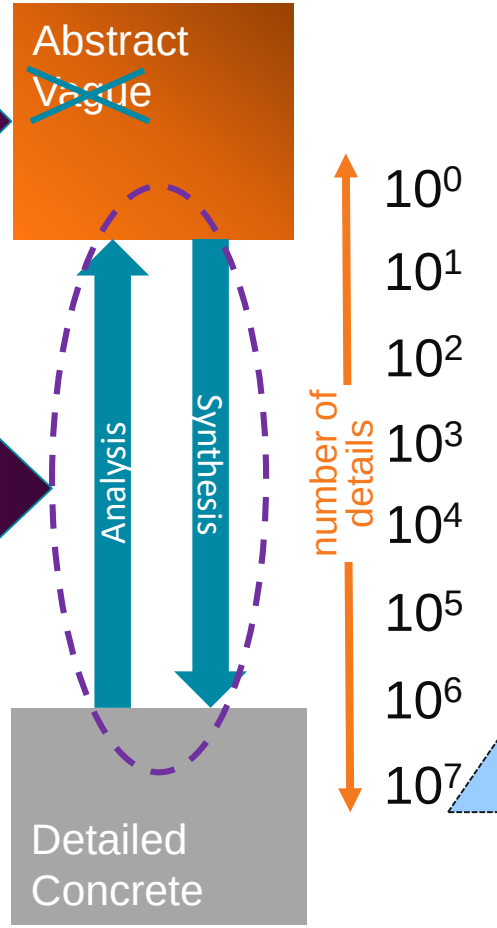
Common challenges

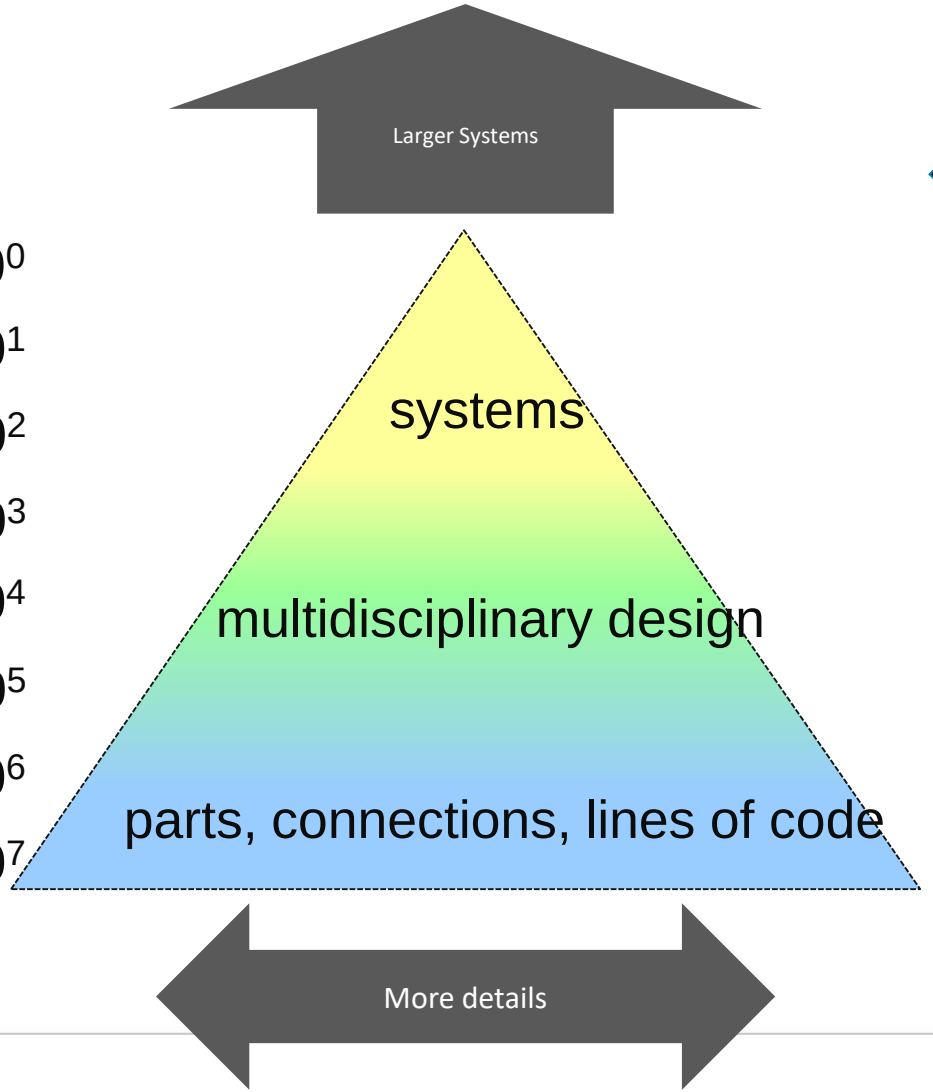
- System complexity
  - Heterogeneity, interdependencies
  - Performance: nm accuracy, strict timing, exact dosage, …
  - Human factors & Business factors
  - Scale: e.g. 100 Mln lines of code
- Formal systems approach across the lifecycle
- Abstraction

Mastering System Complexity across the abstraction levels

Challenge 1
Abstract but:
- **Concrete**
- **Accurate**
- **Trustworthy**
- **Specific**

Challenge 2
Seamlessly move from abstract to details for the various aspects

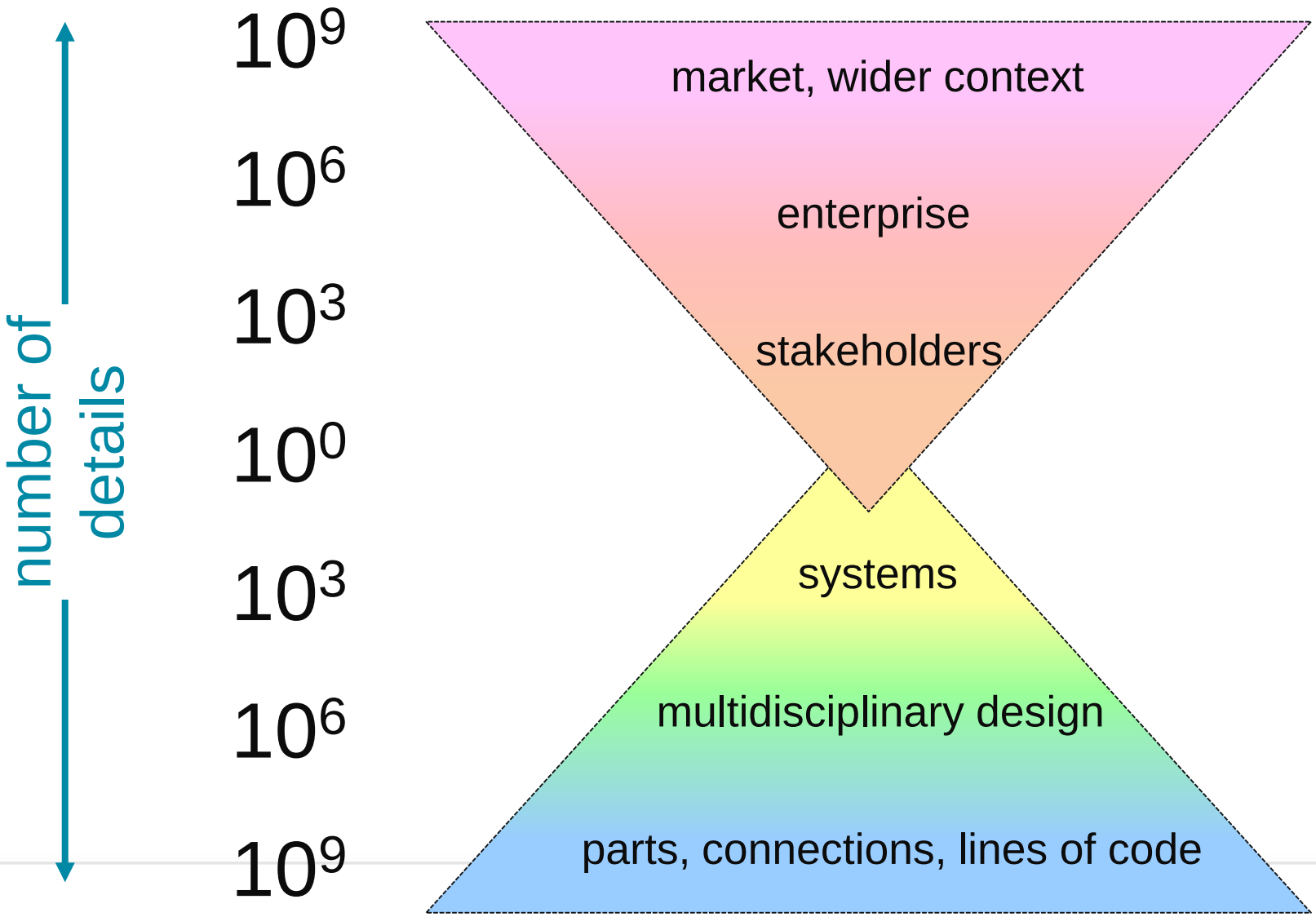




Challenge 3
System approach across aspects:
relations
trade-offs
…

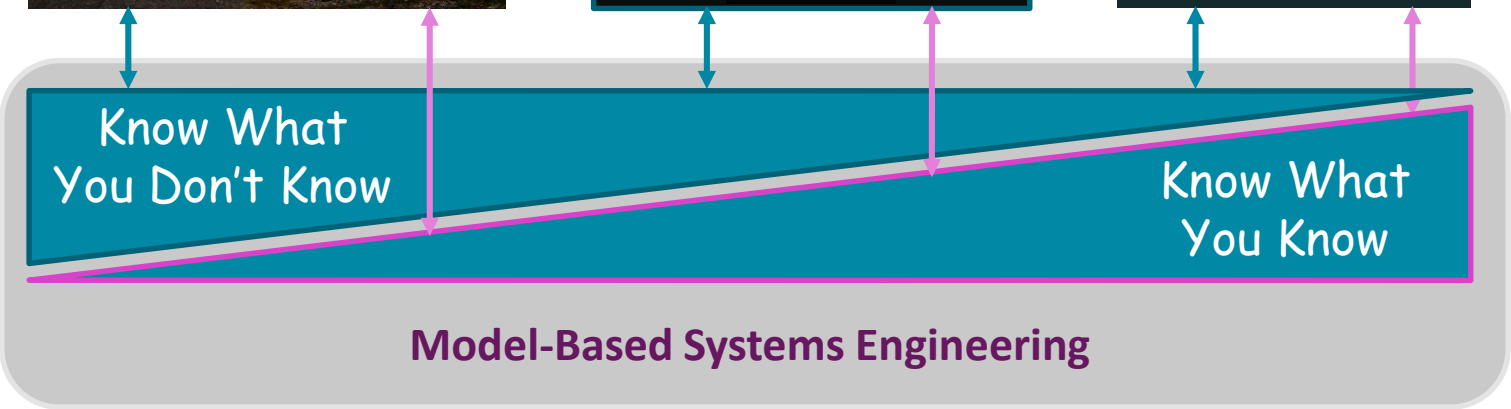
Abstractions in engineering are models and feature at all levels of abstraction

A broader view on systems



Models, models, models, …

Models, models, & models, …



Generic	↔	Domain specific
Descriptive	↔	Analytic
Explorative	↔	Detailed

1459
View of the world
before
the age of discovery

"we know everything"

1525
View of the world
in
the age of discovery

"so much we do not know yet"

From: Yuval Noah Harari - Sapiens

ESI at a glance

Mission: ***"To advance industrial innovation and academic excellence in high-tech systems engineering"***

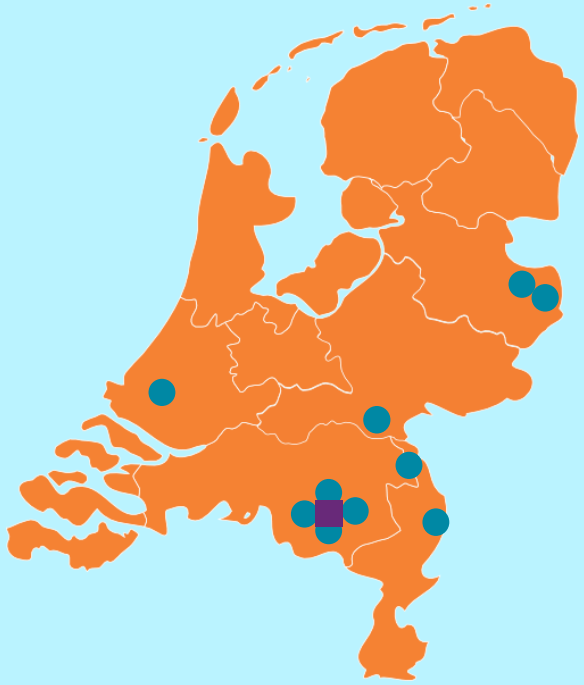
Synopsis

- Foundation ESI started in 2002
- ESI acquired by TNO per January 2013
- ~60 staff members, many with extensive industrial experience
- 5 Part-time Professors
- Working at industry locations
- From embedded systems innovation to embedding innovation
- TNO program turnover 2018: 10Mio €

Partner Board

ASML
PHILIPS
ThermoFisher SCIENTIFIC
océ
NXP
THALES
TNO
TU Delft
TU/e technische universiteit eindhoven
Delft University of Technology
UNIVERSITY OF TWENTE.
Radboud Universiteit Nijmegen

Location



Open Innovation

ASML - Veldhoven

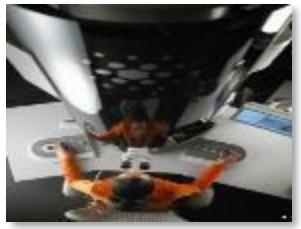
DAF- Eindhoven

Philips Medical - Best

Full access to industry background

Océ - Venlo

Thermo Fisher - Acht



NXP - Eindhoven

Vanderlande - Veghel

Industry specific validation results

Thales - Hengelo

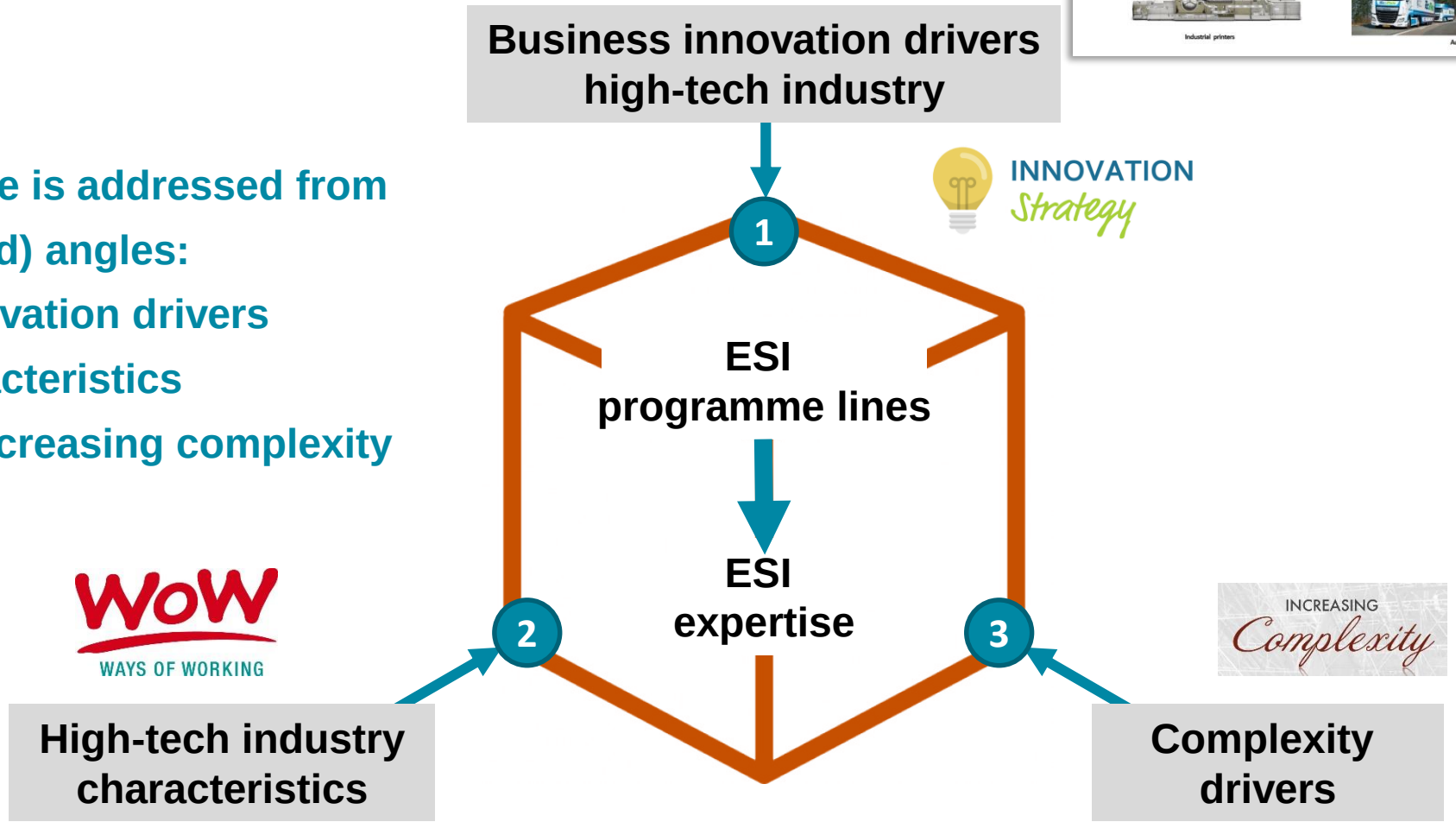
Signify- Eindhoven

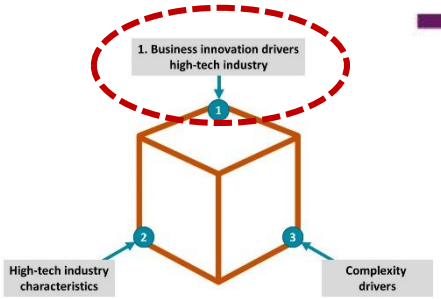
Barco – Kortrijk

From industry challenge to ESI expertise

Industry challenge is addressed from three (inter-related) angles:

1. Business innovation drivers
2. Industry characteristics
3. Continuous increasing complexity





1. Changing business innovation drivers

Box selling

Solution selling

Competition in total cost-of-ownership

Competition in end-user integration

Selling catalogue items

Focus on total cost of ownership

Customer-specific products/ configuration

Integration in application context

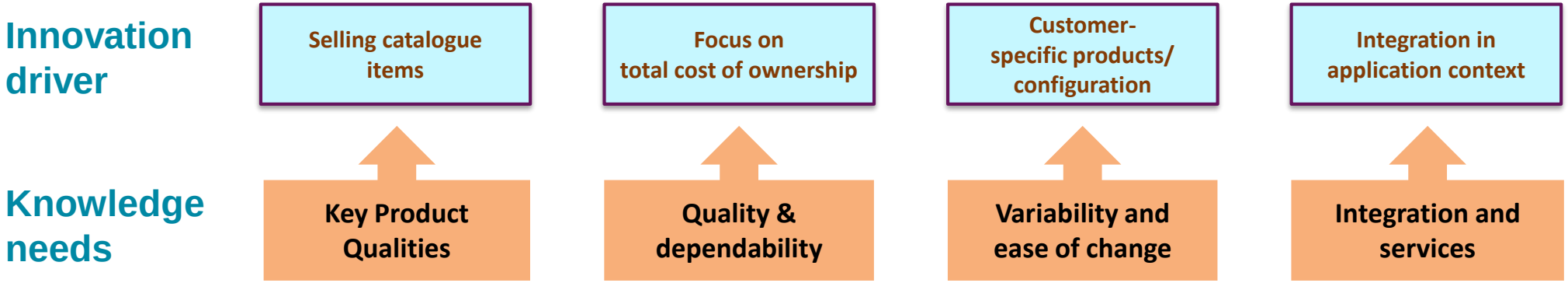
Product design

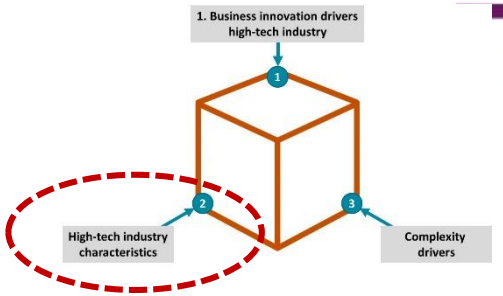
Manufacturing

Lifecycle support

Total life cycle business

1. Innovation drivers and associated knowledge needs





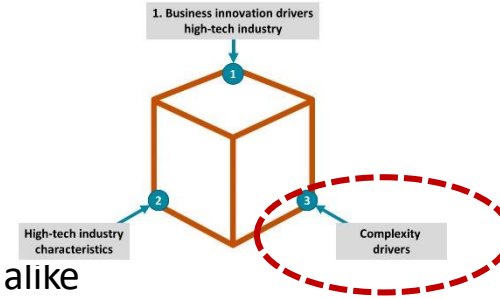
2. High-tech industry characteristics

- **Globalization** has introduced a change in customer mix and entries into emerging economies. **Global diversification** has become yet another challenge
- The success of high-tech companies today increasingly depends on providing services, content and interoperability around their products (**open systems, solution selling**)
- A significant part of the Dutch (but also European) high-tech industry has (re)positioned itself in the **higher value segment**
- Competitive advantages gained from innovations are increasingly **short-lived**
- **Total life-cycle business**, i.e. the sales of new products combined with services to installed products, is an ever more important revenue model
- Companies are increasingly dependent on **partnering within the industry ecosystem** to develop and introduce new products and solutions. **Effective collaboration** among globally dispersed design teams and with external partners has become a necessity

2. Industry characteristics and associated needs

Industry characteristic	Knowledge needs
Global product diversification	*Already covered*: Variability and ease of change
Interoperable systems/solution selling	*Already covered*: Integration, security, focus on providing services
Positioning high value segment	*Already covered*: Key product qualities
Short-lived competitive advantages	Development efficiency and reduced lead-time
Total life-cycle focus	Deal with continuous hardware and software evolution
Partnering and collaboration	Multi-disciplinary, multi-site, multi-team approaches

3. Continuous increasing complexity
What is driving complexity in the next decade?

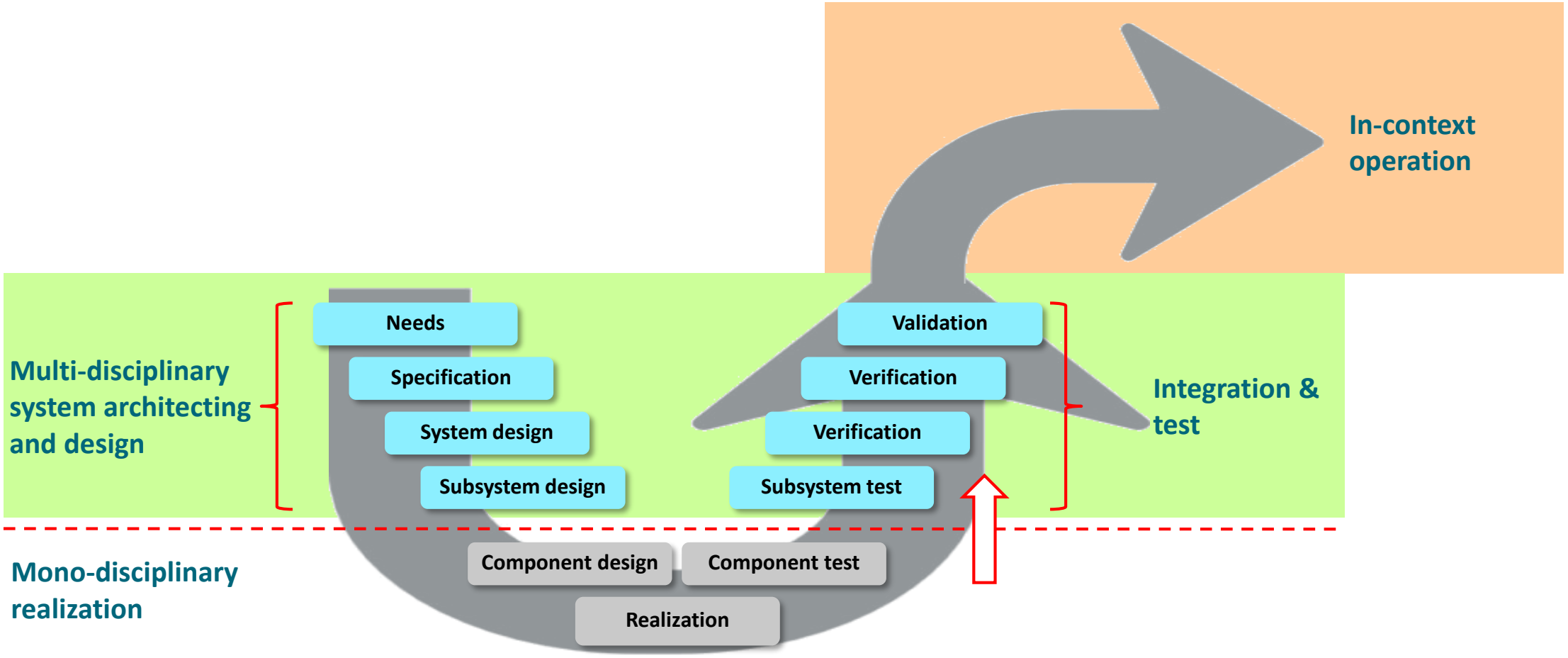


Continuously evolving systems	• The system has both the capability and the need to evolve over time
Series-of-1 Systems	• High level of customization of each system delivered, no two systems alike
Systems of Systems	• The system is an integral part of a larger system without any control of that system
X-as-a-service Systems	• Not the machine, but the service it provides is the manufacturer's value proposition
Autonomous Systems	• System operates without human in the loop, human interaction moves to higher level
Parameters-times-10 Systems	• All current design parameters (e.g. interfaces, LoC) get one (or more) orders more demanding

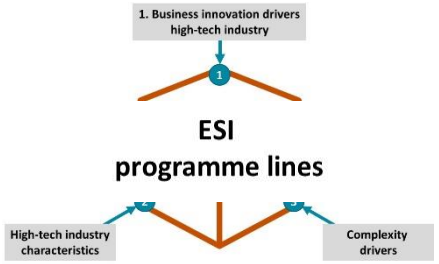
3. Continuous increasing complexity – the need

Complexity drivers	Knowledge needs
Continuously evolving systems Series-of-1 Systems Systems of Systems X-as-a-service Systems Autonomous Systems Parameters-times-10 Systems	Manage cross-disciplinary uncertainty Bridge gap between multi-disciplinary architecting & design and mono-disciplinary realization Raise abstraction level at which (sub)systems are specified, explored, analyzed and synthesized, integrated and tested

Scope


In-context operation
Multi-disciplinary system architecting and design
Needs
Specification
System design
Subsystem design
Validation
Verification
Verification
Subsystem test
Integration & test
Mono-disciplinary realization
Component design
Component test
Realization

Choice for ESI programme lines



Selling catalogue items	Focus on total cost of ownership	Customer-specific products/ configuration	Integration in application context
Key Product Qualities	Quality & dependability	Variability and ease of change	Integration and services

ESI Programme lines

1. System Performance	2. System Dependability	3. System Evolvability	4. Exploiting System Context

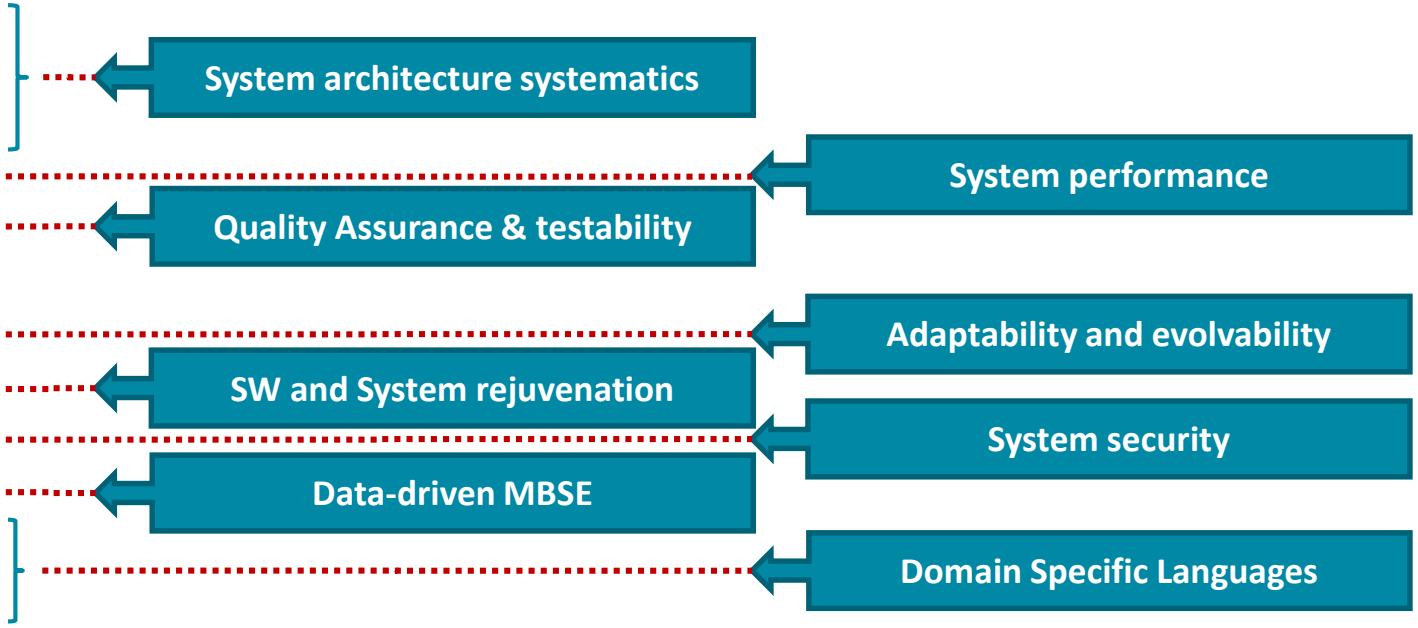
5. System Architecting

Development efficiency and reduced lead-time	Manage cross-disciplinary uncertainty
Deal with continuous hardware and software evolution	Bridge gap between multi-disciplinary architecting & design and mono-disciplinary realization
Multi-disciplinary, multi-site, multi-team approaches	Raise abstraction level at which (sub)systems are specified, explored, analyzed and synthesized, integrated and tested

ESI expertise teams

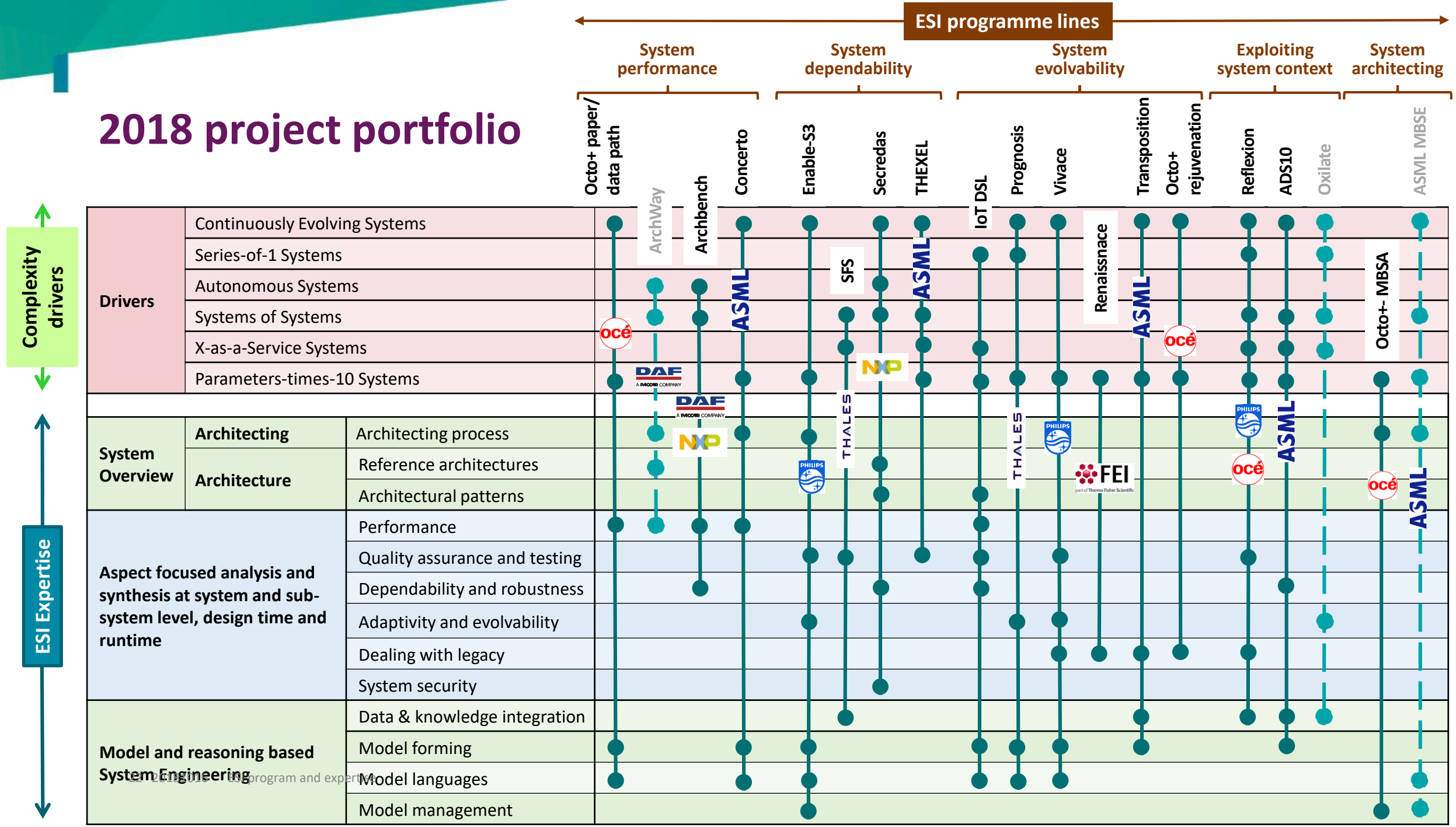
ESI Expertise Areas

System Overview	Architecting	Architecting process
	Architecture	Reference architectures
		Architectural patterns
Aspect focused analysis and synthesis at system and sub-system level, design time and runtime		Performance
		Quality assurance and testing
		Dependability and robustness
		Adaptivity and evolvability
		Dealing with legacy
		System security
Model and reasoning based System Engineering		Data & knowledge integration
		Model forming
		Model languages
		Model management



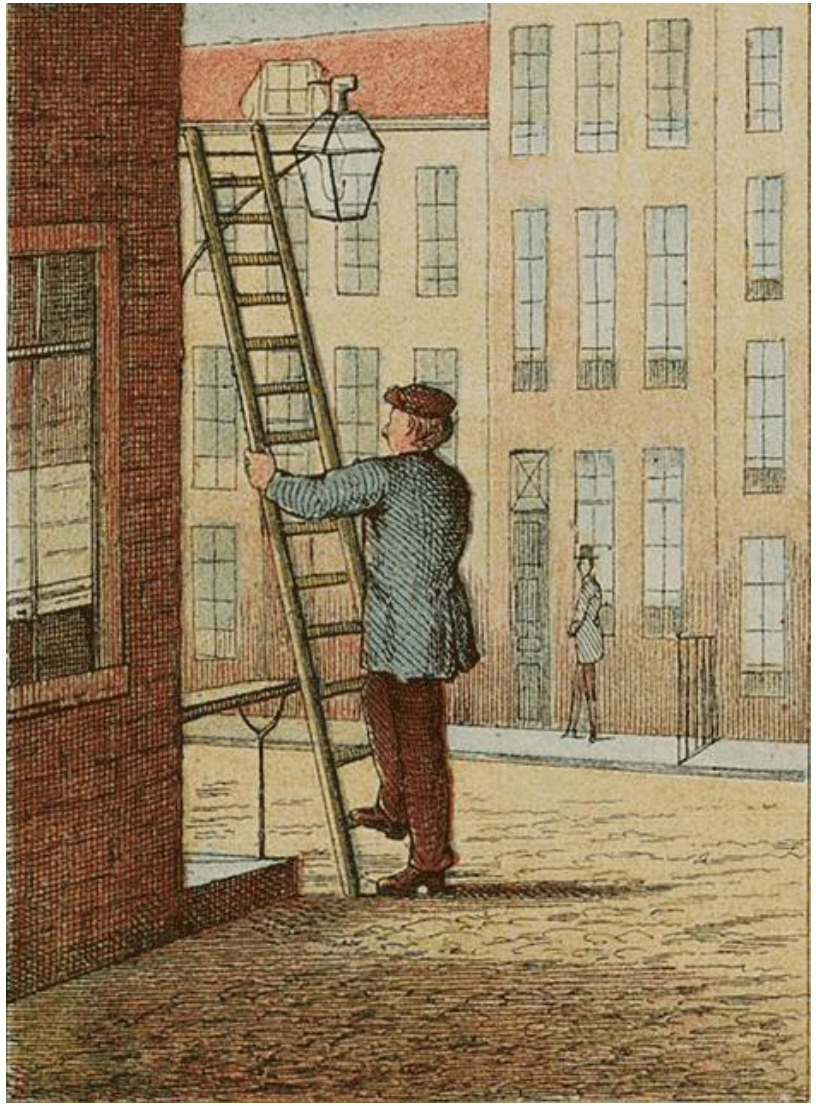
Dependability and robustness: will be a future ESI expertise team once we have build up expertise that can be shared over projects
Model management: topic is being discussed and no decision has been made yet.

2018 project portfolio

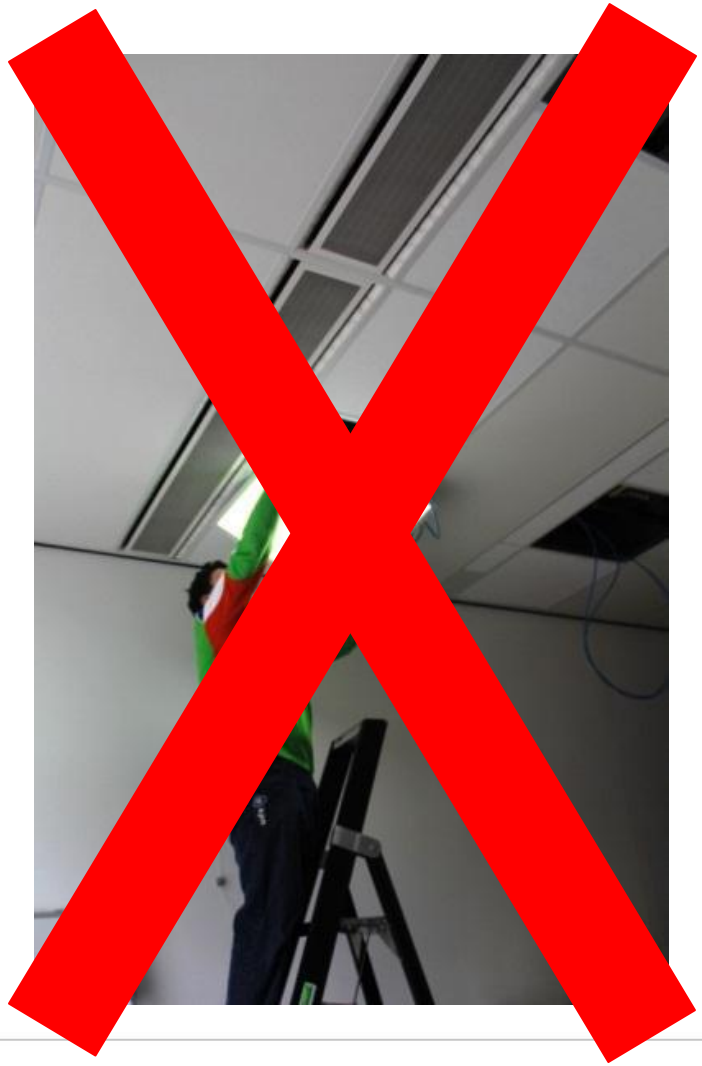


PROJECT 1: IOT DSL

Program: System Evolvability



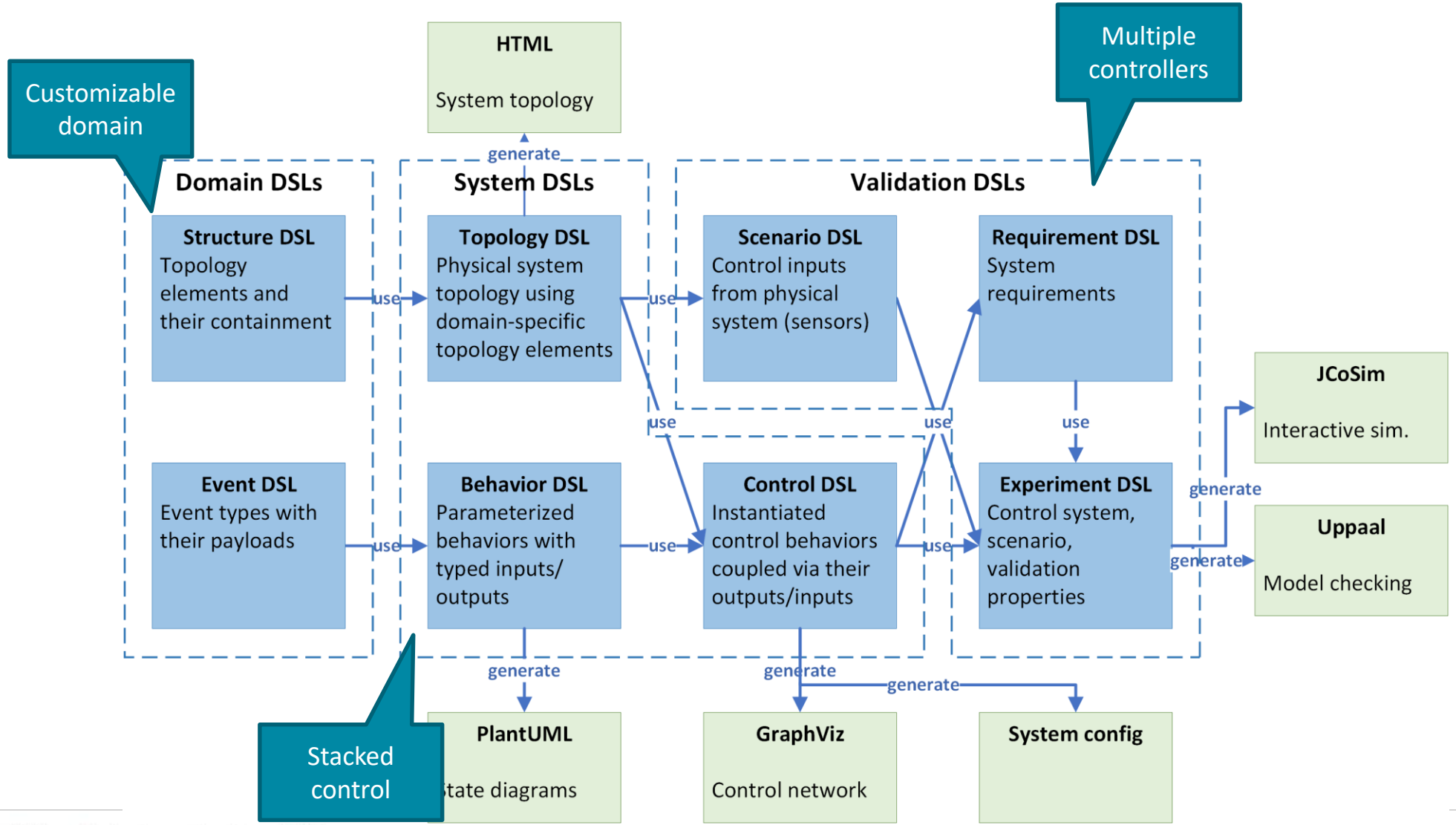
- ✓ 6,000 luminaires
- ✓ 3,000 sensors
- ✓ 100 motions per day/sensor
- ✓ 0.1 reboot per day
- ✓ 5 second boot time
- ✓ 3/1000 message loss



Domain Specific Language (DSL)

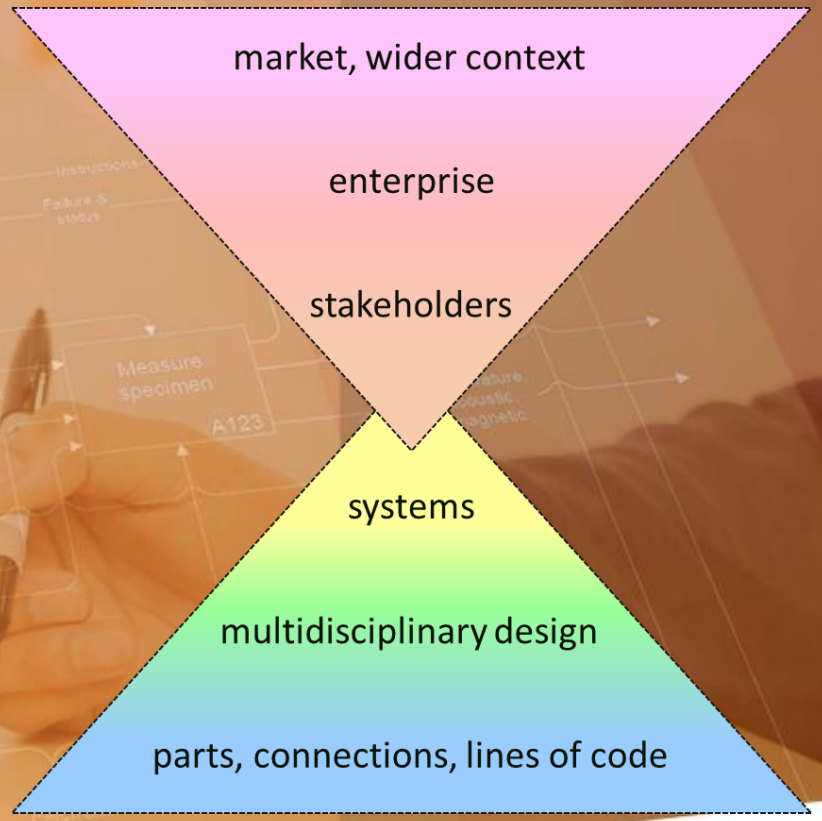
- Easy language to model in a well circumscribed domain
  - Design
  - Generation of code and documentation
  - Testing
  - Commisioning
  - Behaviour and root-cause analysis
  - Reconfiguration
- Originally built for lighting domain
- Generalized to Internet of things:
  - Many connected devices
  - Few different behaviours

IoT DSL Suite: Customizable for domain



PROJECT 2: MODEL BASED SYSTEM ARCHITECTURE

Program System Architecting

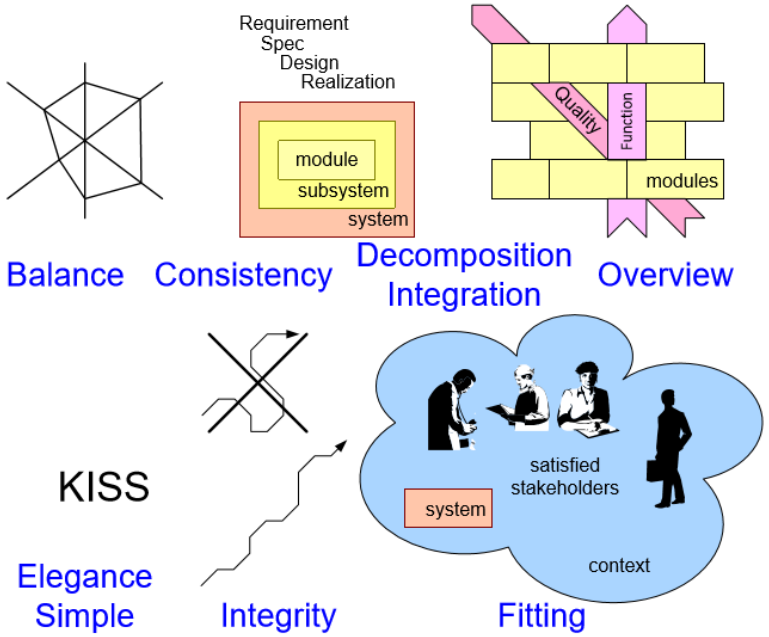


An initiative of industry, academia and TNO

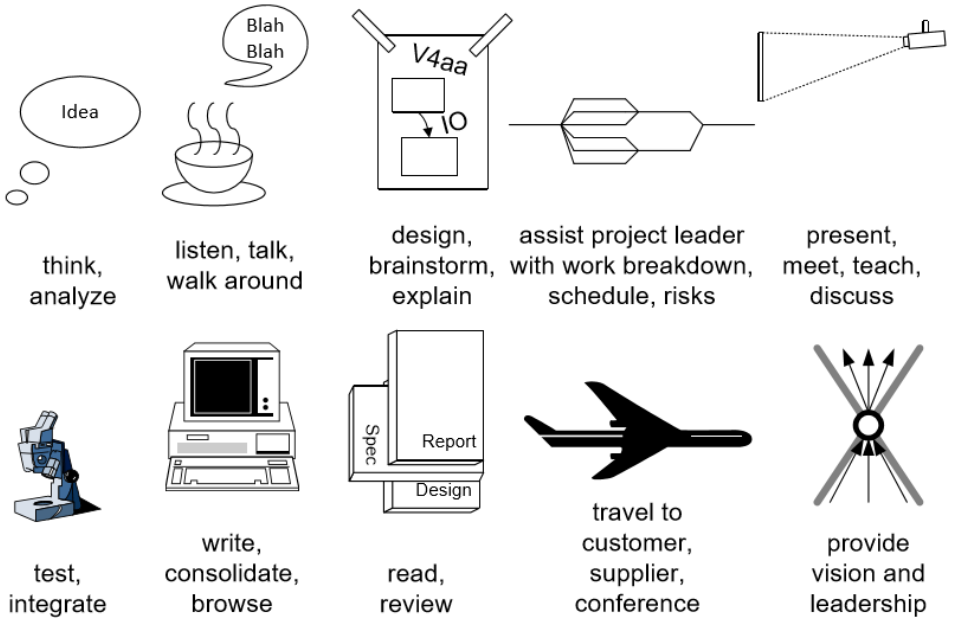
System architect role

- Transformation of business strategy and stakeholder purposes to product qualities and technical solutions

Responsibilities of the System Architect

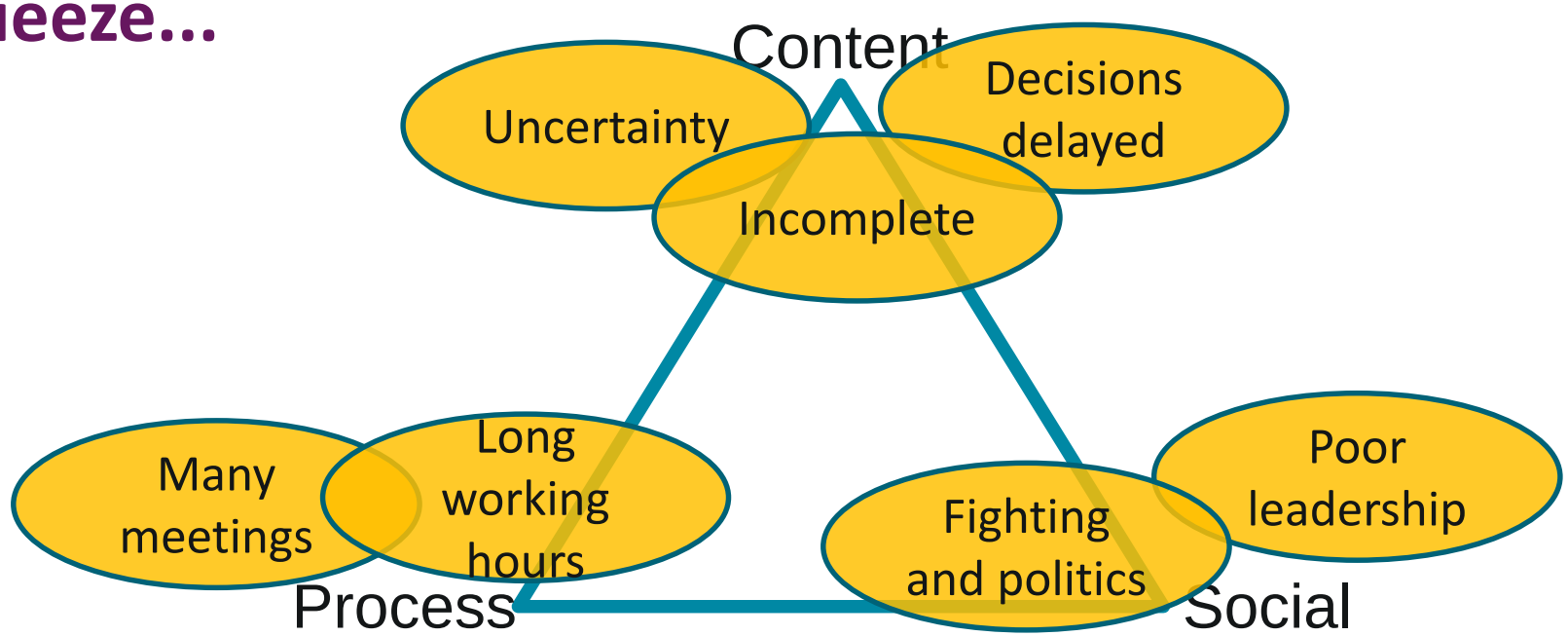


What does the System Architect do?



In the squeeze...

- Symptoms



- How to

  get system overview? → ***"Too much for one brain!"***

  keep a consistent system representation? → ***"Many, many stakeholders"***

  understand consequences of decisions? → ***"Too many dependencies"***

  architect systematically? → ***"No concrete, operational methods"***

Model-based system architecting (a methodology)

- Organizing...
  - cooperation in team
  - ownership
  - transparency
  - systematics
  - abstraction
  - formalization
- Change in way-of-working: from informal language to models

Team process

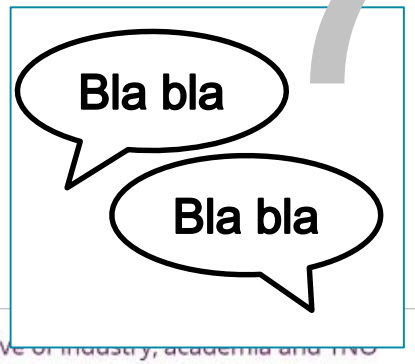
↓

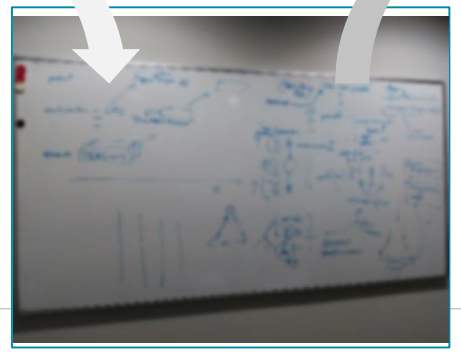
Architecting process

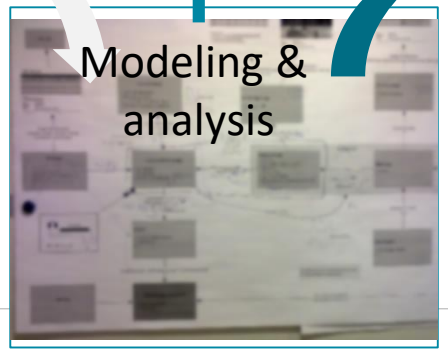
↓

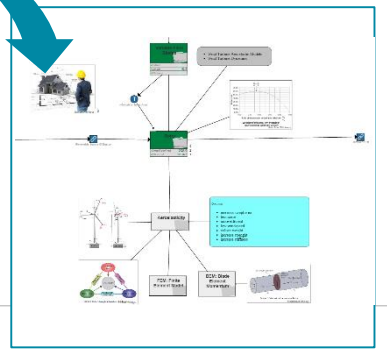
Architectural reasoning

1) Digitized
2) Executable
3) Coupled



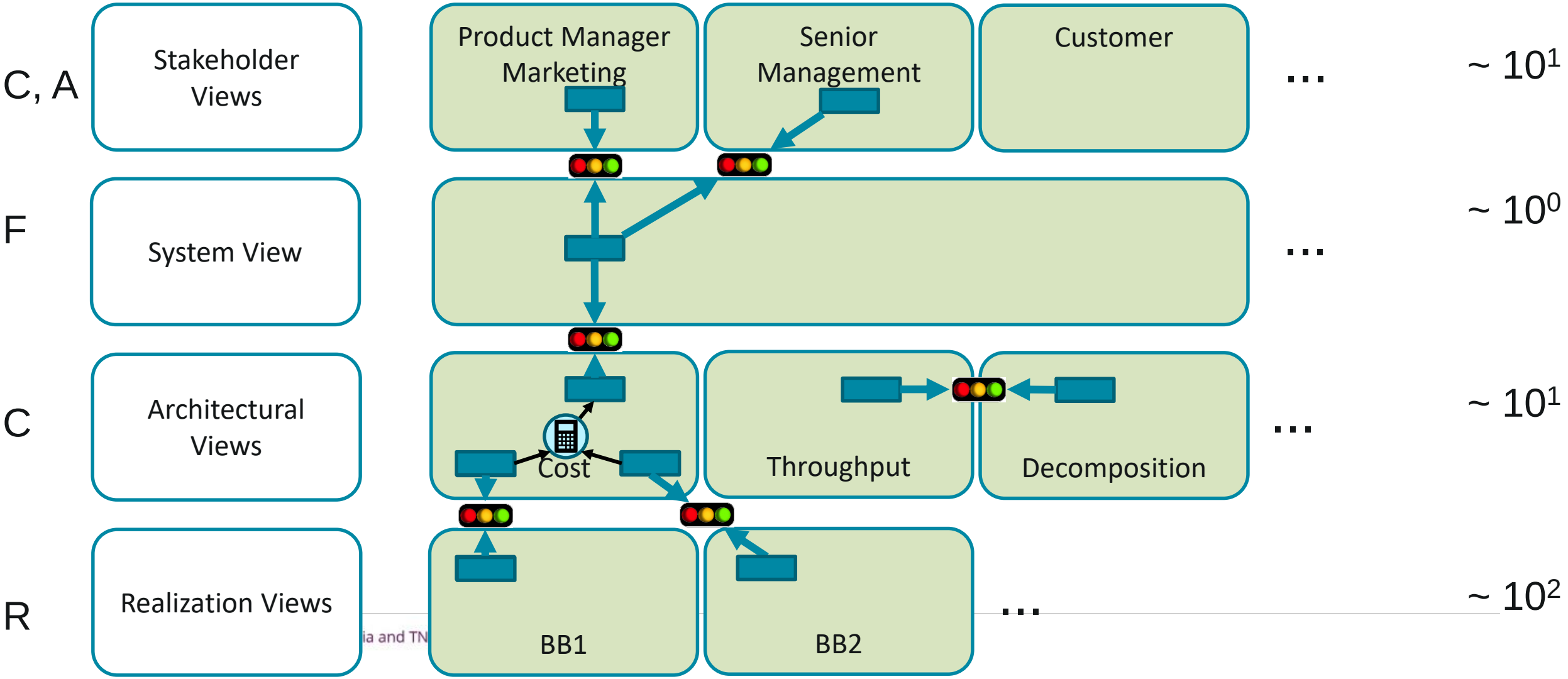






~ 10^0 ~ 10^1 ~ 10^2 ~ 10^3

Organizing the models




Wind Farm
Cost
location
Societal acceptance
Infra-structure

Stakeholders

Entrepreneur




Grid Capacity Planner

Representative of Citizens


System Parameters

System Architect

Architectural Views

Levelized Cost Of Electricity [€/MWh]


Power Generation [MW]

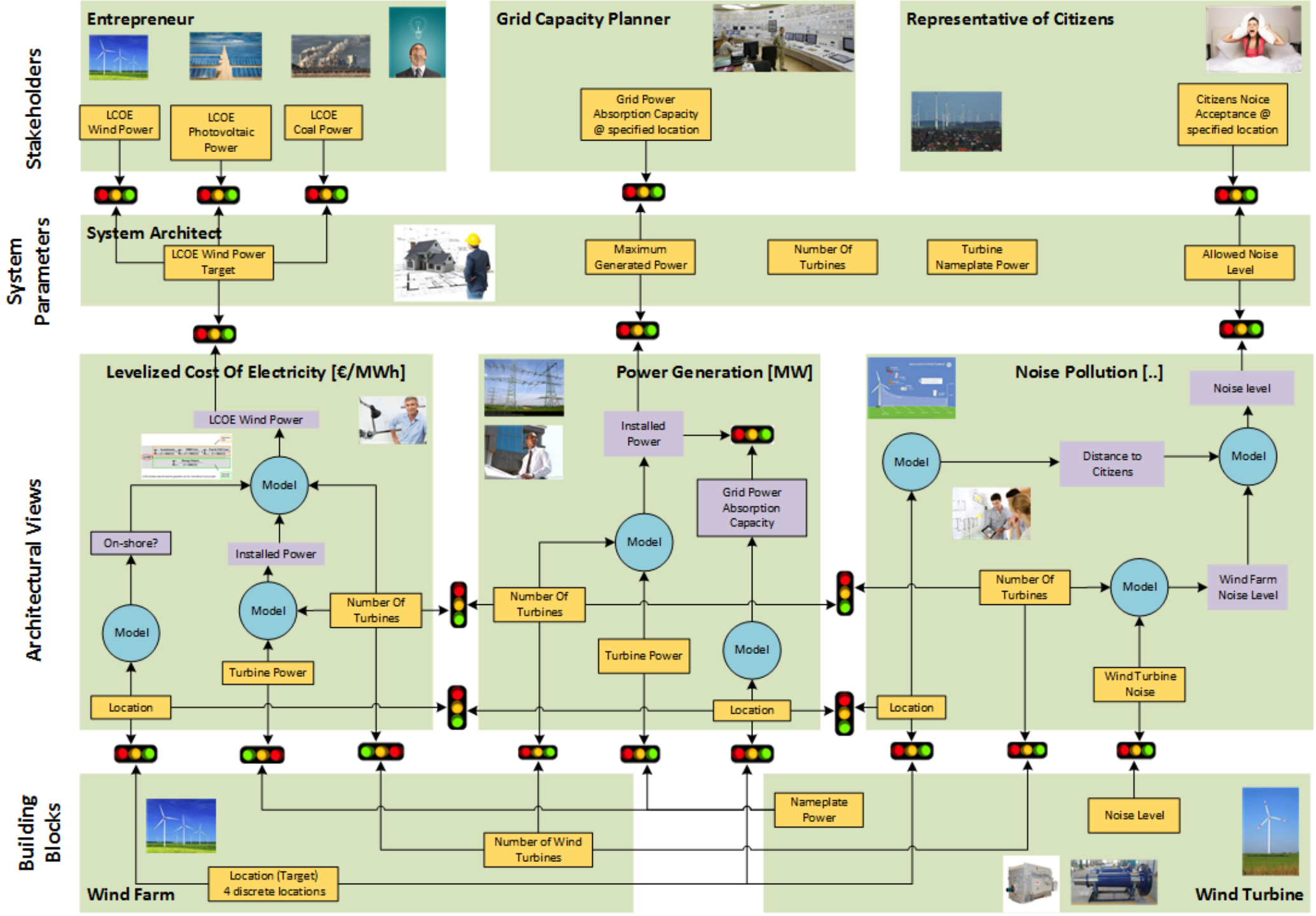

Noise Pollution [..]


Building Blocks

Wind Farm

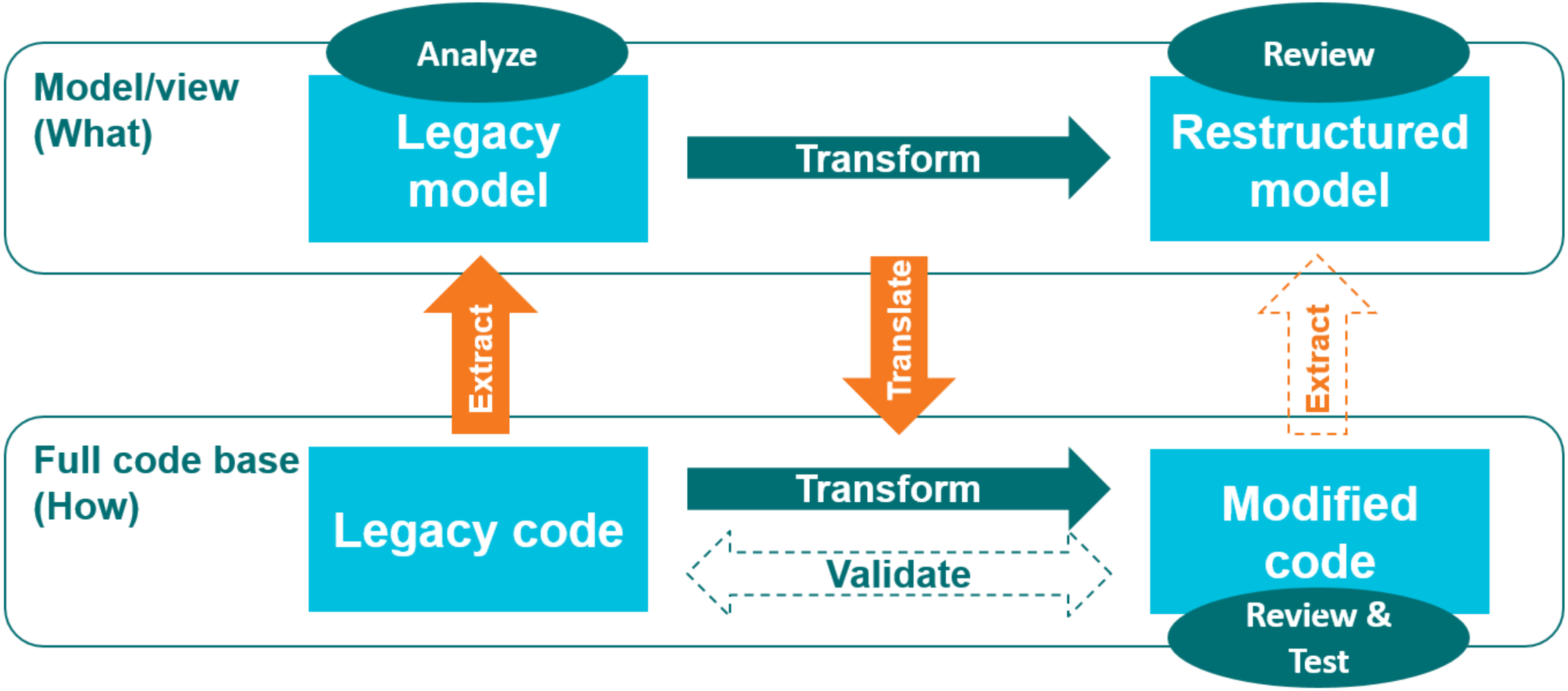


Wind Turbine

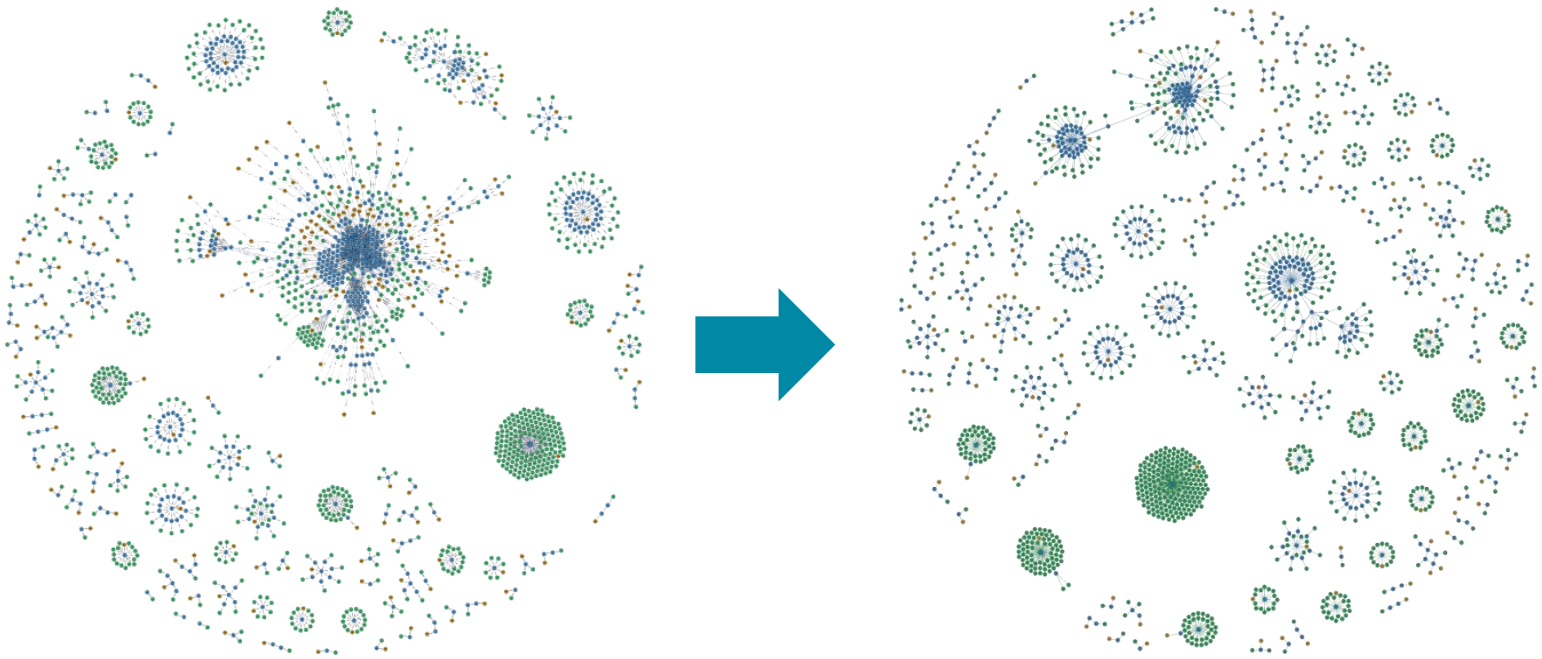

Stakeholders
System Parameters
Architectural Views
Building Blocks
Entrepreneur
LCOE Wind Power
LCOE Photovoltaic Power
LCOE Coal Power
Grid Capacity Planner
Grid Power Absorption Capacity @ specified location
Representative of Citizens
Citizens Noice Acceptance @ specified location
System Architect
LCOE Wind Power Target
Maximum Generated Power
Number Of Turbines
Turbine Nameplate Power
Allowed Noise Level
Levelized Cost Of Electricity [€/MWh]
LCOE Wind Power
Model
On-shore?
Installed Power
Model
Number Of Turbines
Model
Turbine Power
Location
Power Generation [MW]
Installed Power
Grid Power Absorption Capacity
Model
Number Of Turbines
Turbine Power
Model
Location
Noise Pollution [..]
Noise level
Model
Distance to Citizens
Model
Number Of Turbines
Model
Wind Farm Noise Level
Wind Turbine Noise
Location
Nameplate Power
Number of Wind Turbines
Location (Target) 4 discrete locations
Noise Level
Wind Farm
Wind Turbine

PROJECT 3: LEGACY CODE REJUVENATION

Program: System Evolvability


Model/view
(What)
Analyze
Legacy model
Transform
Review
Restructured model
Extract
Translate
Extract
Full code base
(How)
Legacy code
Transform
Validate
Modified code
Review &
Test

Use Case: COM Clean-Up

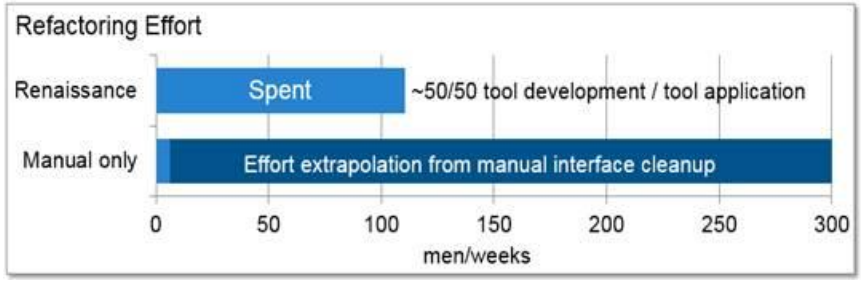


(~6MLoC)

- Yellow Visual Studio Project
- Blue IDL file (COM Interface Definition File)
- Green Interface Names

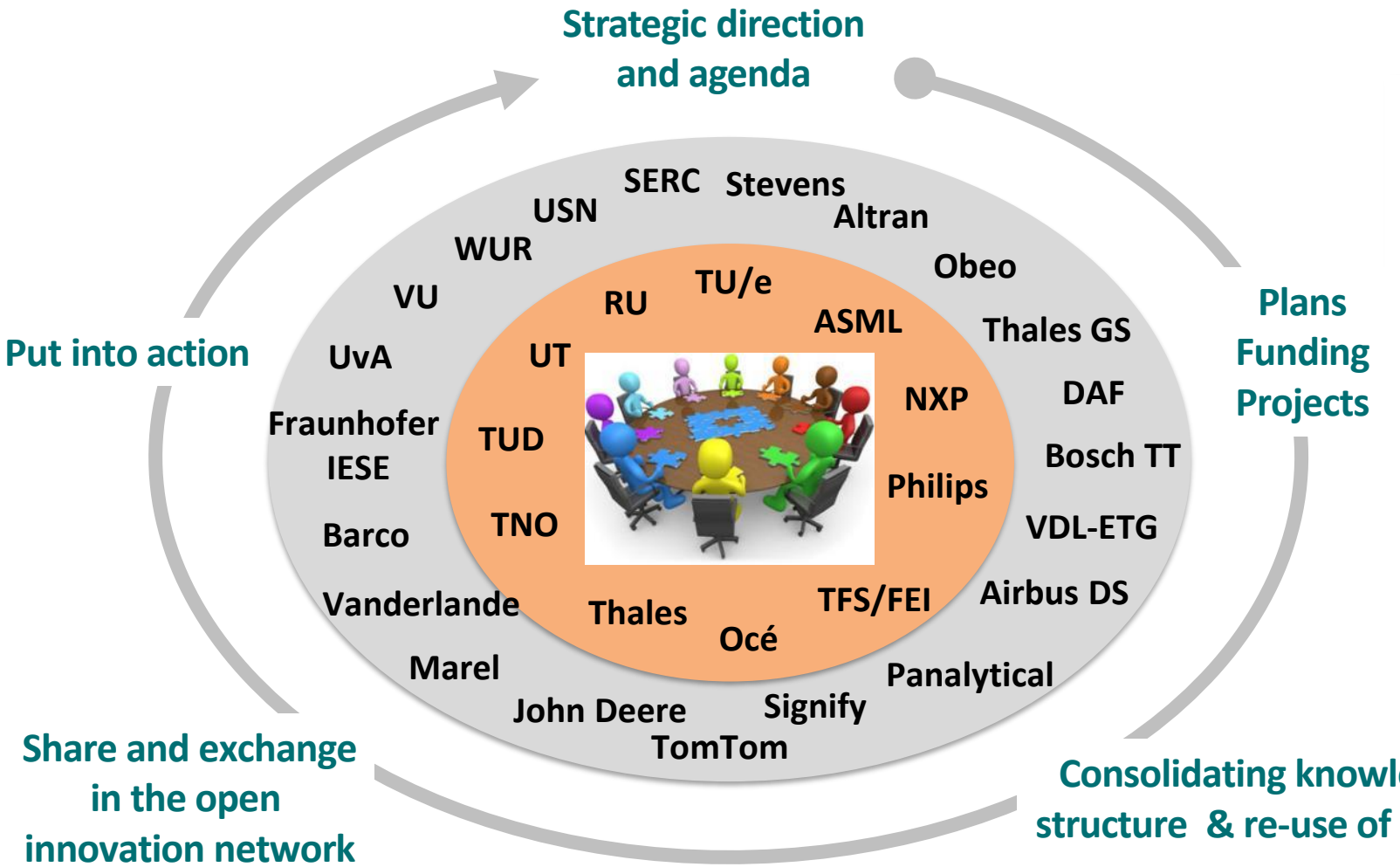
- Target: IDL file is compiled in 1 Visual studio project

- Pictures have been created with Neo4j Graph Database using graphs created from software using the Renaissance Tools



SUMMARIZING …

ESI: SYSTEMS ENGINEERING FOR AN OPEN INNOVATION ECOSYSTEM



An initiative of industry, academia and TNO

THANK YOU!

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ESI