NSE
Nuclear Science & Engineering at MIT
science : systems : society

50 MW MODULAR URBAN NUCLEAR REACTOR

THE ROLE OF HIGH-FIDELITY DIGITAL TWINS

Emilio Baglietto, Associate Professor of NSE

IUS@ArtEZ

Nuclear Batteries blend naturally in a urban environment

J. Buongiorno MIT, Iain Macdonald ArtEZ

“…computational methods drive design”

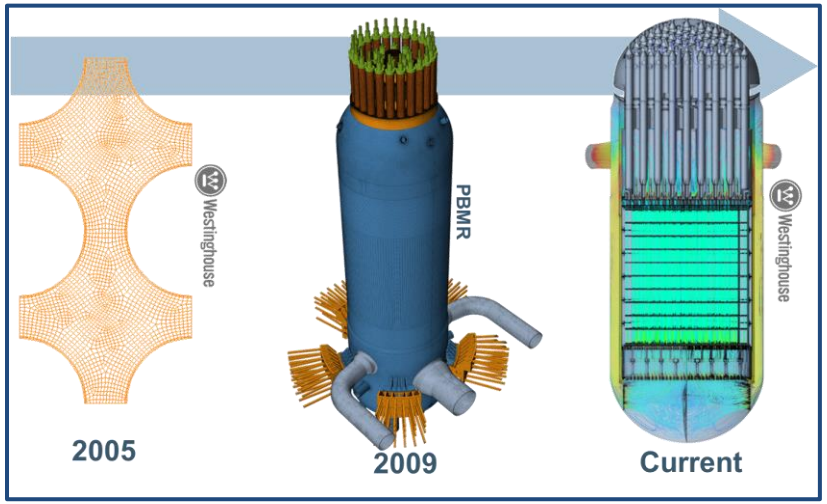
Extensive use of Predictive Simulation have allowed granting of this ETOPS capability prior to the A350 entrance in service

www.youtube.com/user/WorlTop10

Extended range Twin Operations (ETOPS)
aka Engines Turning Or Passengers Swimming

My position in a nutshell

1. **LOW COST DISPATCHABLE ZERO CARBON ENERGY=NUCLEAR POWER** (*I assume we all agree on this point*)
2. I will try to convince you that **predictive Modeling and Simulation (M&S) based on High-fidelity methods** is absolutely necessary for the future of nuclear power
3. I will argue that while **the methods are mature**, their adoption in design and operation is where we need to work.
4. ***I hope to stimulate your reactions***



“…computational methods drive design”

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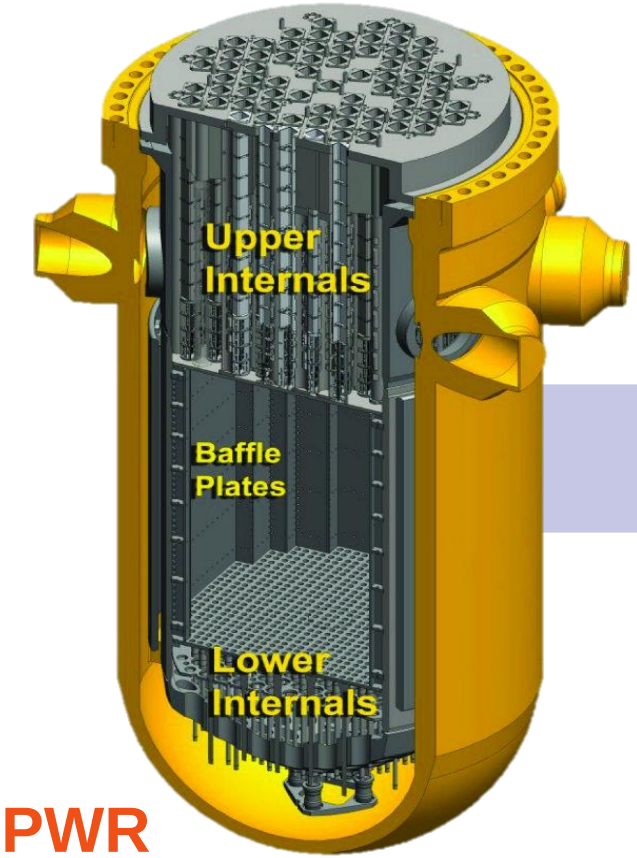
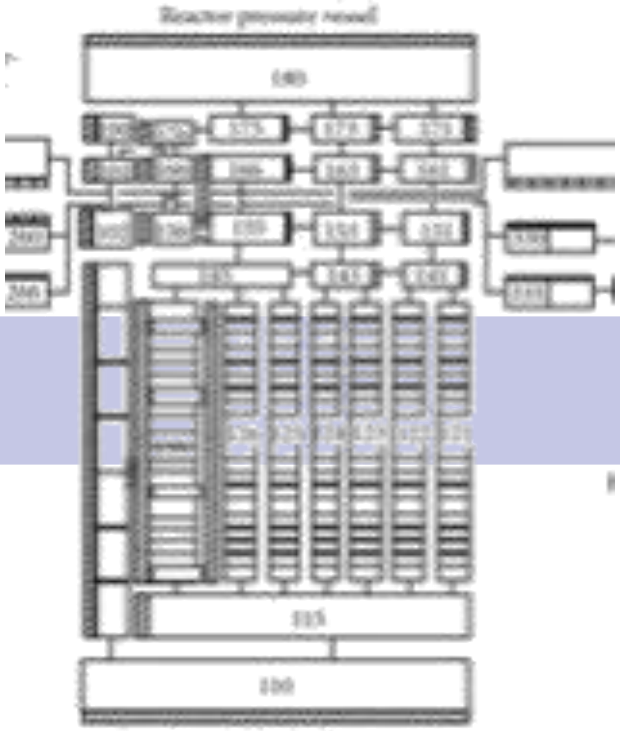
Nuclear Science and Engineering

“…even the bad ones”

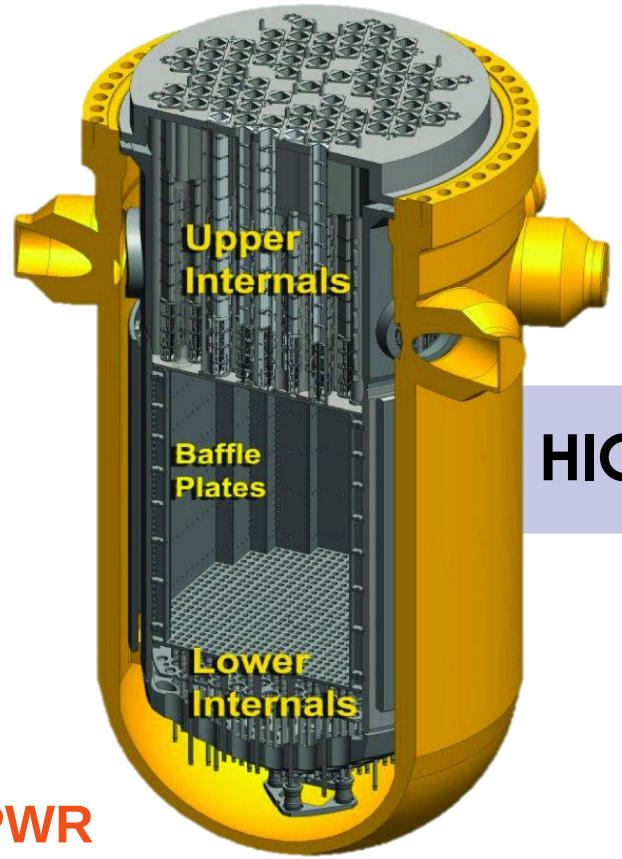


PWR
Reactor Vessel
http://www.neimagazine.com/



Advanced
PWR Vessel

“…computational methods drive design”



PWR
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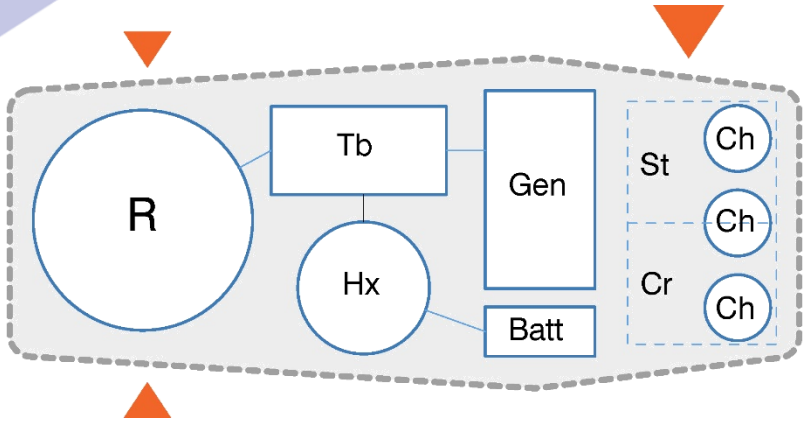
50MW MODULAR URBAN NUCLEAR REACTOR

HIGH-FIDELITY Digital Twins

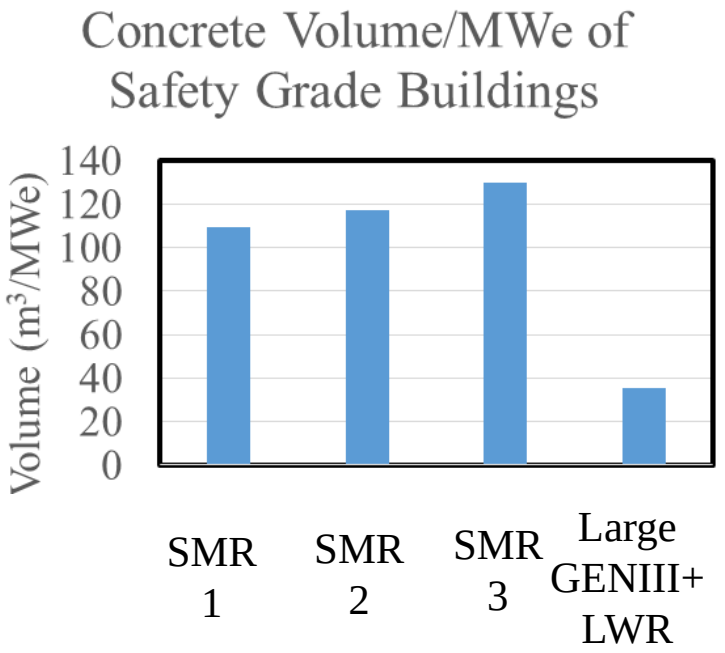


Courtesy of Iain Macdonald

IUS@ArtEZ

New NPP require Digital Optimization

- **High-fidelity Digital Twins** are a key enabling technology supporting a broader need for **Digital Optimization**
- Taking the example of **current SMR** design we clearly see the lack of Optimization
  - ✓ Plants are smaller GENIII+
  - ✓ Onsite Labor hours per MWe for many SMRs are not different than large LWRs
  - ✓ Still require specialized equipment (RPV)



Estimated Numbers -
Prof Koroush Shirvan, MIT

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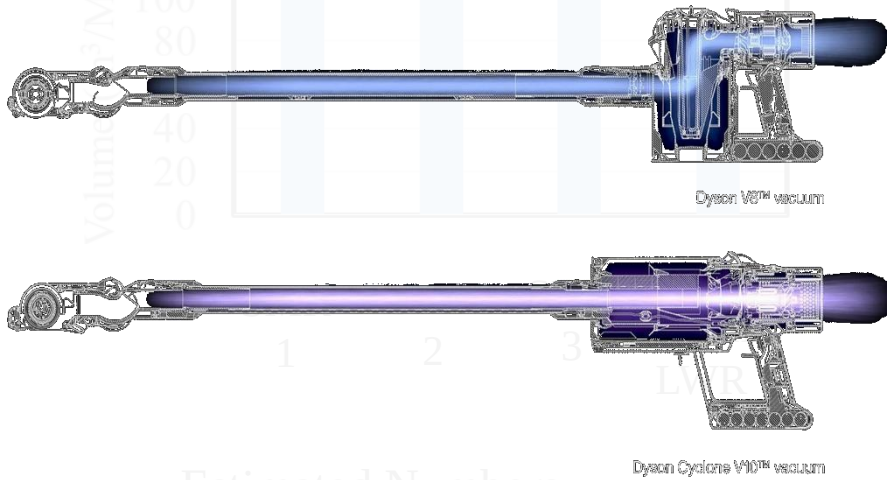
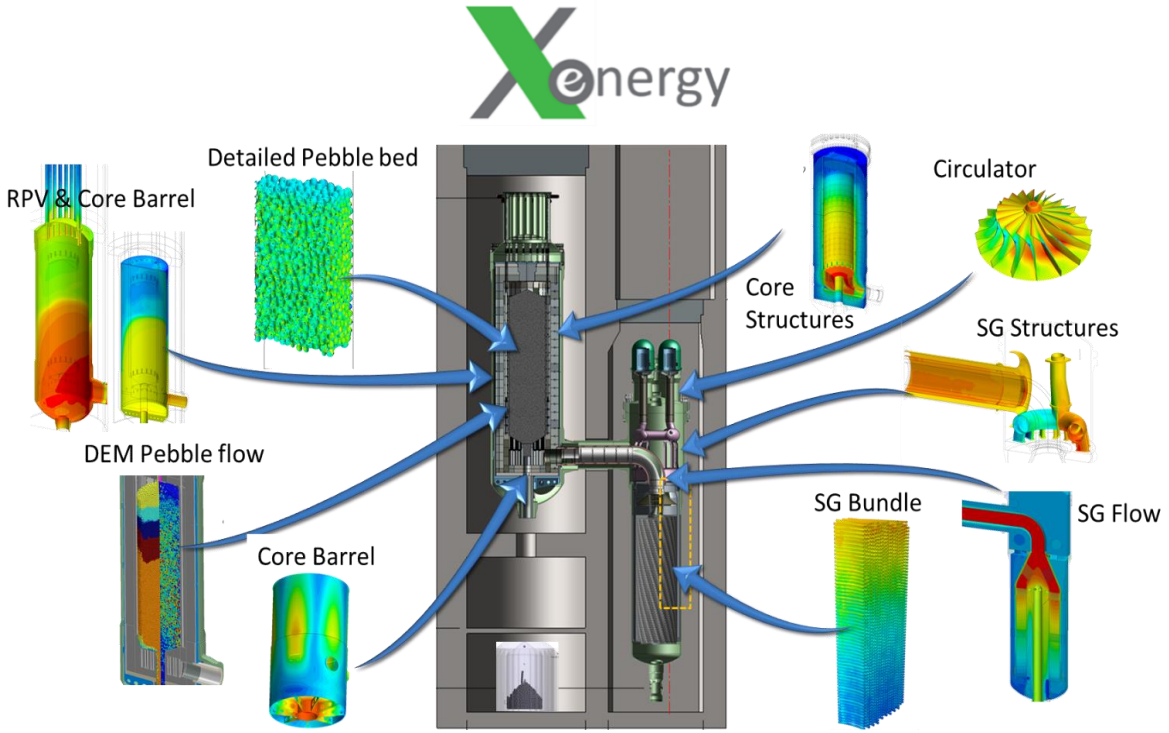
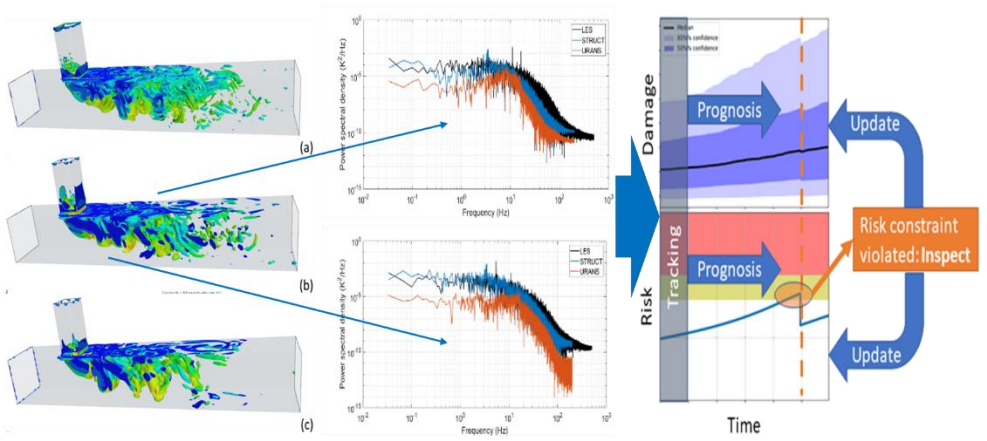
  - ✓ Plants are smaller GENIII+
  - ✓ Onsite Labor hours per MWe for many SMRs are not different than large LWRs
  - ✓ Still require specialized equipment (RPV)
- The **"excuse"** is too often the regulatory environment → Regulators have come a long way

Nuclear Designers Often Invest less then Vacuum Cleaners Designers to optimize their flow efficiency.



High-fidelity Digital Twins are necessary to design, deploy and operate cost-competitive Nuclear Power





Design, deploy

Operate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Thank you for your attention !
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DIGITAL & MODEL BASED PROJECT DELIVERY

Enabler of energy
& Digital revolutions

COMPLEXITY IN ACTION: NUCLEAR NEW BUILD PROJECT

~ 150 elementary systems
(reactor, power unit, HVAC, etc.)

> 50 buildings
(nuclear island, conventional island, etc.)

~ 20,000 inputs/outputs
of control commands

~ 200 contracts
(engineering, suppliers, contractors, etc.)

> 3,000 stakeholders
(just in detailed design activities)

~ 3,500 workers on site
(at peak of staffing)

Generic nuclear newbuild projects

> 500,000 components
(electrical, mechanical, I&C, etc.)

~ 500 km of piping
(across all the plant)

~ 2,000 km of cables
(across all the plant)

~ 500,000 m3 of concrete
(in all the plant)

Volume of reinforcement bars
Equivalent to 10 Tours Eiffel

6 years from the first concrete
to day 1 of operations

>100 millions of unit data
(requirements, reports, schemes, drawings, etc.)

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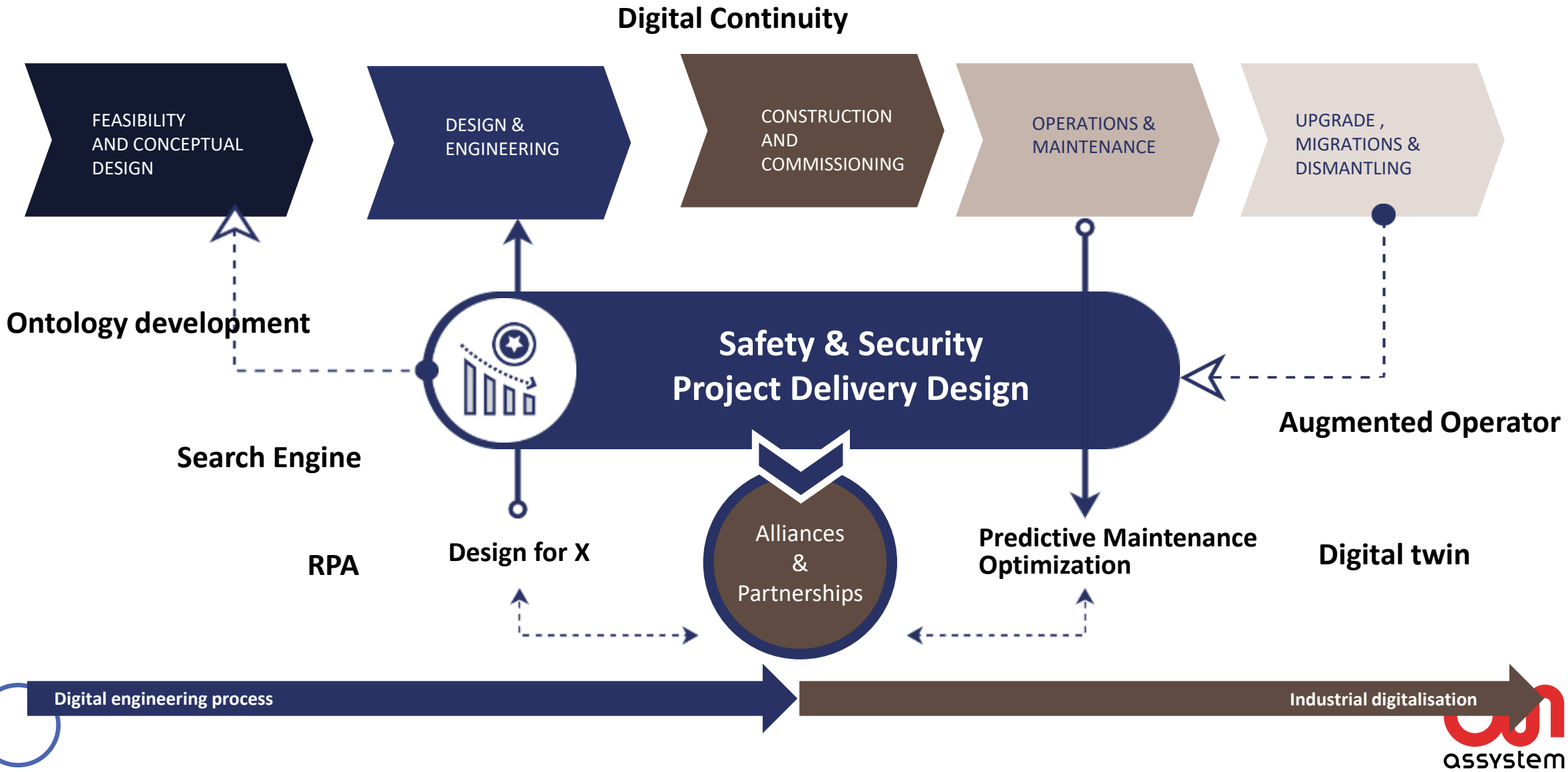
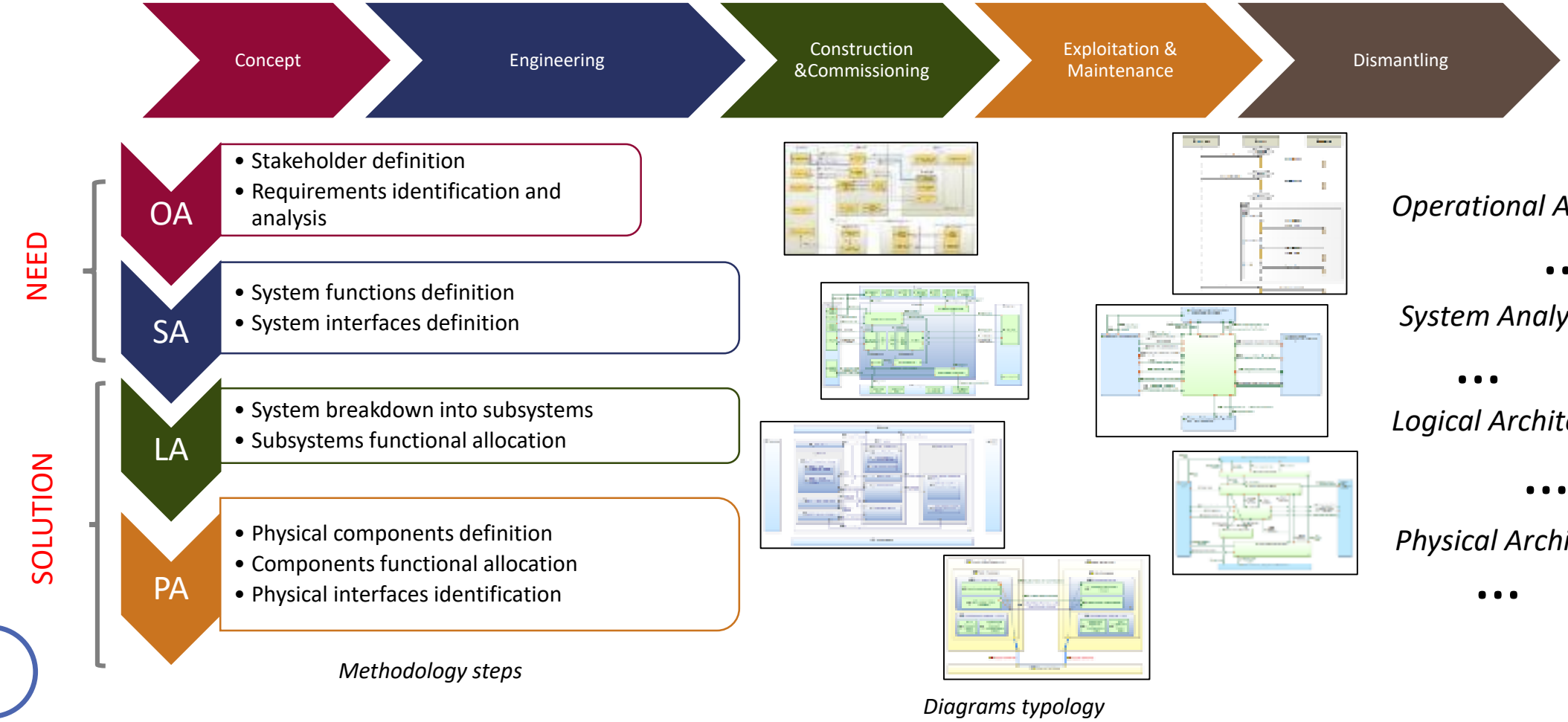
CONVERGENCE BETWEEN DATA AND SYSTEM ENGINEERING

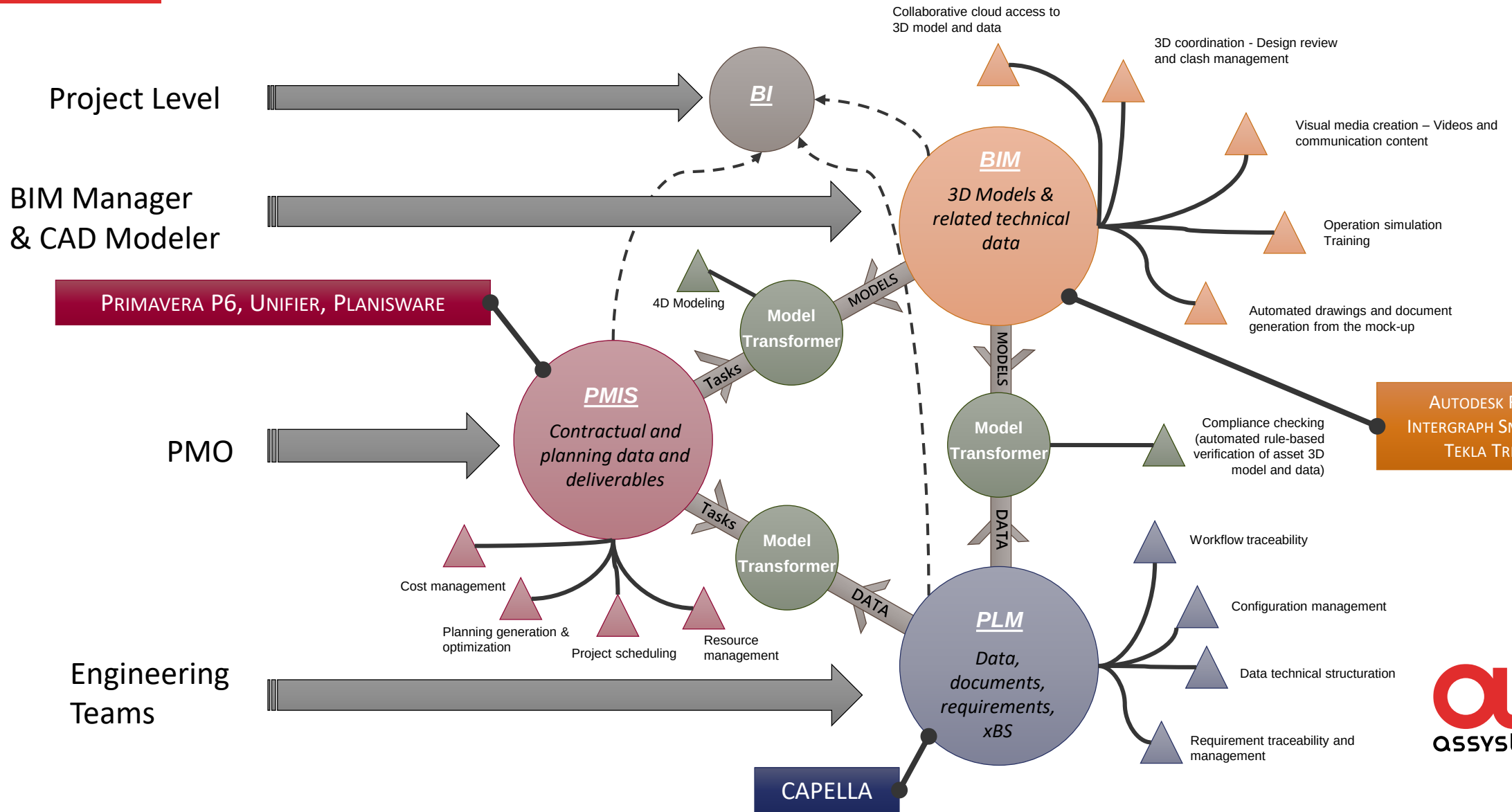


CONVERGENCE BETWEEN MBSE & DATA

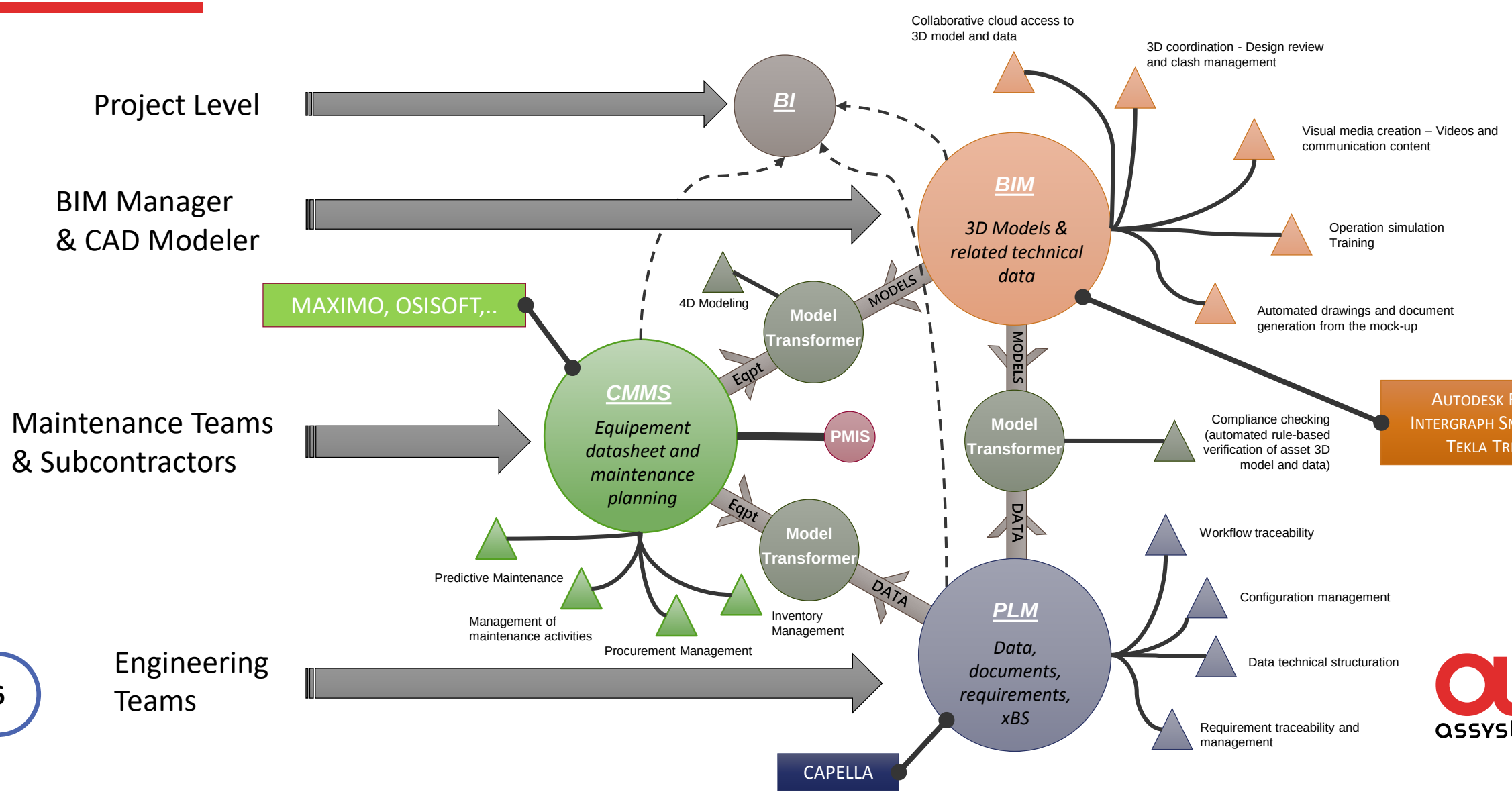
- **Document to Data, Modelling of workflow, process, Project delivery design**



ASSET INFORMATION HUB FOR
DESIGN/CONSTRUCTION/COMMISSIONING

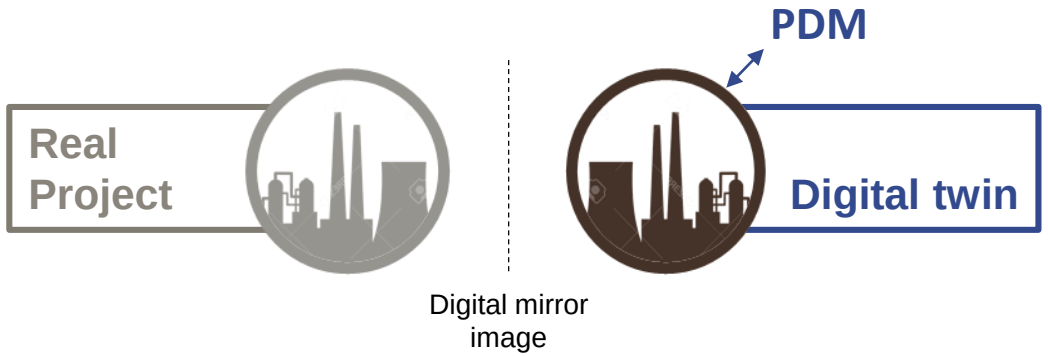


ASSET INFORMATION HUB FOR OPERATION & MAINTENANCE



THE CONCEPT OF DIGITAL TWIN @SYSTEM LEVEL

System based Digital Twin':

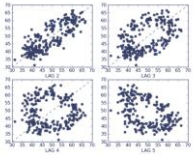


Digital Twin functionalities :

- Seeks out correlations and causality to anticipate risk
- Helps to understand how a particular strategy will impact delivery and its KPIs in the future, and in turn best mitigate the identified risk
- Calculates an 'PDM-based confidence index' for the delivery of the project
- Being able to capture lessons learnt from previous projects

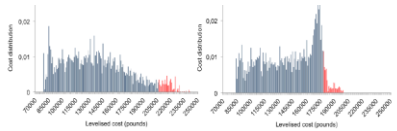
Risk reduction

- Threshold-based alerts
- Anomaly detection
- Root-cause analysis
- Pattern recognition



Decision making

- Advanced visualisation
- What-if scenarios
- Optimisation under constraints
- Multi-agent modelling



Data science techniques

LESSONS LEARNT FROM OTHER SECTORS

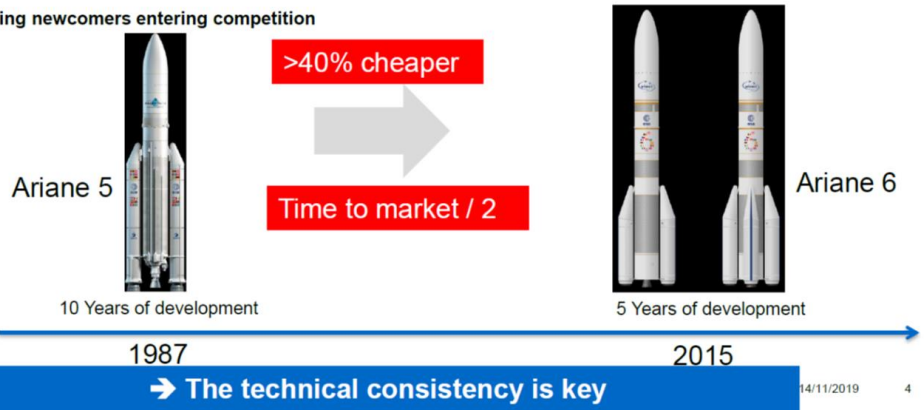
THE SPATIAL CONTEXT : A INCREASING CHALLENGE

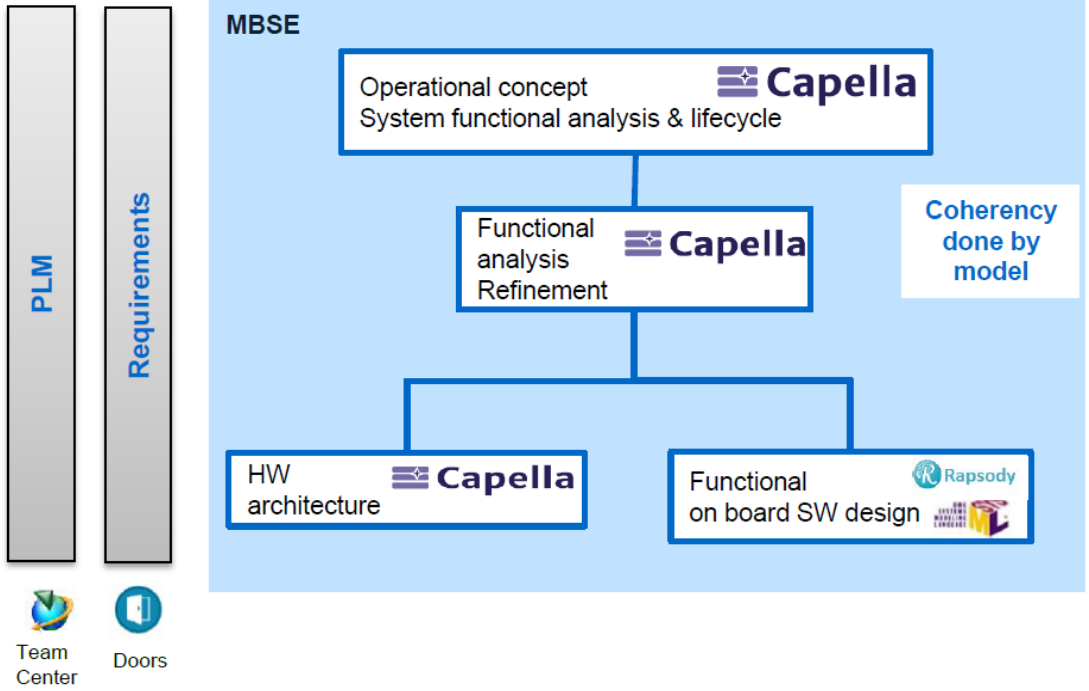
Affordable access to space :

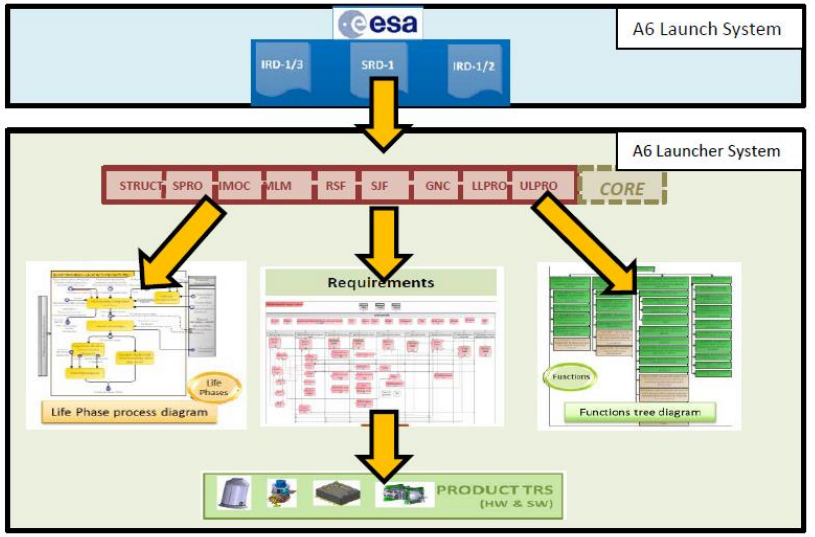
- **Breaking Space Launch "cost barrier" is a main enabler for future Space Economy**

The need for speed :

- Challenging newcomers entering competition







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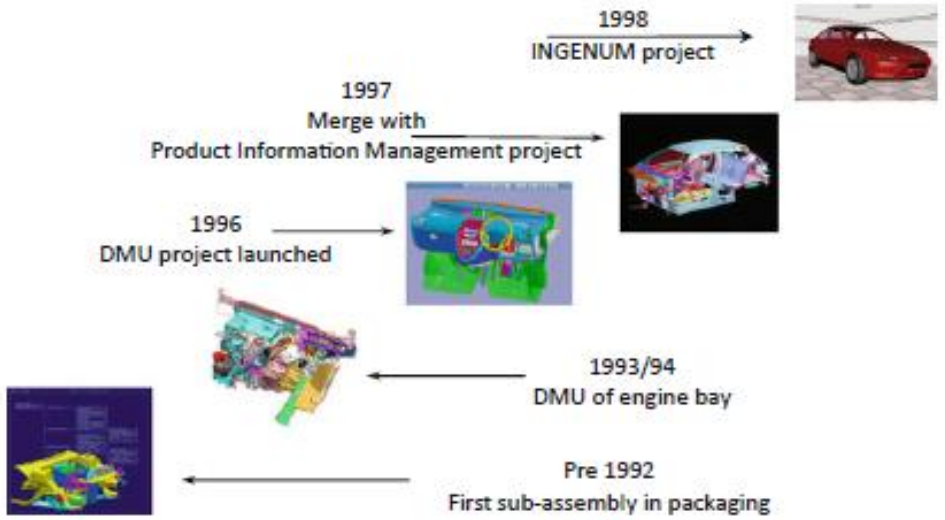
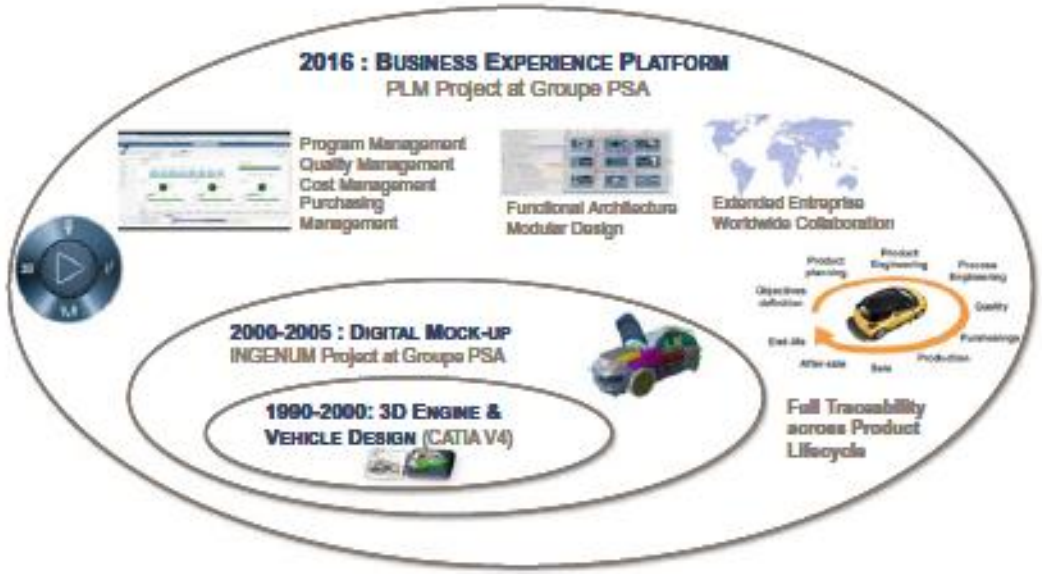
AUTOMOTIVE SECTOR



Standardisation

Modularity

Collaboration & Lessons Learnt



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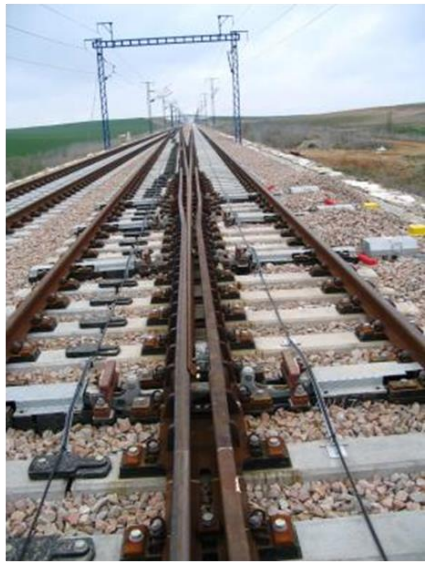
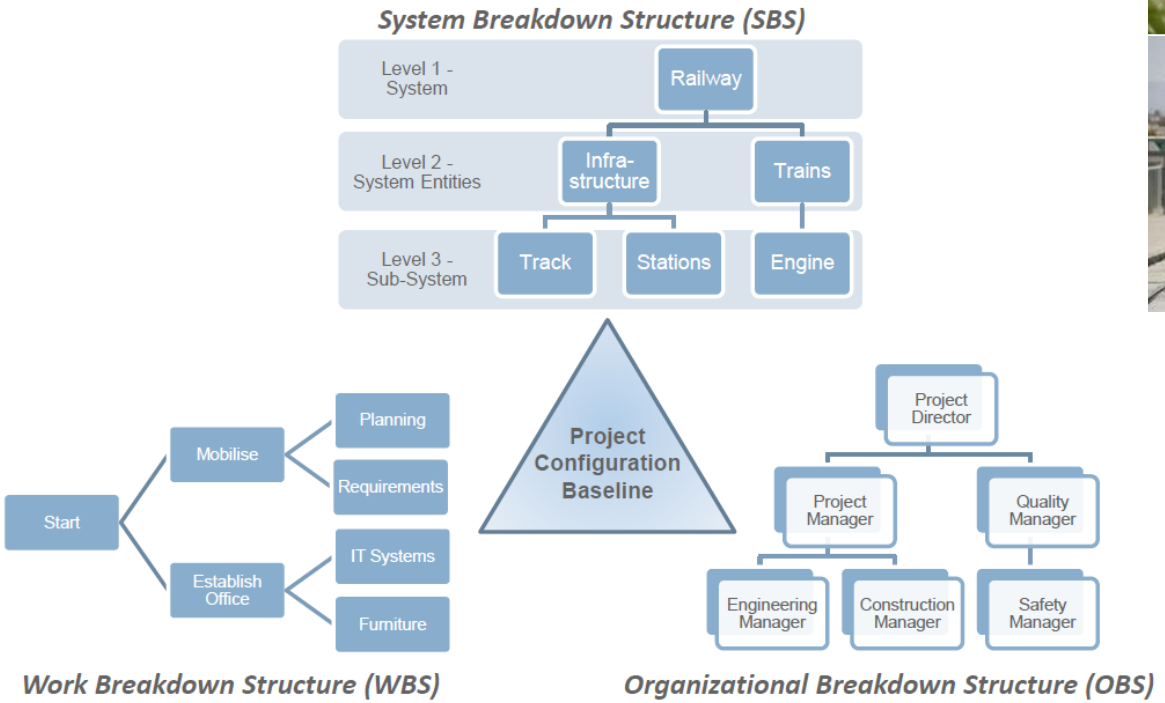
RAILWAY SECTOR

Rolling Stock | Signaling Products | Infrastructure







Platform approach, Modularity

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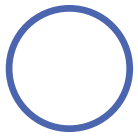
KEY MESSAGES

- ❑ Digital twin at System Level as an enabler of the Project Delivery Model
- ❑ Important to introduce MBSE and Data Centric Approach
- ❑ NLP, Artificial Intelligence used to structure the data and to automatize process/workflows/tasks
- ❑ Lessons learnt from other sectors important and digitalisation of lessons learnt will de-risk the project delivery
- ❑ Nuclear is at the beginning of its industrialization journey



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Rolls-Royce SMR

NEA Workshop on Digital Transformation: Opportunities and Challenges for the Nuclear Sector

27th / 28th May 2021

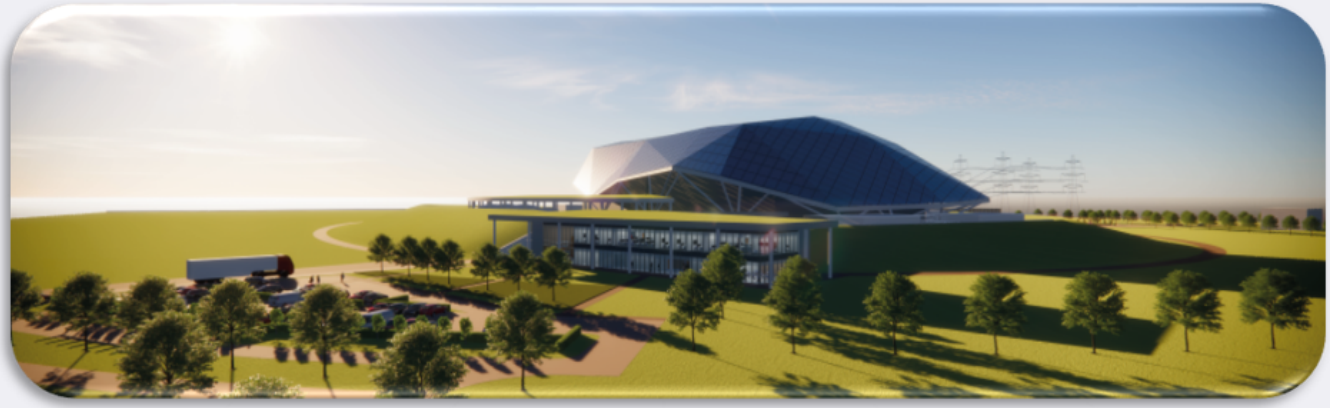
Dr Nigel Hart – Head of Digital

SMR Power Station

The Rolls-Royce SMR is a modular build **power station, not a nuclear reactor**

- ✓ Capital cost under **£1.8 Bn**
- ✓ Typical LCOE of electricity **c.£50 per MWh**
- ✓ **Compact site footprint**
- ✓ **60-year plant lifetime**
- ✓ **Adaptable design**

Integrated Modular Factory Built Power Plant



Low Cost Nuclear

- Use of proven Technology
- Simplified and Standardised Equipment
- Predictable and Repeatable

Deliverable Solution

- Factory Built Commodity
- Site canopy for controlled site environment
- Maximize Productivity and Innovation across Fleet

Investable Product

- Factory solution to build out Fleet
- Significantly reduced construction risk
- Acceptable Completion Risk given commodity nature of product

Innovation for benefit, not for innovation sake

Low Cost Nuclear
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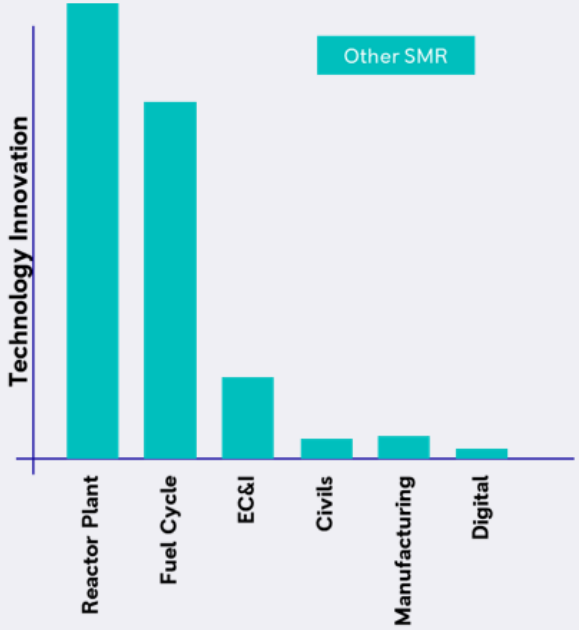

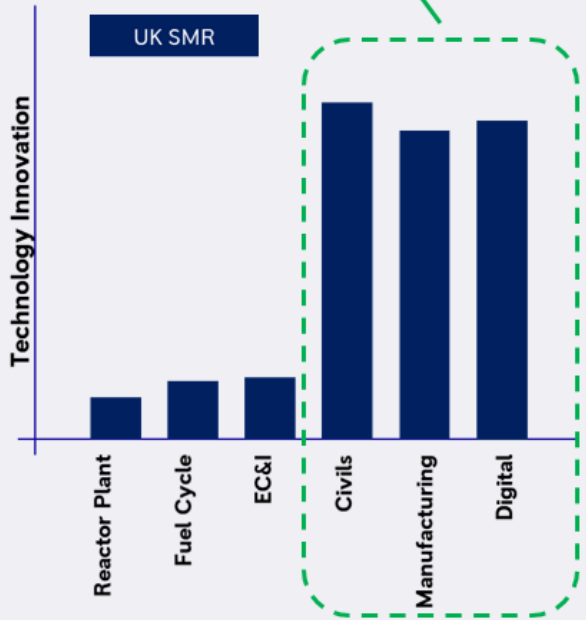

A fleet approach can realise further savings to operators

- Rolls-Royce has extensive experience in Aerospace and Marine in monitoring customer assets to optimise performance
- All units can be monitored against the performance of other units and normalised for age and environmental factors
- Central Ops centre analysis will
  - Optimise performance across the fleet
  - Minimise downtime / increase capacity factor
  - Provide early insights into future demands during maintenance schedules
- Sharing of engineering capability across the fleet

Digitally connected units

Centrally monitoring Ops centre

Rolls-Royce SMR

Dr Nigel Hart

Head of Digital – UK SMR

nigel.hart@rolls-royce.com

NEA Digital Transformation
An Operator/Owner View

Brett Plummer

Why Digital for Nuclear Plants

- Safety and Reliability – Decrease Risk – Decrease Cost
  - "The Human Challenges the Equipment, the Equipment Challenges the Human"
    - Human Performance Error Prevention
    - Self Diagnostics
    - Decision Making
    - Decrease Labor Cost
    - Efficiency in Planning

Why Digital for Nuclear Plants

- Safety and Reliability – Decrease Risk – Decrease Cost
  - Equipment
    - Single Point Vulnerability
    - Condition Based Maintenance – Predictive Analytics
    - Efficiency – Information – Common Platform
    - Trends – Common platform
    - Minimize Inspections and Testing
    - Predictability - Reliability

What is the Challenge for New Plants

- Vision for Future Nuclear
  - Digital Innovation in Development of SMRs
    - Do we need people in local control rooms?
    - Do we have a centralized support center? Big data
    - Do Humans manipulate equipment? Minimize HU events
    - Who do we hire for personnel? IT or typical engineering disciplines or a hybrid?
    - How often do Operators perform training? Level of simulation based on simplicity of the SMRs
    - What is the span of the Regulator? Can we use AI?
    - Who maintains design control?
    - How do we minimize cost?

What is the Challenge

- Barriers to Digitalization
  - Change is Bad – 40 years – Self looking
  - Infrastructure to Support a fleet – chicken and the egg
  - Qualification Process and Cost
  - Installing Digital Systems that are Sustainable
  - The Right Integrated Expertise – Design through Installation
  - Cost Effectiveness