Techno-economic analysis on modularisation and complex project management

Professor Giorgio Locatelli PhD FHEA
Full Professor of Complex Projects Business
School of Management – Politecnico di Milano
Senior Editor – Project Management Journal

Giorgio.Locatelli@polimi.it

Download all my important papers in a click http://bit.ly/2yyVotE
Can we have on time and budget “Nuclear reactors projects”?

Flamanville costs up €2 billion

04 December 2012

France’s first EPR is still on schedule for operation in 2016 but factors including new regulatory requirements and lessons learned from Fukushima have pushed the calculated costs of the project up.
The same old story…

Projected and Actual Construction Costs for Nuclear Power Plants (USA)

<table>
<thead>
<tr>
<th>Year Initiated</th>
<th>Number of Plants</th>
<th>Utilities’ Projections (Thousands of dollars per MW)</th>
<th>Actual (Thousands of dollars per MW)</th>
<th>Overrun (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966 to 1967</td>
<td>11</td>
<td>612</td>
<td>1,279</td>
<td>109</td>
</tr>
<tr>
<td>1968 to 1969</td>
<td>26</td>
<td>741</td>
<td>2,180</td>
<td>194</td>
</tr>
<tr>
<td>1970 to 1971</td>
<td>12</td>
<td>829</td>
<td>2,889</td>
<td>248</td>
</tr>
<tr>
<td>1972 to 1973</td>
<td>7</td>
<td>1,220</td>
<td>3,882</td>
<td>218</td>
</tr>
<tr>
<td>1974 to 1975</td>
<td>14</td>
<td>1,263</td>
<td>4,817</td>
<td>281</td>
</tr>
<tr>
<td>1976 to 1977</td>
<td>5</td>
<td>1,630</td>
<td>4,377</td>
<td>169</td>
</tr>
</tbody>
</table>

| Overall Average | 13               | 938                                                  | 2,959                                | 207               |


Actual = budget X 3
Can we have on time and budget “Nuclear reactors projects”? YES!

CONSTRUCTION TIME FOR THE STANDARD 1 GW KOREAN PWR

CONSTRUCTION STARTED

YEARS

R² = 0.5522
Megaprojects – Some literature


“401 power plant and transmission projects in 57 countries [...] with only 39 projects across the entire sample experiencing no cost overrun”


“Hydroelectric dams and nuclear reactors have the greatest amount and frequency of cost overruns, even when normalized to overrun per installed MW [...] solar and wind projects seem to present the least construction risk.”


“H1 Bigger is bad
H5 - small is beautiful”


“the propensity of big capital investments to systematically deliver poor outcomes easily and unceasingly, and above and beyond their economies of scale and scope.”

Big here is intended as
- Physically Unique, uncommon, expensive, long construction
- With a unique new team of stakeholders
Misunderstanding about economy of scale

Cost

[$/MW]

Single Unit size [Mwe]
Economy of multiples

For the same power, the smaller the plant, more units are built.
We need words to understand


**Monolithic plant**: A plant constructed in the field without extensive use of modules; also referred to as a stick-built plant

**Modularisation**: Process of converting the design and construction of a monolithic or stick-built plant to facilitate factory fabrication of modules for shipment and installation in the field as complete assemblies

**Modularity**: A standard unit assembled onsite from factory produced modules, usually of smaller capacity than a monolithic plant, to maximize the benefit from modularity effects

**Pure Standardisation**: The delivery of (nearly) identical stick-built power plants form a consistent set of stakeholders in the project delivery chain
The two sides of standardisation

Physical standardisation

Project delivery chain

Vendor

Utility

Financer

Regulator

Government

Supplier

NPP
What’s about risk?

• FOAK cost unknown

• Exogenous (construction time related)
  o Exchange rates
  o Interests escalation
  o Legislation changes (Chernobyl / Fukushima events)
  o COVID
  o …

• Endogenous
  o Design mistakes/uncertainties
  o Suppliers mistakes
  o Mistakes in the construction
  o …

True for LR and SMR, but the scale is dramatically different

SMR shorter construction time

Fostered industrial learning (Korean Like)
# Key ideas

<table>
<thead>
<tr>
<th>Stand alone Large</th>
<th>Several “right” SMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark previous projects</td>
<td>![Red Checkmark]</td>
</tr>
</tbody>
</table>
| Start from a completed design! Remember the Rickover Effect  
  - Requires an immense amount of development on apparently trivial items;  
  - Takes a long time to build because of its engineering development problems  
  - Reworks, mistakes in constructions, change requests | ![Red Checkmark] |
| Develop stakeholders accountability  
  - “you won’t get the next projects if you don’t perform well on this one”  
  - Create long term collaboration between stakeholders | ![Red Checkmark] |
| Foster the “economy of multiples”  
  - Learning for all the stakeholders involved  
  - Multiple units in the single site | ![Red Checkmark] |
| Economy of scale  
  - Don’t go to small, don’t go to big! | ![Red Checkmark] |
Techno-economic analysis on modularisation and complex project management

Professor Giorgio Locatelli PhD FHEA
Full Professor of Complex Projects Business

School of Management – Politecnico di Milano
Senior Editor – Project Management Journal

Giorgio.Locatelli@polimi.it

Download all my important papers in a click http://bit.ly/2yyVotE
NEA Workshop on Advanced Construction and Manufacturing Methodologies for New Nuclear Build

Session 3: Improving constructability with small, modular and innovative nuclear designs

Rethinking Nuclear Deployment for Zero-Carbon Energy at Scale – A Vision for 2050

Andrew Sowder, Sr. Technical Executive
Advanced Nuclear Technology Program

March 17, 2022
Rethinking Deployment Scenarios for Advanced Reactors

Scalable Nuclear Energy for Zero-Carbon Synthetic Fuels and Products

Technical Brief — Advanced Nuclear Technology

https://www.epri.com/research/products/000000003002018348
Rethinking Nuclear Deployment: Key Study Tenets

- Move to fabricating entire standardized plant/platform in a fully-engineered environment – *a la* large modern shipyards.

- Deliver plant/platform to point of use via marine conveyance.

- Produce storable, conveyable, drop-in substitutes for fossil fuels in hard-to-decarbonize sectors via floating production, storage, offloading (FPSO) model.

- Supply zero-carbon synthetic fuels and products to market at competitive prices.

One of four scenarios: competitive carbon neutral ammonia for commercial shipping

- conveys 90% of global trade
- difficult to decarbonize
Is this feasible?
What could transformation of nuclear construction do to costs?

$6800/kWe
Reference GWe-class LWR
(Source: EON/EIRP, 2018)

72% Net Cost Reduction =
$1900/kWe
Equivalent plant via serial production
Indicative economics look promising.

<table>
<thead>
<tr>
<th>Product</th>
<th>Benchmark Price (without carbon abatement)</th>
<th>Levelized Zero-Carbon Product Cost</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet A (Kerosene-Type Jet Fuel)</td>
<td>94</td>
<td>82</td>
<td>USD/bbl</td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>200</td>
<td>230 - 290</td>
<td>USD/tonne</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.7 – 1.6</td>
<td>0.9</td>
<td>USD/kg</td>
</tr>
<tr>
<td>Electricity</td>
<td>68.3 – 185ᵃ</td>
<td>43</td>
<td>USD/MWh</td>
</tr>
<tr>
<td></td>
<td>102 – 334ᵇ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desalinated Water</td>
<td>0.64 – 2.86</td>
<td>1.3</td>
<td>USD/m³</td>
</tr>
</tbody>
</table>

ᵃ OECD industrial electricity price range for 2019
ᵇ OECD residential electricity price range for 2019
Together...Shaping the Future of Energy®
The UK Government’s ‘Platform’ approach to industrialised construction

Jaimie Johnston MBE
Director, Head of Global Systems
Bryden Wood

Platform Design Lead,
Construction Innovation Hub
Common challenges across construction

- Safety (often while delivering assets on complex live sites);
- Sustainability (in the broadest sense – environmental, economic, social...);
- Future flexibility (with fast evolving processes / technology);
- Cost (capex and whole life);
- Speed of delivery (on site);
- Ability to delay capital spend to the ‘last responsible moment’;
- Innovation in design and delivery (leveraging wider industry shift);
- What does the world look like post COVID-19?
Click on icons for link

Autumn Statement
‘The government will use its purchasing power to drive adoption of modern methods of construction...’

Construction Innovation Hub awarded £72 million to drive innovation + technological advances in the UK construction and infrastructure sectors.

Platforms: Bridging the gap between construction + manufacturing
Proposal for a New Approach to Building
‘We will use a set of digitally designed components across multiple types of built asset... a single component could be used as part of a school, hospital, prison building or station.’

Platform Design Programme ‘Defining the Need’
‘A mandated approach: in the next two years the government will set out a requirement for platform approaches to be adopted.’

The Construction Playbook
‘We will procure projects based on product platforms comprising of standardised and interoperable components and assemblies, the requirements for which will be part of a digital component catalogue.’
‘Platforms identify features of assets that could be shared and then harmonise those features’

- This approach provides the opportunity to create common ‘kits of parts’.
- Harmonised cross-sector demand enables their manufacture in high volume, with configuration allowing delivery of multiple asset types across sectors (e.g., schools, apartments, healthcare facilities).

Transforming Infrastructure Performance: Roadmap to 2030, IPA, 2021
Transforming Infrastructure Performance

Addressing the need for social infrastructure using a platform approach
Automation through the use of configurators enables a greater focus on value led elements of the design process, and assembly would employ digital workflows, machinery and robotics.

Platforms enable productivity and efficiency akin to the manufacturing industry, creating productive capacity and the creation of inclusive stable manufacturing employment.

Factory conditions in construction - delivery via repeatable productive activities enables predictability and automation to improve health and safety, reduce waste, increase productivity and speed of assembly, and address the skills gap.

Feedback loops - platforms can enable data to inform the whole ecosystem, from rules to product catalogue. Digital models and twins would enable assurance and feedback throughout delivery and use.

Digital configurators

- Some of the greatest design stage benefits of platforms will be realised through the use of applications referred to here as ‘configurators’.
- These configurators marry the rules with component data in the digital catalogue to automate the generation of design, from a schedule of rooms to a digital asset model and could ultimately provide outputs such as a full cost breakdown or a list of approved suppliers.
- Configurators can result in much faster design and the consideration of a greater range of permutations.
- They can enable the involvement of local communities and professionals at earlier stages, and they can support the quality assurance process that enables the tracing and recording of critical data from design through to operation.
Configurators

- REM: Roads, Highways England
- Living Lab: The Tube, TfL
- PRiSM: Homes, Mayor of London
- P2P: Homes, Prism to Platforms
- Data centres
- Robotics, Open source
- RAID: Rail, Network Rail
- SPACED: Cycling, DfT
- SEISMIC: Schools, DfE
- PAC: Pharmaceutical, GSK
- FASTtruss: Industrial, Innovate UK

Bryden Wood
https://www.brydenwood.co.uk/projects/rapid-engineering-model-rem/s92984/
A Platform for Repurposing Coal

- Repurpose 2TWe coal fleet
- De-risk clean energy transition
- Social, economic and environmental justice benefits
Current deployment model is too slow and cannot scale

The Need

2,000 GWe sites/year

The Problems
Costly, slow, risky
Few customers want it
Few suppliers can provide it
What if we took a design approach to systematically address all these challenges?

**The Need**

- 2,000 GWe sites/year

**The Problems**

- Costly, slow, risky
- Few customers want it
- Few suppliers can provide it
What would this new system need to do?

MORE SUPPLIERS

CHEAPER FASTER LESS RISK

MORE CUSTOMERS

$4Tn Advanced Heat-Source (AHS) Market

Global Market of Productised Building Systems

2TWe 2050
Coordinated Platform Approach

INTERACTIONS

PROJECT PROCESSES

BUILT SYSTEMS

MORE SUPPLIERS

CHEAPER FASTER LESS RISK

MORE CUSTOMERS
Built Systems Must Enable Scale and Speed

- Coal plant repurposed
- Efficiently regulated systems & buildings
- Standardised AHS systems
- Standardised building design & components
- Seismic isolation
- Heat-transfer & storage system
Reduce the scope of nuclear systems

Coal plant, grid & many jobs retained

HTSS

AHS (Gen IV Advanced Modular Reactor)

ADVANCED HEAT SOURCE
Reduce the scope of nuclear systems

Coal plant, grid & many jobs retained

HTSS

AHS (Gen IV Advanced Modular Reactor)

HTTS

Coal plant, grid & many jobs retained

AHS
Seismic isolation to enable standardized design

Range of seismic isolation systems means site can be treated as standardised
Standardised Building System - ’Kit of Parts’ designed for manufacturing and assembly

Accommodates AHS variability:

- Standard section
- Variable length

More choice for customers and technology decision postponed
Standardized support systems, designed for manufacturing and assembly

- Standardised AHS Modules
- Standardised Buildings
- Standardised Interfaces
The physical build system enables standardisation while addressing a wide variety of requirements.

- Different Energy and heat requirements
- Different Advanced heat-source (AHS) technologies
- Different Site layouts and local requirements
Project Processes Must Enable Scale and Speed

Screening: Is project viable?

Project Definition: What is the best project?

Pre-Construction: Who will do key activities & how?

Construction: How to stay on schedule & budget?

Commissioned: How to profitably supply end-users?
Customers Assess Viability with Cloud-Based Tool
Automated Design – Components Designed for Manufacture

- Screening
- Project Definition
- Pre-Construction

- Reference design
- Project-specific design
- Standard info for suppliers
- Standard info for regulators
Manufactured Components Assembled On-Site

Screening

Project Definition

Pre-Construction

Construction

Reference design

Project-specific design

Standard info for suppliers

Standard info for regulators
Heat can be Delivered as a Service

Screening

Project Definition

Pre-Construction

Construction

Operation

Reference design

Project-specific design

Standard info for suppliers

Standard info for regulators

Wide nuclear materials / waste supply-chain
Mass Deployment

PROJECT DEVELOPMENT

ADVANCED HEAT SOURCE DEVELOPMENT
Interactions Must Be Redesigned to Enable Scale and Speed

Suppliers

AHS vendors

Assemblers

Designers

Regulators

Nuclear service providers

Investors

Customers
Reduce interaction cost and increase scale of opportunity
Enable supplier/stakeholder access to expanding project pipeline
Mass Deployment

100’s of Projects

Multiple Heat Sources Products

2028
This Platform Can Repurpose 2TWe of Coal

- 100’s of new suppliers
- INTERACTIONS
- PROJECT PROCESSES
- BUILT SYSTEMS
- MORE SUPPLIERS
- CHEAPER
- FASTER
- LESS RISK
- MORE CUSTOMERS
- $4Tn Advanced Heat-Source (AHS) Market
- 1,000’s of Projects
- Global Market of Productised Building Systems
- Less than $2,000/ kW
- 2TWe
- 2050

Global Market of Productised Building Systems

Terra Praxis

Bryden Wood