Life Cycle Analysis – a 7DSM Future

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A Challenging Future

- Simple → Complex
- Static → Dynamic
- Certain → Uncertain
- Capital Efficiency → Life Cycle Effectiveness
- Build for decades → Build for generations
- The Bottom Line → Triple Bottom Line
- Safety Focus → Hazard Avoided
- Business Case → Scenario Based Resiliency
7D\textsuperscript{SM} – The Future in Seven Dimension
These represent the common spatial dimensions that we are most familiar with
- Spatially defining; discrete; finite; static, **certain**
- Component linked
In a 7D\textsuperscript{SM} future these dimensions are more complex

- We must reflect positional uncertainty (tolerances)
  - If we built perfectly there would be no need for as-builts
  - Do “fuzzy” locations lead us to “fuzzy analysis”?
Fuzzy Spatial Positioning
In a 7D<sup>SM</sup> future these dimensions are more complex

- Vendor supplied products may vary between manufacturing locations; model revisions; sub-component suppliers – details vary and details matter
- Components remain important but “assemblies” rise due to growing use of fabrication and modularization
The Rise of Assemblies
This rise of assemblies changes spatial context
- Relative position in the facility, but also
- Relative position in the assembly

Assembly to assembly “connections” augment spatial understanding associated previously with component to component connections

Assemblies may arise from:
- Bespoke design (today)
- Pattern recognition technology applied to library of prior facilities (tomorrow?)
- Standard catalogue designs (7D<sub>SM</sub> future)
Assembly Level Attributes

- Assembly level attributes incorporated
  - Supply chain interface points
    - Vendor shop
    - Logistical chain
  - Sequence of construction (precursors)
    - Labor, equipment, materials requirements
    - Training and other prerequisite activities
    - Preparatory works
    - Means and methods plan
  - Physical interface points
  - Assembly level inspection
  - Pre-commissioning requirements
  - Transient hazards
Notion of Assemblies is a Key Change
Today’s 4th dimension is primarily associated with the initial delivery of a capital asset

- We show design progress; construction progress; commissioning progress (more possibility than reality)
- We link “physical” progress to project progress
  - Management systems and BIM systems increasingly being linked
The 4th dimension in a 7D future is a cradle to grave (or longer) timeline
- Influences our optimization points (first instance vs life cycle)
Dimension 4 (Time)

- The 4\textsuperscript{th} dimension in a 7D\textsuperscript{SM} future is a cradle to grave (or longer) timeline
  - Opens the door to:
    - Dynamic, changeable futures
    - Designing, building, operating for renewal and replacement
    - Scenario based futures
5D BIM today is really 4½ D BIM!
- 5\textsuperscript{th} dimension is essentially a set of attributes associated with first delivery of an asset
  - Component level properties such as materials of construction; pressure rating; temperature rating; direct cost and so forth
  - Most systems influenced by intended use and as such only address “½ “ of this dimension as currently conceived

<table>
<thead>
<tr>
<th>Name</th>
<th>Cost</th>
<th>Hazard Rating</th>
<th>Quality Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifier</td>
<td>Warranty Duration</td>
<td>Cooling</td>
<td>Date Manufactured</td>
</tr>
<tr>
<td>Vendor</td>
<td>Material</td>
<td>Heating</td>
<td>Date Shipped</td>
</tr>
<tr>
<td>Model</td>
<td>Weld</td>
<td>Cost</td>
<td>Port of Embarkation</td>
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<tr>
<td>Elevation</td>
<td>Bolt Size</td>
<td>Logistics</td>
<td>Date at Arrival Port</td>
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<tr>
<td>Weight</td>
<td>Power</td>
<td>Tax #</td>
<td>Port of Arrival</td>
</tr>
<tr>
<td>Temperature Rating</td>
<td>Grid x</td>
<td>Spec #</td>
<td>Date Received at Site</td>
</tr>
<tr>
<td></td>
<td>Grid y</td>
<td>PO #</td>
<td>Date Installed</td>
</tr>
<tr>
<td></td>
<td>Grid z</td>
<td>Inspector</td>
<td>Date Commissioned</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inspection date</td>
<td>Date of 1\textsuperscript{st} Maintenance</td>
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</tbody>
</table>
5th dimension in a 7D future is significantly different

- A “complete” dimension based on today’s frameworks
  - Safety, training, tools, indirect costs, risks
- Includes uncertainty
- Assembly level attributes incorporated
- Includes all benefits and impacts
- Triple bottom line considerations
  - Environmental and Social bottom lines

\[ \sigma_T = \sqrt{\sum \sigma_e^2} \]
A Complete Dimension

◆ A “complete” dimension based on today’s frameworks

◆ Added considerations include (but not limited to)
  – Hazard identification at component and assembly level considering anticipated erection and installation means and methods
    • Means and methods related attributes significantly enhance construction planning and safe delivery of the initial asset
    • Safety equipment, training and certifications required are treated as both component and assembly attributes and may vary from the fabrication yard to the final site and link to means and methods attributes as well as spatial relationships at time of activity
A Complete Dimension

- Added considerations include (continued)
  - Training and tools required by supervisors, craft labor, safety and other inspectors
  - Indirect costs calculation and analysis beyond just factoring
    - Opens the door to attack indirect costs in a more systematic way
    - Risks associated with the design, construction and commissioning carry forward and link to a dynamic risk register
Benefits Included

- **Benefits**
  - Linkage to volume purchasing agreements, rebates
  - Tax advantaged purchasing
    - Purchasing and payment jurisdictions
    - Country of manufacture
    - Final site
  - Available tax credits and requirements for preservation and actualization
  - Favorable impacts on indirects including logistical chain; construction camps; labor market availability and premium labor costs
  - Avoided costs
  - Favorable cash flows/purchasing agreements
  - Warranty and service features
Environmental & Social Bottom Line

- Environmental Bottom Line impacts associated with first delivery
  - Embedded carbon
  - Water footprint
  - Waste fractions

- Social Bottom Line impacts with first delivery
  - Local or targeted community sourcing (SB/WBE/DBE)
  - Verified labor practices (wages, work conditions)
  - Job creation
  - New industry creation
  - Secondary value creation
    - Example – construction camp built as permanent housing for operating labor force and their families
  - Cultural considerations
Dimension 6 (Life Cycle Attributes)

- Life cycle defined as encompassing
  - planning → design → procurement → construction → commissioning → operations → maintenance → decommissioning → end of life

- Life cycle attributes consider
  - O&M and End-of-Life benefits and impacts
  - Triple bottom line considerations
  - Scenario based and time series values

- Transition of BIM to:
  - Asset Management System (operations as well as maintenance)
  - Business Planning System (dynamic and changing futures)
    - AND MORE
Triple Bottom Line focus highlights common drivers, systemic risks, wild cards and constraints.
True measure of a well managed asset is not just one configured to provide the lowest life cycle cost but rather the highest life cycle returns

- Serve an evolving market

Developing and implementing cost-effective strategies recognizing the long-term purpose and nature of these assets

Monitoring, maintaining and where possible enhancing asset performance.

Anticipating, mitigating and managing risks associated with asset degradation and failures
6th Dimension as Enabler

- Sharpens Asset Management focus
  - Defines the minimum level of detail for an asset (what assets to track)
  - Identify the probability and consequence of failure of an asset (asset risk)
  - Reduced materials/spare parts costs
  - Increased productivity
  - More efficient scheduling and execution of work
  - Integration of Lean principles into operational and production work processes.
  - Accurate spare parts inventory
  - Accurate equipment lists for each location
Enables robust life cycle planning
- Up front scenario planning
- Dynamic asset and business reconfiguration
  - Improved Refurbishment and Replacement (R&R) planning arising from asset knowledge greatly improves the quality of capital funding strategies

Guides BIM based Asset Management to Predictive Asset management
- Assess real time conditions and implications
- Asset O&M optimization strategies
  - Systems level view
  - Deploying the limited financial, physical and human resources of the asset owner in an efficient, effective and sustainable manner. It is about making informed tradeoffs as part of our decision making process
6th Dimension – A Function of Time

- Time series which impact an asset's value
  - Revenue
  - Life Cycle Costs (O&M and End of Life)
  - Indirect Asset Costs
  - Externalities
  - Dynamic risks embedded in each of the above
Revenue

- First Revenue Date
- Plant Availability Factor and Ramp-Up Period and Rate
- Asset Life (Duration from First Revenue during analysis period)
- Scheduled Shutdowns (Regulatory, Seasonal, Maintenance)
- Supply/Demand Balance Normalized Price (Market Size; Competitor Actions)
- Capacity or Throughput
- Byproduct Value Captured
- Tax Credits Realized
- Inflation Adjustments to Normalized Pricing (Inflation; Currency Exchange Rates)
Indirect Asset Costs

- Land use*
- Tax Regime
  - Taxable
  - Tax Credit
  - Tax Exempt
- Financing structures*

- Common factors
  - Financial factors – hyper inflation, deflation, uninsured portion of disasters (natural, manmade, or Natech)
  - Environmental factors – climate change
  - Social factors – change in user behavior, change in surrounding community behavior with respect to the facility
  - Correlated risks
Land Use

- Land use impacts include:
  - Land use (the plant site)
    - Emissions to air
    - Emissions to water
    - Emissions to soils.
  - Land use change
    - Mineral and fossil fuel use
    - Land transformation
    - Land occupation
    - Soil erosion, compaction and sealing
  - Often ignored in LCA but taking on increasing importance.

- ISO 14040 – 14043, largely developed from industrial perspective and do not mention land use as an impact category

- Land use considers following factors:
  - Concurrent availability – site is available on some basis for use by other facilities. Important when evaluating large program or asset portfolio design. May be either:
    - Constrained or limited
    - Unconstrained or unlimited (except with respect to limiting attributes of the site independent of the facility’s presence at the site)
  - Concurrent unavailability – the site is not available for other current use due to the facility’s presence at the site.
  - Loss of optionality – site use, post facility closure, is limited because of the prior presence of the facility
  - Permanent unavailability – use of the site, post closure, is not reasonably possible
Financing structures considered in a life cycle analysis influenced by many factors including:
- asset characterization
- governing financial metrics (ROE, ROI, IRR, ROA)
- asset lifetimes before refurbishment or replacement
- refinance periods
- construction and operations cash flows
- residual value of asset

<table>
<thead>
<tr>
<th>Financing Structures</th>
<th>Equity</th>
<th>Debt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partnership Interest</td>
<td>Capital Contribution</td>
<td>Return of capital; ordinary income</td>
</tr>
<tr>
<td>Stock Ownership</td>
<td>Investment</td>
<td>Return on equity; capital gain</td>
</tr>
<tr>
<td>Senior Debt</td>
<td>Bank Debt</td>
<td>Principal; taxable interest income</td>
</tr>
<tr>
<td>Taxable Bond</td>
<td></td>
<td>Principal; taxable interest income</td>
</tr>
<tr>
<td>Tax Exempt Bond</td>
<td></td>
<td>Principal; tax exempt income</td>
</tr>
<tr>
<td>Subordinated Debt</td>
<td>Same forms as Senior Debt</td>
<td>Junior credit instrument</td>
</tr>
</tbody>
</table>
Externalities

- Intangibles such as brand value
- Complexity
- Assumption migration associated with longer time frames (*dynamic risks*)
- Stakeholder trust
- Susceptibility to “Black Swan” type risks
- “Strategic speed”
  - capture greater market share through quick response or first mover advantages
  - “Time to market” is especially important in IP driven facility needs where patent expiration effectively defines the most valuable portion of the life-cycle.
- Regulatory taxes and subsidies

- Potential “Black Swan” factors to be considered in life cycle analysis include:
  - Financial factors – hyper inflation, deflation, uninsured portion of disasters (natural, manmade, or Natech)
  - Environmental factors – climate change
  - Social factors – change in user behavior, change in surrounding community behavior with respect to the facility
  - Correlated risks
Dynamic Risks

- Today, we average risk across the entire duration of a project, but in long lived construction programs, sometimes approaching 20 or more years, this may not be appropriate.

- Risk parameters with defined means and variances today can change significantly over the life of a program, creating different risk hierarchies and consequentially different risk management strategies and emphasis.

- Even more significant as we consider the extended operations and maintenance phase which we must consider in lifecycle analysis.

- **Intra-Organizational**
  - Changed funding availability/cost
  - Changes to assumptions
  - Modified review/approval processes
  - Disruptive economic factors

- **Inter-Organizational**
  - Emergence of new risk drivers
  - Increase in constraint coupling
  - Cumulative impact of changes

- **Extra-Organizational**
  - Litigation
  - Change of law/regulation
  - New labor or material constraints
  - Political actions
  - Social actions

- **Phasing**
  - Unanticipated step changes as program moves phase to phase
7th Dimension reflects the inherent capability of our 6D system to adopt and respond in ways it was not explicitly intended to do when first conceived.

We use words like these to describe these system level properties:
- Flexibility
- Adaptability
- Responsiveness

... or F-A-R ness

We also refer to these system level properties with words like RESILIENCE.
7th Dimension is Dynamic

- $7D^{SM}$ “states” are function of:
  - How designed and built
  - Equipment and materials choices we made
  - How we operated and maintained
  - Events we have experienced
  - Knowledge gained and captured
  - Externalities and how they have changed and are changing
  - Insights we have embedded into our asset decisions
Focus on Life Cycle Analysis is an Imperative

Life Cycle Analysis is a comprehensive cradle to grave evaluation of capital asset performance (benefits and impacts) that incorporates risk and uncertainty and considers all three of the bottom lines of the Triple Bottom Line.
7D℠ Future

- 7D℠ future expands and “completes” the current “dimensions” used in the industry as well as adding a couple new ones.

- Today’s frameworks fall short of tomorrow’s needs
  - Must include
    - Risks, uncertainties and multiple possible futures (scenarios)
    - Holistic consideration of the Triple Bottom Line

- Today’s BIM and other tools represent an important first step but a much longer journey is in store
7D<sub>SM</sub> Future is Essential for Optioneering

- Optioneering – more robust scenario analysis at earliest stages of asset “conception”
  - Solution sets will be multi-dimensional Pareto optimal fronts

- 7<sup>th</sup> Dimension will allow stress testing for Resilience

\[
\text{LCA}_{\text{NPV(Confidence)}} = \sum_{t=1}^{P} \left[ \left( \sum_{n=1}^{\text{All}} C(n(\sigma, \text{PDF}), t, q, \text{Scenario}_N, \text{Config}_x, D#(t, \text{Scenario}_N), \text{Limit#}(t, D, \text{Scenario}_N)) \times q \right) - \left( \sum_{n=1}^{\text{All}} R(n(\sigma, \text{PDF}), t, q, \text{Scenario}_N, \text{Config}_x, D#(t, \text{Scenario}_N), \text{Limit#}(t, D, \text{Scenario}_N)) \times q \right) \right]
\]
**7D℠ Enables Life Cycle Optimization**

- Brings a broadened perspective to traditional life cycle methodologies:
  - Revenue and its timing are incorporated (Scenarios)
  - Risk and uncertainty are specifically addressed in modeling and subsequent optimization (Positional and Dynamic)
  - Benefits, uncertainties and impacts are considered not only from an economic bottom line perspective but similarly from an environmental and social bottom line perspective (Holistic)

- Framework provides a basis for periodic reconfirmation of adopted strategies or reconfiguration guidance if changed future states so dictate

- It is intended not just as an up-front option assessment or validation tool but a dynamic life cycle based management tool essential in managing today’s capital asset portfolios.
Role of National Institute of Building Sciences in Achieving a 7D<sup>SM</sup> Future

- **NIBS Focus** - identification and resolution of problems and potential problems that hamper the construction of safe, affordable structures for housing, commerce and industry

- **NIBS Mission** - supporting advances in building sciences and technologies for the purpose of improving the performance of our nation's buildings while reducing waste and conserving energy and resources

- **NIBS mission requires a 7D<sup>SM</sup> future**