Applied Research Briefing on KPI and Smart Cities

Calvin Kam PhD, AIA, PE, LEED AP
Adjunct Professor
Center for Integrated Facility Engineering, Stanford University

Founder & CEO
Strategic Building Innovation · bimSCORE (USA, Singapore, Hong Kong)

Calvin.Kam@SBI.International
1. Develop a two-fold meta-evaluation framework (model) with AEC perspective.
AEC Industry is not isolated anymore!

Past | Present | Future?

AEC Industry is not isolated anymore!

Past

Present

Future?

Being “Smart”

Being “Smart”

Being “Smart”

Being “Smart”

Being “Smart”

Teicholz Productivity Curve.
Performance Dashboard for Innovative & Industrialized Construction

161 projects from the CIFE VDC Certificate Program:

- **811** total performance indicators
- **535** unique performance indicators

### Schedule

1. **19** % conformance to plan
2. **3** Planned percent complete
3. **2** # activities done according to production plan
4. **1** % action on time
5. **1** Schedule completion
Shortlisted Key Performance Indicators

<table>
<thead>
<tr>
<th>Indicators (Formulae)</th>
<th>Units</th>
<th>Category</th>
<th>CIFE Categories</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of accidents/work hours</td>
<td>#:/part</td>
<td>Quality</td>
<td>Usable, Buildable</td>
<td>Owners</td>
</tr>
<tr>
<td>Clashes unresolved/Clashes detected</td>
<td>N/A</td>
<td>Quality</td>
<td>Buildable, Operable</td>
<td>Contractors and Designers</td>
</tr>
<tr>
<td>Cost of Punchlist work/Cost of work performed</td>
<td>N/A</td>
<td>Quality</td>
<td>Buildable, Usable</td>
<td>Contractors</td>
</tr>
<tr>
<td>Issues reported/Maintenance tests</td>
<td>N/A</td>
<td>Quality</td>
<td>Usable, Operable</td>
<td>O&amp;M</td>
</tr>
<tr>
<td>Rework Hours/Total work hours</td>
<td>N/A</td>
<td>Quality</td>
<td>Sustainable, Operable</td>
<td>Contractors</td>
</tr>
<tr>
<td>Remaining inspections / total inspections per area</td>
<td>N/A</td>
<td>Quality</td>
<td>Operable, Usable</td>
<td>Owners</td>
</tr>
<tr>
<td>Outstanding RFIs/Total RFIs</td>
<td>N/A</td>
<td>Quality</td>
<td>Usable, Buildable</td>
<td>Contractors and Designers</td>
</tr>
<tr>
<td>Cost of change orders/Cost of work performed</td>
<td>N/A</td>
<td>Quality</td>
<td>Sustainable, Buildable</td>
<td>Owners</td>
</tr>
<tr>
<td>Usage/Baseline Usage per year</td>
<td>%</td>
<td>Efficiency</td>
<td>Sustainable, Operable</td>
<td>Owners and Operators</td>
</tr>
<tr>
<td>Issues unresolved/Issues Schedule per meeting</td>
<td>%</td>
<td>Efficiency</td>
<td>Operable</td>
<td>Contractors</td>
</tr>
<tr>
<td>Quantity installed / Quantity planned per hour</td>
<td>%</td>
<td>Efficiency</td>
<td>Buildable</td>
<td>Contractors</td>
</tr>
<tr>
<td>Activities completed/Planned activities per week</td>
<td>%</td>
<td>Efficiency</td>
<td>Buildable</td>
<td>Owners</td>
</tr>
<tr>
<td>Earned value / planned value per milestone</td>
<td>%</td>
<td>Efficiency</td>
<td>Buildable</td>
<td>Owners</td>
</tr>
<tr>
<td>Design milestones met/ Milestones planned per month</td>
<td>%</td>
<td>Efficiency</td>
<td>Buildable</td>
<td>Designers</td>
</tr>
<tr>
<td>Issues resolved/Issues reported per month</td>
<td>%</td>
<td>Efficiency</td>
<td>Operable, Usable</td>
<td>O&amp;M</td>
</tr>
<tr>
<td>Owner Decision Changes/Owner Decisions</td>
<td>%</td>
<td>Reliability</td>
<td>Buildable, Operable</td>
<td>Contractors and Designers</td>
</tr>
</tbody>
</table>
With an interactive Dashboard, projects can find the optimal KPIs subject to their available resources.

1. Standardized indicators 
2. ‘KEY’ indicators

- Compare and improve
- Maximize information gain

CIFE Performance Dashboard

Candidates
- RFI
- change order
- PPC
- # changes
- Comp. Score
- # clashes

KPI set: \( n = 3 \) indicators
Understanding different VDC Implementations and their ROIs: a data-driven approach

143 AEC Project Studies (as of 2015)
- 16 Countries
- 11 Facility Types
- 7 Project Phases

51 VDC Features
- e.g. documentation of VDC objectives
- e.g. % stakeholders involved in VDC
A Scientific Approach to VDC Implementation

1 Score

4 Areas

10 Divisions

50+ Measures

Scorecard Framework

PLANNING

OBJECTIVES

FORMALIZATION

STAKEHOLDER BENEFIT

STANDARDS

BIM / VDC INTENT

GUIDELINE DEVELOPMENT

PREPARATION

BEP / VDC CONTENT

OBJECTIVE CATEGORIES

ORGANIZATION

MANAGEMENT OBJECTIVES

SOFTWARE AVAILABILITY

PROCESS

IMPLEMENTATION BUDGET

APPLICATION

BIM / VDC PROCESS ROLES

APPLICATION

ORGANIZATION

PROCESS

APPLICATION

APPLICATION

PROCESS

APPLICATION

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS

APPLICATION

PROCESS
VDC Scorecard: Formulation, Application, and Validation

Calvin Kam, Ph.D., P.E.; Min Ho Song; and Devini Senaratna

Abstract:
The authors have developed the virtual design and construction (VDC) Scorecard to encompass two characteristics, in which existing VDC assessment frameworks are weak: a holistic framework and adaptive scoring criteria. First, the Scorecard framework was developed to be holistic by including the vocabularies for measuring how well VDC is supporting its objectives. To make the framework holistic, the authors first developed the higher-level structure of the framework based on literature with holistic VDC themes and then refined the lower-level structure of the framework with nested interviews. Second, the scoring criteria were developed to be adaptive to evolving industry norms, which cannot be ignored in a field that is driven by rapid evolution of technology. To make the scoring criteria adaptive, the authors used iterative sampling and comparison methods for establishing the criteria. The resulting assessment framework is able to quantitatively and statistically represent the relationships between VDC and its objectives, providing a holistic assessment framework. This research also presents a plausible methodology for developing scoring criteria that gradually evolves with the industry norms, making the scoring criteria adaptive.
## Global Benchmarking

<table>
<thead>
<tr>
<th>Planning</th>
<th>Conventional</th>
<th>Typical</th>
<th>Advanced</th>
<th>Best</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>lacks overall vision and measurable objectives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Adoption**
- **Technology**
- **Performance**
Planning – Government Standard and BIM requirement

- Lower costs: 33%
- Faster delivery: 50%
- Lower emissions: 50%
- Improvement in exports: 50%

The global construction market is forecast to grow by over 70% by 2025.

Napkin sketch by Mr. Mark Bew, Chairman of UK BIM Task Group
Dear Readers,

Welcome to Build Smart, the first issue of BCA's dedicated magazine on all things relating to construction productivity.

Indeed, while it is not a new idea, “productivity” is the new buzzword that is at the top of our economic agenda these days. Why the renewed interest?

Singapore has been experiencing good economic growth in the last few decades, largely based on manpower capacity. In order to achieve sustained and inclusive growth, Singapore needs to grow based on skills, innovation and productivity. The government is targeting 2% to 3% productivity growth per year for the next decade. The construction sector is among the twelve sectors identified with productivity-based growth opportunities to help sustain our economy. Hence, this presents an opportune time for change.

Source: BCA
<table>
<thead>
<tr>
<th>Global Benchmarking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning</strong></td>
</tr>
<tr>
<td>Conventional:</td>
</tr>
<tr>
<td>- lacks overall vision and measurable objectives</td>
</tr>
<tr>
<td>Typical:</td>
</tr>
<tr>
<td>Advanced:</td>
</tr>
<tr>
<td>Best:</td>
</tr>
<tr>
<td>Innovation:</td>
</tr>
<tr>
<td><strong>Adoption</strong></td>
</tr>
<tr>
<td>- engaging the whole ecosystem</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
</tr>
<tr>
<td><strong>Performance</strong></td>
</tr>
</tbody>
</table>
Common BIM Requirements 2012

Common BIM Requirement 2012, COBIM, is based on the BIM Requirements published in. The update project was funded by Senate Properties in addition to owners and developers, construction companies and software vendors. Built21 also in the financing of the project. As a result, the updated Series 1-9 and n FIN in Finnish on March 27th 2012.

Series 1: General part
Series 2: Modeling of the starting situation
Series 3: Architectural design
Series 4: MEP design
Series 5: Structural design
Series 6: Quality assurance
Series 7: Quantity take-off
Series 8: Use of models for visualization
Series 9: Use of models in MEP analyses
Series 10: Energy analysis
Series 11: Management of a BIM project
Series 12: Use of models in facility management
Series 13: Use of models in construction
## Global Benchmarking

<table>
<thead>
<tr>
<th>Planning</th>
<th>Conventional</th>
<th>Typical</th>
<th>Advanced</th>
<th>Best</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lacks overall vision and measurable objectives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption</td>
<td>engaging the whole ecosystem</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>from representation to optimization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
National 3D-4D-BIM Program

- 2003: Program founded
- 2006: First project requirements
  - Spatial program validation for final concepts
- 2014: Updated project requirements
  - Open-standard spatial and facility management data throughout the project & facility lifecycle
GSA’s Central Facility Repository (CFR): An Overview
Efficiencies Created

- **Business Case**: Location of Current Conditions for Emergency Purposes
  - Prior to CFR: Average 12 Hours
  - After CFR: Accessible in 33 seconds

- **Business Case**: Locating Legacy Documentation for Project Inception
  - Prior to CFR: 2 weeks
  - After CFR: Minutes

- **Business Case**: Transfer Large Files
  - Prior to CFR: .069 Mb/s (500 Mb in 2 hours)
  - After CFR: 1.3 Mb/s
## Global Benchmarking

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Typical</th>
<th>Advanced</th>
<th>Best</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning</strong></td>
<td>lacks overall vision and measurable objectives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Adoption</strong></td>
<td>engaging the whole ecosystem</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>from representation to optimization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td>positive return on investments?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Conventional
- Typical
- Advanced
- Best
- Innovation
An Example of HDB EOI - A1 Concept Design Submission Panel
(1st EOI of 2000 DU, Time 3 weeks, 11 Staff 418 Man-Hr)
Module D (28 Mar 2016)
### Metric Comparison of 2 EOI projects carried out by AVPL in Aug & Oct 2015

<table>
<thead>
<tr>
<th>EOI</th>
<th>Project Size (DU)</th>
<th>EOI Duration (week)</th>
<th>Staff Involved</th>
<th>Man-Hr (Hr)</th>
<th>Man-Hr Cost ($)</th>
<th>Man-Hr Cost/ Week ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2000</td>
<td>3</td>
<td>11</td>
<td>418</td>
<td>19,095</td>
<td>6,365</td>
</tr>
<tr>
<td>2nd</td>
<td>2000</td>
<td>3</td>
<td>8</td>
<td>288</td>
<td>13,190</td>
<td>4,396</td>
</tr>
<tr>
<td>Saving</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>130</td>
<td>5,905</td>
<td>1,969</td>
</tr>
<tr>
<td>Saving (%)</td>
<td>-</td>
<td>-</td>
<td>27%</td>
<td>31%</td>
<td>31%</td>
<td>31%</td>
</tr>
</tbody>
</table>

### Metric of 2nd EOI project qualified for Stage 2 Tender from 16 Dec 2015 & 3 Feb

<table>
<thead>
<tr>
<th>EOI</th>
<th>Project Size (DU)</th>
<th>EOI Duration (week)</th>
<th>16</th>
<th>Man-Hr (Hr)</th>
<th>Man-Hr Cost ($)</th>
<th>Man-Hr Cost/ Week ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 2 Tender of 2nd EOI</td>
<td>2000</td>
<td>7</td>
<td>9</td>
<td>764</td>
<td>37,040</td>
<td>5,291</td>
</tr>
</tbody>
</table>

**OBSERVATION:**
1. Level of design and detail required are different for EOI and Stage 2 Tender. Stage 2 design details are much higher.
2. Man-Hour Cost/Week for 2nd EOI at Stage 2 Tender stage maintained at $5,291 (lower than 1st EOI but higher than 2nd EOI) proves that effective application of VDC processes by the design team for preparation of design and documentation for competitive tender can improve productivity and save cost while maintaining design quality at high level. The Man-Hour Cost/Week at $5,291 is considered satisfactory and acceptable (all staff do not charge overtime pay for tender project).
From Various Economies --
- BIM Start-up Guide
- Guide to Metrics and Green Building

To World-class Data Analytics platform --
- Global BIM Value Analysis Report

To Enterprise Level --
- Enterprise Workflow Evaluation and Optimization

To Specific Project Level --
- Project Evaluation and Advisory

21 economies
- 8 countries
- over 10s and 10s of enterprises
- over 100s of project
Understanding different VDC Implementations and their ROIs: a data-driven approach

3 Project Outcomes

- ROI of VDC Implementation
- Achievement of qualitative objectives
- Achievement of quantitative objectives
Prediction model with multilayer Artificial Neural Network (ANN)

ANNs with 3-5 layers are trained
Number of units in each layer vary from 5 to 100
Input layer has L1 regularization:
   L1 favors selection of important features
   Source: http://cs.nyu.edu/~rostami/presentations/L1_vs_L2.pdf
Hidden layers have L2 regularization:
   L2 produces slightly better prediction in general
Tested with 10-fold cross-validation:

**79.2% categorization accuracy for ROI**
- layer 2: 60 units; layer 3: 30 units; max # of iterations: 1000
- L1 penalty: 2; L2 penalty: 0.1

**70.0% categorization accuracy for qualitative objective achievement**
- layer 2 = 50 units, layer 3 = 20 units; max # of iterations: 1000
- L1 penalty: 0.01; L2 penalty: 0.04

**70.7% categorization accuracy for quantitative objective achievement**
- layer 2: 50 units; layer 3: 20 units; max # of iterations: 1000
- L1 penalty: 0.5; L2 penalty: 0.1
Applied Research Briefing on KPI and Smart Cities

Calvin Kam PhD, AIA, PE, LEED AP
Adjunct Professor
Center for Integrated Facility Engineering, Stanford University
calvin.kam@stanford.edu

Founder & CEO
Strategic Building Innovation · bimSCORE (USA, Singapore, Hong Kong)
Calvin.Kam@SBI.International