The Vision for a Redefined Global Infrastructure Sector

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<table>
<thead>
<tr>
<th>Year Range</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988-2000</td>
<td>BIM</td>
</tr>
<tr>
<td>2000-2010</td>
<td>VDC</td>
</tr>
<tr>
<td>2010+</td>
<td>Optimizing Facility Performance</td>
</tr>
</tbody>
</table>
Prepare your organization for the future

Strategy Diamond Framework

The value added per workhour has remained flat in the last 50 years.

Source: Paul Teicholz, Stanford University
... make that 100 years

Figure courtesy of Todd Zabelle, SPS

Source: "Productivity Tends in the United States" (1909 = 100)
Vision
A future I would like to make happen

• Every workhour
• builds the right product
• safely and productively

Definition of Vision by Robert Burgelman, GSB, Stanford
Creating Customer Value: Tesla Gigafactory, Sparks, Nevada, 2016 - 2017

- 5 Buildings
- 3.5 million Square Feet
- 32,000 tons of structural steel
- 2,500 tons of rebar

- Gigafactory top out on November 7, 2016
- All steel and rebar shop drawings from GPLA HD BIM
- 7 months from first phone call

September 15, 2016 Building D’ Steel Complete
Creating Customer Value: Robust Structural System for Layout Flexibility

• Design objectives: speed & adaptability
• Equipment changed frequently
• Structural system must accommodate drastic design changes at any time with little or no rework
• Most members standardized based on worst-case loading scenario
• Strongbacks and Buckling Restrained Braces (BRBs) allow for **dramatic** changes in building configuration with little/no rework
Creating customer value:
Compare the two lateral bracing systems and the flexibility it offers Tesla

First building

Second set of buildings
Tesla Gigafactory: High-Definition BIM
Doing your job vs. creating a high-performance building

“Incomplete design is the source of many of the problems in our industry.”

“In light of the potential offered by the digital revolution, the traditional design process is an anachronism that we can no longer afford.”

“My job is to create a high-performance building.”

“It is not to create a model or a set of drawings.”
The main leverage is early in a project

Figure courtesy SPS. Ability to Influence Curve adapted from Gluck & Foster HBR September 1975
Usability, buildability, operability, and sustainability concerns should be considered concurrently.
Projects are a combination of supply chains

- Inventory (finished drawings / specs) to decouple engineering from fabrication enabling optimization of technical and fabrication capacity / materials utilization — may also be required by outside stakeholders.
- Inventory (finished goods) to decouple fabrication from site installation enabling optimization of capacity use including transportation.
- Work-in-process (inventory) and or time to decouple operations between trades or crews enabling optimization of capacity onsite.
- Inventory to optimize use of capacity onsite.

Figure courtesy SPS
Designing a truss today

Select structure type → Select truss topology → Select primary member sizes → Select all member sizes → Detail connections
Designing a truss today

Select structure type → Select truss topology → Select primary member sizes → Select all member sizes → Detail connections
Designing a truss with concurrent engineering

Select structure type

Select truss topology

Select primary member sizes

Select all member sizes

Detail connections

Estimate Cost, etc.
An engineer using today’s tools in isolation cannot compete with an engineer with the same tools that are connected.

<table>
<thead>
<tr>
<th></th>
<th>Engineer with today’s tools</th>
<th>Engineer with connected tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total steel weight</td>
<td>2,728 mt</td>
<td>2,292 mt</td>
</tr>
<tr>
<td>Cost savings</td>
<td></td>
<td>$4M</td>
</tr>
<tr>
<td># alternatives evaluated</td>
<td>39</td>
<td>12,800</td>
</tr>
<tr>
<td>Design time per alternative</td>
<td>4 hours</td>
<td>3 seconds</td>
</tr>
<tr>
<td>Total design time</td>
<td>~200 hrs</td>
<td>~200 hrs</td>
</tr>
</tbody>
</table>

Roof truss design for a soccer stadium in the Middle East
Work by Forest Flager and John Haymaker in collaboration with Arup Sports, London
Optimize across all cost components of a steel frame

Design Cycle Time: 8-24 weeks

<table>
<thead>
<tr>
<th></th>
<th>Original Frame</th>
<th>Value-Engineered Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Weight</td>
<td>-</td>
<td>+8%</td>
</tr>
<tr>
<td>Total Cost</td>
<td>-</td>
<td>-13%</td>
</tr>
<tr>
<td>Procurement Time</td>
<td>-</td>
<td>-20%</td>
</tr>
</tbody>
</table>

Work by Forest Flager, Pratyush Havelia, Henry Hamamji, Filippo Ranalli, Bo Peng, Thomas Trinelle in collaboration with SOM, Herrick, Autodesk
“The automated execution of processes changes everything.”
(Alan Perlis, 1961)
Creating a construction schedule today

Select construction methods → Create list of activities → Sequence activities → Assign resources → Schedule project
Creating a construction schedule today

Select construction methods → Create list of activities → Sequence activities → Assign resources → Schedule project
Creating a construction schedule with concurrent engineering
Construction Scheduling Workshop at CIFE on May 25, 26, and 28, 2018

Find the “best” formwork and sequencing option for a high-rise building project

Participants:
- Skanska Property Development, Construction, and Quality Control
- ALICE
- CIFE-Stanford Researchers
Key construction decisions: formwork and sequencing

- **Peri RCS Rail Climbing System**
  - $165,000 / month
  - Time to raise / set up formwork: 20 hours
  - Time to close formwork: 6 hours
  - Crane required to raise and close formwork

- **Peri ACS Core 400 Self-Climbing System**
  - $295,000 / month
  - Time to raise / set up formwork: 10 hours
  - Time to close formwork: 2 hours
  - No crane required to raise and close formwork
Results overview: cost and schedule

Cost breakdown (Zloty)

<table>
<thead>
<tr>
<th>RCS Rail Sequential</th>
<th>RCS Rail Parallel</th>
<th>ACS Rail Sequential</th>
<th>ACS Rail Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1M</td>
<td>2.95M</td>
<td>3.56M</td>
<td>3.57M</td>
</tr>
<tr>
<td>Slab Formwork Cost ($/m²)</td>
<td>0.81 M</td>
<td>0.68 M</td>
<td>0.65 M</td>
</tr>
<tr>
<td>Column Formwork Cost ($/m³)</td>
<td>0.54 M</td>
<td>0.54 M</td>
<td>0.51 M</td>
</tr>
<tr>
<td>Concrete Pump Cost ($/month)</td>
<td>1.05 M</td>
<td>1.04 M</td>
<td>1.77 M</td>
</tr>
<tr>
<td>Edge Formwork Cost ($/month)</td>
<td>1.05 M</td>
<td>1.04 M</td>
<td>1.77 M</td>
</tr>
<tr>
<td>Core Formwork Cost ($/month)</td>
<td>1.05 M</td>
<td>1.04 M</td>
<td>1.77 M</td>
</tr>
</tbody>
</table>

Schedule duration (calendar days)

<table>
<thead>
<tr>
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<th>ACS Rail Sequential</th>
<th>ACS Rail Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>191</td>
<td>189</td>
<td>180</td>
<td>179</td>
</tr>
</tbody>
</table>
Results Overview – Slab + Column Formwork

Find slab and column formwork required to achieve the “optimal” schedule for each option

<table>
<thead>
<tr>
<th>Option</th>
<th>Formwork Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCS Sequential</td>
<td>3,182 m²</td>
</tr>
<tr>
<td>RCS Parallel</td>
<td>2,701 m²</td>
</tr>
<tr>
<td>ACS Sequential</td>
<td>2,701 m²</td>
</tr>
<tr>
<td>ACS Parallel</td>
<td>2,701 m²</td>
</tr>
</tbody>
</table>
Key simulation and collaboration information

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<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># Schedule scenarios generated</td>
<td>341</td>
</tr>
<tr>
<td># Optimization runs</td>
<td>65</td>
</tr>
<tr>
<td># Schedule scenarios used for analysis</td>
<td>24</td>
</tr>
<tr>
<td>Average time to reschedule</td>
<td>10 mins</td>
</tr>
</tbody>
</table>
BIM simplification and zone breakdown

Input: Structural Model
Required Revit modeling time: 2 days

3,860 building components
344 construction elements
Construction recipes
Given the recipes and BIM, ALICE generated 4D models automatically
Develop calibrated schedules

Issue: Central core rising too fast, waiting for too long to start slabs on zone 1 and 3
Develop calibrated schedules

Issue: Central core rising too fast, waiting for too long to start slabs on zone 1 and 3

Issue: Zone 3 slab has not added rebar before zone 2 pour
Develop calibrated schedules

Issue: Central core rising too fast, waiting for too long to start slabs on zone 1 and 3

Issue: Zone 3 slab has not added rebar before zone 2 pour

Issue: Cannot have cranes working on adjacent cores even on different levels.
ALICE supports set-based construction scheduling

Update Unit Costs and Activity Durations

Calibrated Models

RCS Sequential

RCS Parallel

ACS Sequential

ACS Parallel

Calculate Total Costs and Schedule Durations
... for many conditions or situations
Projects are better when we ...
... collaborate early and frequently

Image courtesy DPR
... use technology well

Image courtesy DPR
... pay attention to our processes

Image courtesy DPR
... set goals and objectives and track KPIs

Image courtesy DPR
When we put it all together, projects deliver higher customer value and are more fun and rewarding.
Which decisions are you making on the basis of visualization, integrated information, or automation?

- Visualization
- Integrated Information
- Automation

Open the whole Eden Valley Medical Center hospital on budget and 30% earlier than typical

Highly reliable construction

Pictures courtesy DPR, BuildingSP, and Max Bögl