You can't always get what you want, but if you use operations and data science you may get what you need

Or: The next practice of engineering and managing capital projects

Martin Fischer
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Director, Center for Integrated Facility Engineering (CIFE)
Senior Fellow, Precourt Institute for Energy (PIE)
Stanford University
Member, Technical Committee, PPI
National Academy of Construction
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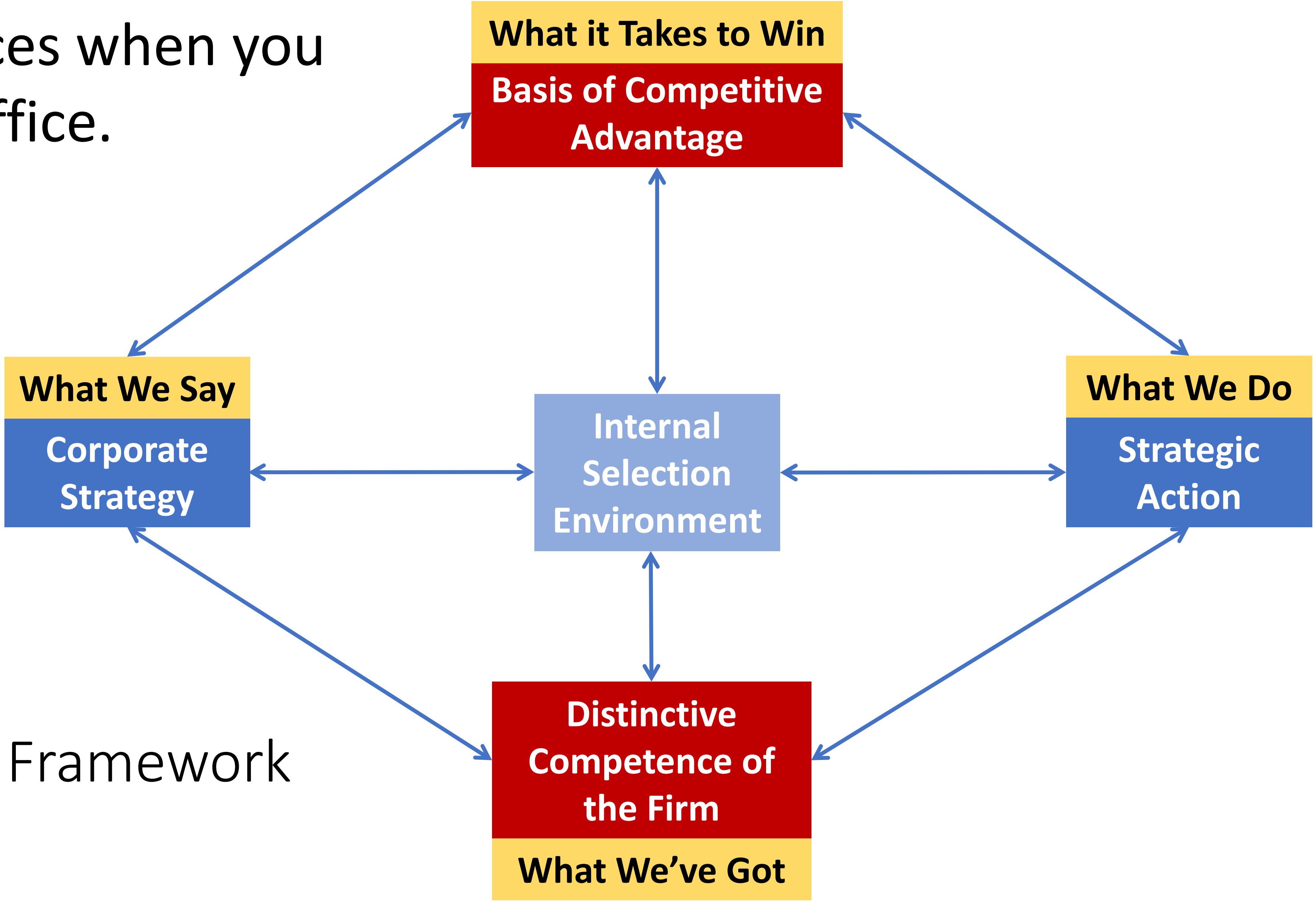
You must decide how to allocate your firm's resources when you get back to your office.



Strategy Diamond Framework

Many technology and management developments

Mobile
- from just-in-case to just-the-right information

Cloud
- anytime (push and pull, bi-directional, ”unlimited”)

Parallelization
- fast

Location / dimensional measurement
- accuracy, dimensional control, off-site / on-site

Machine learning
- experience and data

Robotics, additive manufacturing
- virtual ←→ real, safety, environmental impact

Internet of Things (IoT)
- virtual ←→ real

Virtual Environments
- test!

Collaboration
- concurrent knowledge

Lean
- lower uncertainty, lower risk, customer, pull, purpose → value

The combination of these developments creates significant opportunities for dramatic change.

”You are an idiot if you are not using the best tool possible.”

Manfred Fischer, 1972

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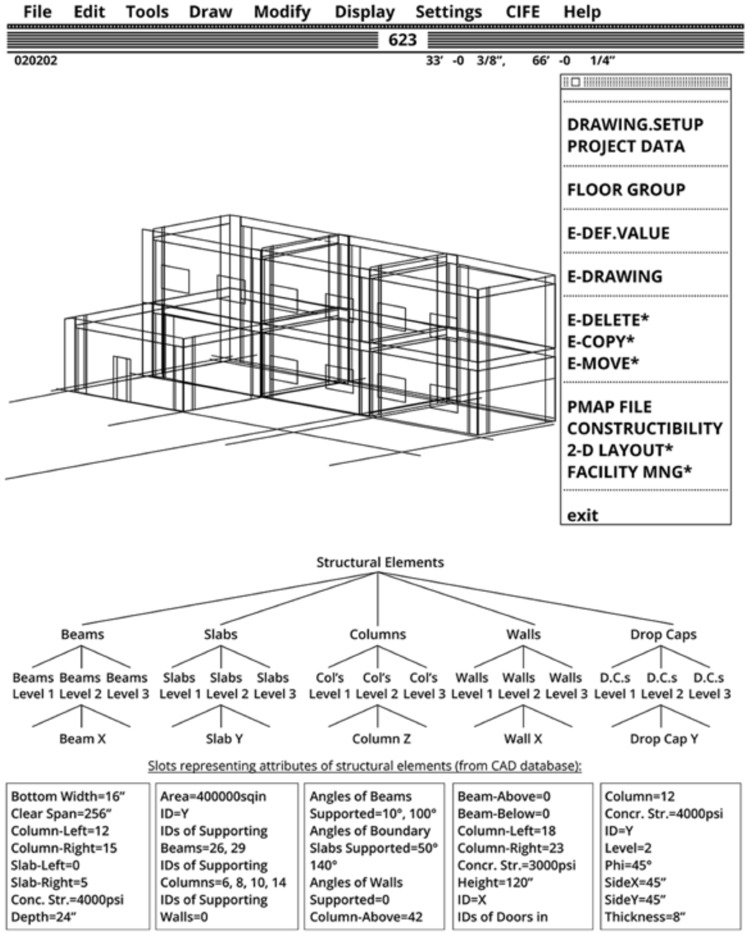
Frustrating

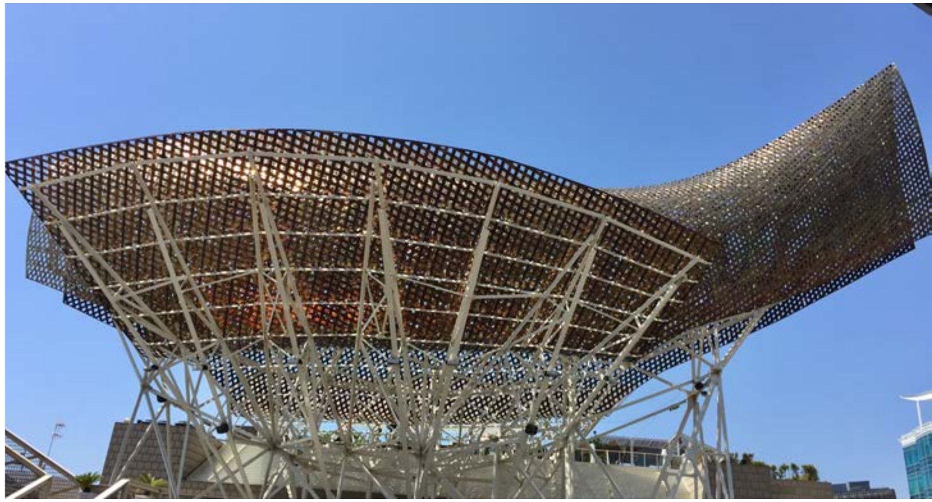
First attempt

Inspiring

Picture courtesy Michael Veegh



From CIFE Technical Report Nr. 64,
https://stacks.stanford.edu/file/druid:vy646gd5926/TR064.pdf



Picture taken by Martin Fischer

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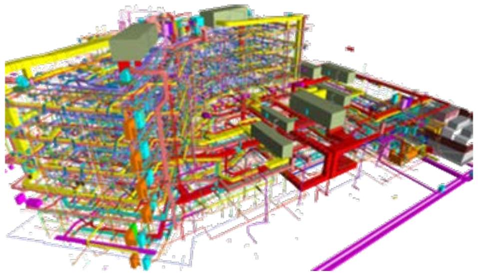
Today’s best practice: VDC Virtual Design and Construction

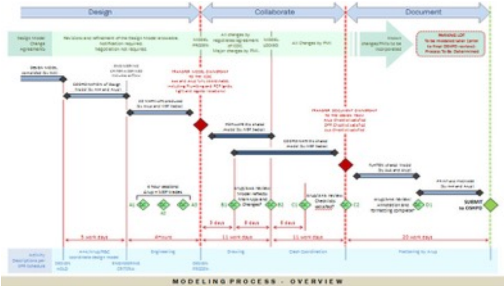
Client Objectives

Project Objectives

Integrated Concurrent Engineering (ICE)

Building Information Modeling (BIM)





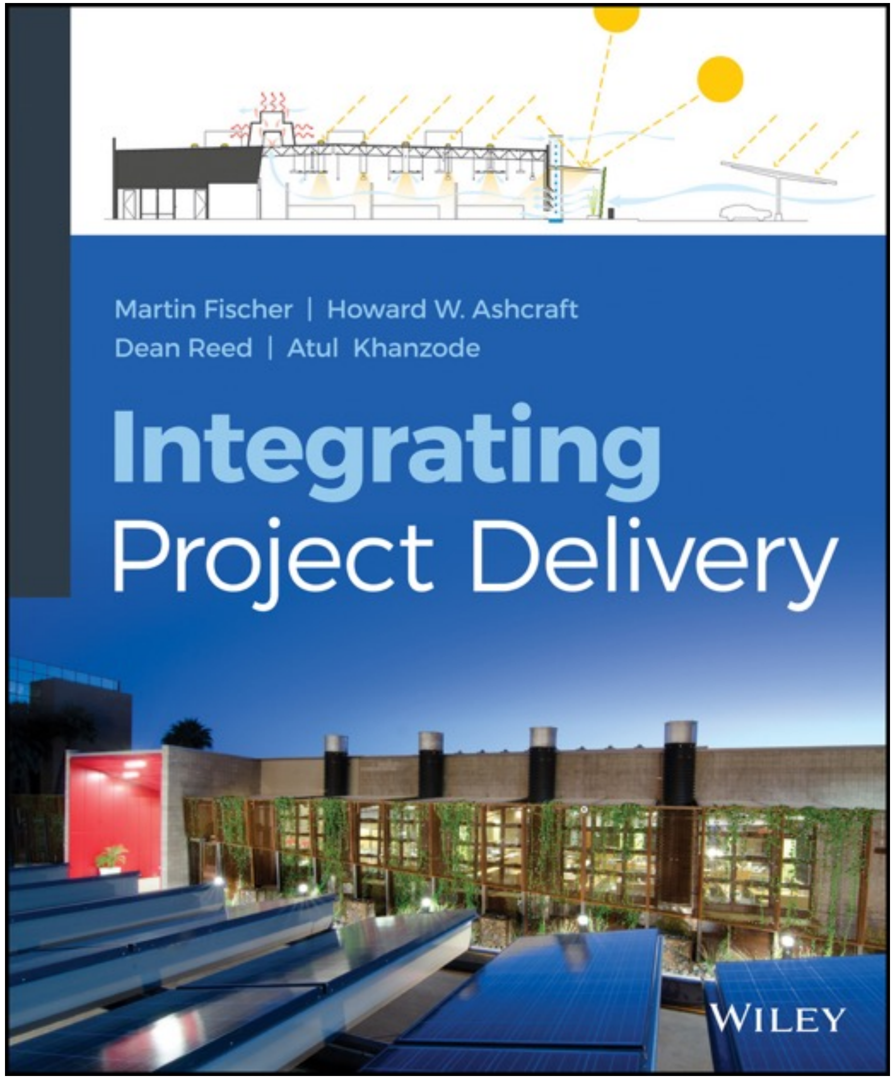
Project Production Management (PPM)

Images courtesy DPR Construction

Images courtesy DPR Construction

INTEGRATING PROJECT DELIVERY

A Strategic Model for Project Integration



- Theory and Practice
- 450 pages
- 50 Projects
- 123 Examples
- Textbook published by Wiley 2017

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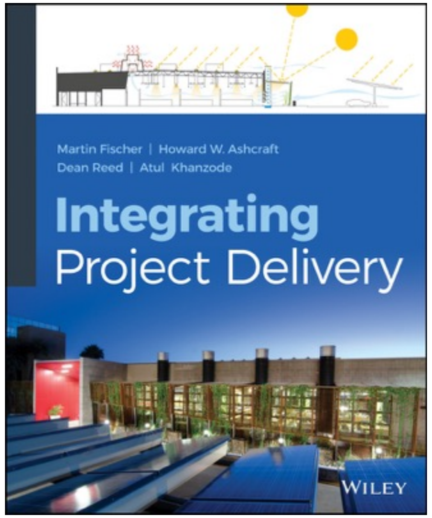
The Simple Framework for IPD



Measurable Value

Production Management

Collaboration Colocation

Simulation Visualization

High Performing Facility ← Integrated Systems ← Integrated Process ← Integrated Organization ← Integrated Information

Agreement/ Framework

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Do you need to complete your projects fast or at low cost?

Most need to do both.

Then there are two more related questions:

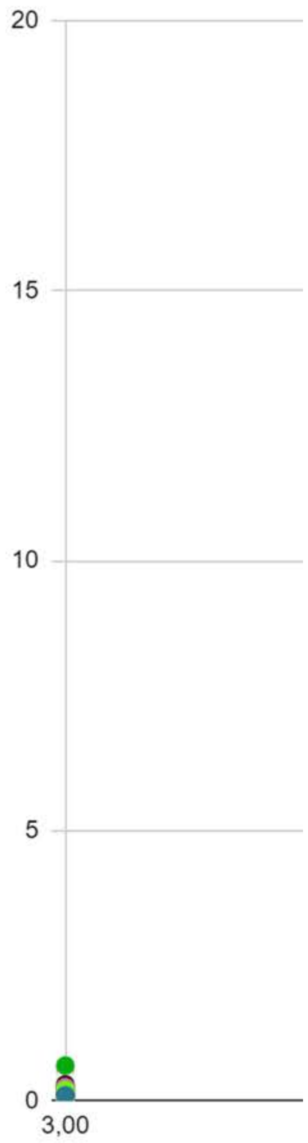
Do you have the same amount of work each day?

The same amount of resources you can count on?

Let’s see how good 200 Norwegian owners, engineers, and contractors can produce fast and at low cost with variable demand and supply

Capacity Utilization Simulation

Legend:
X-axis: Extra capacity
Y-axis: Average unmet demand



Capacity Utilization Simulation

Legend:
X-axis: Extra capacity
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Capacity Utilization Simulation

Legend:
X-axis: Extra capacity
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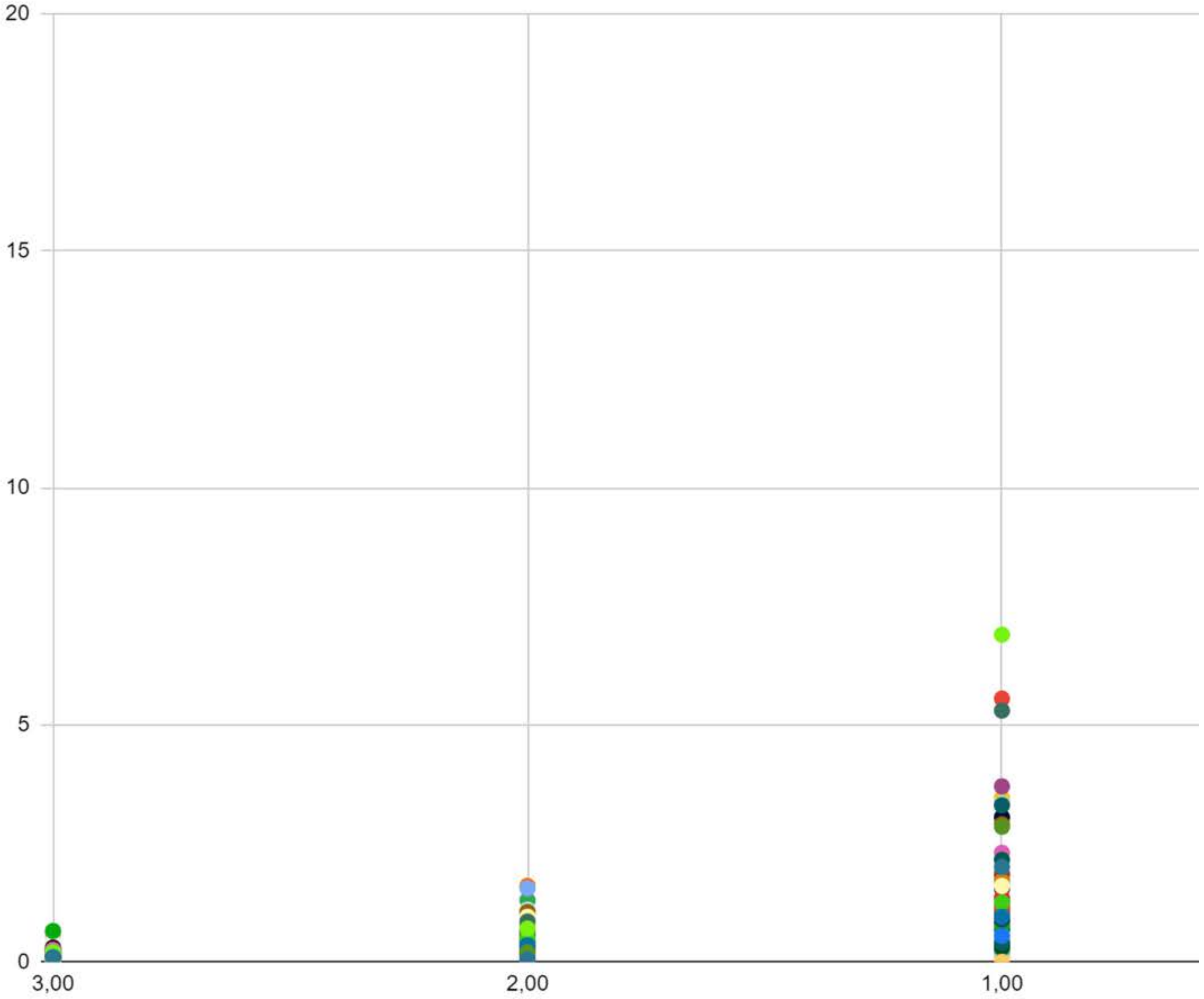
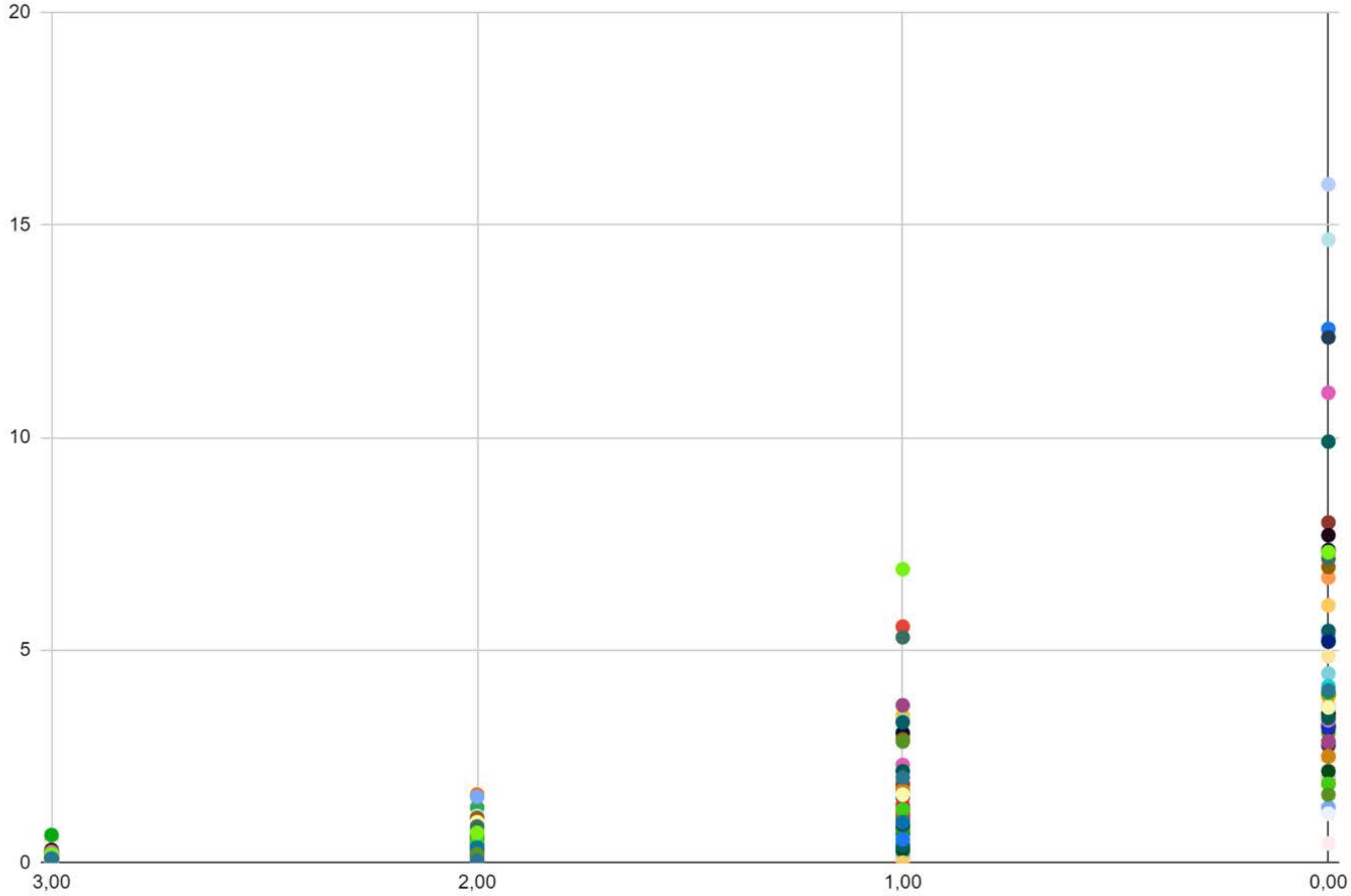


Capacity Utilization Simulation

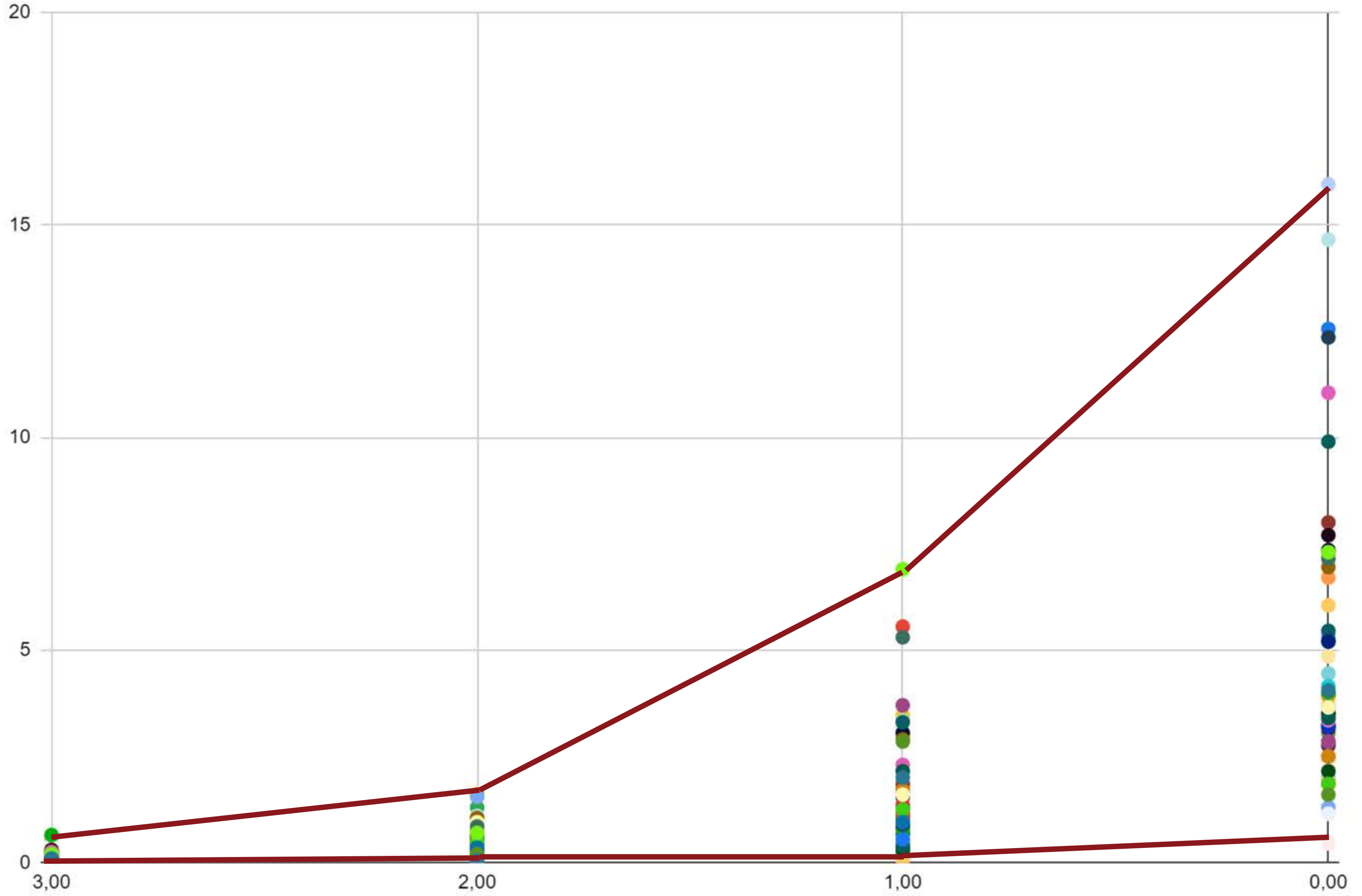
Legend:
X-axis: Extra capacity
Y-axis: Average unmet demand



Capacity Utilization Simulation

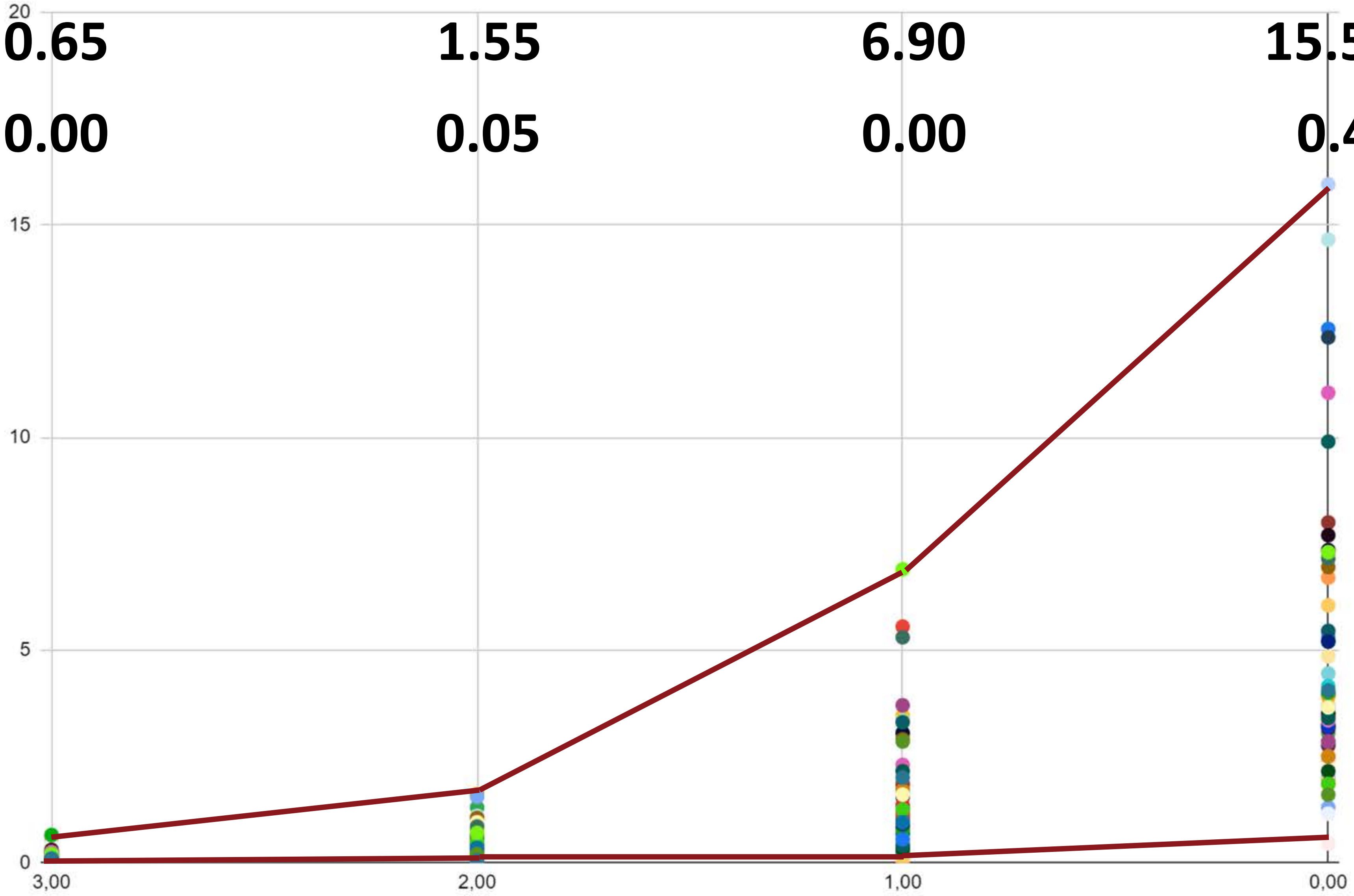
With less extra capacity, it takes longer to meet demand and performance is less predictable

Legend:
X-axis: Extra capacity
Y-axis: Average unmet demand



Capacity Utilization Simulation

worst	**0.65**	**1.60**	**6.90**	**15.95**
spread	**0.65**	**1.55**	**6.90**	**15.50**
best	**0.00**	**0.05**	**0.00**	**0.45**



Lots of WIP gives you lots of possibilities, but ties up lots of $ and stays a long time in the production system

http://www.rainydaysaver.net/2010/06/stocking-up-your-pantry-yea-or-nay.html

https://glimpseofsonshine.blogspot.com/2010/03/saving-money-with-full-freezer-and.html

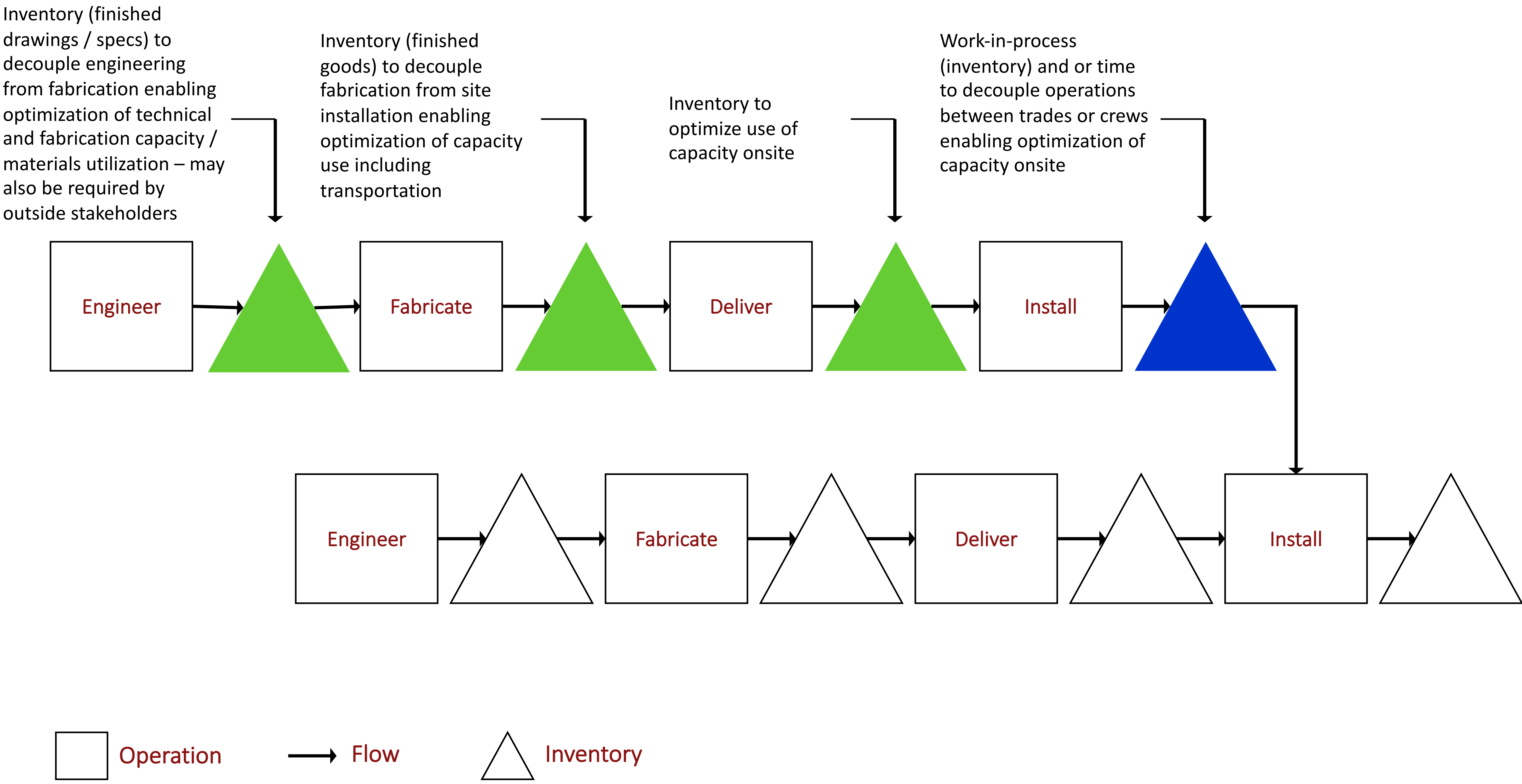


Figure courtesy SPS

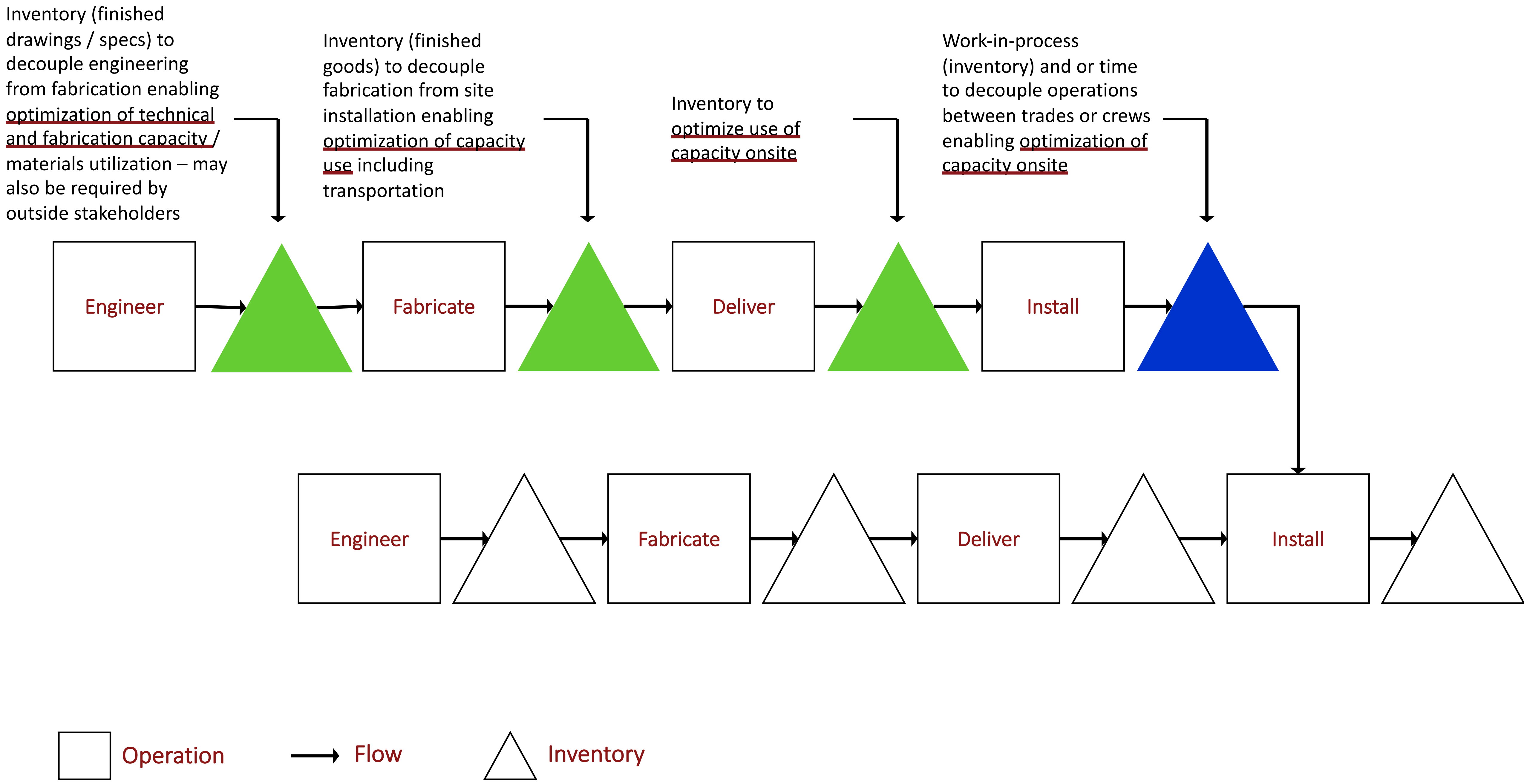


Figure courtesy SPS

Projects consists of many supply chains

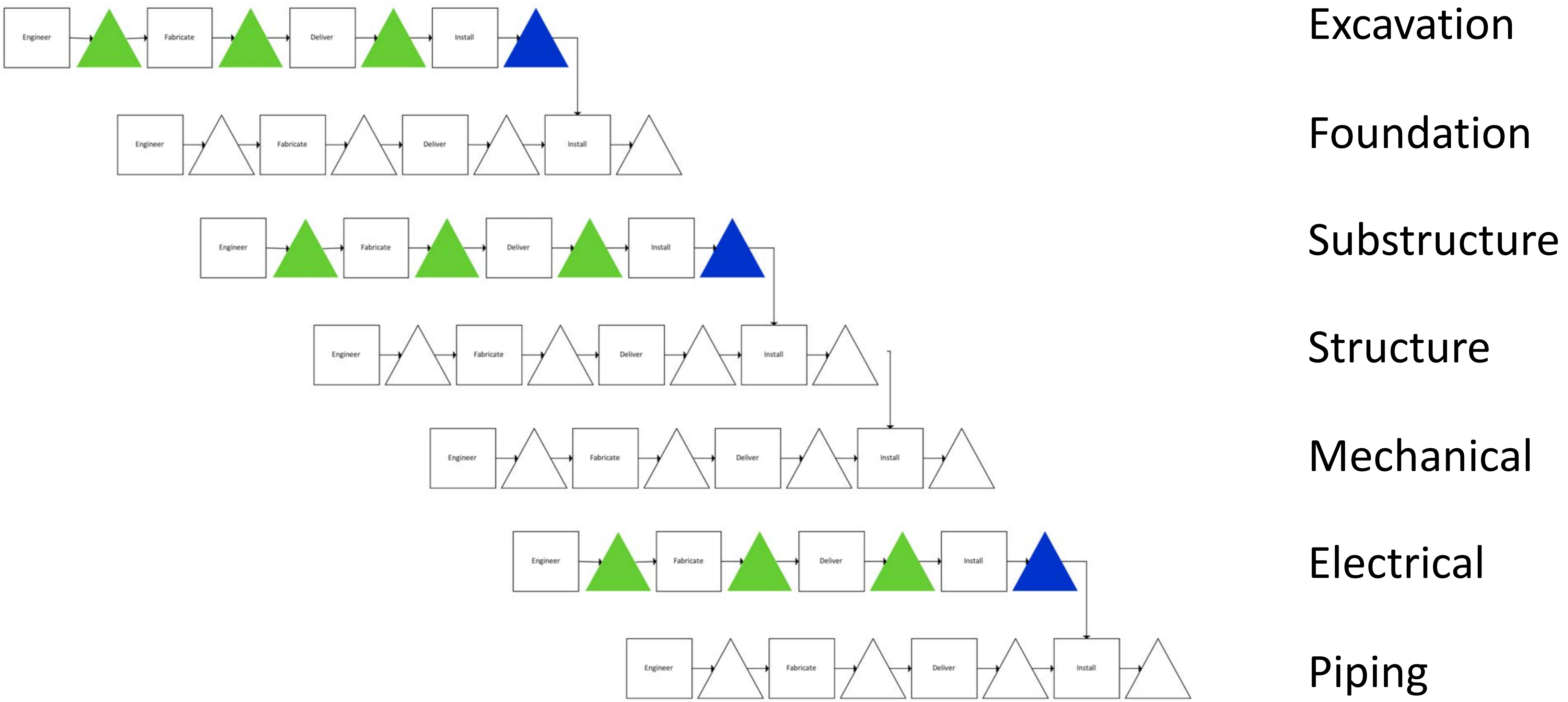
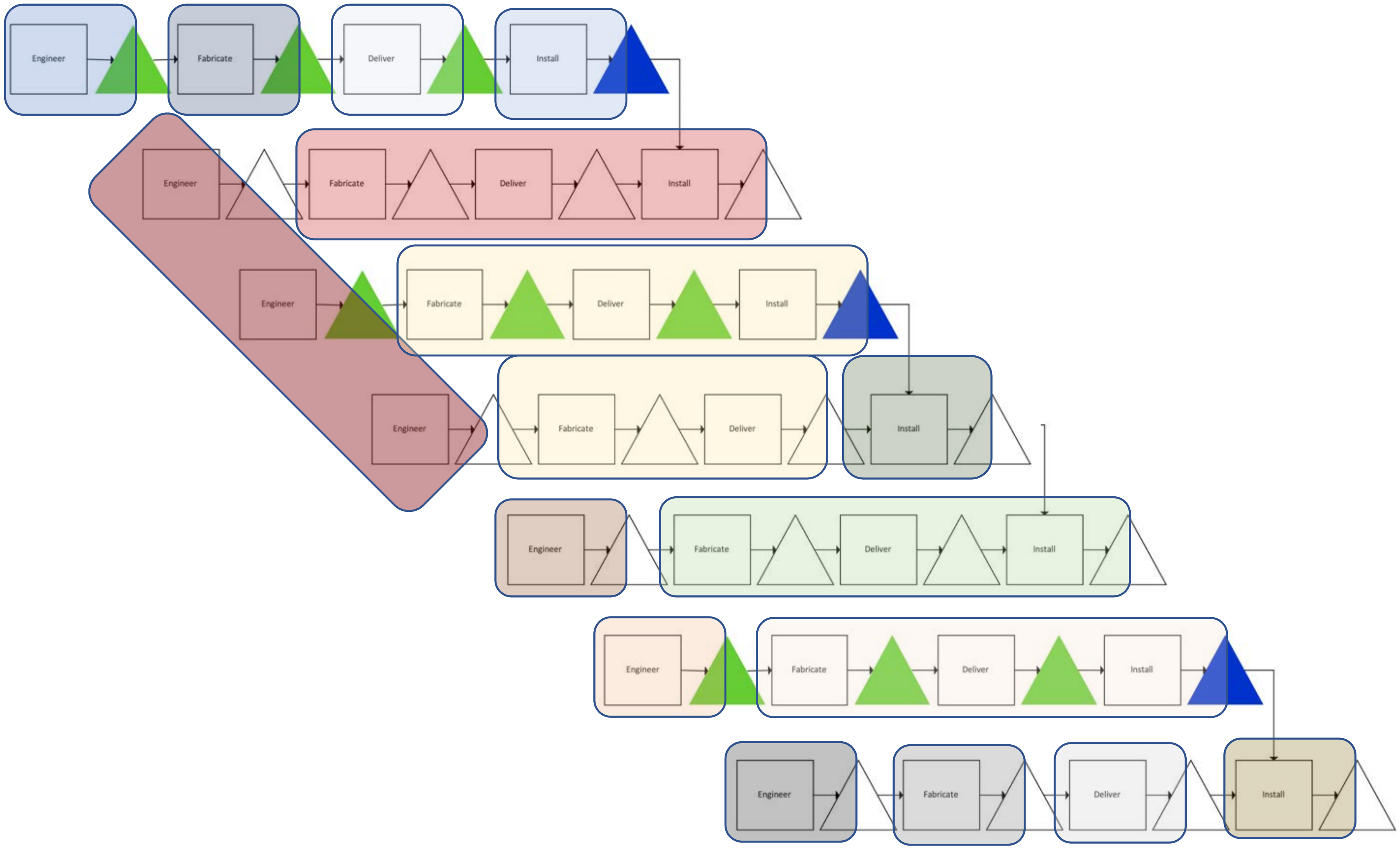


Figure courtesy SPS

Projects consists of many supply chains with many organizational boundaries



Excavation

Foundation

Substructure

Structure

Mechanical

Electrical

Piping

Figure courtesy SPS

To be successful, you really only have to do one thing:

Use your resources efficiently for the right thing.

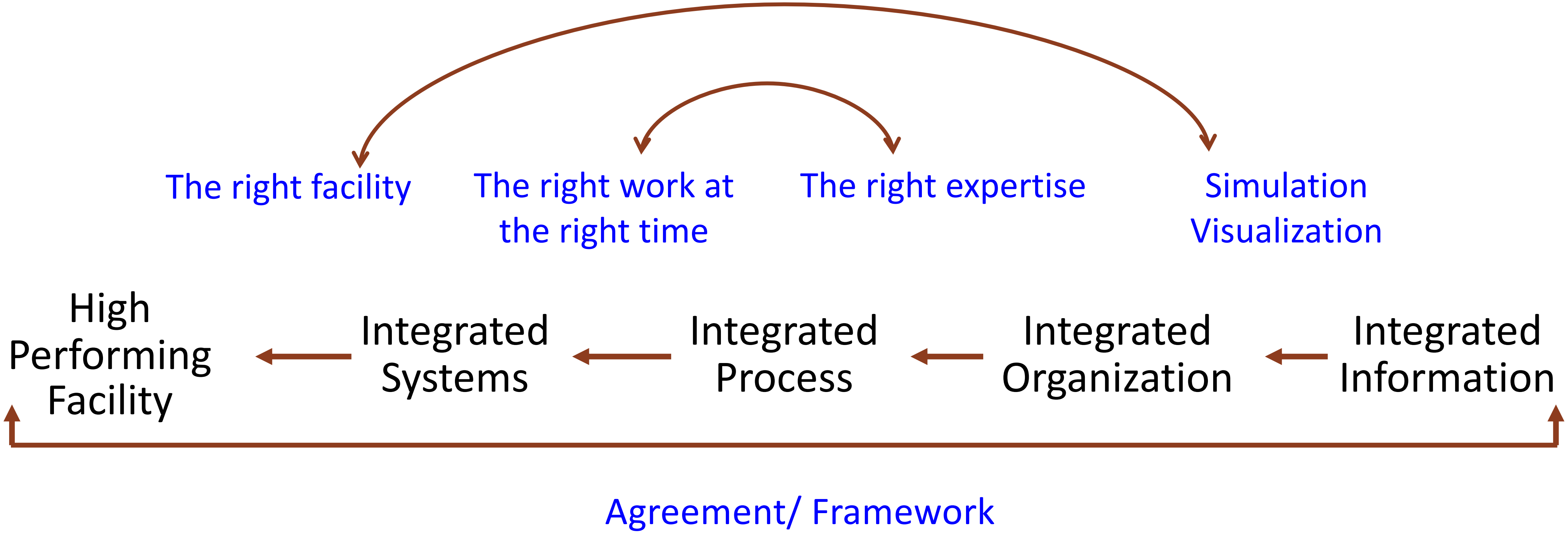
In other words:

You must match demand and supply.

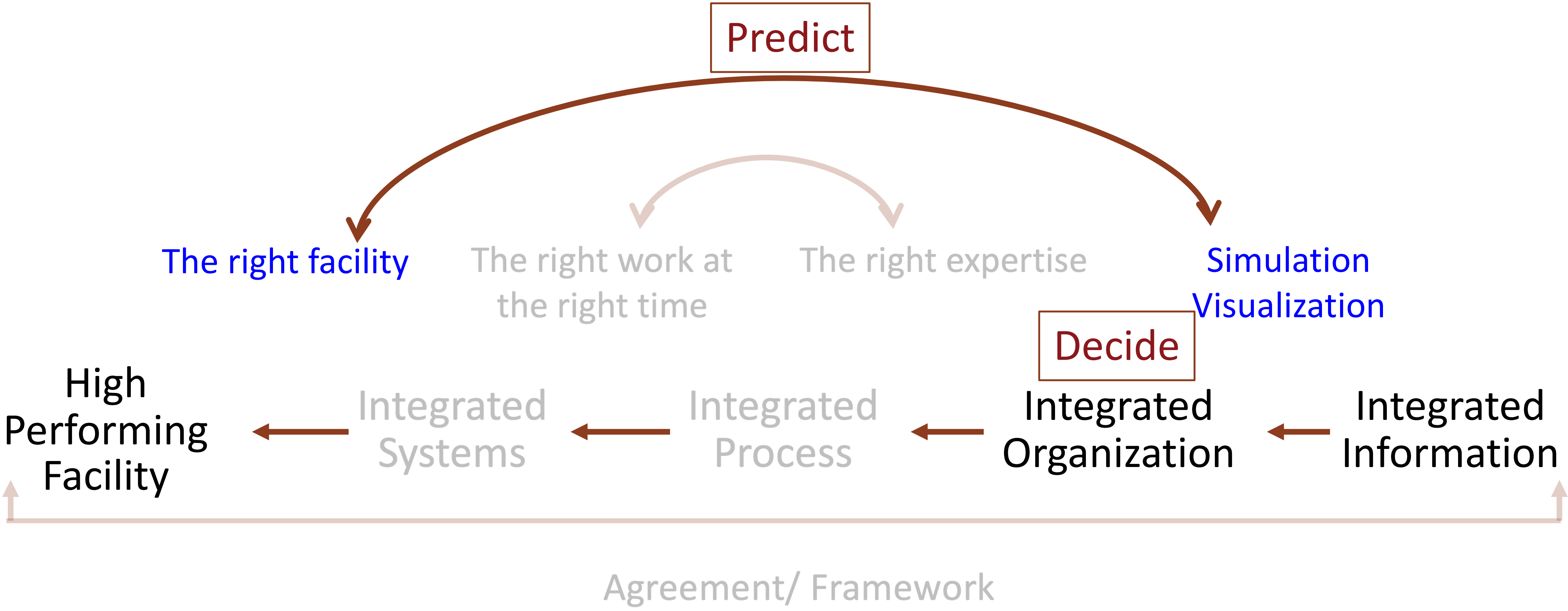
Which means:

You must plan and predict.
(Or pay lots of money for WIP and a slow project.)

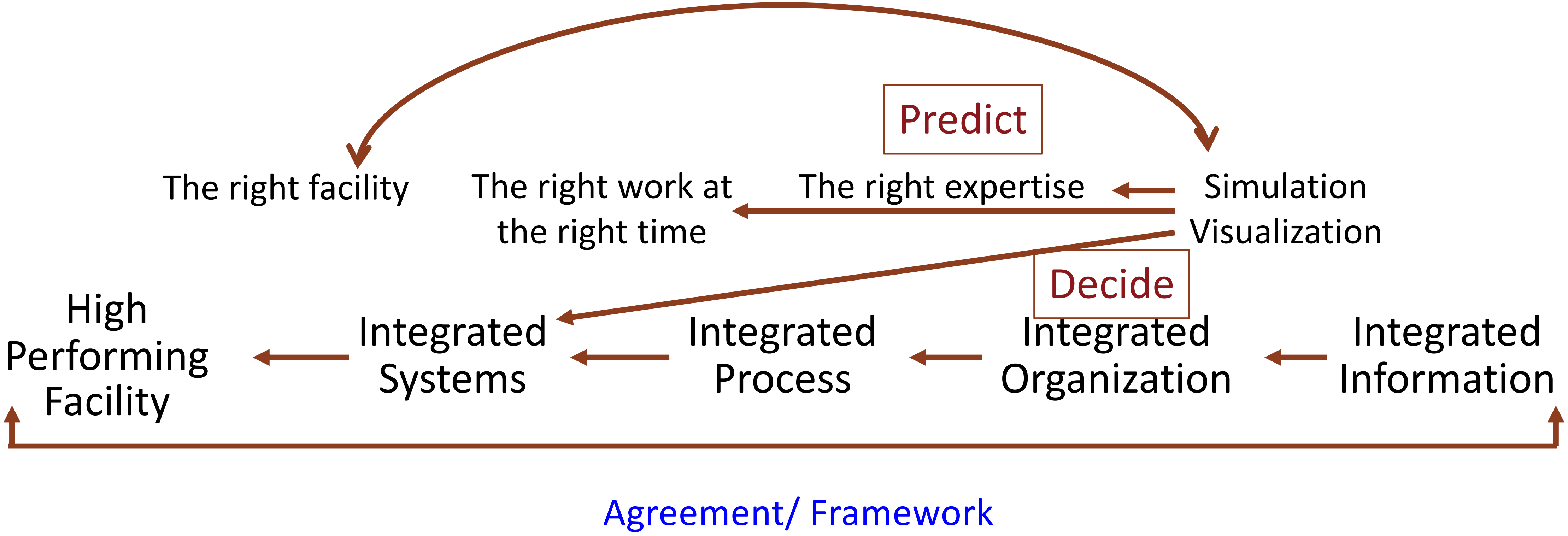
The Simple Framework for IPD



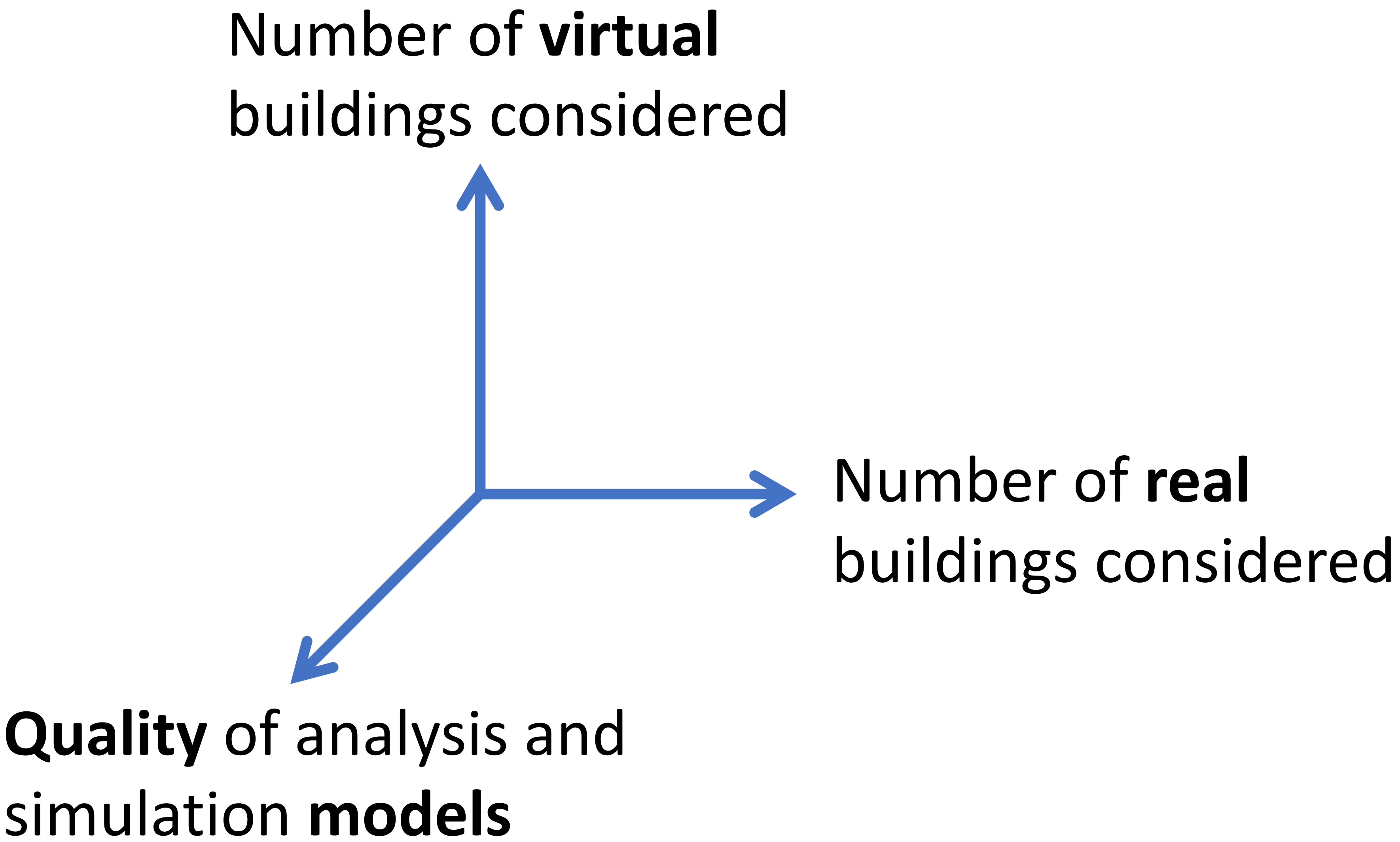
The Simple Framework for IPD



The Simple Framework for IPD



Your success depends on the quality of your predictions
→ how will you improve performance predictions?



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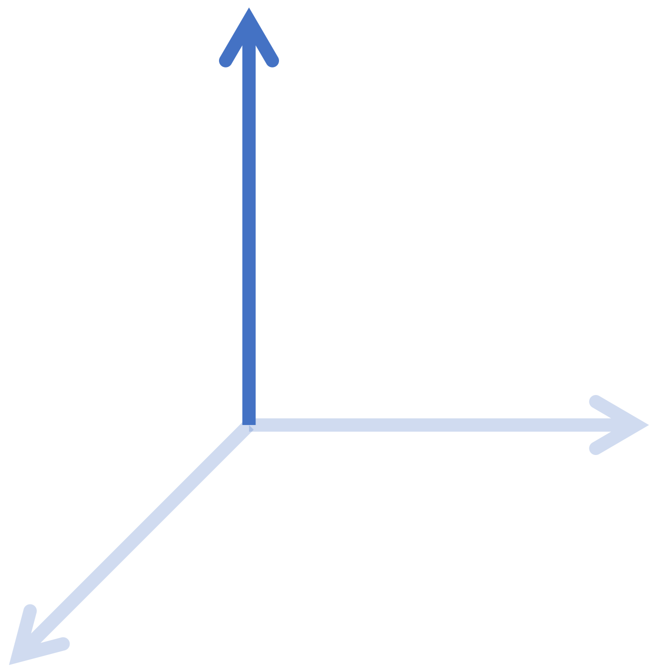

Optimal structural design

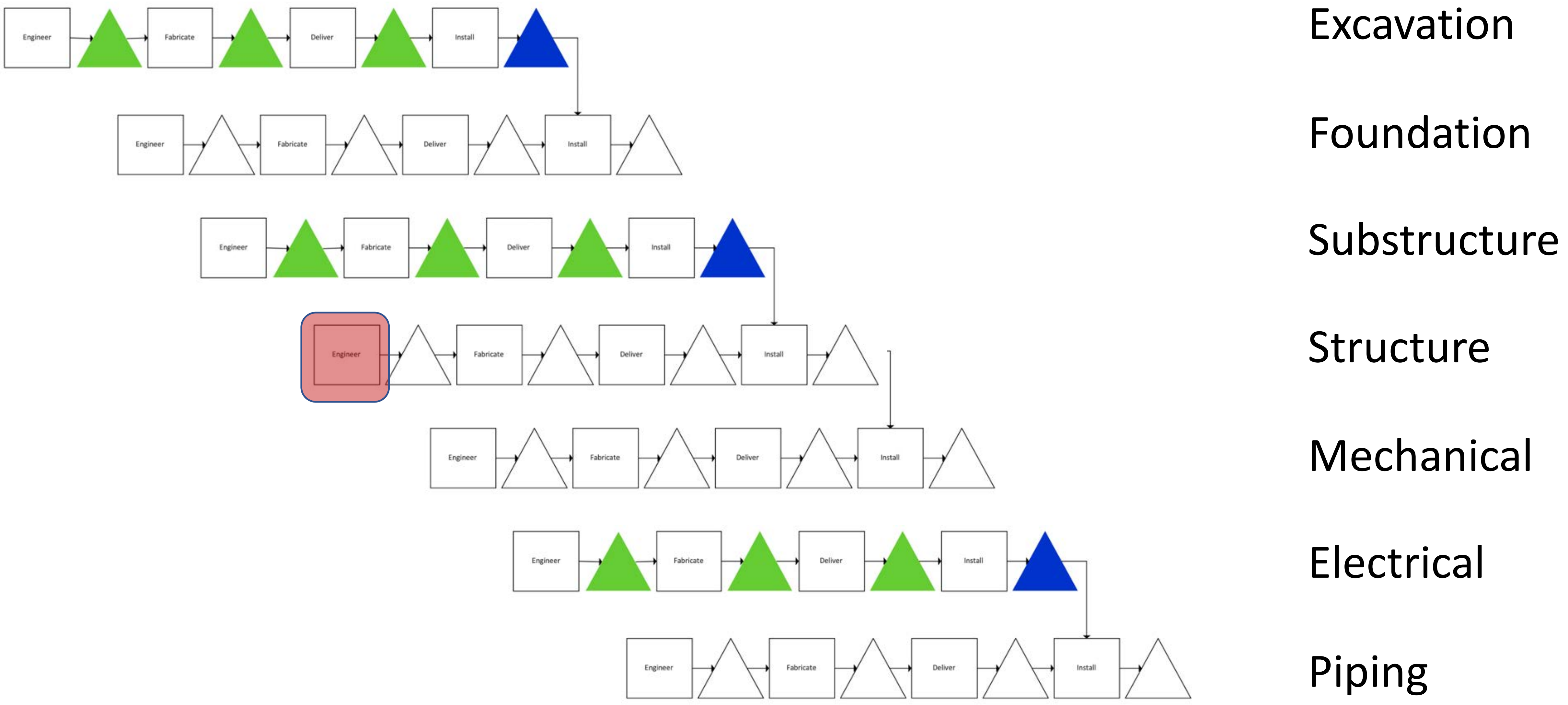

Figure courtesy SPS

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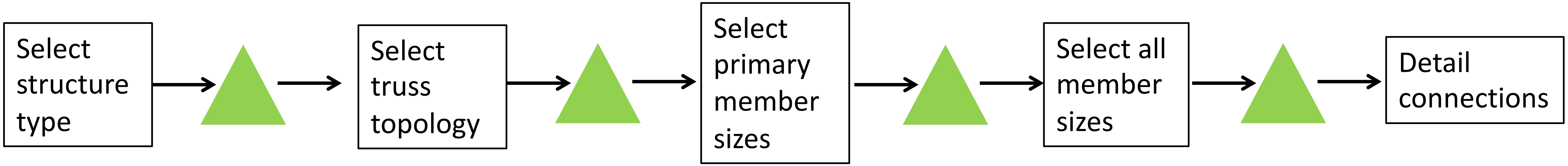
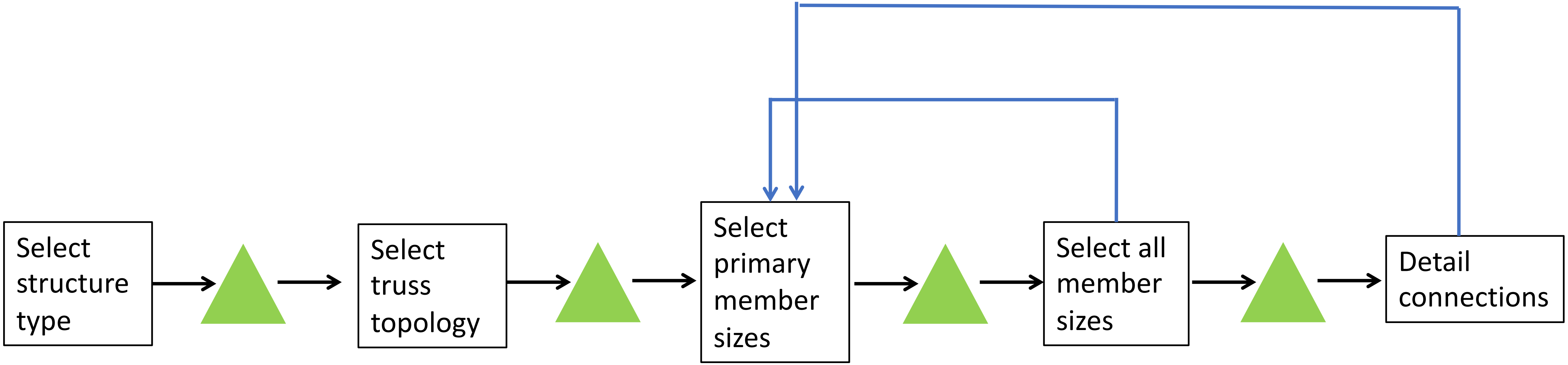
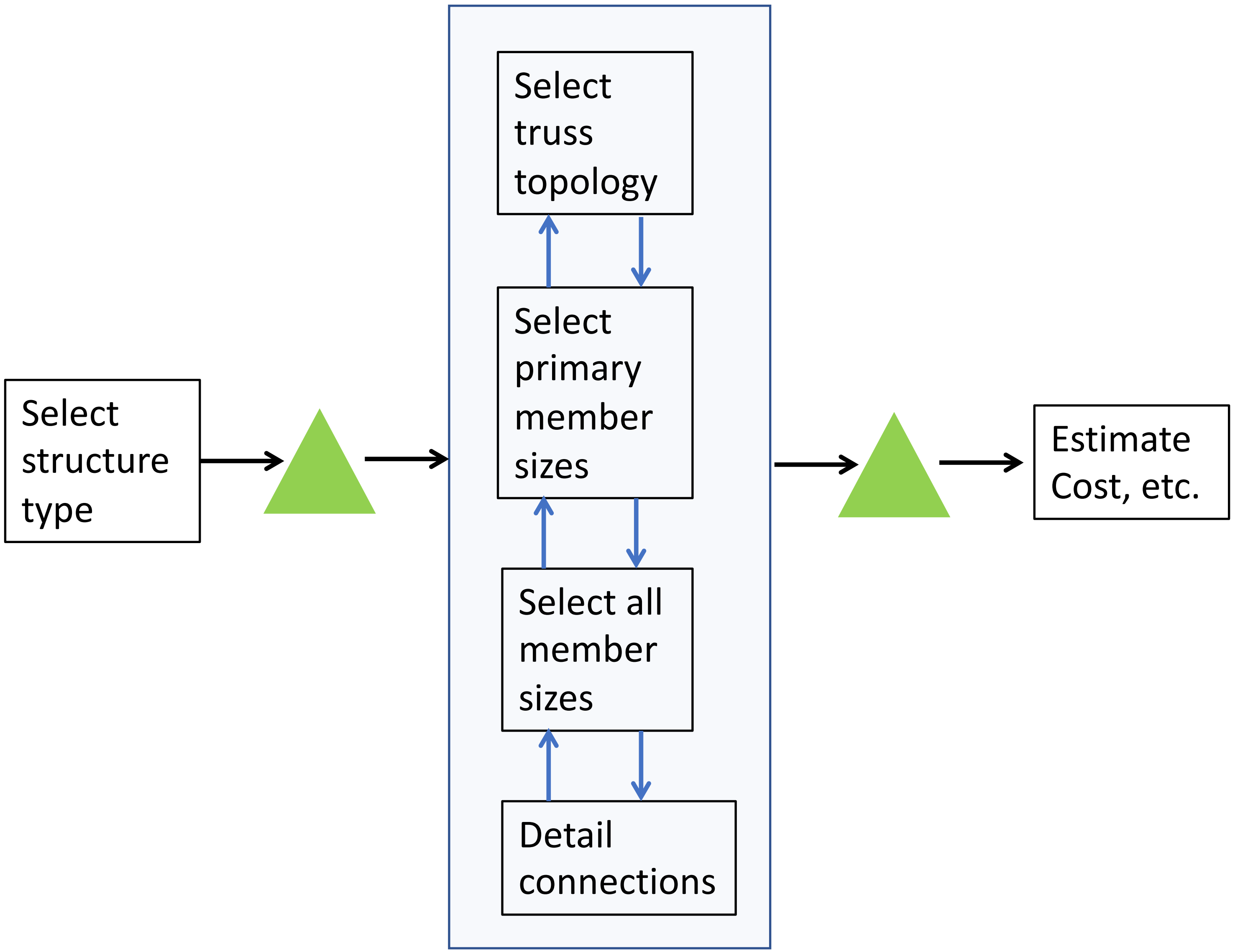
Designing a structural system today



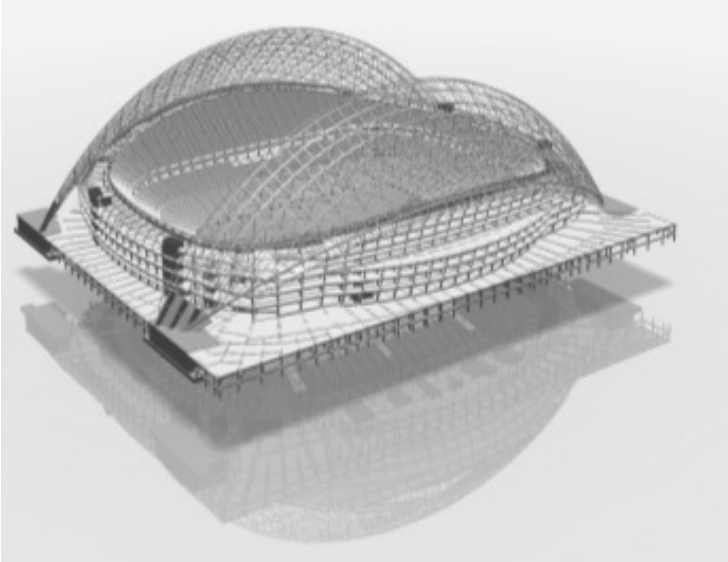
Designing a structural system today



Designing a truss with concurrent engineering



An engineer using digital tools with today's process cannot compete with an engineer with connected tools



	Engineer with today's tools	Engineer with connected tools
Total steel weight	2,728 mt	2,292 mt
Cost savings		$4M
# alternatives evaluated	39	12,800
Design time per alternative	4 hours	3 seconds
Total design time	~200 hrs	~200 hrs

Roof truss design for a soccer stadium in the Middle East
Work by Forest Flager and John Haymaker in collaboration with Arup Sports, London

More optimal structural design

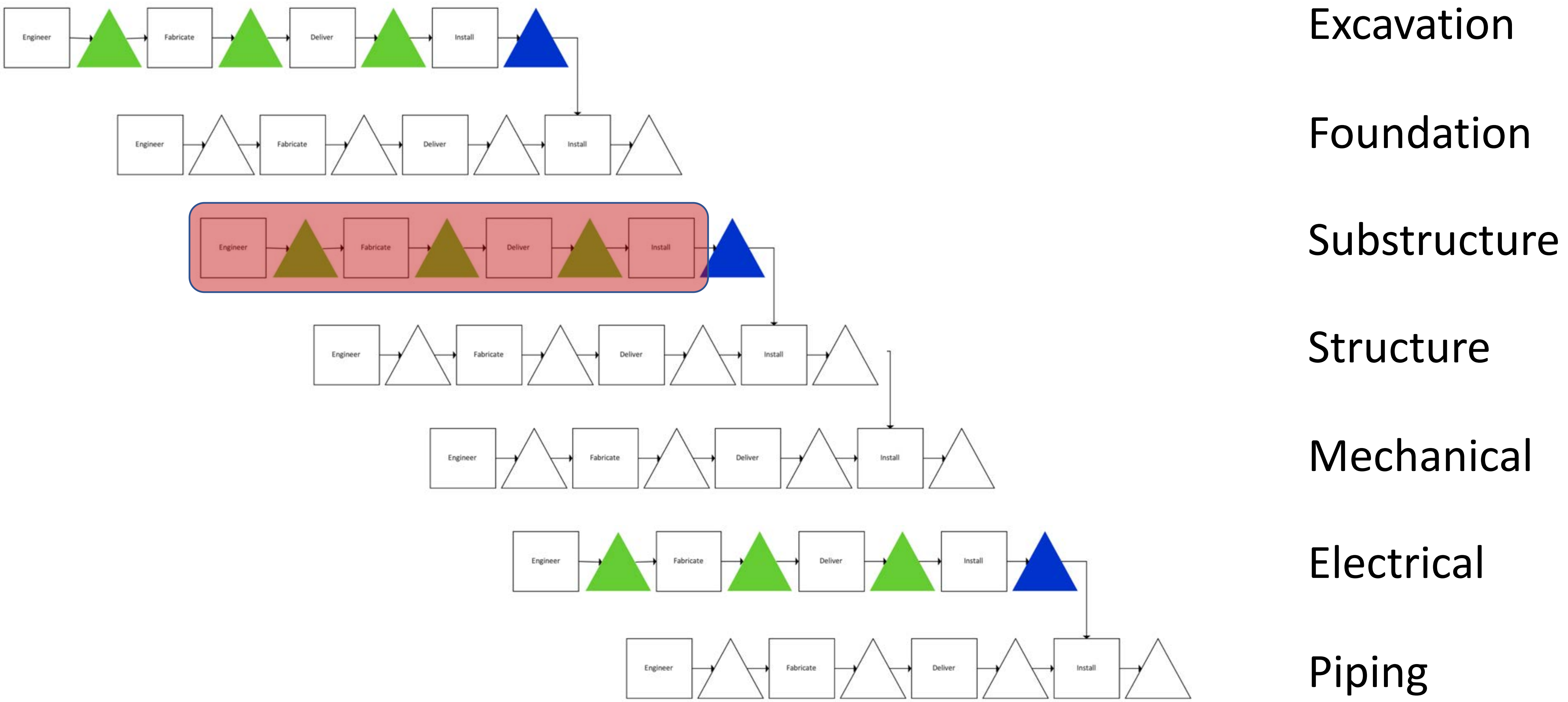
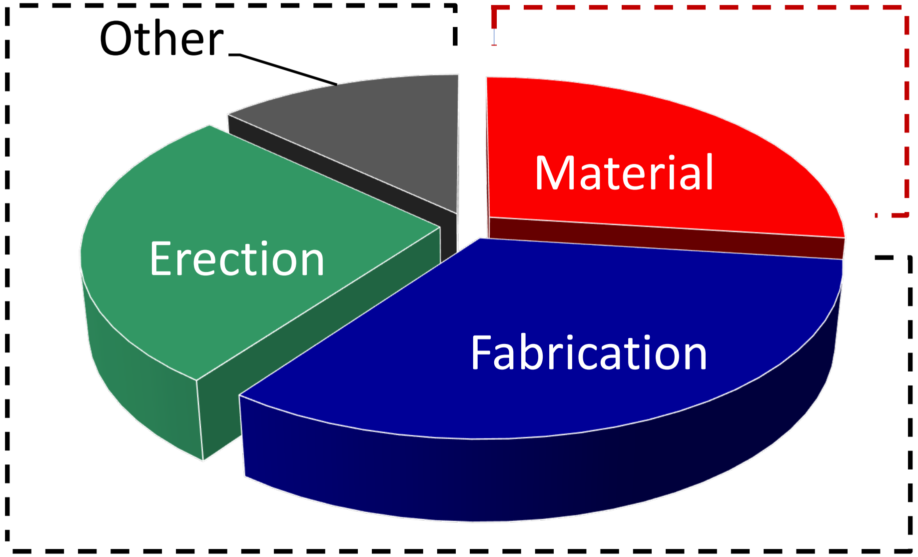
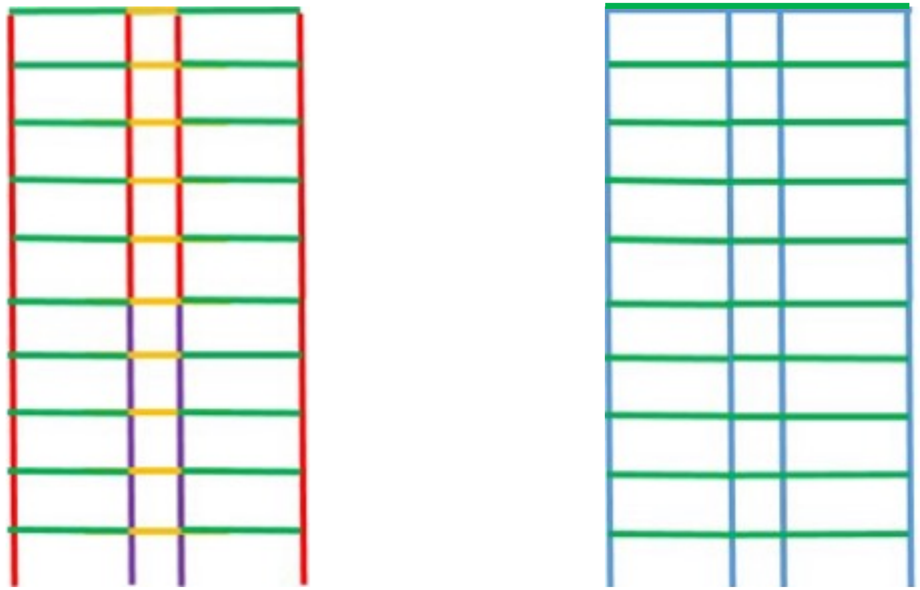


Figure courtesy SPS

Optimize across all cost components of a steel frame

Design Cycle Time: 8-24 weeks





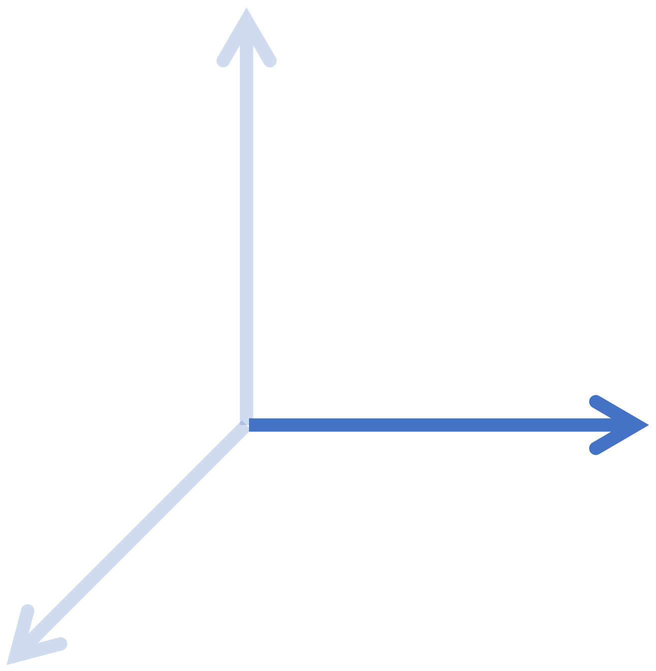
	Original Frame	Value-Engineered Frame
Steel Weight	-	+8%
Total Cost	-	-13%
Procurement Time	-	-20%

Work by Forest Flager, Pratyush Havelia, Henry Hamamji, Filippo Ranalli, Bo Peng, Thomas Trinelle in collaboration with SOM, Herrick, Autodesk

You can only optimize “things” for which you have good data.

Your success depends on the quality of your predictions
→ how will you improve performance predictions?

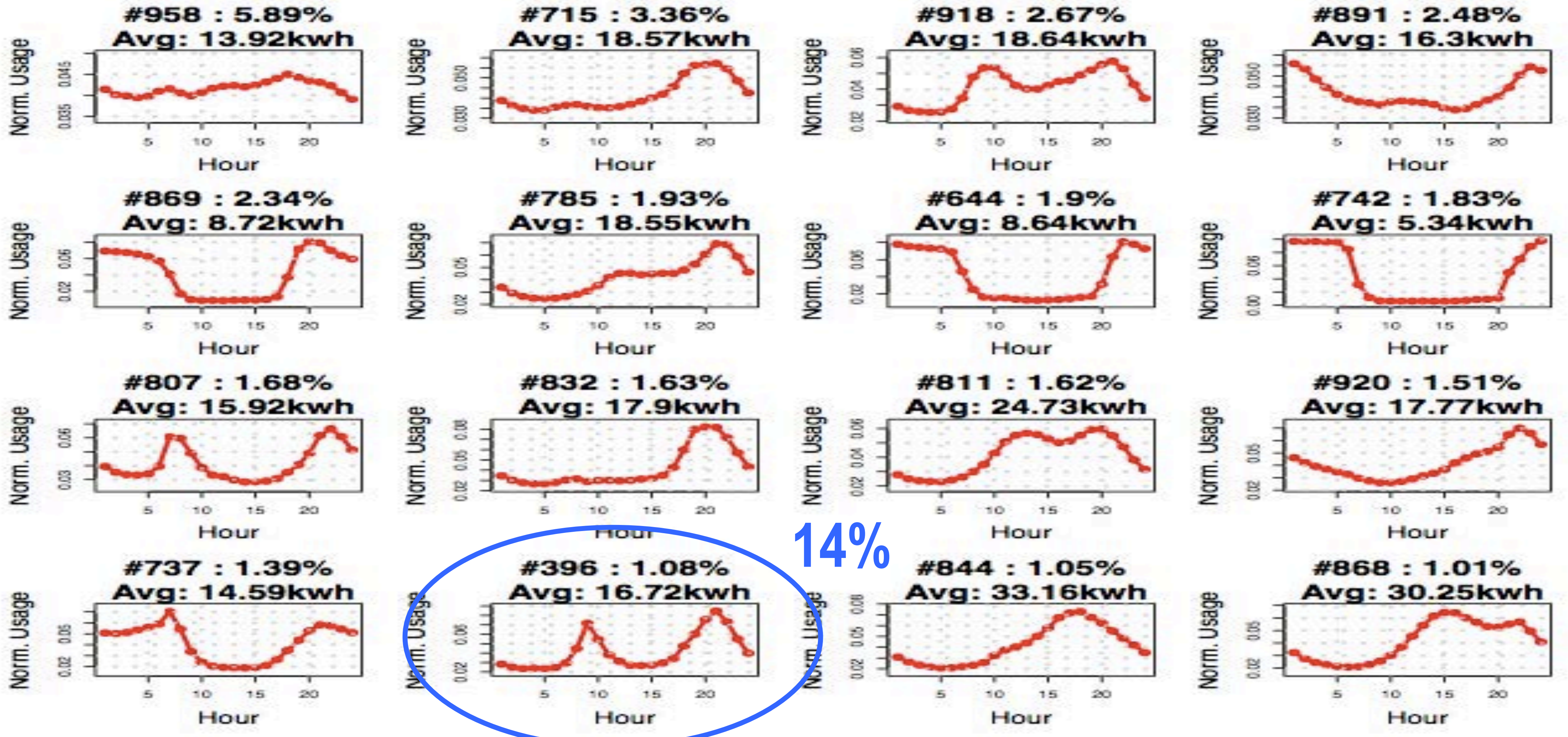
Number of **virtual** buildings considered



Number of **real** buildings considered

Quality of analysis and simulation **models**

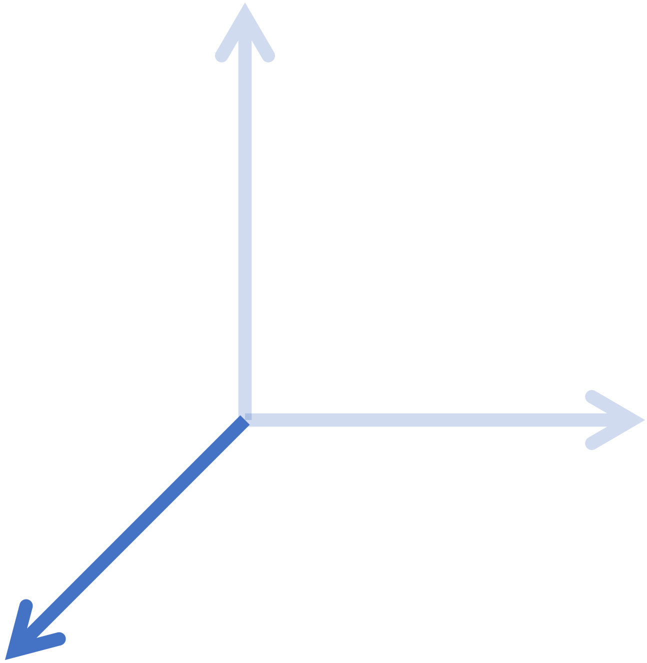
Consumption Patterns



Household Energy Consumption Segmentation Using Hourly Data, J. Kwac, J. Flora and R. Rajagopal, IEEE Trans. Smart Grid, 5:1, pp 420-430, 2014.

Your success depends on the quality of your predictions
→ how will you improve performance predictions?

Number of **virtual** buildings considered



Number of **real** buildings considered

Quality of analysis and simulation **models**

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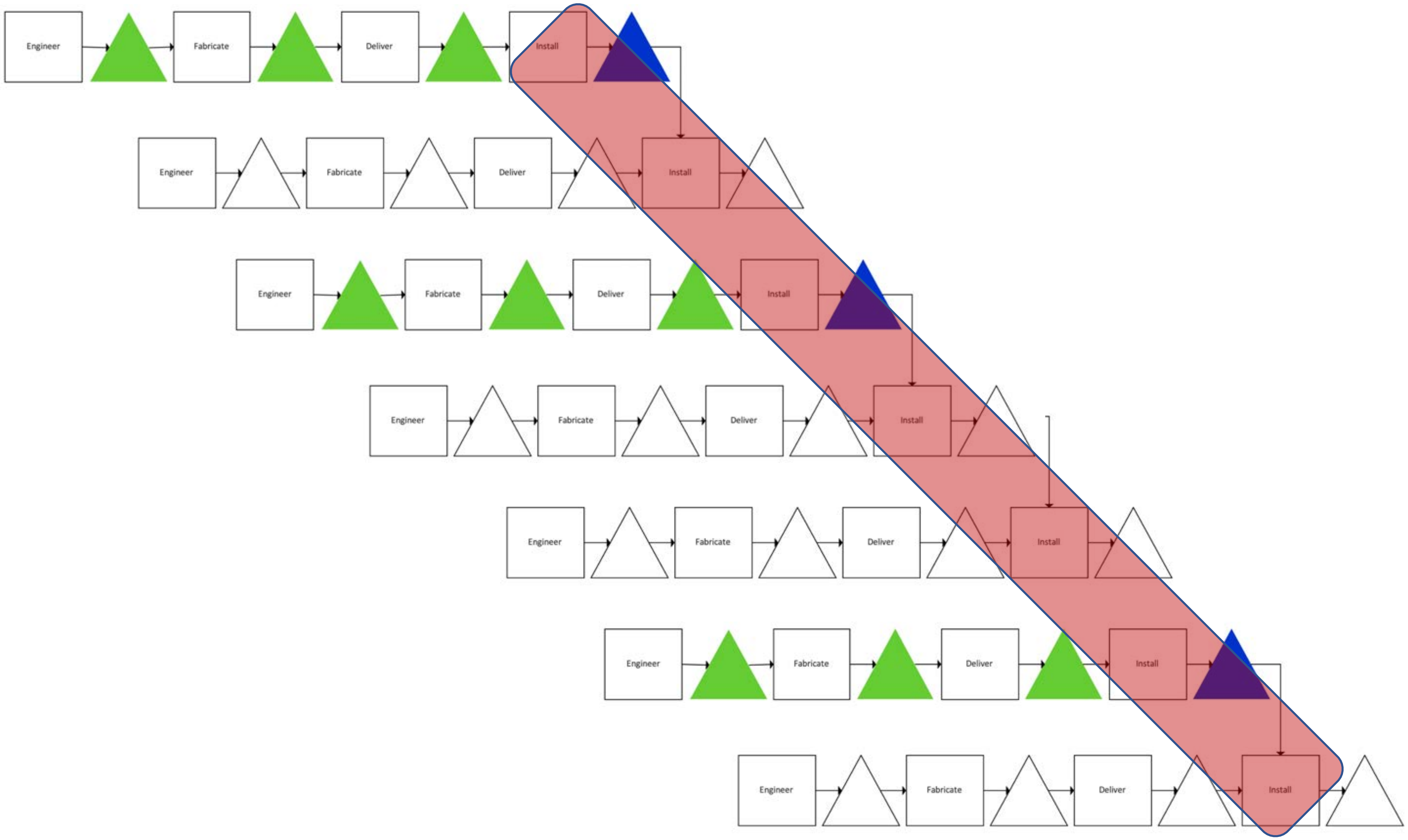
Optimal construction schedule



Excavation

Foundation

Substructure

Structure

Mechanical

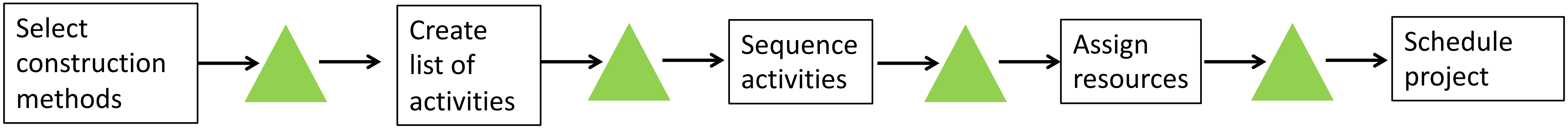
Electrical

Finishes

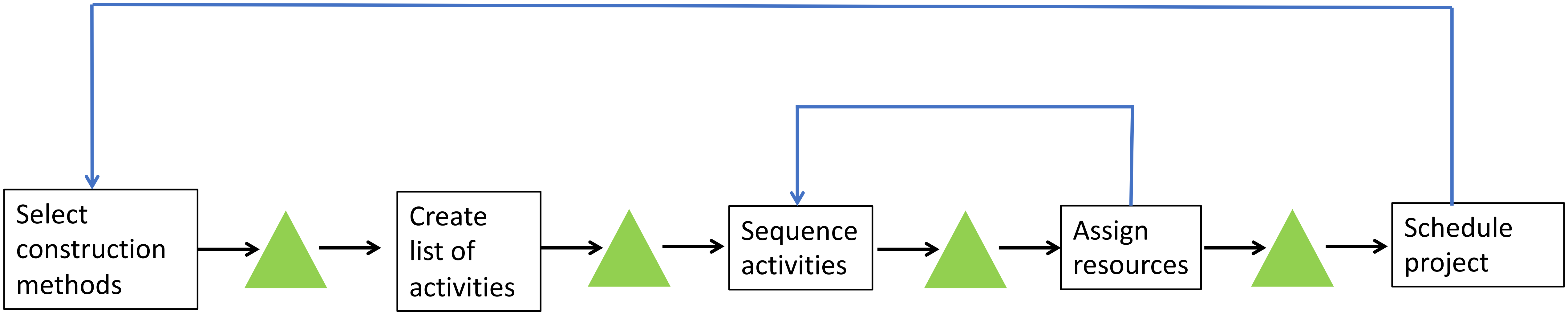
Etc.

Figure courtesy SPS

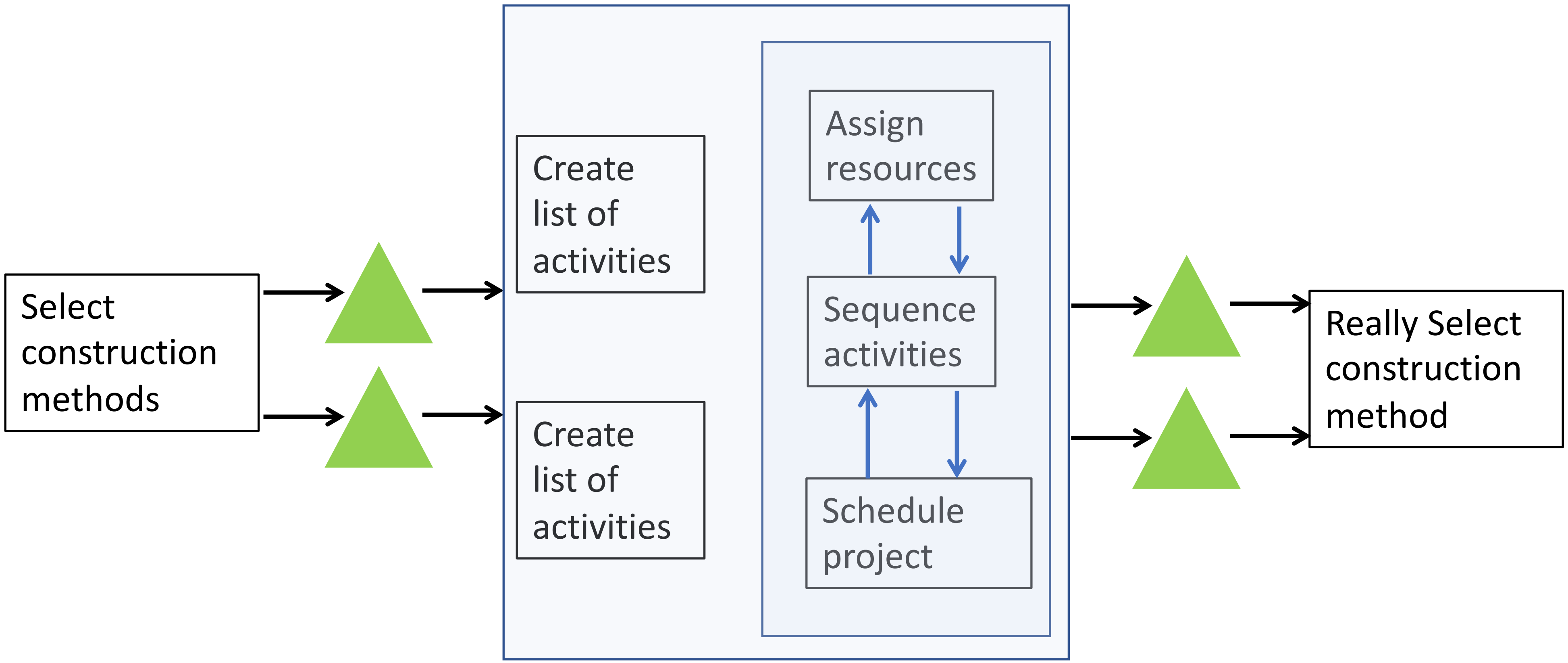
Creating a construction schedule today



Creating a construction schedule today



Creating a construction schedule with concurrent engineering



Construction Schedule Workshop 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
  (a start-up based on 25 years of scheduling research in Martin Fischer’s research group, Martin Fischer is an advisor and small shareholder in the company)
- CIFE-Stanford Researchers

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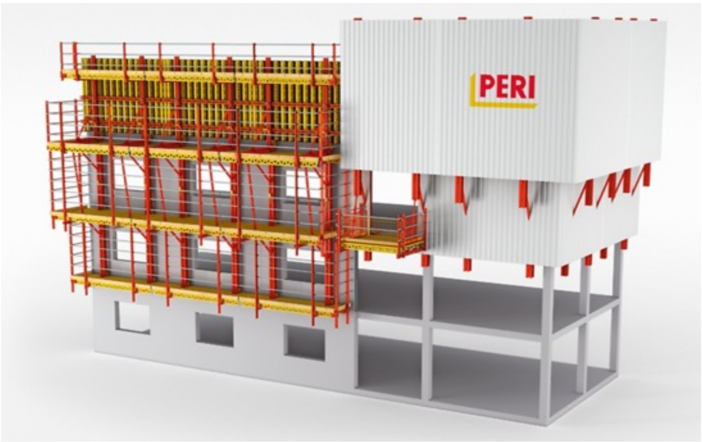
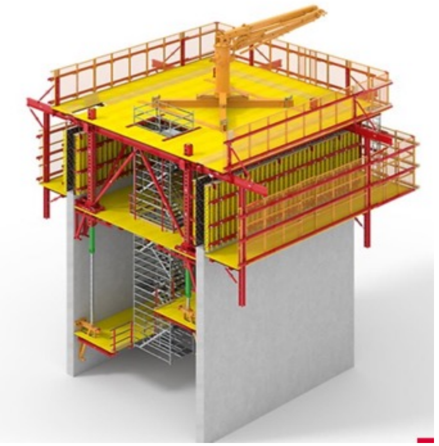
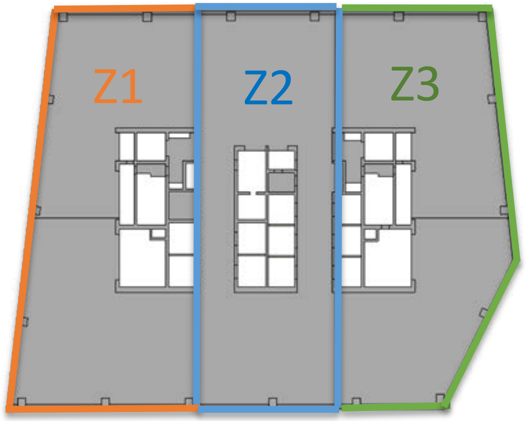
Key construction decisions: formwork and sequencing







- **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

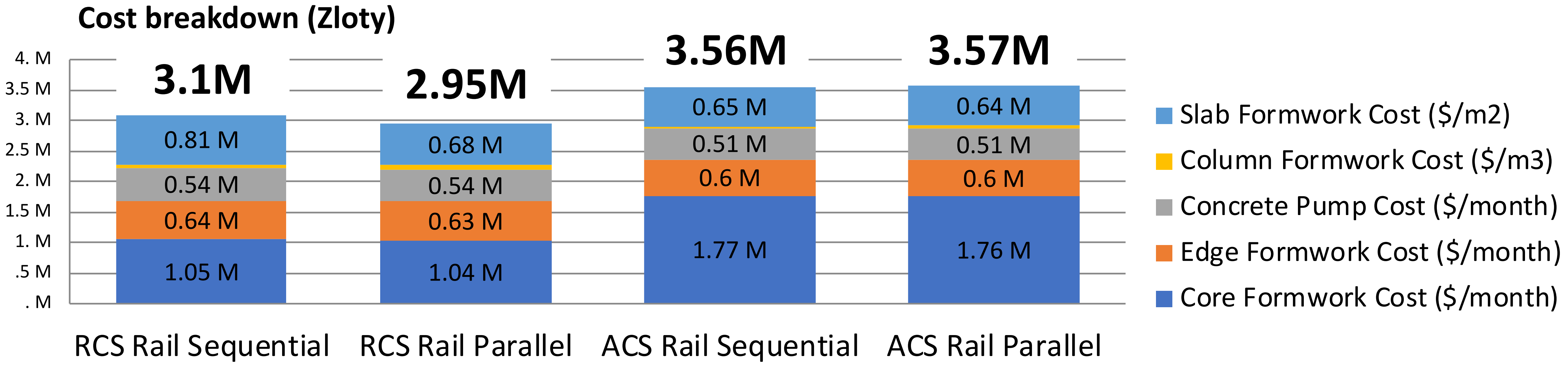
Z1 → Z2 → Z3

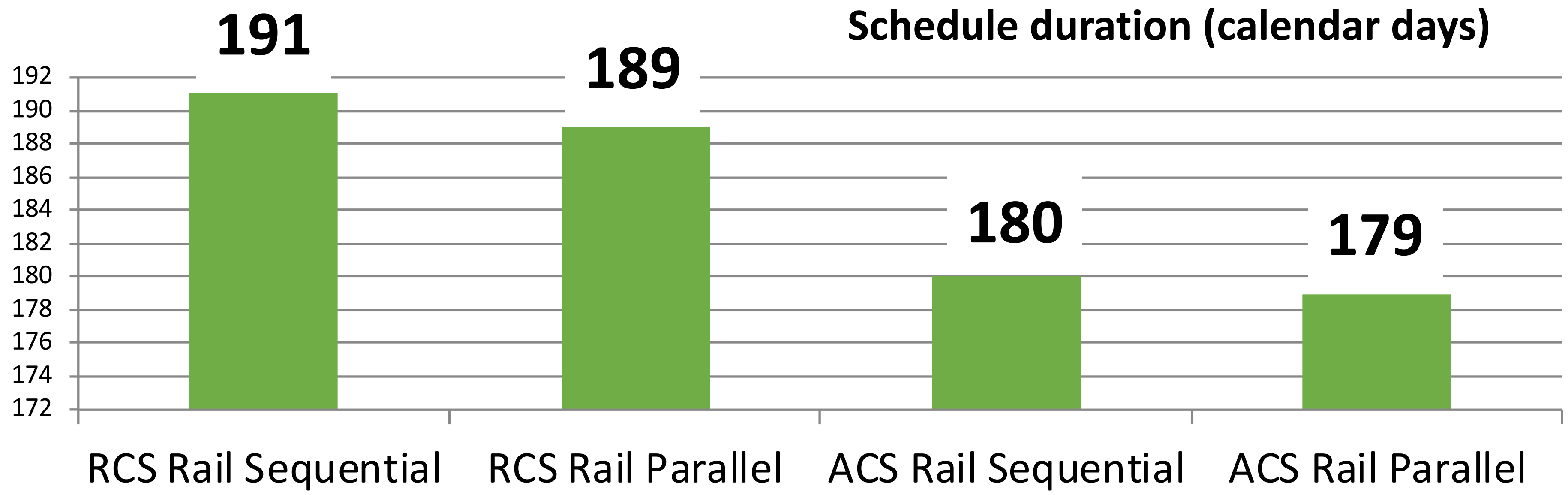
Sequential

Z1 ← Z2 → Z3

Parallel

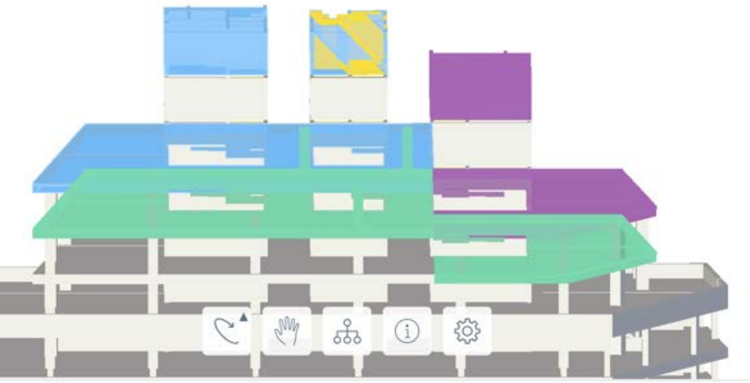
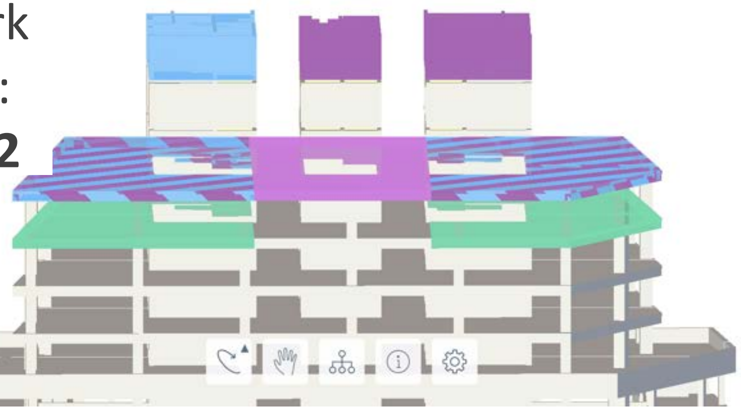
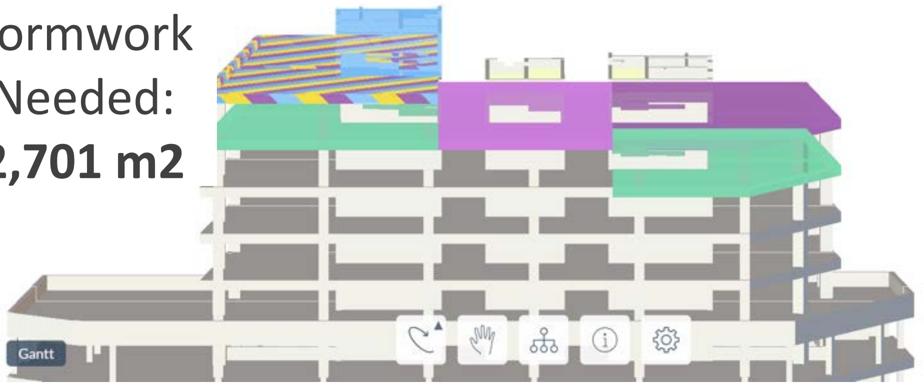
Results overview: cost and schedule





Results Overview – Slab + Column Formwork

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

	Sequential	Parallel
RCS	Formwork Needed: **3,182 m2** 	Formwork Needed: **2,701 m2** 
ACS	Formwork Needed: **2,701 m2** 	Formwork Needed: **2,701 m2** 

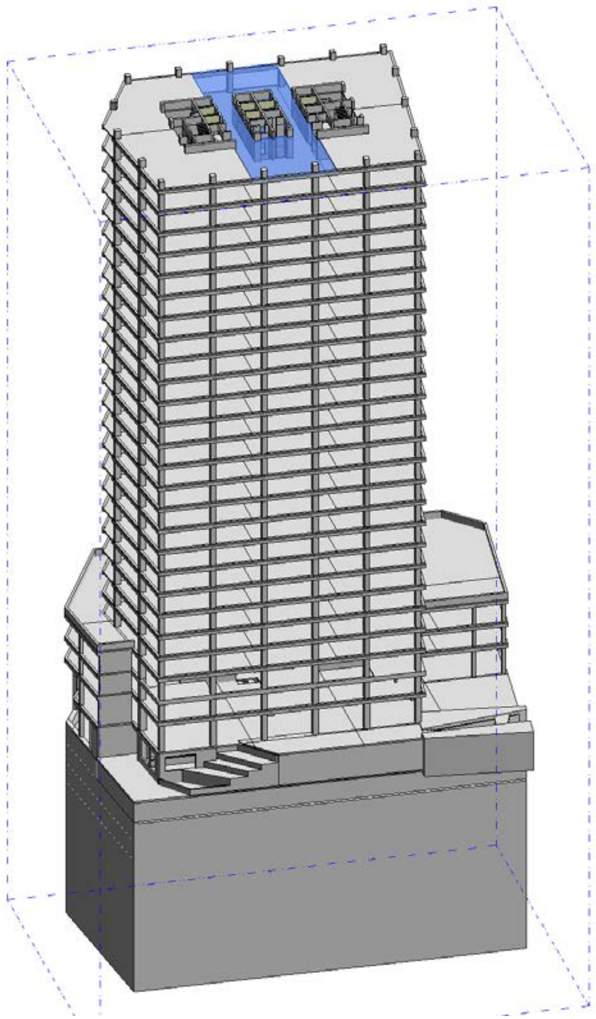
Key simulation and collaboration information

# Schedule scenarios generated	341
# Optimization runs	65
# Schedule scenarios used for analysis	24
Average time to reschedule	10 mins

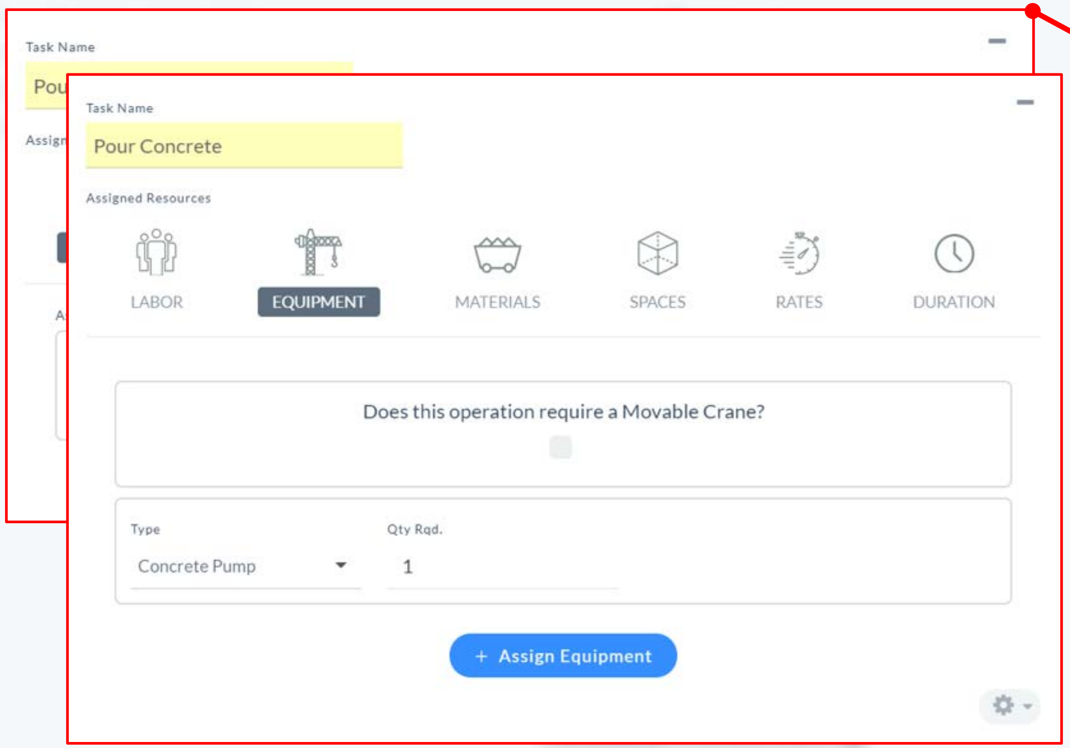
BIM simplification and zone breakdown

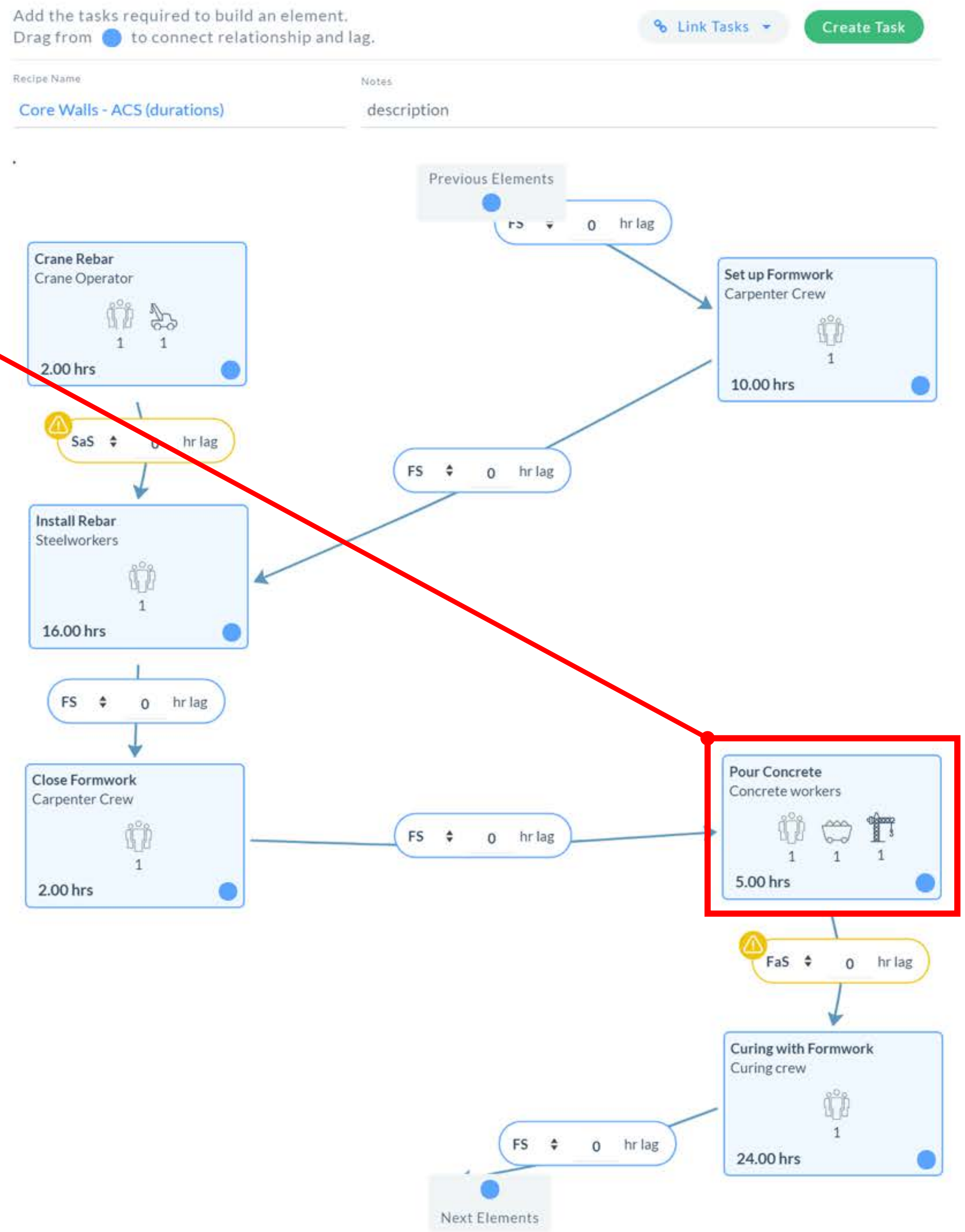
Input: Structural Model
Required Revit modeling time: 2 days

3,860 building components
344 construction elements

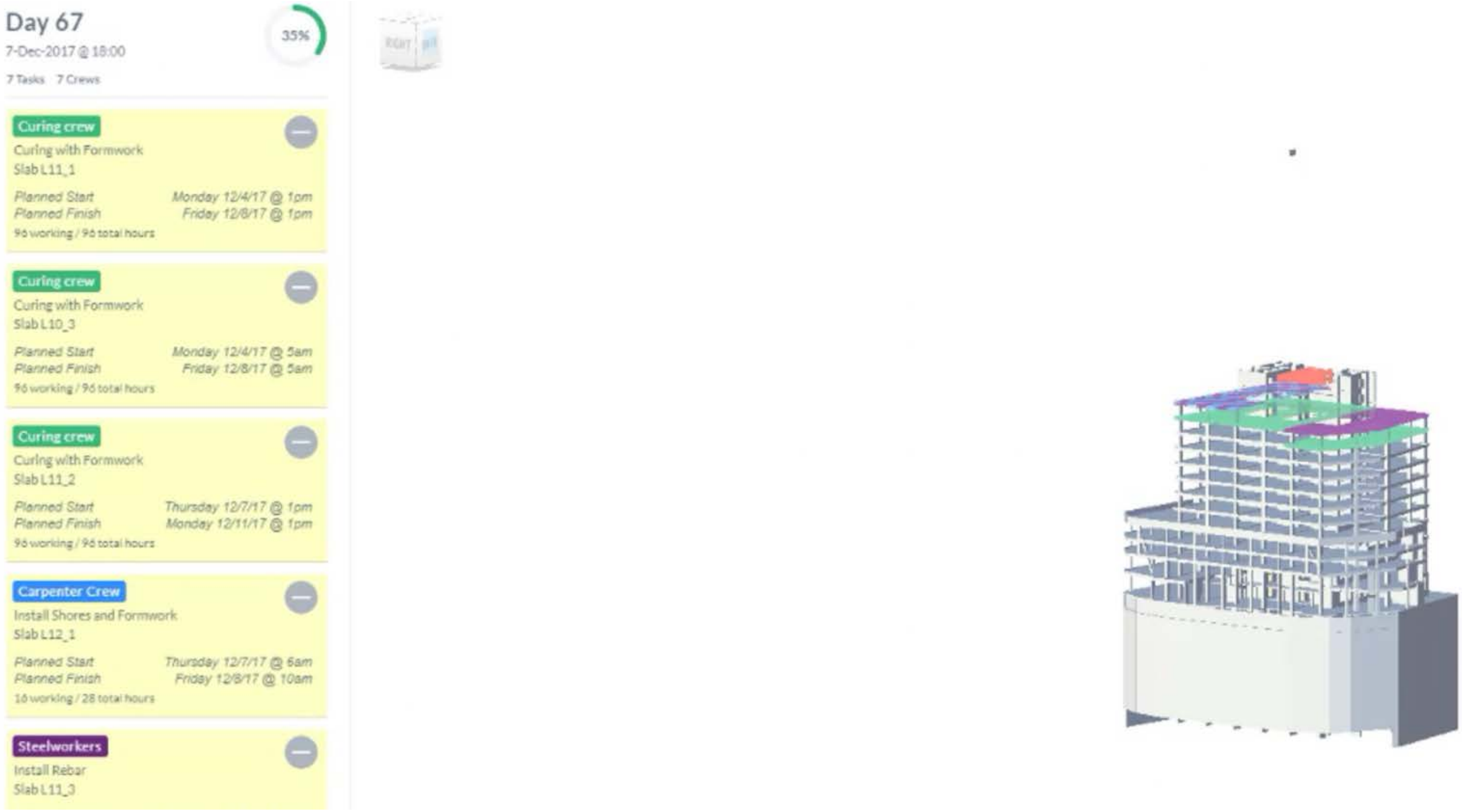


Construction recipes

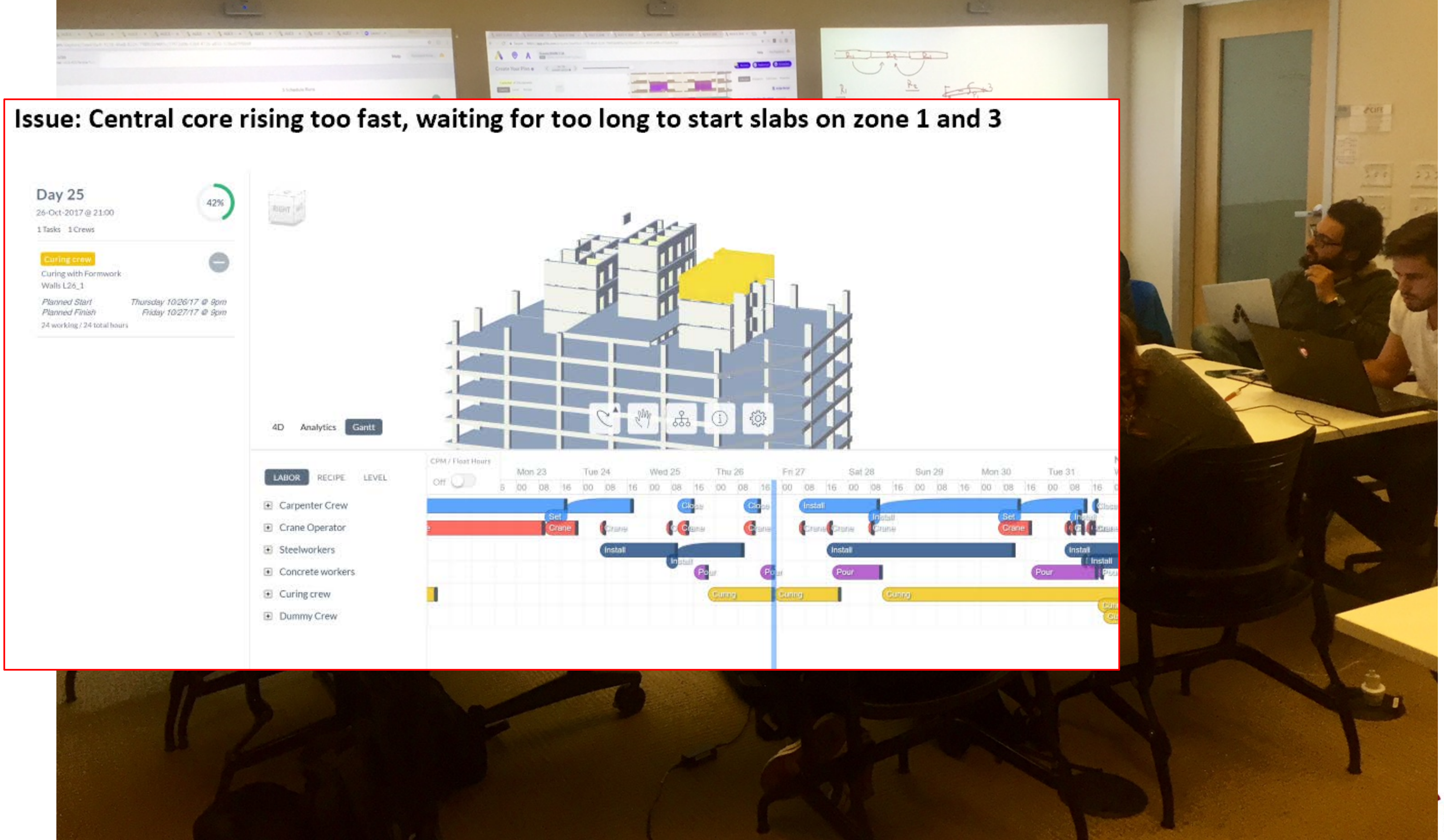




Given the recipes and BIM, ALICE generates 4D models automatically



Develop calibrated schedules



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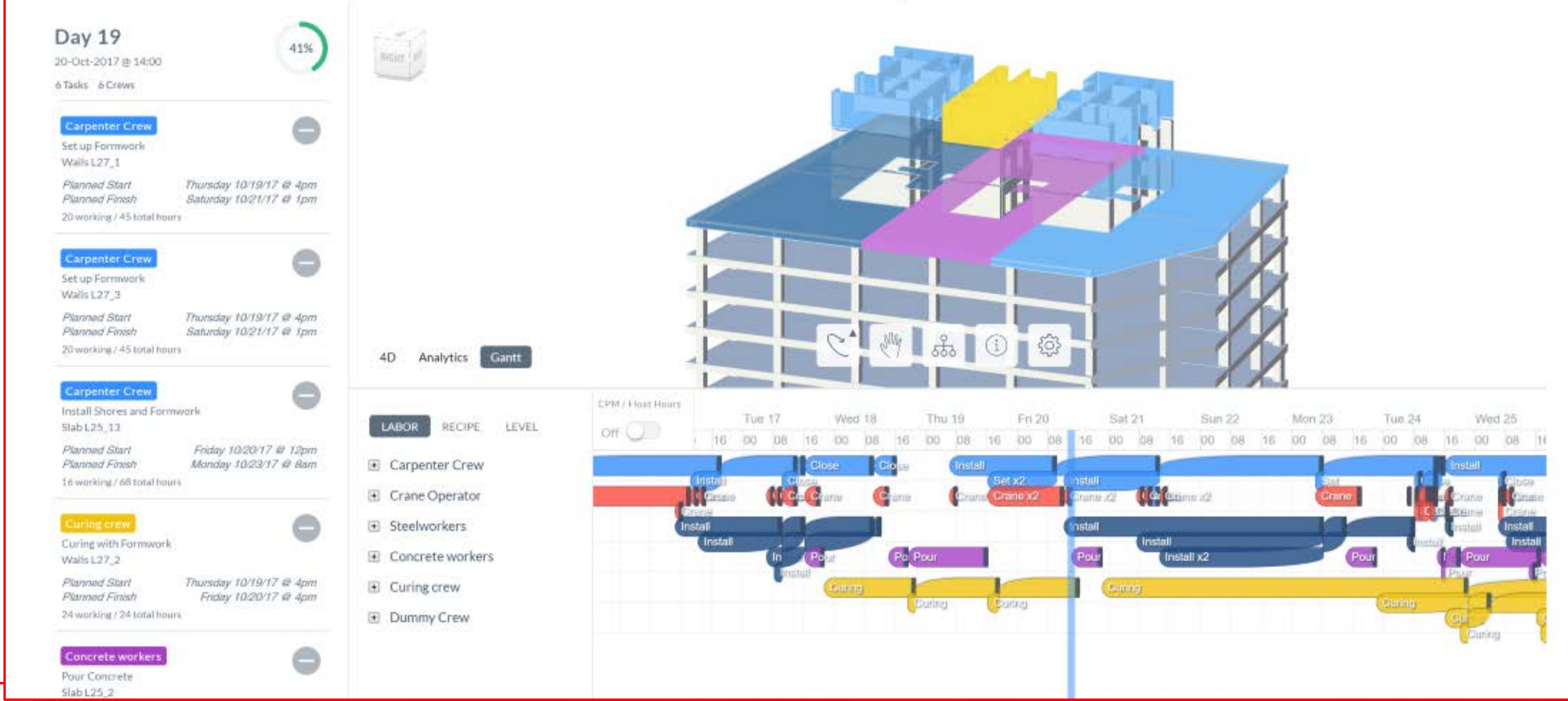
Develop calibrated schedules

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

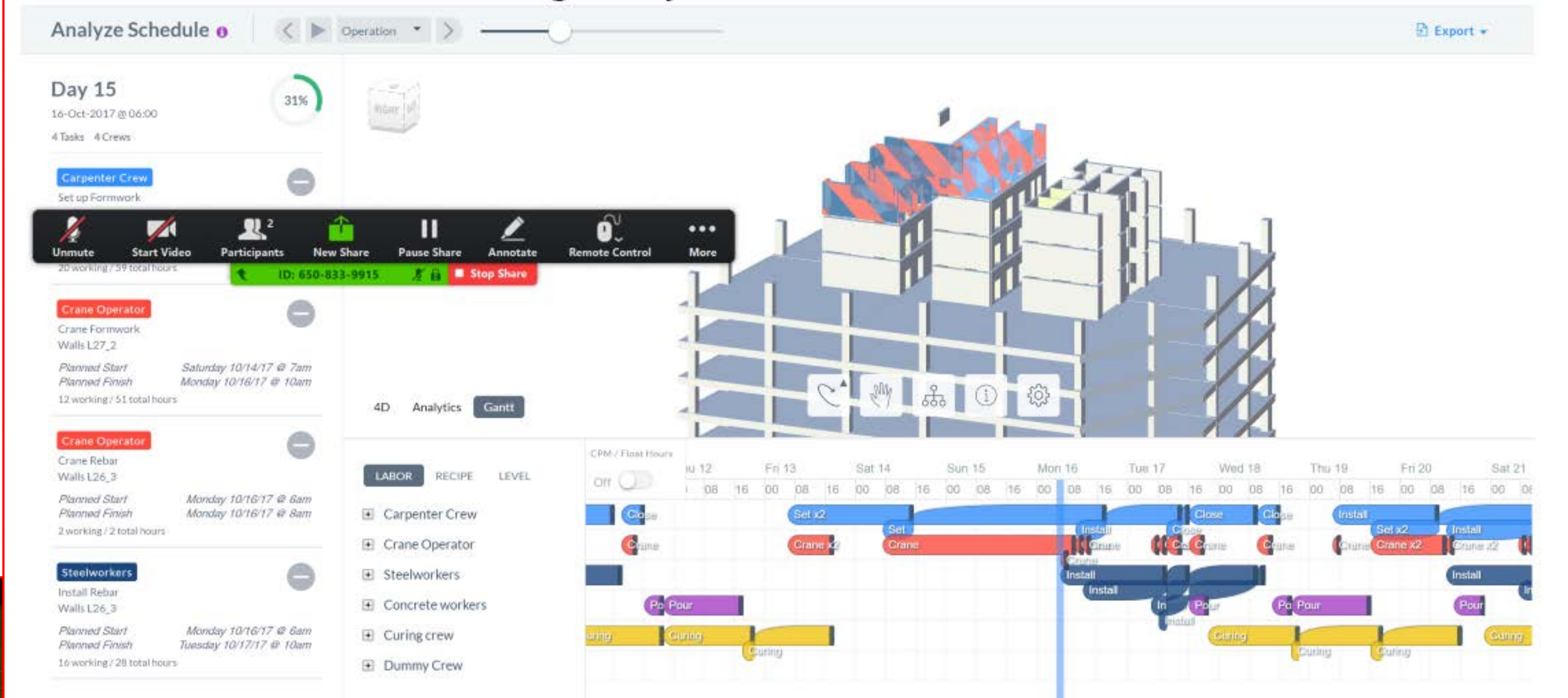


Develop calibrated schedules

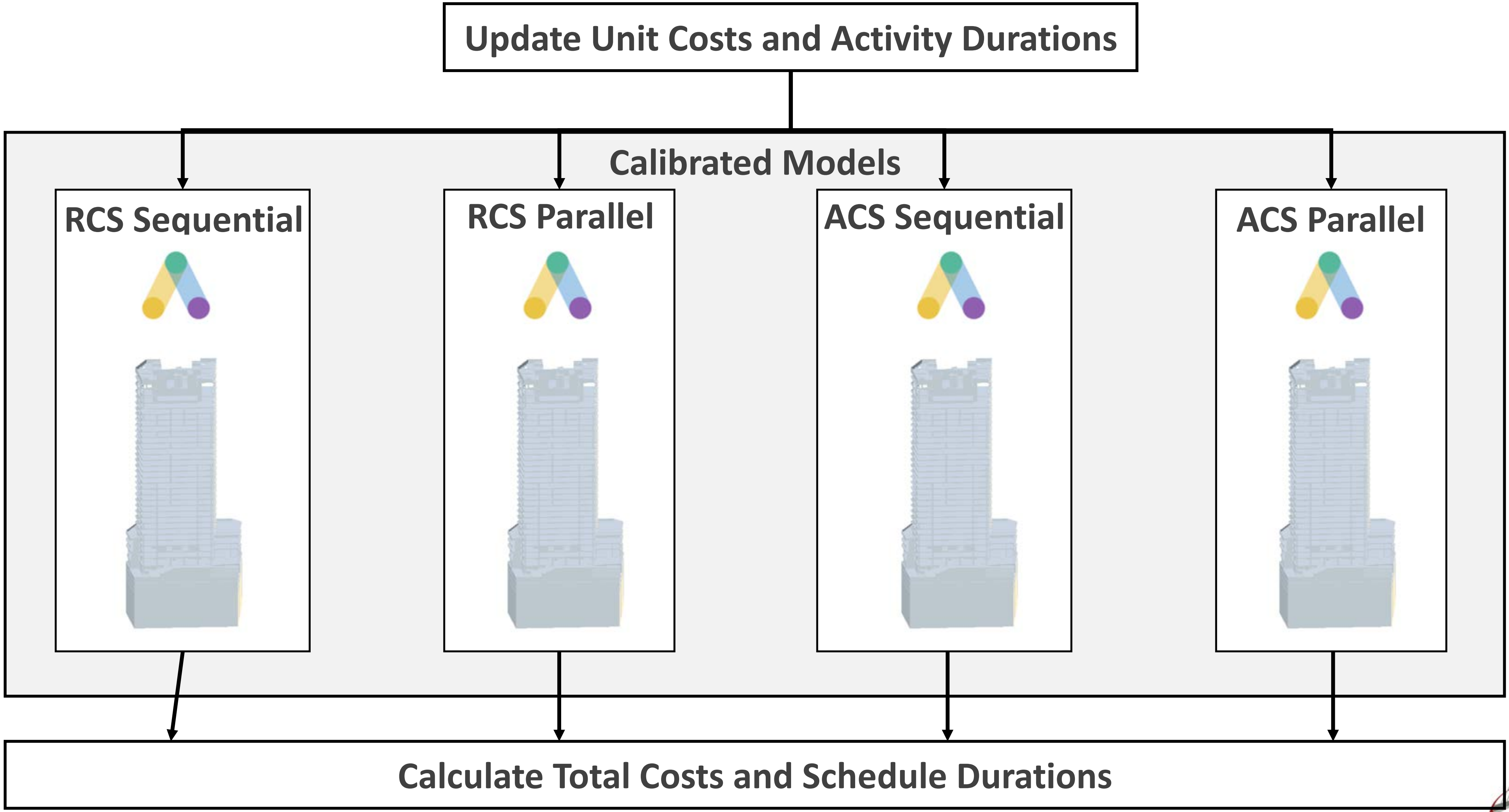
Issue: Central core rising too fast, waiting for too long to start slabs on zone 1 and 3

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

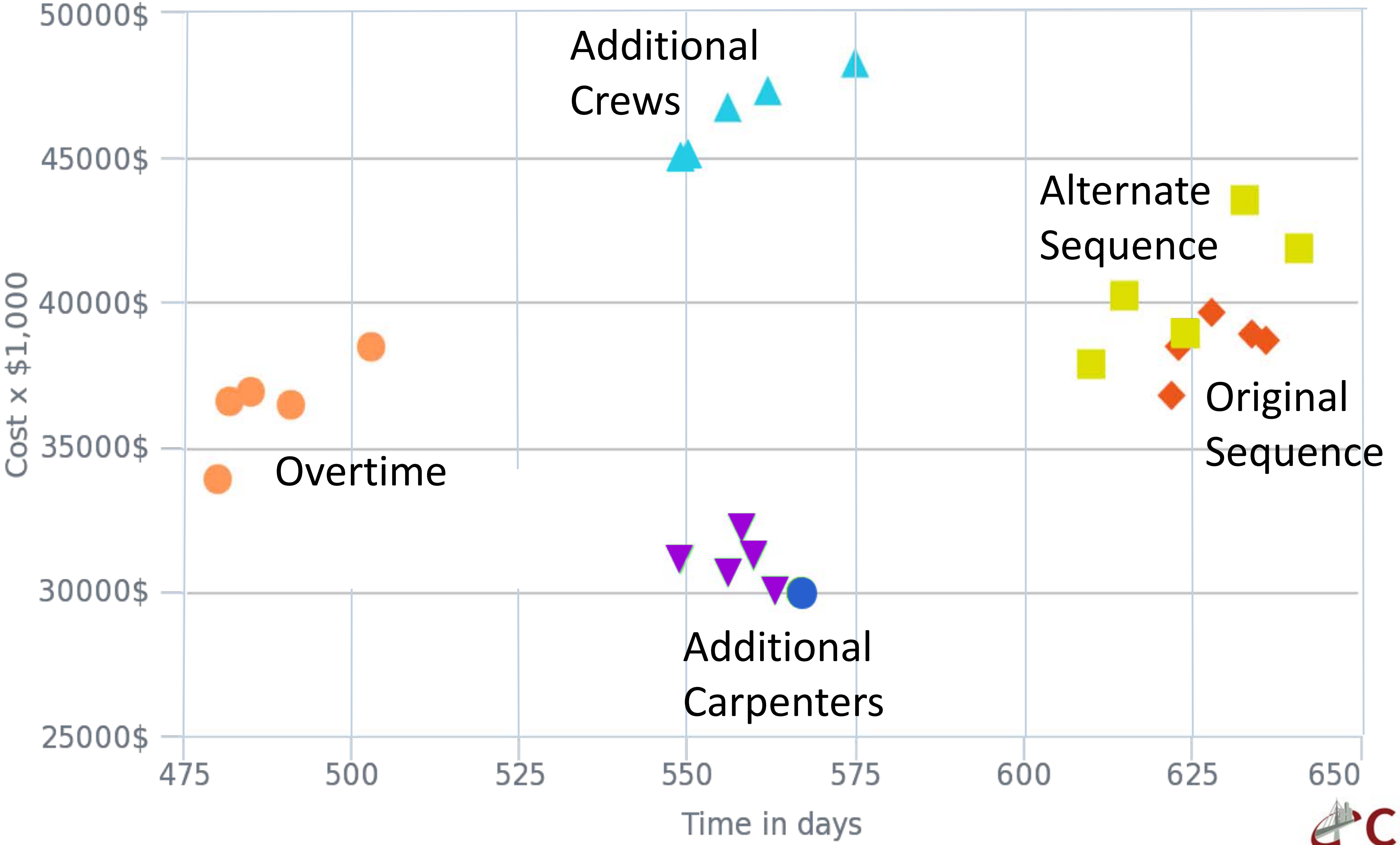
Issue: Cannot have cranes working on adjacent cores even on different levels.



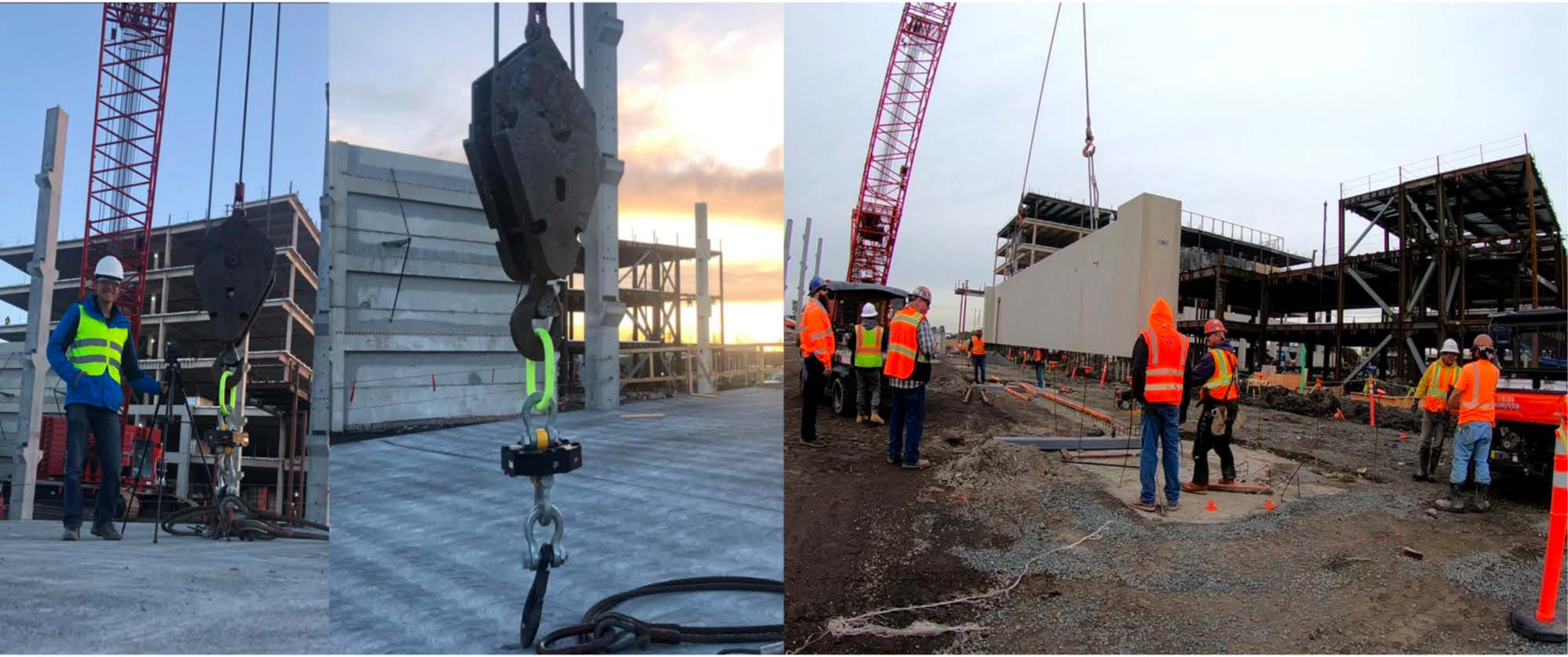
ALICE allows set-based construction scheduling



… for many conditions or situations



Measuring the variability of construction activities



Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

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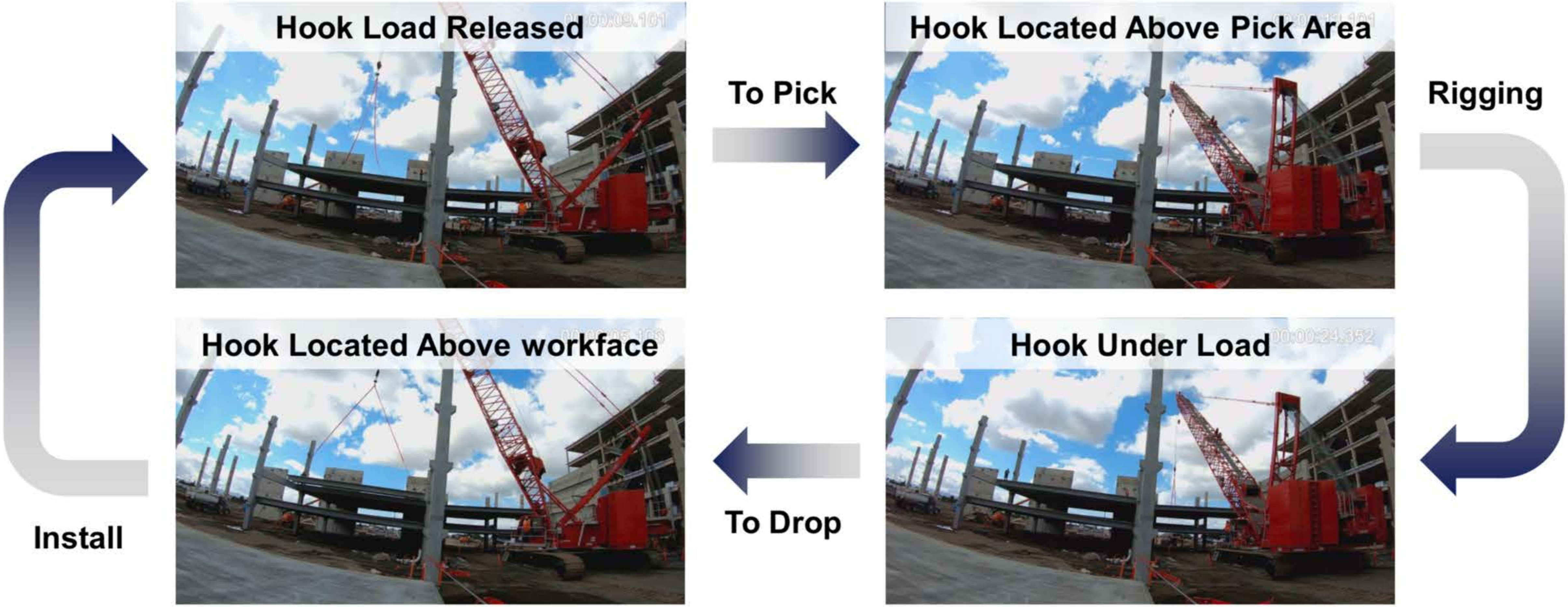
4-Step Installation Cycle

Total Cycle Time = To Pick + Rigging + To Drop + Installation



Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

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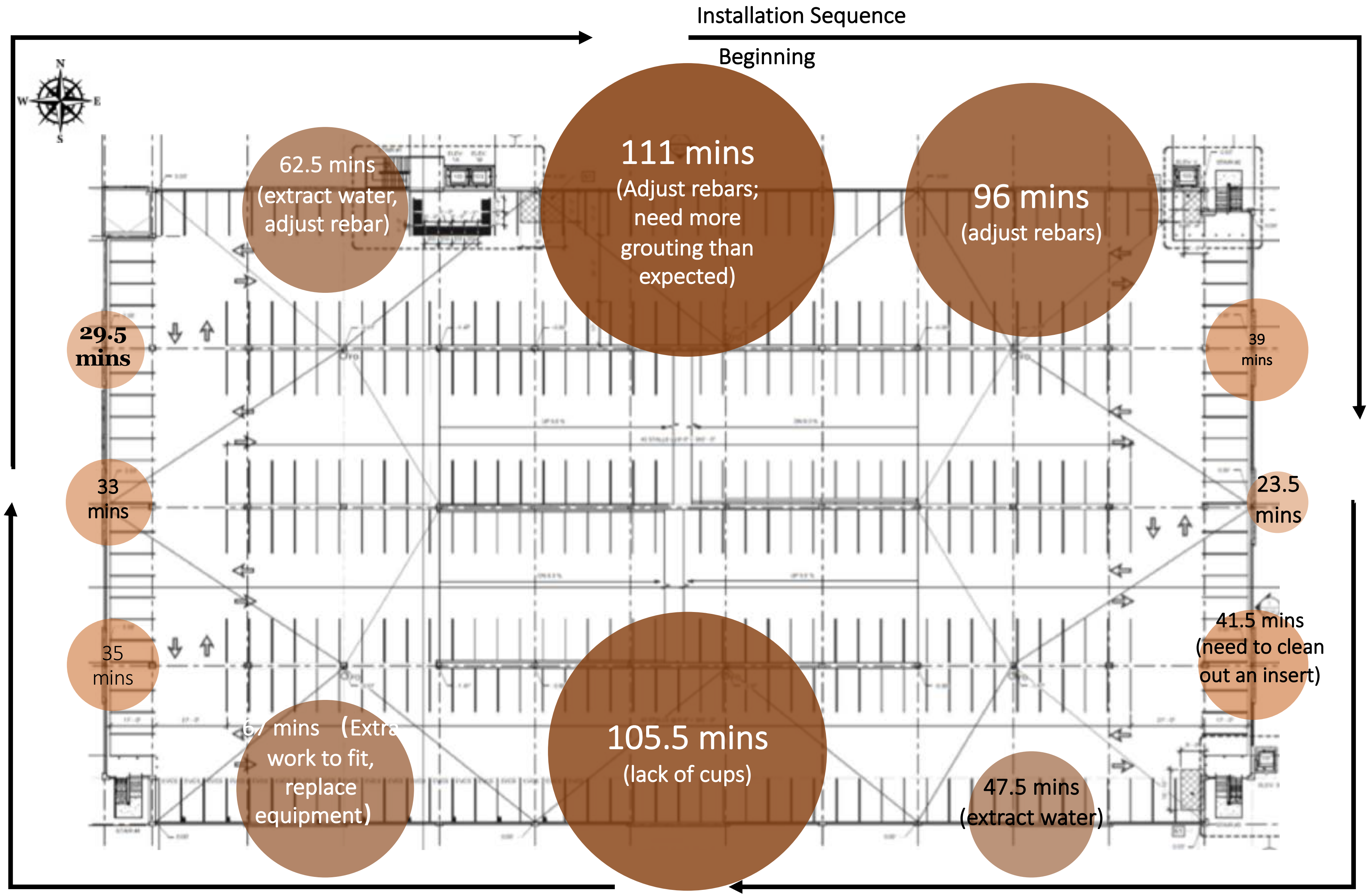
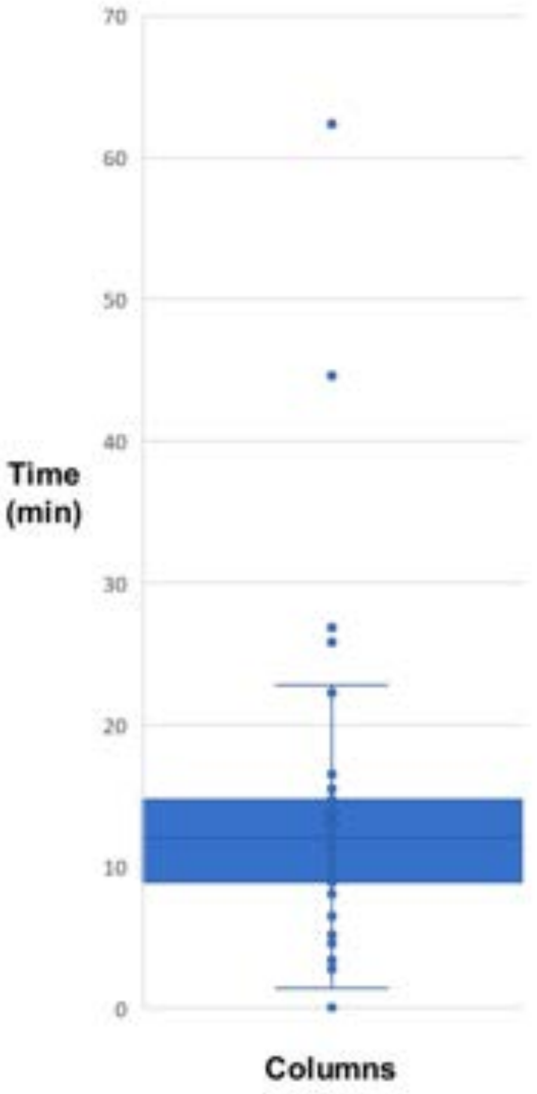
Collecting as-built data for every task to close the loop with pre-construction



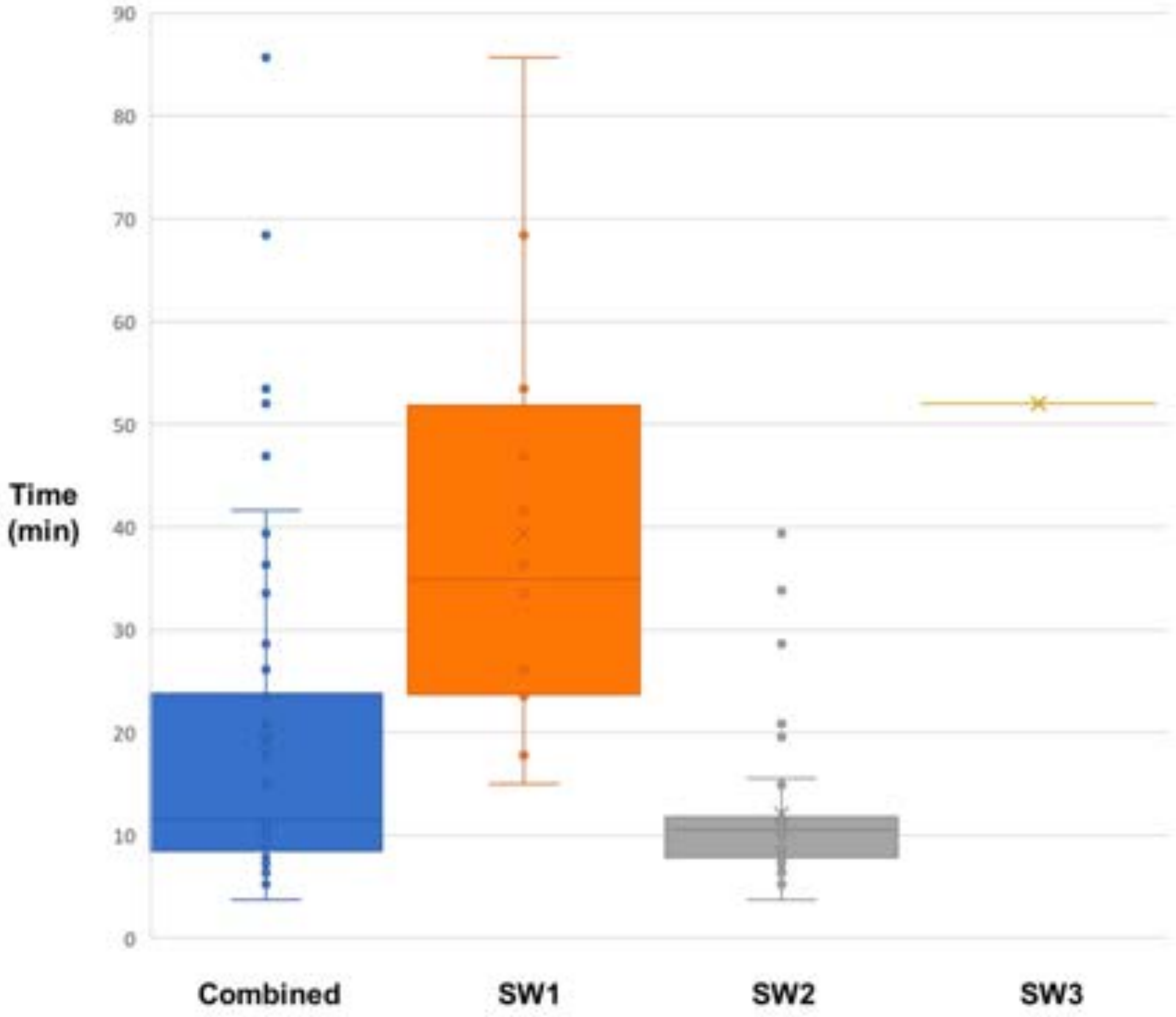
Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

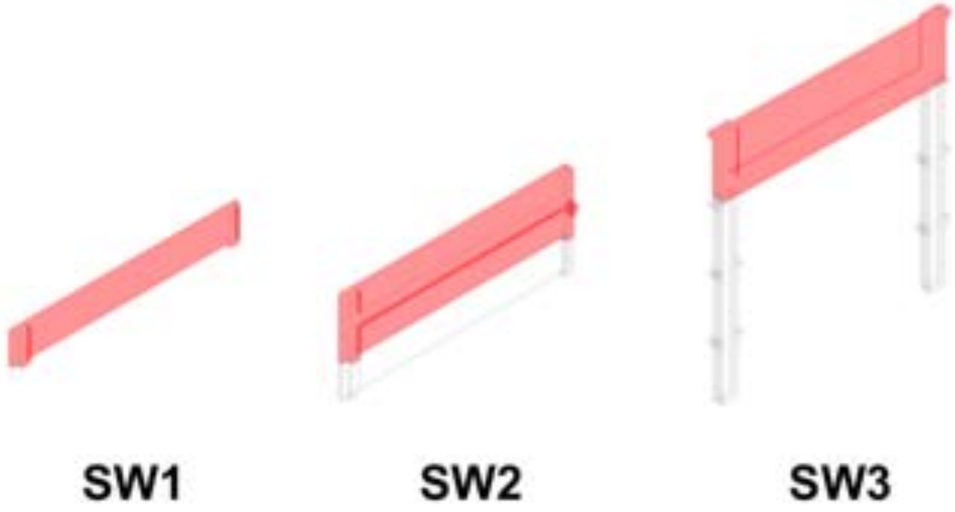
Column installation durations



Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

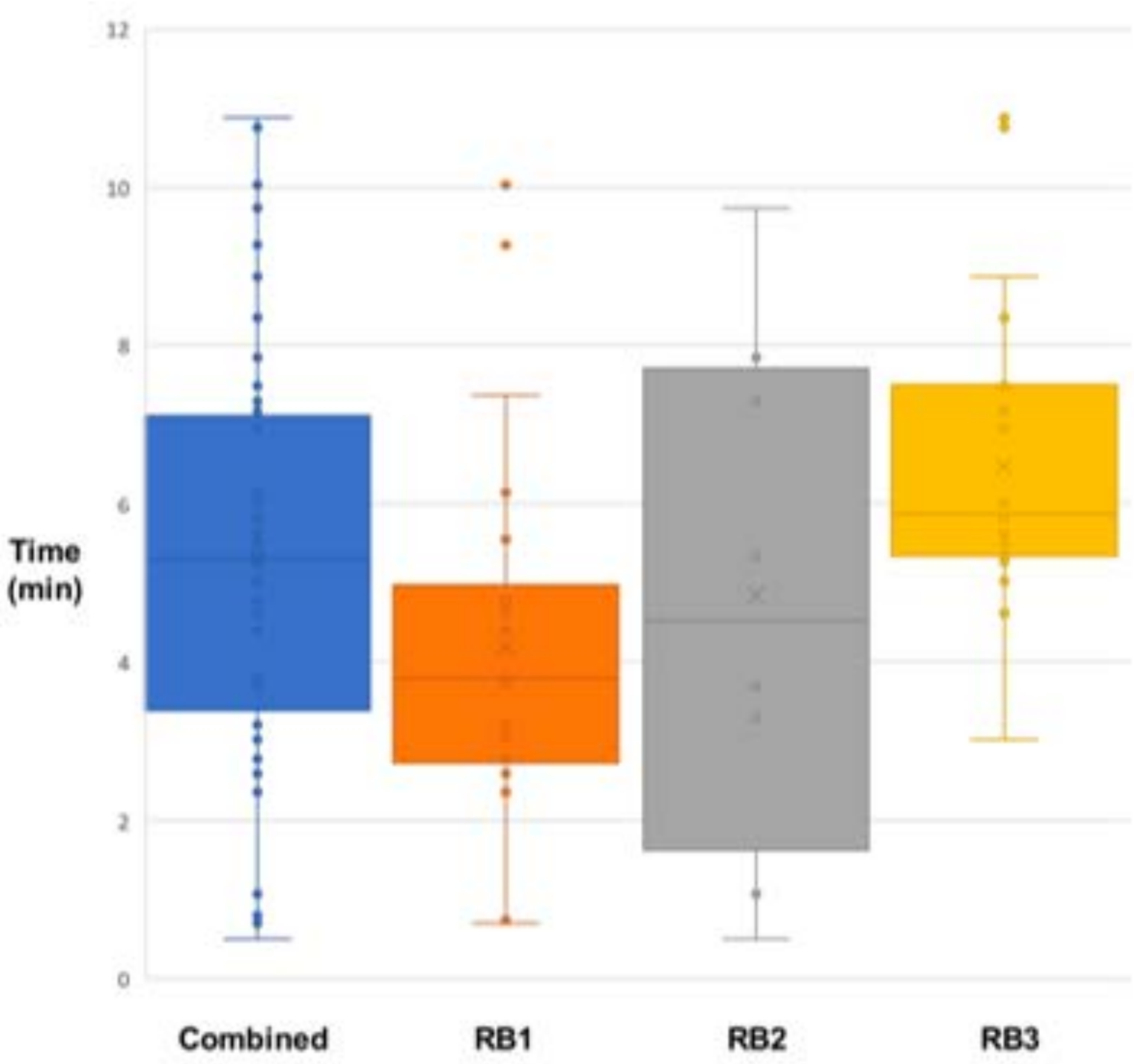
Shear wall installation durations

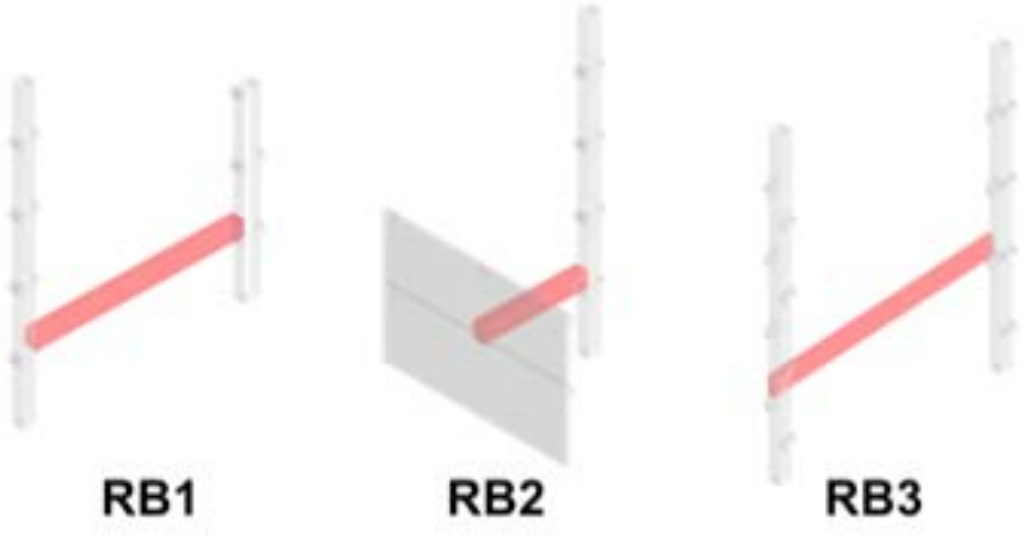




Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

Beam installation durations





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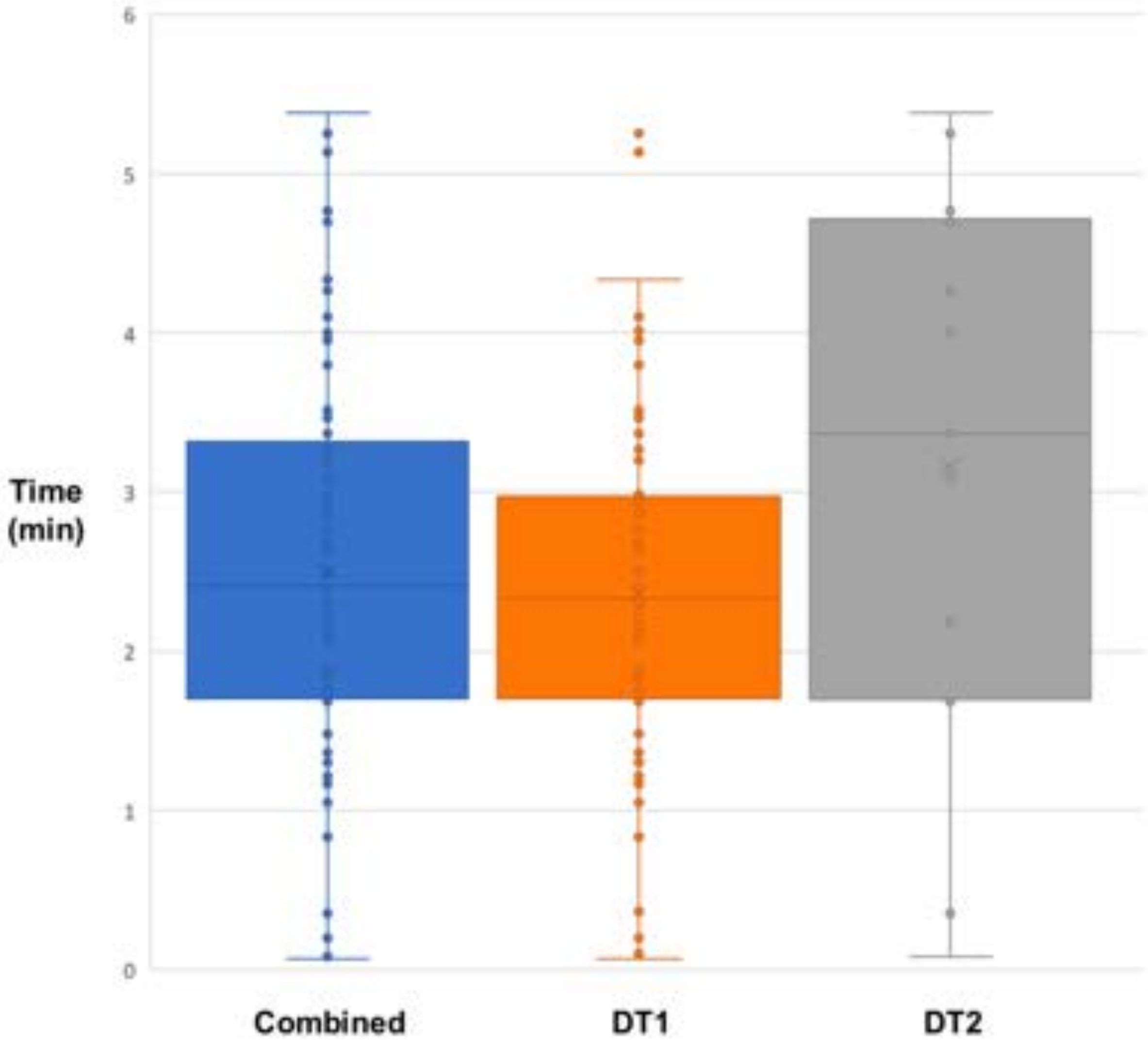
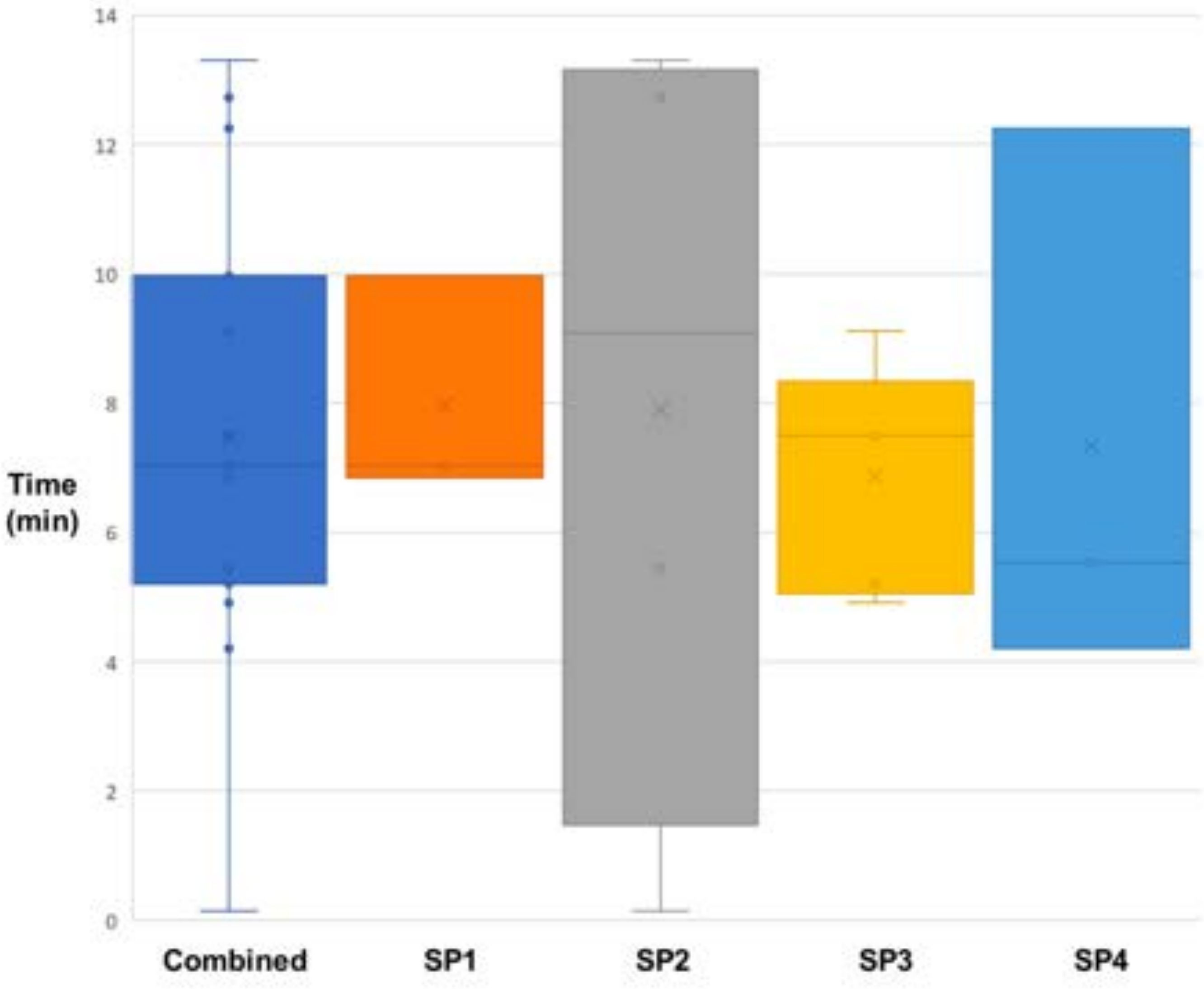
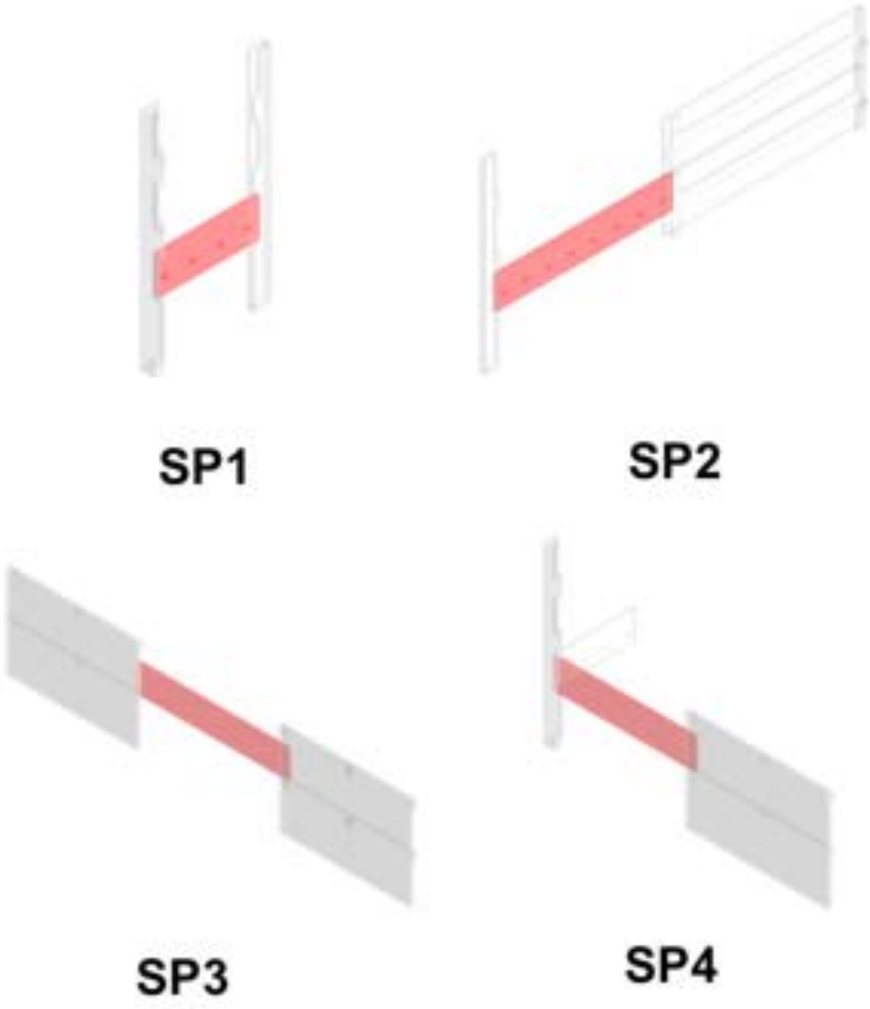
Double tee installation durations



Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

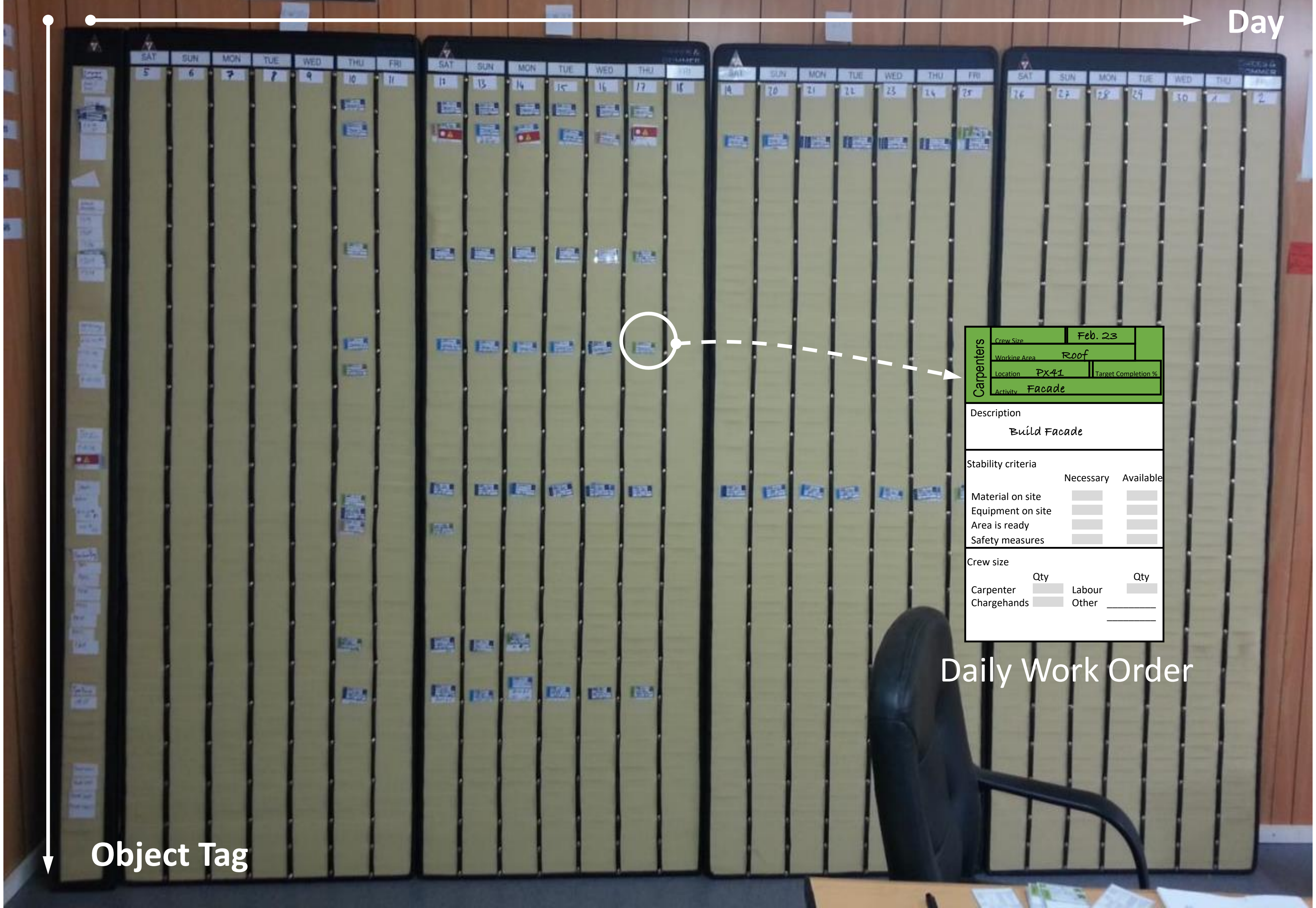
Spandrel installation durations





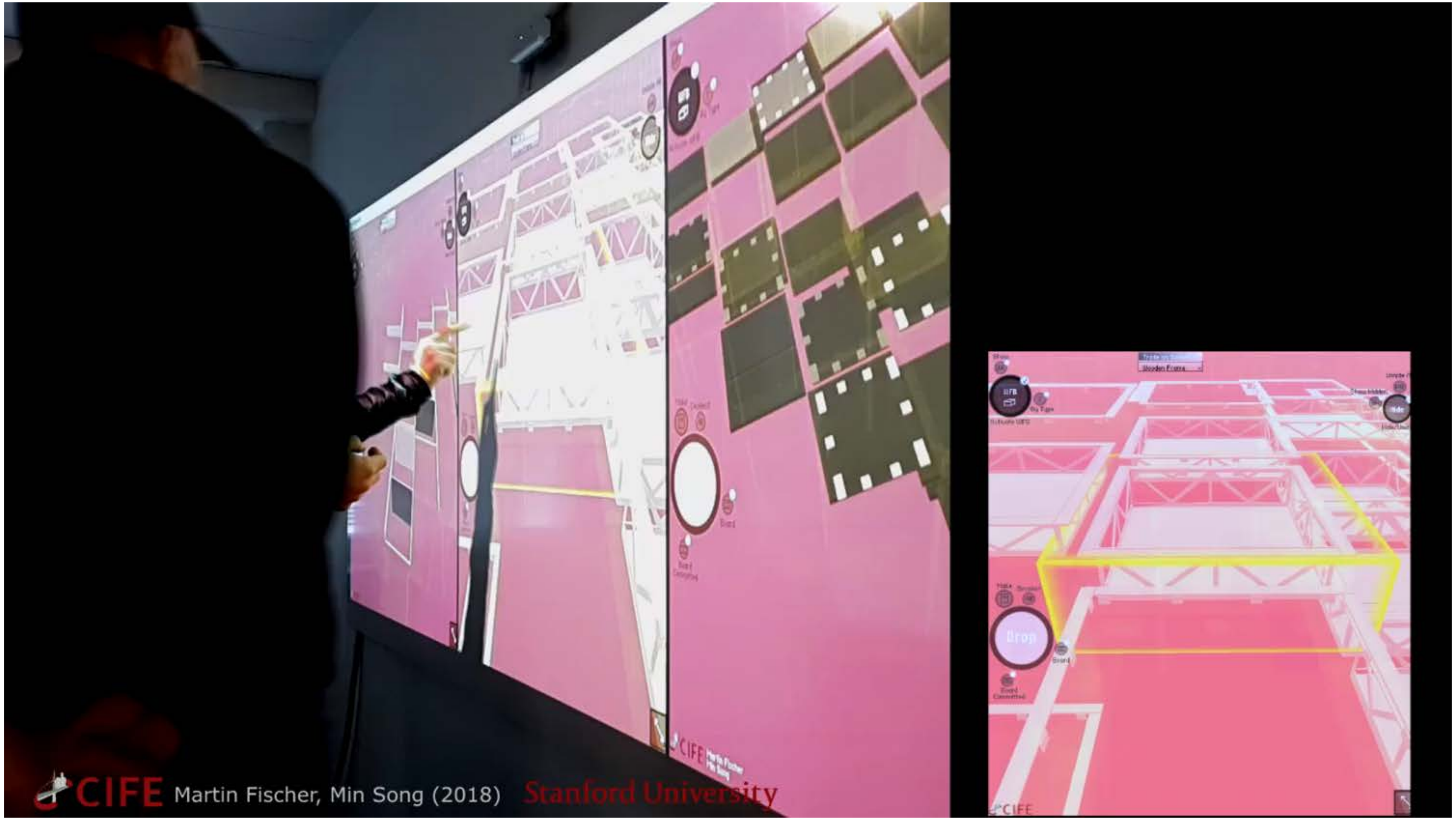
Work by Yan-Ping Wang and Rui Liu in collaboration with Clark Pacific and Versatile Natures

We are seeing lots of digitization of analog practices



Picture courtesy Min Song, DS Consulting, and CCC

Digital daily planning on site



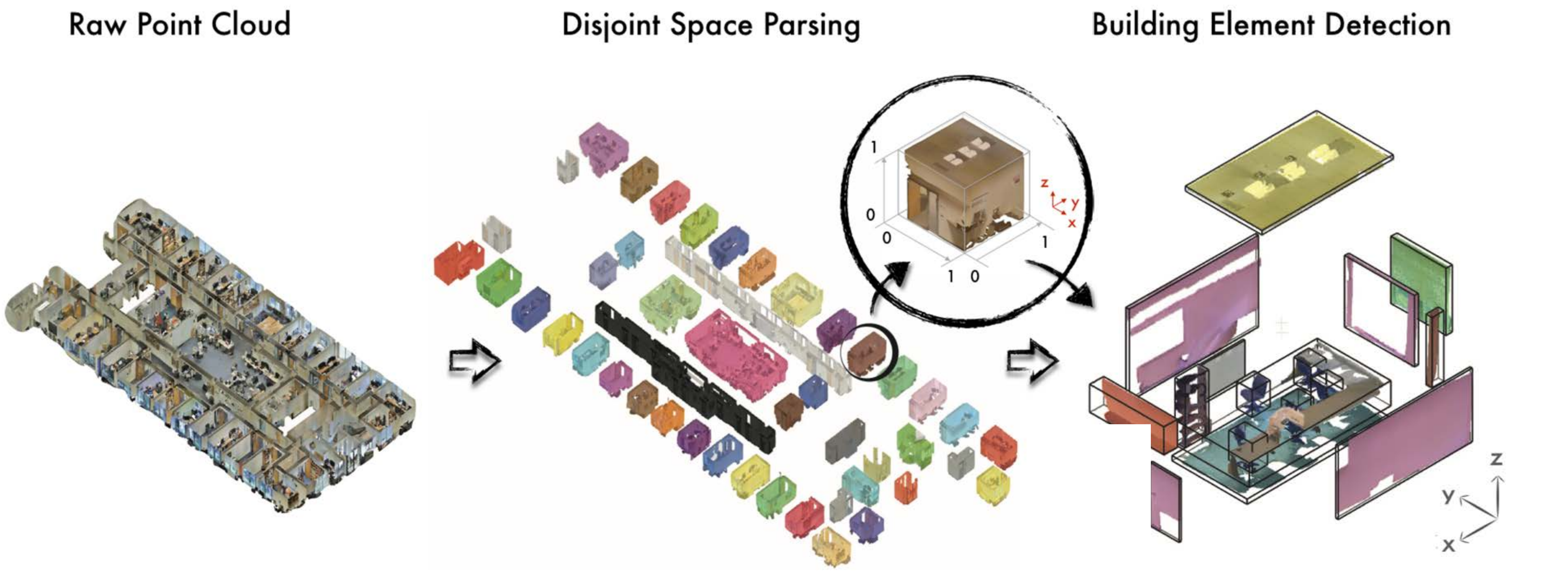
Work by Min Song

Average time spent for training: 17 min 30 sec

Foremen's native language in 5 experiments:

Arabic
Filipino
Swedish
Spanish
English

Deploying Computer Vision and Pattern Recognition Methods to Make BIM for Existing Facilities Affordable

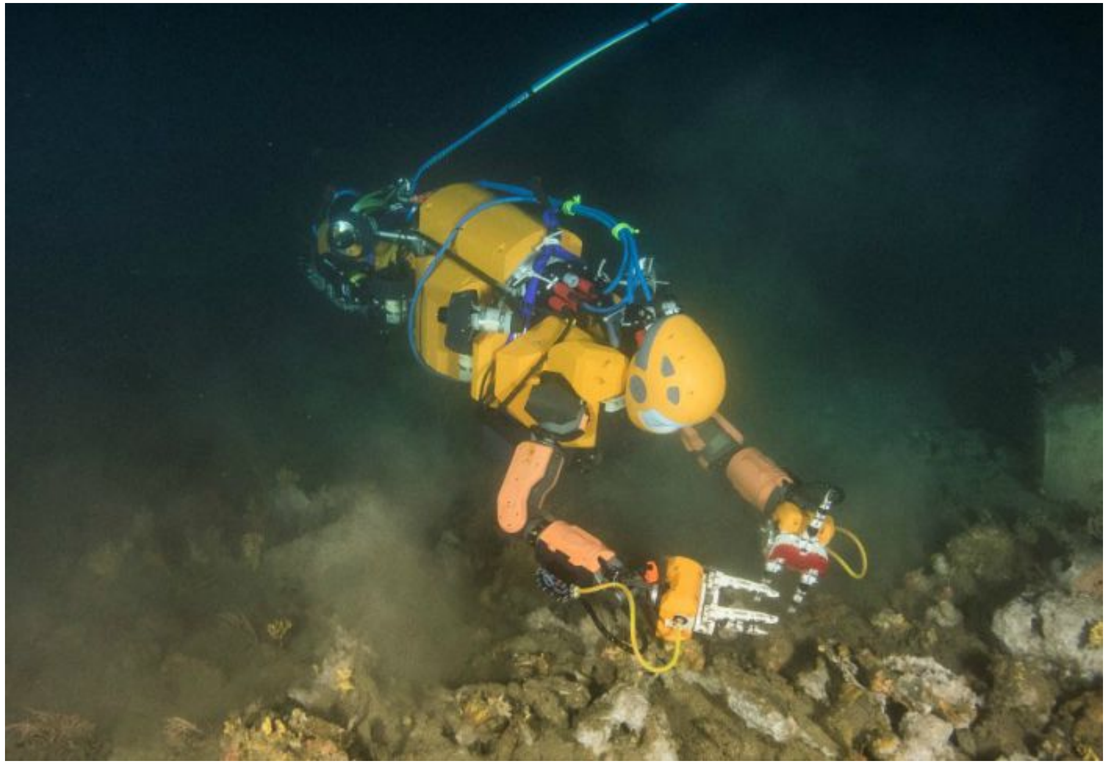


Semantic Building Parser Research

With Silvio Savarese, Iro Armeni, Amir Zamir, buildingparser.stanford.edu

Merging robotics, sensing, vision, haptics, and VR

OceanOne by Oussama Khatib, Robotics Lab, Stanford University



We must act with an understanding of our immediate and broader context

Andrew Ng

https://www.mma-fl.com/best-methods-to-reduce-construction-site-injuries/

I have made all my generals out of mud.

Napoleon

Picture by Martin Fischer

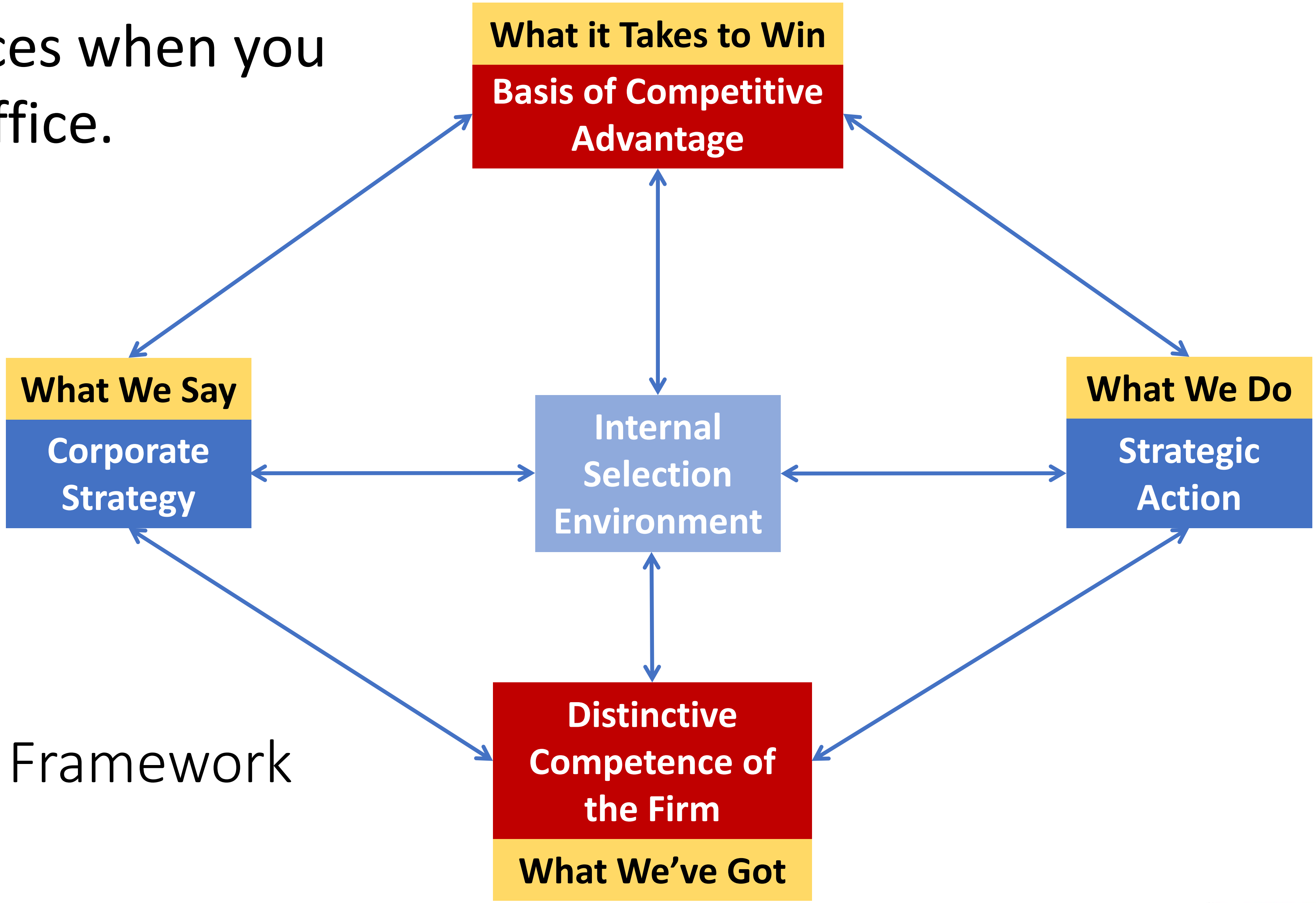
CIFE
CENTER FOR INTEGRATED FACILITY ENGINEERING

Interact in a virtual environment

Screenshots courtesy Brandon Fischer

- Rapidly understand and update:
  - target
  - team
  - roles
  - progress
  - obstacles
  - individual / team performance
- Frequent communication, feedback

You must decide how to allocate your firm's resources when you get back to your office.



Strategy Diamond Framework

© Source: Robert A. Burgelman, Stanford Graduate School of Business, Lecture Materials, 2014.

You can't always get what you want, but if you use operations and data science you may get what you need

Or: The next practice of engineering and managing capital projects

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