Robots for Construction

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Industry and Academic Perspective

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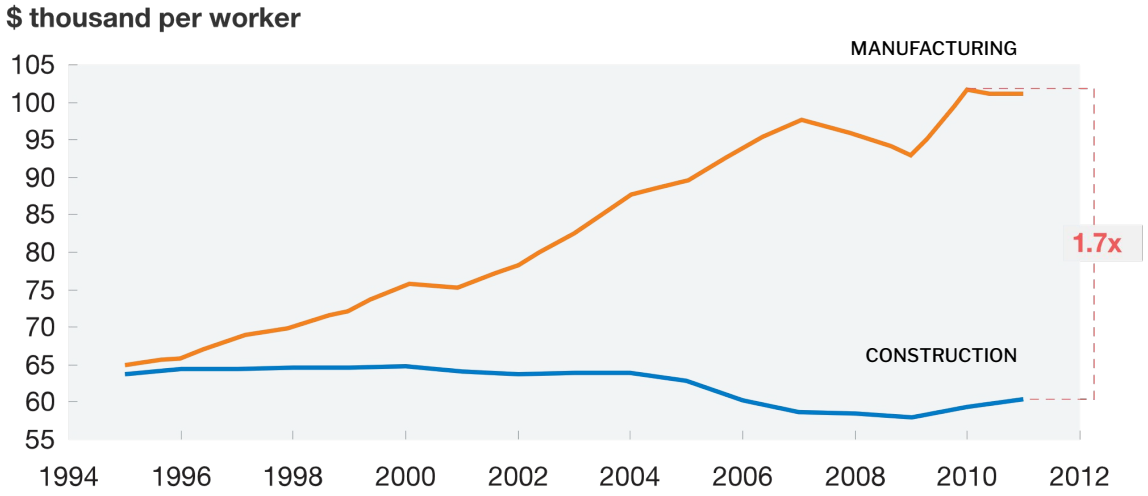
1. <u>Overview of construction problems and AI solutions</u>
2. Case study: Interior Layout
3. AI/Robotic solutions being explored
4. Where should AI and AEC be heading?
5. Discussion

The build industry is facing several challenges over the next decade

INDUSTRY PRODUCTIVITY



SOURCE: PAUL TEICHOLZ, CIFE

URBAN GROWTH

- 90% of population growth is expected to be urban
- 70% of the population will be in cities by 2050

PRODUCTIVITY

- Productivity per worker in the construction space has been declining since the 1960s, showcasing a need for investment in the space

MANUFACTURING

- By moving to a manufacturing production system, the industry will see up to 10x productivity boost and drastic operational improvements

DESIGN DOCUMENT QUALITY

- Both Mortenson and our customers experience budget overruns and margin erosion due to inadequate design.
- The current fragmented and siloed nature of design does not lend itself to a manufacturing approach to construction.

INDUSTRY TODAY

- The AEC Industry continually experiences declining productivity.
- Owner's continue to have less-than satisfying experiences
- Skilled craft workforce availability is a growing problem
- Facilities are generally built in similar ways they were decades ago
- Fragmentation has stunted the industry

The industry is ripe for disruption

WE ALSO RECOGNIZE THE WORLD IS RAPIDLY CHANGING


Urbanization


Sustainability in Design


City Resiliency

Community Engagement


Industrialization of Construction


Building Performance


Lean Construction


Prefabrication

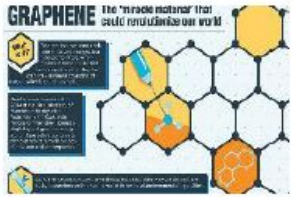

Robotics, AI & Machine Learning


Computational Design


Autonomous Vehicles


Mobile & Cloud Computing


3D Printing



Innovative Materials

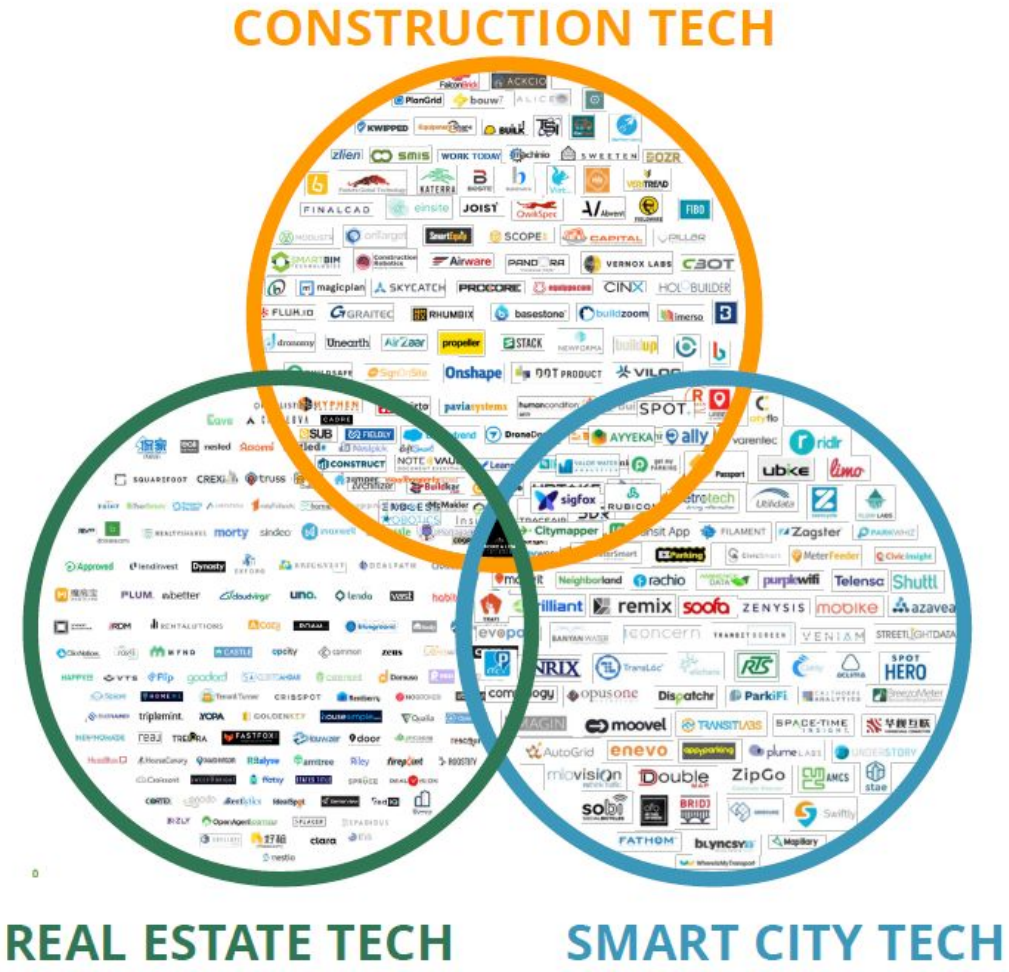

AR & VR

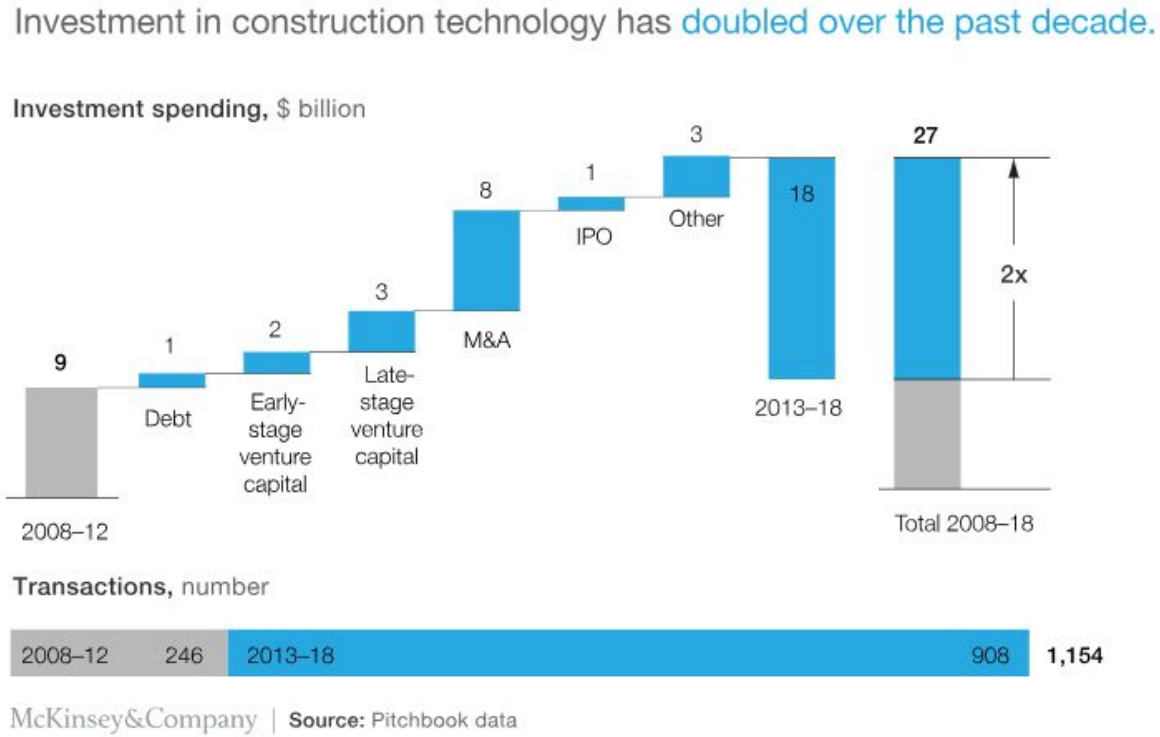

Internet of Things & Big Data

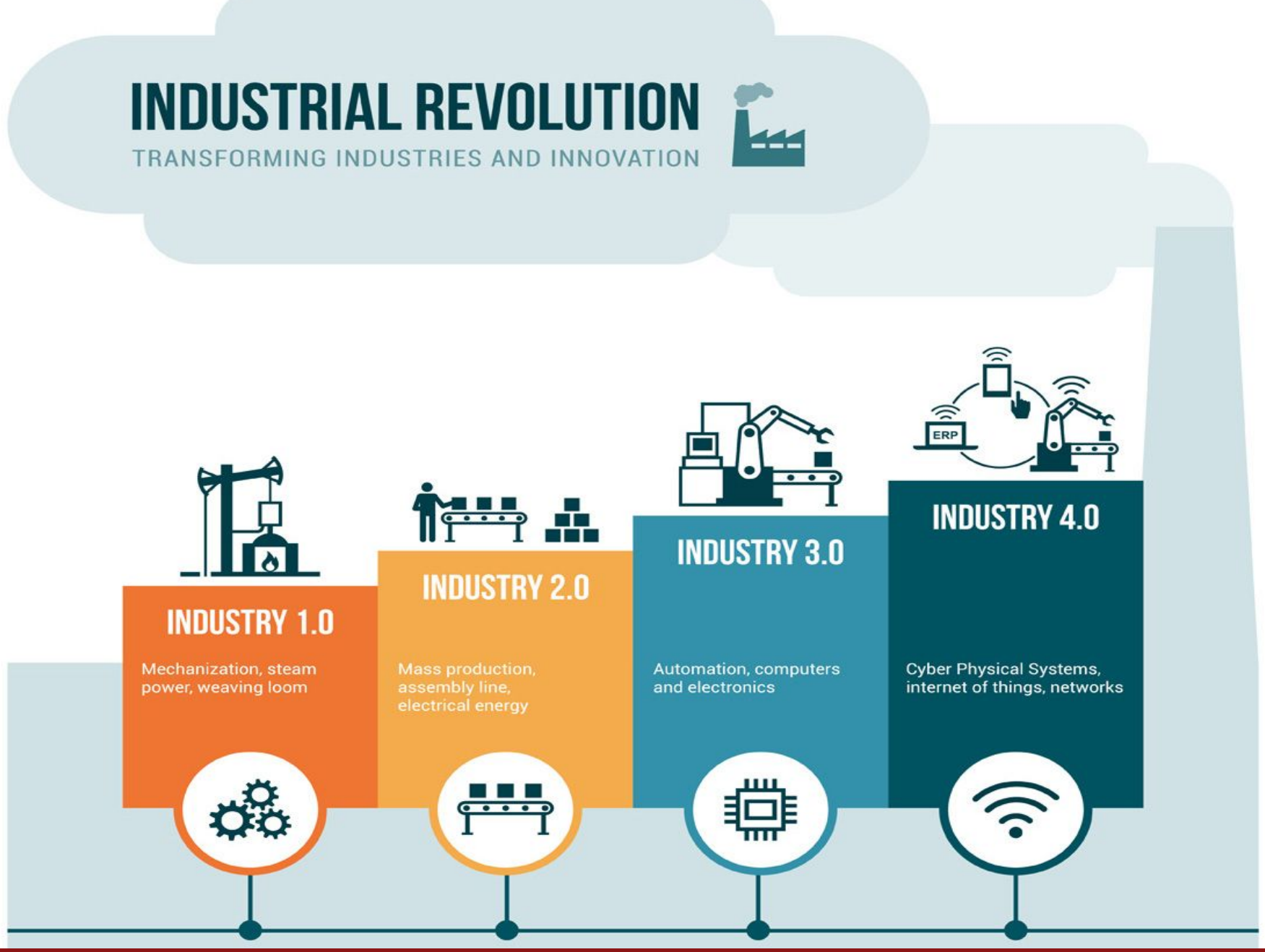

Drones & UAVs


BIM & 3D Design

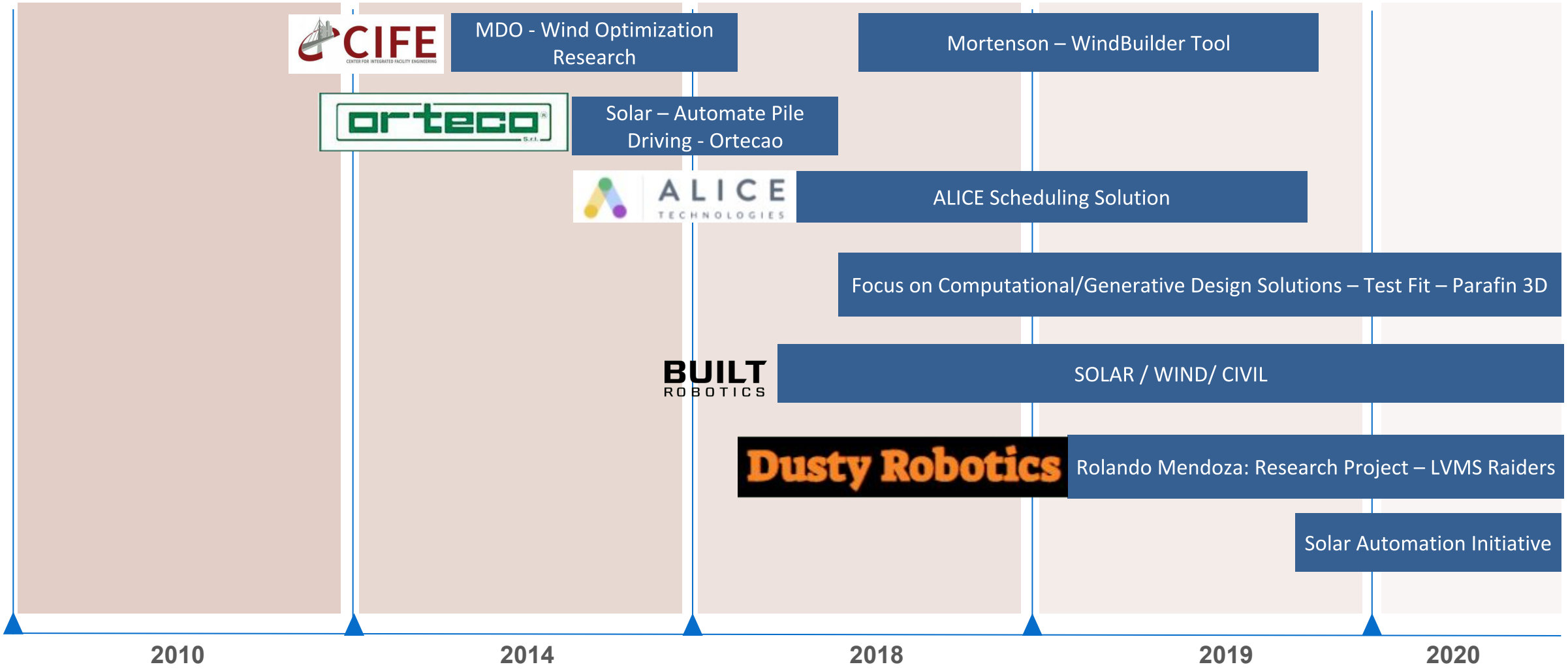
And that the AEC industry is attracting new investment



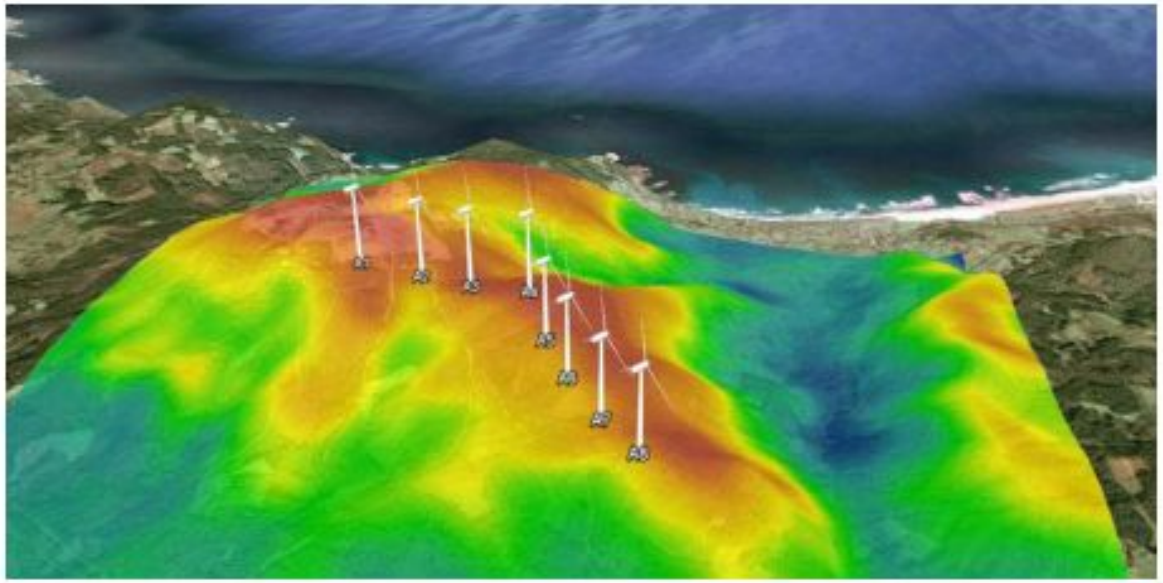



INDUSTRIAL REVOLUTION
TRANSFORMING INDUSTRIES AND INNOVATION
ERP
INDUSTRY 1.0
Mechanization, steam power, weaving loom
INDUSTRY 2.0
Mass production, assembly line, electrical energy
INDUSTRY 3.0
Automation, computers and electronics
INDUSTRY 4.0
Cyber Physical Systems, internet of things, networks

Progression of use of AI at Mortenson



Improving design phase outcomes



WIND FARM DESIGN

Scope:	Life-cycle cost and revenue, including infrastructure
Partners:	Mortenson AWS TruePower
Team	Ramon Iglesias Martin Fischer

Leveraging research to innovate how we work!

Conventional vs MDO method

Wind Farm Case Studies

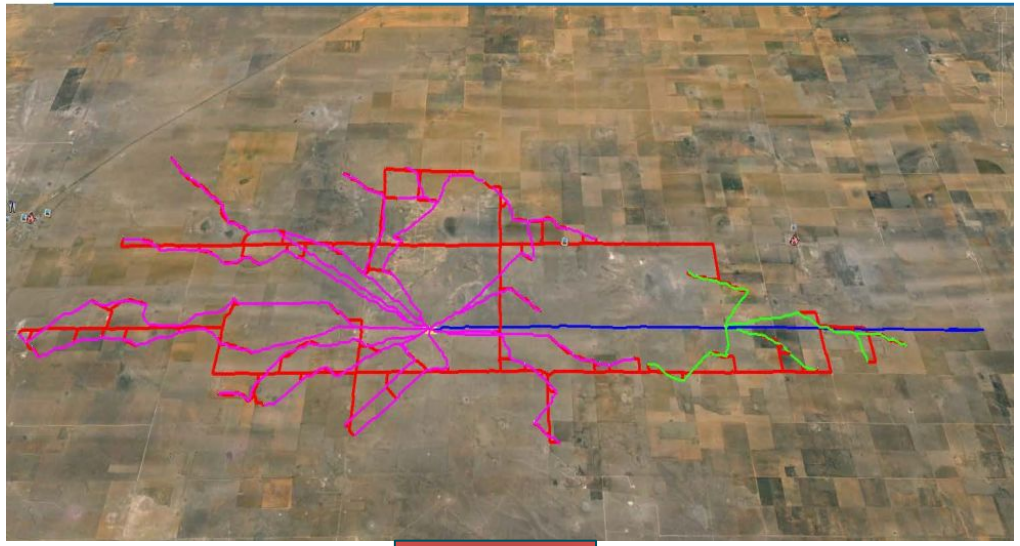
PROJECT #2

- 300 MW
- 62,000 contiguous acres
- 150 turbines

Case Study #2 Summary of Results

#	Option	Construction Cost / Δ (M USD)	Net Energy (GWh)	Cost of Energy (USD / MWh)
1	As Built	**90.37**	**1450**	**36.28**
2	Fixed Substation	**-4.90** (5.4%)	**1448**	**-0.43** (1.2%)
3	Optimized Substation	**-4.17** (4.6%)	**1457**	**-1.18** (2.8%)

Case Study #2 Proposed Layout



Case Study #2 MDO Layout

Applying similar Optimization Methods to Improve Design

Robot example 1: Autonomous equipment

PROBLEM:

Shortage of skilled operators in rural areas, especially wind turbine projects.

BUILT ROBOTICS PARTNERSHIP

What if we can work 24 hours a day?
Humans work during the day, while autonomous vehicles work the night shift.
Skilled operators take on more challenging work.
Increased accuracy, safety, and efficiency of excavation process.

We are testing and validating this today!

Robot example 2: Virtual Punch List with Robots

EARLY ROBOT (OUTDOOR)

- Not yet autonomous, guided by iPad
- Provided advantages in accessing barricaded-off areas that needed to be scanned per schedule

INDOOR AUTONOMOUS ROBOT

- Autonomous solution for laser scanning areas at predefined points and paths
- The robot can detect and reroute around obstacles to the next defined point with a *collision avoidance scanner*
- The robot is equipped with a scissor lift that reaches up to six feet!

Robot example 2: Virtual Punch List with Robots

Spot, Boston Dynamics

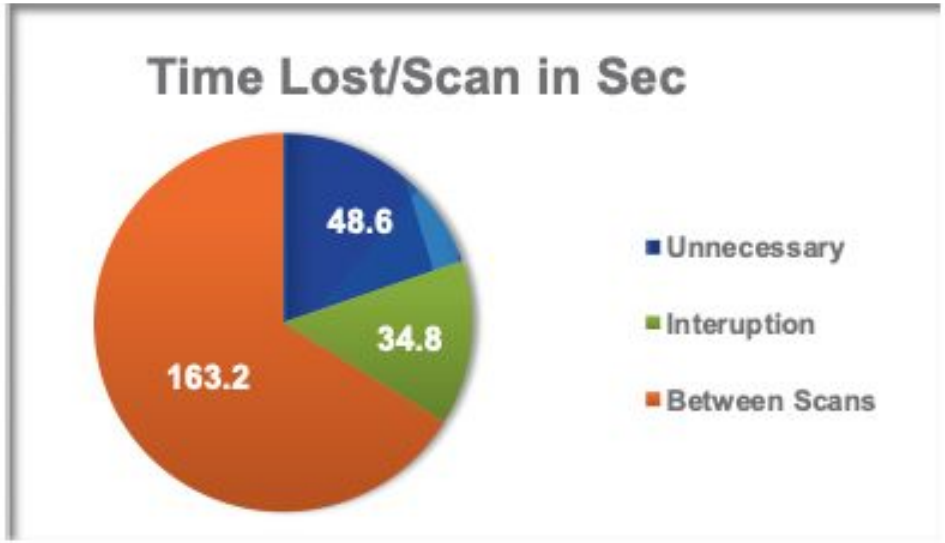
Anymal, ETH

Robot example 2: Virtual Punch List with Robots

Efficiencies

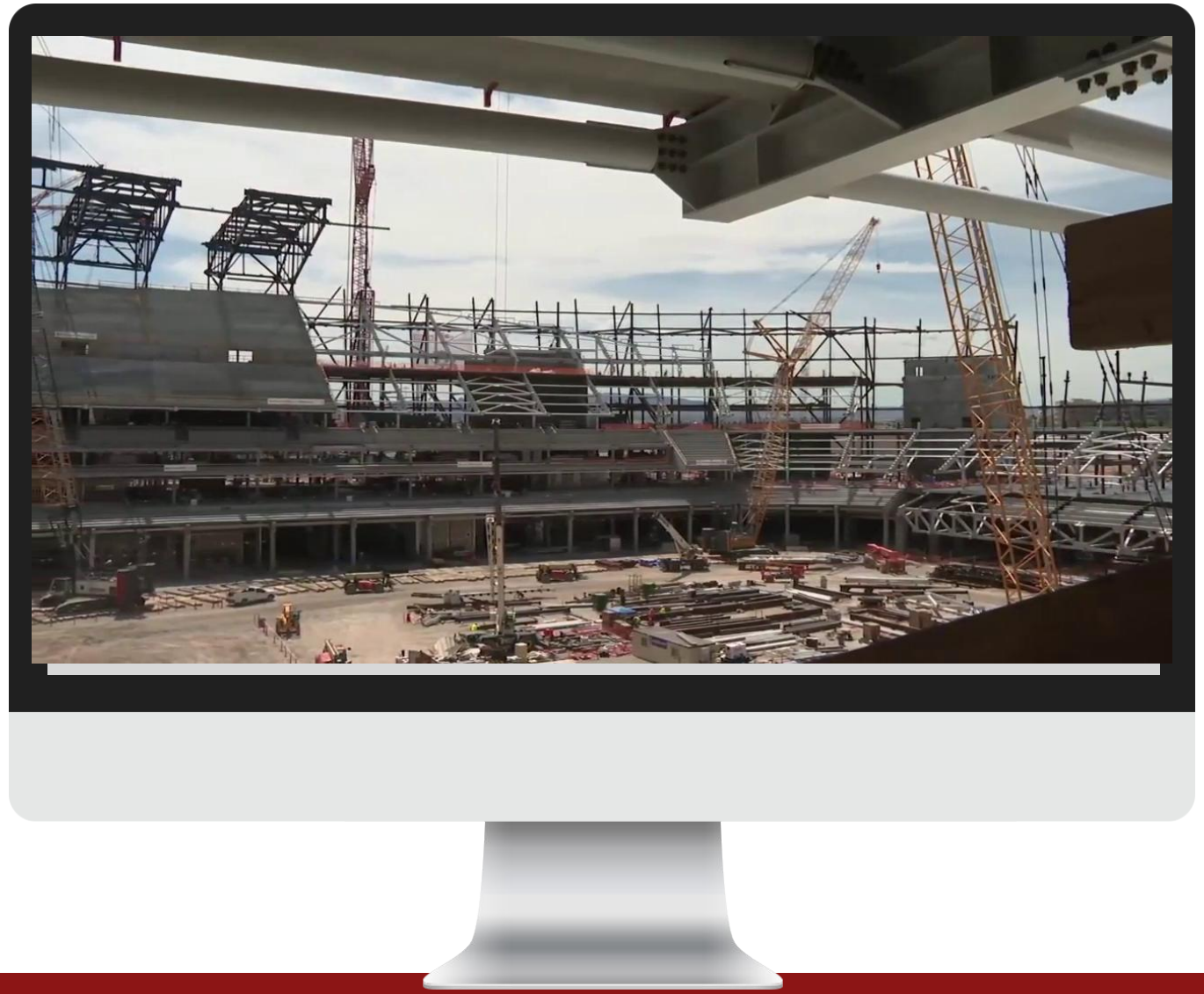
% Scan Time to Leverage

41%



Total Scans to Date		Avg. Time	Avg. Time Lost/Scan to Scanning	Avg. Time Lost/Scan to Interuption	Avg. Time Lost/Scan to Unnecessary Scans
3262		5.94	2.72	0.58	0.81
Avg. Total Time Spent Scanning in Minutes		19379.78	8865.81	1892.62	2626.88
Avg. Total Time Spent Scanning in Hours		323.00	147.76	31.54	43.78

Robot example 3: Reimagining layout in the field



PROBLEM

How might we optimize trade flow to leverage non-utilized & non-work areas on our job sites?

DUSTY ROBOTICS

Robots turn design into reality by automating manual work

- Productivity, safety, quality improve

Robots are digitally native:

- Progress tracked in real time
- Data collected on field conditions

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3. Interior layout with total station

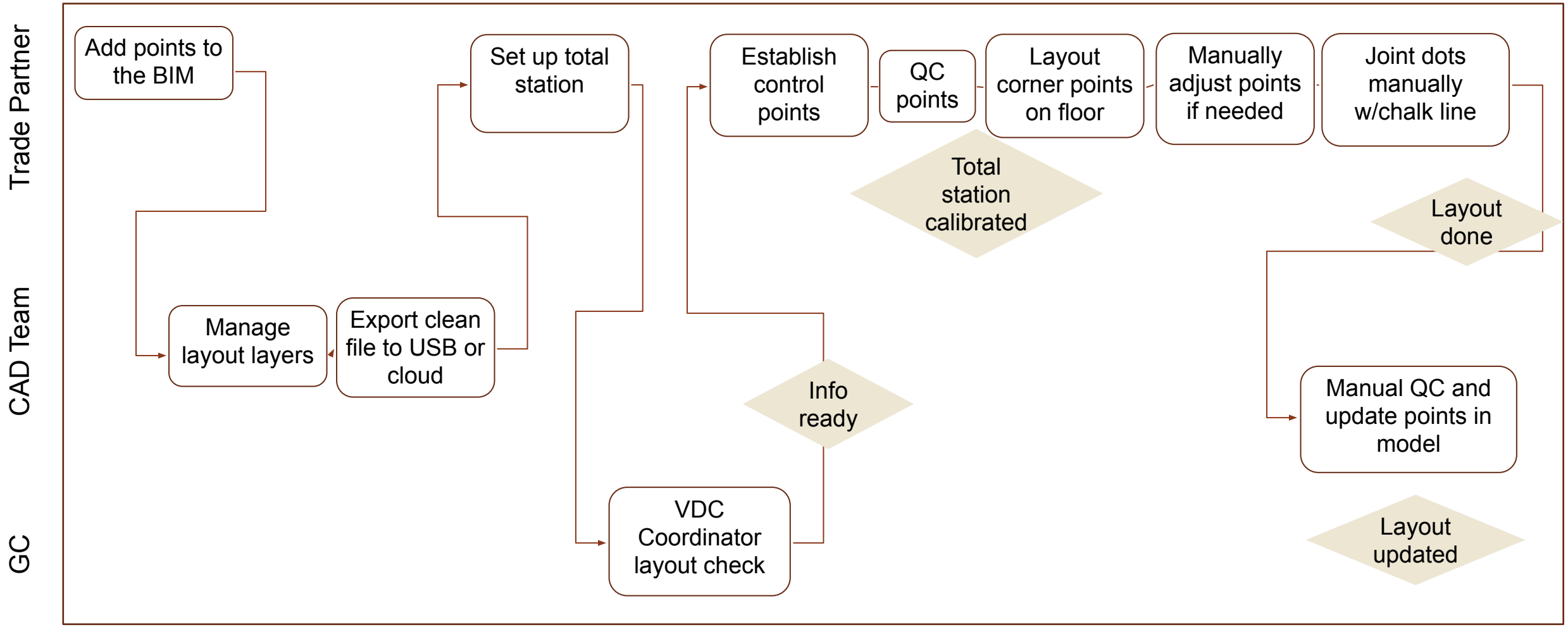
No progress data tracked

Rework chalk lines

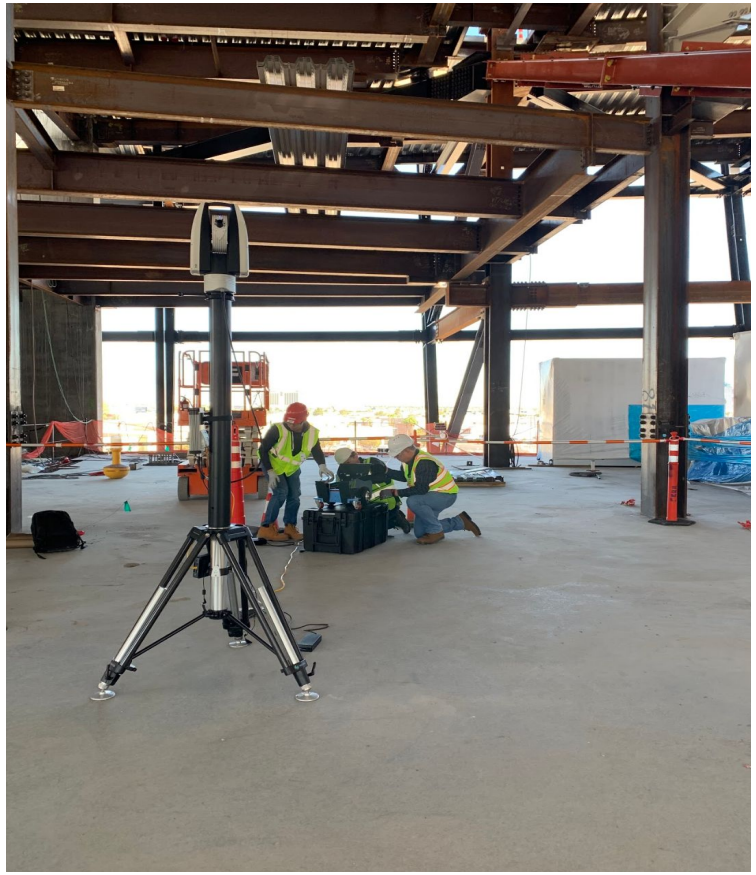
Manual effort

3. Interior layout with robot and total station

Current Layout Process and Participants



Robotic Layout Test Case

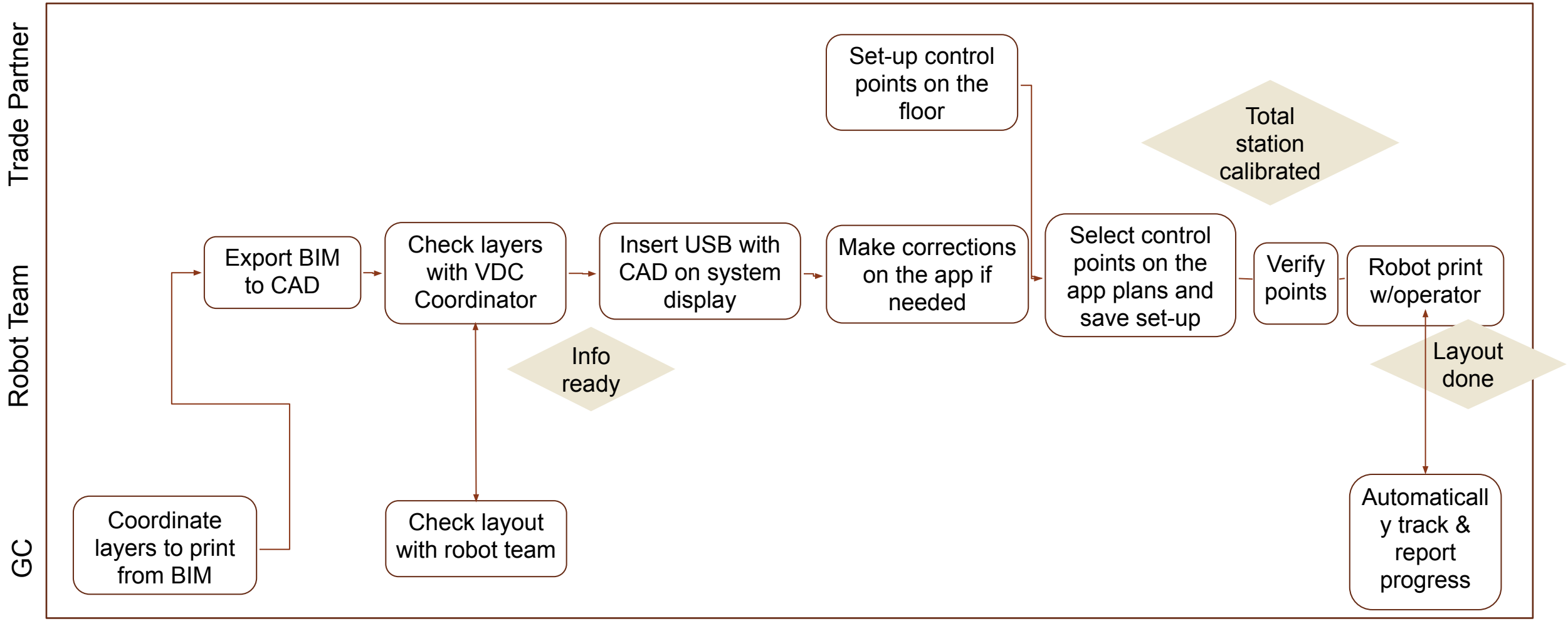


Moving platform + total station (LOS to total station of 25m)

Control points on clear and dry floorplate

Robotic Layout Process

Robotic Layout Process and Participants



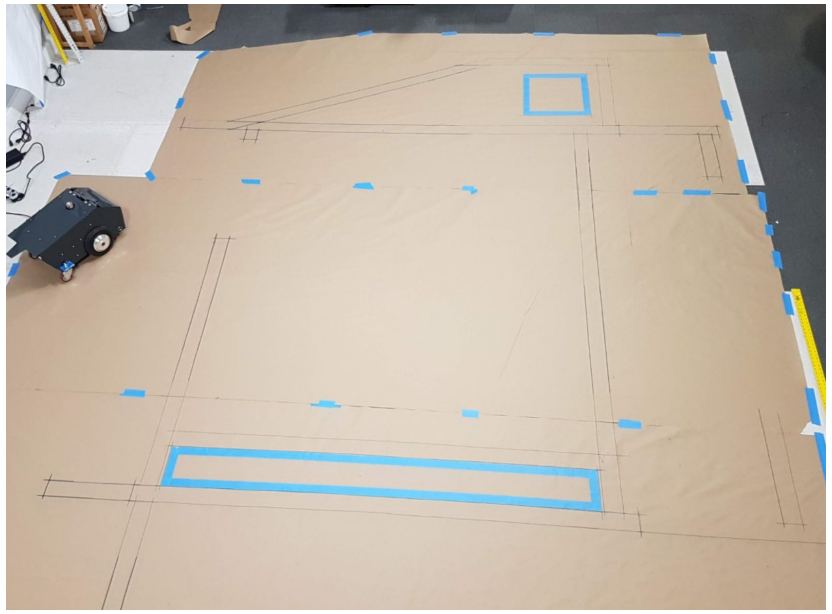
Current and Robotic layout comparison:

Safety

Quality

Schedule

Cost



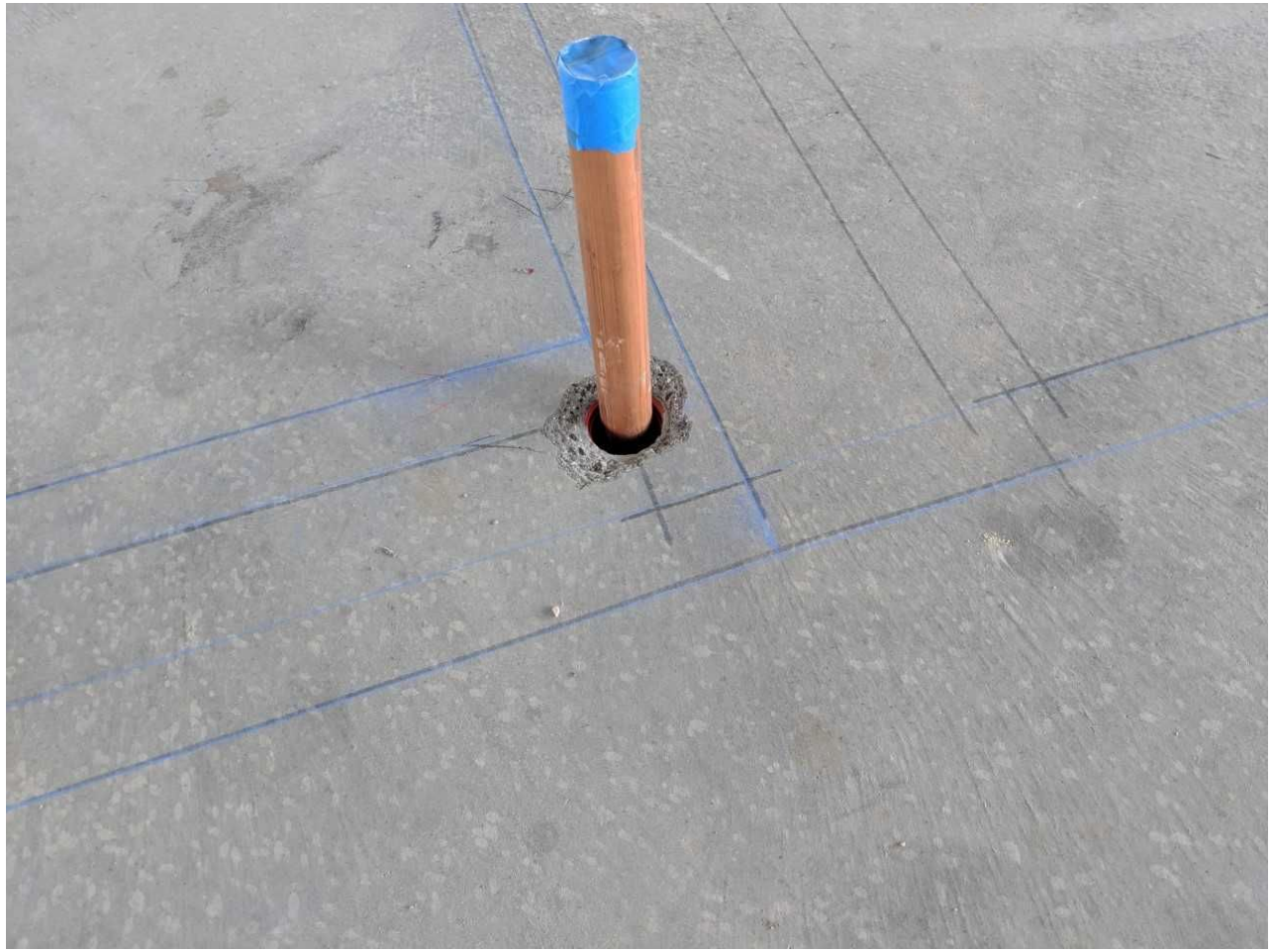
Safety Benefits of Robotic Layout

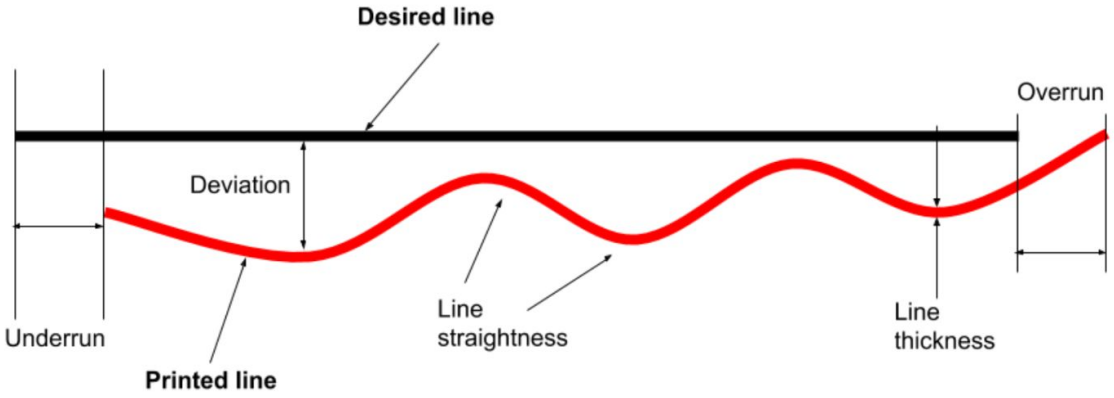
- Reduce manual repetitive task

  (45 m /zone/worker)

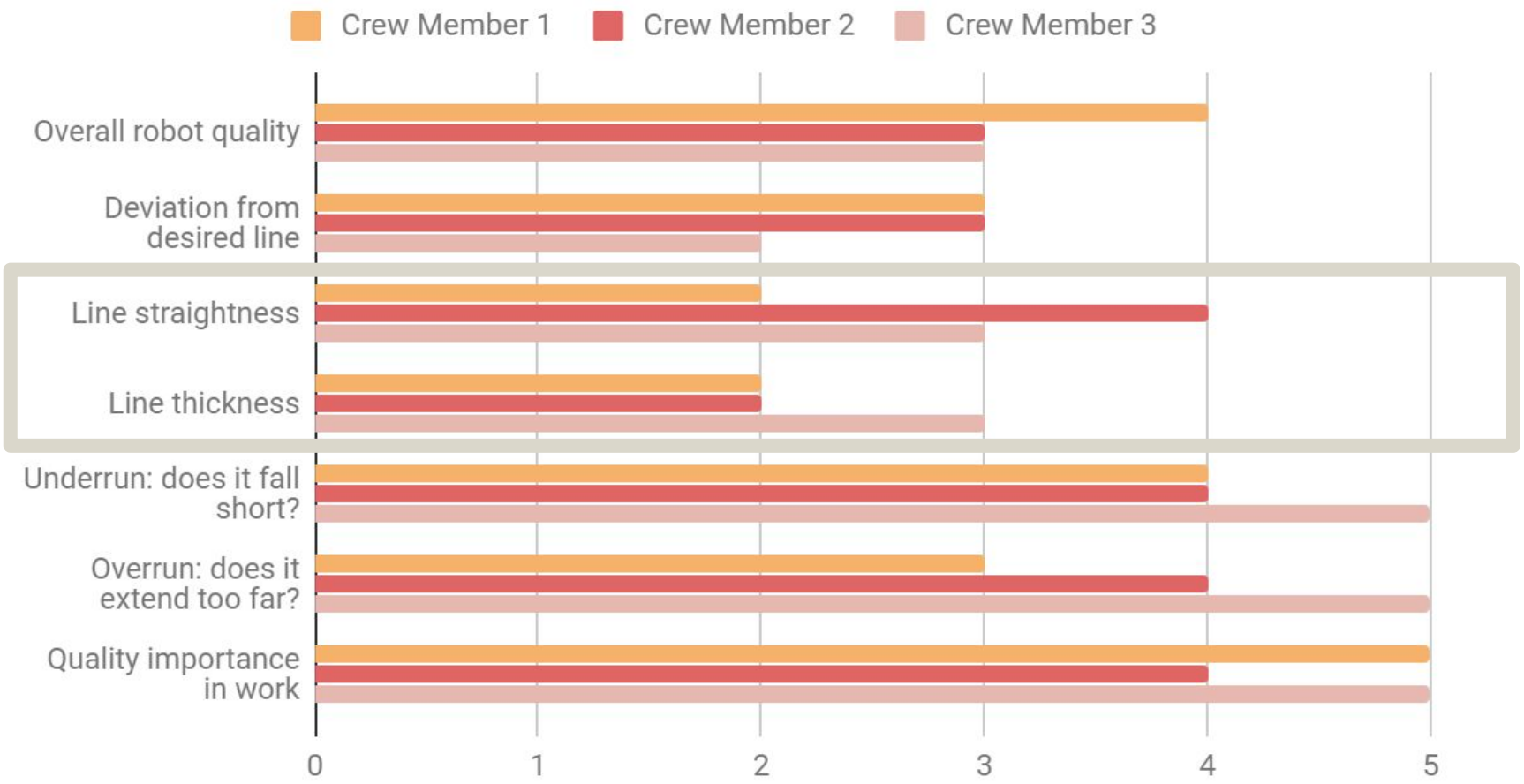
- Perform work under drop object hazard areas

Quality: Robot vs. Manual Layout Accuracy





First Test Quality Assessment Survey



0 = inaccurate / 5 = Perfect

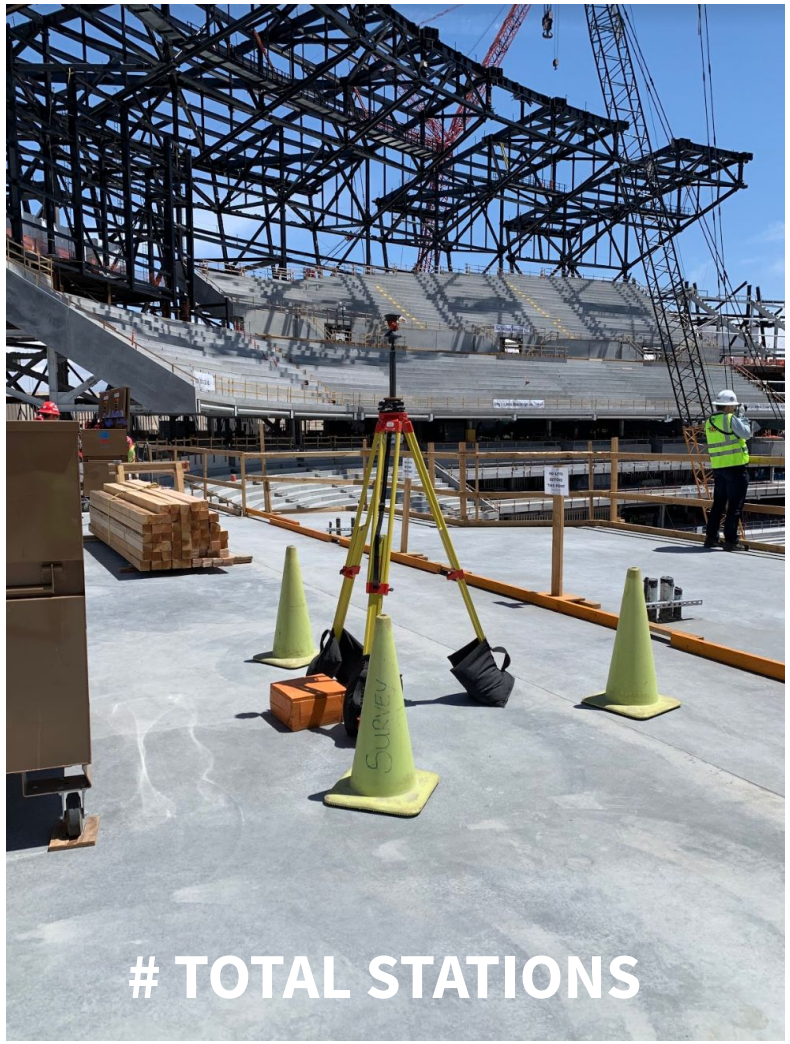
Manual vs. Robot Layout Productivity

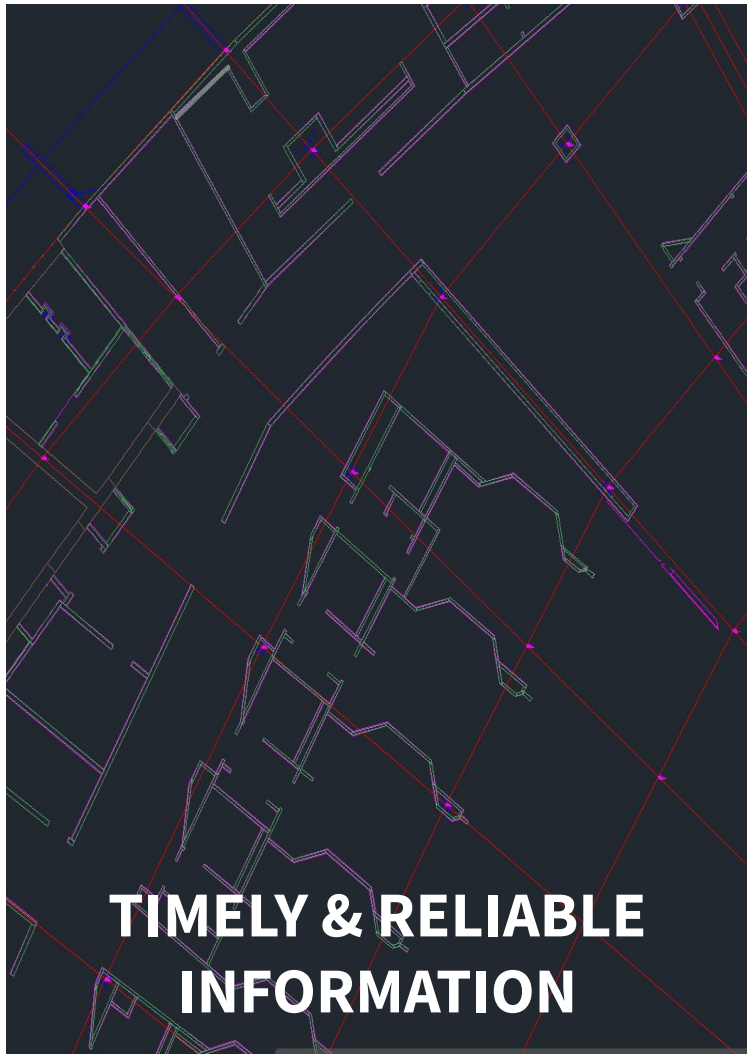
	Manual (2 operators)		Robot (1 operator)	
	w/set-up (min/lnft)	w/o set-up (min/lnft)	w/set-up (min/lnft)	w/o set-up (min/lnft)
Test 1 (715 lnft)	0.07	0.06	0.27	0.12
Test 2 (1332 lnft)	-	-	0.17	0.07

Brosque et al., (2020)
10.1109/HORA49412.2020.9152871

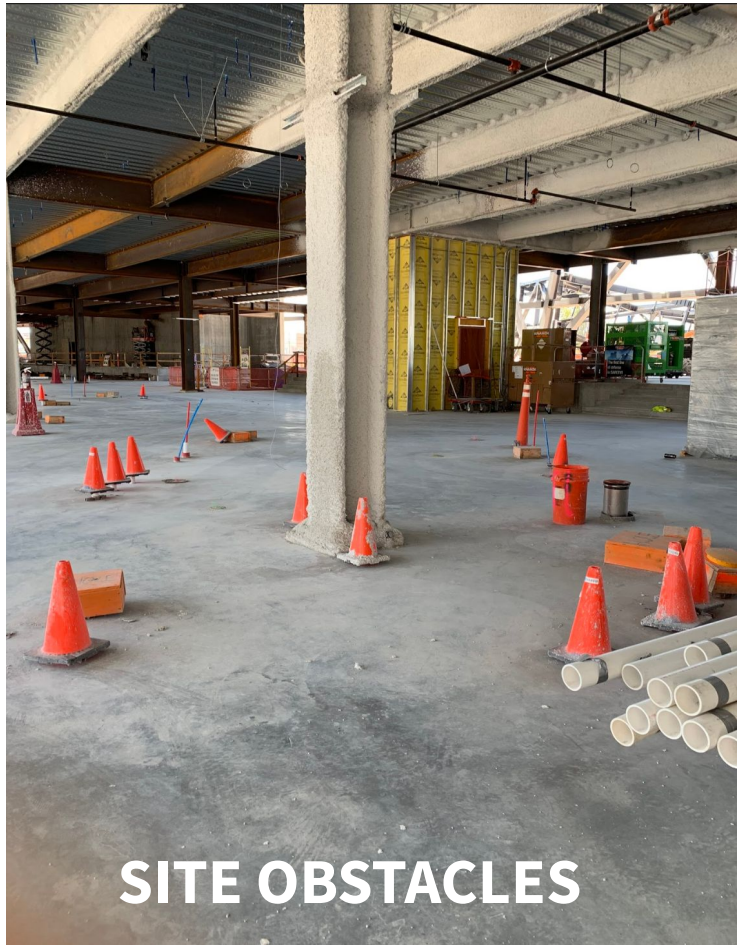
*The first test focused on layout quality, while the second tested printing 3 colors, linewidths, and text.

Manual Factors that Impact Layout Schedule





Robot Factors that Impact Layout Schedule



Manual vs. Robot Layout Cost

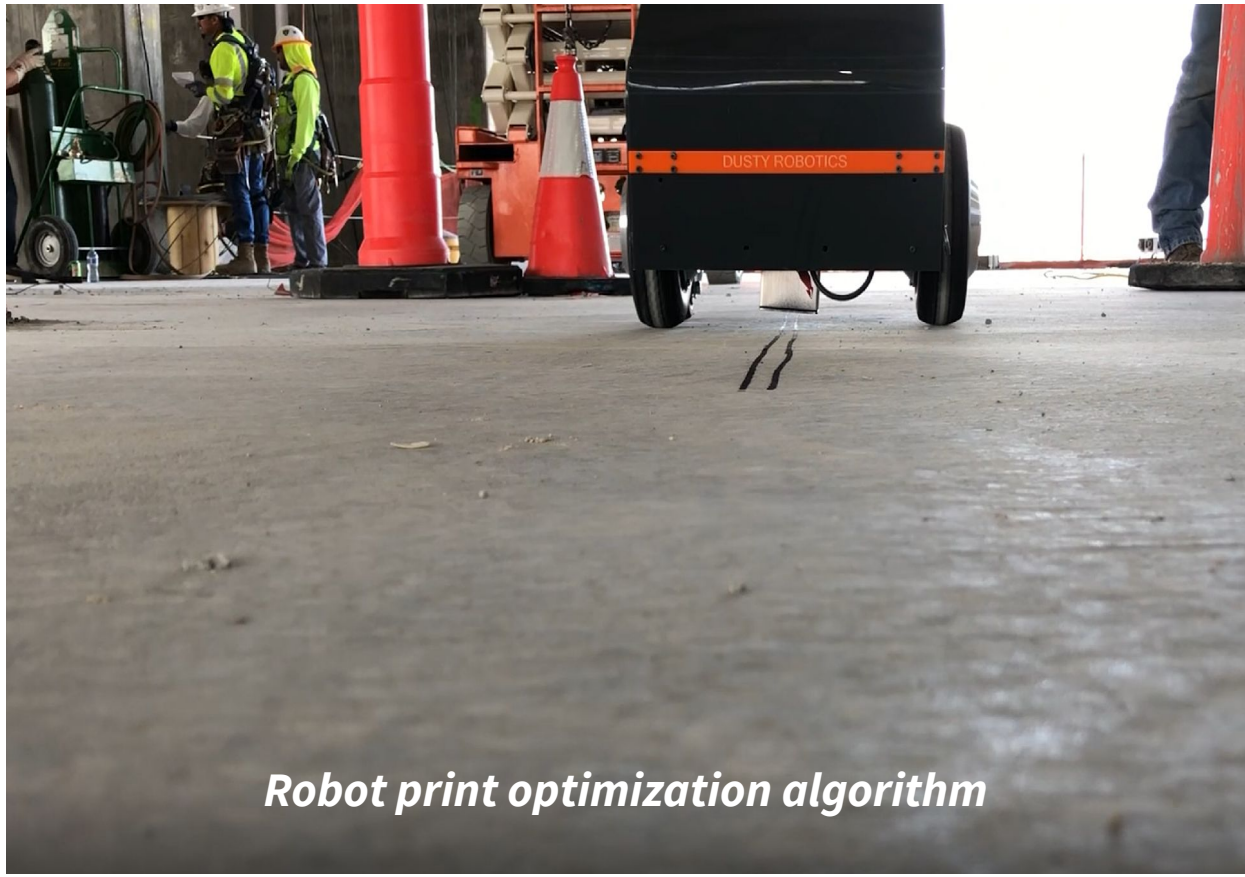
Trade partner cost ($44.5/hr each journeyman, $100/hr superintendent)

Total station cost = $70,000

Robot offered as service to match current cost (hourly rate TBD)

What is hard to do right now?

Dusty Robotics Operator



Robot print optimization algorithm

What would be foreseeable in the future?

- Improve quality, safety & ensure production rates
- Integrate trades and layout types in one pass
- Improved perception with sensing and AI
- Oversee multiple robots
- Unlock the night-shift
- Report site deviations from the BIM
- Capture progress data
- Extend battery use
- Schedule continous robot work

Key insights of applying the layout robot

Would you prefer to layout with robotic assistance? Why or why not?

"Yes.

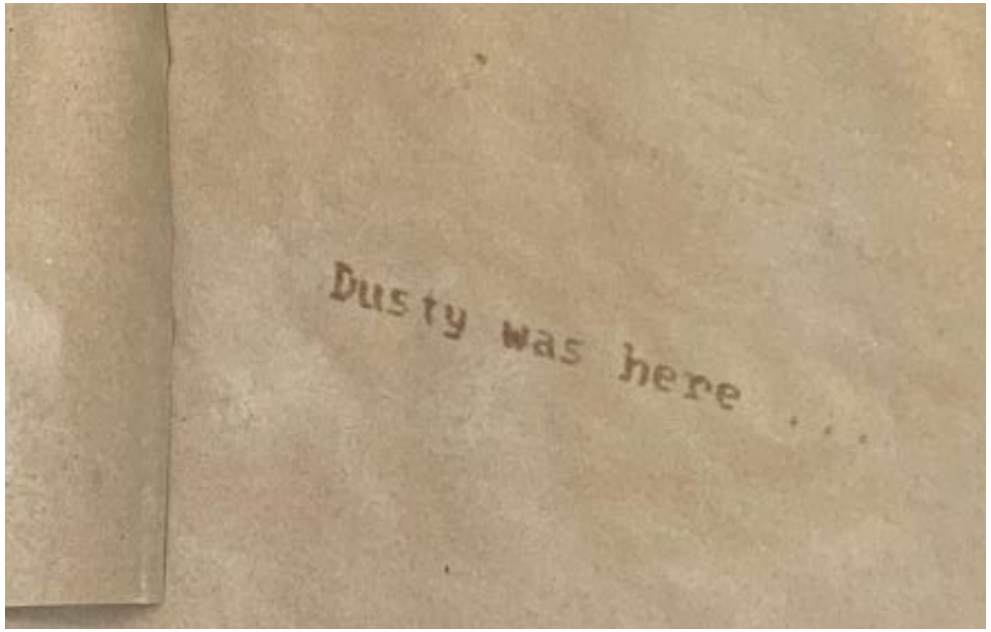
Speed of layout, precision, ability to print more data."

"Focus labor elsewhere."

"Eliminate math errors."

"Improve working conditions."

Field Layout PCI workers



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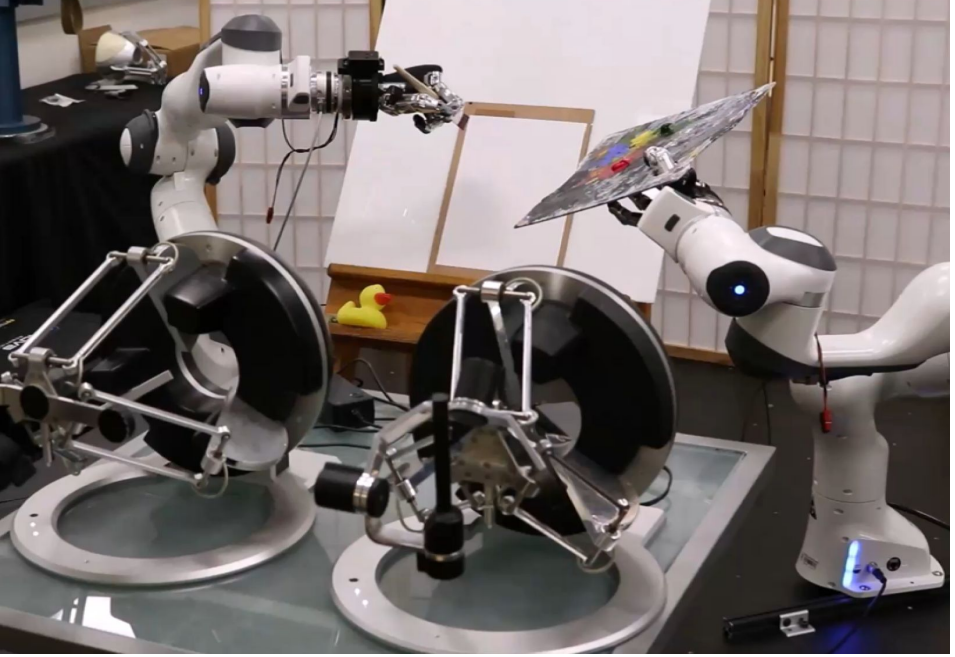
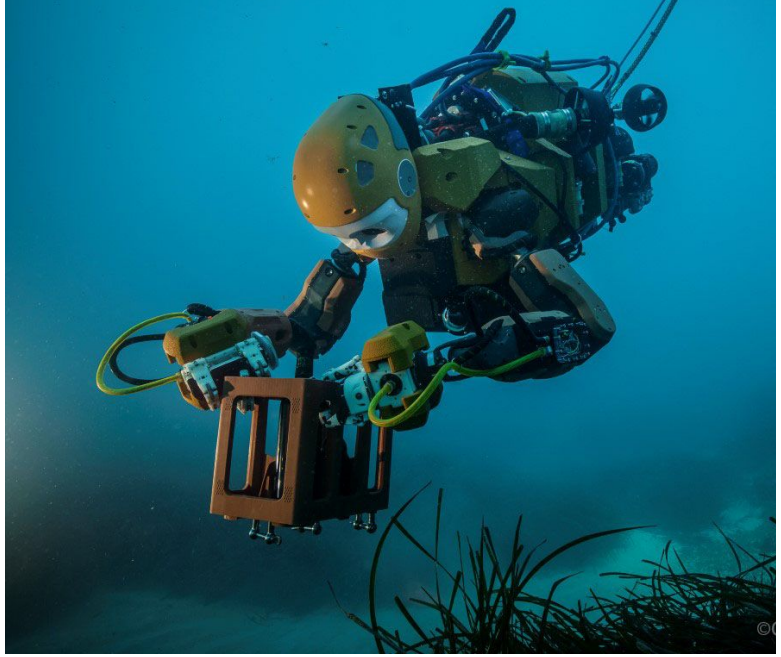
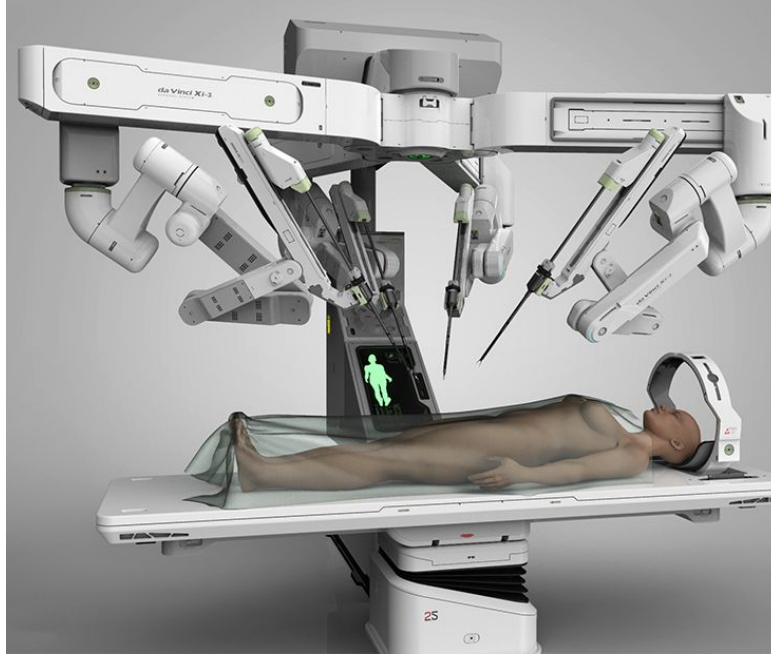
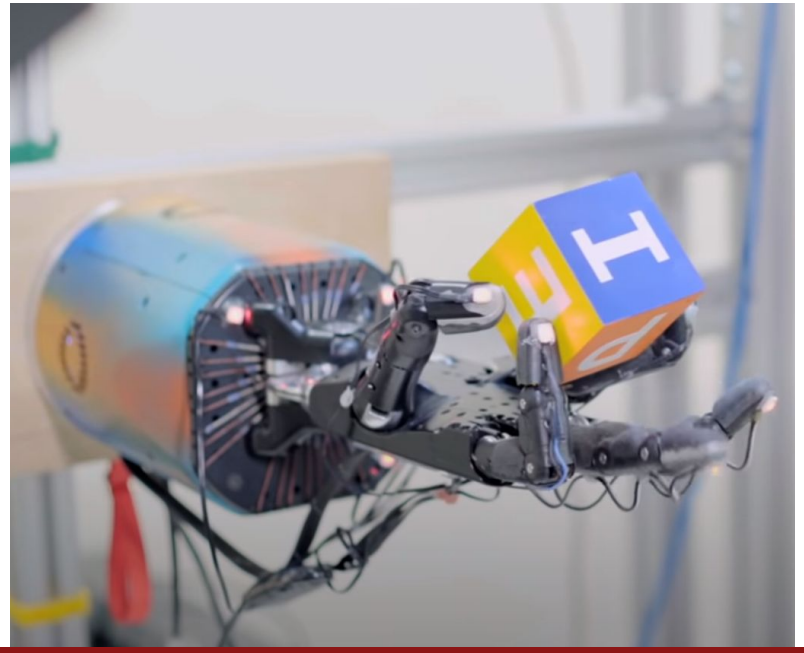
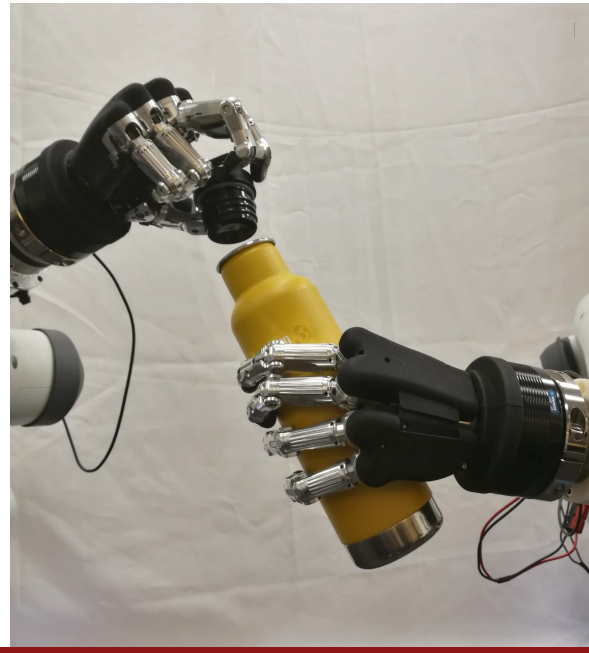
Robotics Perspective











How do we program robots?

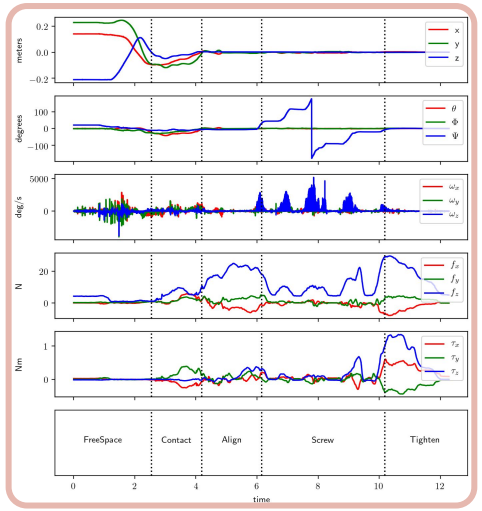
Preprogrammed Motions

Adaptable Skills

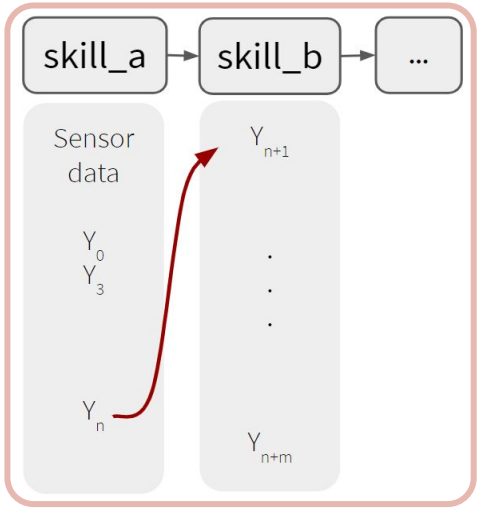
Learning and Planning with Skills

Human demonstration

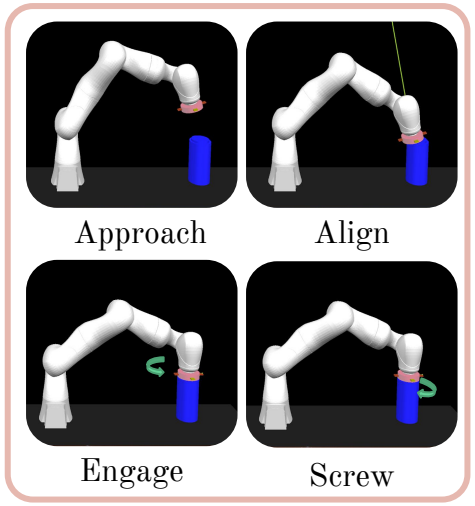
Task Segmentation



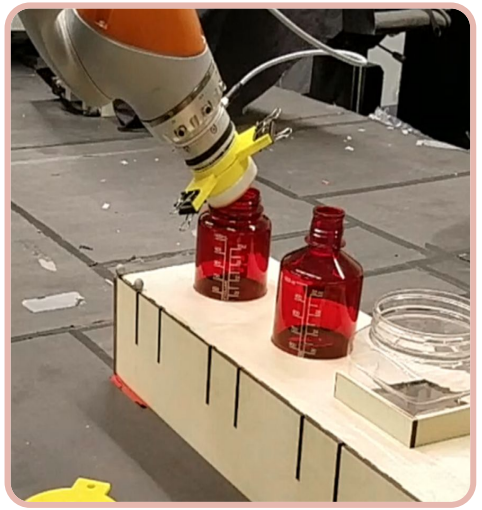
Learn Transition Model



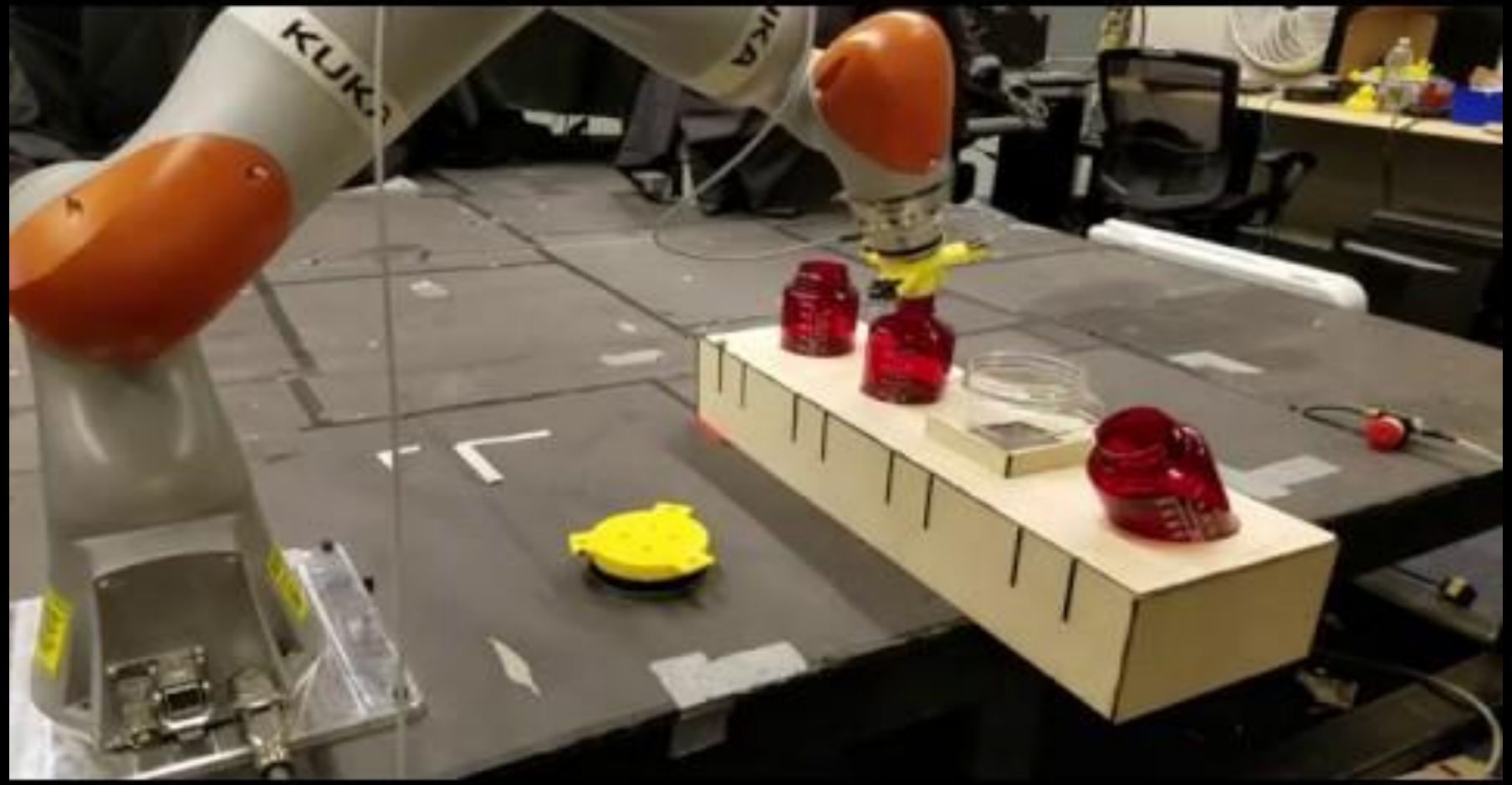
Task Execution in Sim



Task Execution on Hardware



What is possible?



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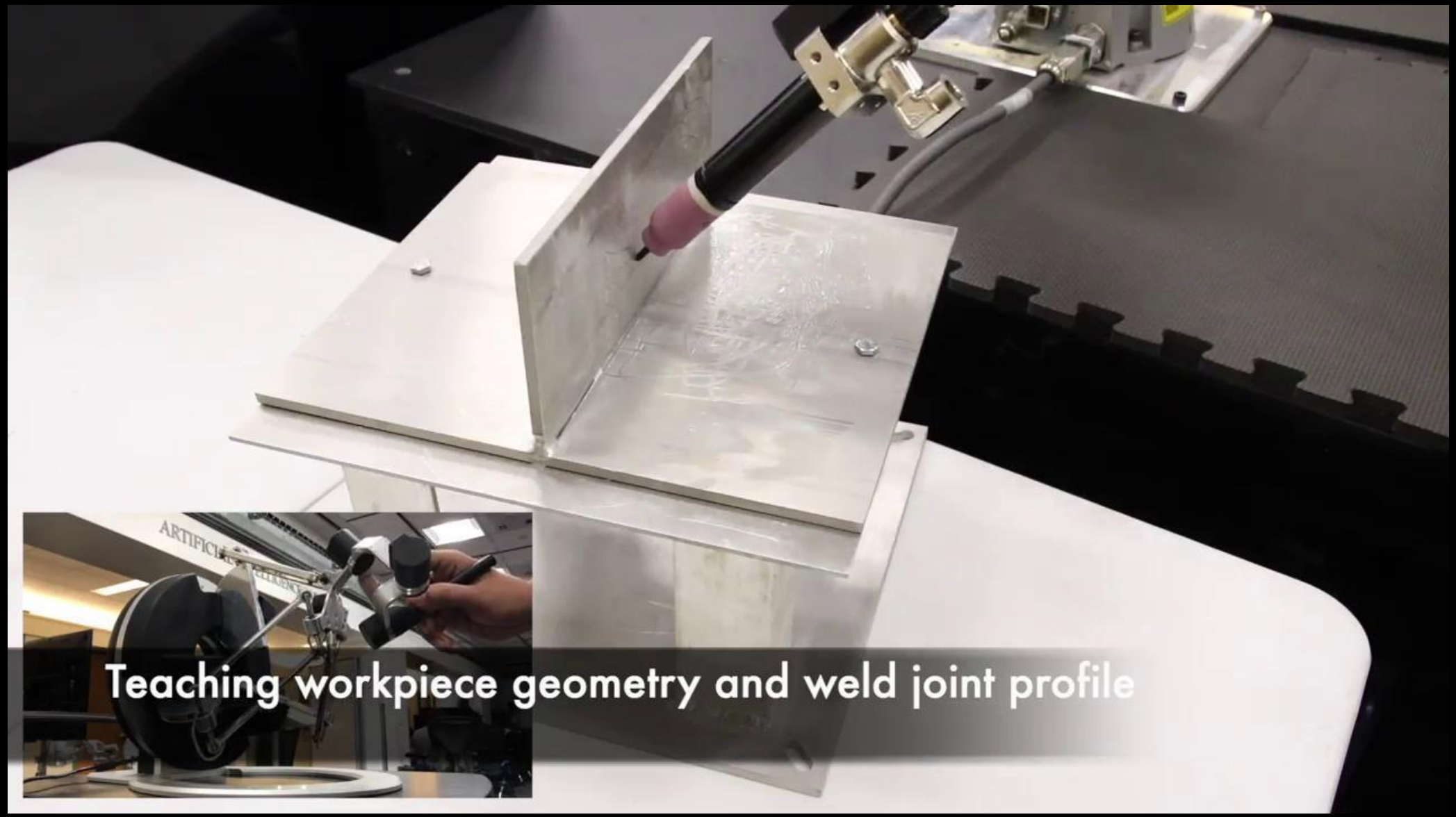
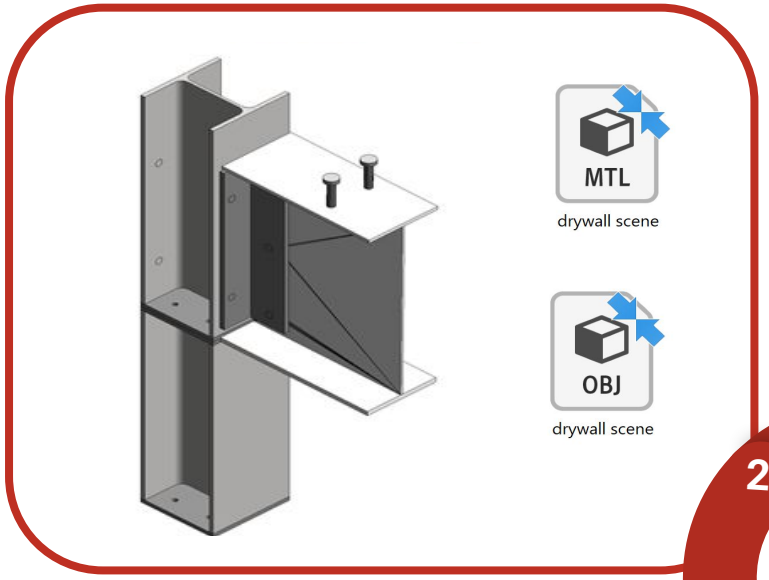


What is possible?

Robotic Manipulation - Enabling Interaction



GOLDBECK

C. Brosque, E. Galbally, O. Khatib and M. Fischer, (2020) *10.1109/HORA49412.2020.9152888*

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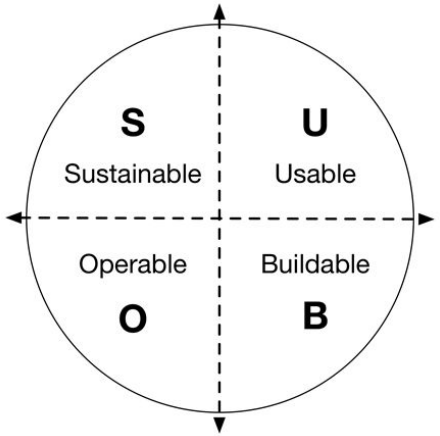
What is the ideal result & process?

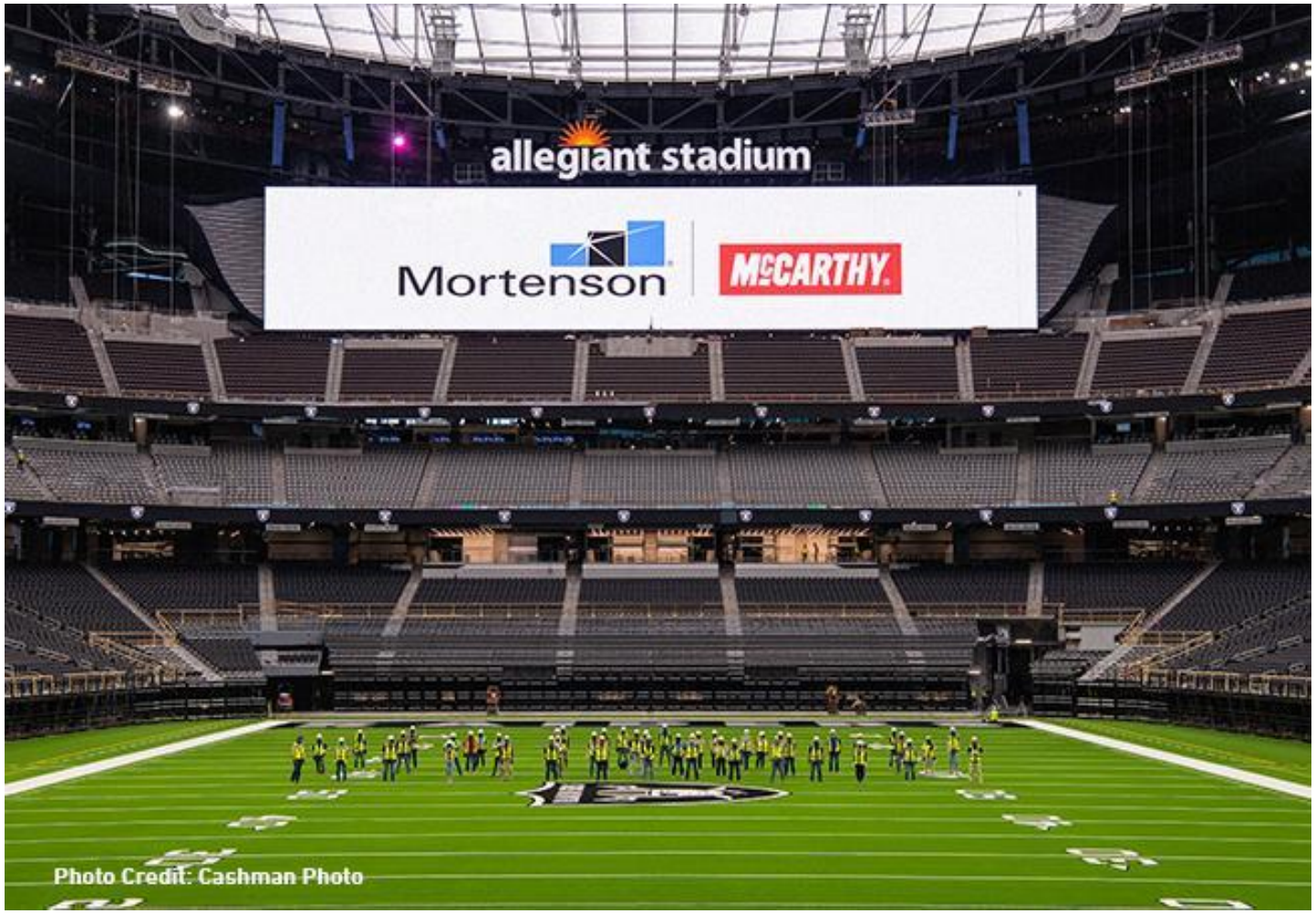
Automation and robot technology becomes ubiquitous: T Bock (2015).



Rethink construction product and processes for automation

Leverage prefabrication and standardization

Lean Management of Processes



AI design and investment

PROBLEM

Building Design/Engineering is mostly rules based, so how might we create a rules engine to automate the problem that is currently solved by multiple disciplines?

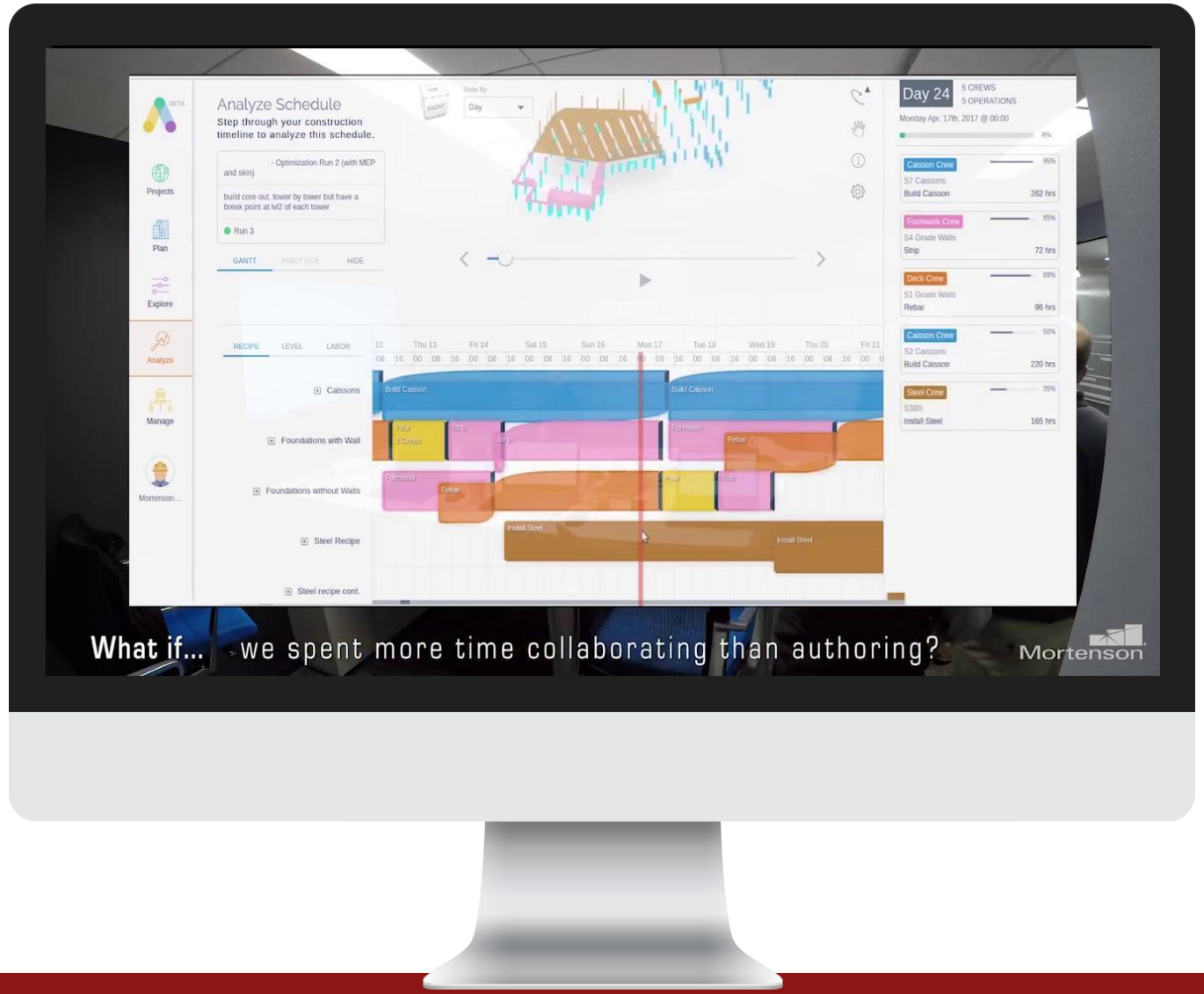
TELLING COMPUTERS WHAT WE WANT TO ACHIEVE

Imagine if a developer can tell the computer to check for the feasibility and viability of a property and identify what is the best product fit for the location?

PARAFIN 3D

Think like a Developer / Design like a million architects. PARAFIN accelerates the lengthy, complex, and costly site acquisition process by rapidly generating optimized design concepts, budgets, and investment proforma for real estate developers.

Scheduling with AI: ALICE TECHNOLOGIES



PROBLEM

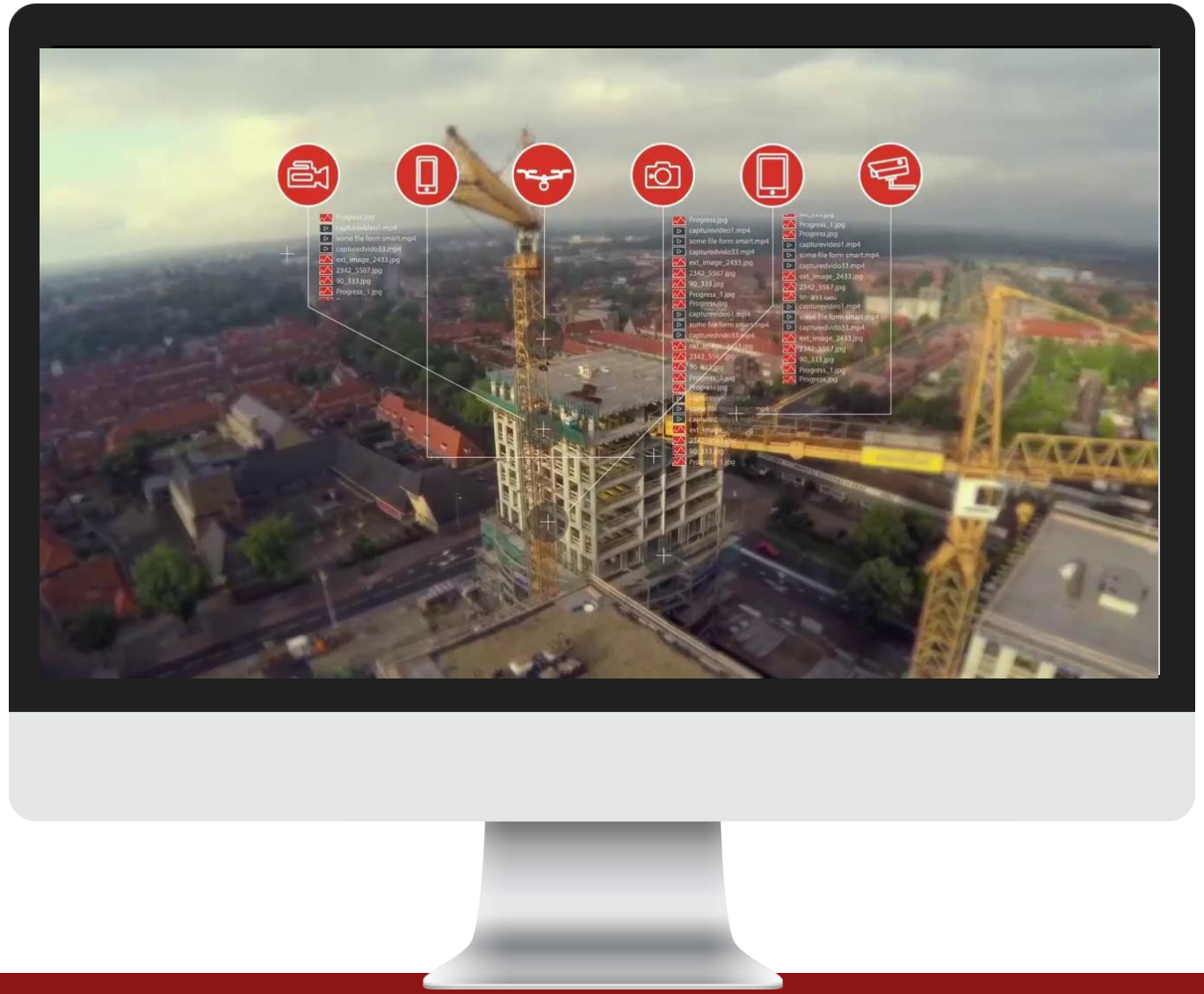
What if we spent more time collaborating, and less time authoring project schedules.

We can then leverage the most valuable asset in the best possible way.

ALICE TECHNOLOGIES

Construction planning, scheduling and management reinvented.
Artificial Intelligence speeds up the planning process exponentially.

Image recognition algorithms to assess safety



PROBLEM

How can we better leverage field data that will help us move from lagging to predictive indicators?

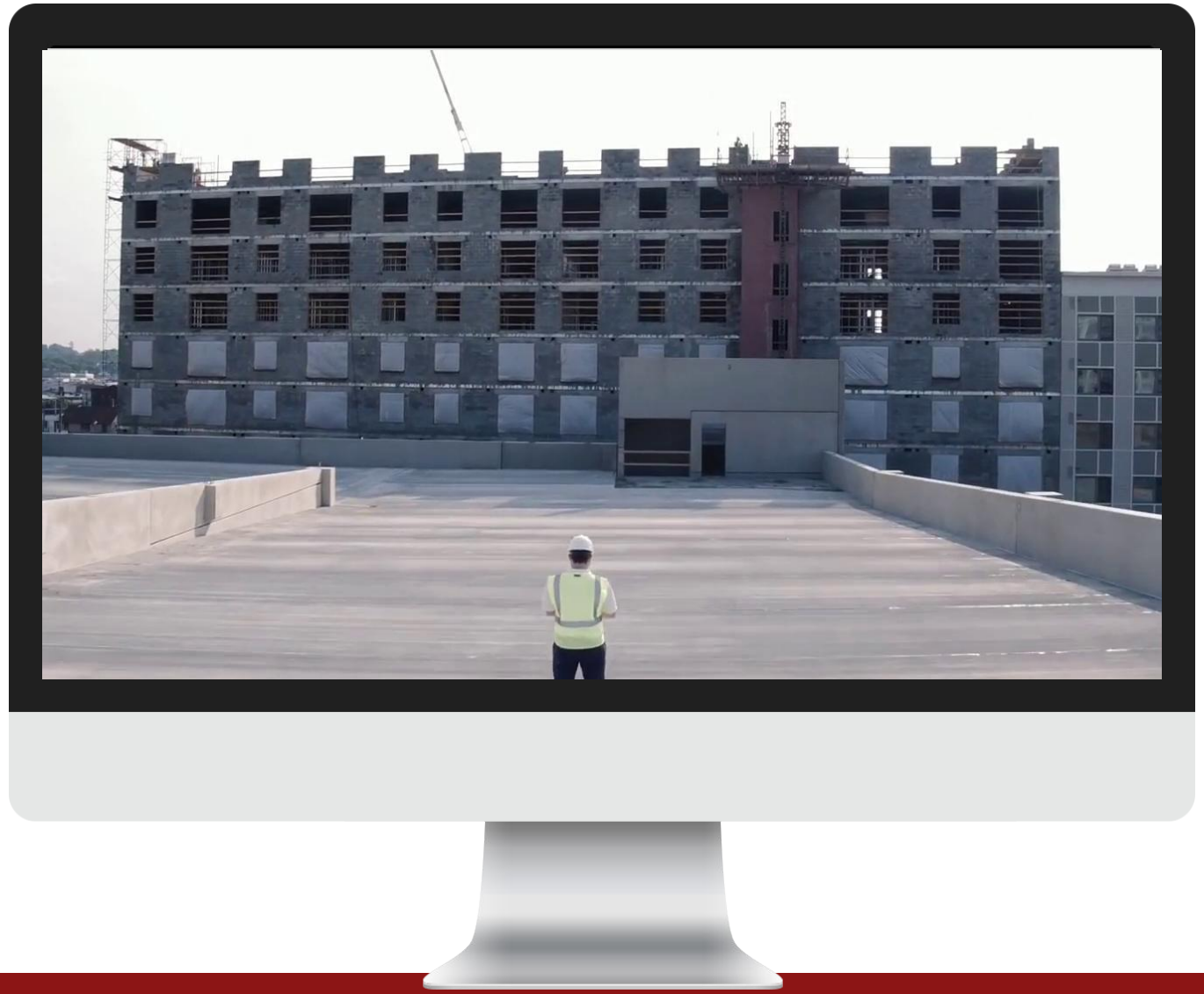
MACHINE LEARNING TO JOBSITE PHOTOS AND VIDEOS

We've been photo documenting projects for decades. Now using machine learning technologies, we are able to gain insight into these data sources to improve safety!

SMARTVID.IO

Using image recognition algorithms to automatically identify safety risks through photos and videos taken on project sites.

Real-time production control



PROBLEM

How might we borrow from other industries that automated data capture in the field or on the factory line to dramatically improve production control?

INTERNET OF THINGS (IOT)

A connected jobsite with location awareness will allow us better manage resources (people, equipment, material and tools) to move us from lagging indicators to predictive indicators.

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Discussion

1. How can we best leverage trades' knowledge and also provide training to operate robots?
2. What's the right level of robot autonomy?
3. Should robots be a tool or service?
4. Do we need to develop standard environments with prefabrication?
5. How can we schedule continuous robot work? Which tools? E.g. 4D models, Alice scheduling, other?
6. How can we provide faster and better construction information to the robot?

Questions?

Thank you