

# Interactive Visual Analysis of Robot Base Placement and Trajectory Optimization

Michael Oppermann<sup>1</sup>, Alexander Wachter<sup>2</sup>, Christian Hartl-Nesic<sup>2</sup>, and Lisa Diamond<sup>1</sup>

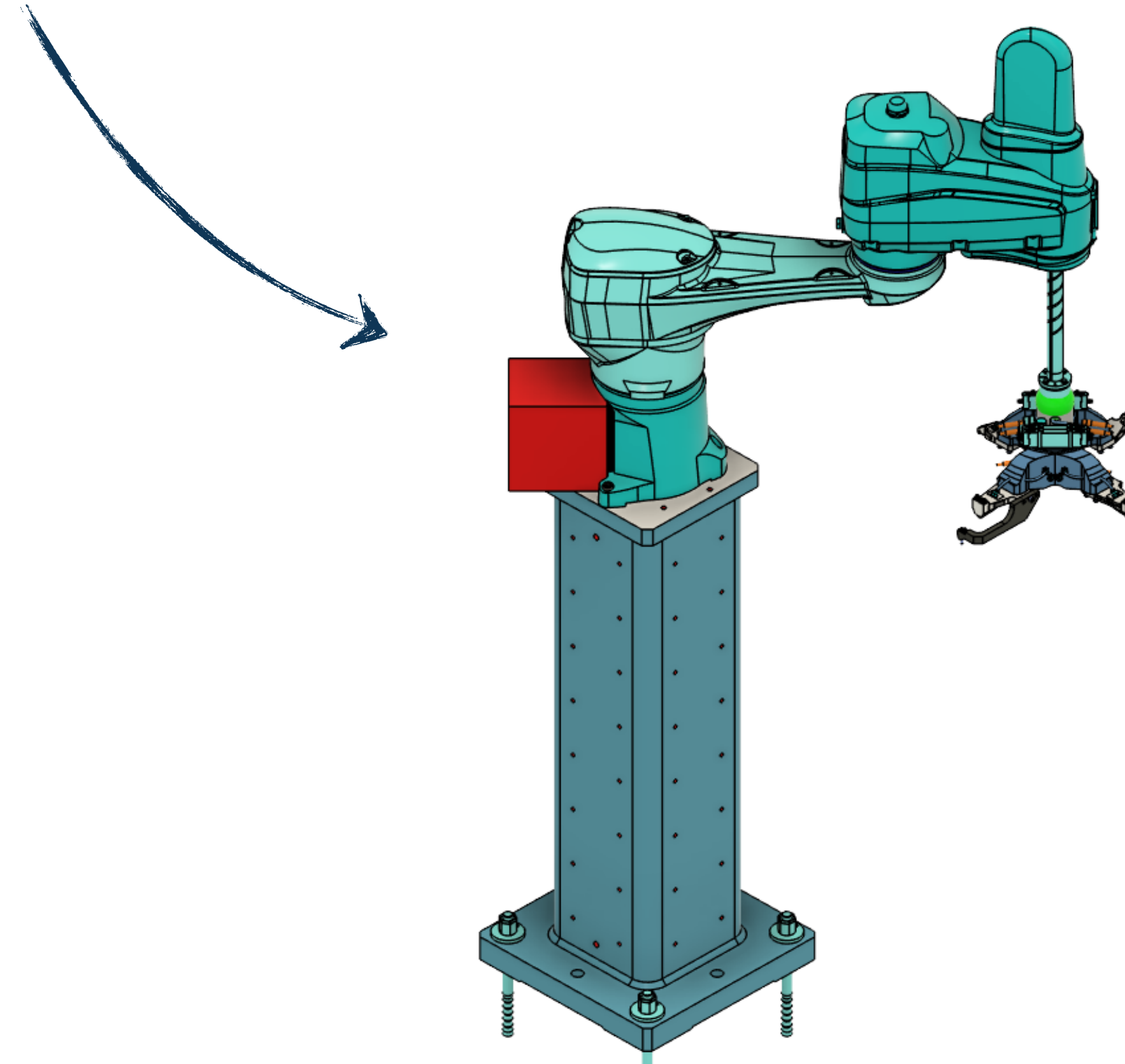
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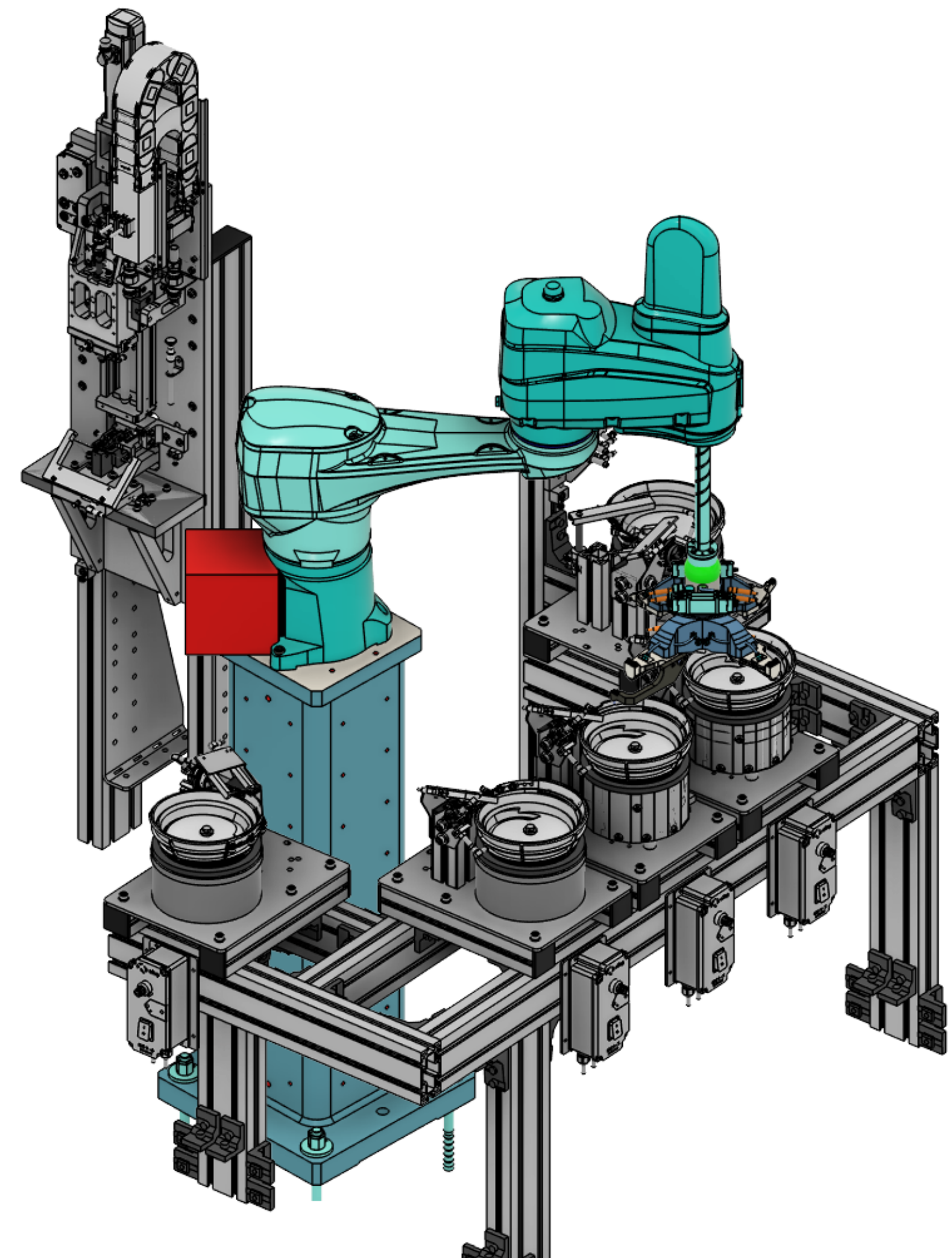


# Multi-joint industrial robot



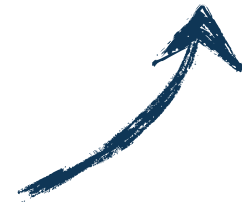
# Flexible robotic work cells in industrial manufacturing

Support product individualization,  
small batch sizes, and frequent  
reconfigurations.



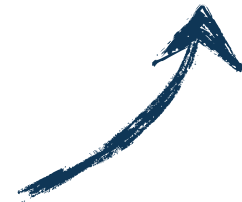
# ***Robot base placement*** *and trajectory optimization*

Where do we  
position the robot?



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How does it  
move over time?

Where do we  
position the robot?

Compute solution for  
given constraints and objective

**Robot base placement and trajectory optimization**

How does it  
move over time?



# Potential objectives

TRADITIONALLY



**Cycle time**

# Potential objectives

## TRADITIONALLY



**Cycle time**

## NEW



**Energy demand**



**Mechanical wear (rate of change of acceleration)**



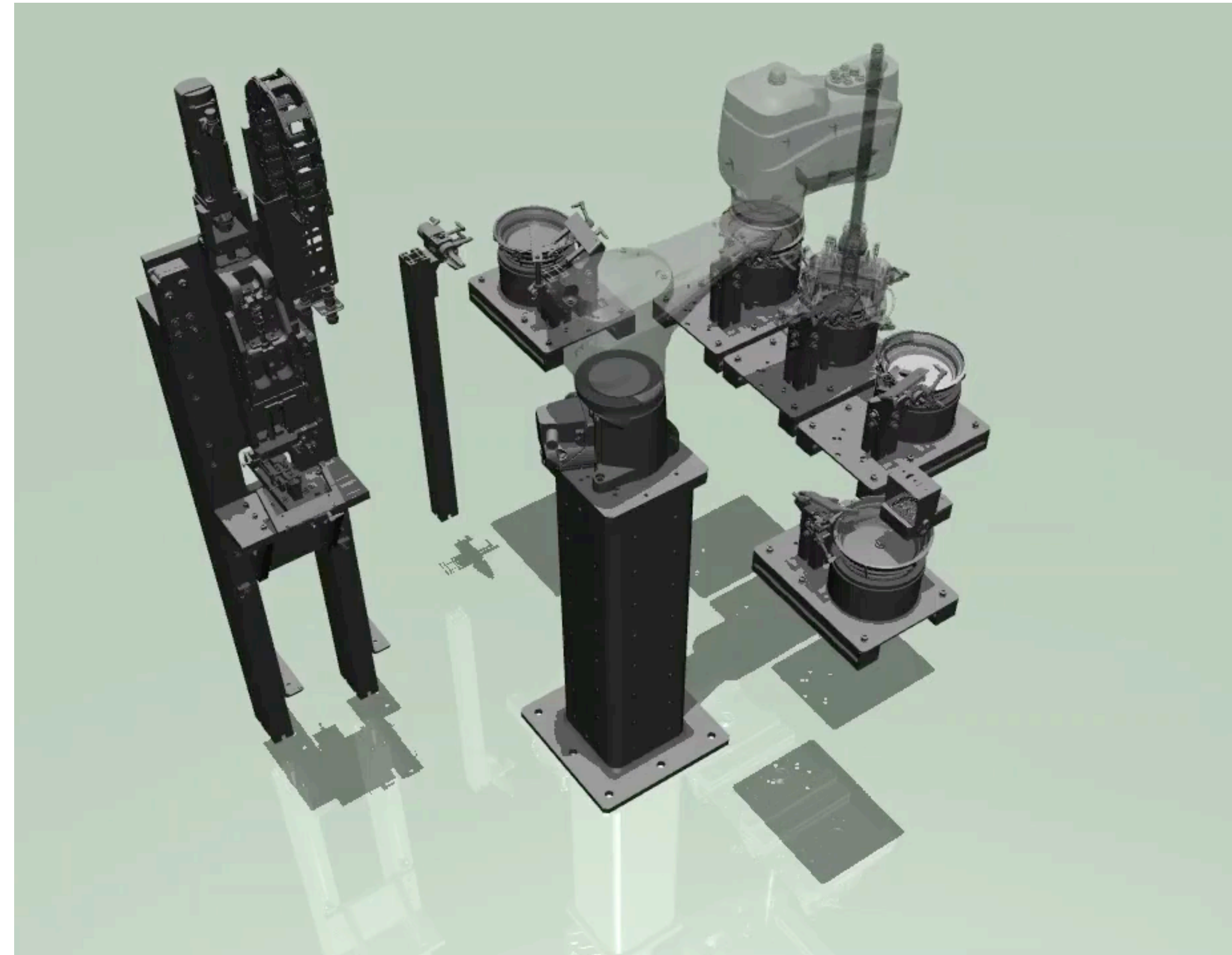
***Custom weighted objectives***

# Optimization

- Optimization workflows usually lead to a single *optimal* solution.
- Inspected or validated using a robotic simulation.

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# Challenges

- Limited support for understanding the broader solution space.
- Difficult to reason about trade-offs, or to explain why certain configurations perform better than others.

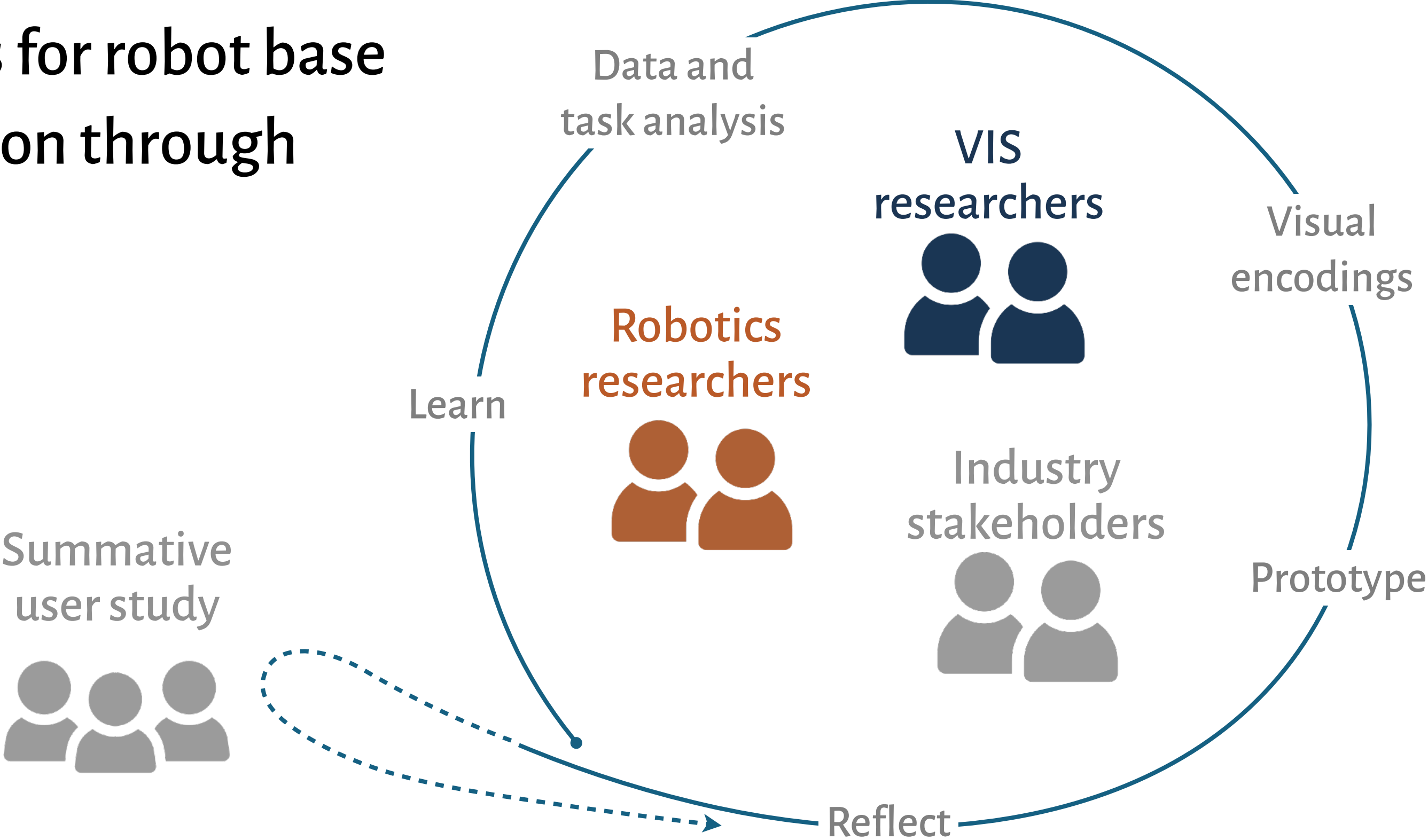
# Visualization design study

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How can visual analysis support users in exploring and reasoning about solution spaces for robot base placement and trajectory optimization through different visual encodings?

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# Data

Generated by an optimization model that evaluates feasible combinations.



## Robot base parameters

Spatial placement of the robot base in the work cell (e.g., x, y, rotation)

## Trajectory data

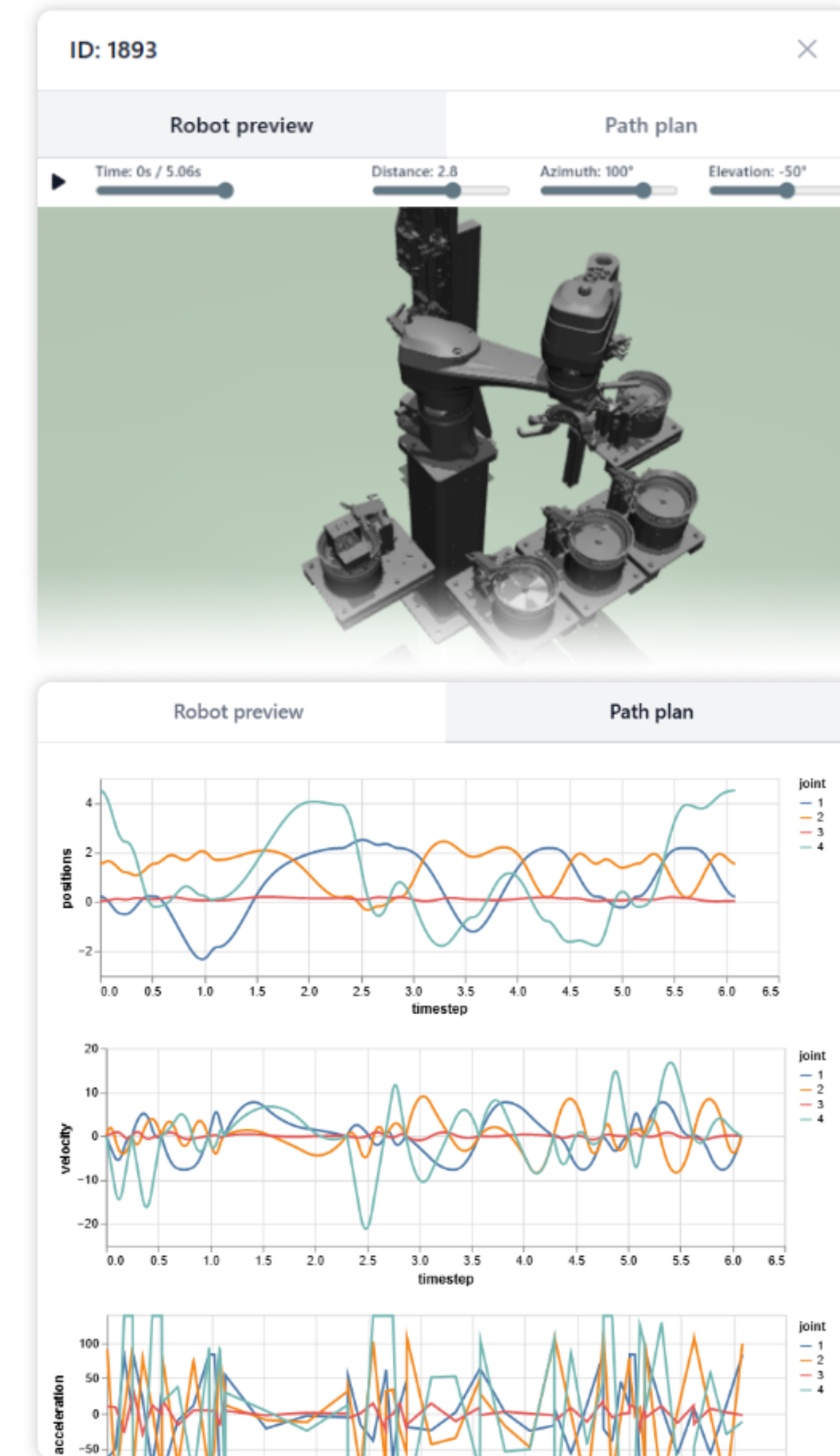
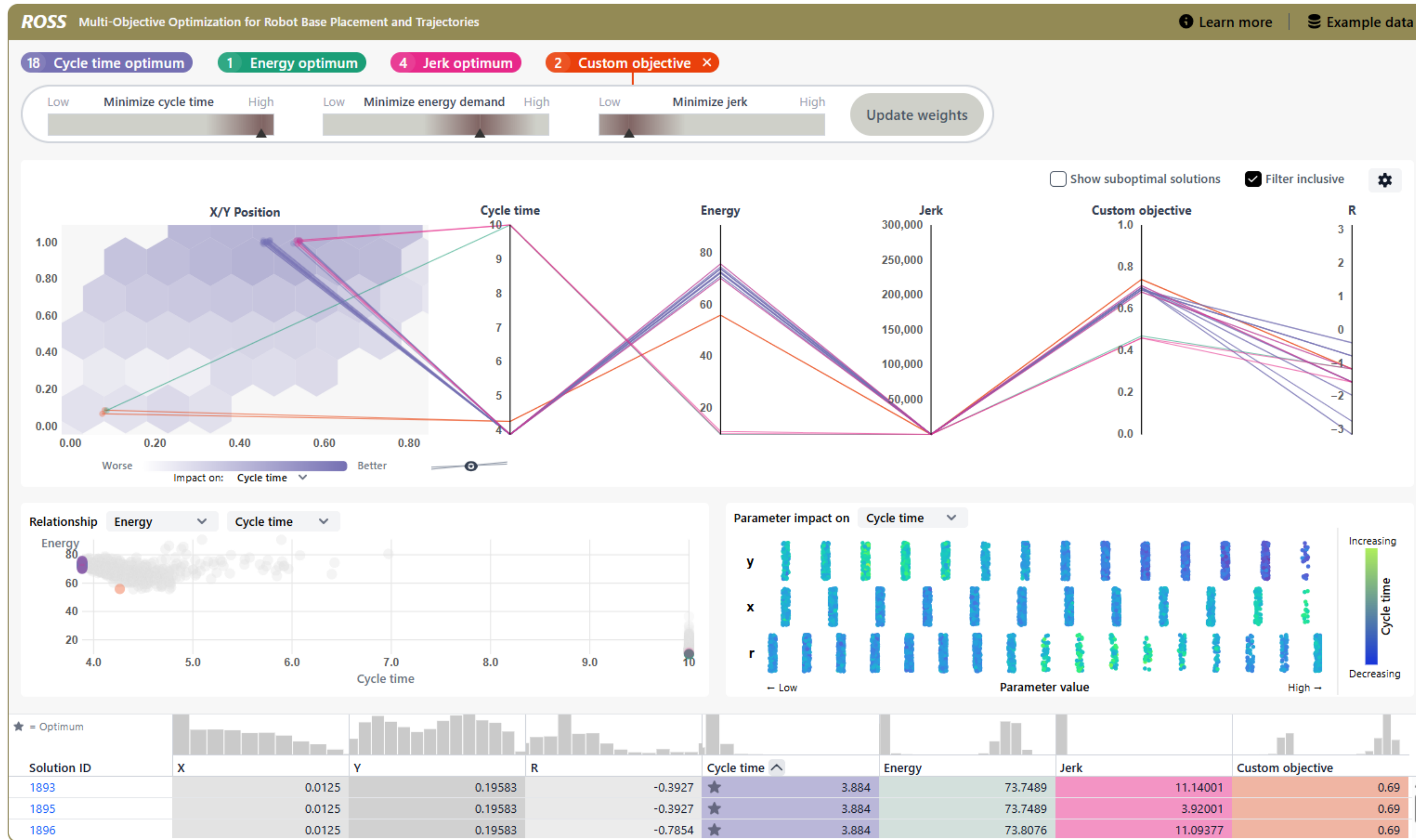
Positions, velocities, and accelerations for each joint

## Derived outcome metrics

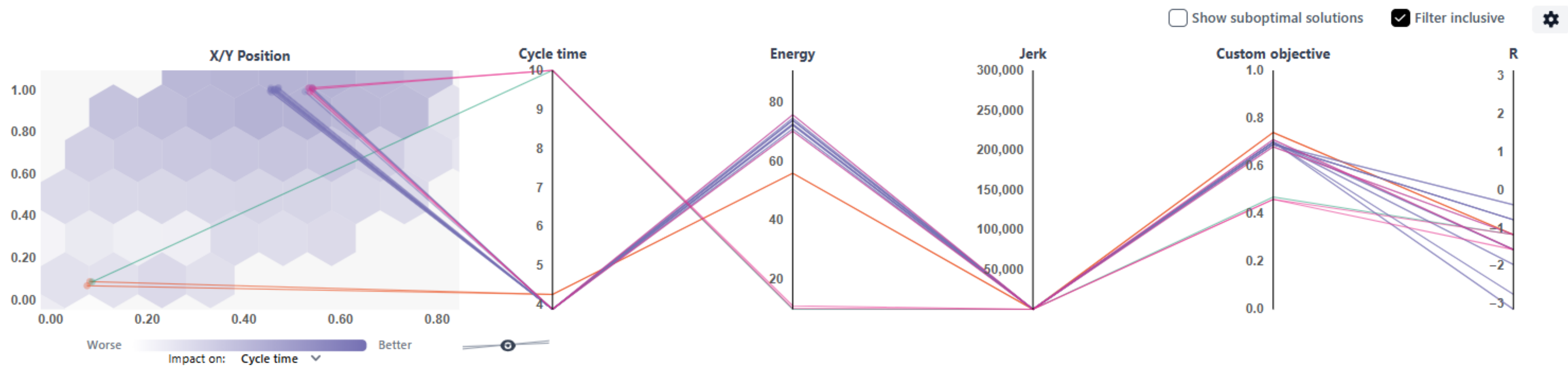
Quantitative performance measures (e.g., cycle time, energy demand)

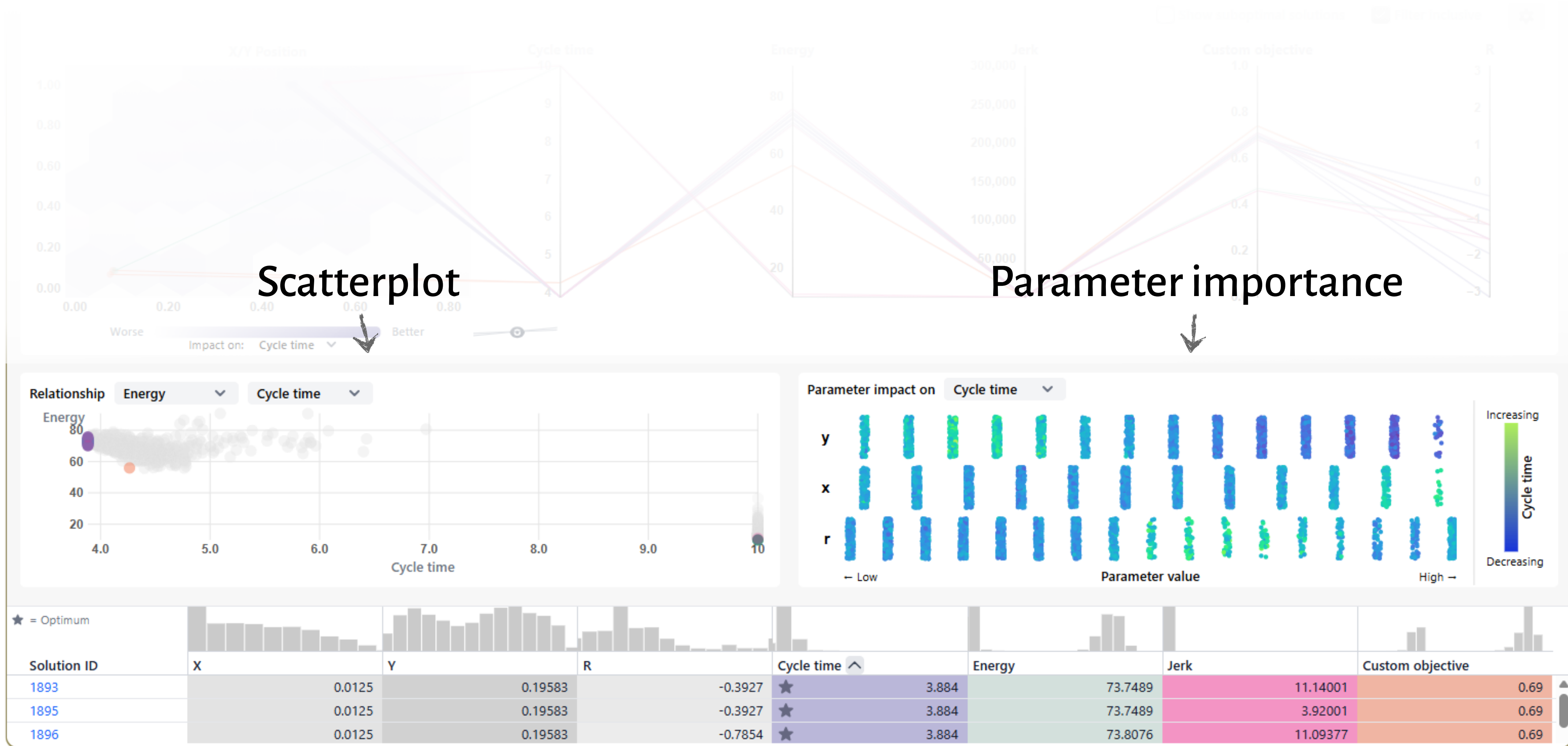
# ***ROSS: Visual Exploration of the Solution Space***

# ROSS: Visual Exploration of the Solution Space



# Spatially-linked parallel coordinates plot





## Multi-attribute ranking

# Filter and custom objectives



ROSS Multi-Objective Optimization for Robot Base Placement and Trajectories Learn more Example data

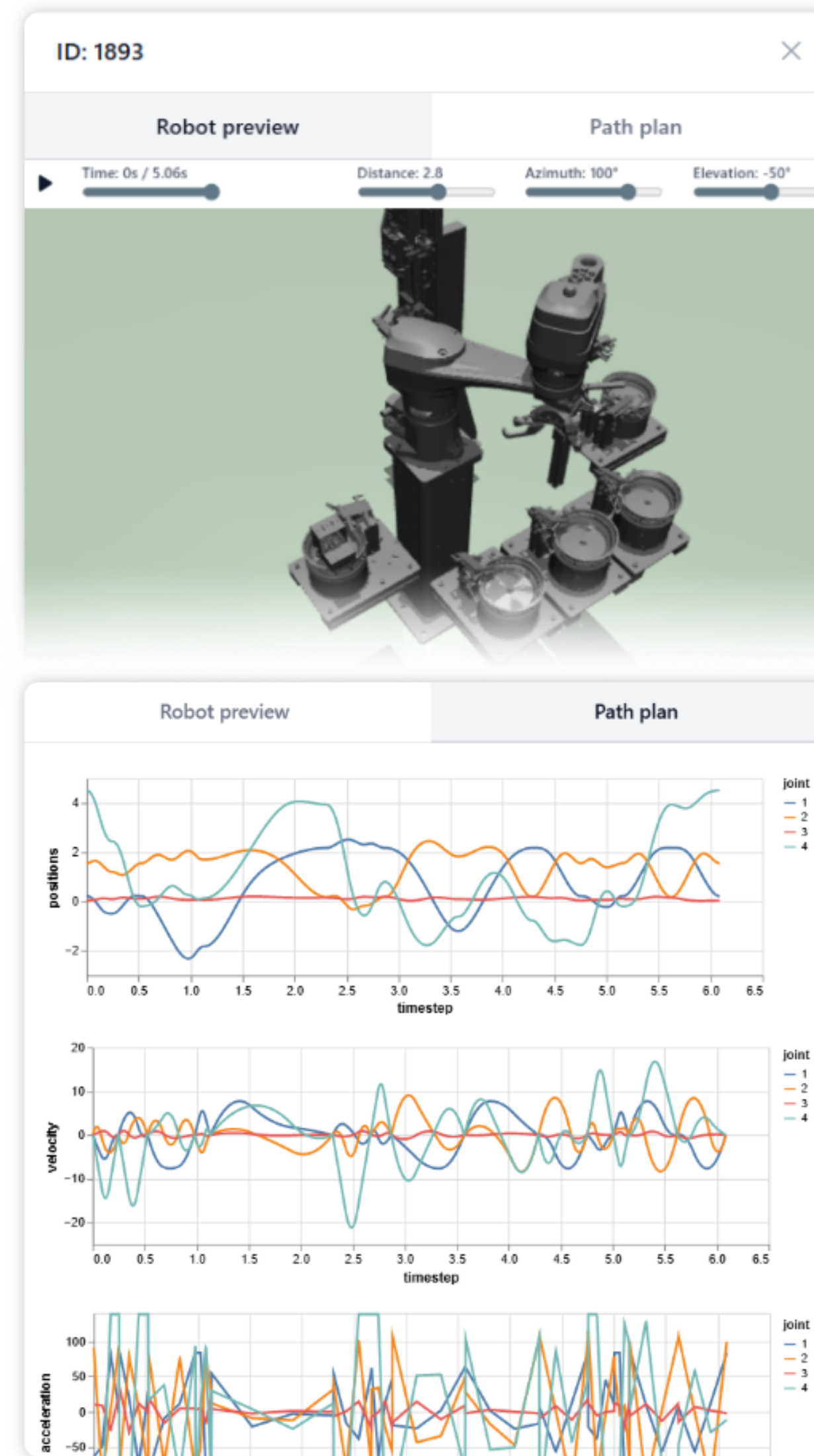
18 Cycle time optimum 1 Energy optimum 4 Jerk optimum 2 Custom objective ×

Low Minimize cycle time High Low Minimize energy demand High Low Minimize jerk High Update weights

Show suboptimal solutions  Filter inclusive ⚙️

X/Y Position	Cycle time	Energy	Jerk	Custom objective	R
1,000	10		300,000	1.0	3

Solution details →



# Supports analysis tasks

1. Overview of distribution and structure of feasible solutions
2. Refinement: adjusting parameter ranges, comparing objectives, and exploring custom weights.
3. Compare subsets of solutions to reason about trade-offs and evaluate alternatives.
4. Examine individual solutions and simulate robot movement.

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1. Overview of distribution and structure of feasible solutions
  2. Refinement: adjusting parameter ranges, comparing objectives, and exploring custom weights.
  3. Compare subsets of solutions to reason about trade-offs and evaluate alternatives.
  4. Examine individual solutions and simulate robot movement.
- ➡ Generic parameters & objectives; extensible to other dimensions.

# Results and discussion

Observed distinct analysis strategies

*Multi-view scanning vs. anchor-view*

→ Overlapping encodings valued as complementary, not redundant

Different preferences for *algorithmic support vs. manual visual exploration*

→ Automated mechanisms should be carefully integrated; on-demand

Barriers for deployment in practice (fragmented tooling, data transfer issues)

→ Better integration into existing CAD workflows

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- Analysis of data and tasks for exploring robot base placement and trajectory optimization results.
- ROSS, an interactive visual analysis tool supporting such tasks.
- Qualitative insights from formative industry feedback and a small-scale summative user study.

