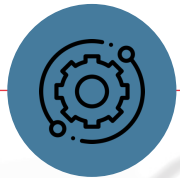


# PARAMETRIC MECHANISM DESIGN THROUGH NUMERICAL OPTIMIZATION AND PHYSICS SIMULATION

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# THE DESIGN-BUILD-TEST APPROACH IS FLAWED

- ▮ Lengthy development time, high cost for TRL 7+ hardware.
- ▮ Limited testing capabilities due to environment differences.
- ▮ Unoptimized hardware wastes resources.

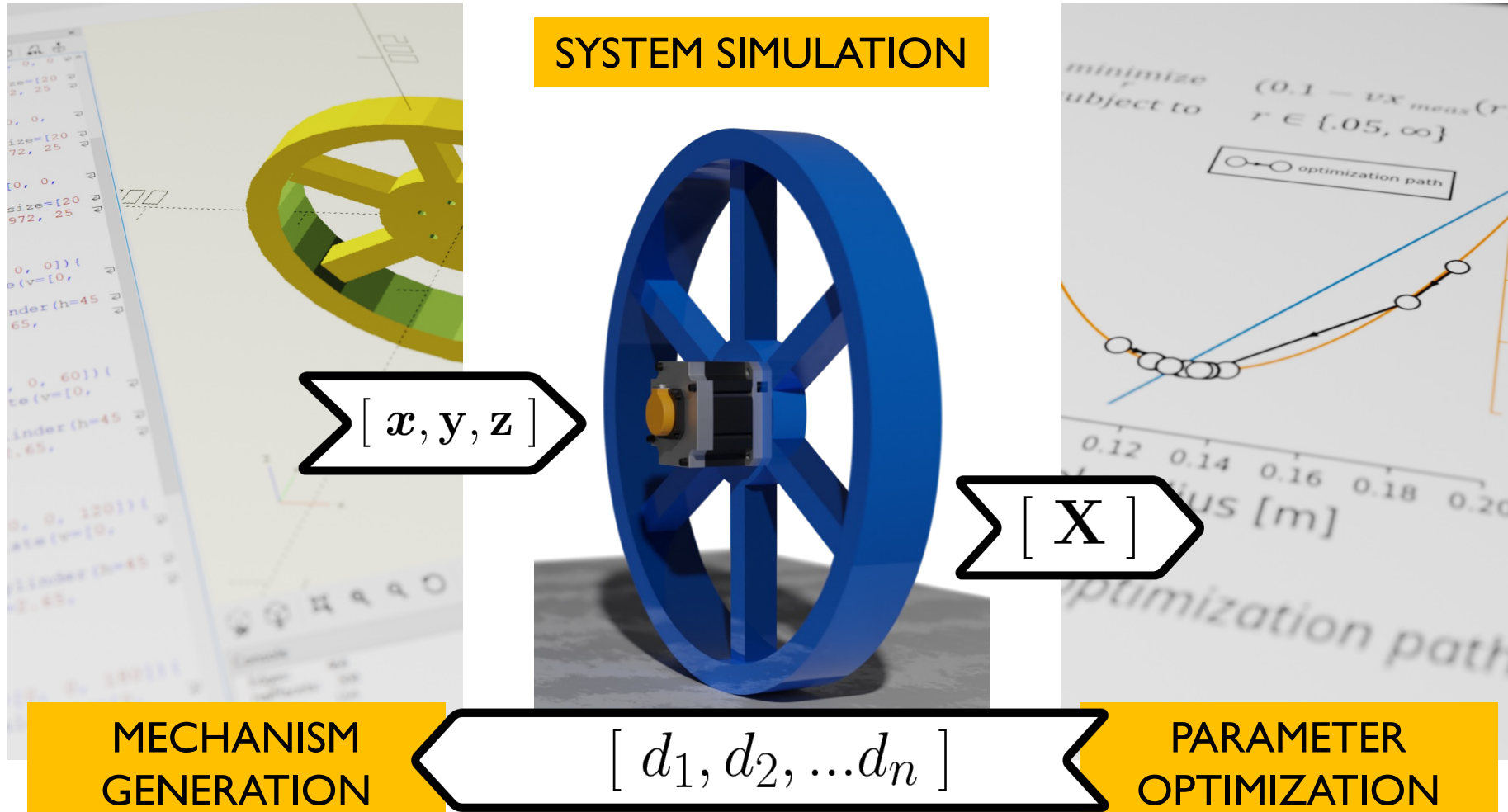


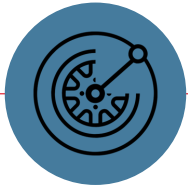
## DESIGN CAN (AND SHOULD!) BE LARGELY AUTOMATED

Optimization-based design with physical simulation can reduce the time, effort, and cost required to develop and deploy hardware that is *optimized for its operating environment*.

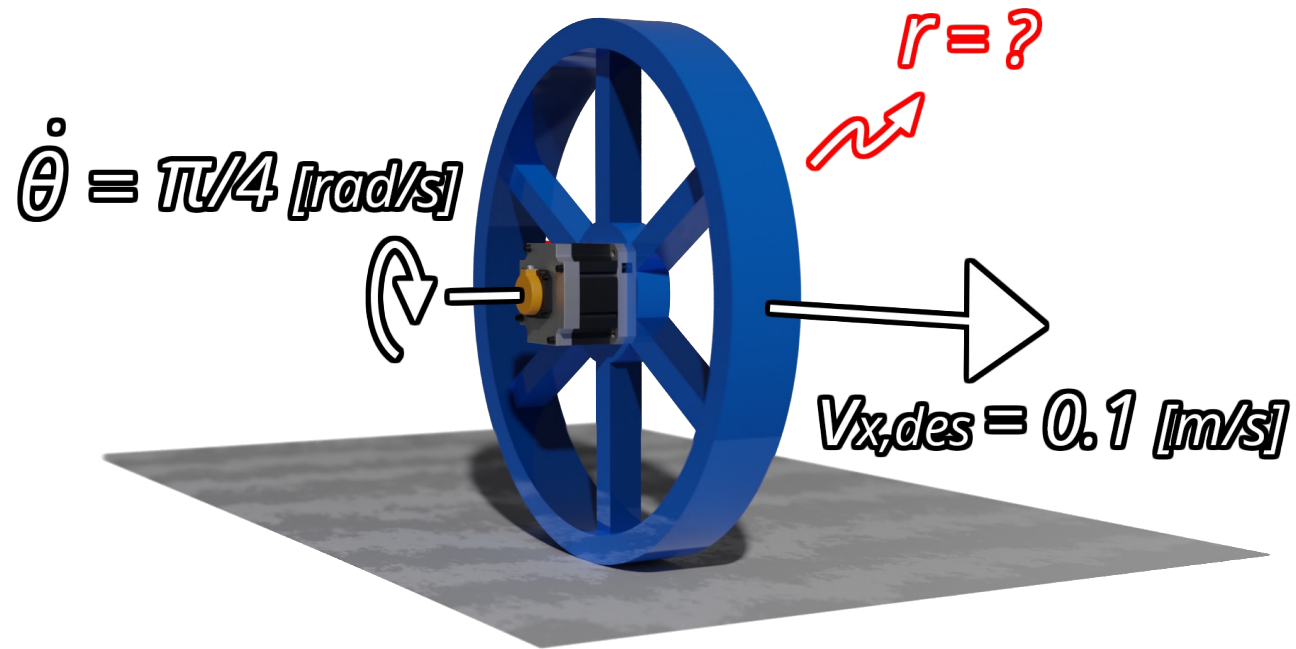


# MECHANISM OPTIMIZATION TOOLCHAIN





## EXAMPLE: WHEEL RADIUS OPTIMIZATION

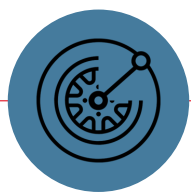


Wheel mechanism.

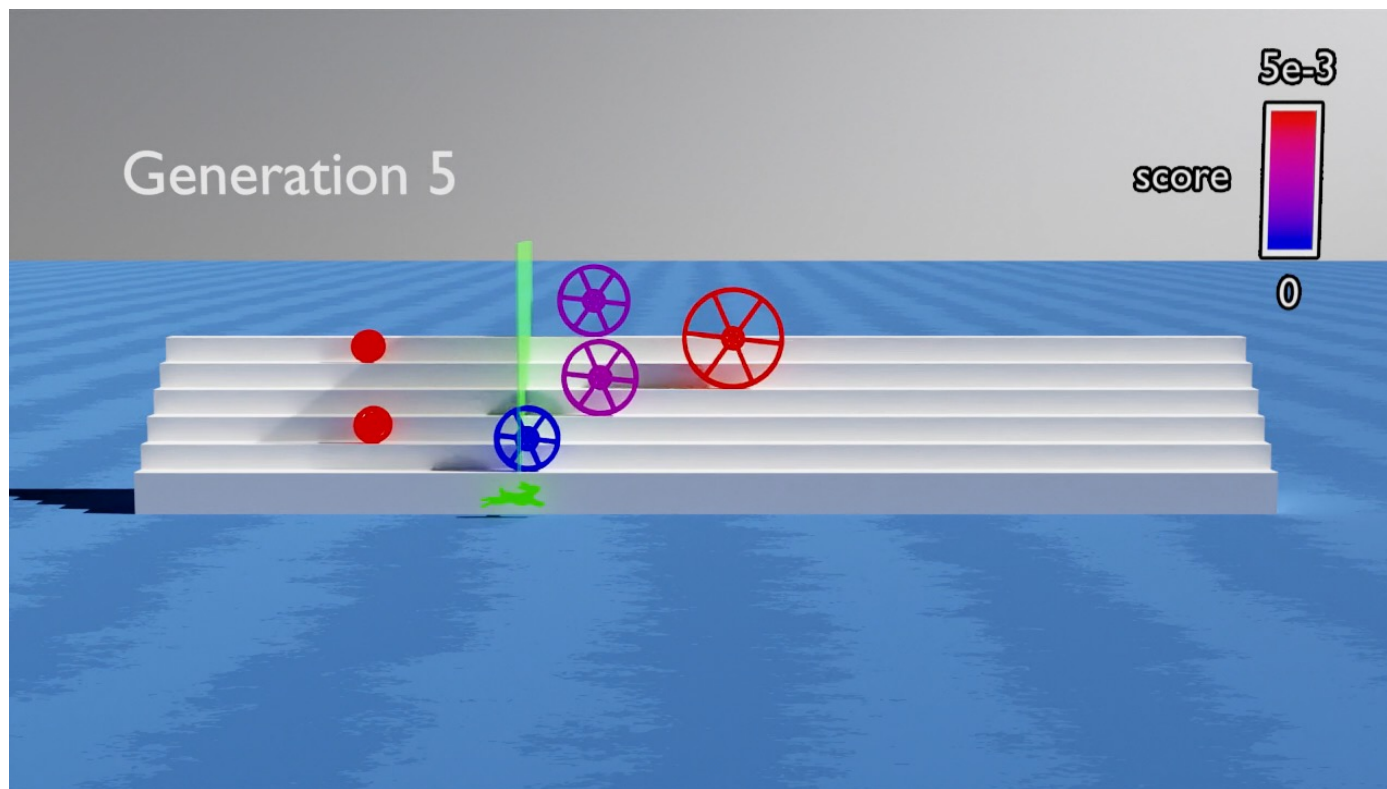
■ Analytically:

■  $v = r\dot{\theta}$

■  $r = 127.3 \text{ [mm]}$

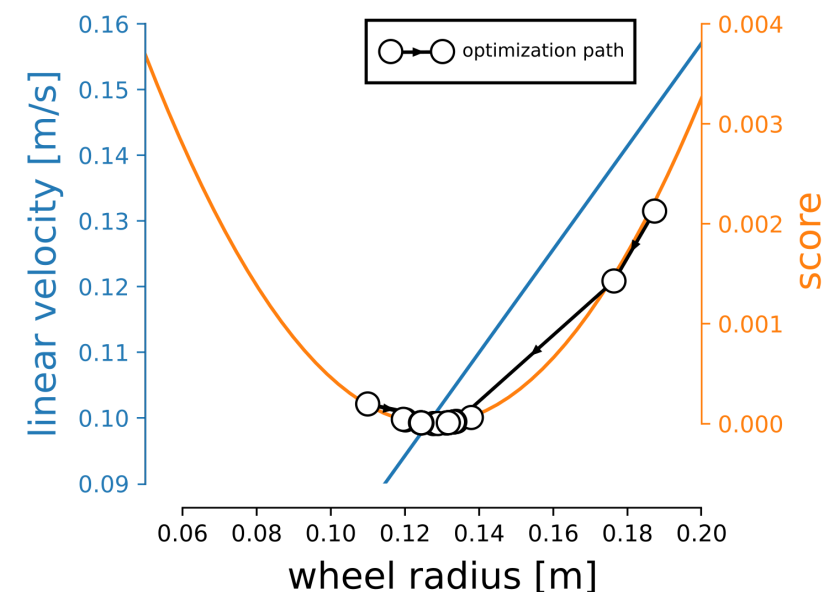


# EXAMPLE: WHEEL RADIUS OPTIMIZATION (CONT'D)

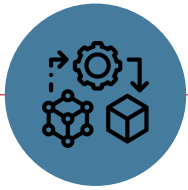


*Wheel radius optimization in simulation environment via CMA-ES [1].*

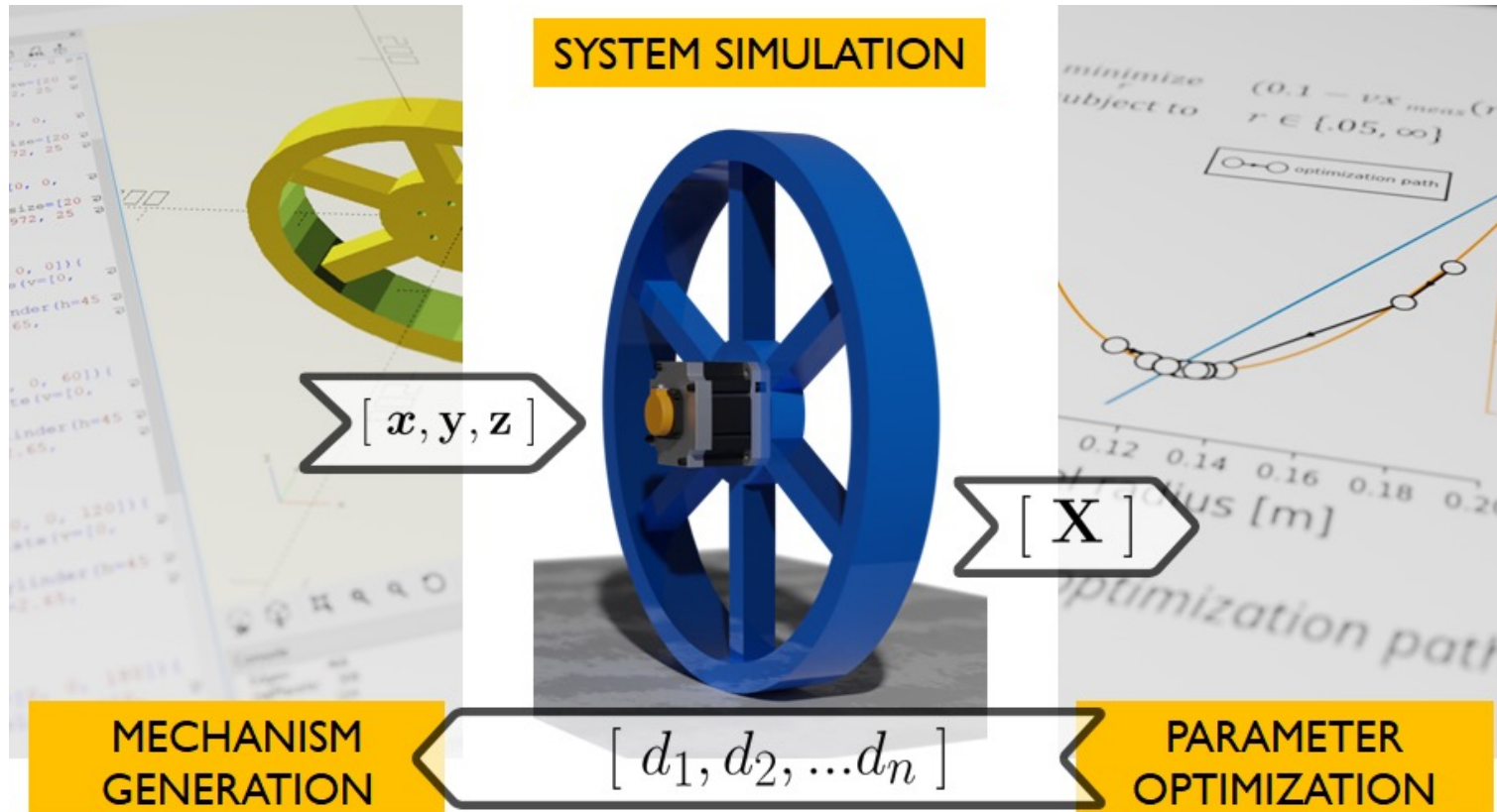
$$\begin{aligned} \underset{r}{\text{minimize}} \quad & g(r) = (0.1 - vx_{meas}(r))^2 \\ \text{subject to} \quad & r \in \{.05, \infty\} \end{aligned}$$



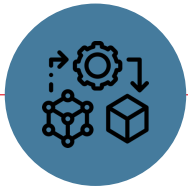
*Cost space and optimization path.*



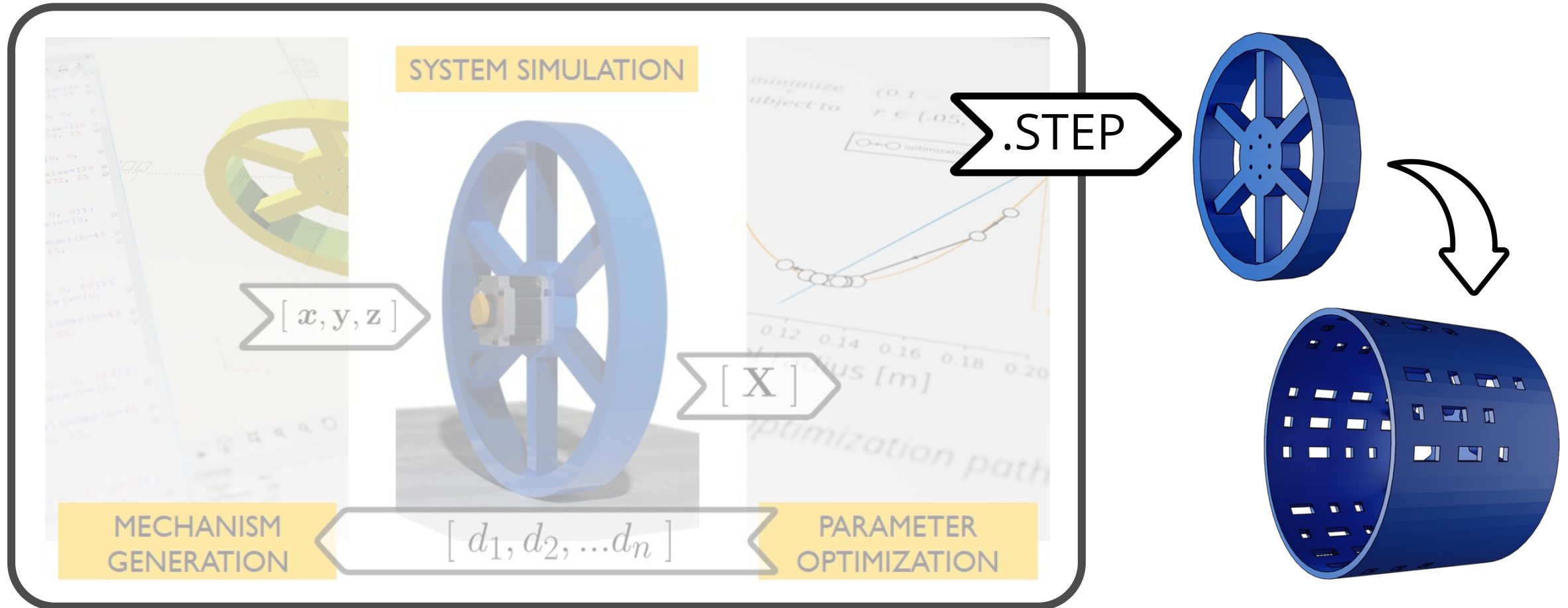
# MECHANISM DESIGN TOOLCHAIN



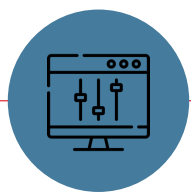




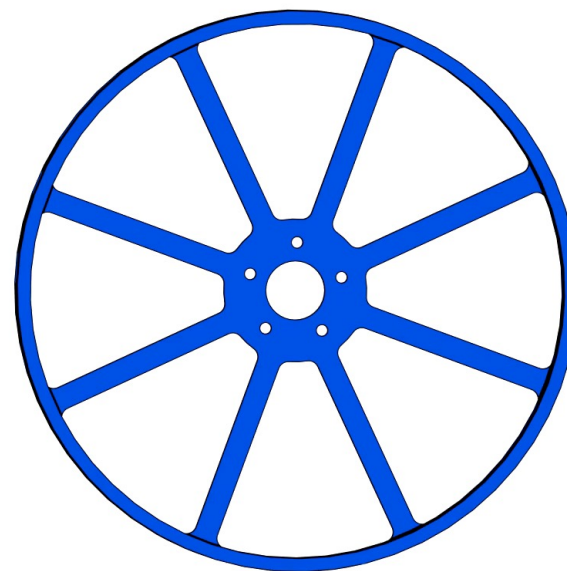
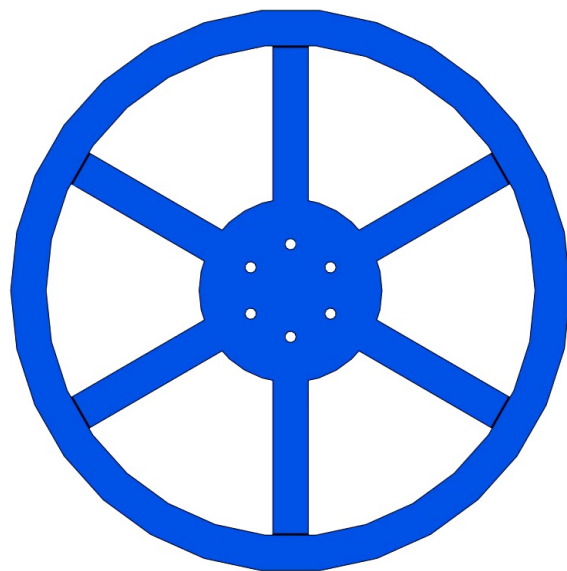
# MECHANISM DESIGN TOOLCHAIN

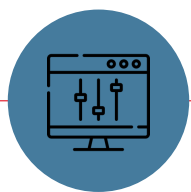




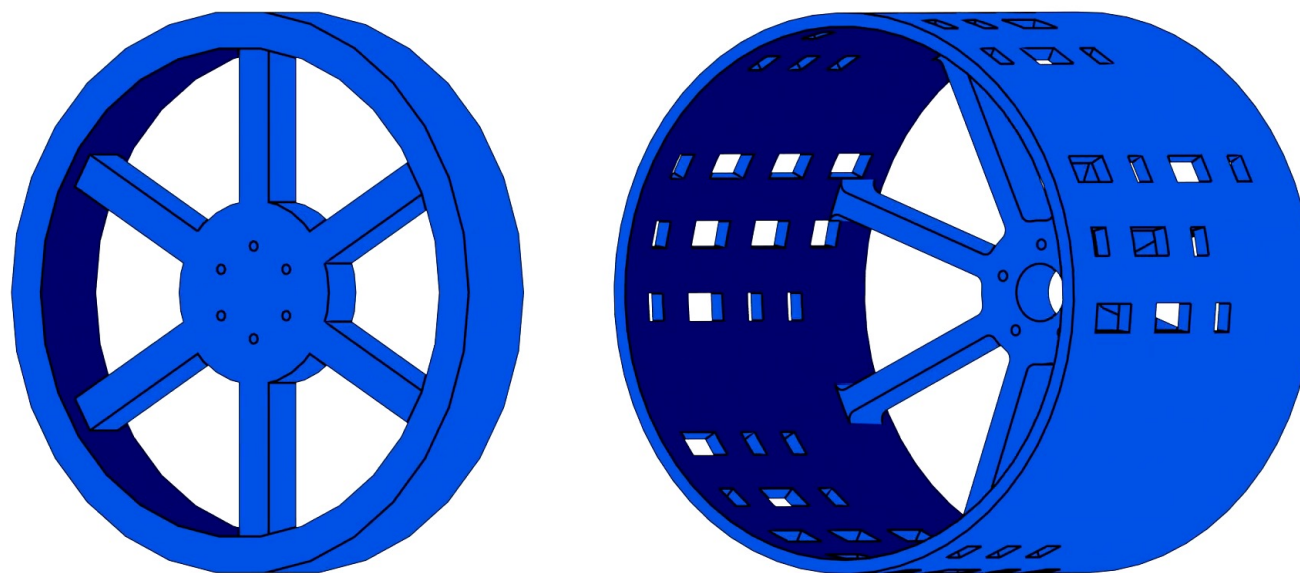


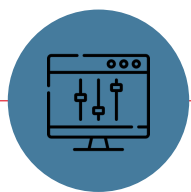
# OPTIMIZED MECHANISMS ARE PARAMETRIC AND REMAIN FULLY EDITABLE



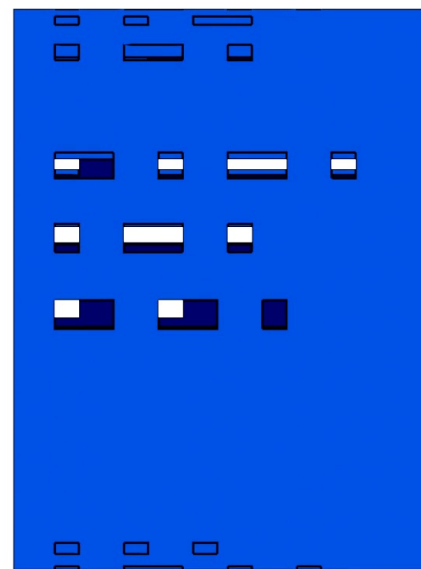


# OPTIMIZED MECHANISMS ARE PARAMETRIC AND REMAIN FULLY EDITABLE



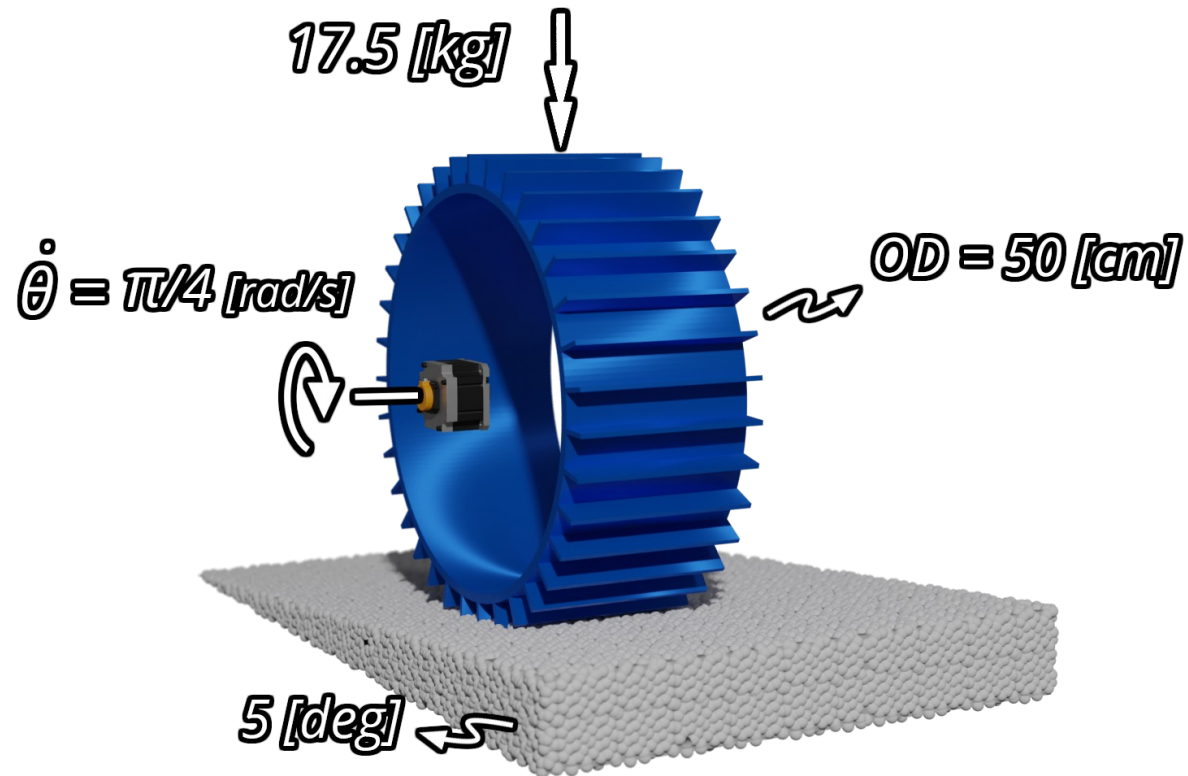


# OPTIMIZED MECHANISMS ARE PARAMETRIC AND REMAIN FULLY EDITABLE





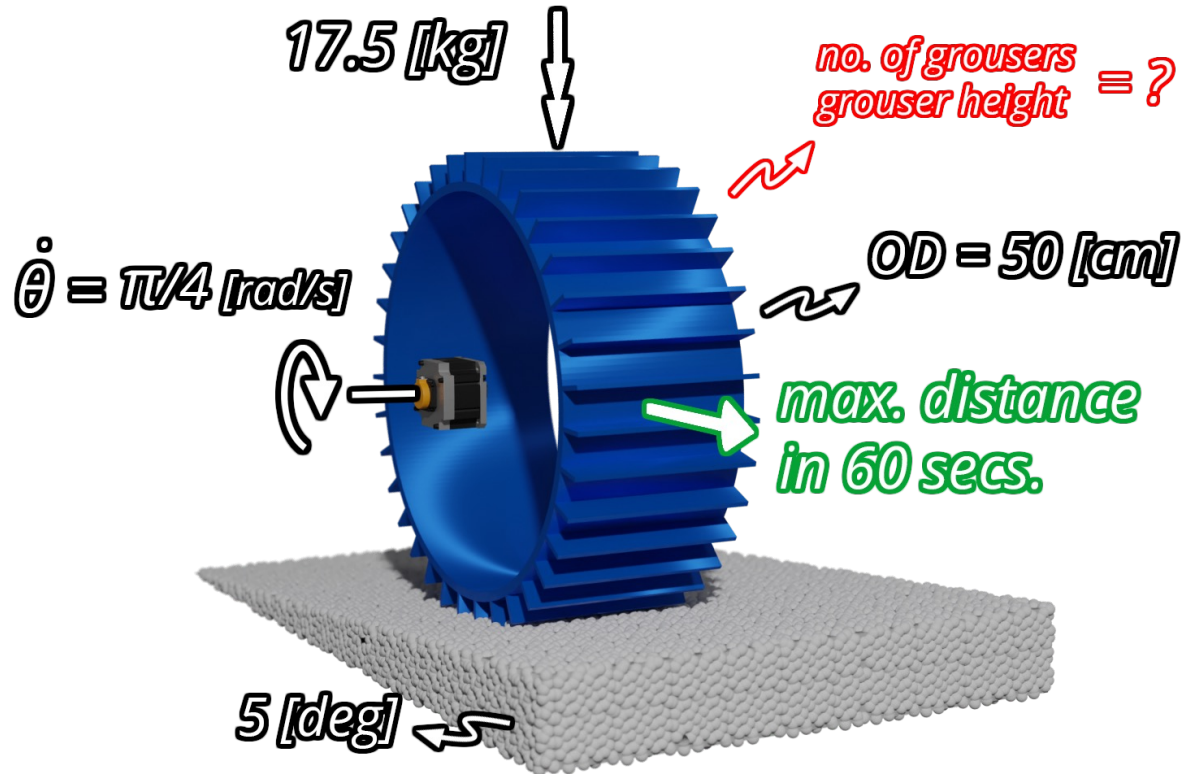
# MULTI-DIMENSIONAL OPTIMIZATION



*2D wheel optimization problem in granular media.*



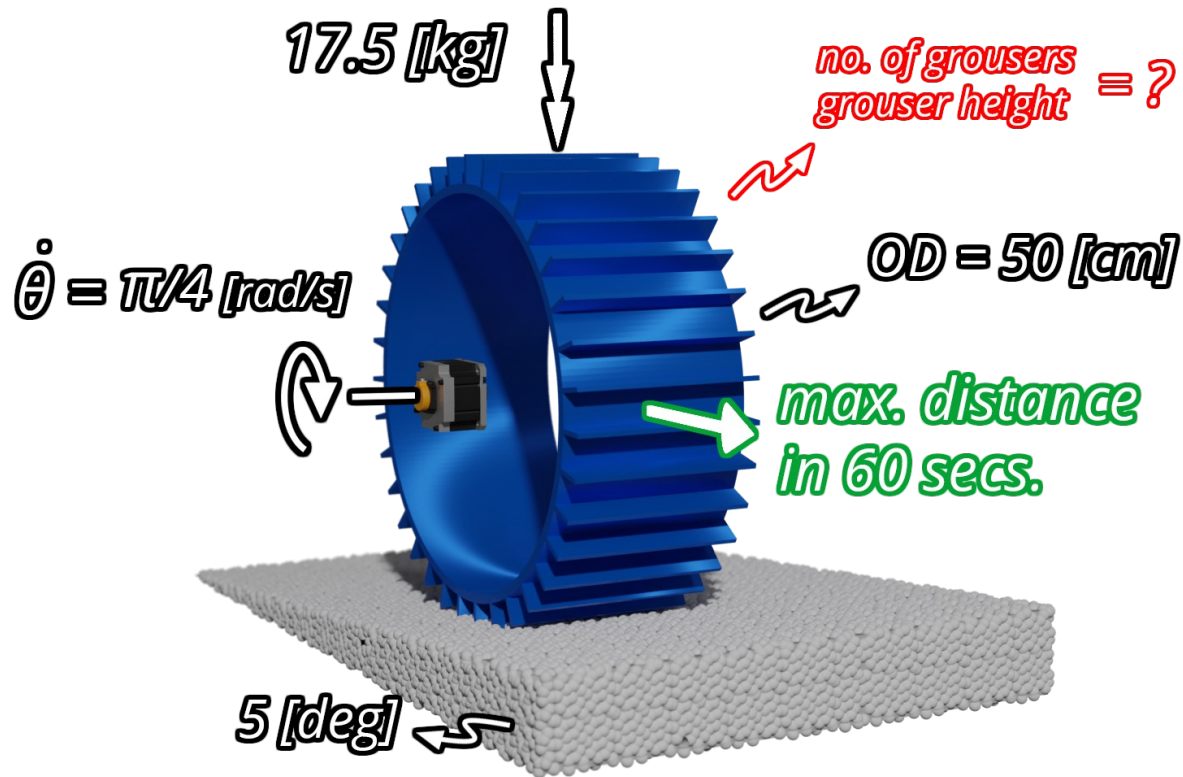
# MULTI-DIMENSIONAL OPTIMIZATION



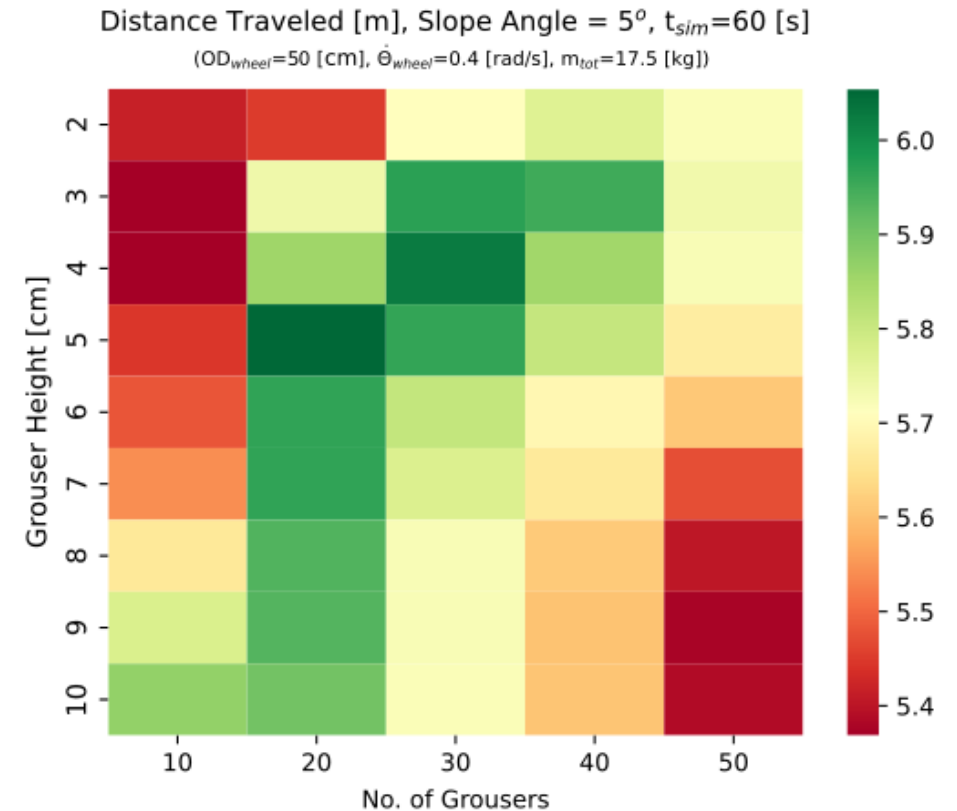
2D wheel optimization problem in granular media.



# MULTI-DIMENSIONAL OPTIMIZATION



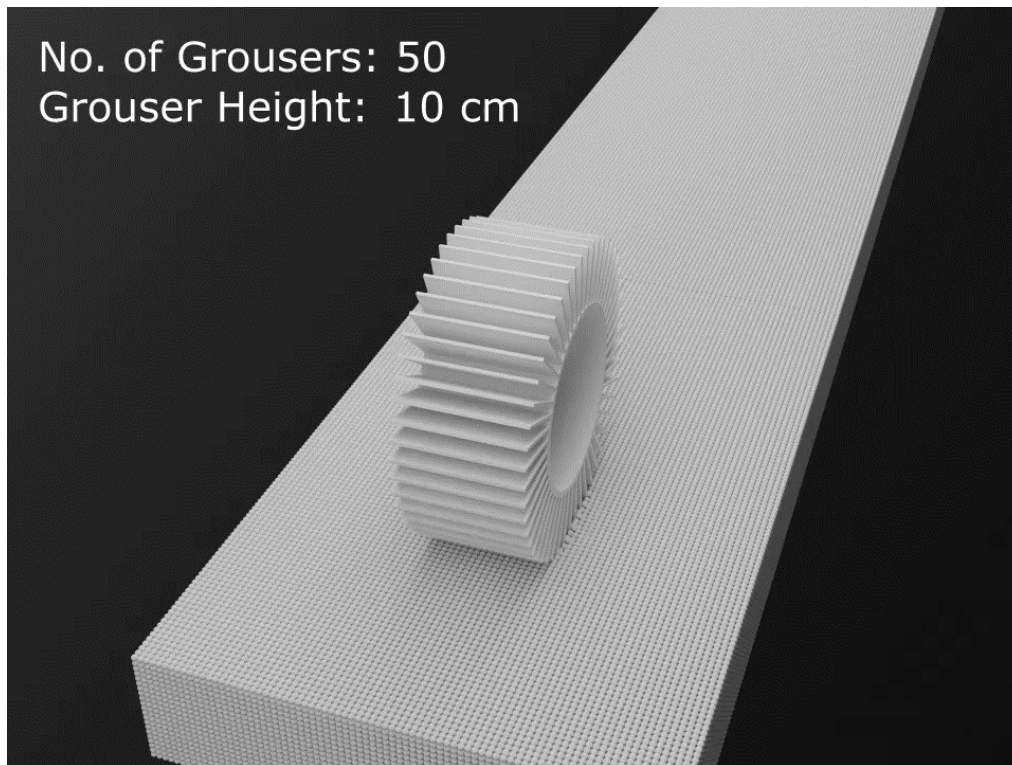
2D wheel optimization problem in granular media.



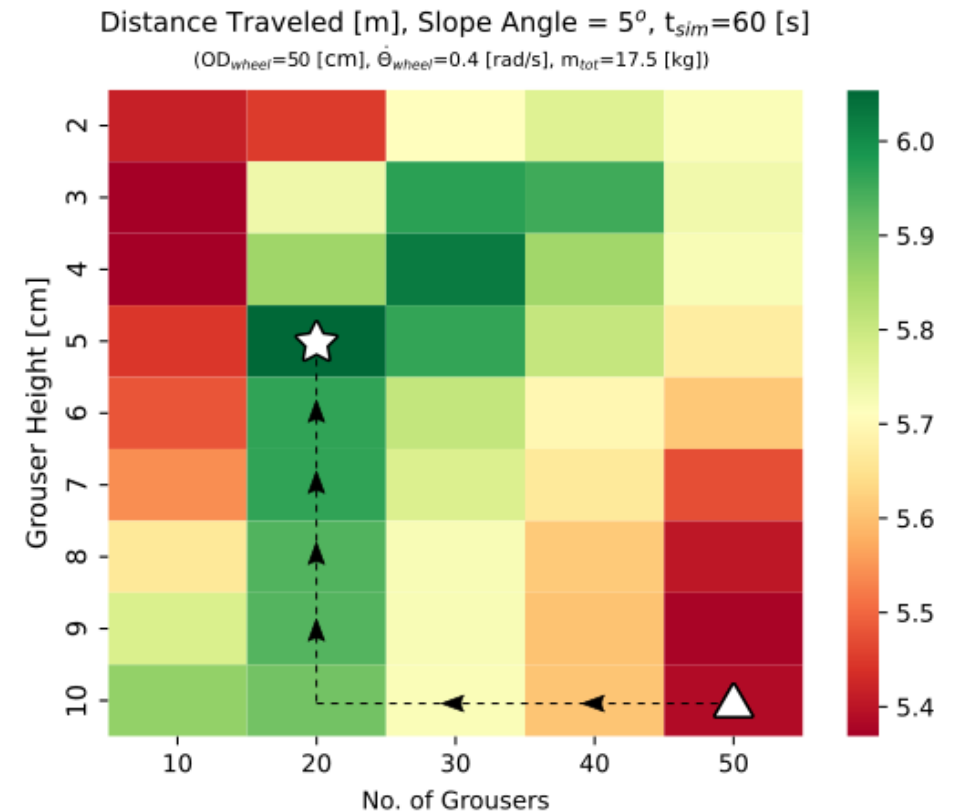
Design space parameter sweep. Simulated in Chrono [2].



# MULTI-DIMENSIONAL OPTIMIZATION

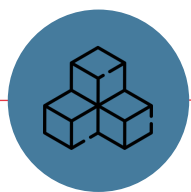


*Wheel simulations.*

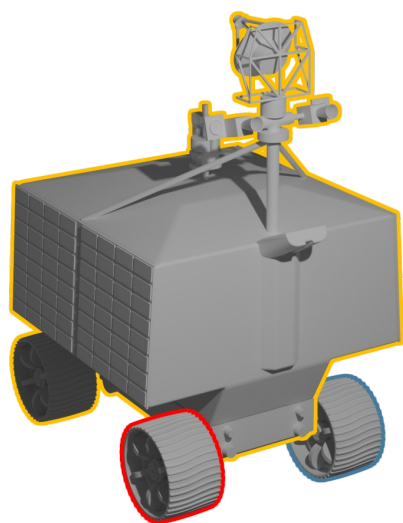


*Parameter optimization using discrete hill climbing.*

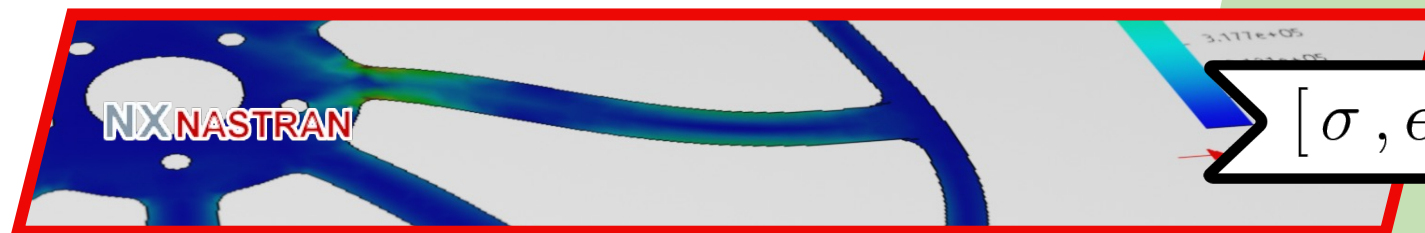




# MULTI-OBJECTIVE FORMULATION ENABLES MODULARITY AND CO-OPTIMIZATION



$[\mathbf{F}, \tau]$

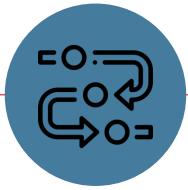


$[\sigma, \epsilon]$

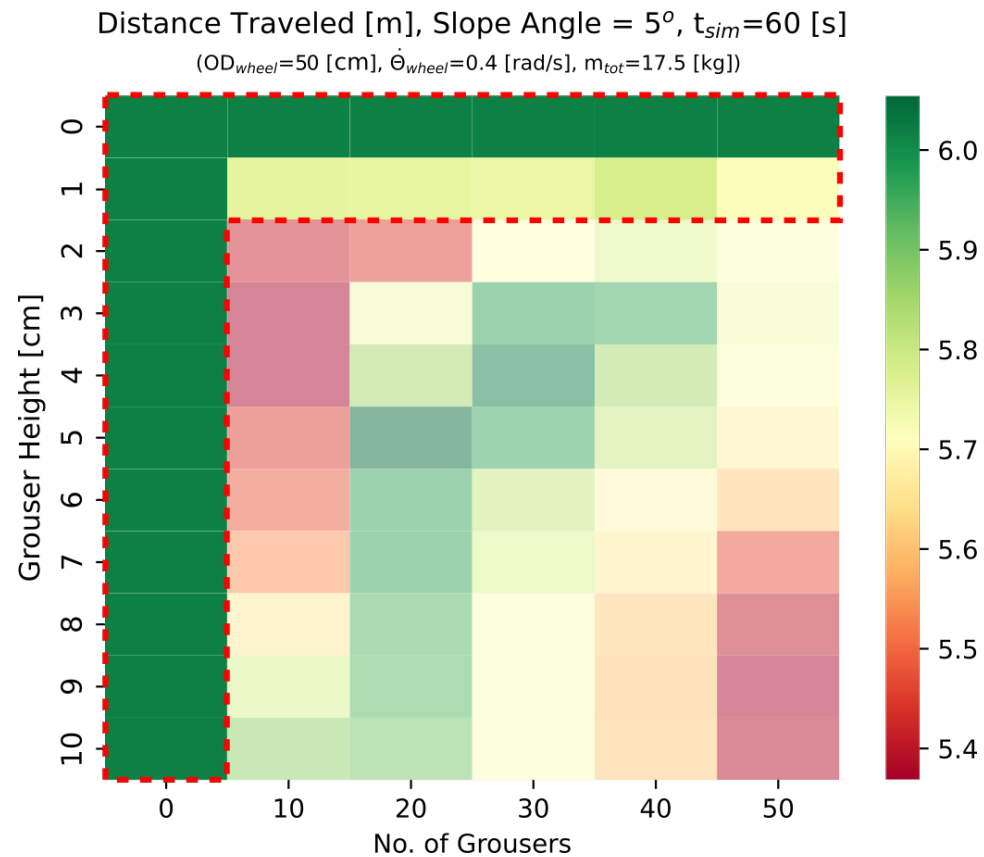
$g(\mathbf{x})$



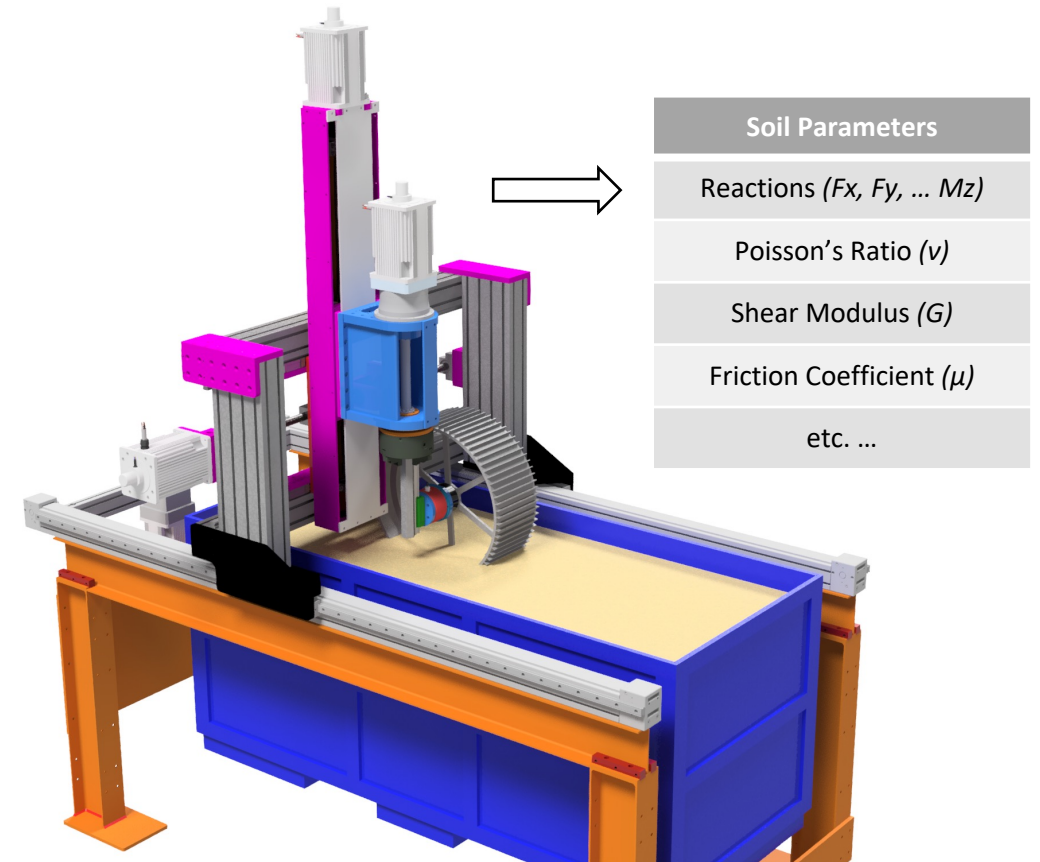
$[\mathbf{k}]$




## NEXT STEPS



*Soil model should be tuned to range of interest.*



*GRC Soil Characterization Rig.*

The background of the slide features a close-up, slightly blurred image of two metallic-looking logos resting on a textured, grey surface. On the left is the NASA logo, which includes the word "NASA" in its characteristic font, surrounded by stars and a swoosh. On the right is the Artemis logo, which consists of a stylized "A" with a crescent moon and the word "ARTEMIS" below it. The lighting creates highlights and shadows on the logos, giving them a three-dimensional appearance.

# THANK YOU! QUESTIONS?



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Sources:

[1] N. Hansen and A. Ostermeier. Completely derandomized self-adaptation in evolution strategies. *Evolutionary Computation* 9(2).

[2] A. Tasora *et al.* Chrono: An open source multi-physics dynamics engine. *High Performance Computing in Science and Engineering – Lecture Notes in Computer Science*, Springer, 2016.