

Functionality-aware Retargeting of Mechanisms to 3D Shapes

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Motivation

Functional objects design



CNC



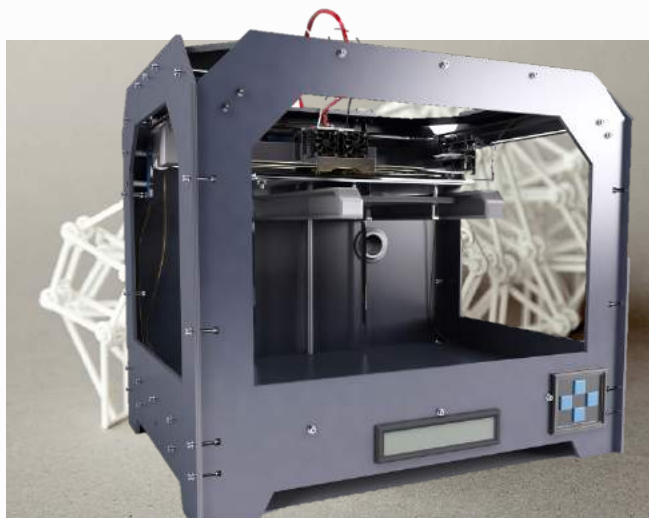
Laser cutting



Architecture

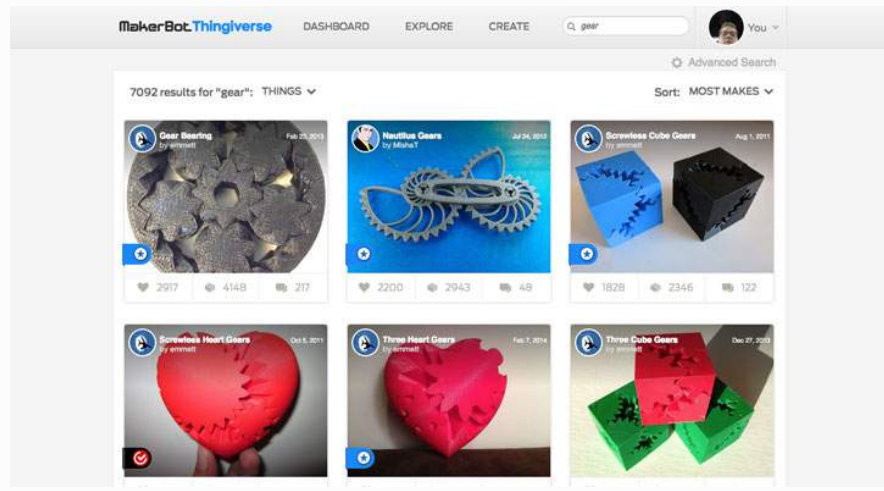
Motivation

Functional objects design

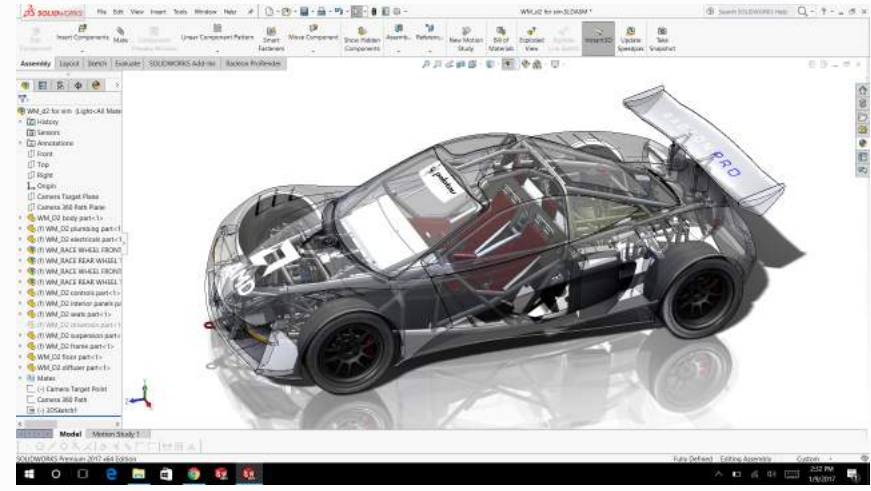


Motivation

Functional objects design



Thingivers



Solidworks

Motivation

Function vs form

“Form follows function”

-Louis Sullivan

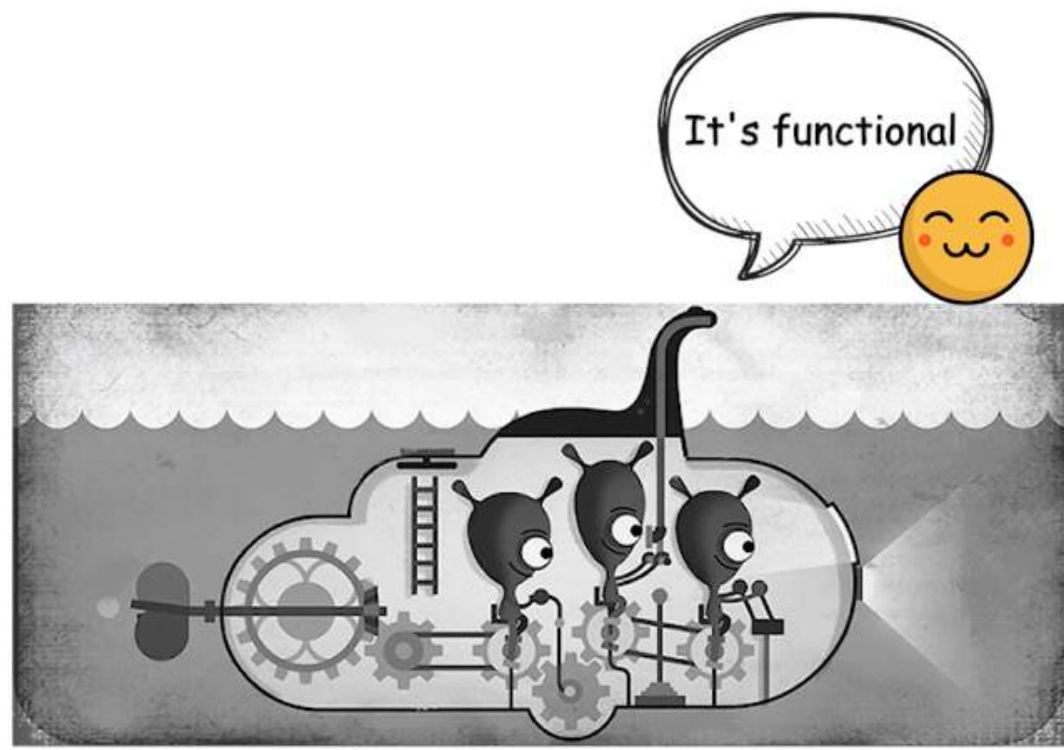
Motivation

Reusing underlying structure



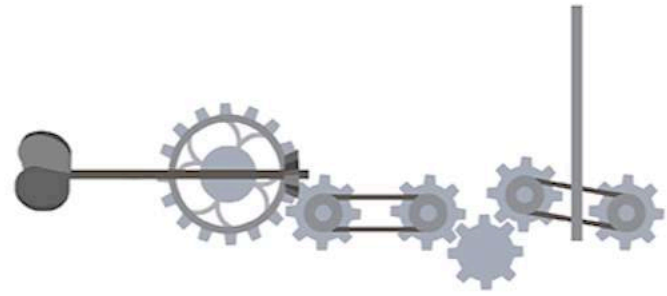
Motivation

Problems



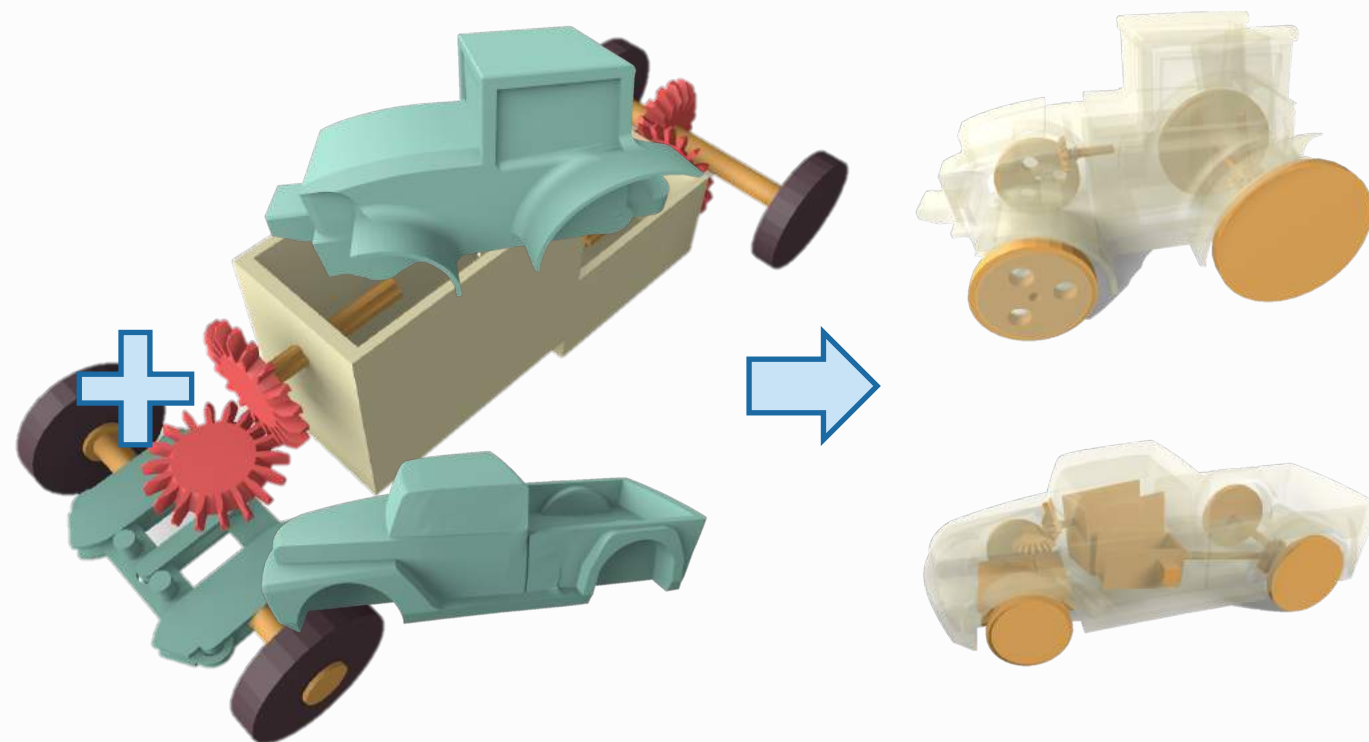
Motivation

Problems



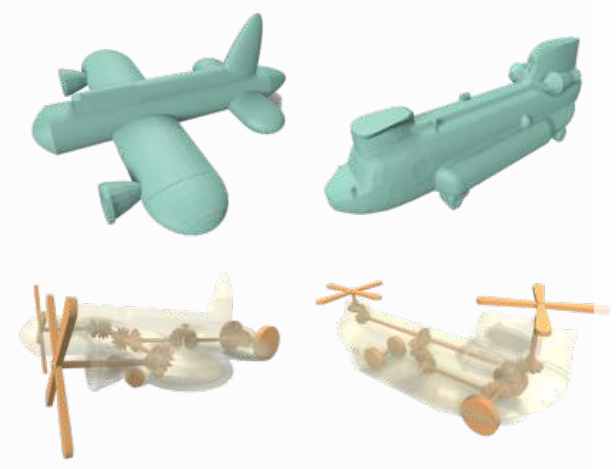
Motivation

Retargeting problem

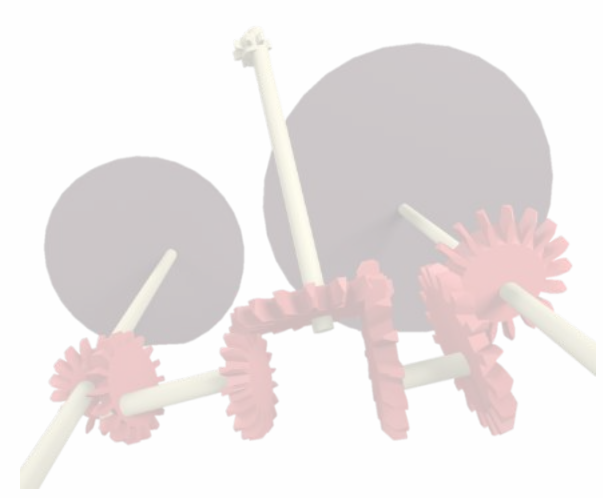


Motivation

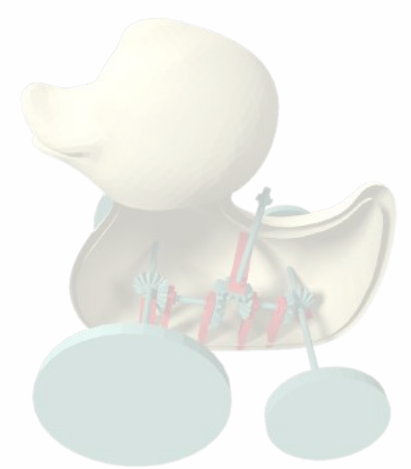
Challenges



Configuration



Functionality



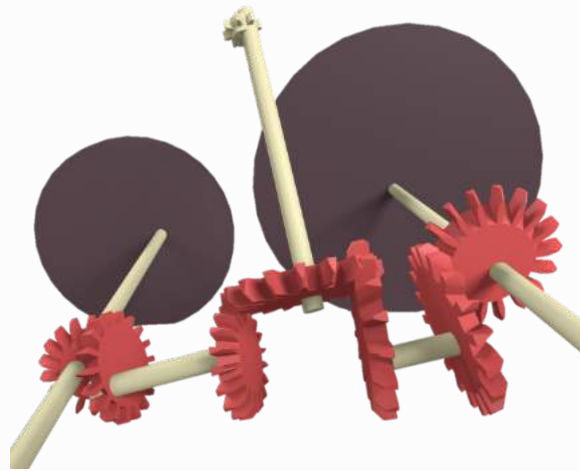
Fabrication

Motivation

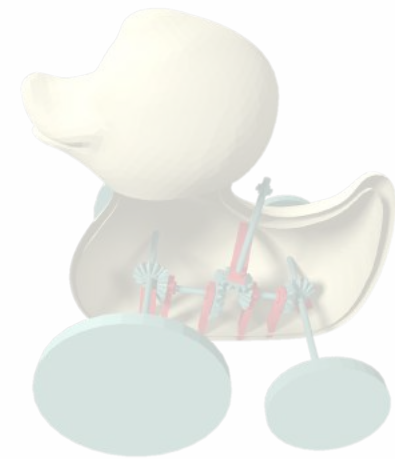
Challenges



Configuration



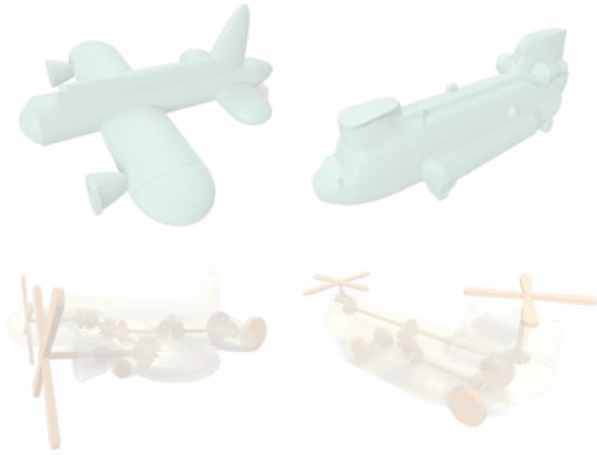
Functionality



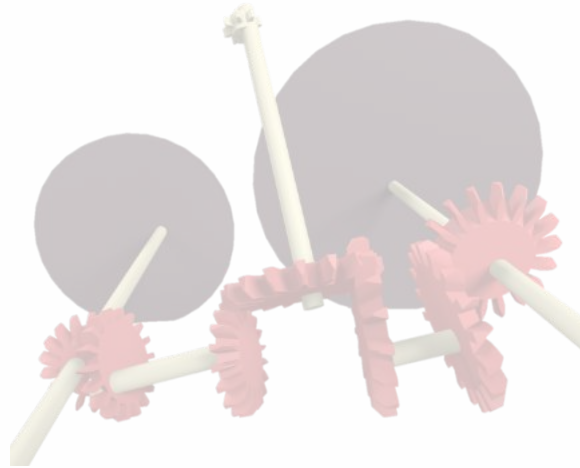
Fabrication

Motivation

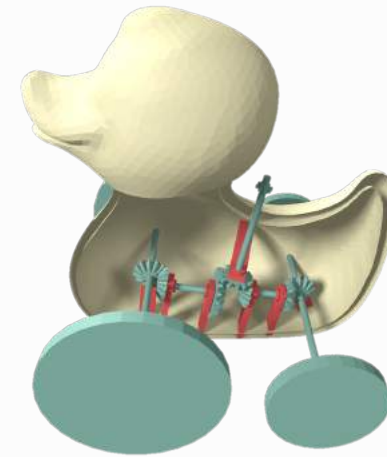
Challenges



Configuration



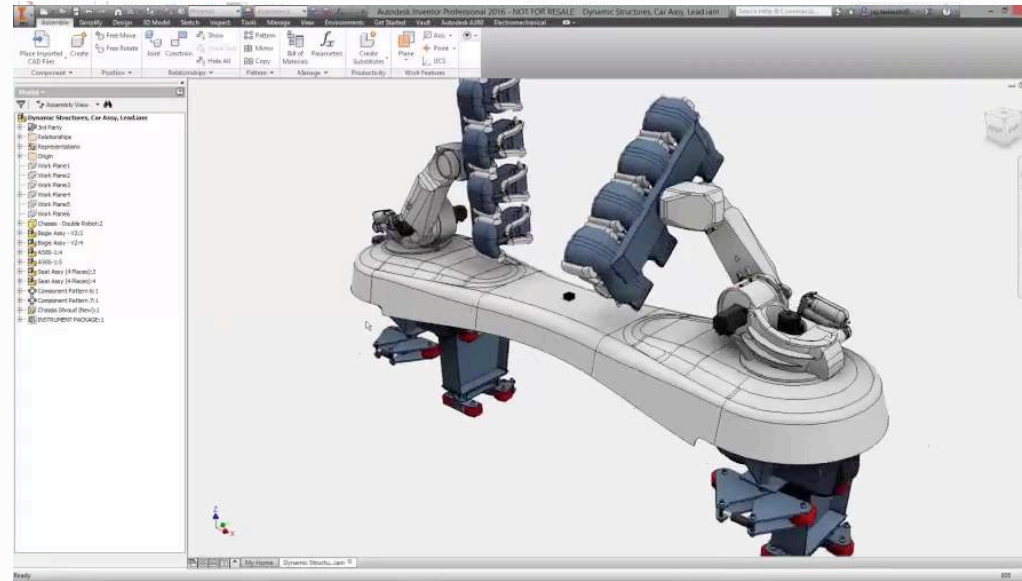
Functionality



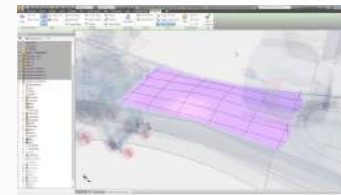
Fabrication

Related work

Traditional design workflow



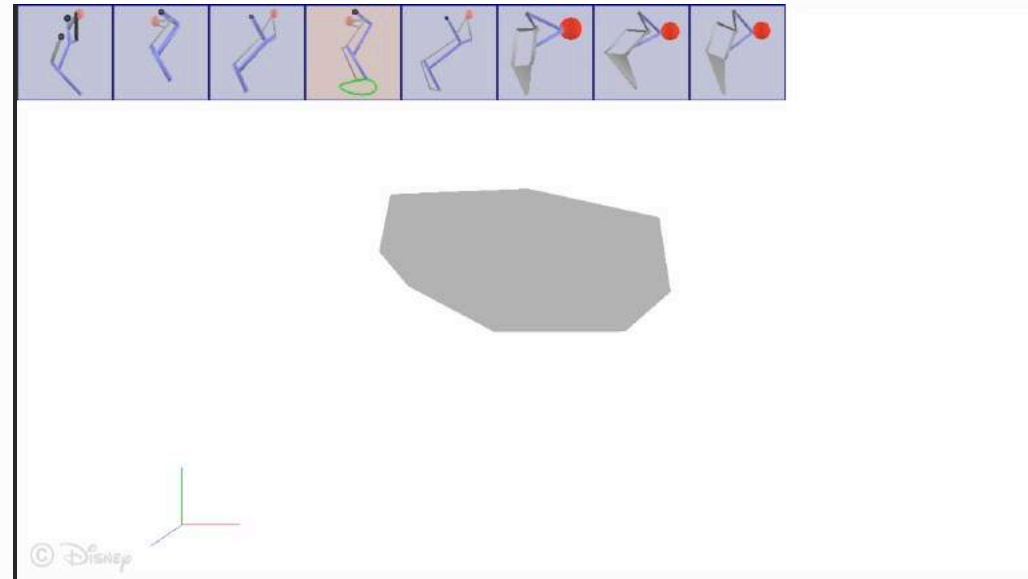
[Solidworks]



[Inventor]

Related work

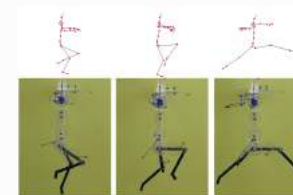
Computational mechanism design



[Zhu, et al. 2012]



[Coros, et al. 2013]



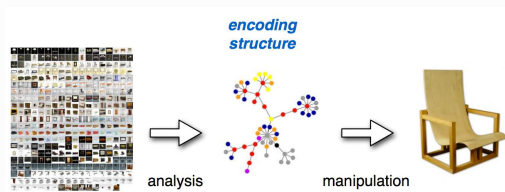
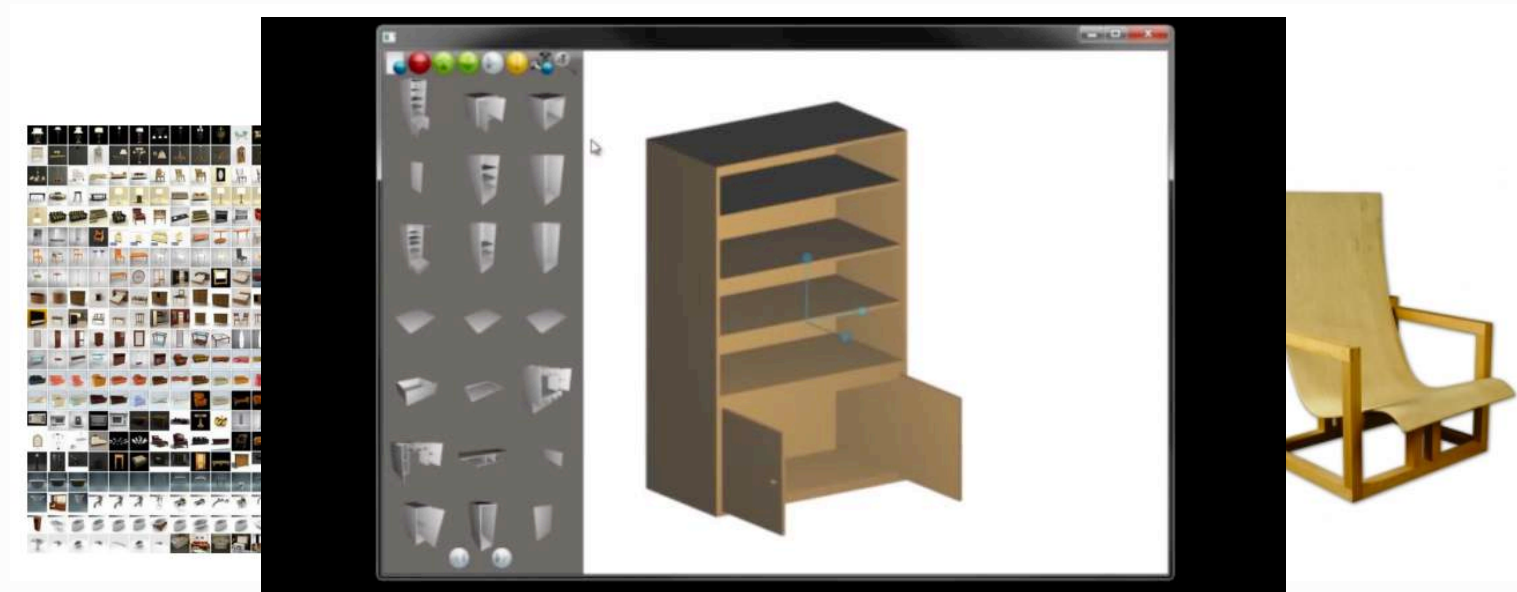
[Ceylan, et al. 2013]



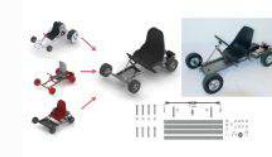
[Bharaj, et al. 2015]

Related work

Example based modeling



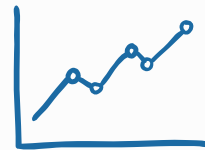
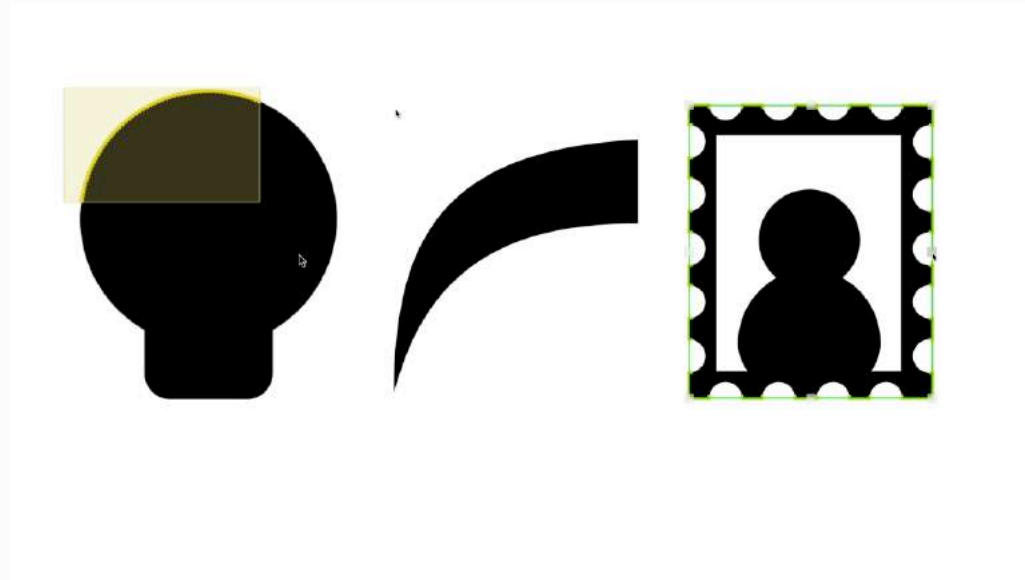
[Mitra, et al. 2014]



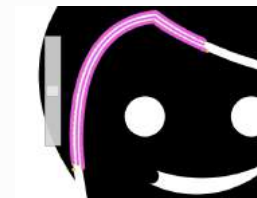
[Schulz, et al. 2015]

Related work

Constraint-based editing

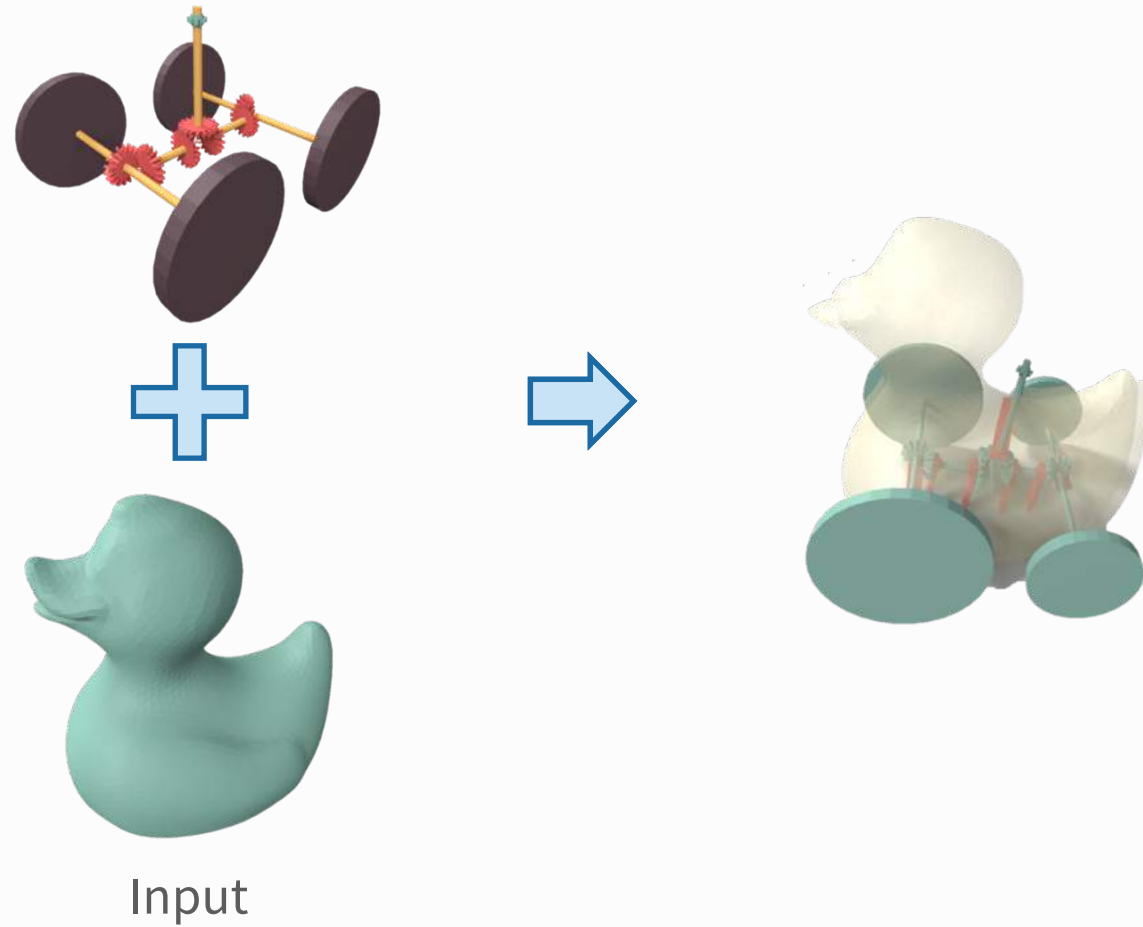


[Bächer, et al. 2015]

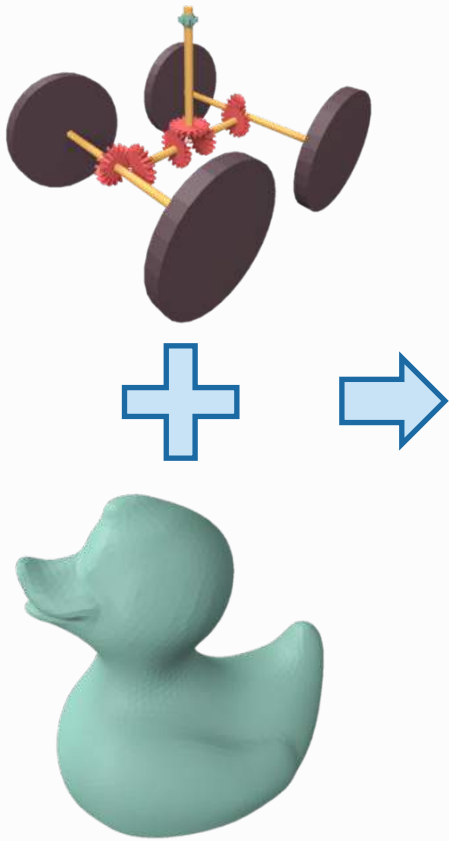


[Bernstein, et al. 2013]

Pipeline



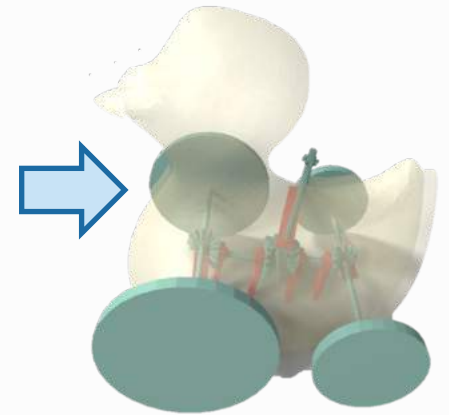
Pipeline



Input

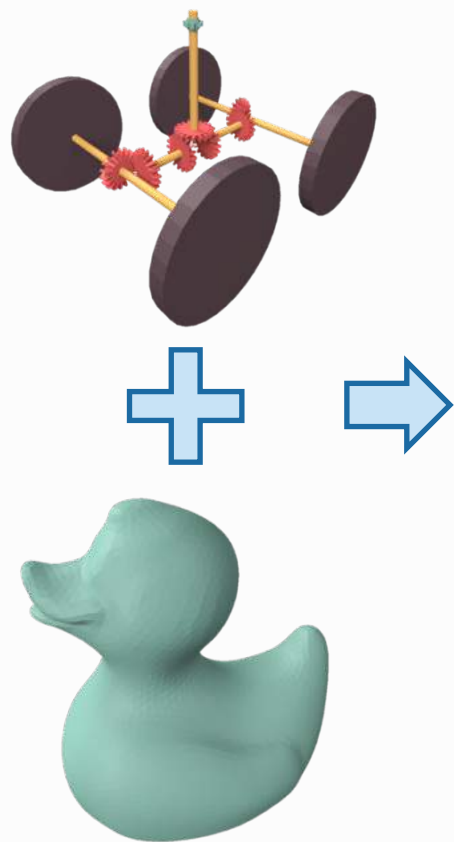


Interactive design system



Output

Pipeline

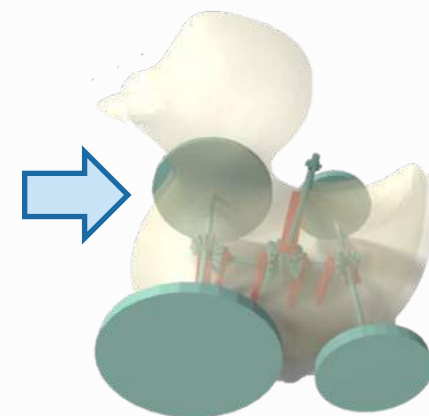


Input



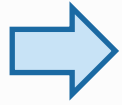
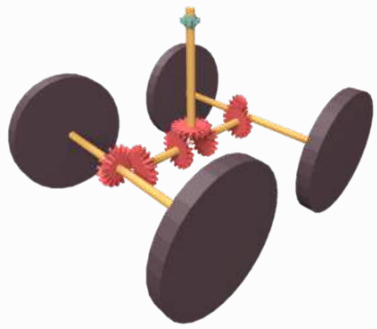
Optimization

Post processing

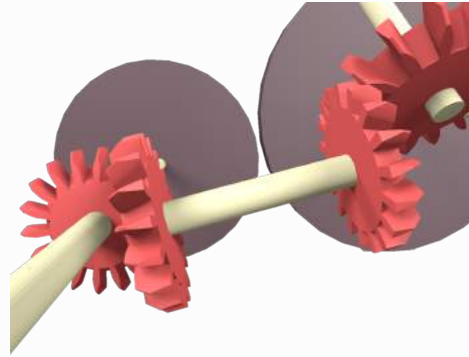


Output

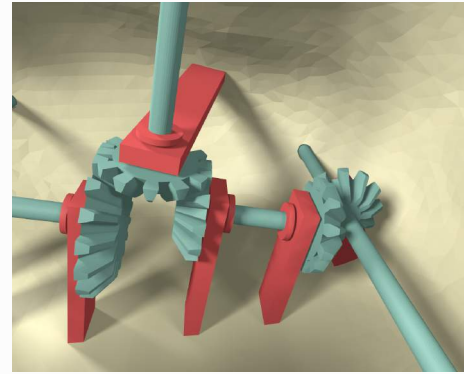
Pipeline



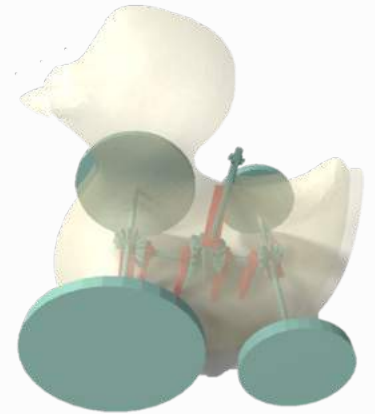
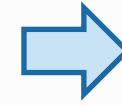
Input



Optimization

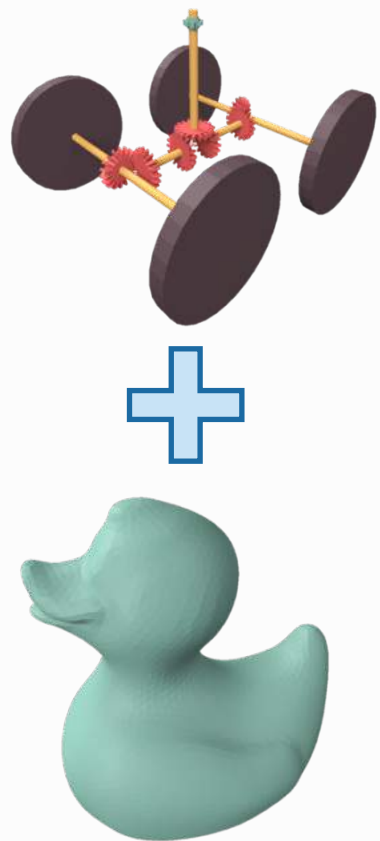


Post processing

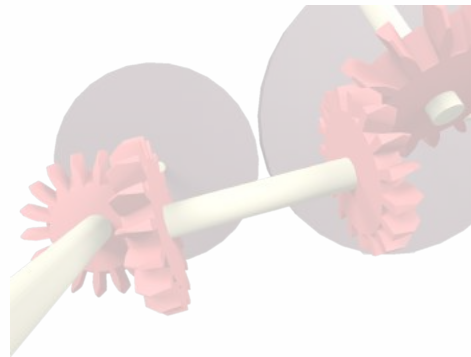


Output

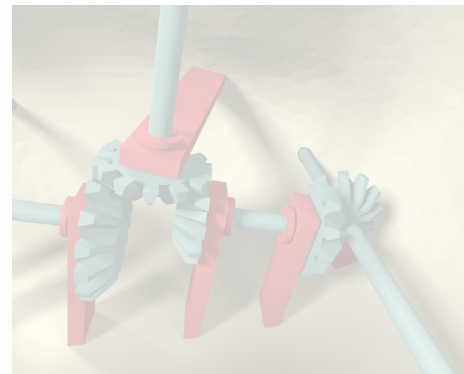
Pipeline



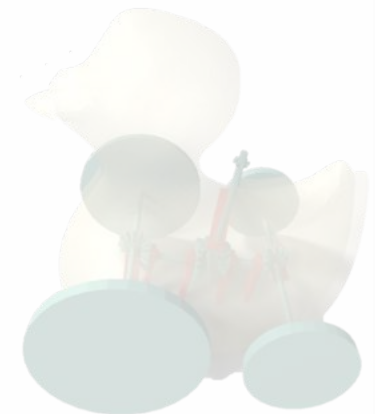
Input



Optimization



Post processing

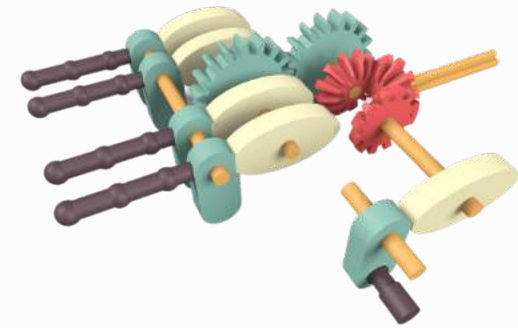
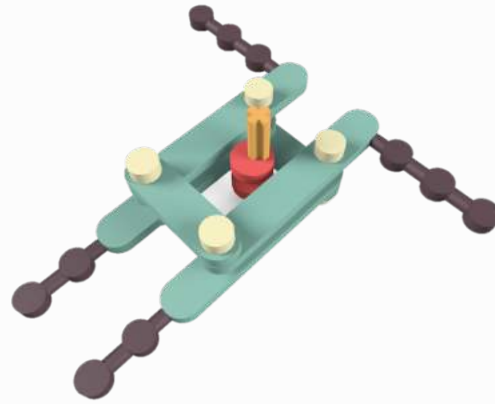
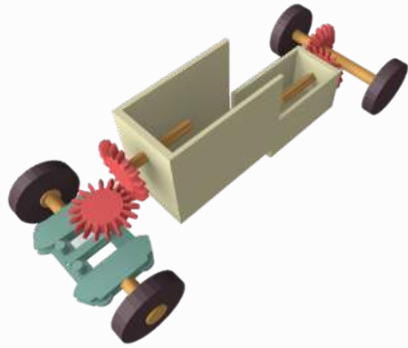


Output

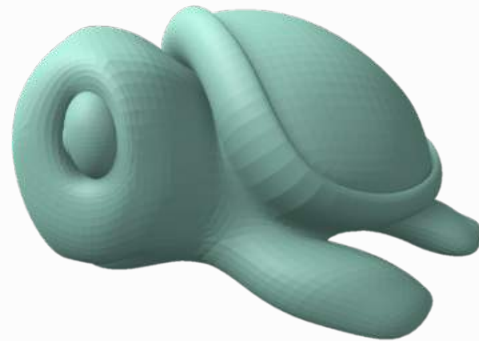
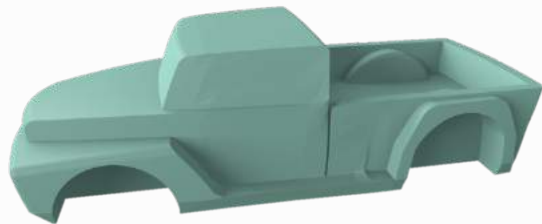
Template

Inputs

Templates

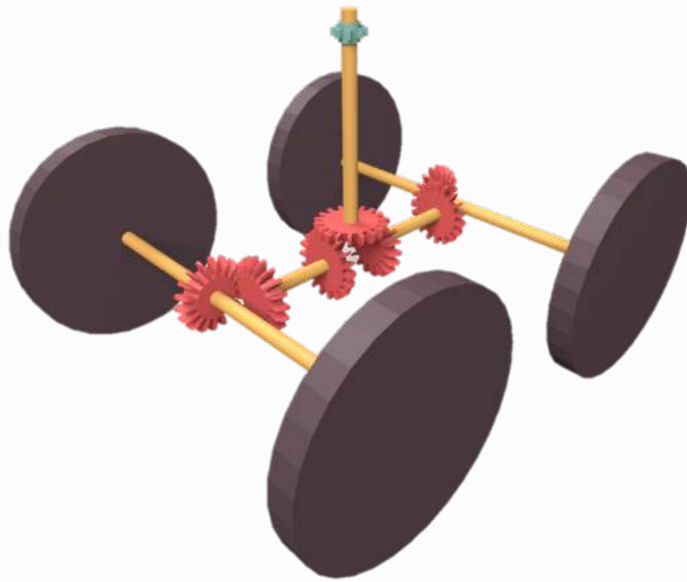


Target shapes

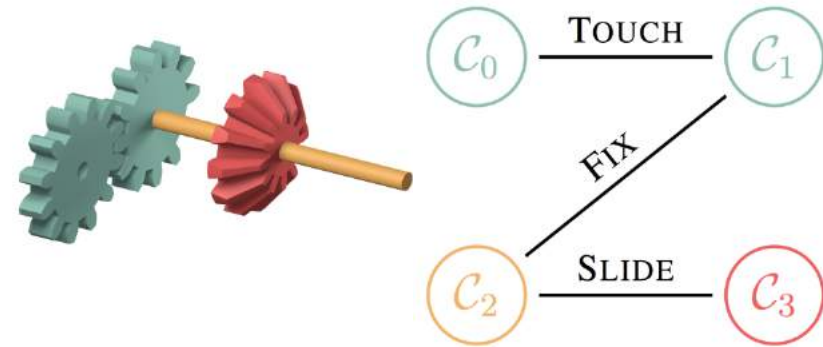
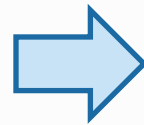


Template

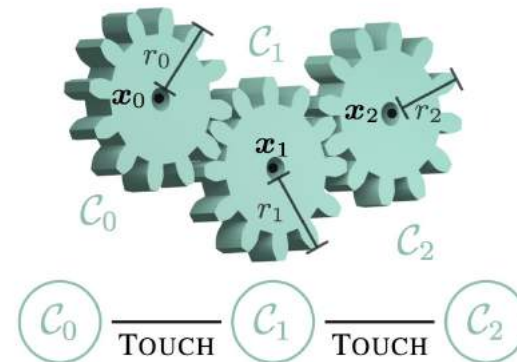
Parsing process



Template

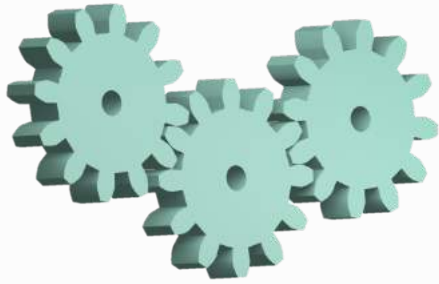


Components and connections

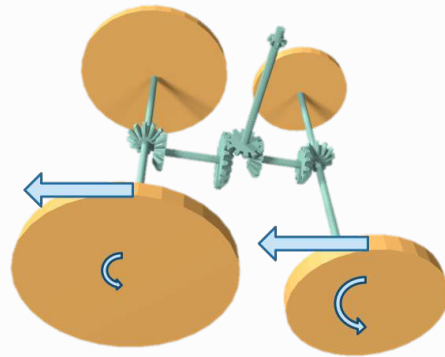


Constraints

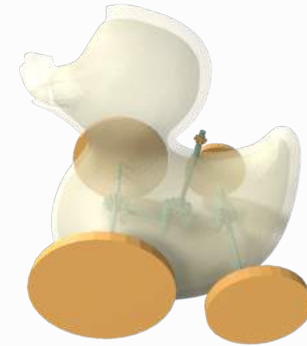
Constraints



Mechanical constraints



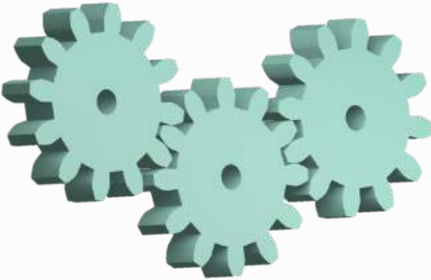
Functional constraints



Spatial constraints

Constraints

Mechanical constraints



Mechanical constraints

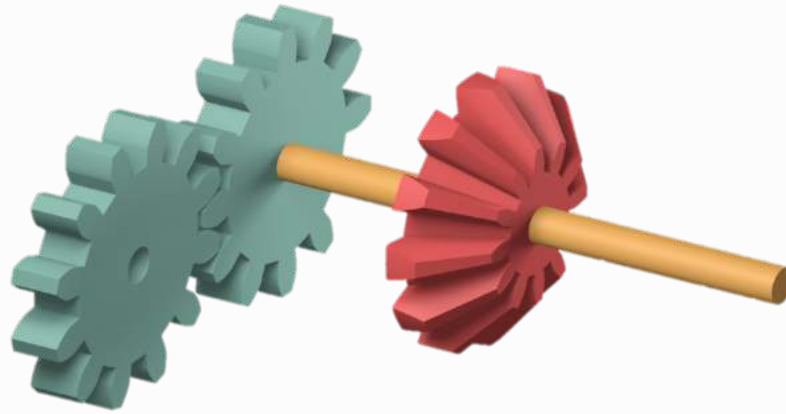
A diagram illustrating functional and spatial constraints. On the left, a mechanism with orange circular components and grey connecting rods is shown. Blue arrows indicate the direction of movement or force, and curved arrows indicate rotation. On the right, a white, bird-like object is shown with orange circular components positioned near its base, illustrating spatial constraints. The entire diagram is enclosed in a light grey border with vertical dashed lines separating the two parts.

Functional constraints

Spatial constraints

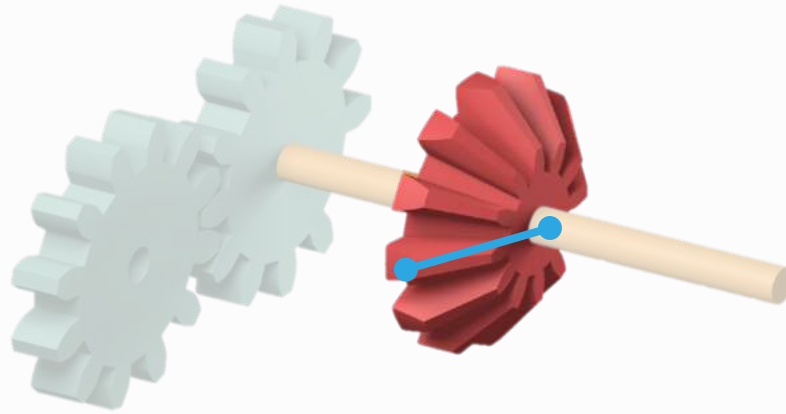
Constraints

Mechanical constraints



Constraints

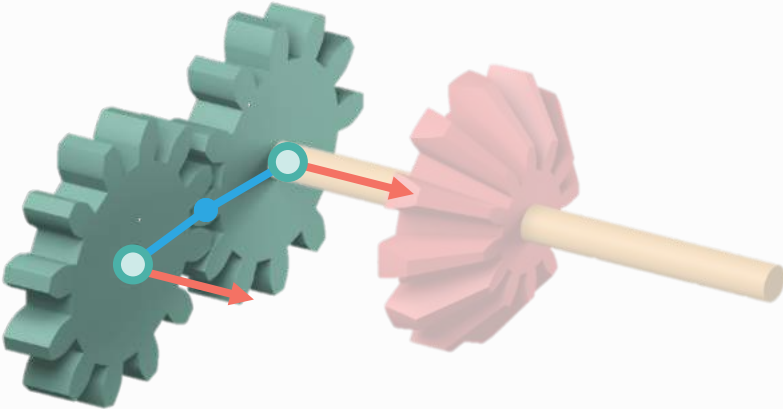
Mechanical constraints



Unary constraints

Constraints

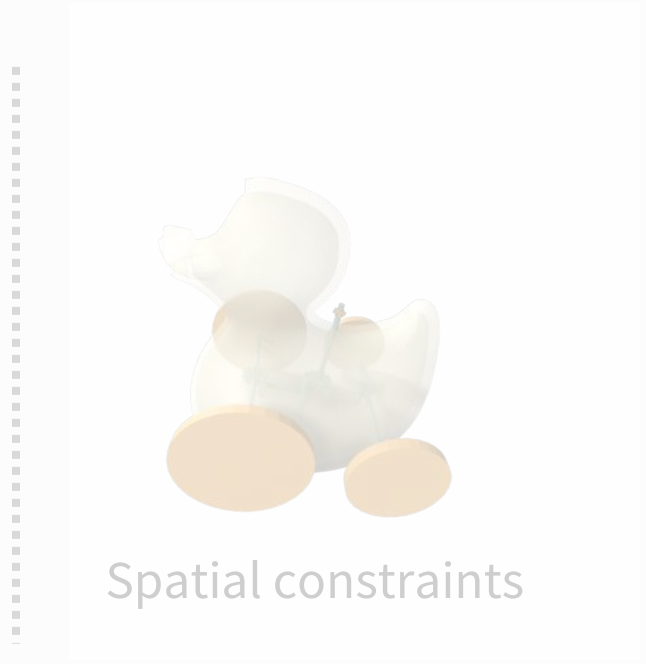
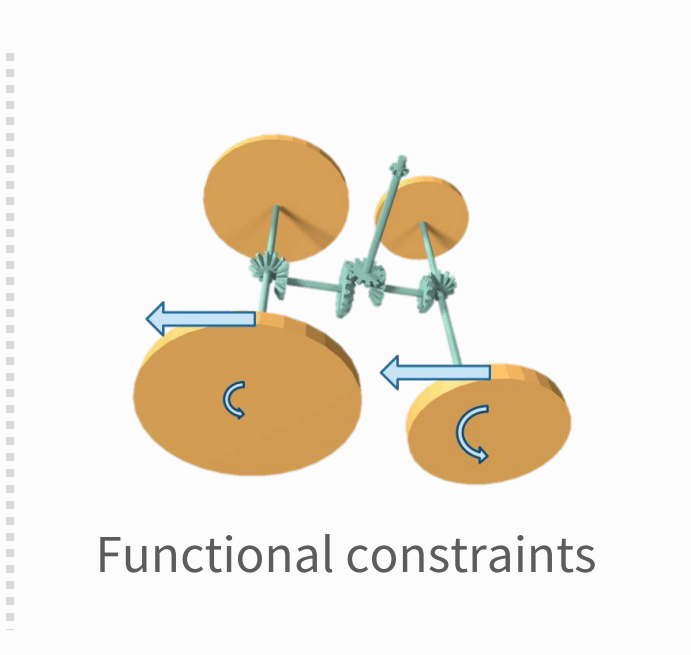
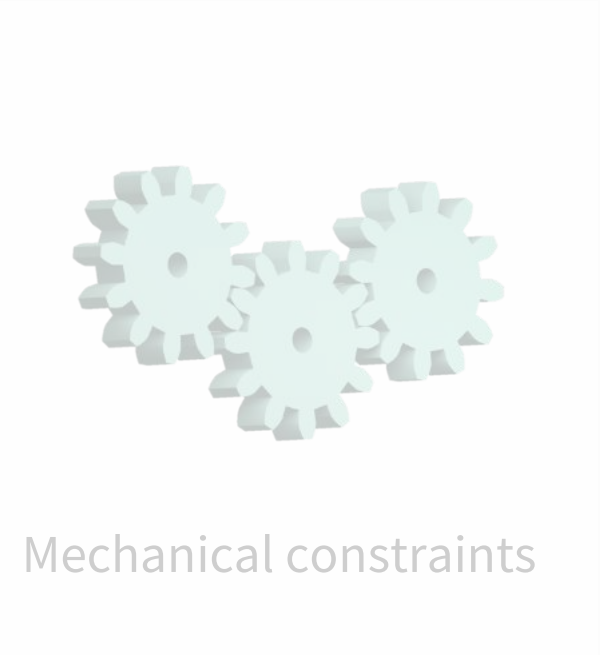
Mechanical constraints



Binary constraints

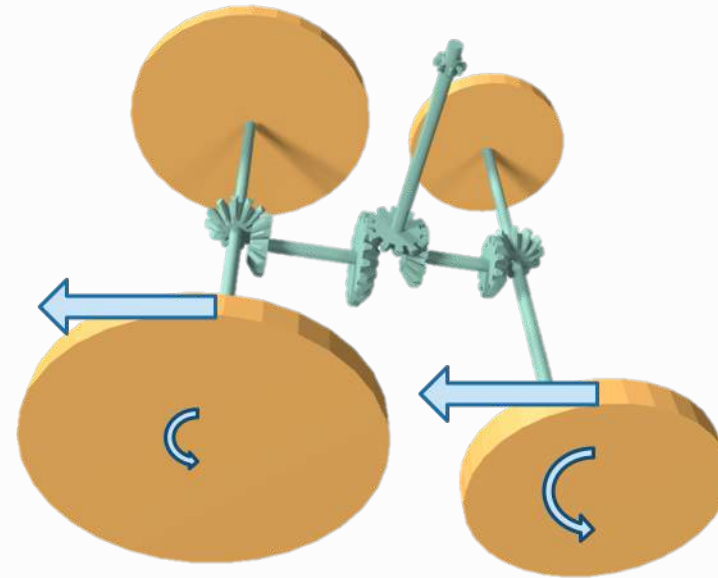
Constraints

Functional constraints



Constraints

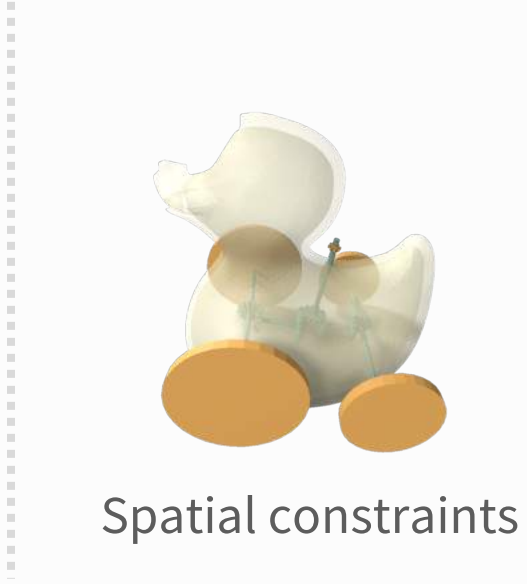
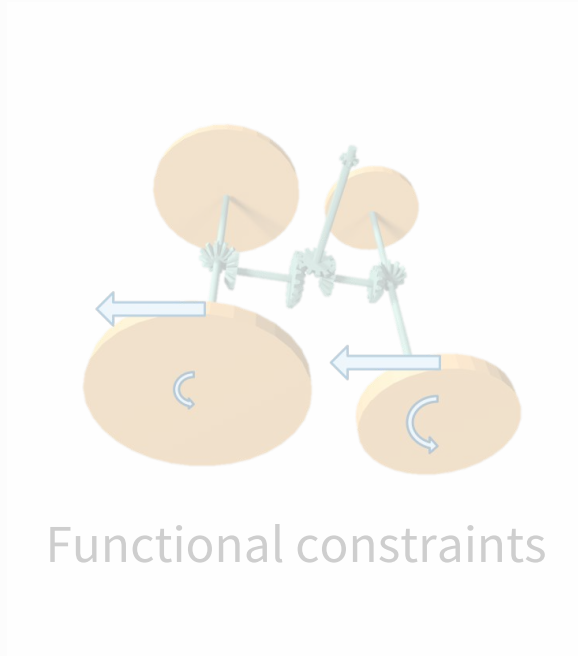
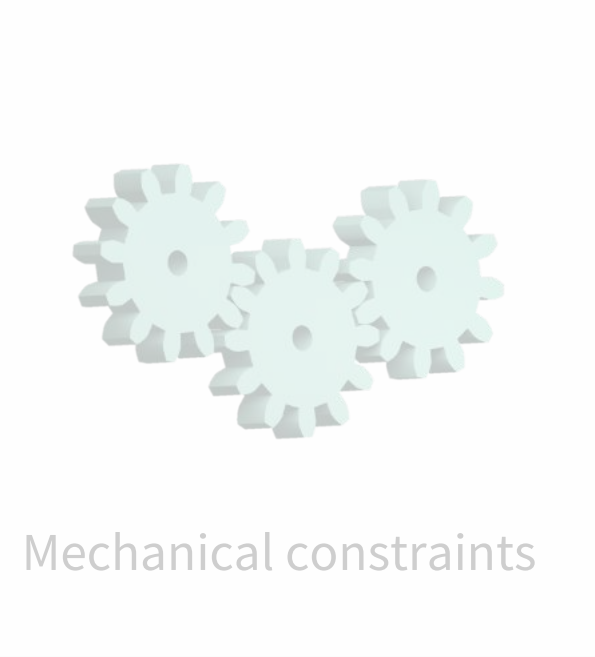
Functional constraints



Linear speed constraints

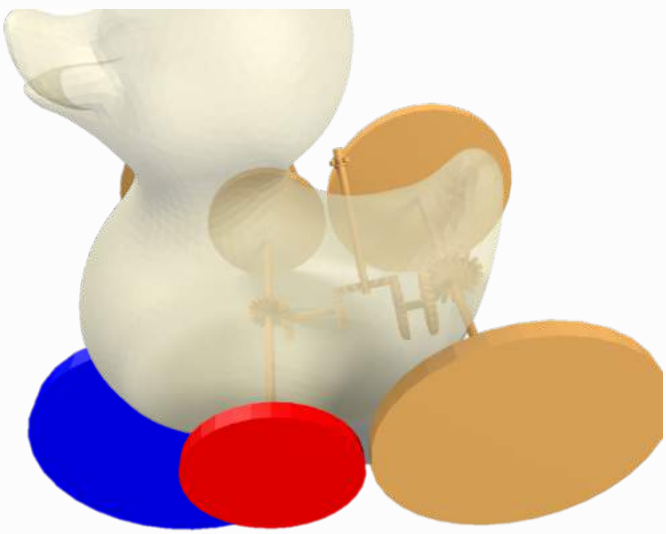
Constraints

Spatial constraints



Constraints

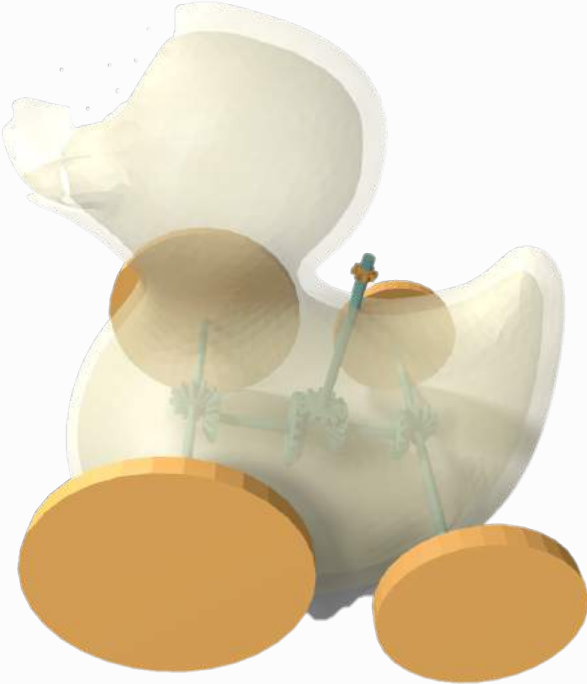
Spatial constraints



User placement constraints

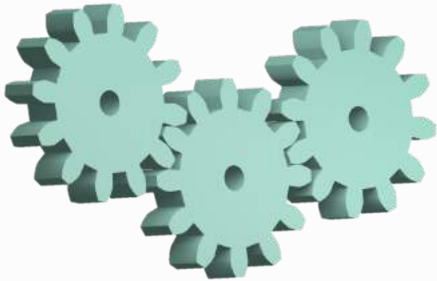
Constraints

Spatial constraints

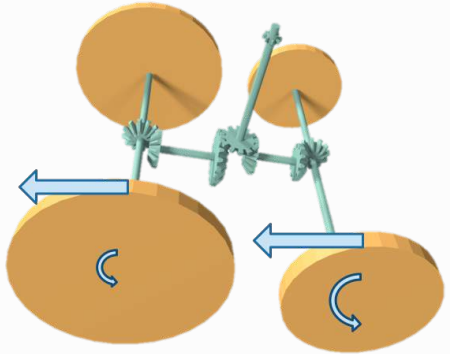


Containment constraints

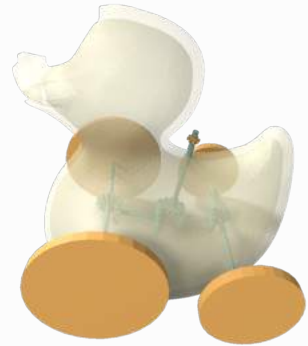
Constraints



Mechanical constraints



Functional Constraints



Spatial constraints

Constraints

$$E_{mech} \geq 0$$

$$E_{func} \geq 0$$

$$E_{spatial} \geq 0$$

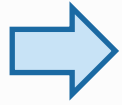
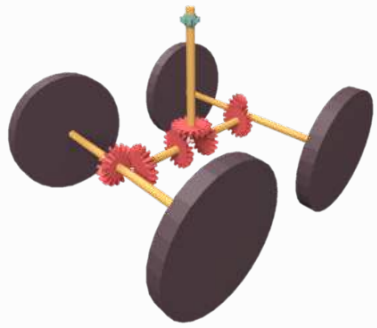


Hard constraints

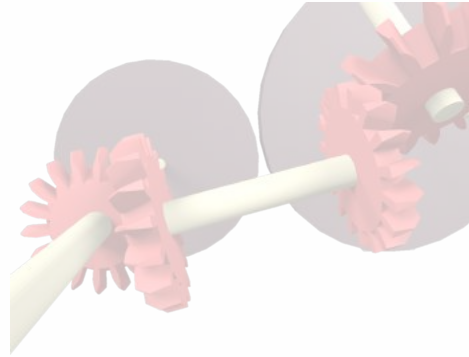


Soft constraints

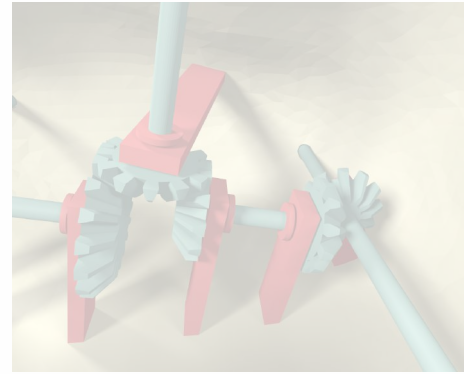
Pipeline



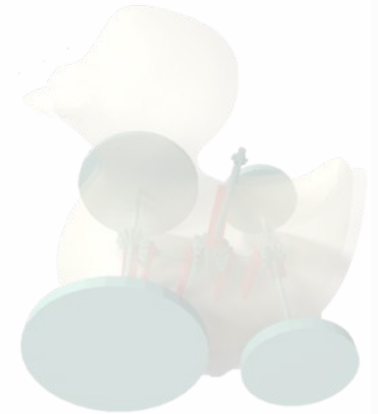
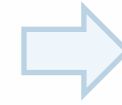
Input



Optimization

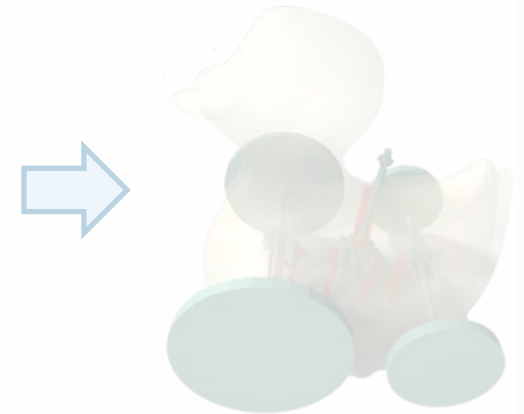
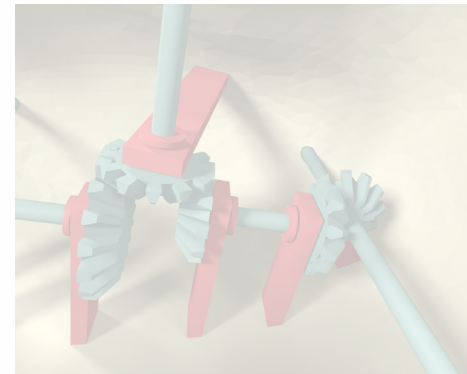
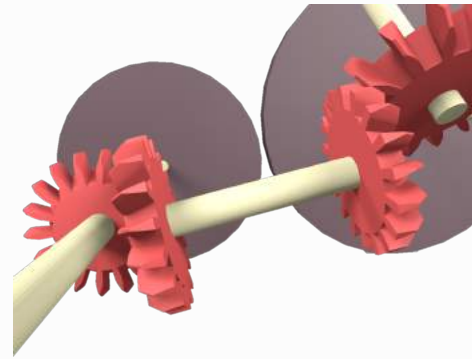
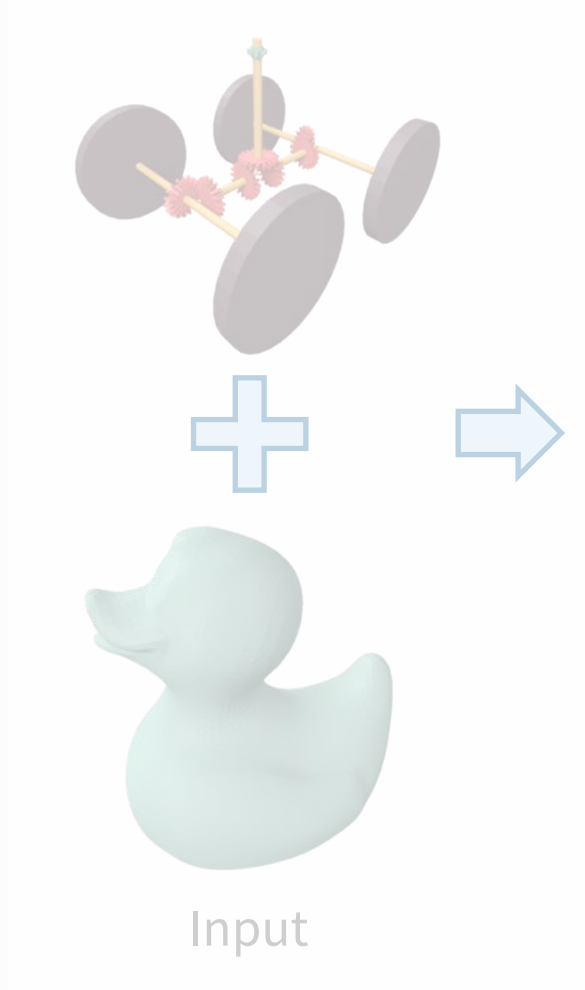


Post processing



Output

Pipeline



Optimization

Formulation

$$E_{mech} \geq 0$$

$$E_{func} \geq 0$$

$$E_{spatial} \geq 0$$



Hard constraints



Soft constraints

Optimization

Formulation

$$\operatorname{argmin}_p E_{spatial}$$

$$\text{s.t. } E_{mech}, E_{func}$$

$$E_{mech}$$

$$E_{func}$$



Hard constraints

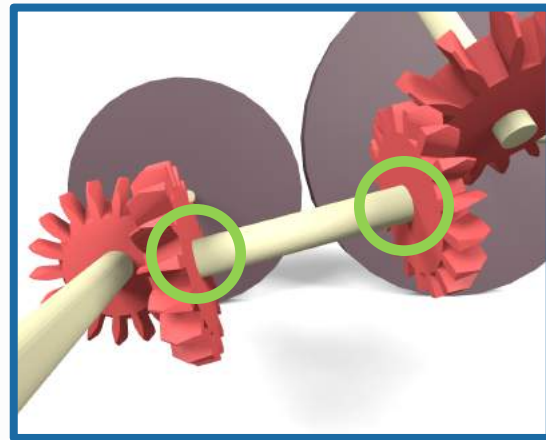
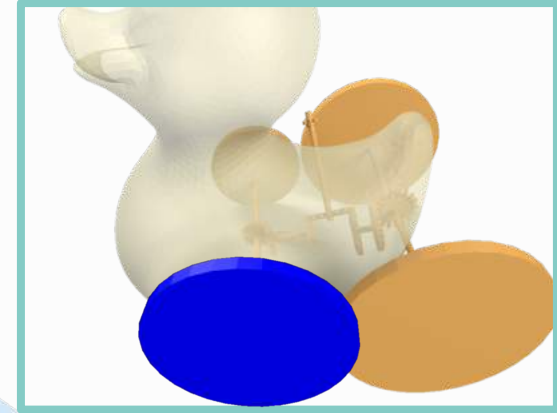
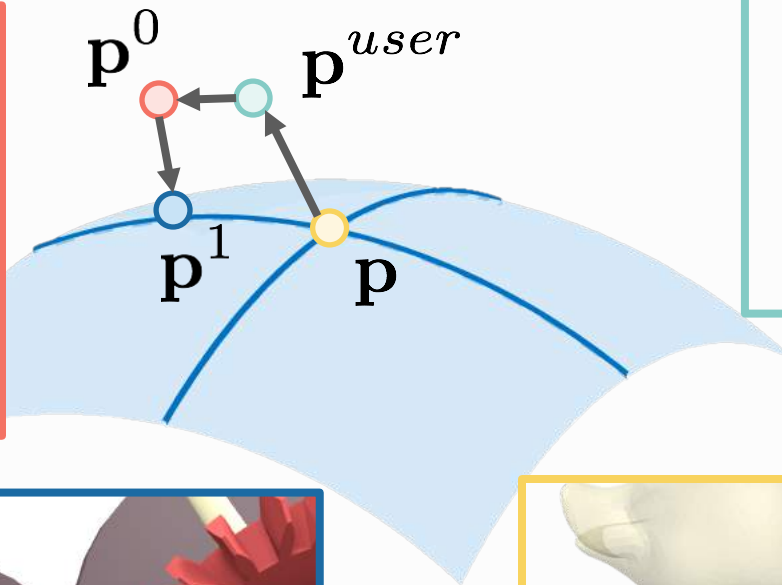
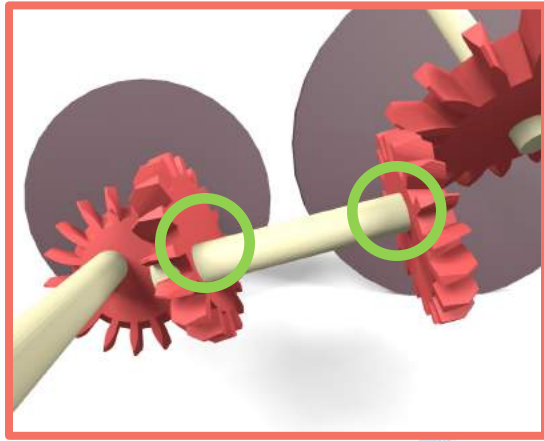
$$E_{spatial}$$



Soft constraints

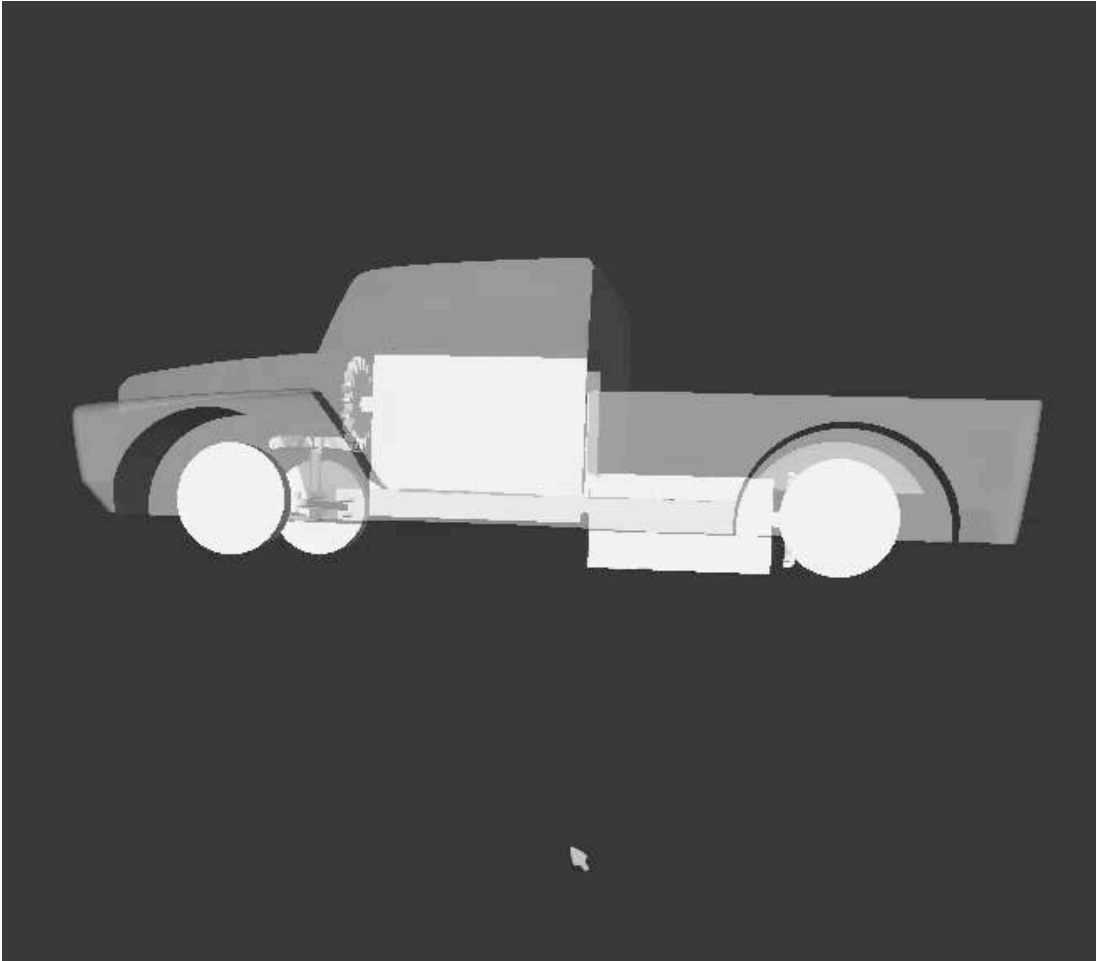
Optimization

Differential manipulation

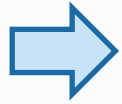
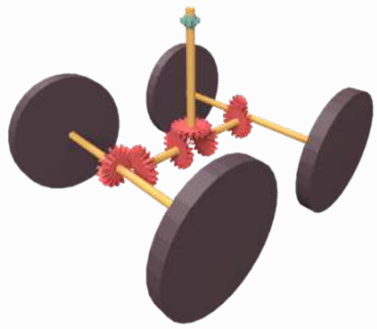


Optimization

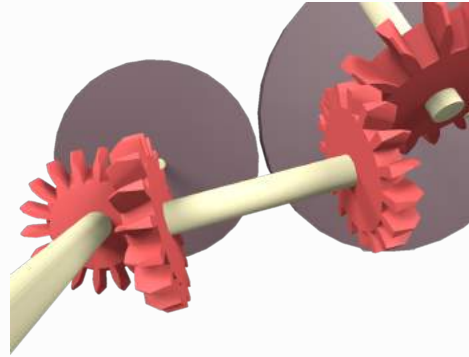
User interaction



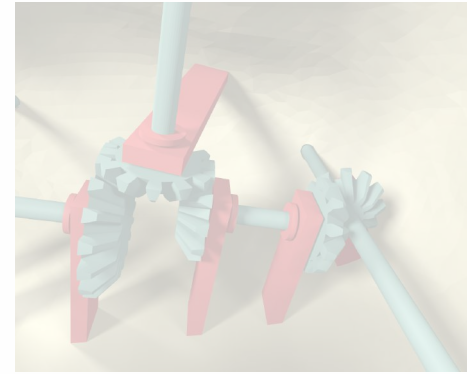
Pipeline



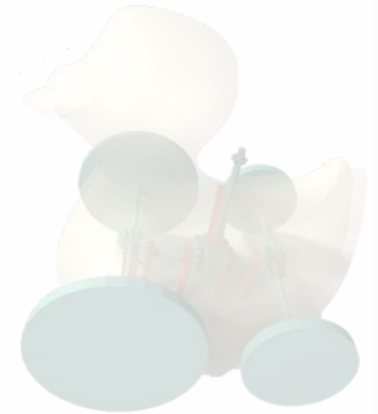
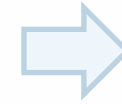
Input



Optimization



Post processing

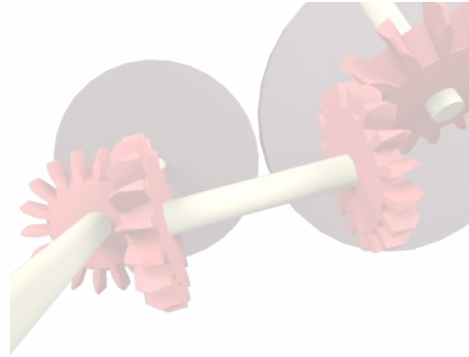
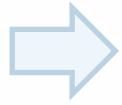


Output

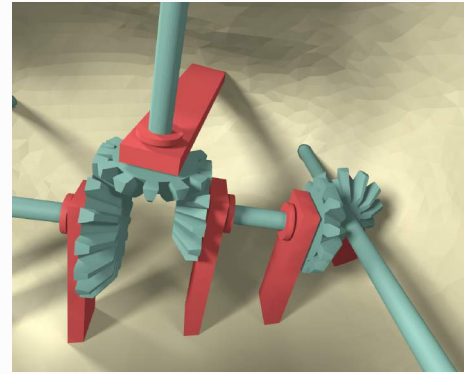
Pipeline



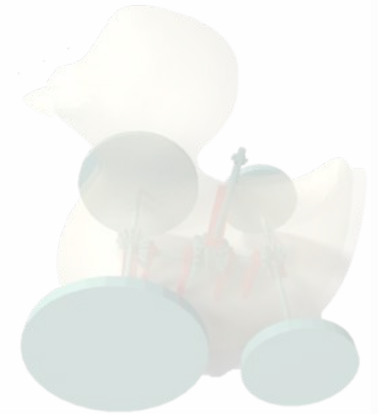
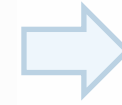
Input



Optimization



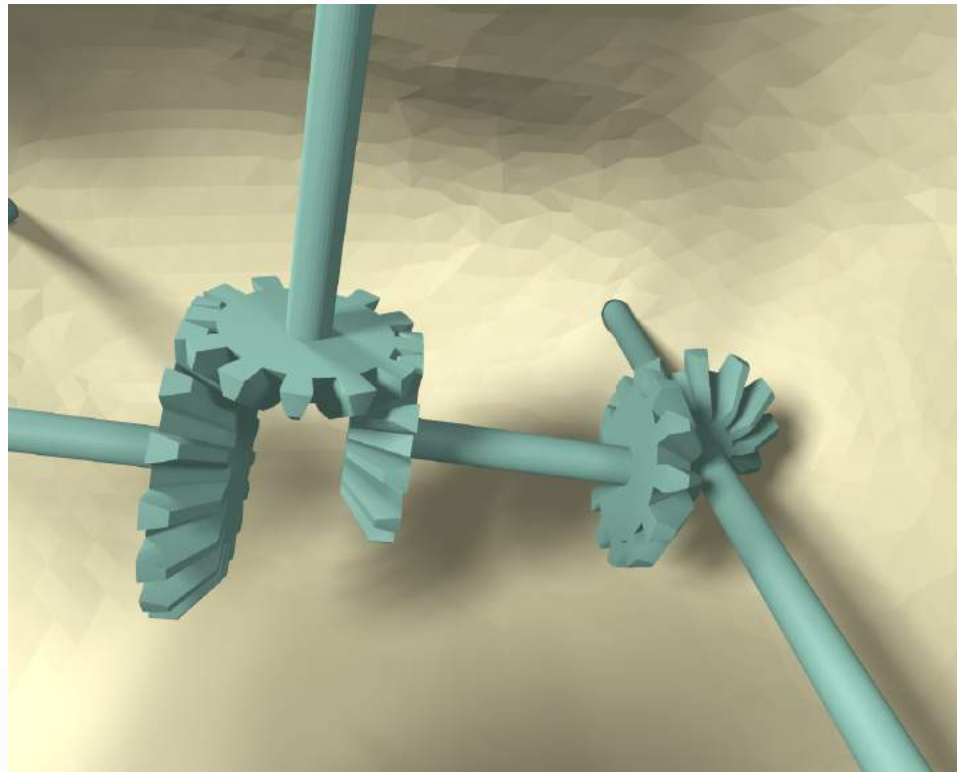
Post processing



Output

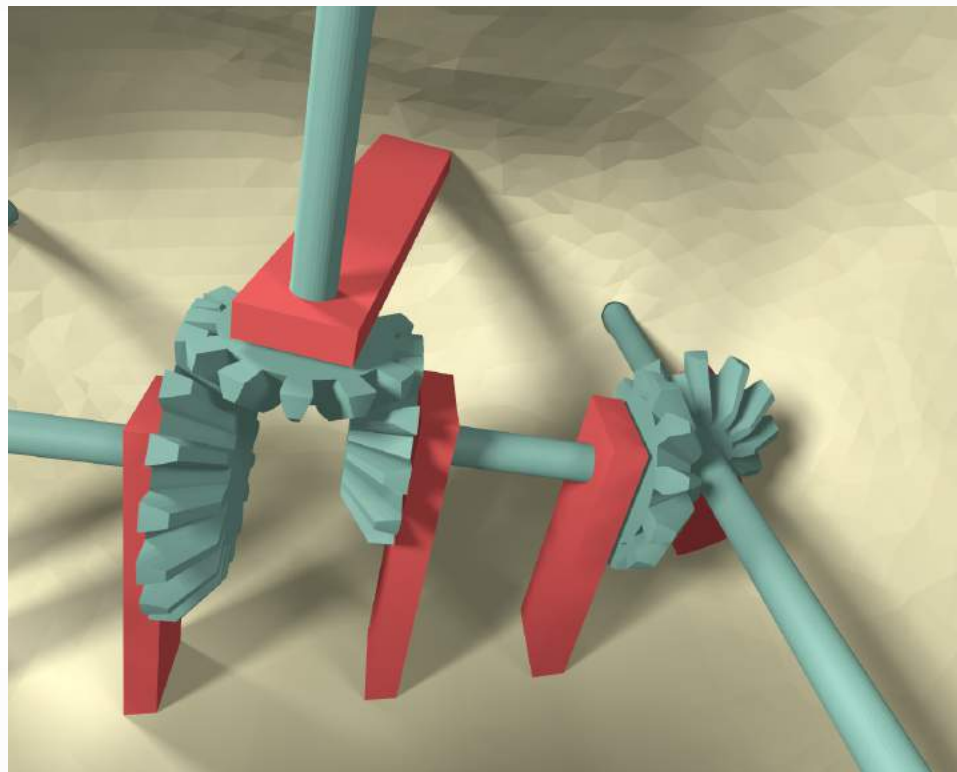
Post processing

Fixations



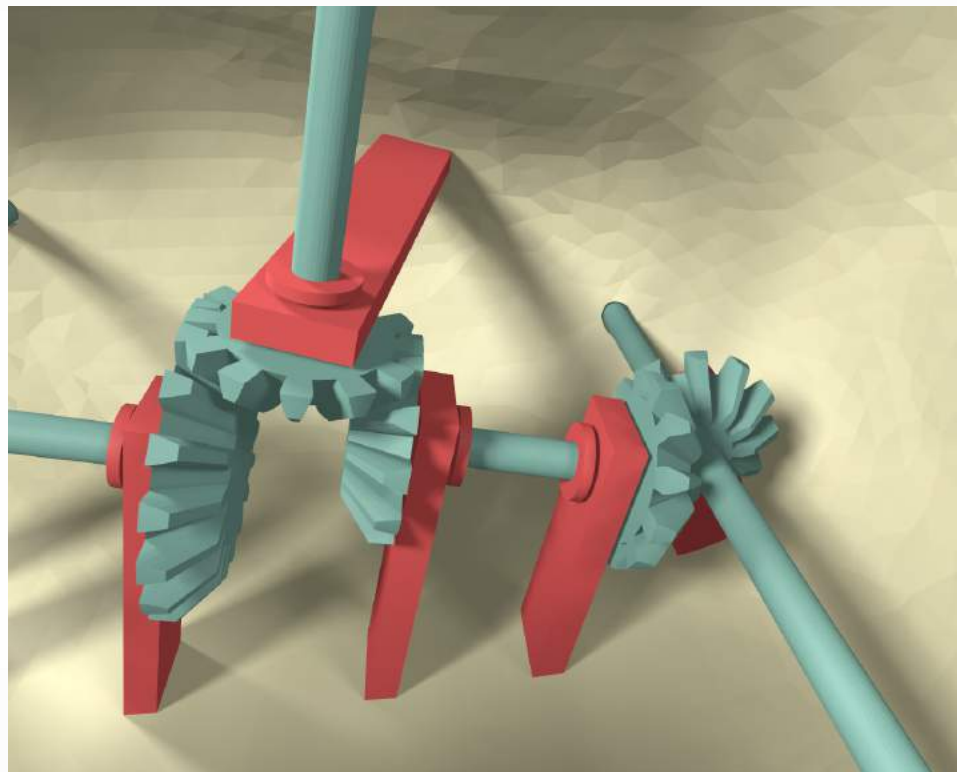
Post processing

Fixations



Post processing

Fixations

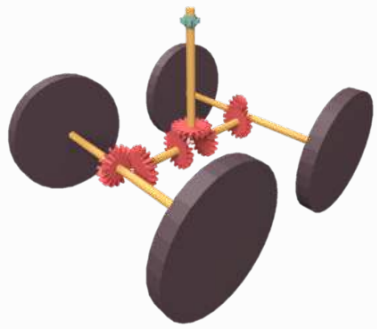


Post processing

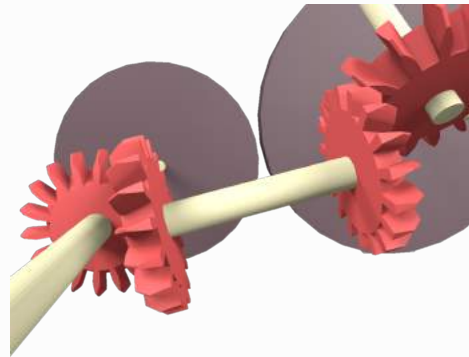
Cutaways



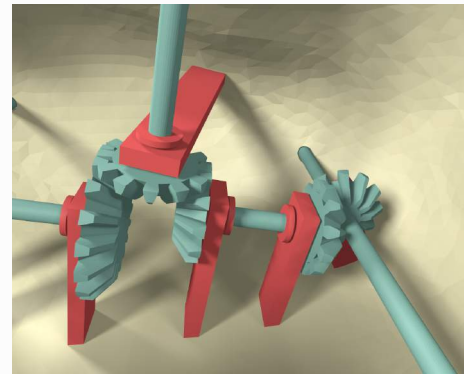
Pipeline



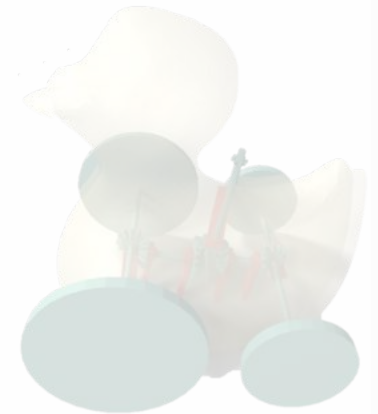
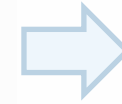
Input



Optimization



Post processing

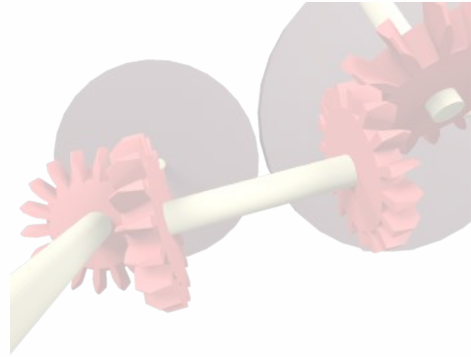
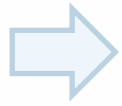


Output

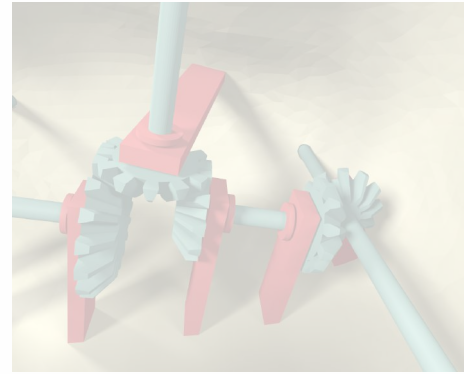
Pipeline



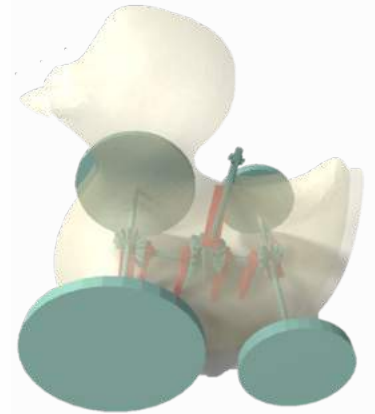
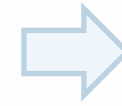
Input



Optimization



Post processing



Output

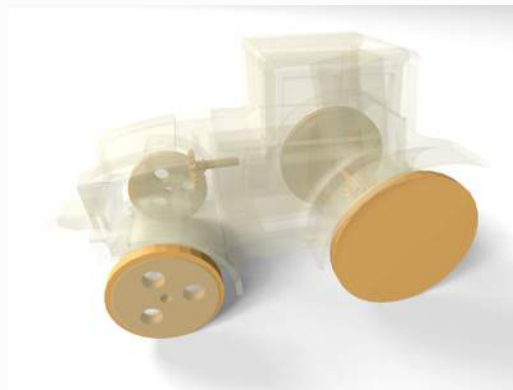
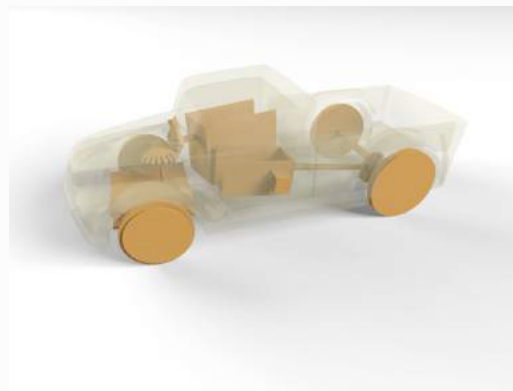
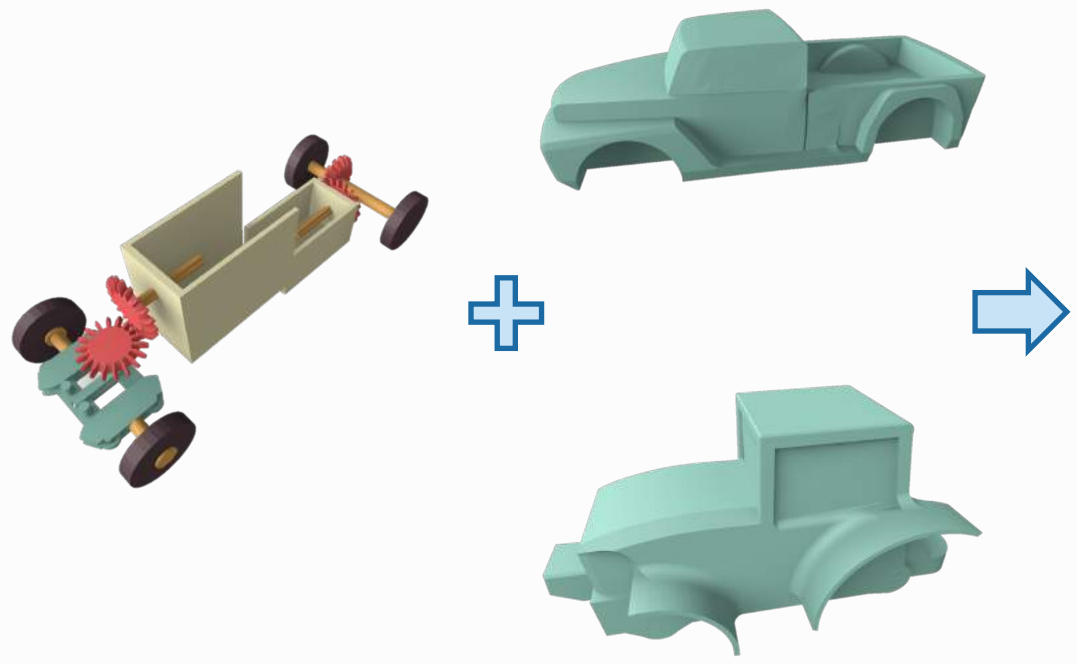
Printing

Hooray!



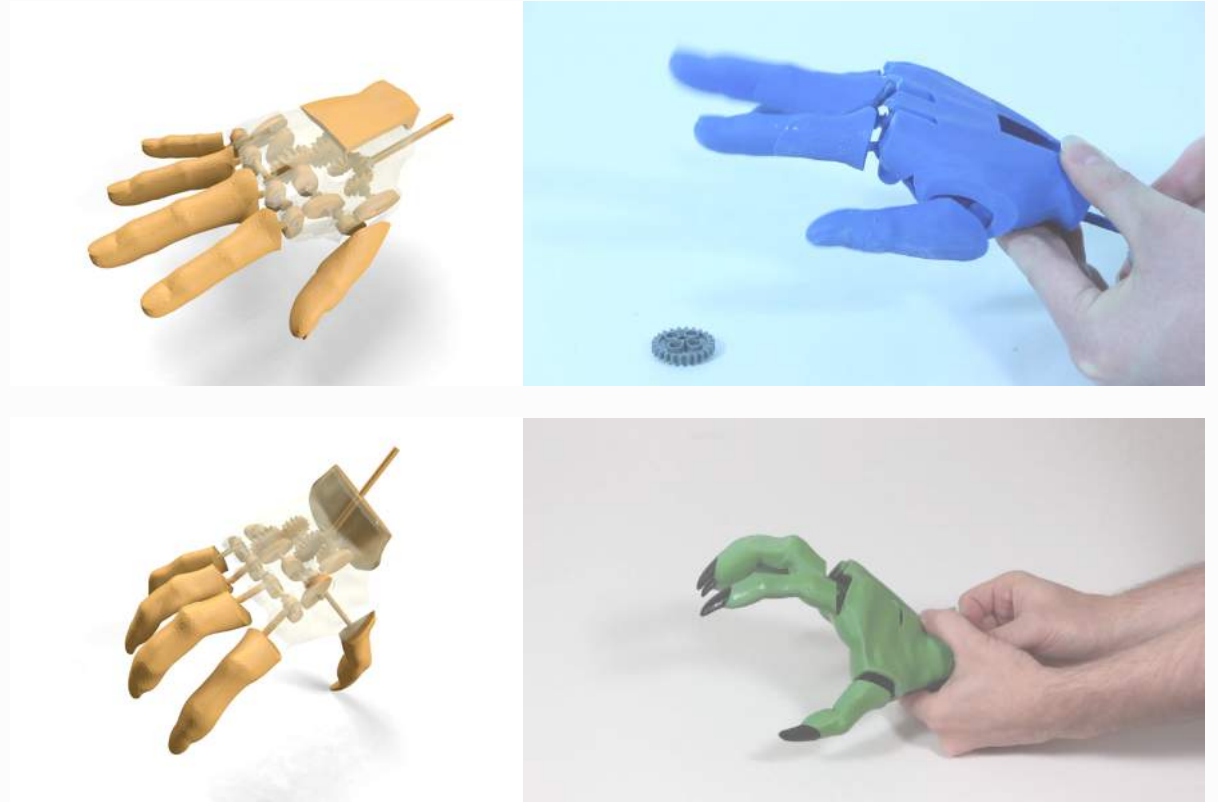
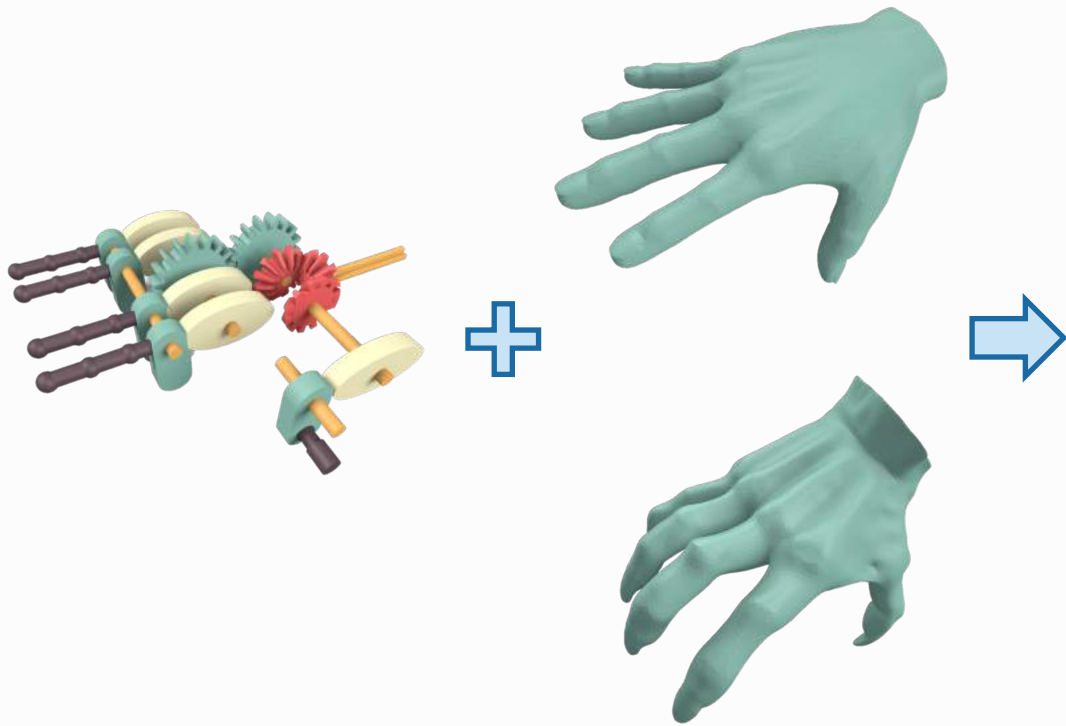
Results

Drivetrain



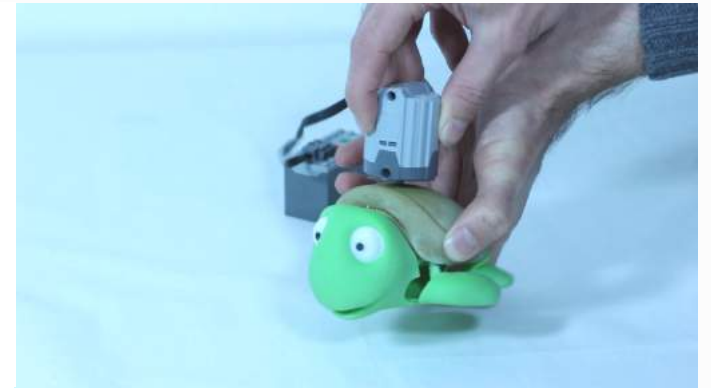
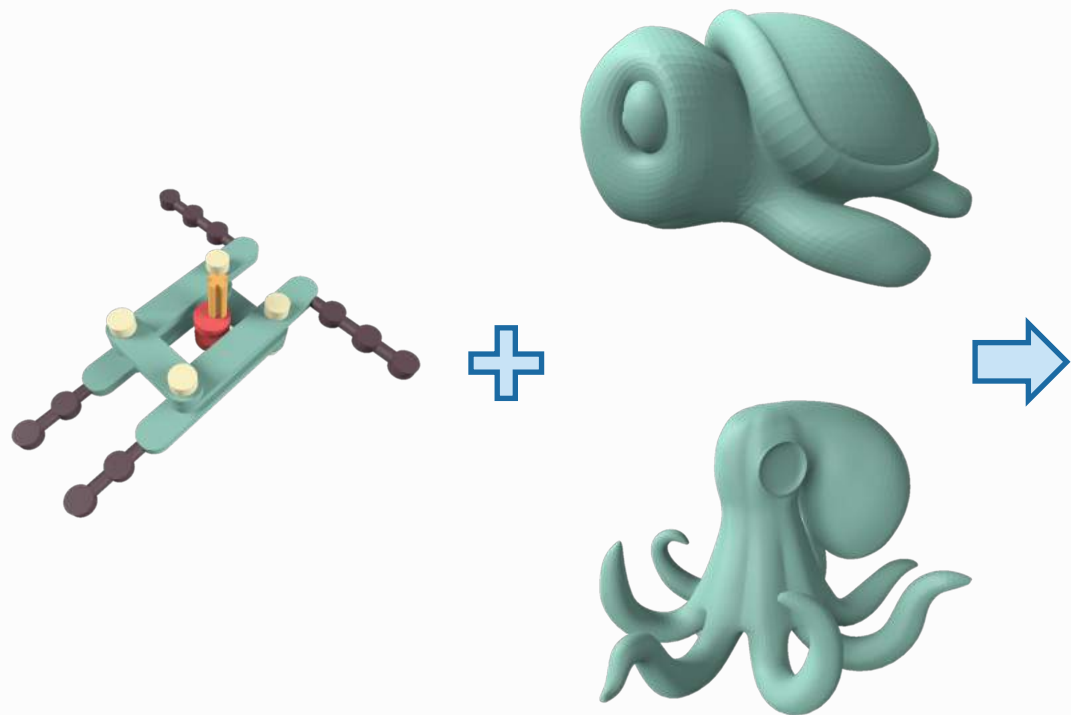
Results

Tapping



Results

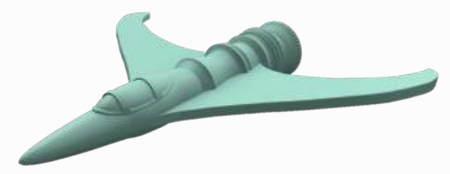
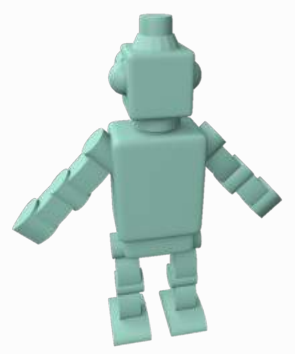
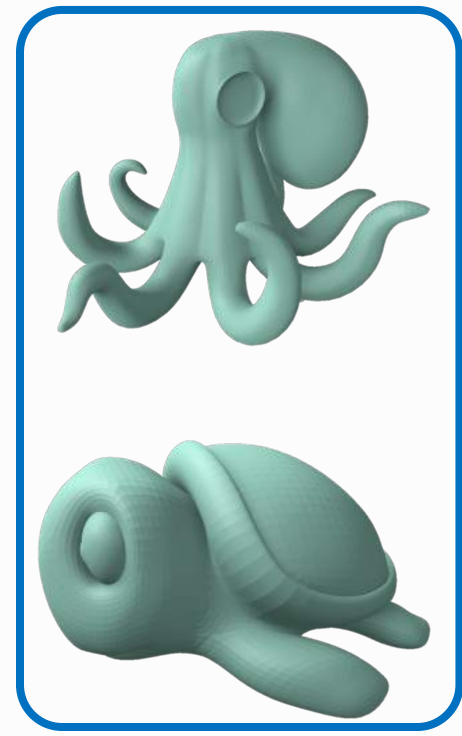
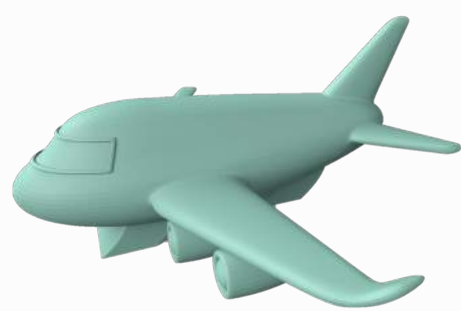
Wind-up



Results

User study and evaluation

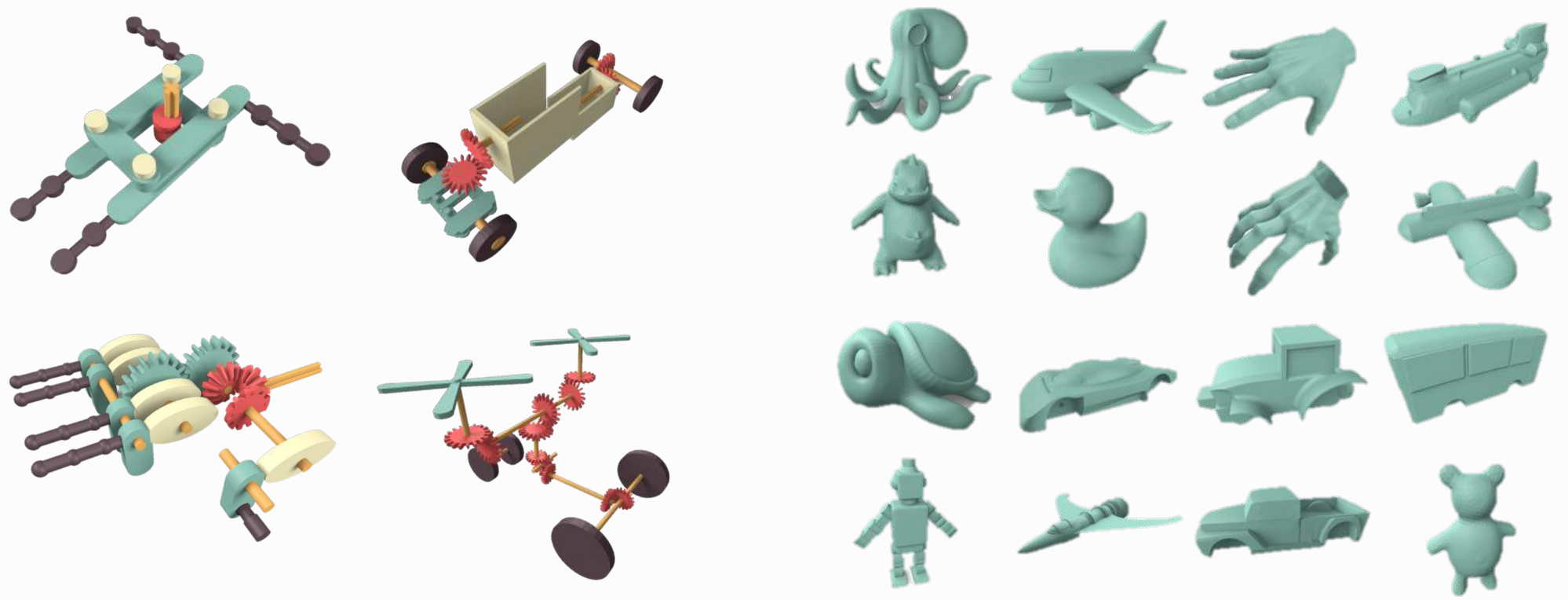
- 3 artists, 6 on-site created target shapes, 12 retargeting tasks



Results

User study and evaluation

- 3 artists, 6 on-site created target shapes, 12 retargeting tasks
- 4 templates, 16 different target shapes in total



Results

User study and evaluation

- 3 artists, 6 on-site created target shapes, 12 retargeting tasks
- 4 templates, 16 different target shapes in total
- Up to 48 components, 459 variables, 64 hard constraints



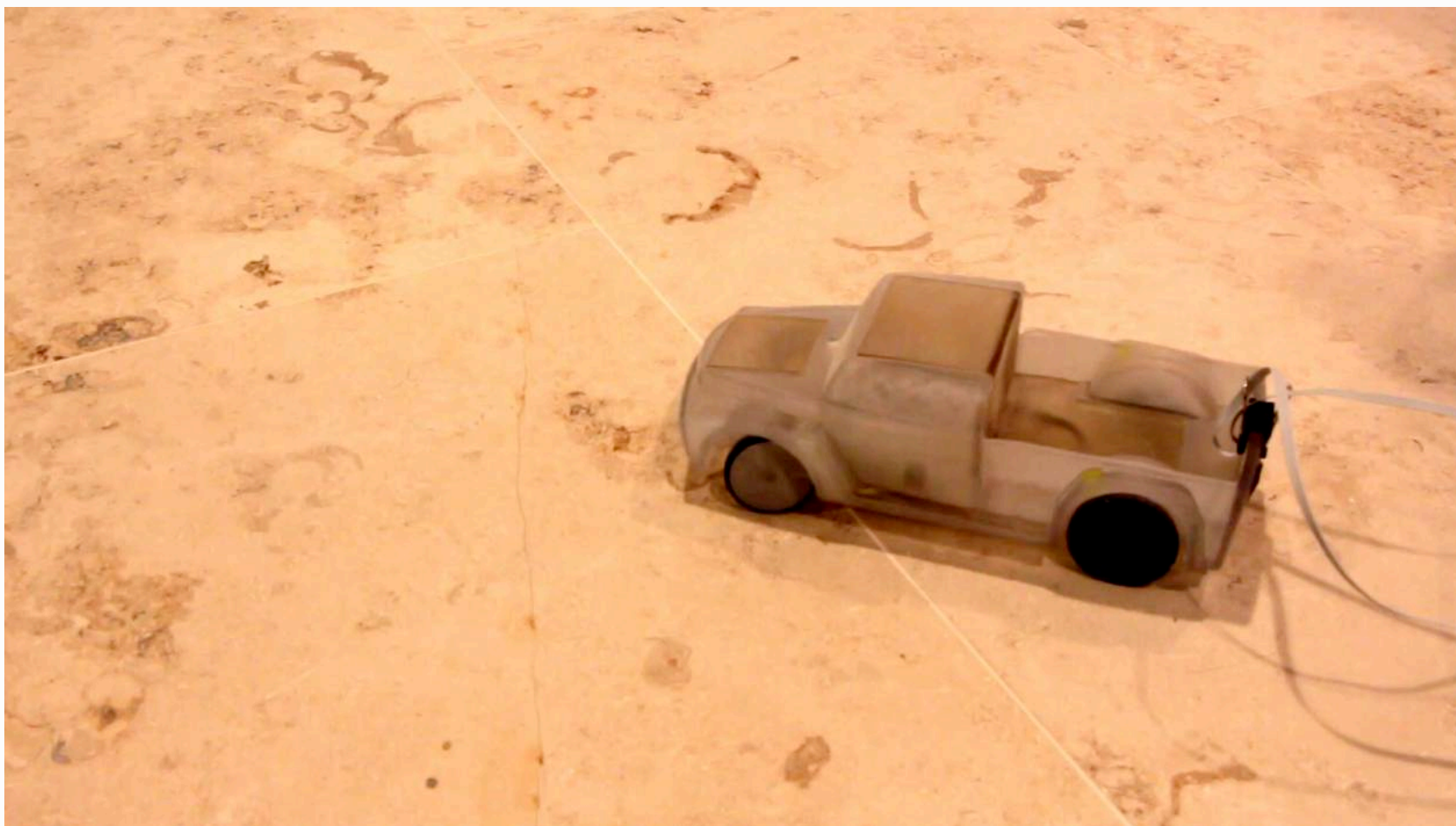
Conclusion

- **Novel workflow based on retargeting**
- **Interactivity through differential manipulation**
- **Fabrication-ready customization**

Future work

- **Non-differentiable constraints**
- **More physics (stability, friction...)**
- **Involving more geometry editing**
- **Optimization with discrete components**

Models ready to go!



<http://visualcomputing.ist.ac.at/publications/2017/MechRet/>

Visual Computing lab at IST Austria



Bernd Bickel
Assistant Professor

Digital fabrication
Computational design

SIGGRAPH Significant
new researcher award
2017



Chris Wojtan
Professor

Fluid simulation
Physical simulation

SIGGRAPH Significant
new researcher award
2016

<http://visualcomputing.ist.ac.at/openpositions/>



High5!

Thank you for your attention!

- Special thanks to Abbas Saleh, Daniel Bösze, and David Ronnes for participating in our user study and allowing us to use their models created during the user study, and the authors of the remaining models for sharing them on Thingiverse.
- This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 642841 and under the European Research Council (ERC) grant agreement No 715767.



The DiSTRO logo, with the word 'DiSTRO' in a bold, green, sans-serif font.



European Research Council
Established by the European Commission

Backup slides

- Solidworks export xml
- Parsing xml to connection graph

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Results

User study and evaluation

- 3 artists, 6 on-site created target shapes, 12 retargeting tasks

