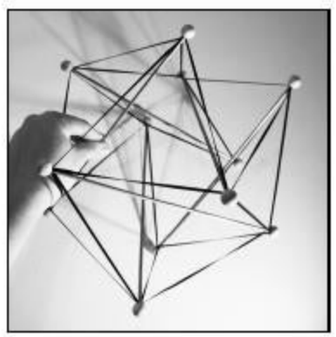
August 2013
University College London,

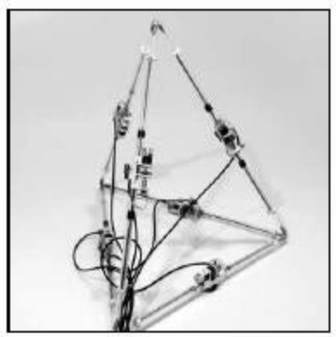
Inherent Motives

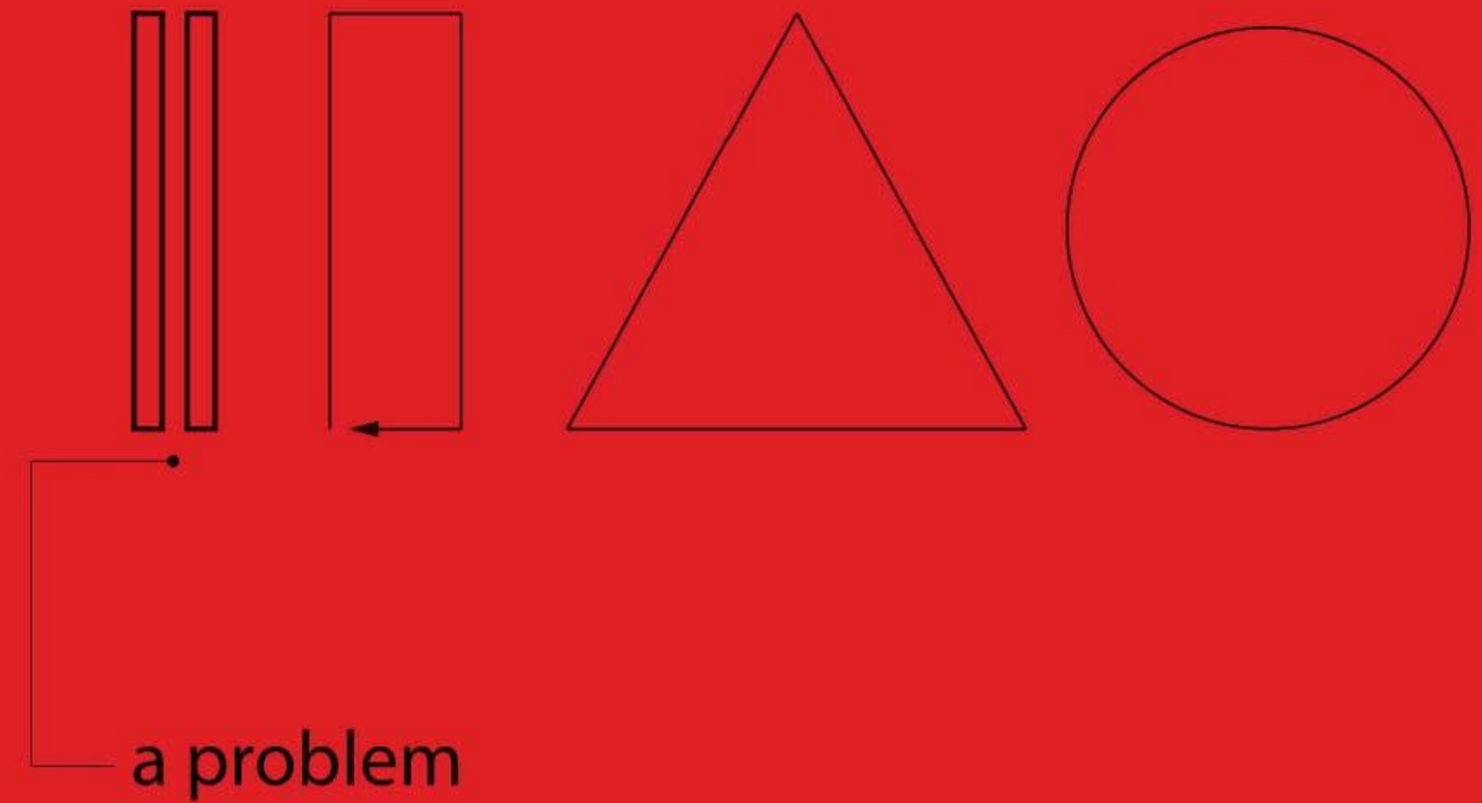
A PROBLEM, A SOLUTION, A PROTOTYPE AND A PLAN

William Bondin
The Bartlett School of Architecture



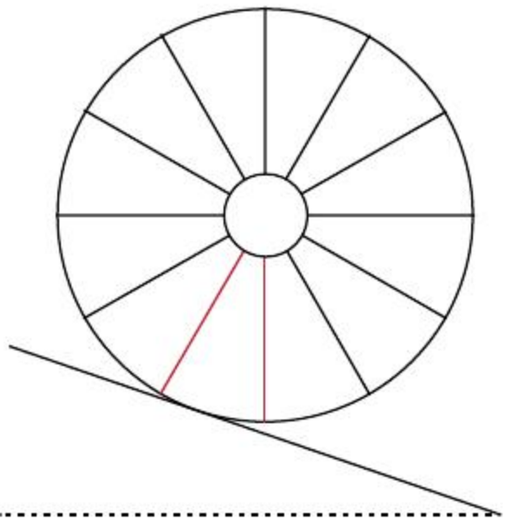





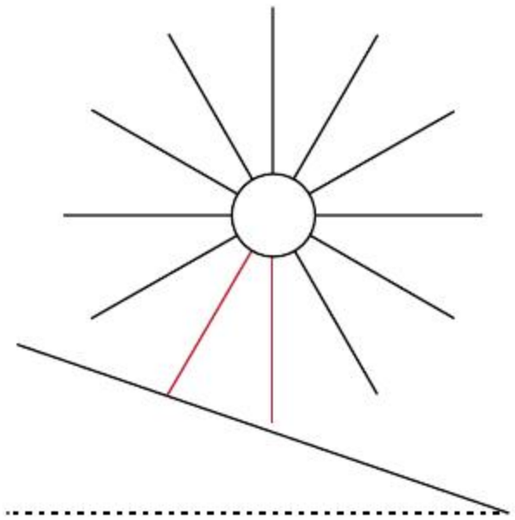



a problem

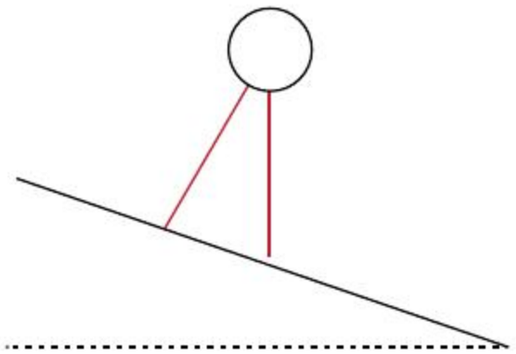
The Passive Dynamic Walker



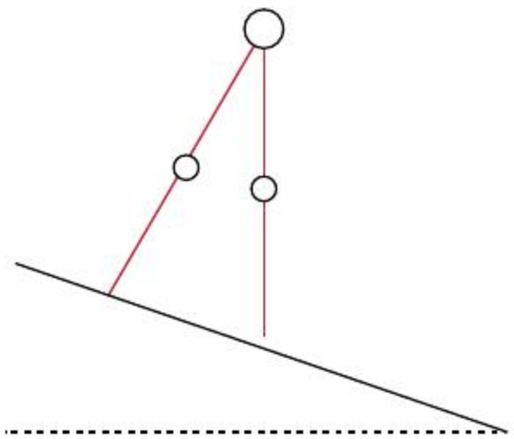
Wheel



Rimless wheel



Compass gait

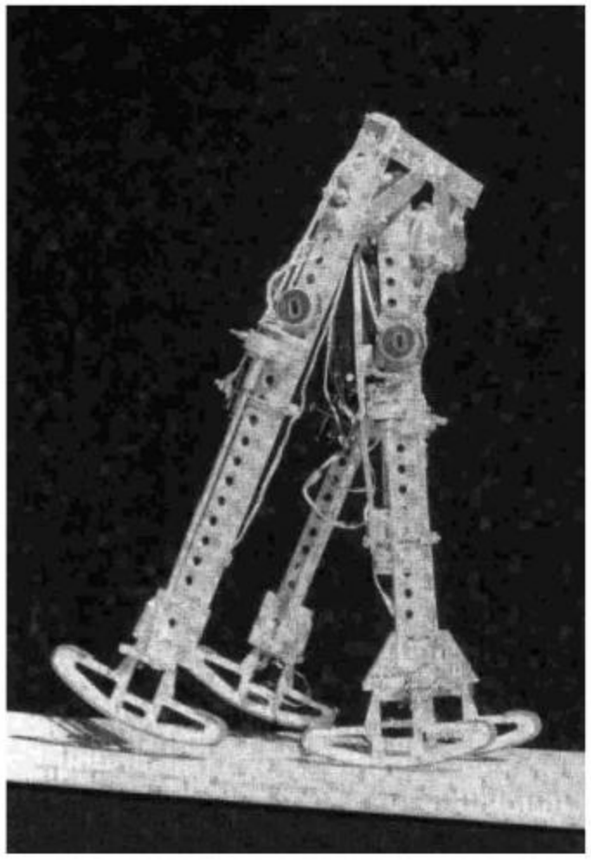


Passive dynamic walker

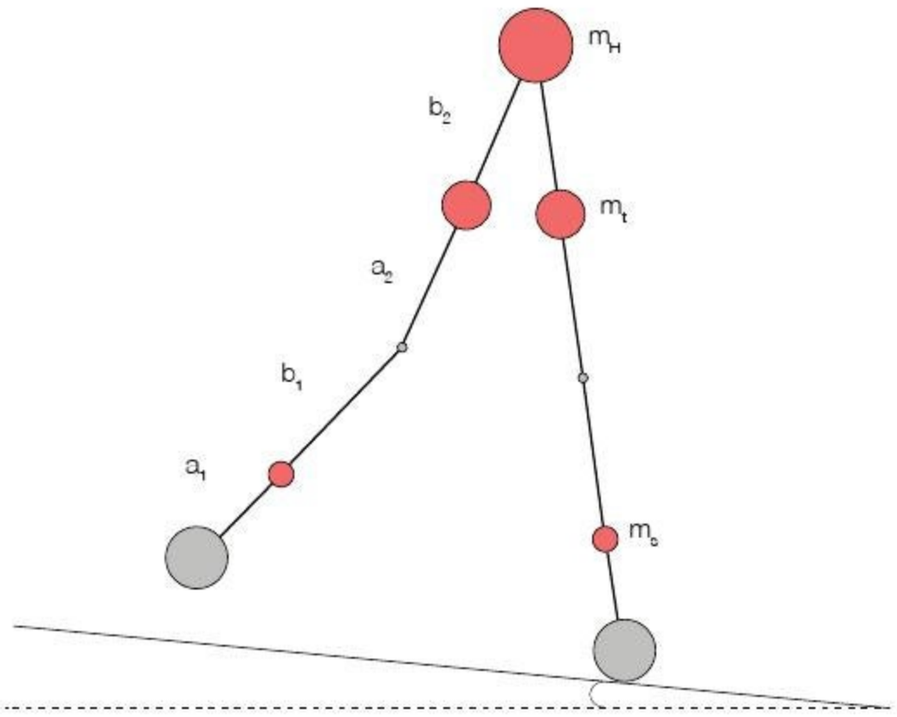
Developed at Fujimoto Laboratory,
Nagoya Institute of Technology, Japan
source: http://www.nitech.ac.jp/
retrieved on: 6/12/12

Developed by Derek Koop and Dean Ferley
source: Koop, D., Ferley, D. Passive Dynamic Walking with Kneec
University of Manitoba

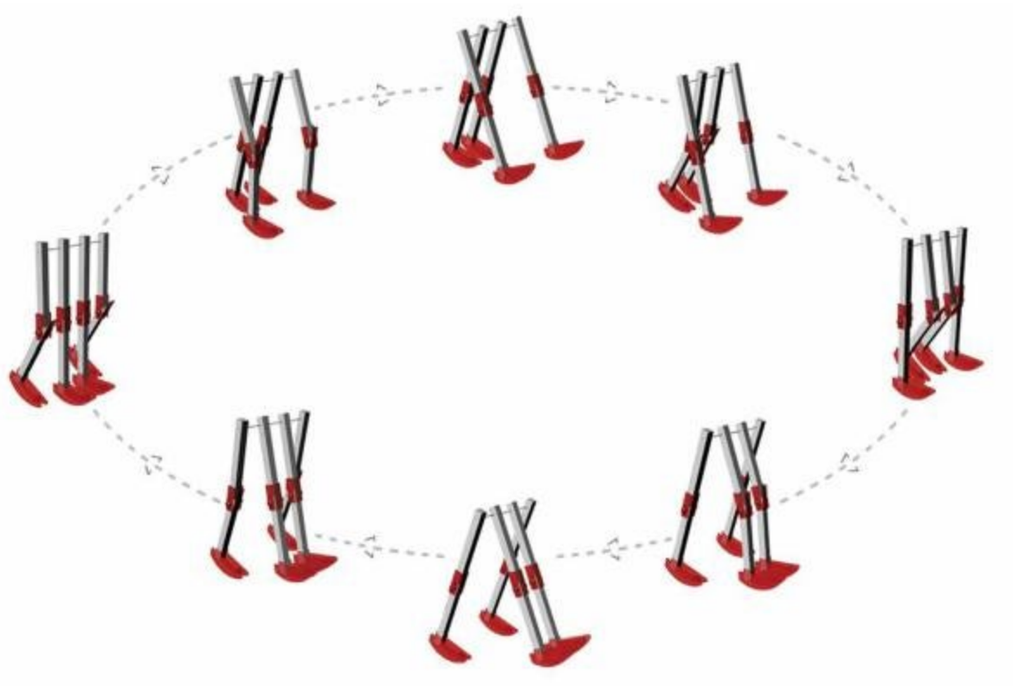
Developed by Tad Mc Geer
source: Mc Geer, T. Passive Dynamic Walking,
in: International Journal of Robotics Research, 9:62. 1990



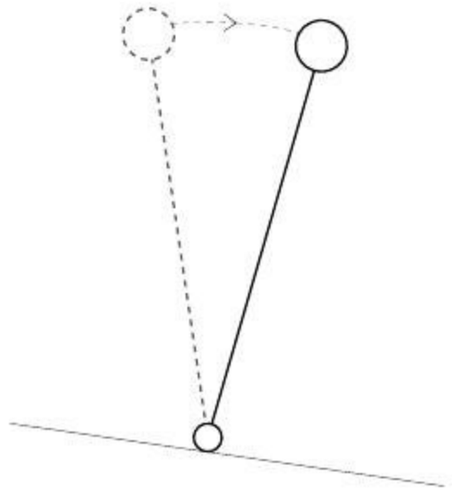
Mechanism for a Passive Dynamic Walker



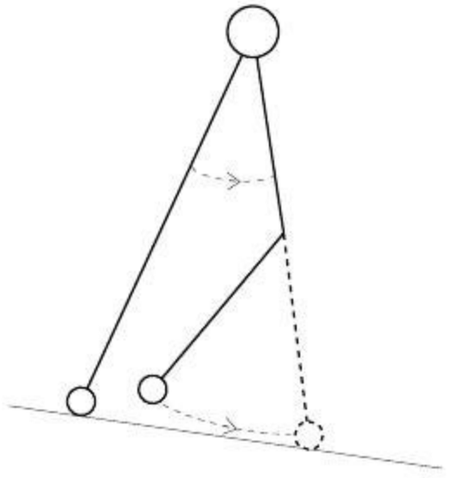
Schematic drawing illustrating the different design parameters
adapted from: Chen, V. Passive Dynamic Walking with Knees: A Point Foot Model. MIT. (2005)



Step cycle for passive dynamic walker, based on parametric model



A. Schematic for a step cycle
principle: Inverted pendulum
purpose: 'walk' forward



B. Schematic for a step cycle
principle: compound pendulum
purpose: avoid foot/ground collision

Simulation

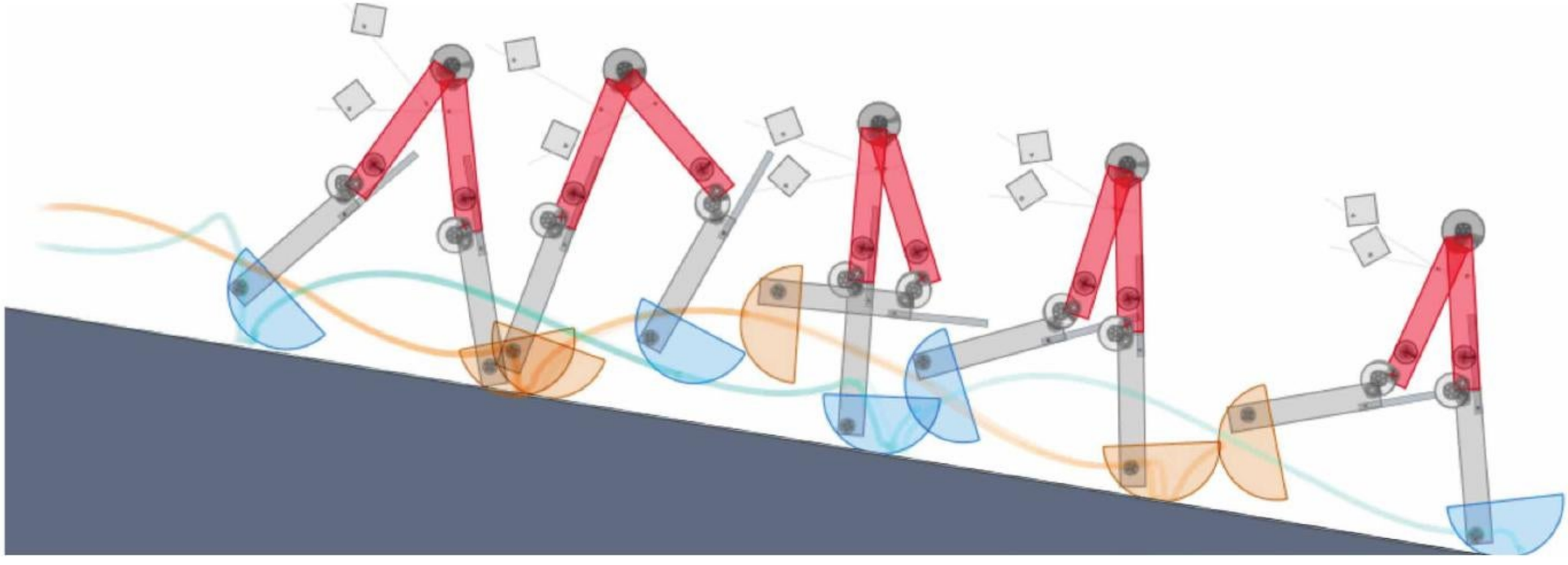
Parameter	Symbol	Unit	Value
leg length	L	mm	400
shank length below centre of gravity	a_1	mm	100
shank length above centre of gravity	b_1	mm	100
thigh length below centre of gravity	a_2	mm	100
thigh length above centre of gravity	b_2	mm	100
hip mass	m_H	kg	0.38
thigh mass	m_t	kg	0.125
shank mass	m_s	kg	0.012
inclination of ramp	γ	deg.	10.0

Table 3: Data for Simulation D4

Parameter	Symbol	Unit	Value
leg length	L	mm	560
shank length below centre of gravity	a_1	mm	140
shank length above centre of gravity	b_1	mm	140
thigh length below centre of gravity	a_2	mm	140
thigh length above centre of gravity	b_2	mm	140
hip mass	m_H	kg	0.155
thigh mass	m_t	kg	0.125
shank mass	m_s	kg	0.070
inclination of ramp	γ	deg.	10.0

Table 4: Data for simulation D5

Physics simulation



Prototye - Iteration 1

Height: 300 mm
Weight: 0.8 kg
Materials: Aluminium and MDF

No. of steps: 0
Walking speed: N/A

Control: N/A

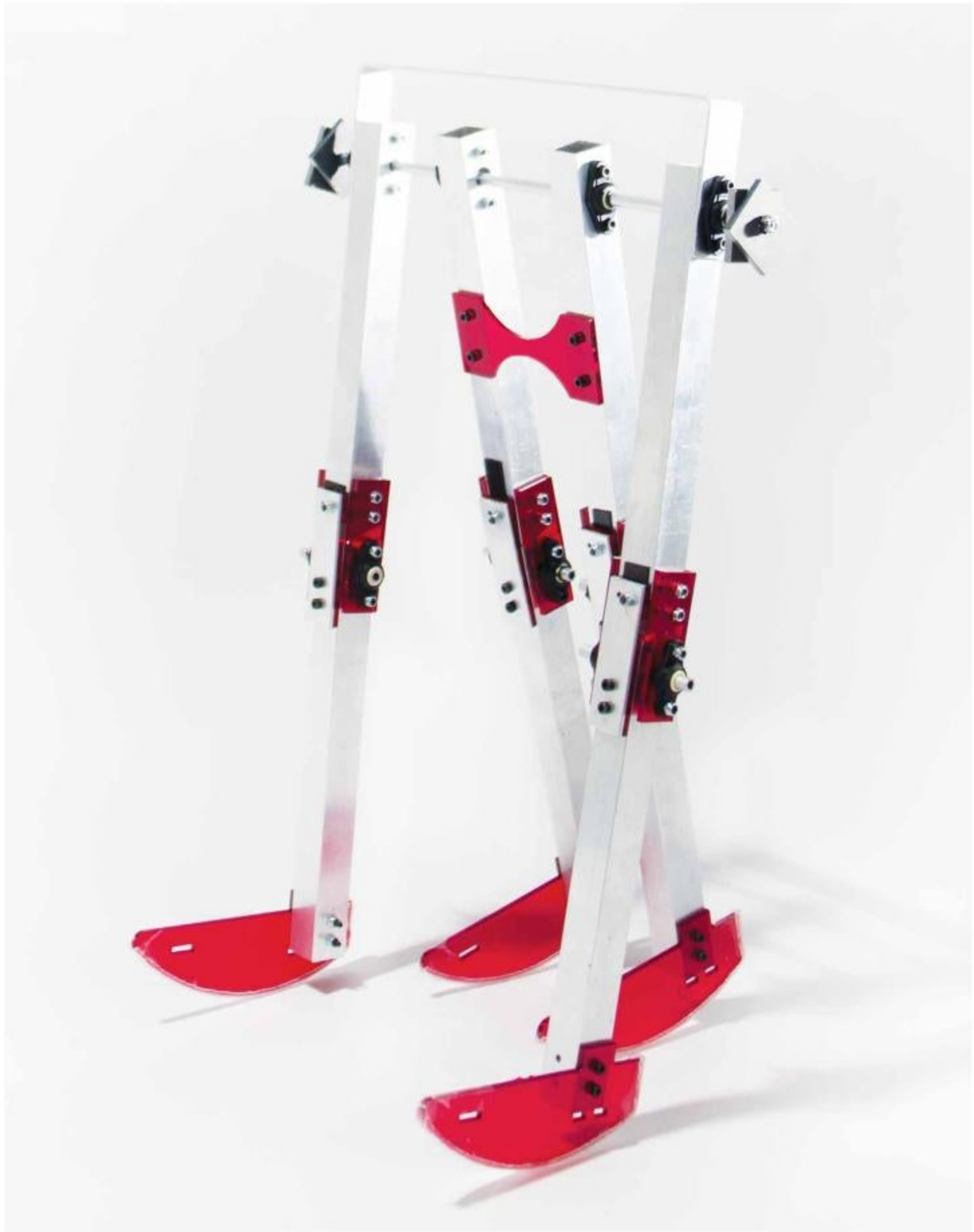
Trial launch for the passive walker

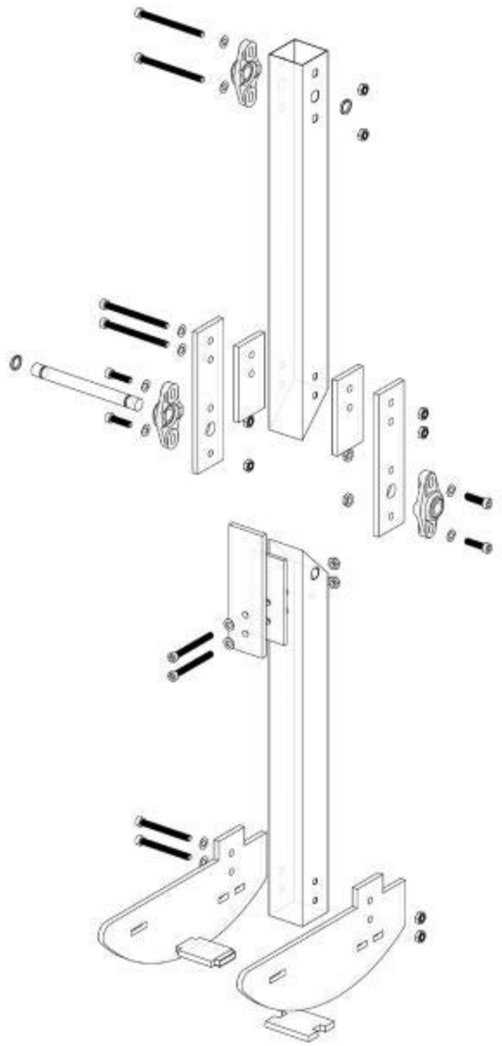
Prototype - Iteration 2

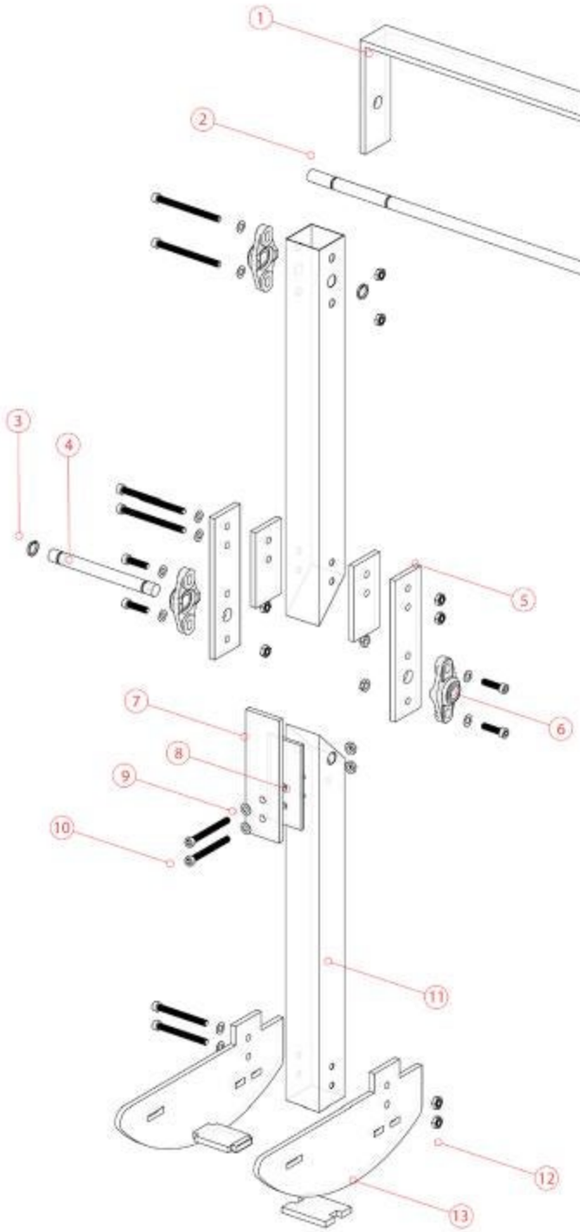
Height: 400 mm
Weight: 1.1 kg
Materials: Aluminium and Polymethyl methacrylate

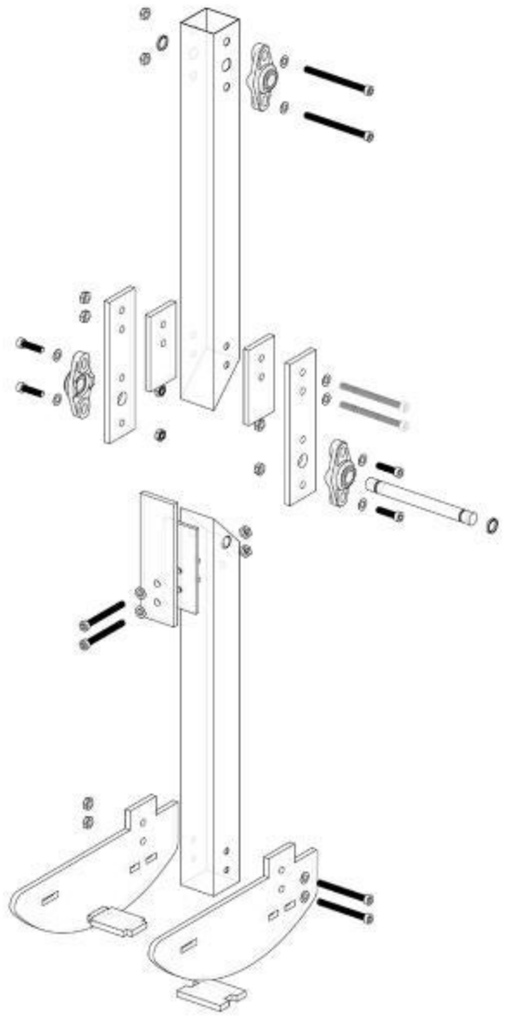
No. of steps: 5
Walking speed: approx. 8 kmph

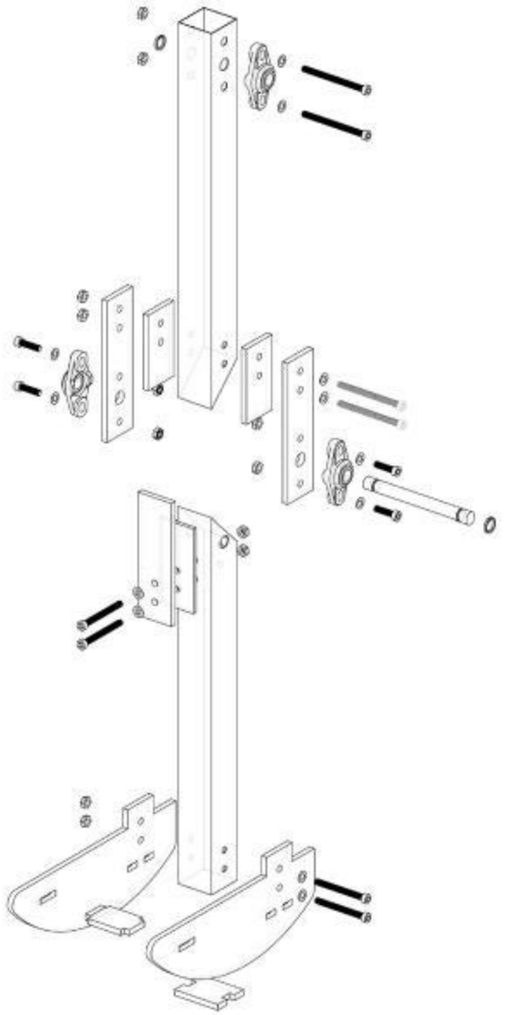
Control: N/A











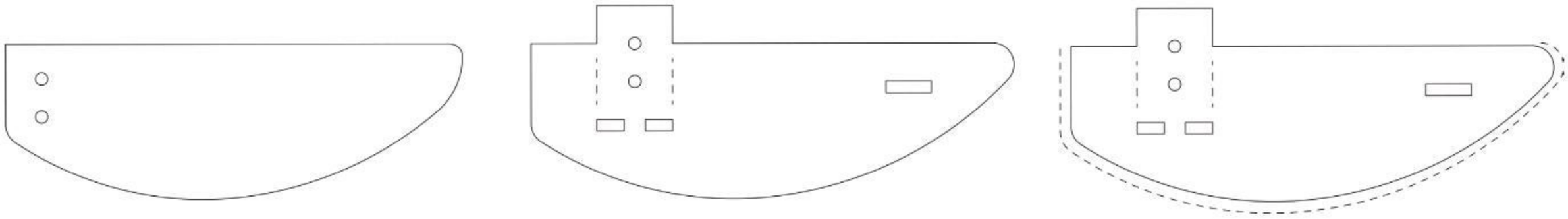
1. mild steel flat bar
2. mild steel shaft 6mm Ø
3. circlip
4. mild steel shaft 6mm Ø
5. acrylic mounts and spacer
6. nylon flange bearing 6mm bore Ø
7. aluminium knee-strike plate
8. acrylic spacer
9. M3 washer
10. M3 machine screw
11. 20mm square section aluminium
12. M3 nyloc nut
13. laser-cut acrylic feet

Fabrication

Friction at pin joints
First build (left) : very low-friction but unreliable and not constant
Second build (right): constant low-friction

Co-ordination of Legs 2 and 3
First build (left) : robust connection
Second build (right) : lightweight robust connection

Fabrication



Feet design and friction
First build (left) : MDF, high friction
Second build (centre): acrylic. very low friction
Second build (right): silicone contact, adequate non-slip

Co-ordination of leg 1 and 4
First build (left) : system got disassembled over a short period of time
Second build (right): rigid connection

Knee Lock
First build (left) : high rebound from aluminium plate
Second build (right): temporary adhesive-tape lock

Testing and Analysis

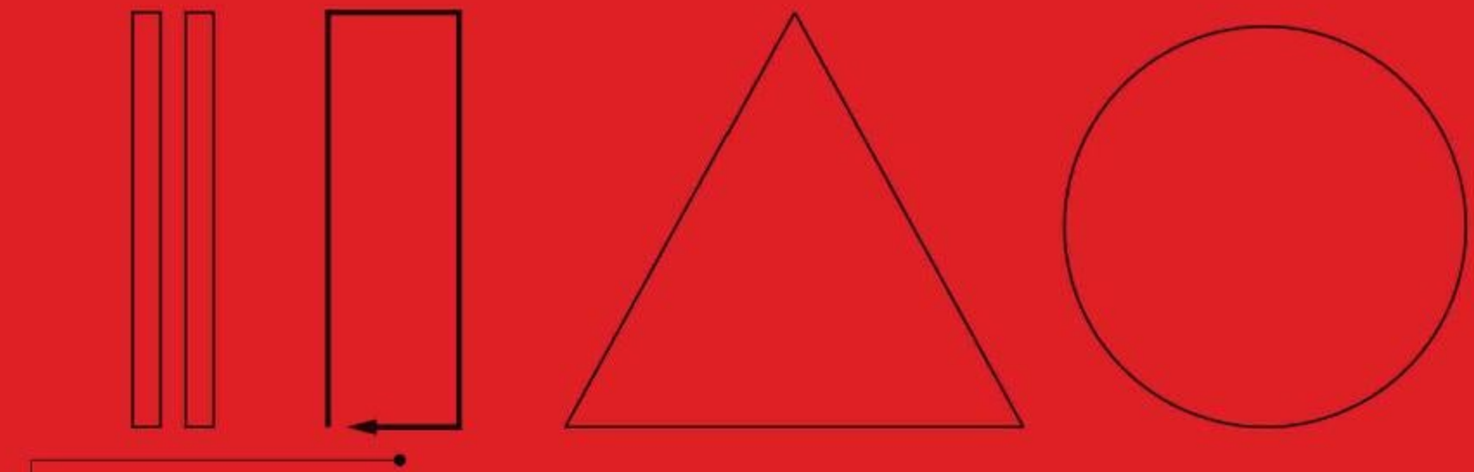
Parameter	Symbol	Unit	Value
leg length	L	mm	400
shank length below centre of gravity	a_1	mm	100
shank length above centre of gravity	b_1	mm	100
thigh length below centre of gravity	a_2	mm	100
thigh length above centre of gravity	b_2	mm	100
hip mass	m_H	kg	0.215
thigh mass	m_t	kg	0.106
shank mass	m_s	kg	0.095
inclination of ramp	γ	deg.	2.6

Table 1: Data for Walker D3. Trial A

Parameter	Symbol	Unit	Value
leg length	L	mm	400
shank length below centre of gravity	a_1	mm	100
shank length above centre of gravity	b_1	mm	100
thigh length below centre of gravity	a_2	mm	100
thigh length above centre of gravity	b_2	mm	100
hip mass	m_H	kg	0.241
thigh mass	m_t	kg	0.132
shank mass	m_s	kg	0.095
inclination of ramp	γ	deg.	3.1

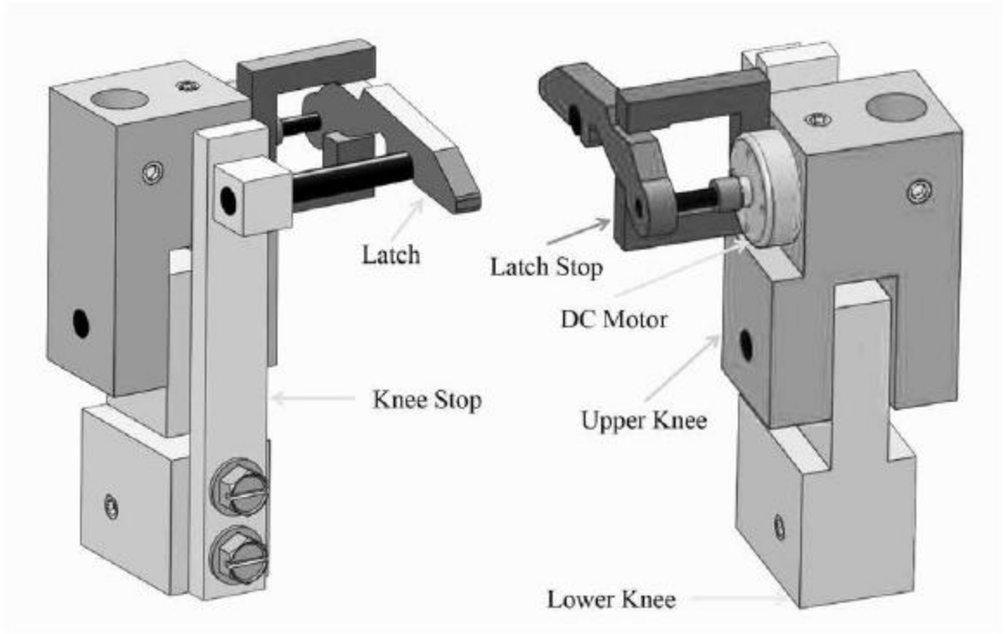
Table 2: Data for Walker D3. Trial B

Step Cycle

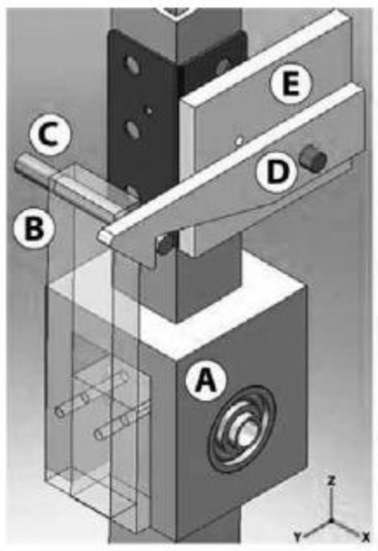


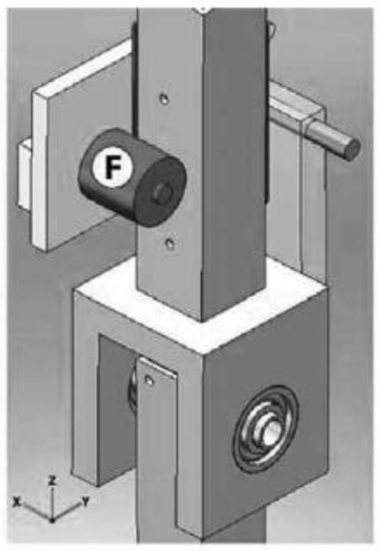
a solution

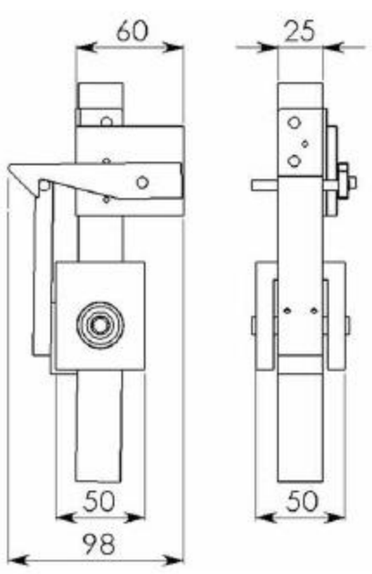
Feedback as Error Correction



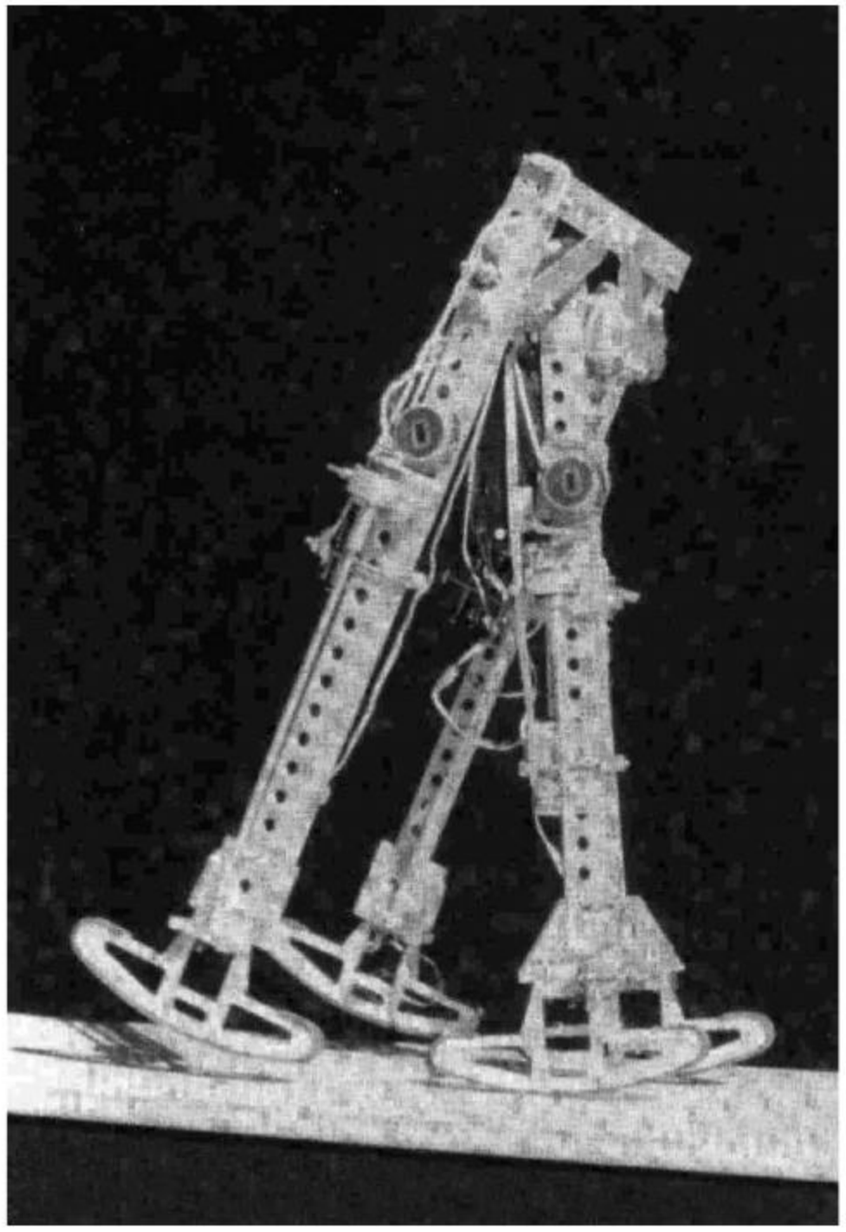
Graph of number of trials against number of steps for both Active and Magnetic Locks
source: Trifonov, K., Hashimoto, S.
Active Knee-release Mechanism for Passive-dynamic Walking Machines. Japan





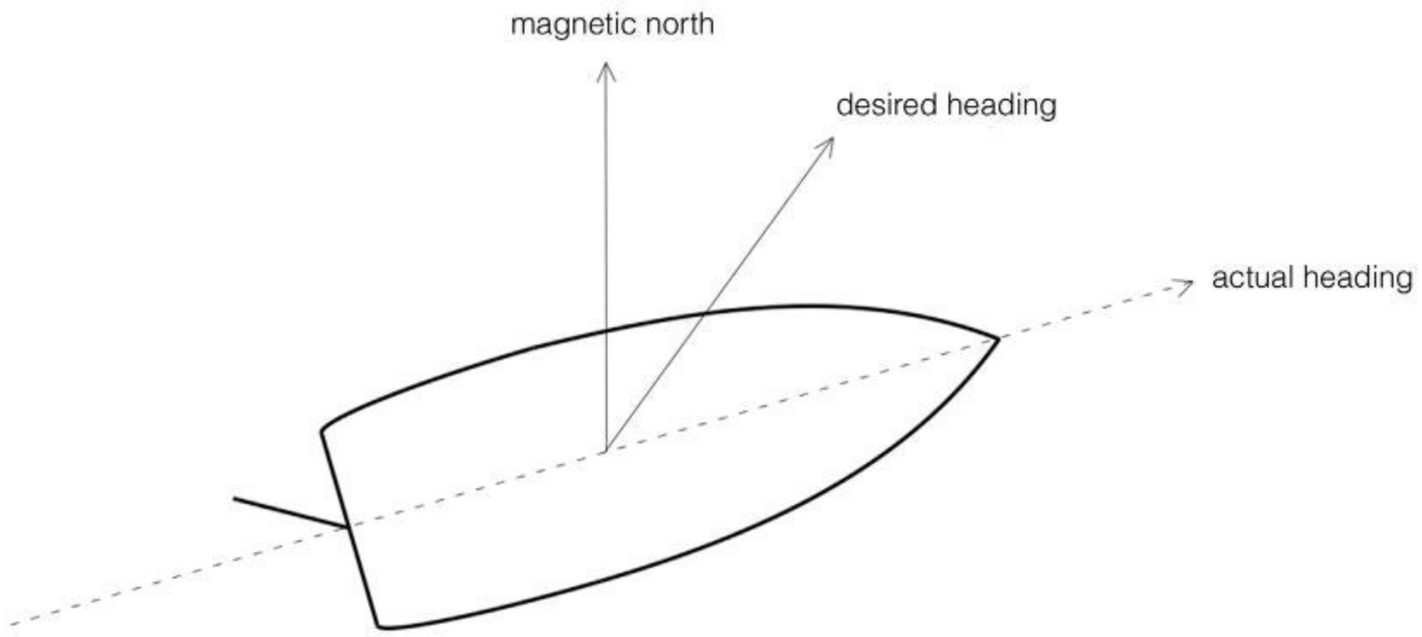


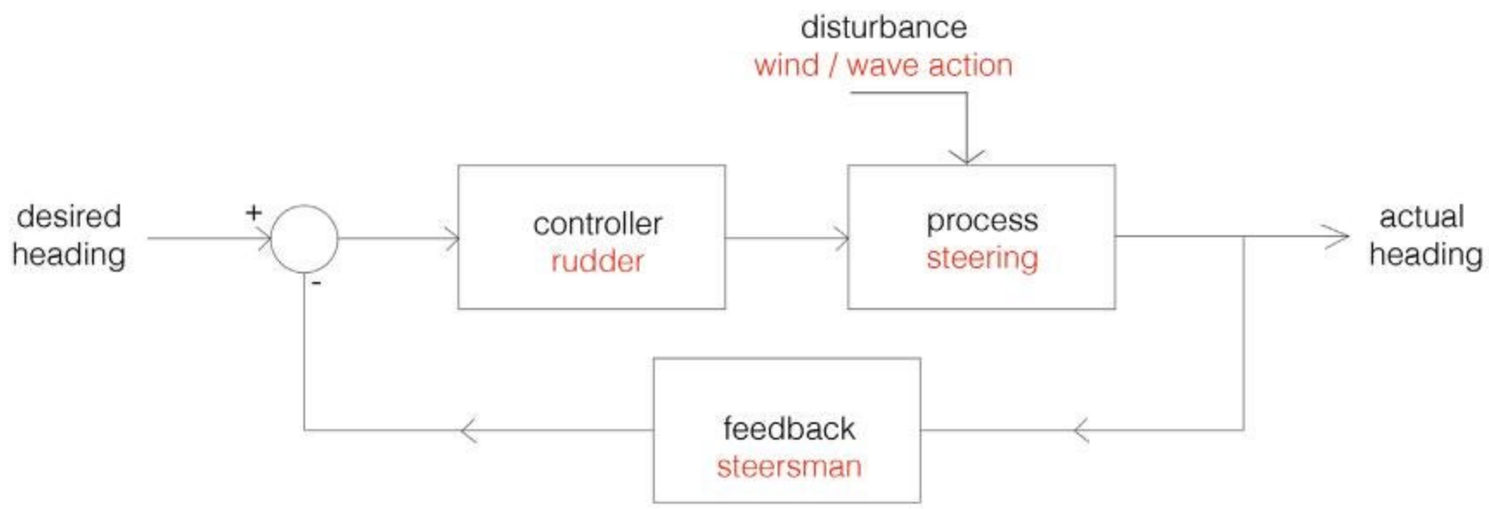
Design for an active lock mechanism
source: Trifonov, K., Hashimoto, S.
Active Knee-release Mechanism for Passive-dynamic Walking Machines. Japan



Ted Mc Geer's Passive Dynamic Walker
source: Mc Geer, T.
Passive Dynamic Walking,
in: International Journal of Robotics Research, 9:62. 1990

Principles of Feedback for Error Correction





Schematic for a closed feedback loop

Embodied Computation

source: barrettskent.co.uk
retrieved on: 6 / 12 / 2012

Asimo

developed by Honda

Height: 1300 mm
Weight: 54 kg
Materials: Magnesium allow and plastic resin
Power source: 51.8 V Li-ION battery

Operating time: 1hr
Walking speed: 2.7 kmph

Control: 32 servos

Cost of manufacture: 600,000 - 800,000 GBP

source: Trifonov, K., Hachimoto, S.
Active Knee-release Mechanism for Passive-dynamic Walking Machines. Japan

Passive Dynamic Walker

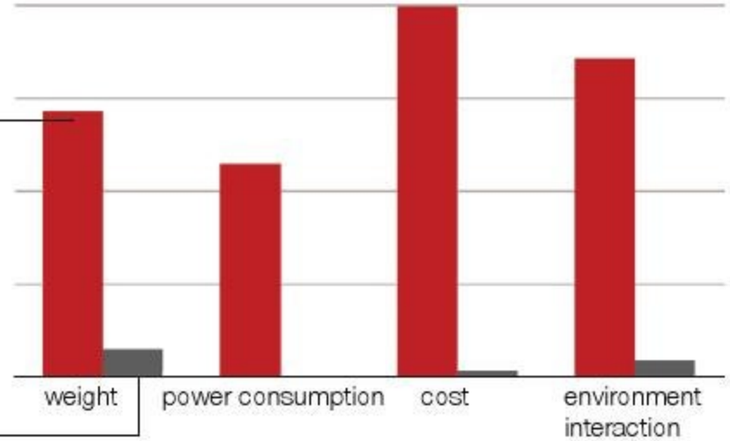
developed at
Waseda University
Japan

Height: 890 mm
Weight: 4.5 kg
Materials: Aluminium
Power source: N/A

Operating time: N/A
Walking speed: N/A

Control: 4 electromagnetic knee-locking mechanisms

Cost of manufacture: N/A



Relative comparison for different criteria

Embodied Dynamics

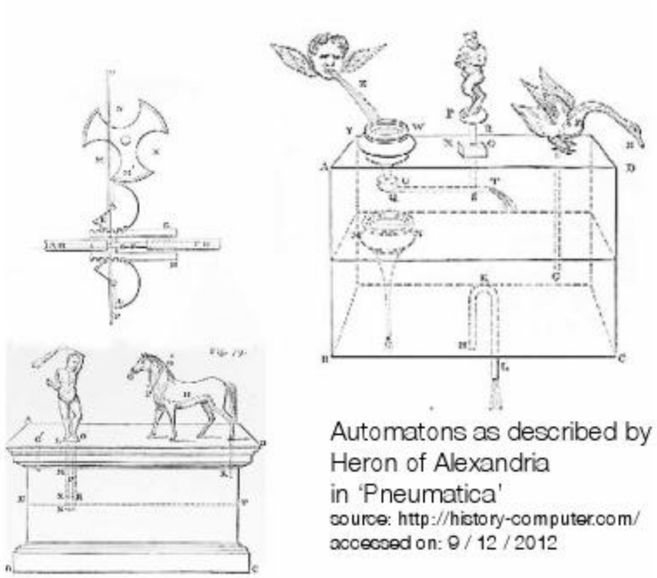
Cowl on top of an oast
source: http://www.geograph.org.uk
accessed on: 9 / 12 / 2012

"[one does not] need complex control systems to achieve complex behavior, but it can be achieved through **morphological** and **material** characteristics, and the **environment**"

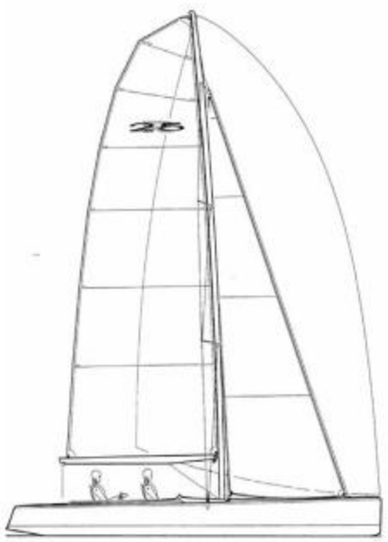
Rolf Pfiefer
On the role of embodiment in the emergence of cognition. eSMCs Summer School, San Sebastian, 2011
source: http://www.vimeo.com
accessed on: 24 / 11 / 2012

Automatic passive window opener
source: http://suchandsuchfarm.com/
accessed on: 16 / 03 / 2013

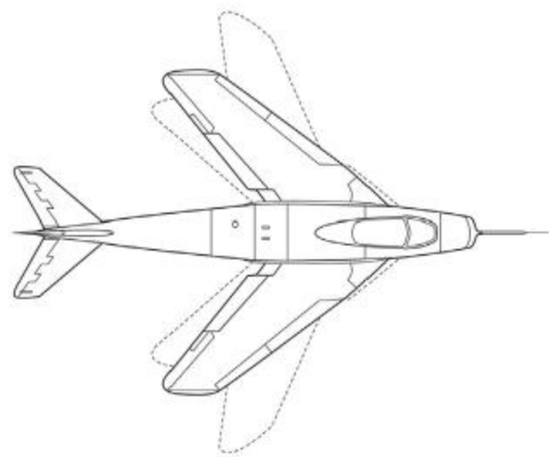
Wax actuated thermostat
source: http://www.germansupply.com/
accessed on: 16 / 03 / 2013



Automatons as described by Heron of Alexandria in 'Pneumatica'
source: http://history-computer.com/
accessed on: 9 / 12 / 2012



Racing Yacht
source: http://www.runnalldesign.com/
accessed on: 9 / 12 / 2012



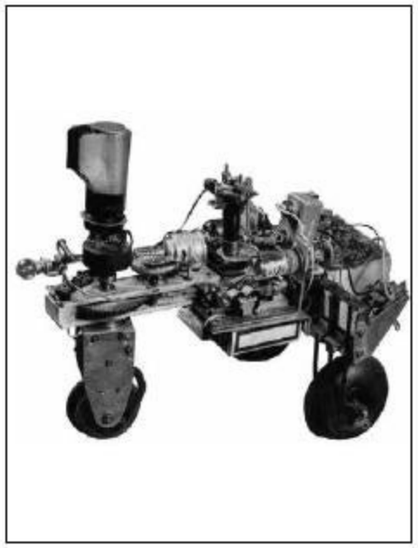
Bell X-5 (1951)
source: http://hyperboreanvibrations.blogspot.co.uk/
accessed on: 9 / 12 / 2012

Old A.I. to New A.I.

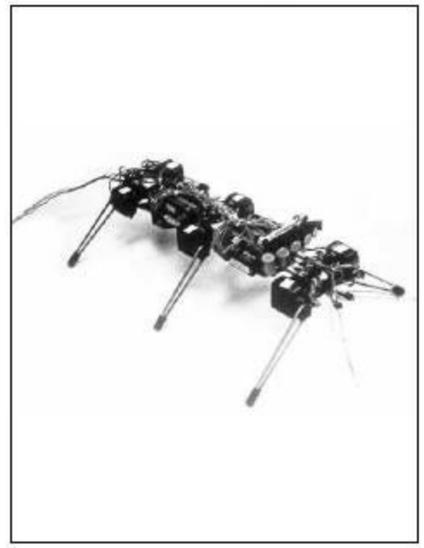
Shakey the robot

Sony's Qrio

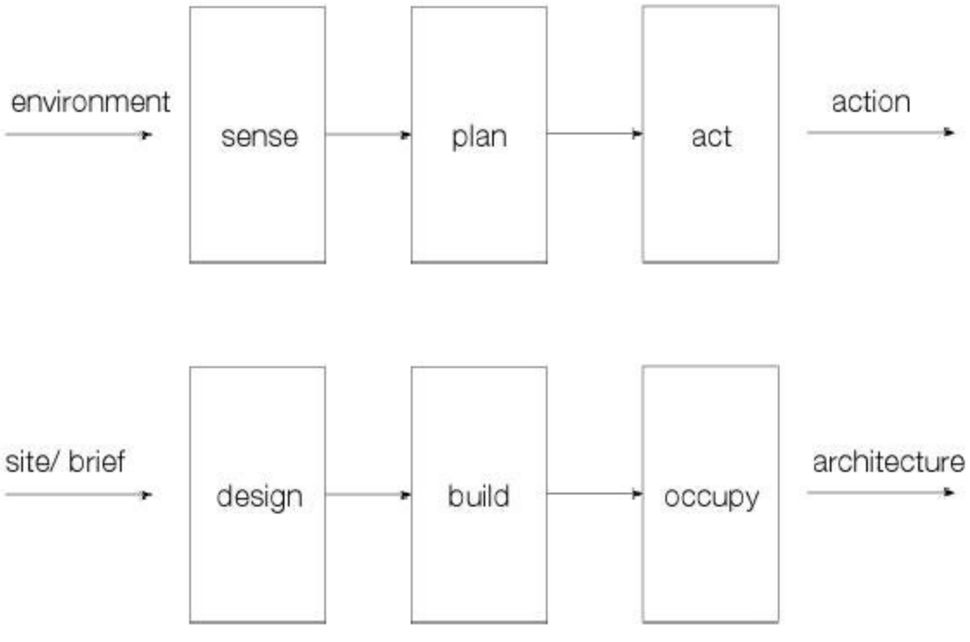
Grey Walter's Elsie



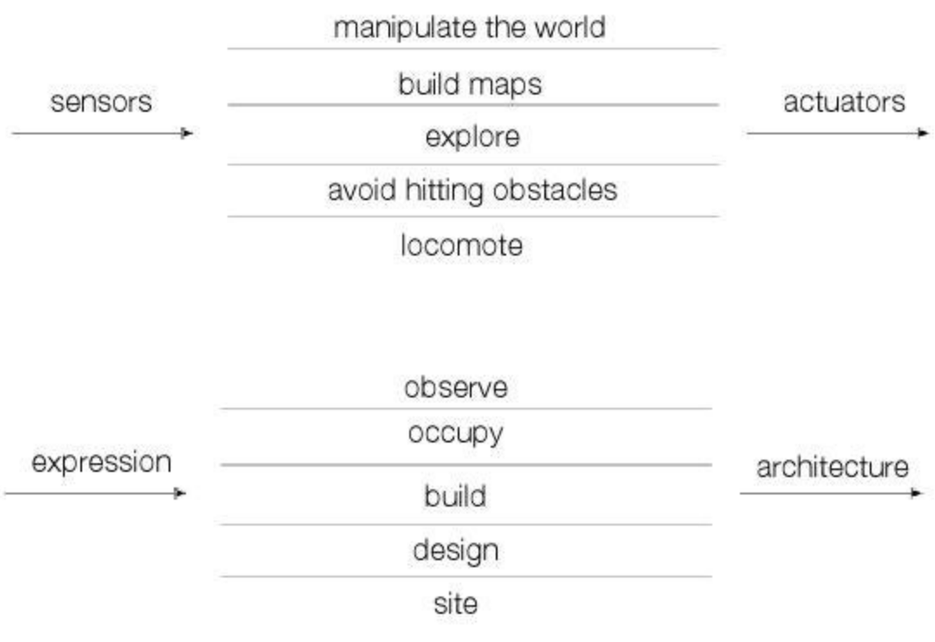
Brooks' Genghis



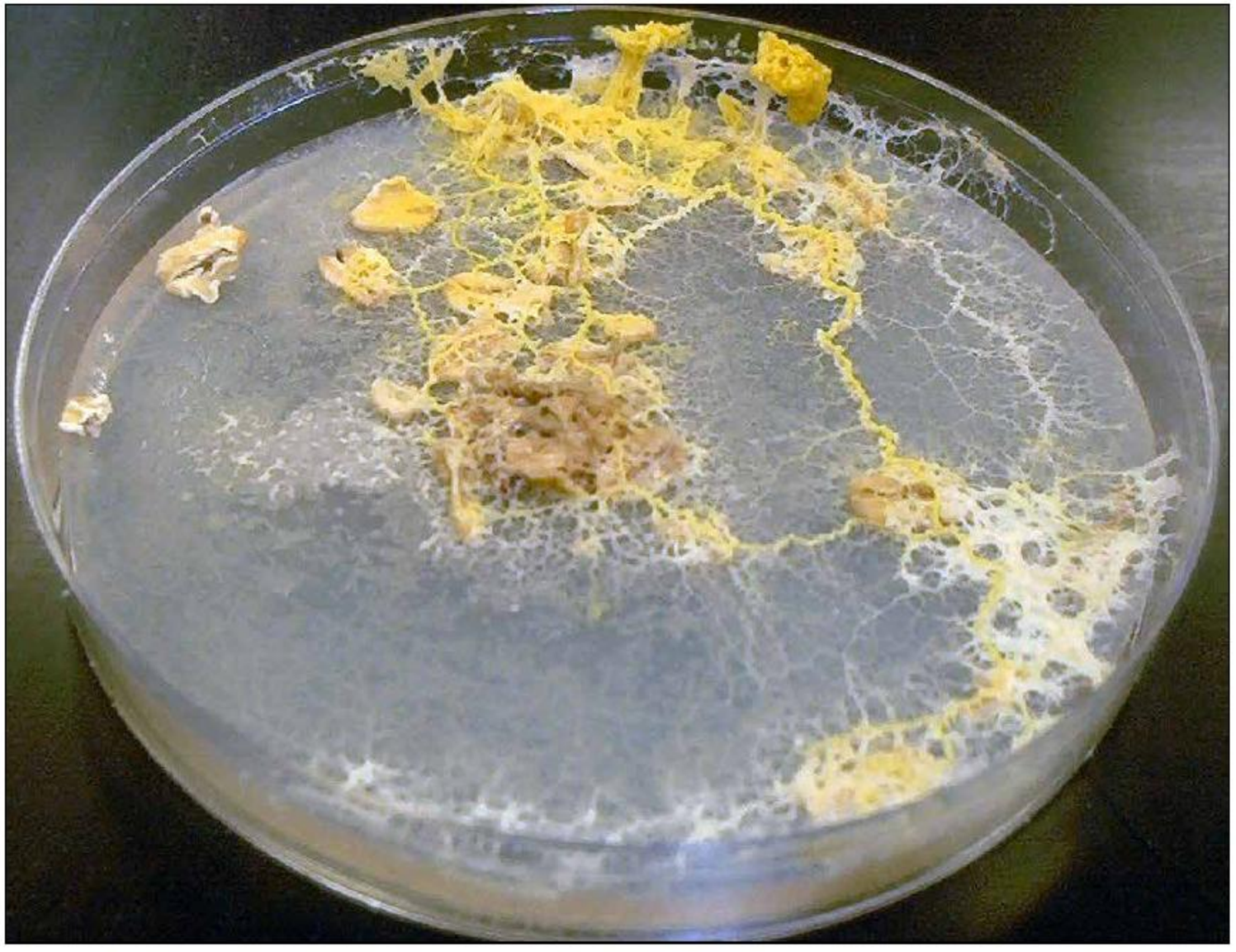
top-down approach



bottom-up approach

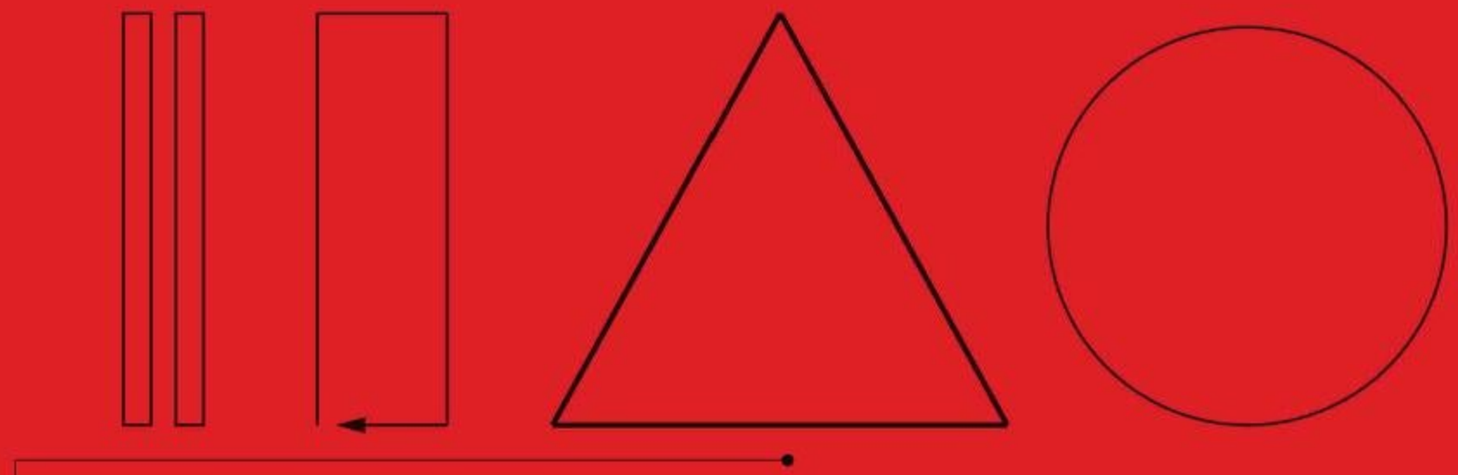


Feedback in Biological Organisms



Plasmodium of Physarum polycephalum
source: http://biology.unm.edu/ccouncil/Biology_203/Summaries/Fungi.htm
accessed on: 15/03/2013

Slime Mold
source: http://www.designswan.com/archives/beautiful-macro-photography-shots-slime-mold.html
accessed on: 15/03/2013

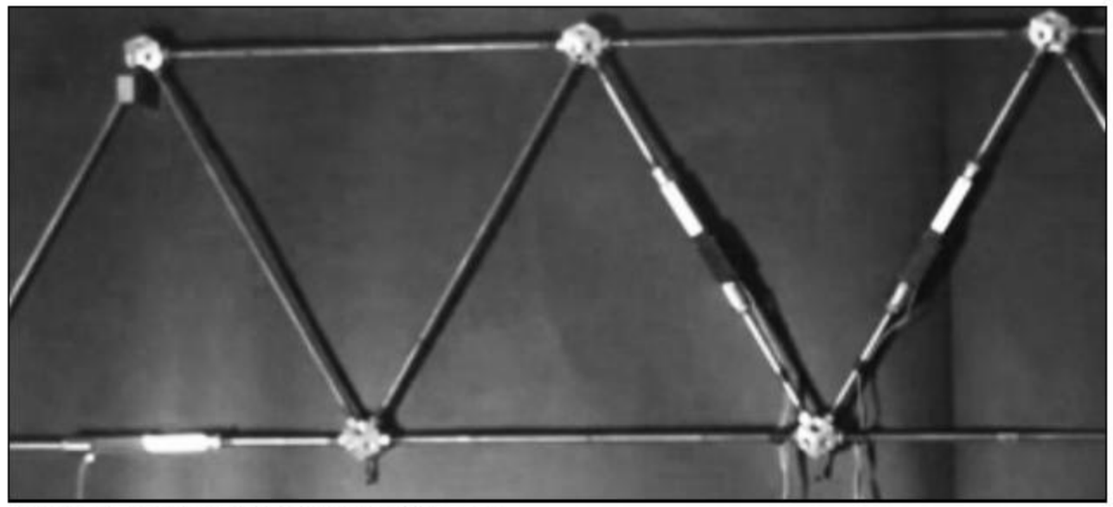


a prototype

Adaptive Trusses

References

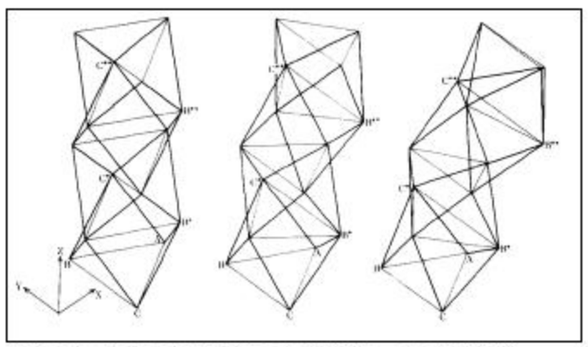
Muscle I and Muscle II by Oosterhuis, et al. (2008)
source: Interactions with proactive architectural spaces: the muscle projects, *Communications of the ACM*, vol. 51, no. 6, pp. 70–78.

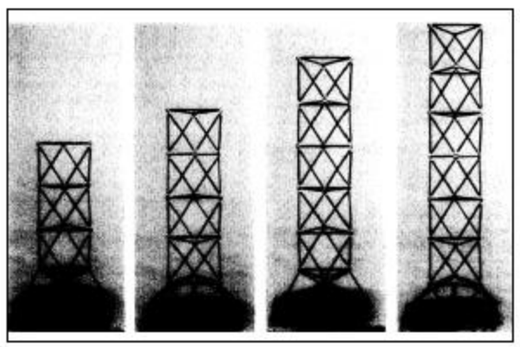


Adaptive Truss by Gennaro Senatore (2008)
source: https://vimeo.com/47368636
accessed on: 06/02/2013

Topotensegrity by 5Subzero (2002)
source: http://www.5subzero.at/,%20actuatedTruss.pdf
accessed on: 14/02/2013

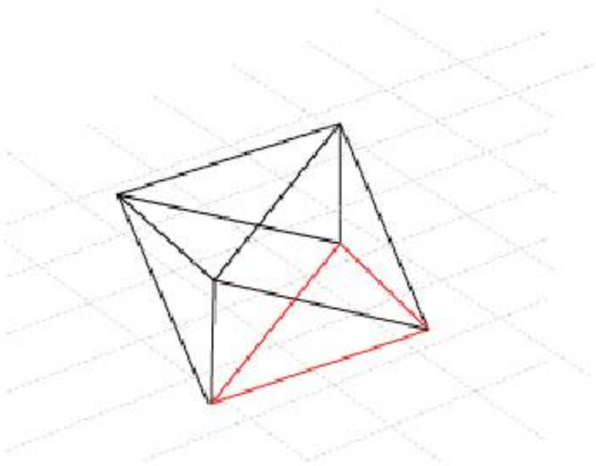
Muscle Tower by Kilian, et al (2006)
source: http://musclesfrombrussels.blogspot.com
accessed on: 08/02/2013



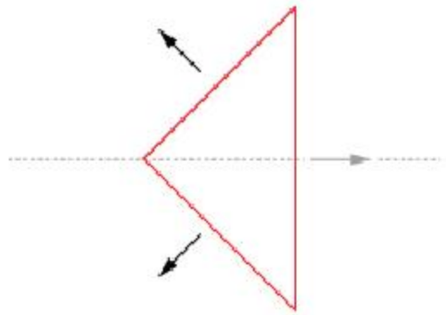


Variable Geometry Truss by Miura, et al (1985)
source: Miura, K., Furuya, H., & Suzuki, K. (1985). Variable geometry truss and its application to deployable truss and space crane arm. *Acta Astronautica*, 12(7-8), 599–607.

Walking Behaviour for an Octahedron

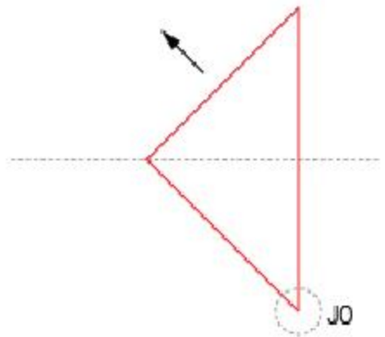


Everytime the octahedron is at rest, one of its eight faces is facing the ground.



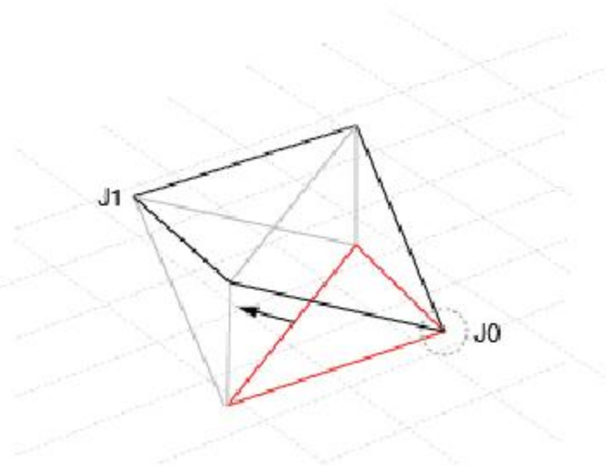
The next step can occur in three directions.
Either: backwards
forward left
forward right

In order to move forward, the next axis of rotation has to be the one closest to the local vector (t).



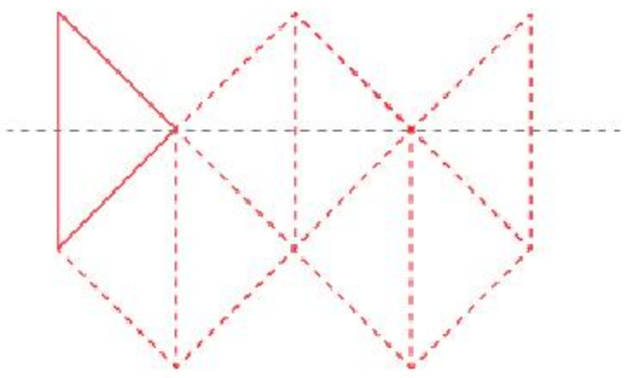
The members connected to the joint opposite the axis of rotation shall extend in the gait sequence.

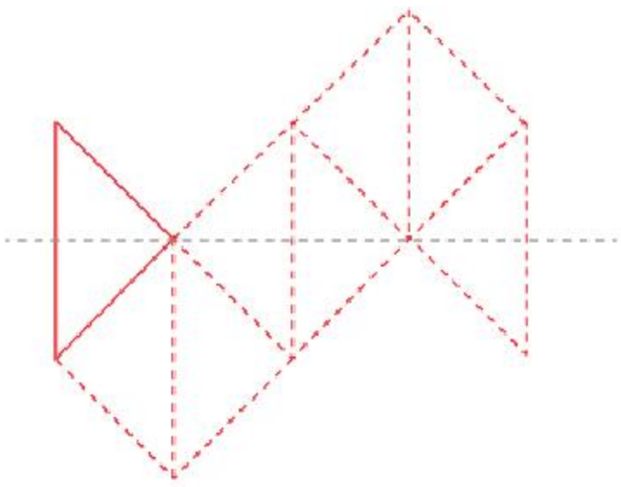
There are 2 joints which fit this condition, one touching the ground (J0) and one not (J1).

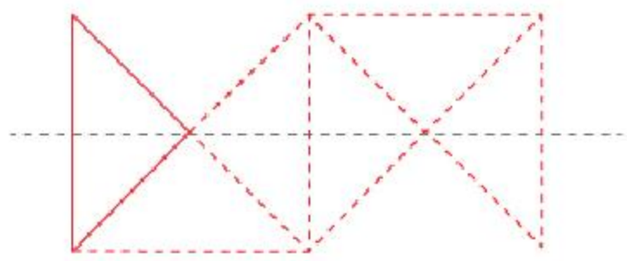


The members connected to J0 extend first, followed by the members connected to J1. Half a cycle is performed when both J1 and J0 touch the ground.

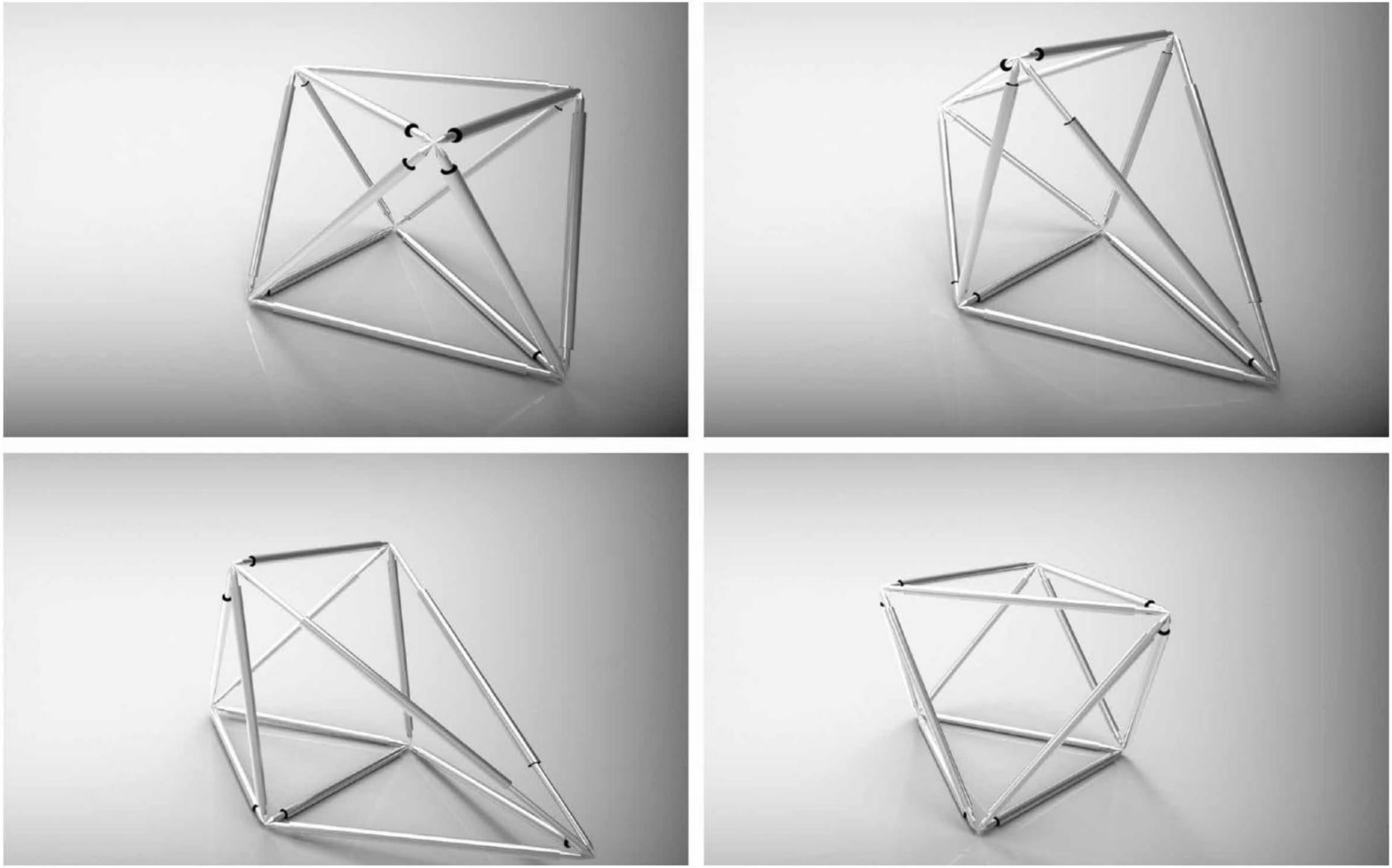
The cycle is ended by retracting the members attached to J1 first, followed by those attached to J0.





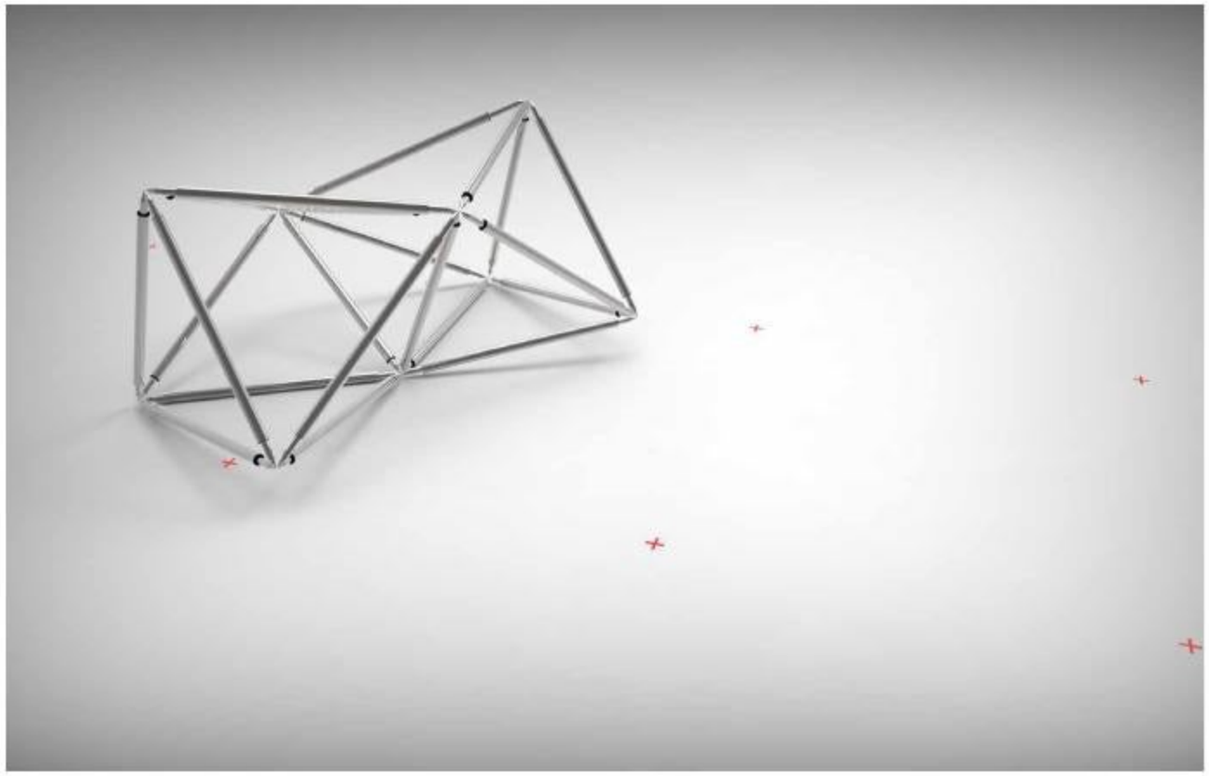


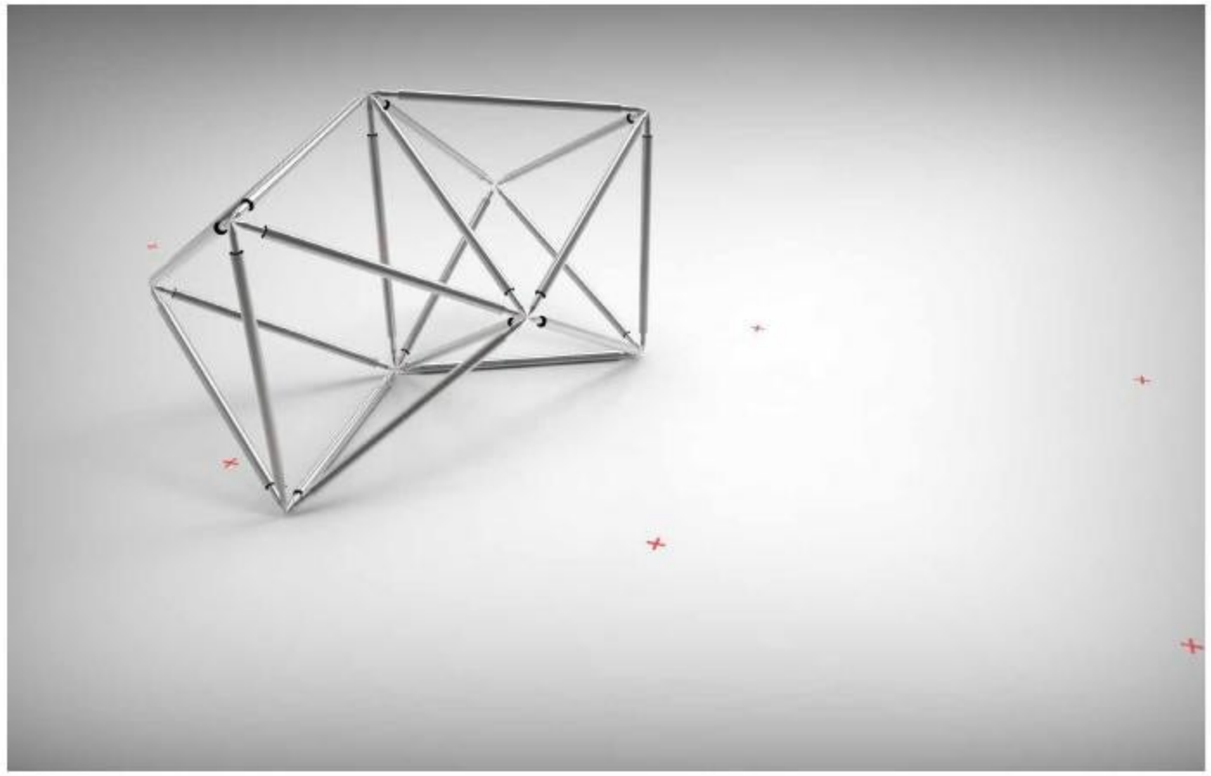
Simulated Walking Behaviour for an Octahedron

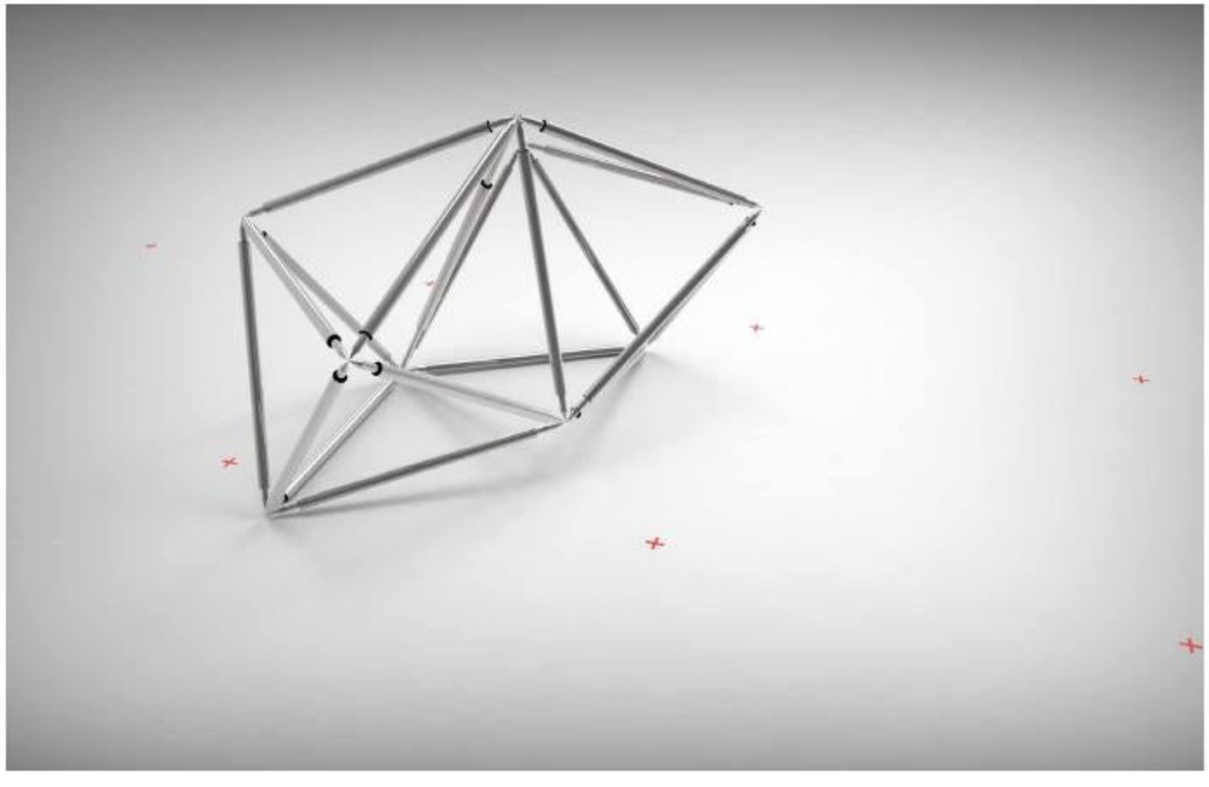


Frames from simulation for a walking octahedron carried out in Kangaroo and Grashopper

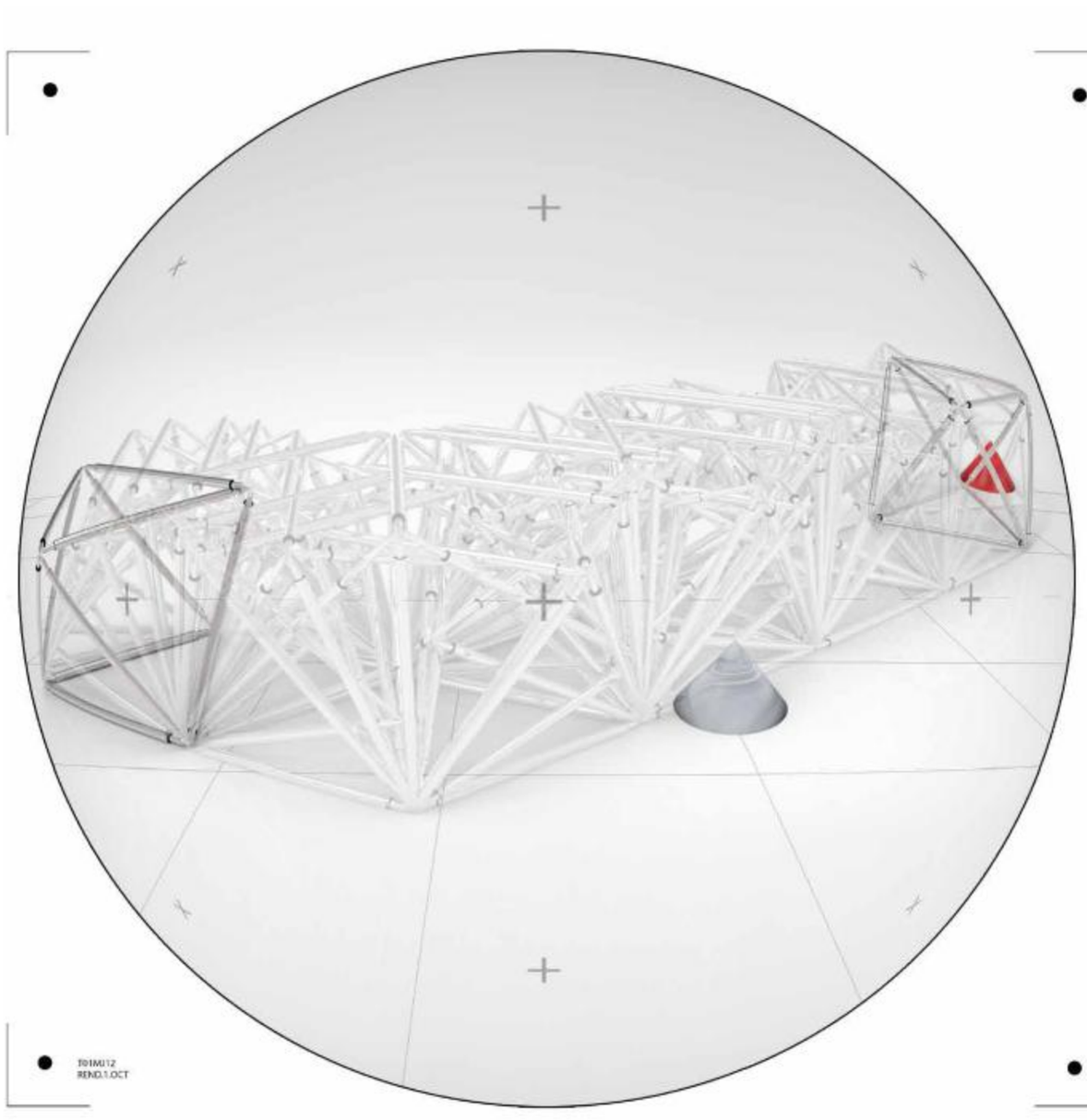
Simulated Walking Behaviour for a double Octahedron

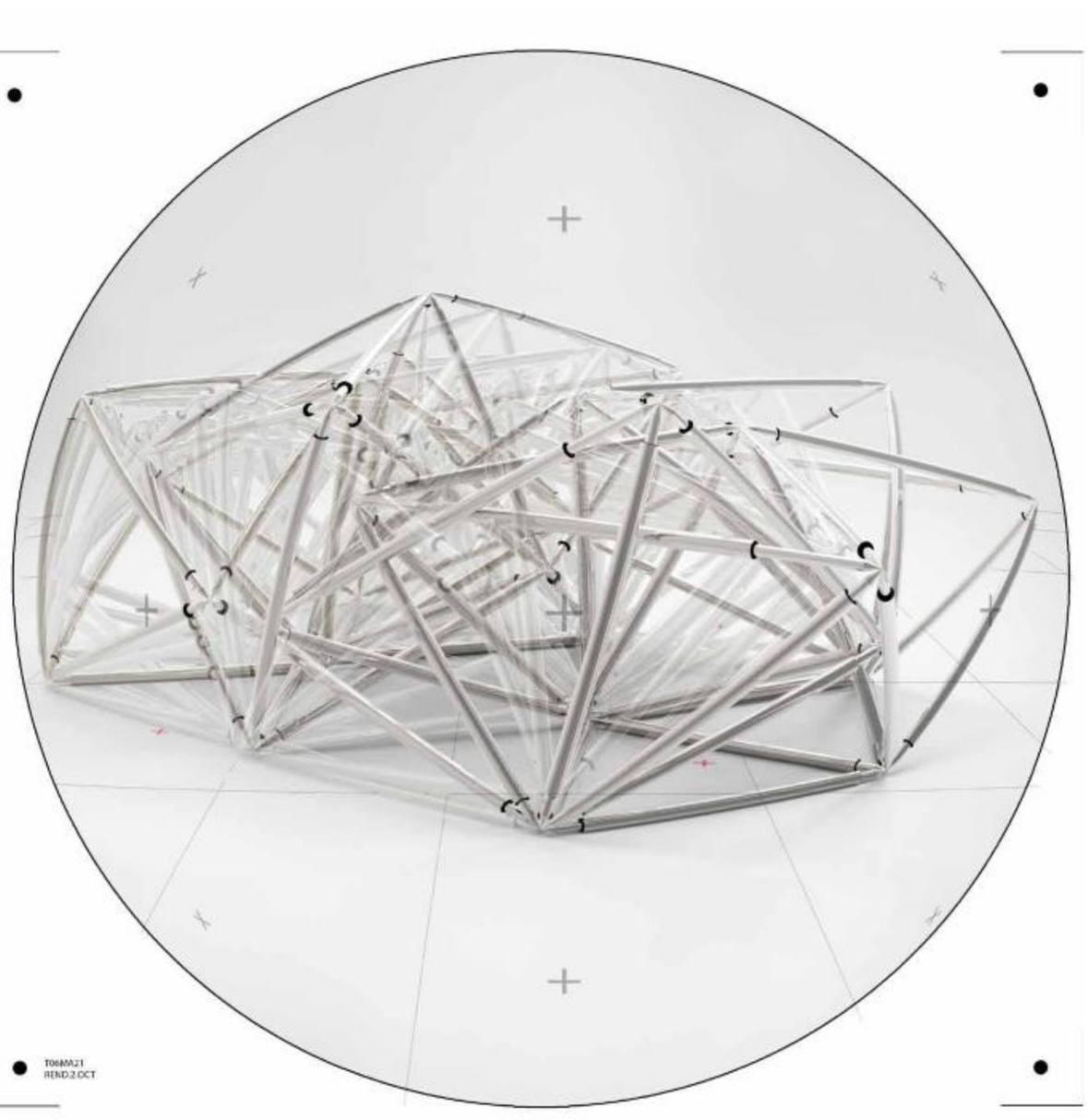




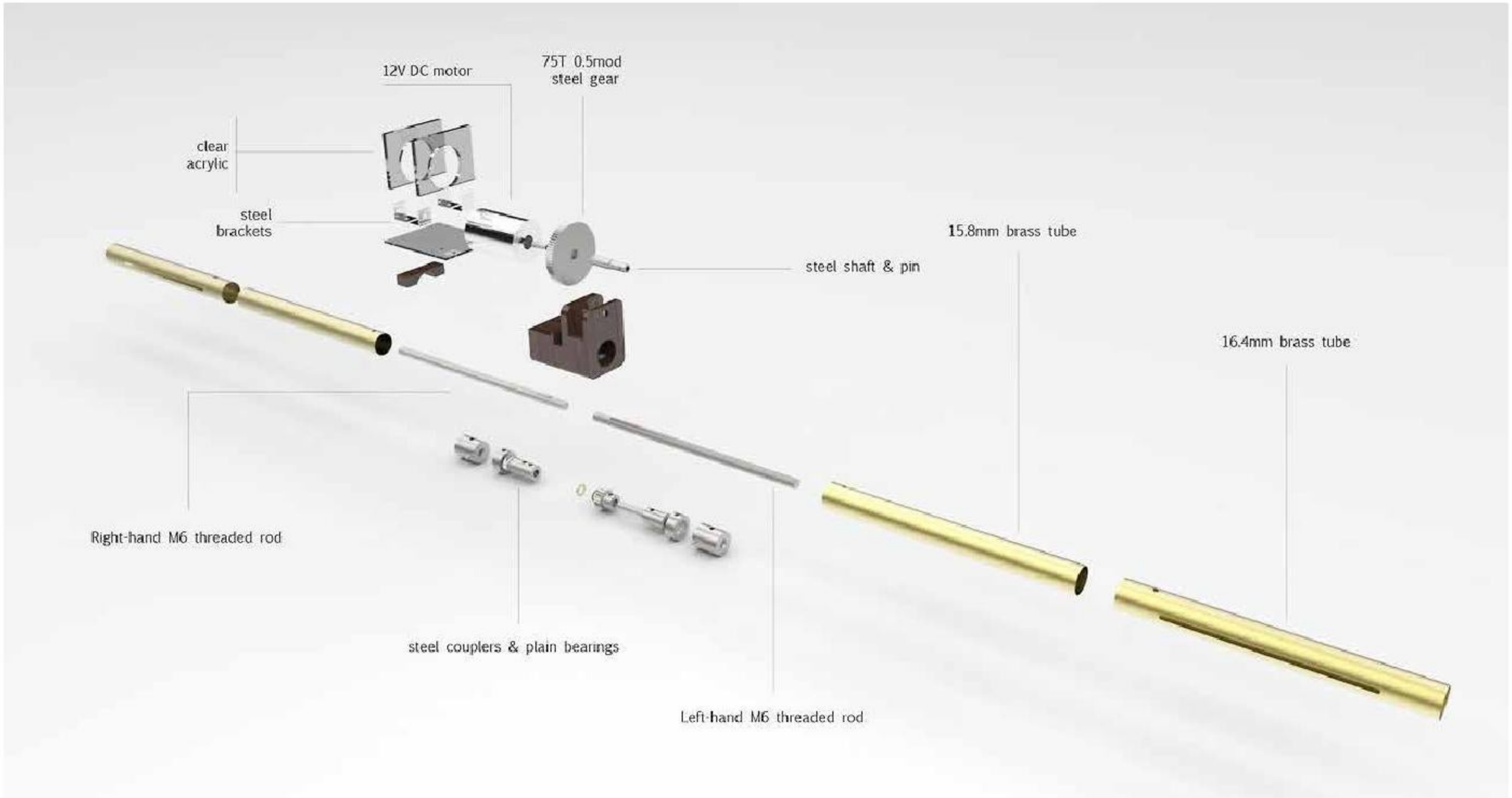


Simulated Gaits

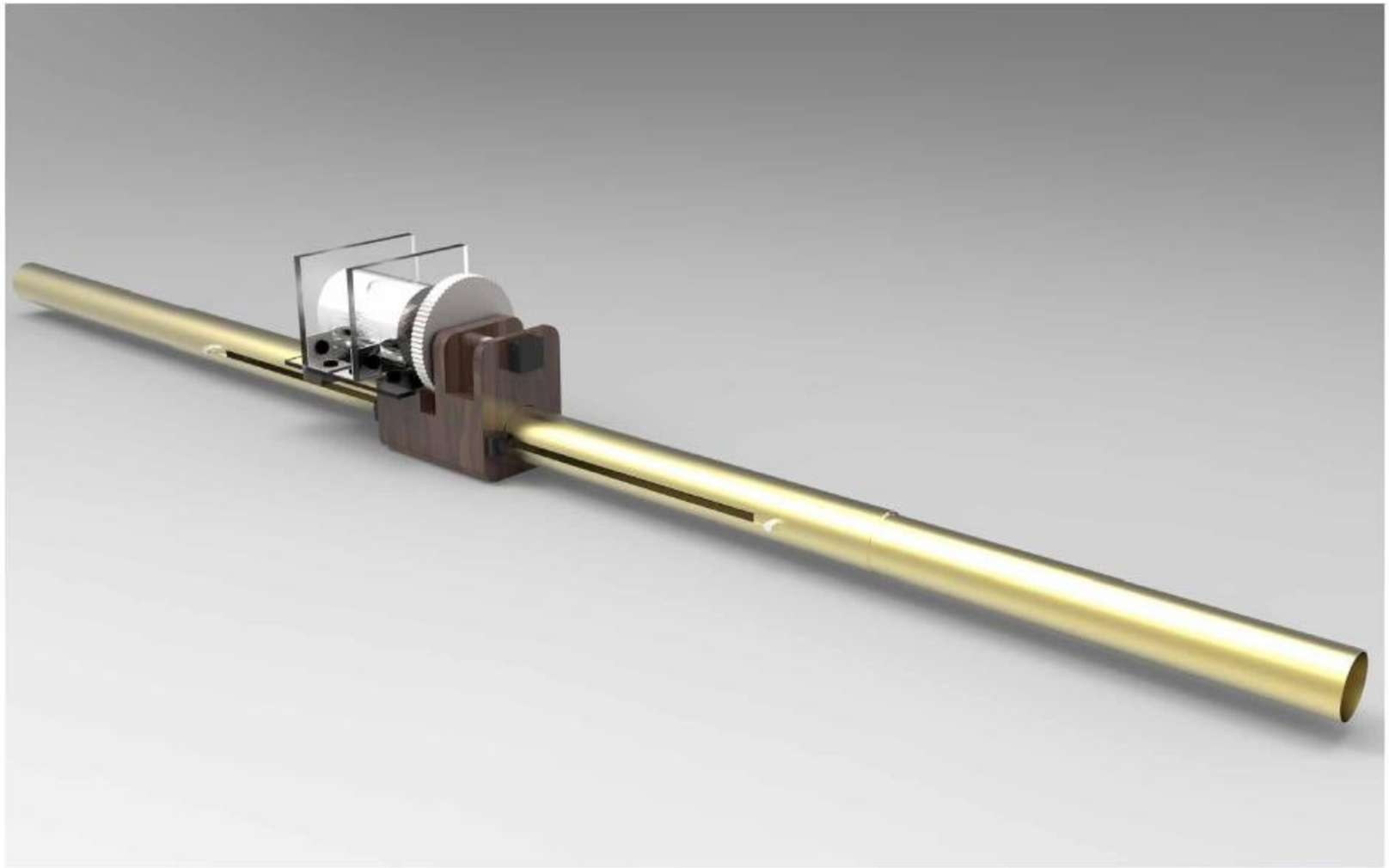




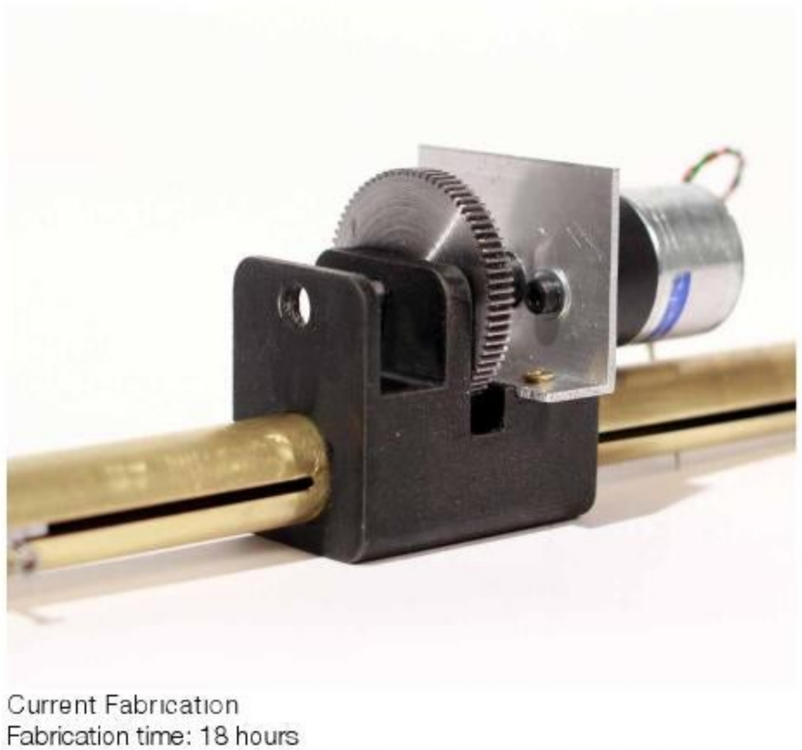
Generation 1: Bi-Linear Actuators



Prototype Mechanism



Visual of Fully Extended Position



Current Fabrication
Fabrication time: 18 hours
Tools/ Machines: Manual lathe with automatic feed, SLS additive manufacturing, pillar drill, hand tools
Assembly: 2 hours

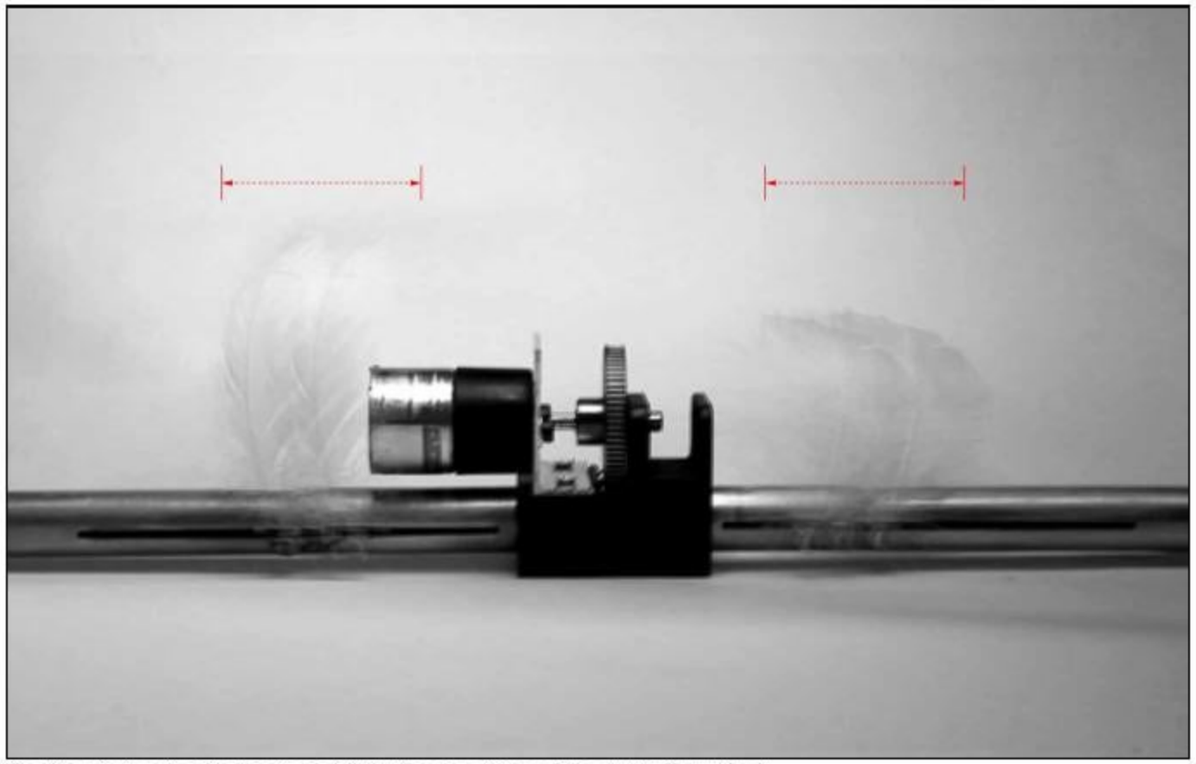
Future Fabrication
Fabrication time: 20 minutes
Tools/ Machines: Digital lathe, CNC milling machine
Assembly: Assembly line, estimated: 40 minutes

Fabricated components

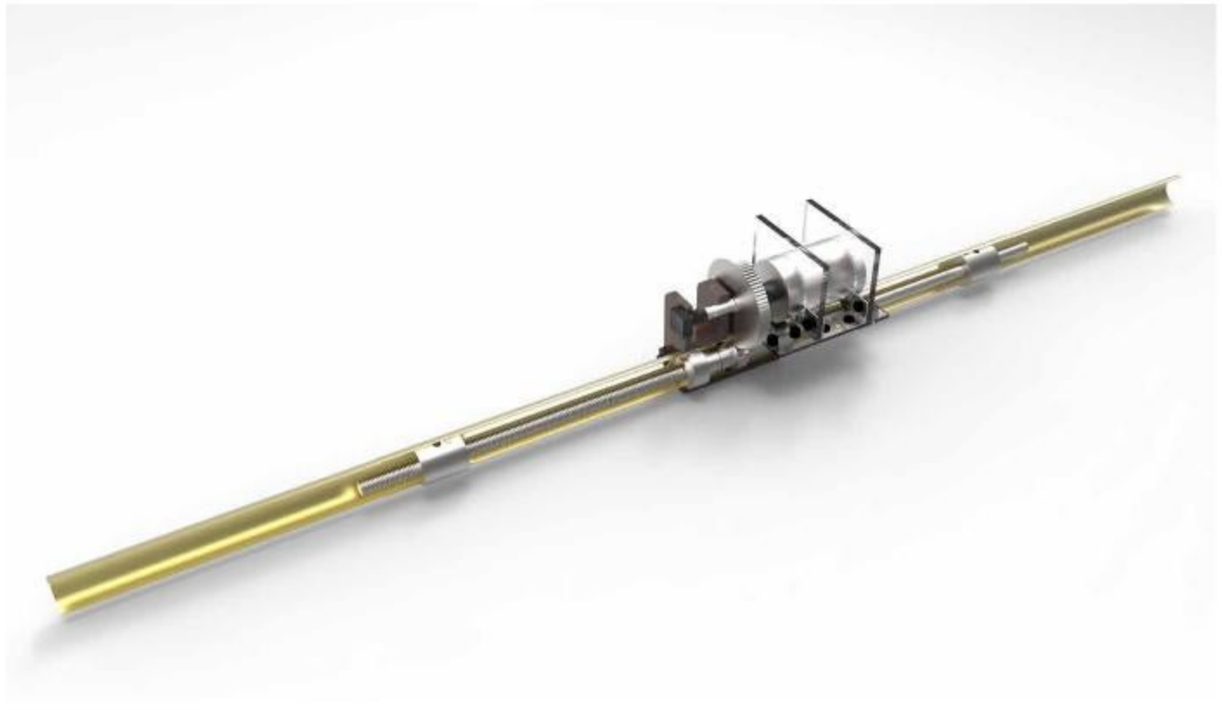
Assembled central couplers, gear and plain bearings

Assembled internal rod

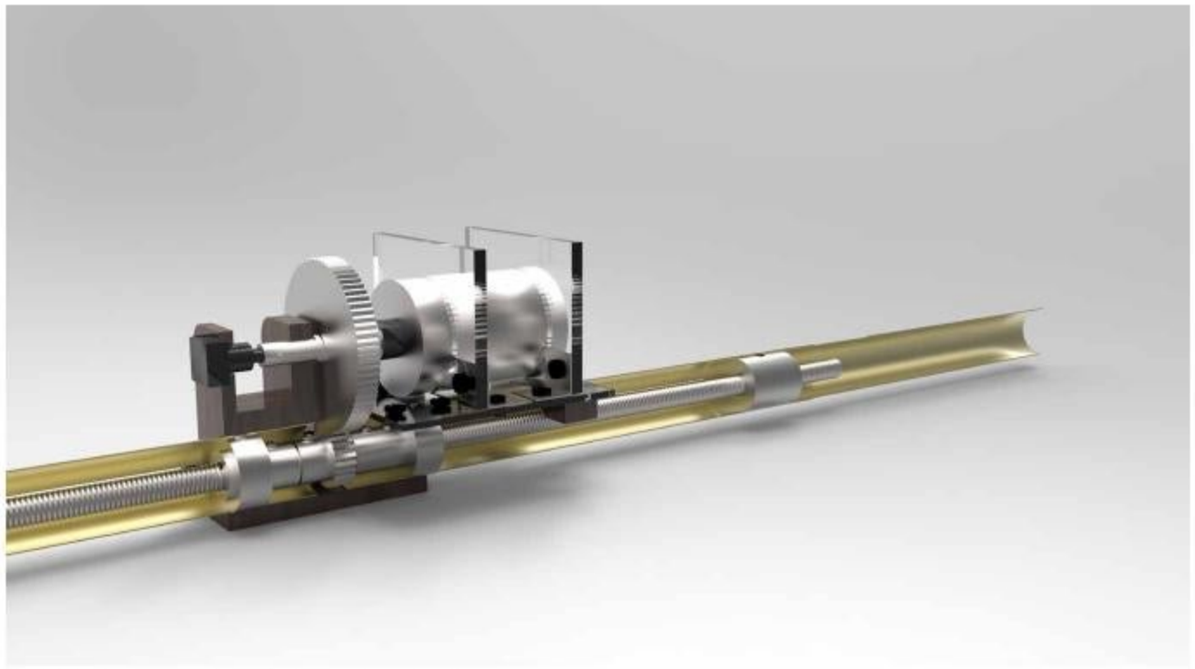
Design and Prototyping



Testing (note: the feathers highlight the location of the travelling pins)



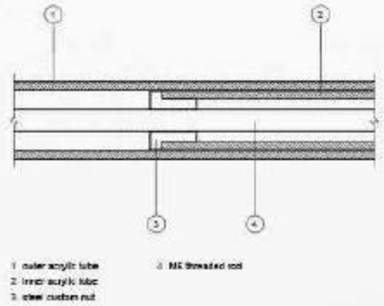
Sectional Perspective: render

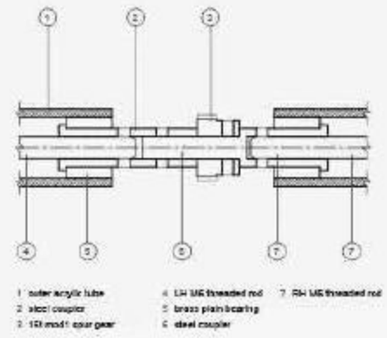


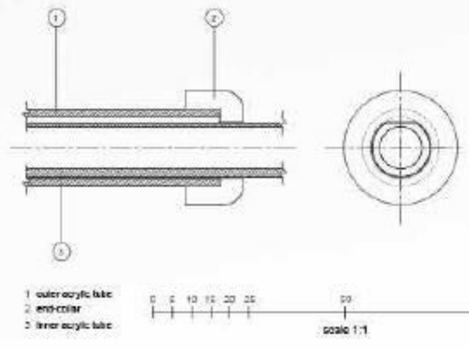
Sectional perspective of alternative detail

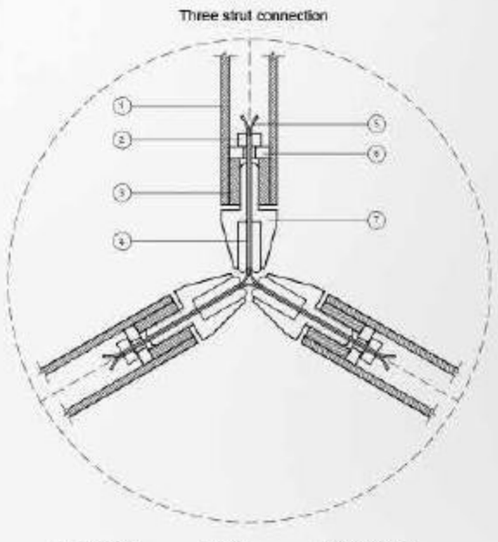
Partial extension: top photograph

Generation 2: Partial Flexibility

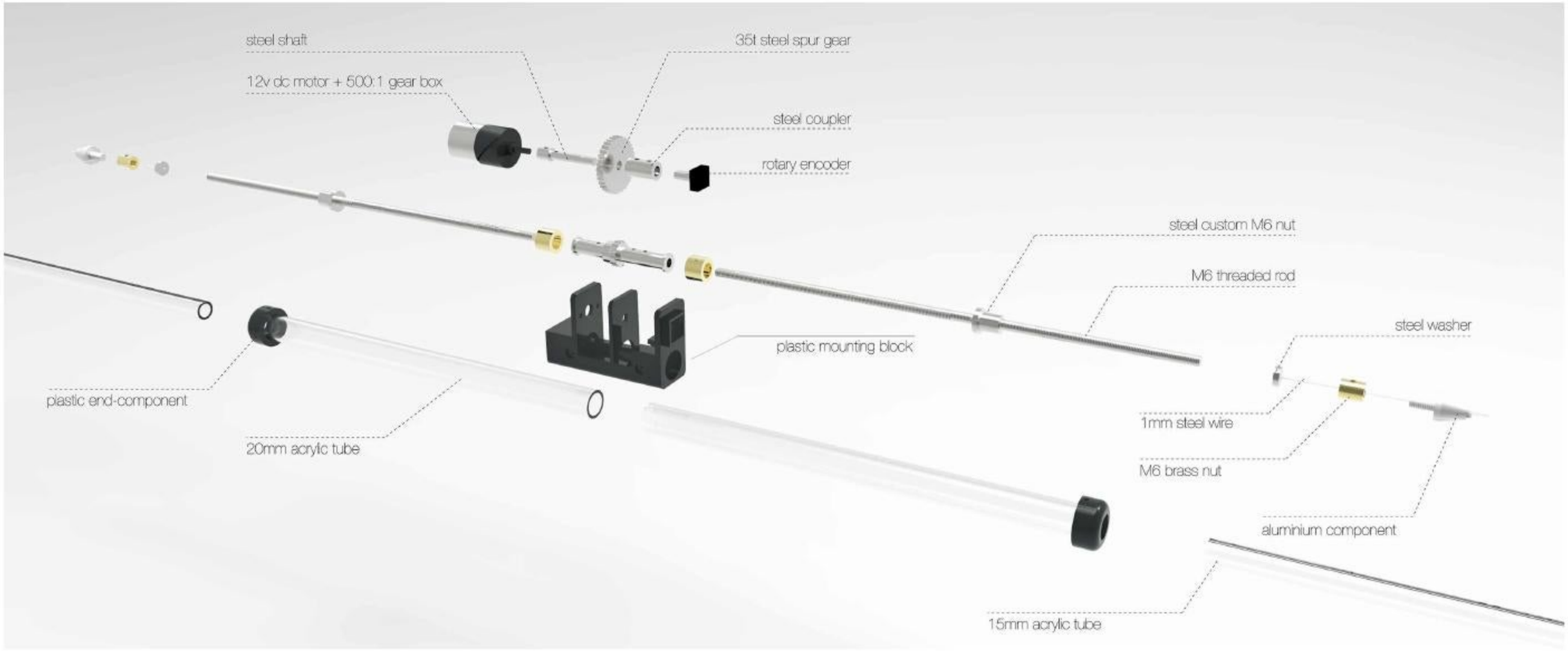


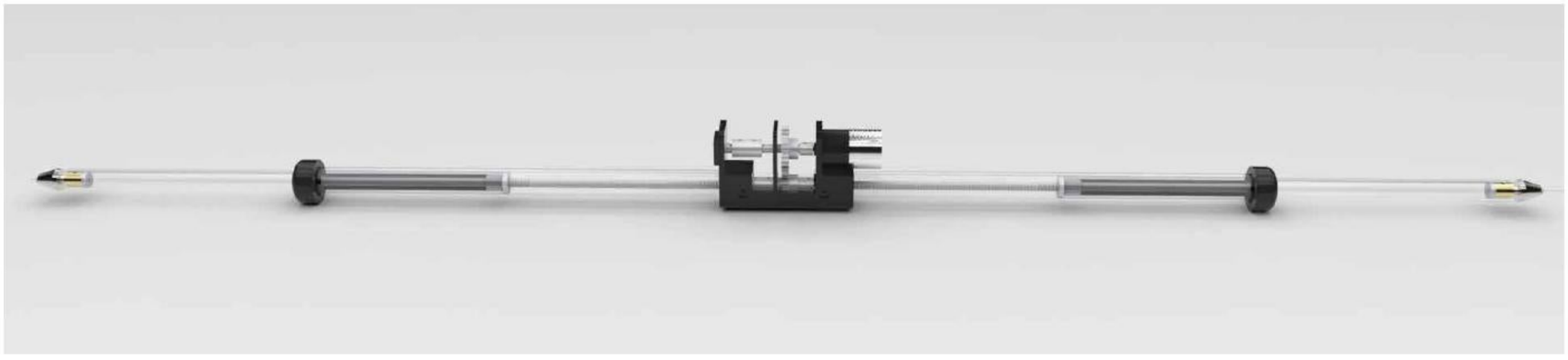




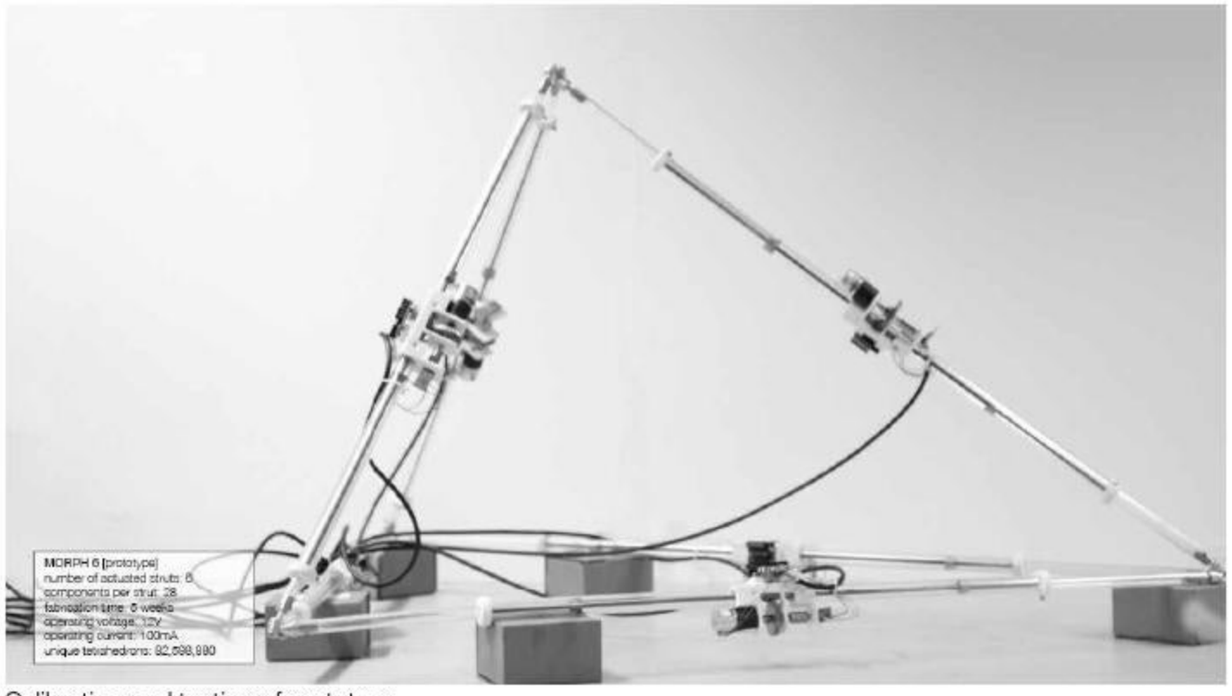


Design of Single Unit





Prototyping/ Design



Calibration and testing of prototype

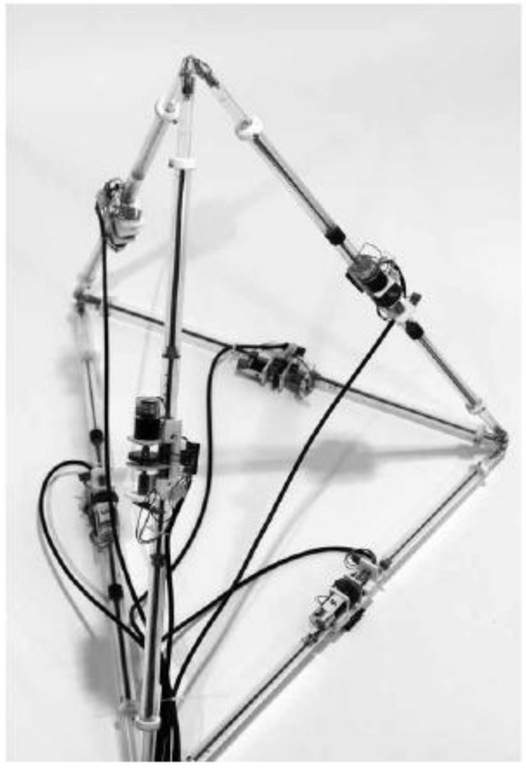
Partial extension: top-view

Internal central mechanism

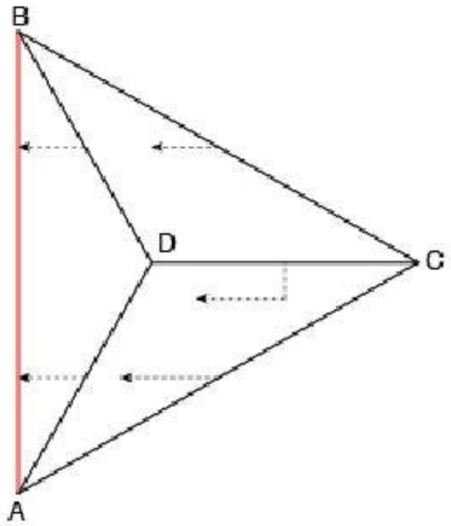
3d Model of components

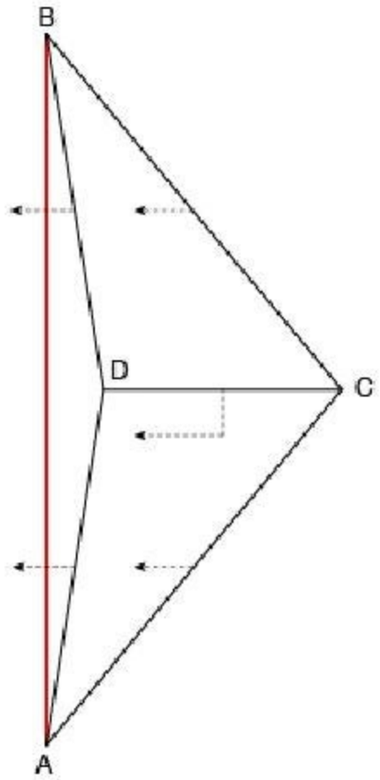
Design for joint detail

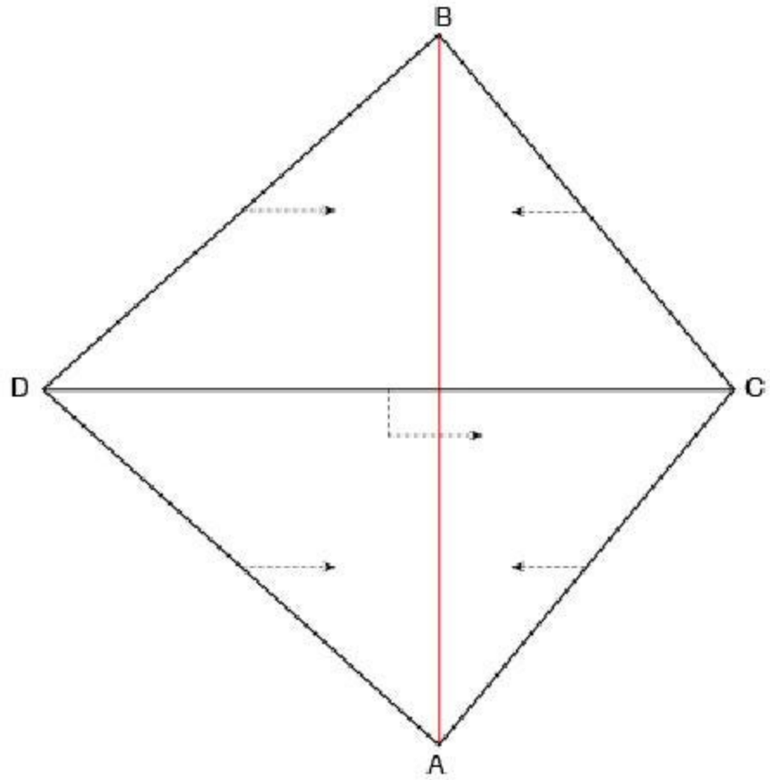
Generation 2: Prototype

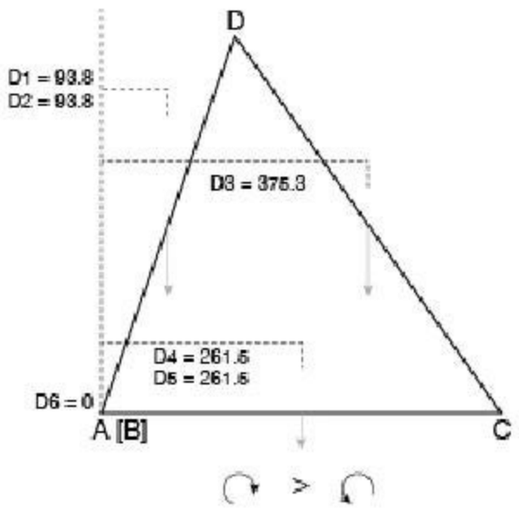


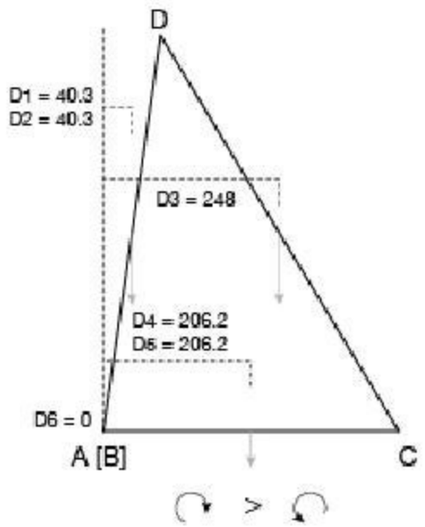
Turning Moments

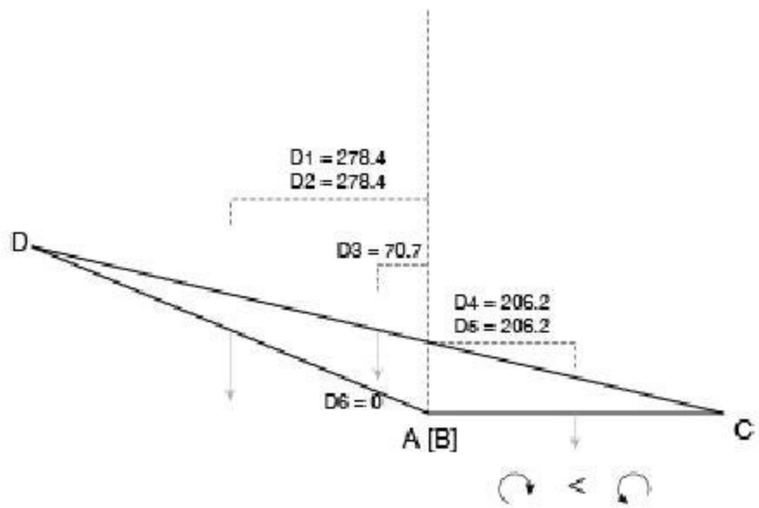




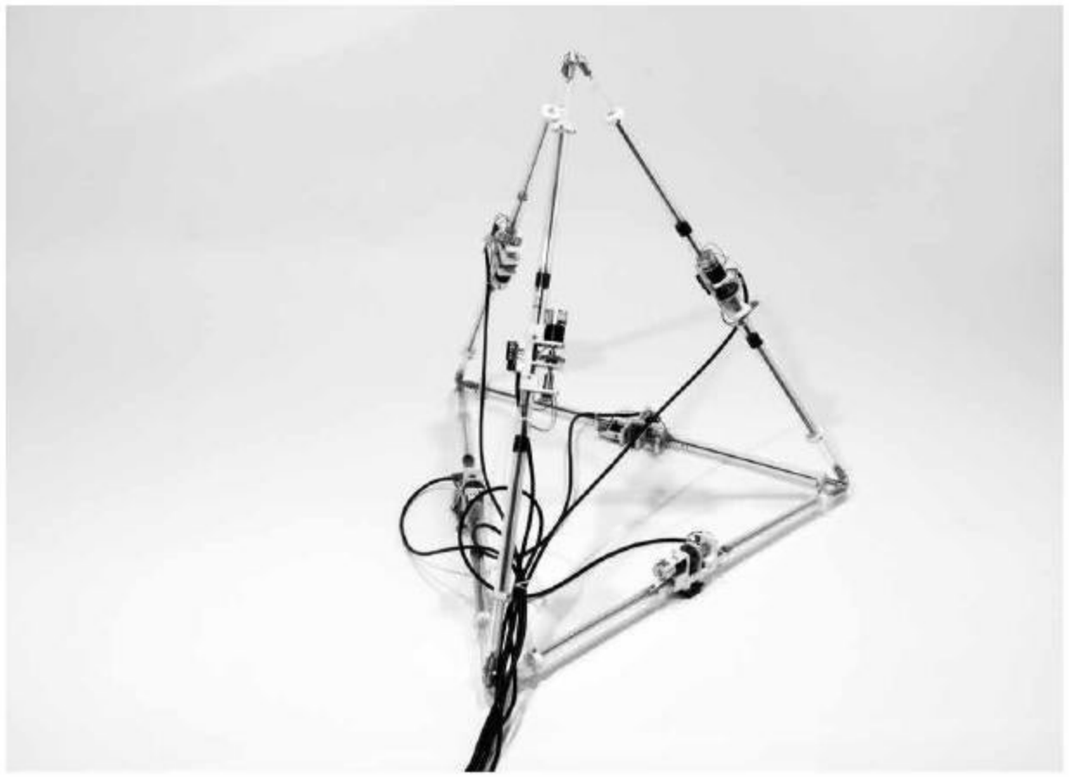


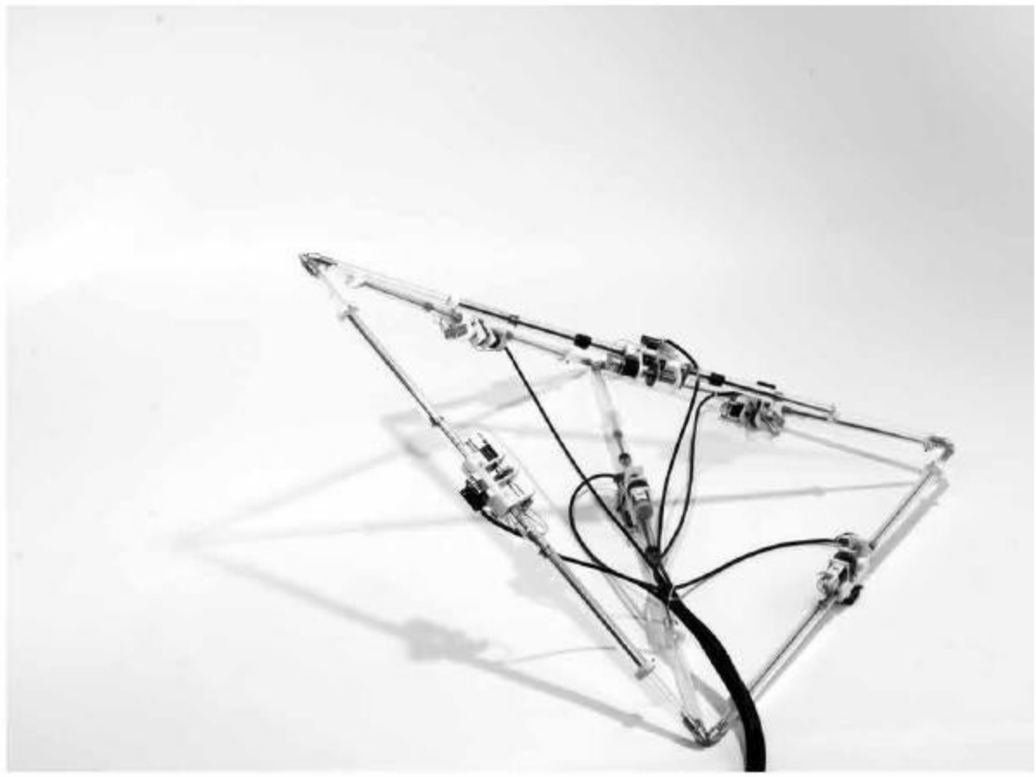


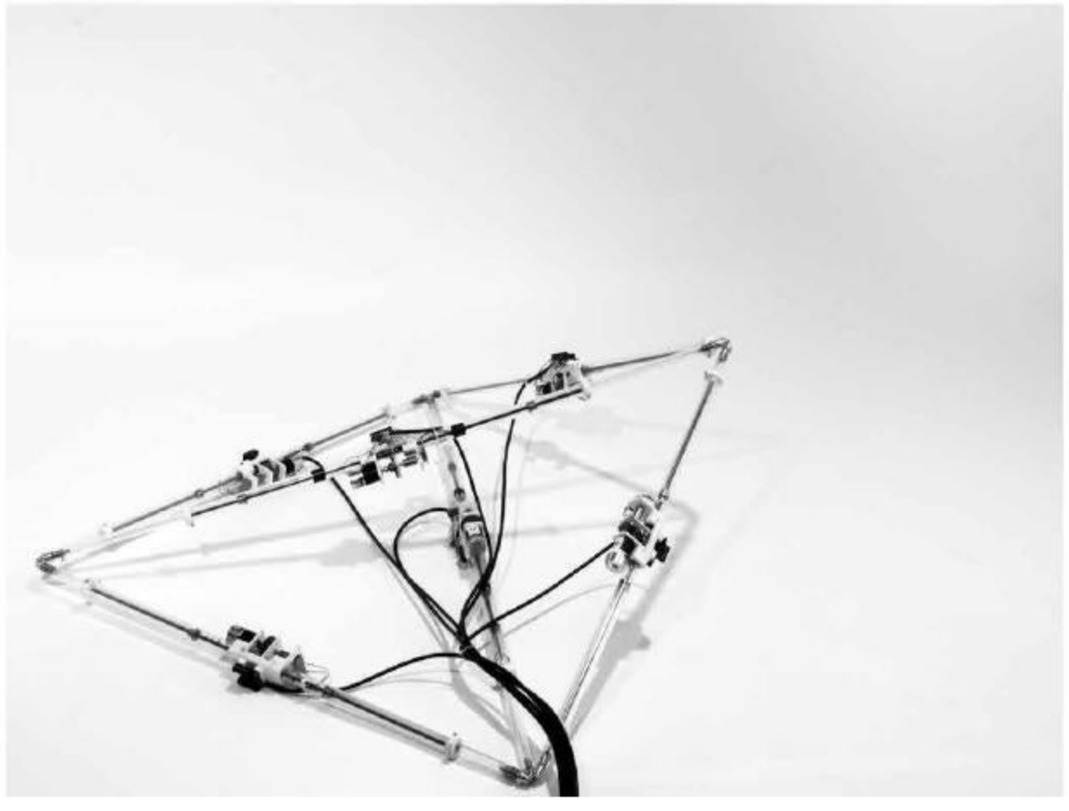


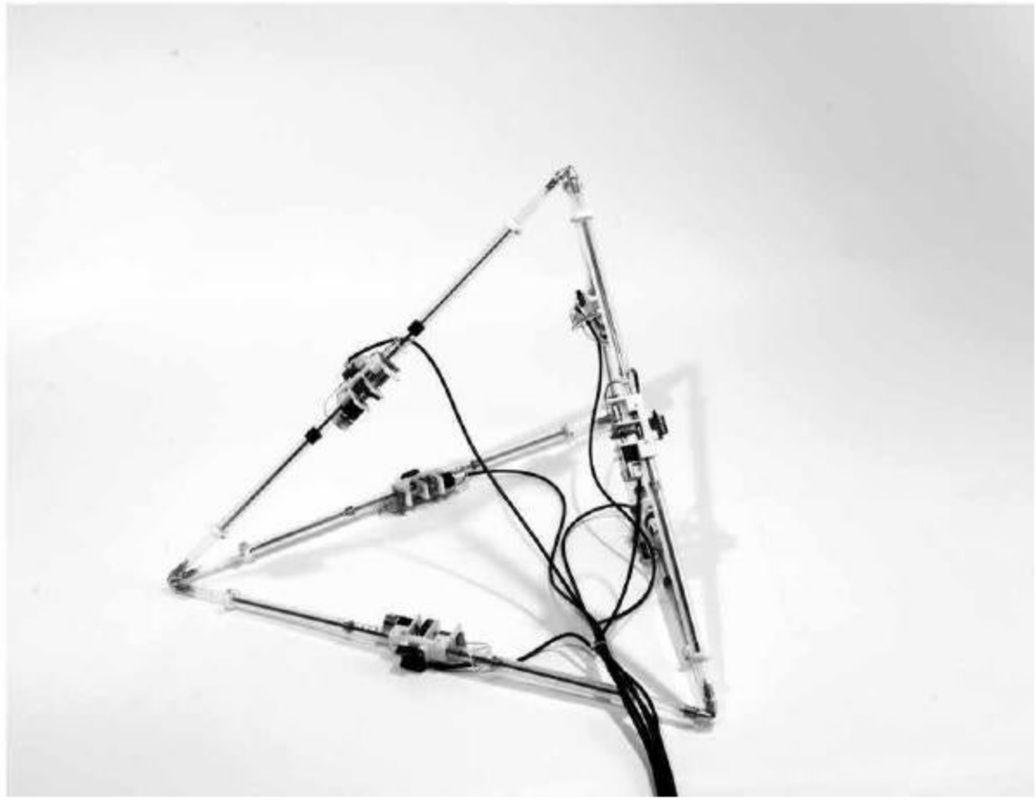


Step Cycle for a Tetrahedron









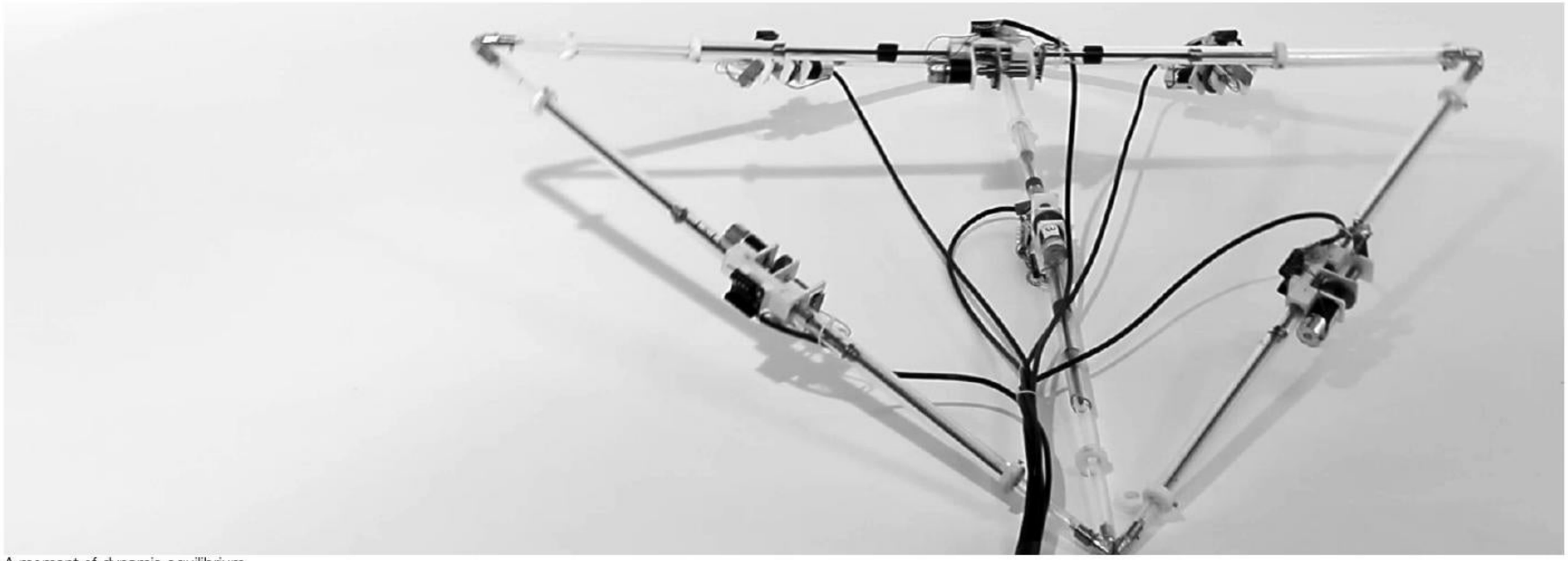
Duration: 12minutes

Vcc: 17.5V
Vnominal: 12V

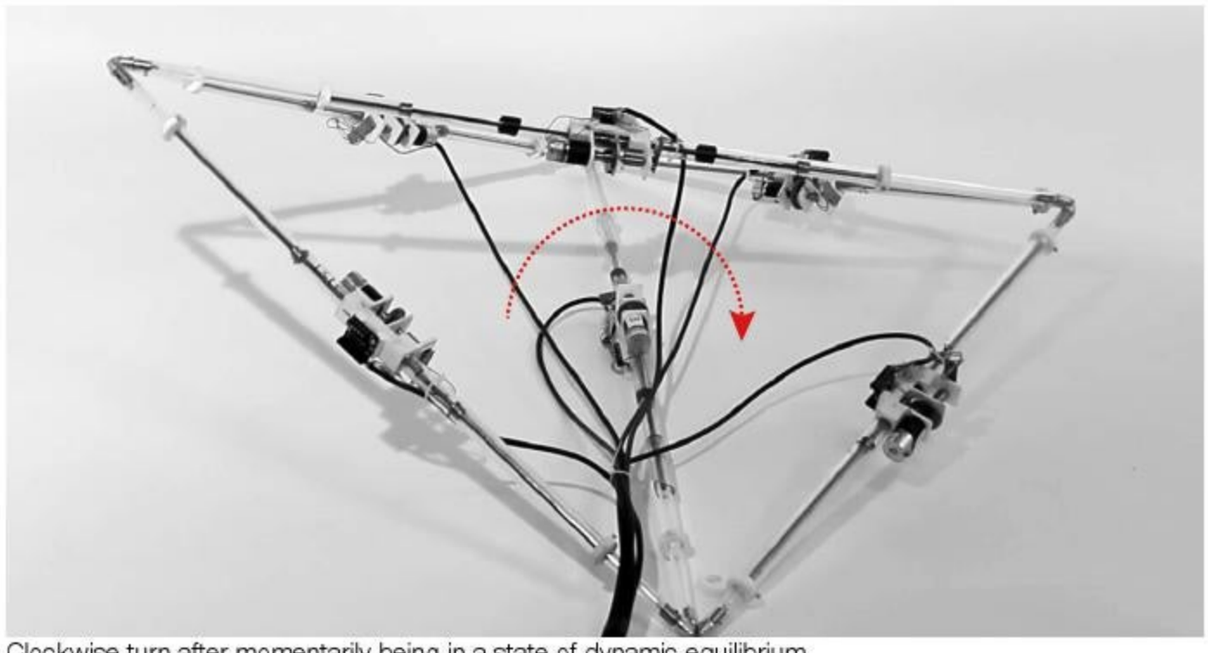
Isupplied: 200mA
Inominal: 50mA

Iinital: 1200mA

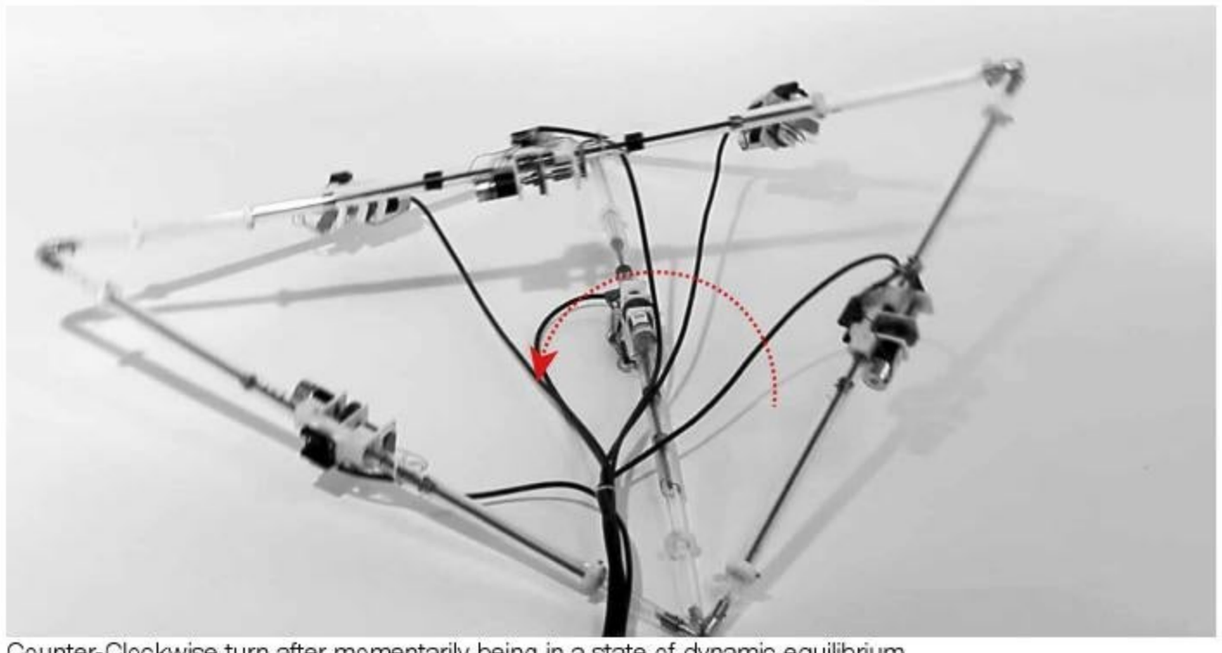
Dynamic Equilibrium



A moment of dynamic equilibrium



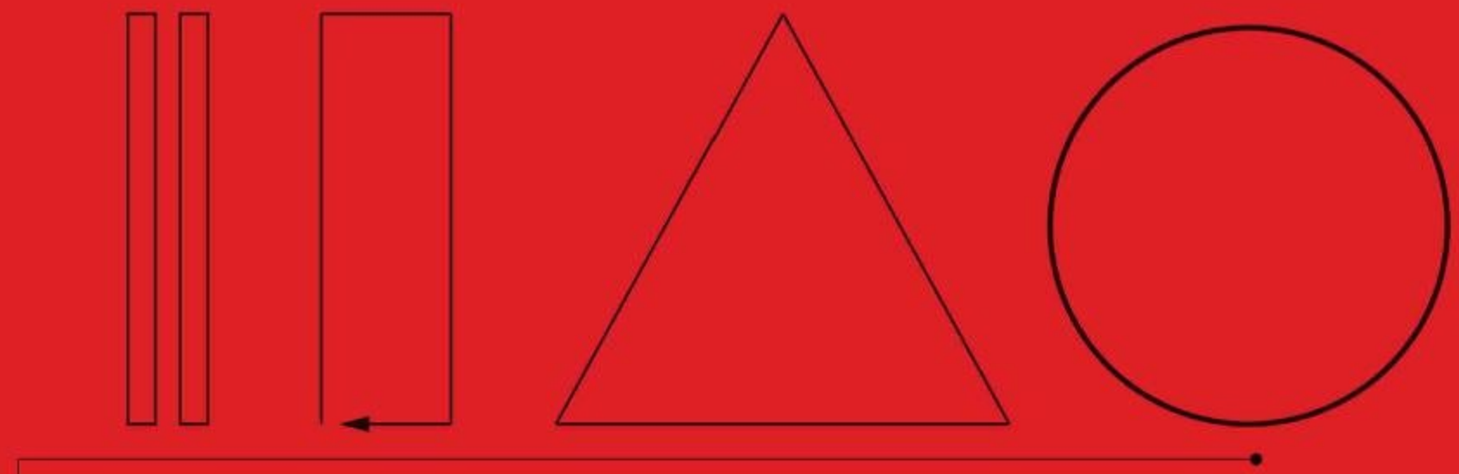
Clockwise turn after momentarily being in a state of dynamic equilibrium



Counter-Clockwise turn after momentarily being in a state of dynamic equilibrium

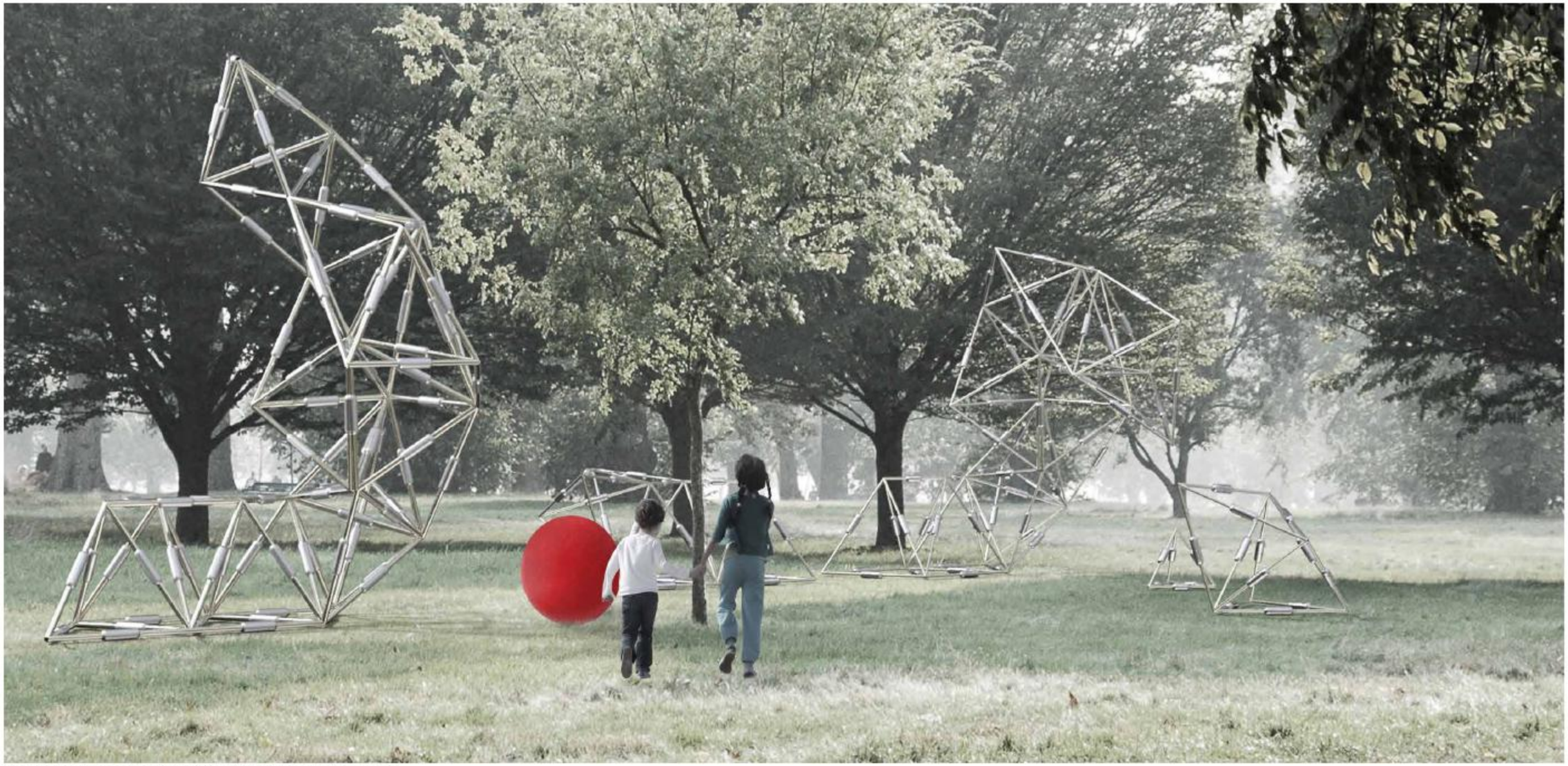
Temporal Geometries

Overlay of Tetrahedron during step cycle



a plan

Mobile Reconfigurable Polyhedra [MORPHs]

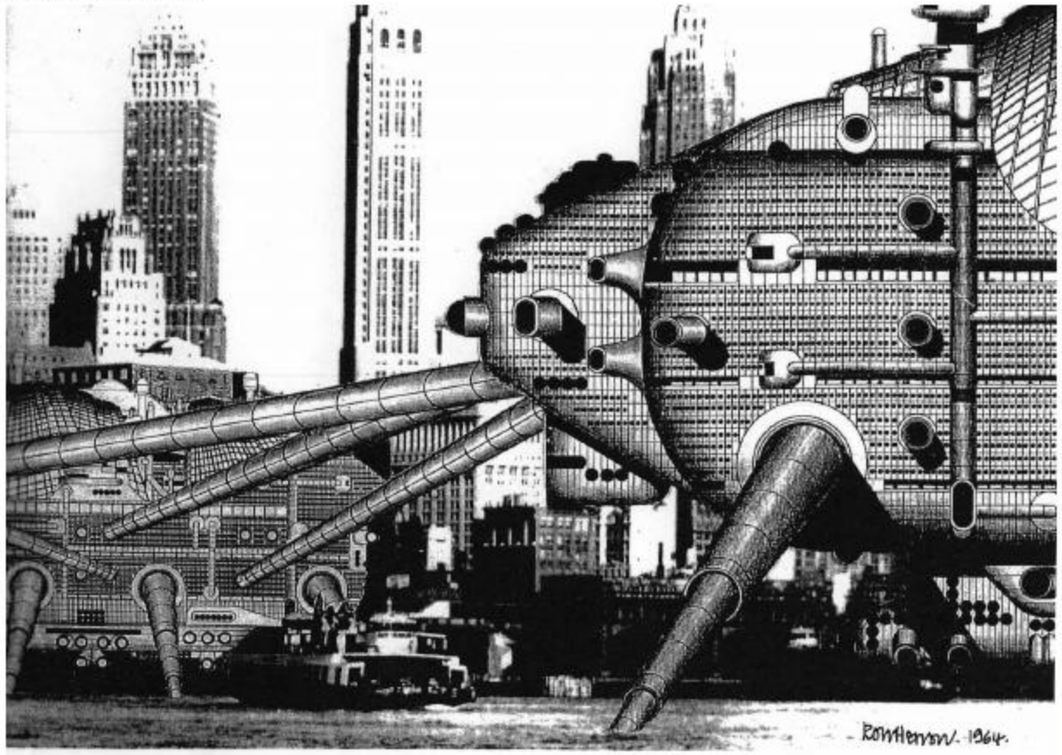


Photomontage of performative structures, seeking light

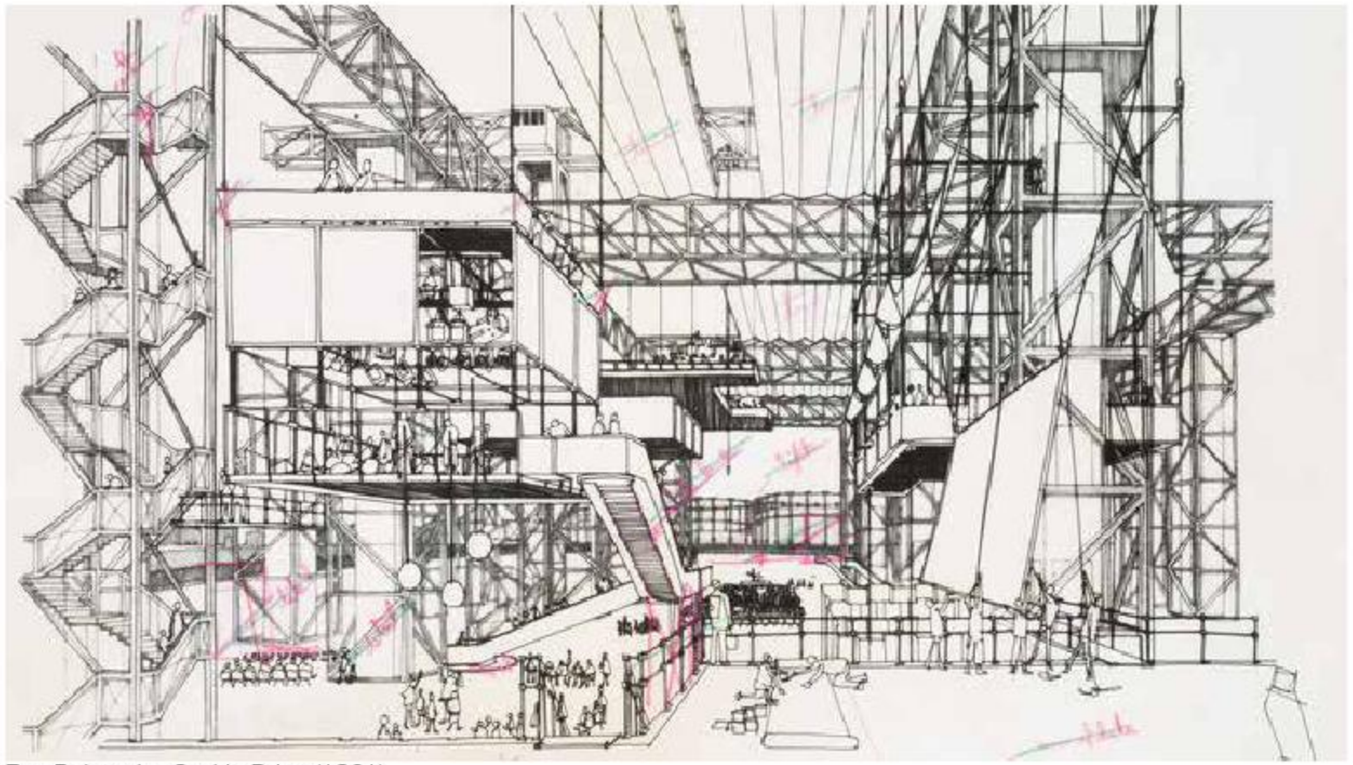
Mobile Reconfiguration

Megastructures of the 1960's: Inspiration from the Old A.I.

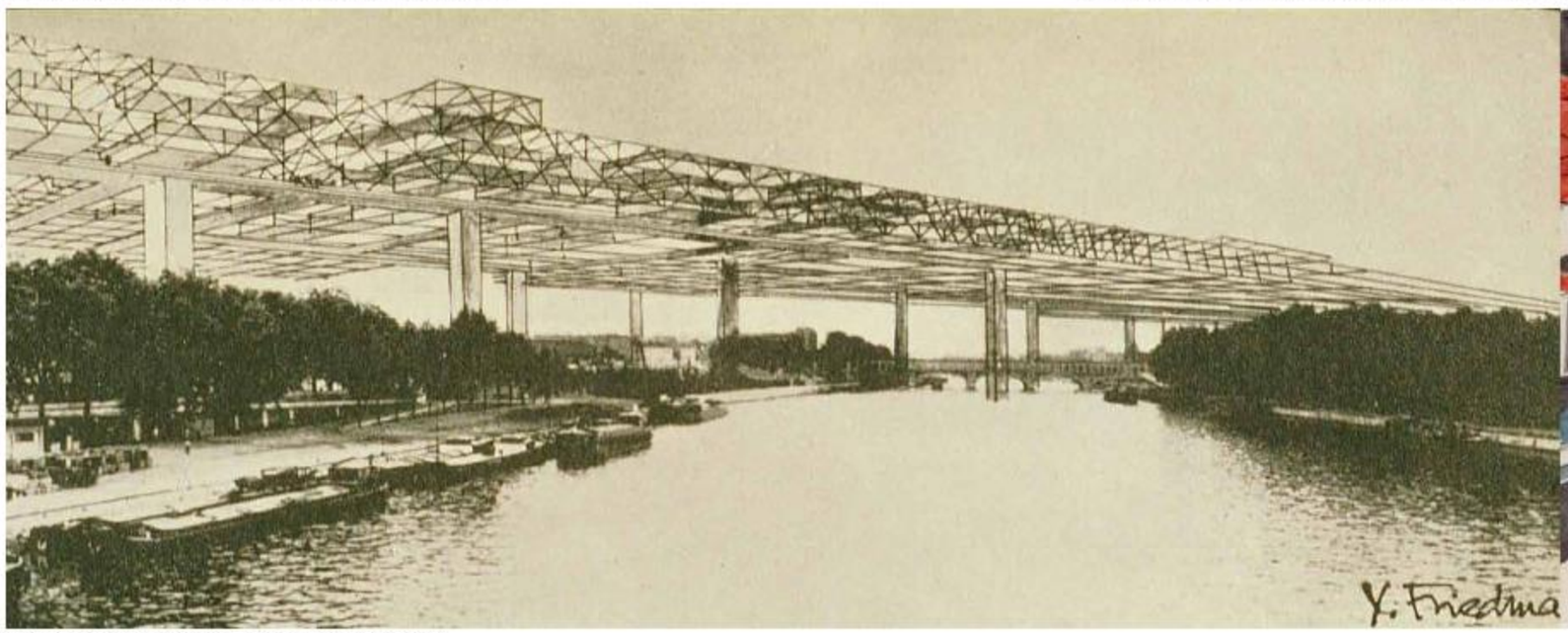
Reference Works

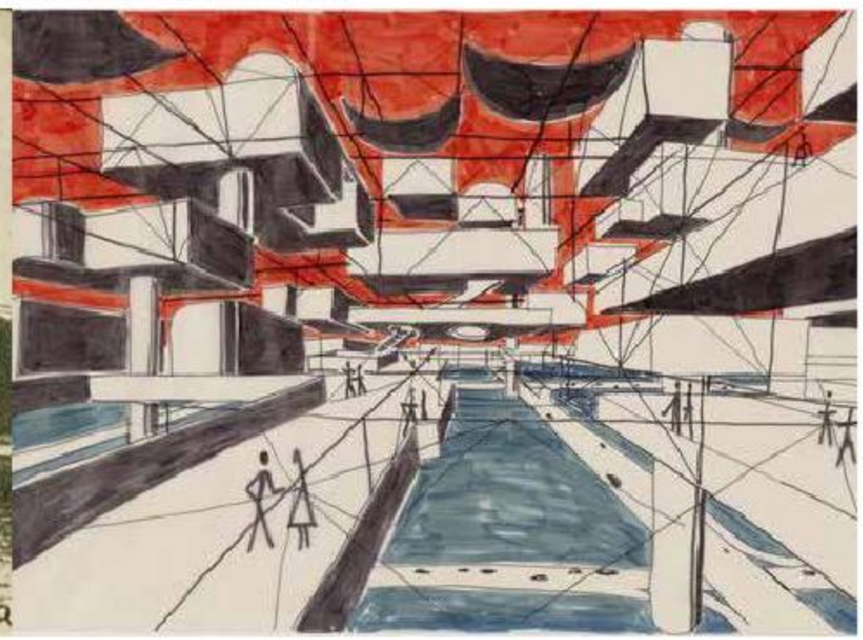


Walking City in New York by Ron Herron (1964)
source: http://archigram.westminster.ac.uk/project.php?id=60



Fun Palace by Cedric Price (1961)
source: http://www.ads.org.uk/recource_files/thumbs/thumb_4856_dr1996-0188-526-003-001.jpg





Spatial City by Yona Friedman (1958/59)
source: http://www.htvdeijsberg.nl/wp-content/uploads/2009/06/yona-friedman_spatial-city-1960.jpg

behaviour as a product of

5. observers
4. control organisation
3. communication
2. body
1. site

Victoria Park

site restraints

Aerial photograph showing main approaches and site boundaries

Playground, pond and court

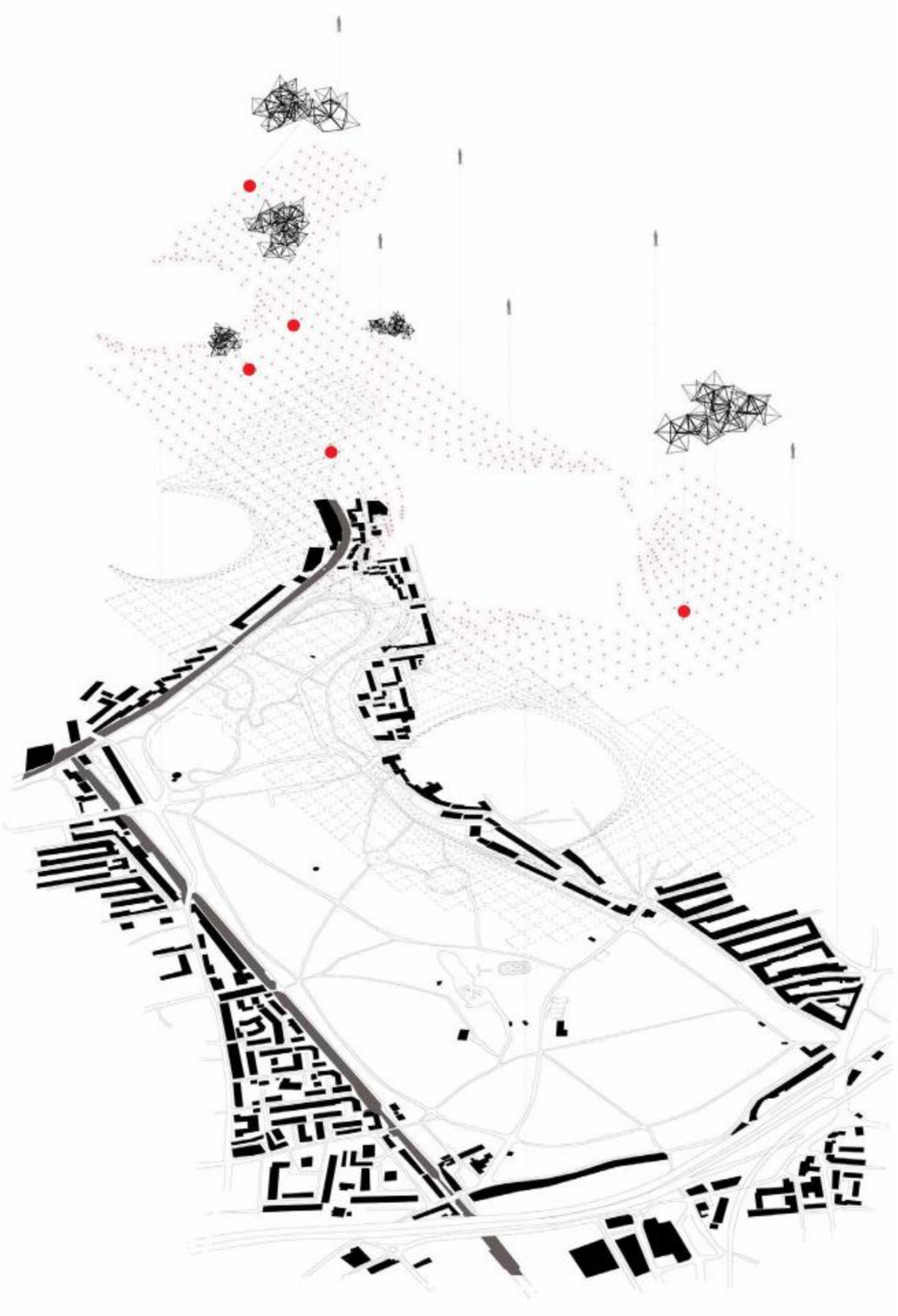
Canals flange the site along the West and South Boundaries

Victoria Park

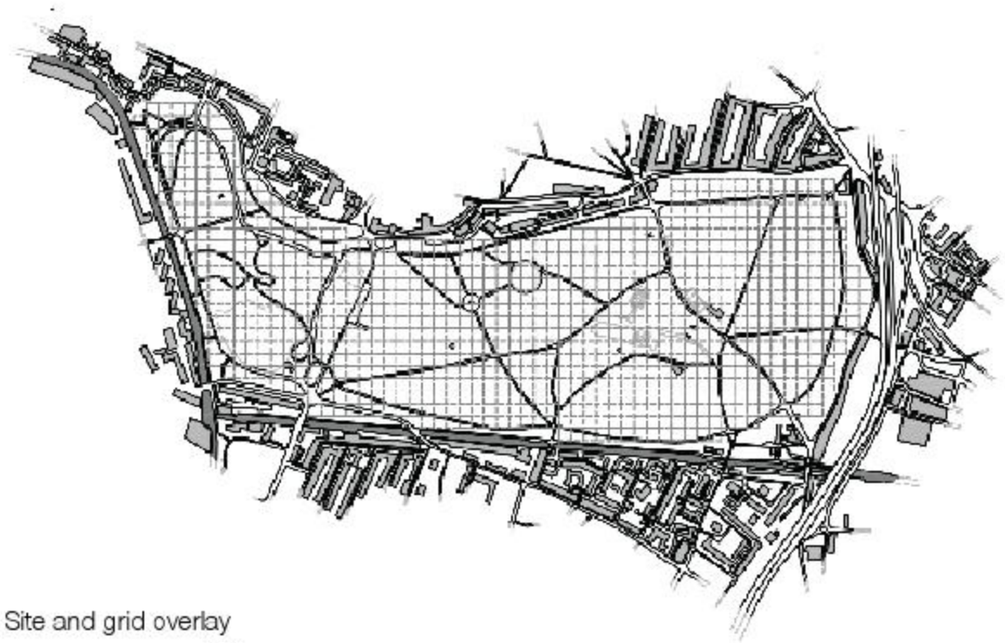
Proposed Layers

A grid of sensors provide realtime feedback which assists with path selection and goal updating

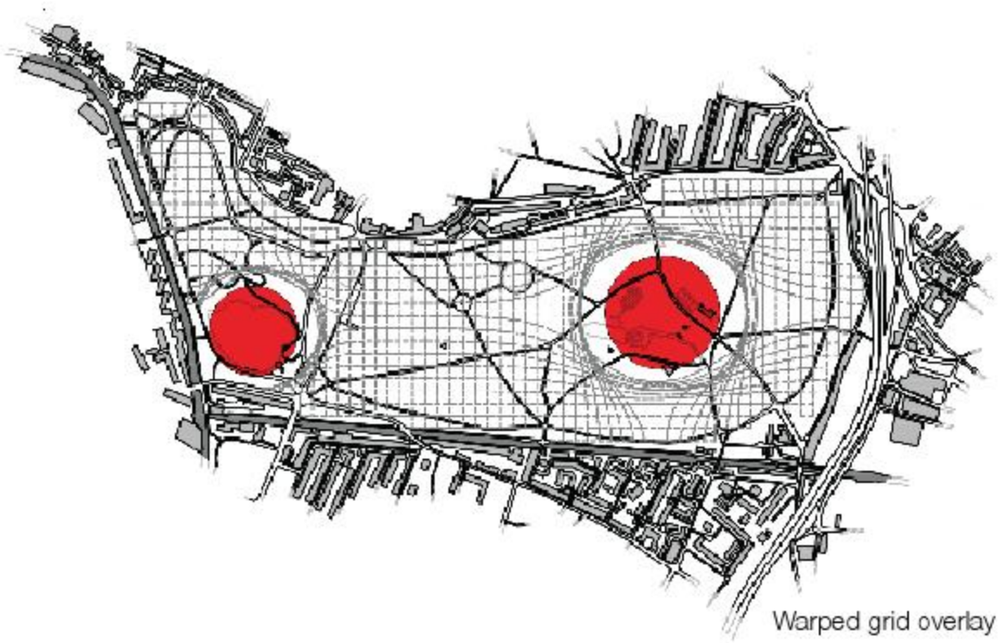
The project is to cater for the erratic nature of temporary events



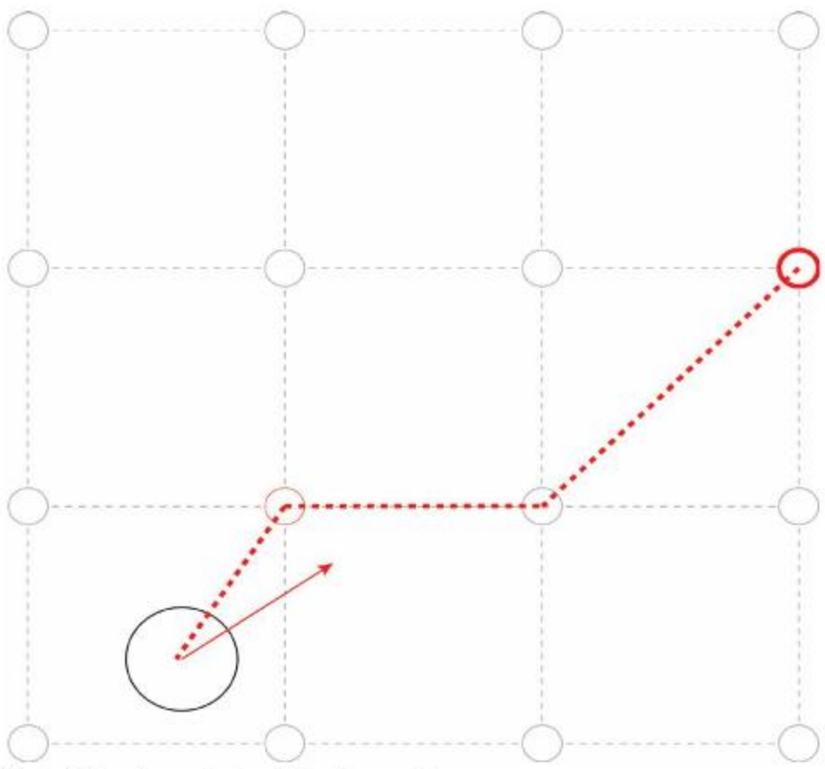
Nodal Points



Site and grid overlay

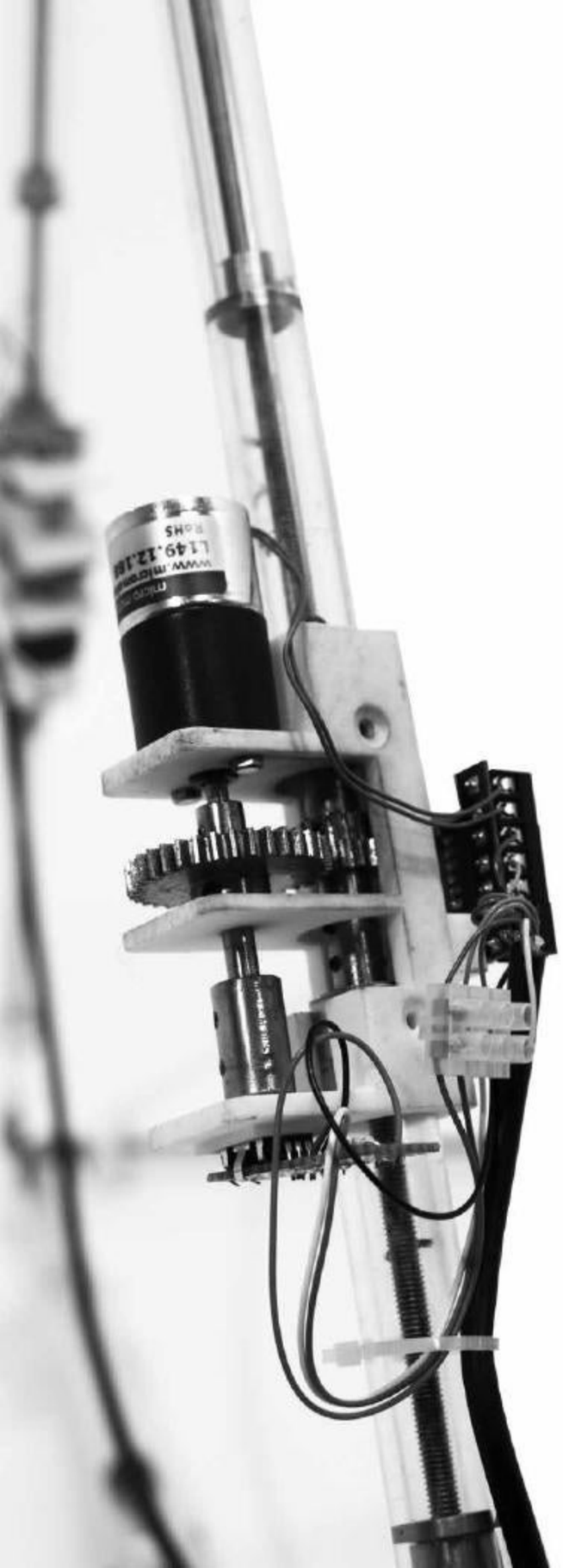


Warped grid overlay



Node Selection: shortest Euclidean distance

Sunny path finding and obstacle avoidance based on slime mould's cognitive mechanism



behaviour as a product of

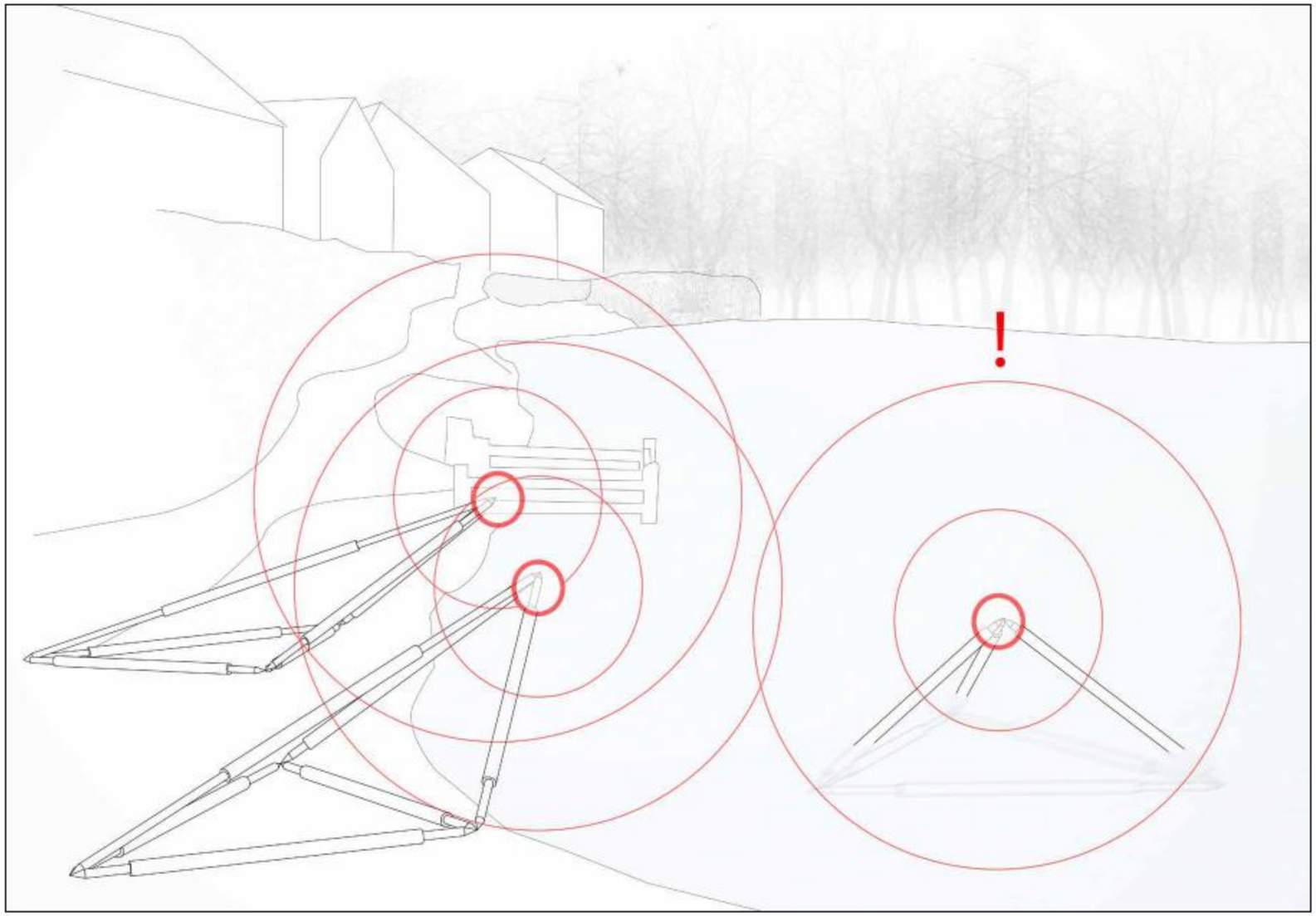
5. observers
4. control organisation
3. communication
2. body
1. site

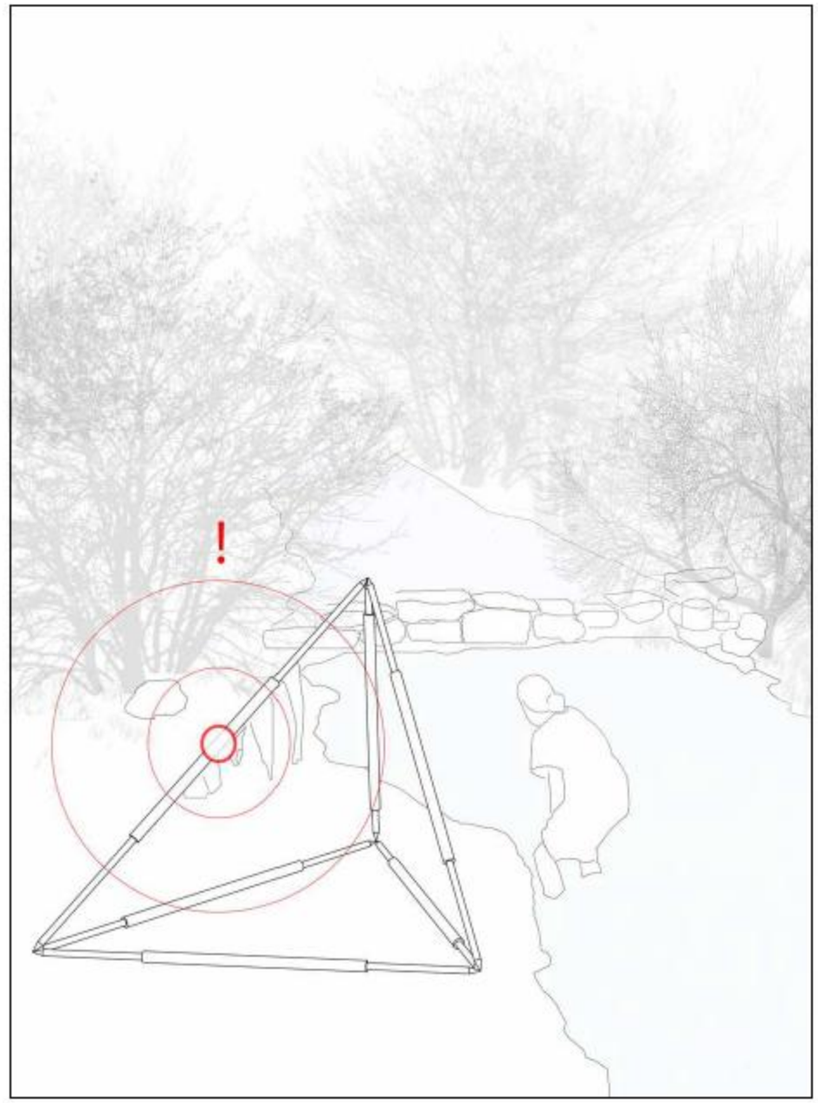
Fundamental (low-level) Behaviours

Aquaphobia

Fundamental (low-level) Behaviours

Aquaphobia





does not go into water

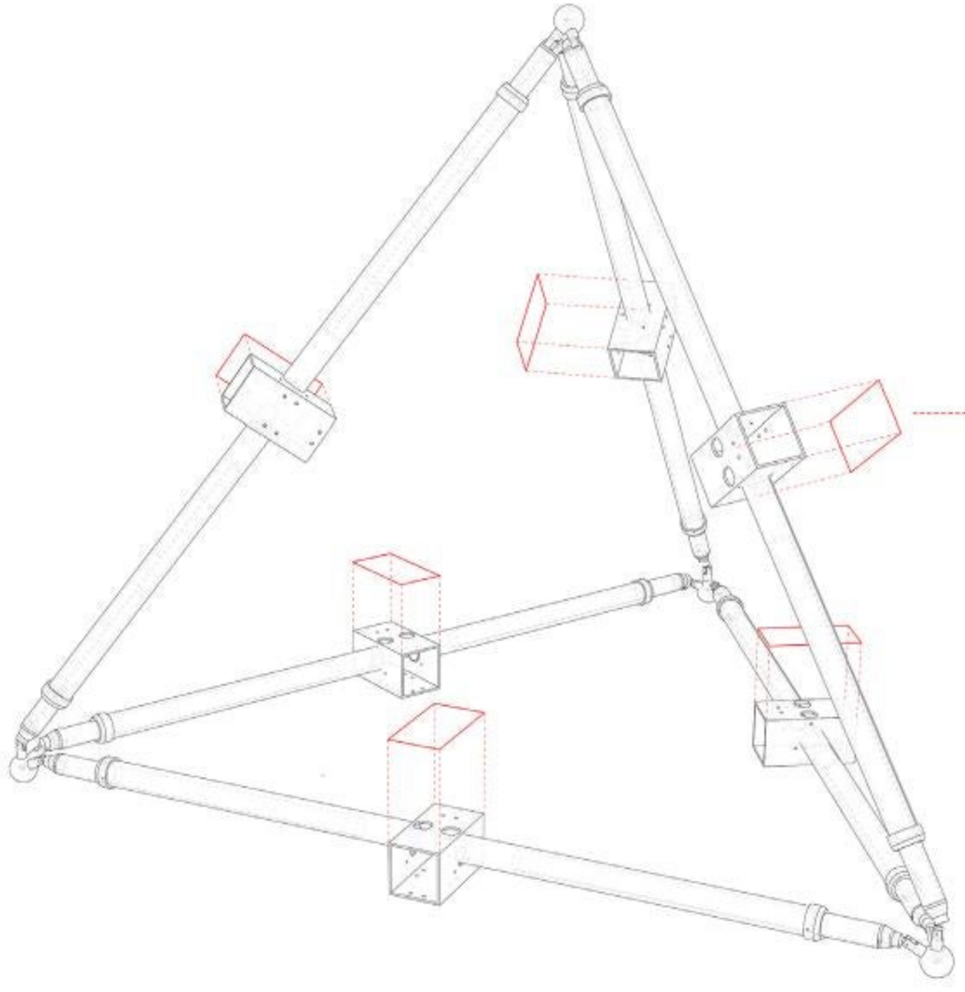
does not shape-shift in rain/ wet conditions

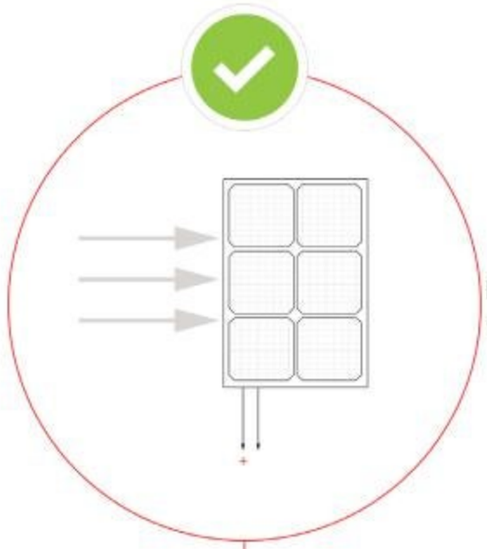
can call for help / attention

can supress other layers

Fundamental (low-level) Behaviours

Light Seeking

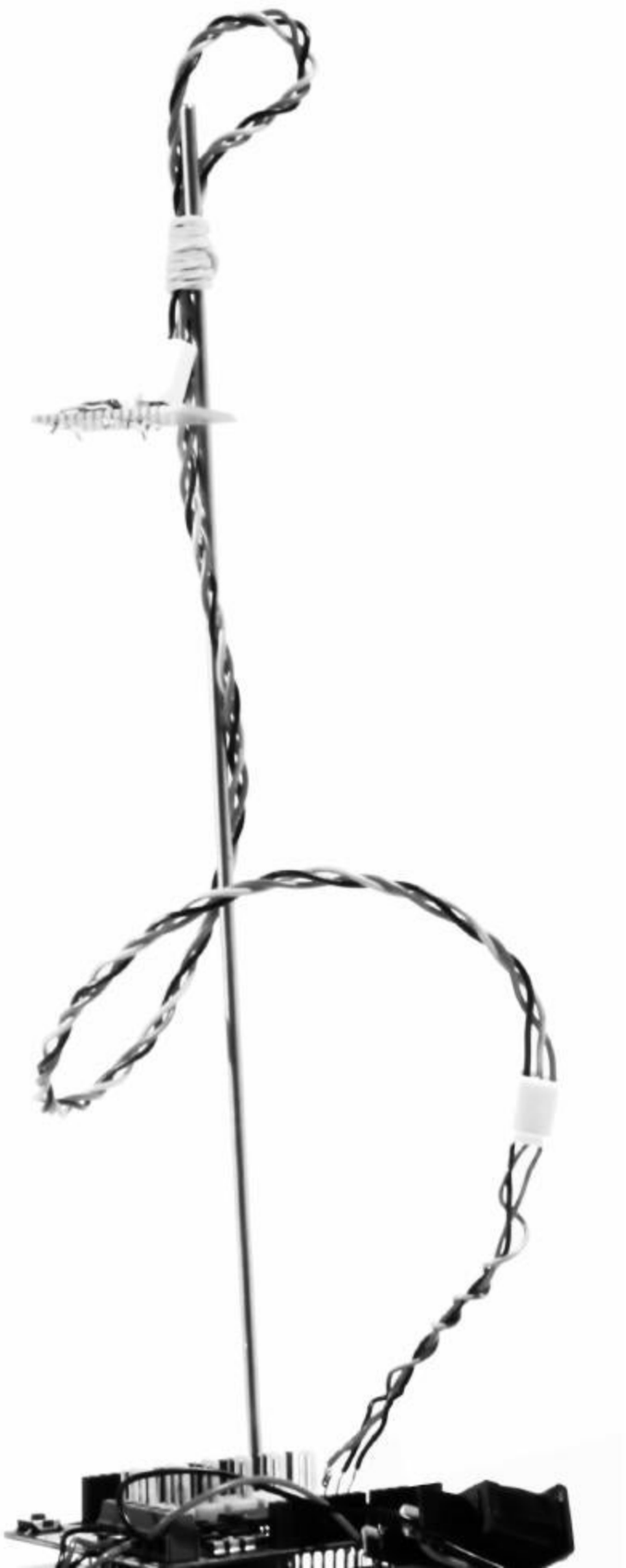




PV cells trickle charge the on-board batteries

does not go into shadows

does not travel at night time

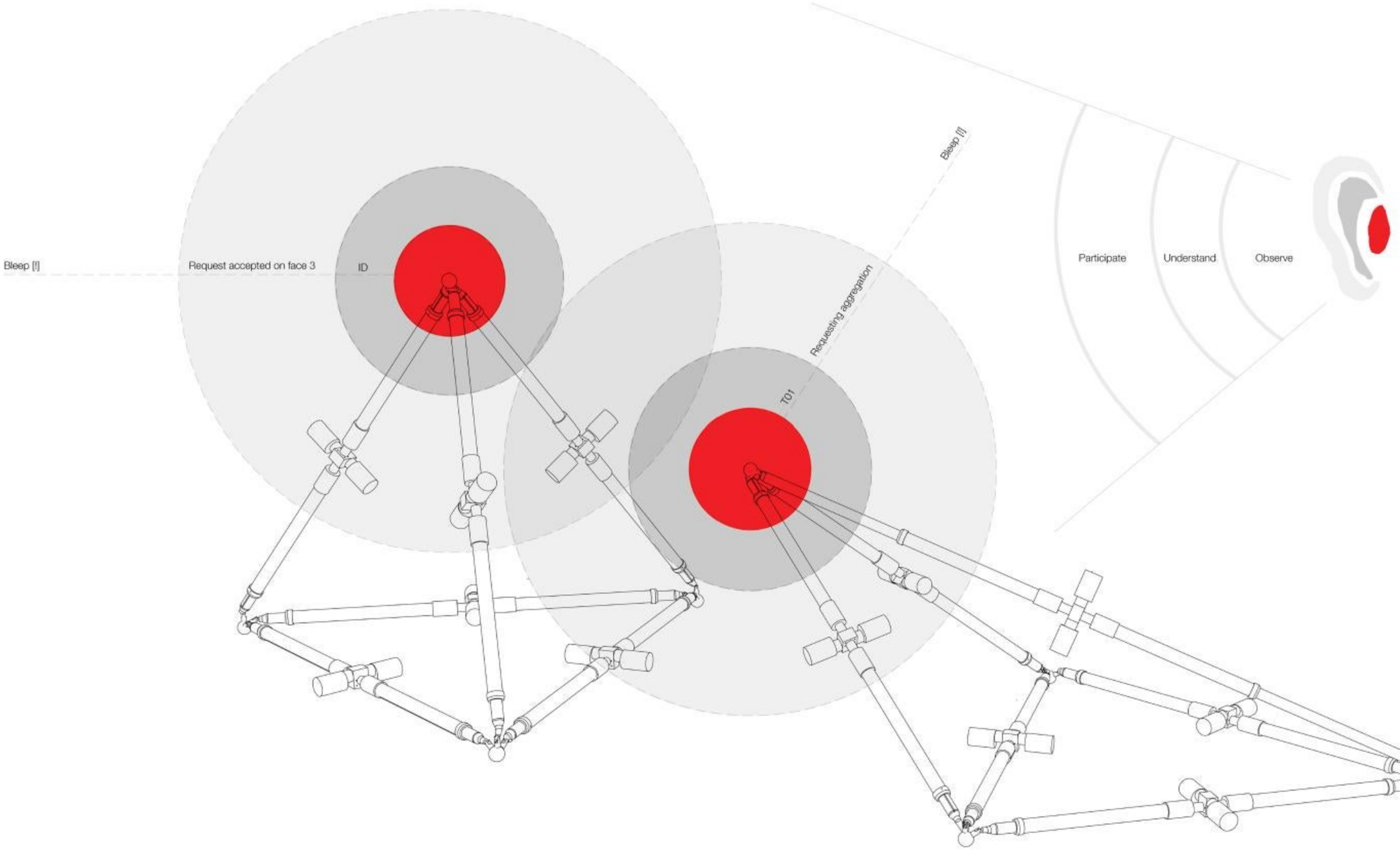


behaviour as a product of

5. observers
4. control organisation
3. communication
2. body
1. site

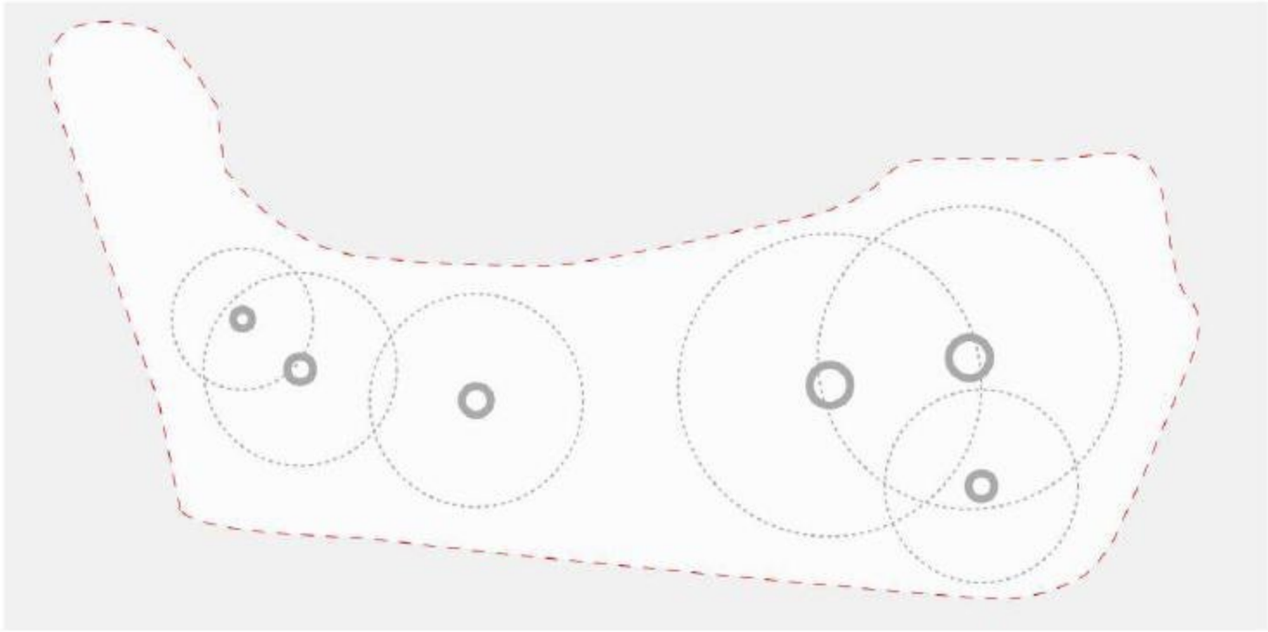
Communication

Audibility



Fundamental (low-level) Behaviours

Call for help

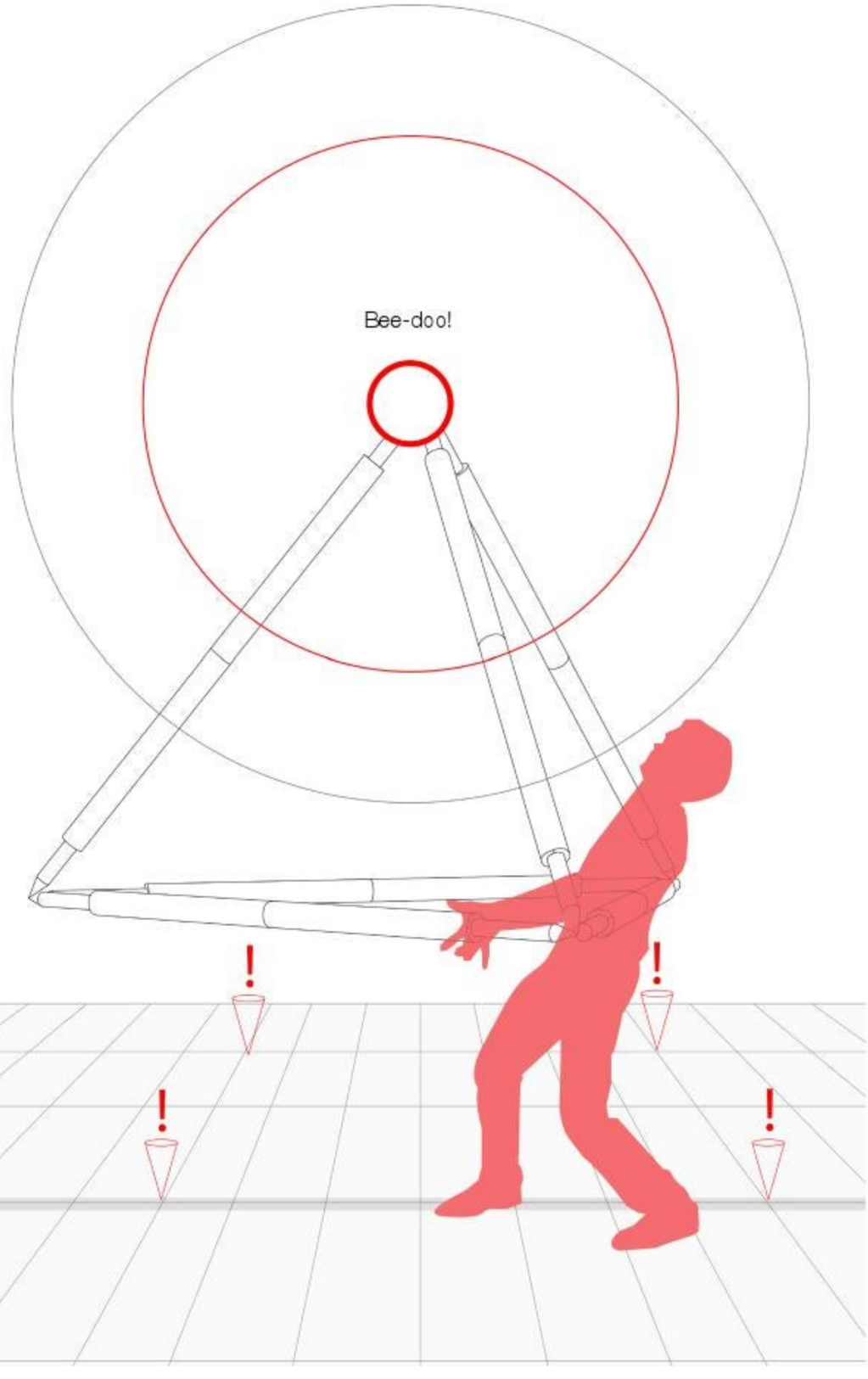


Park boundary and preferred locations

register location of last visited node

calls others for help/ alert the public when out of boundary

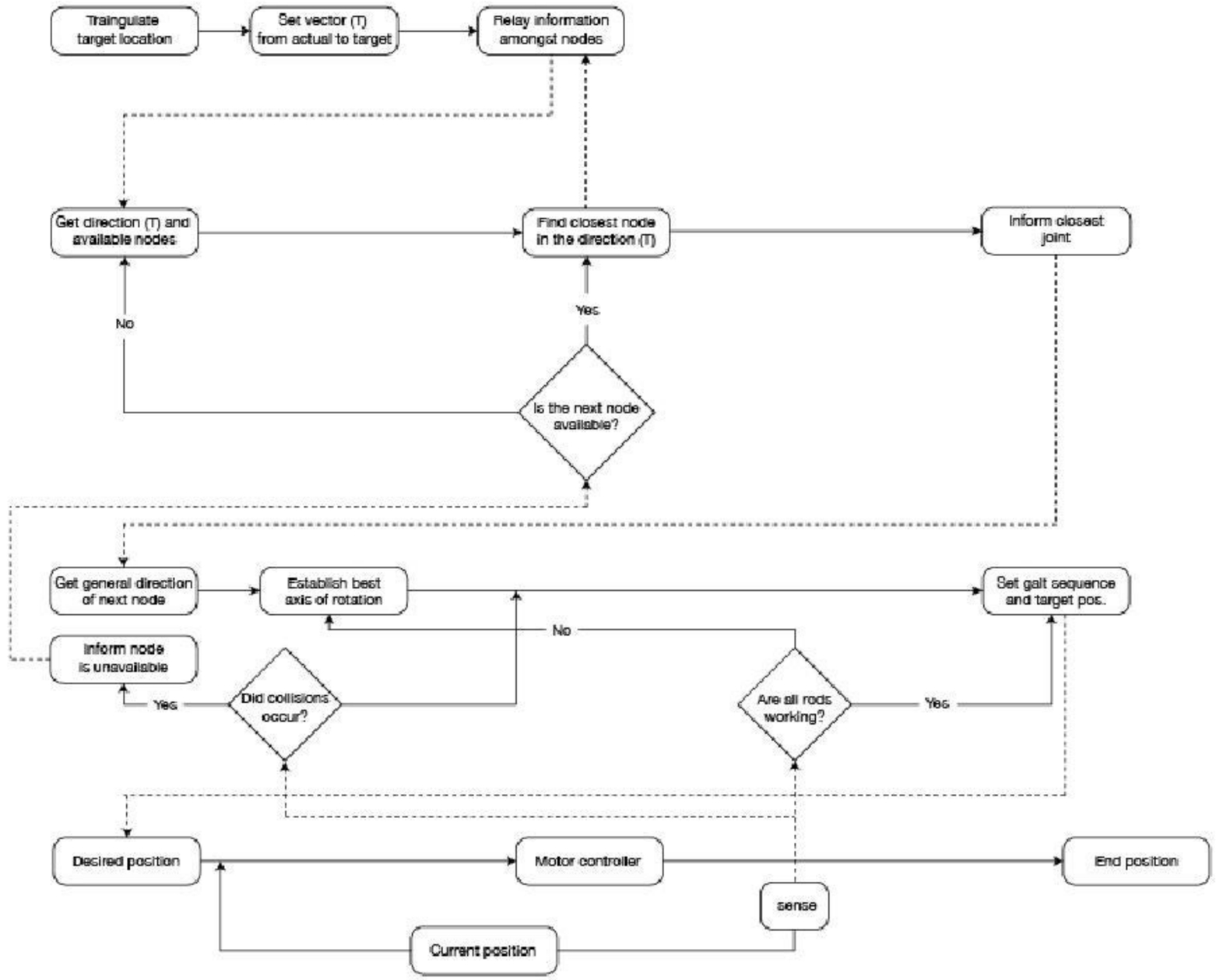
does not like areas near the park's boundary

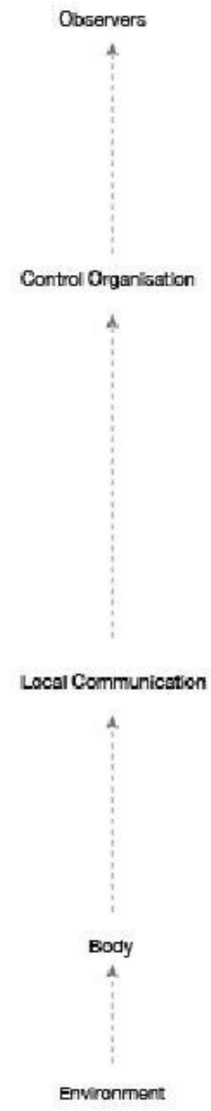


behaviour as a product of

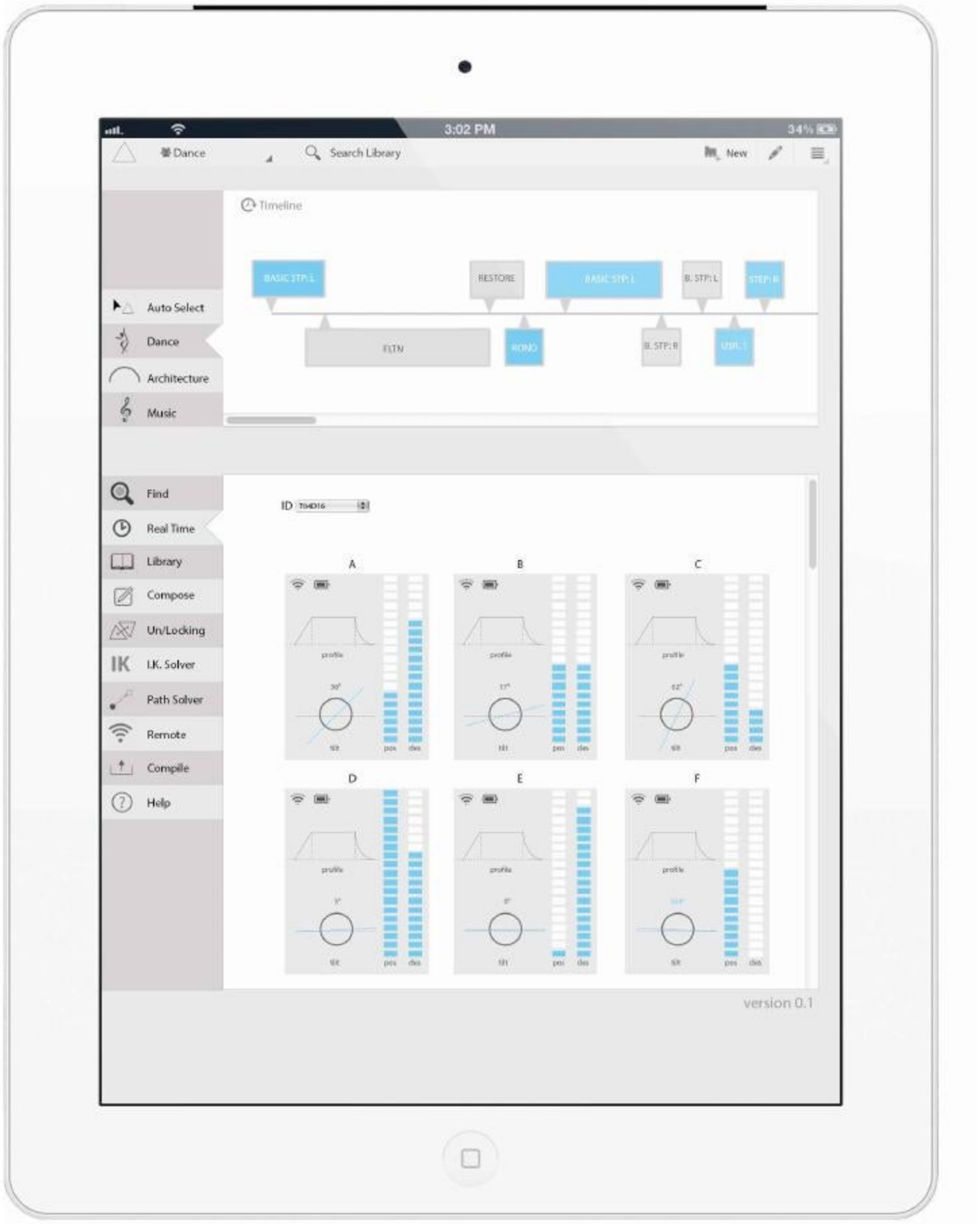
5. observers
4. control organisation
3. communication
2. body
1. site

Control Organisation





Control Interface



Choreography Timeline
Add pre-defined components eg: step right, flatten
Add user-defined components from on-line library
Select class of MORPH
Auto detect will chose the closest MORPH in the area

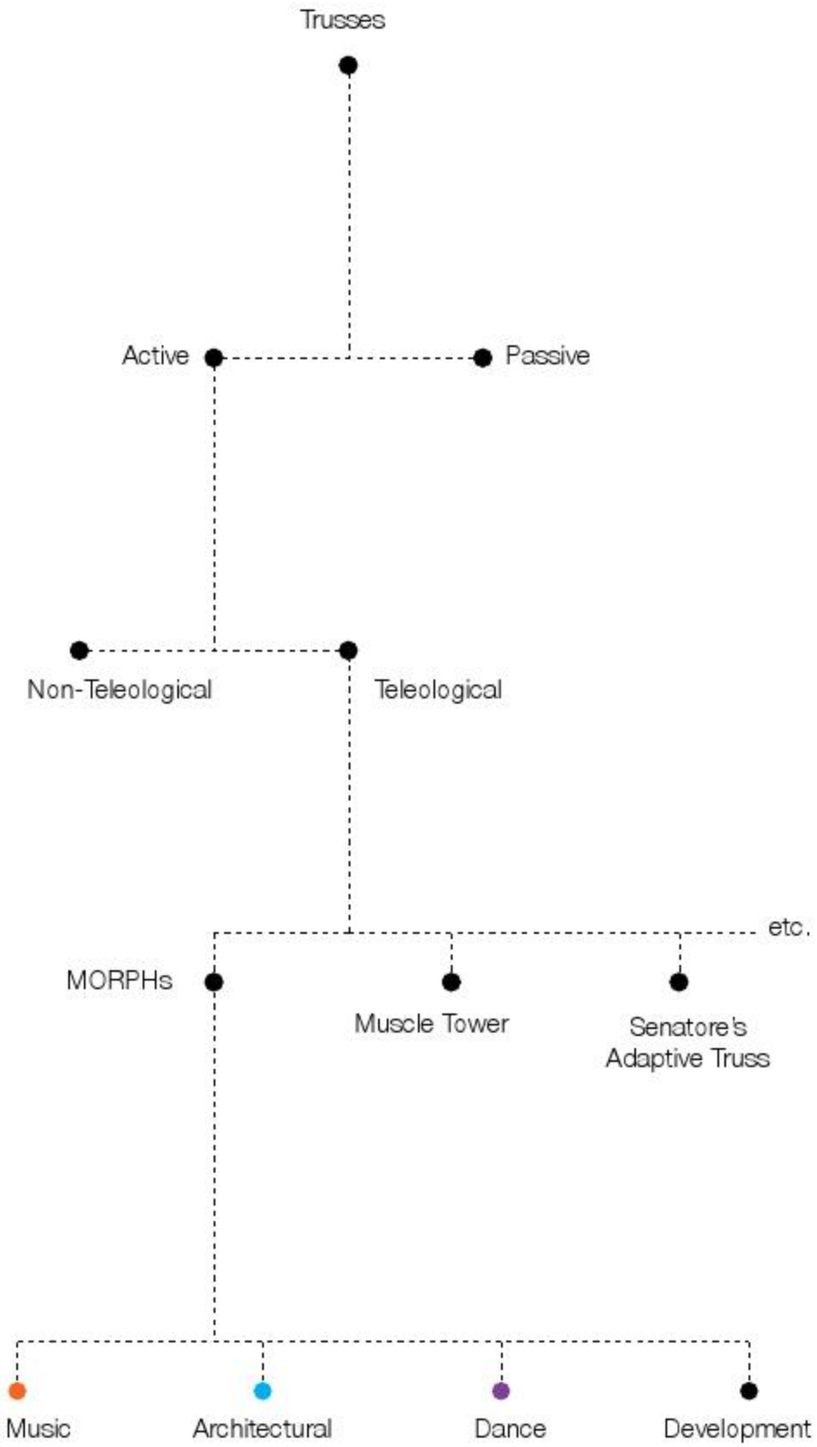
Find available MORPHs
Control units in real-time
Search on-line library of other users routines
Compose new routines
Lock or unlock quick release mechanism
Compute inverse kinematics
Solve paths using nodal network and direct units along a path
Allow remote control of units

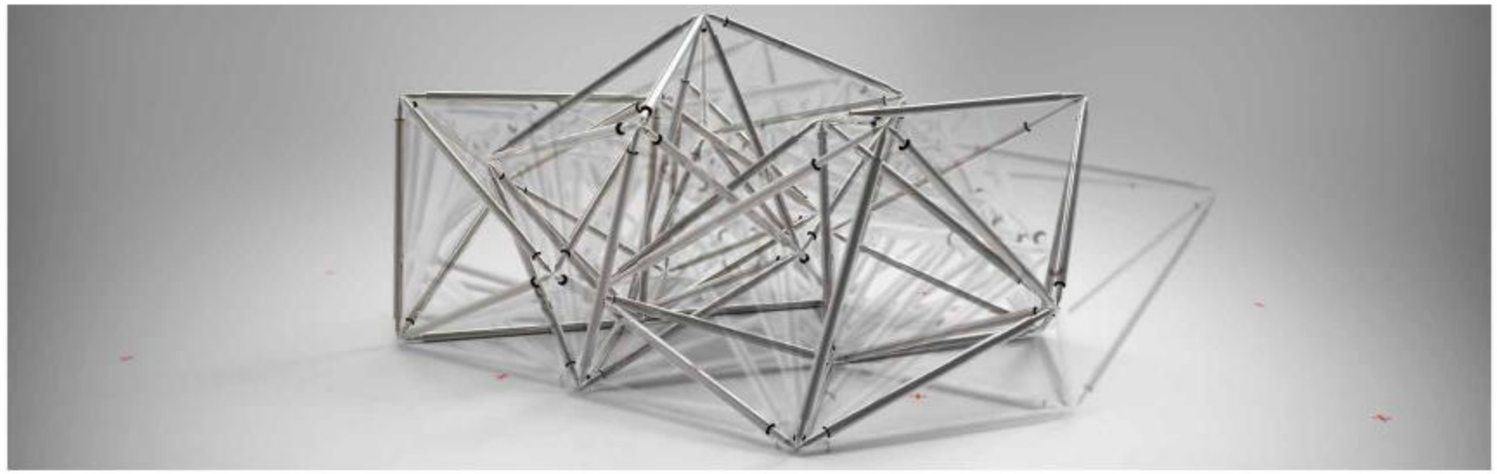
behaviour as a product of

5. observers
4. control organisation
3. communication
2. body
1. site

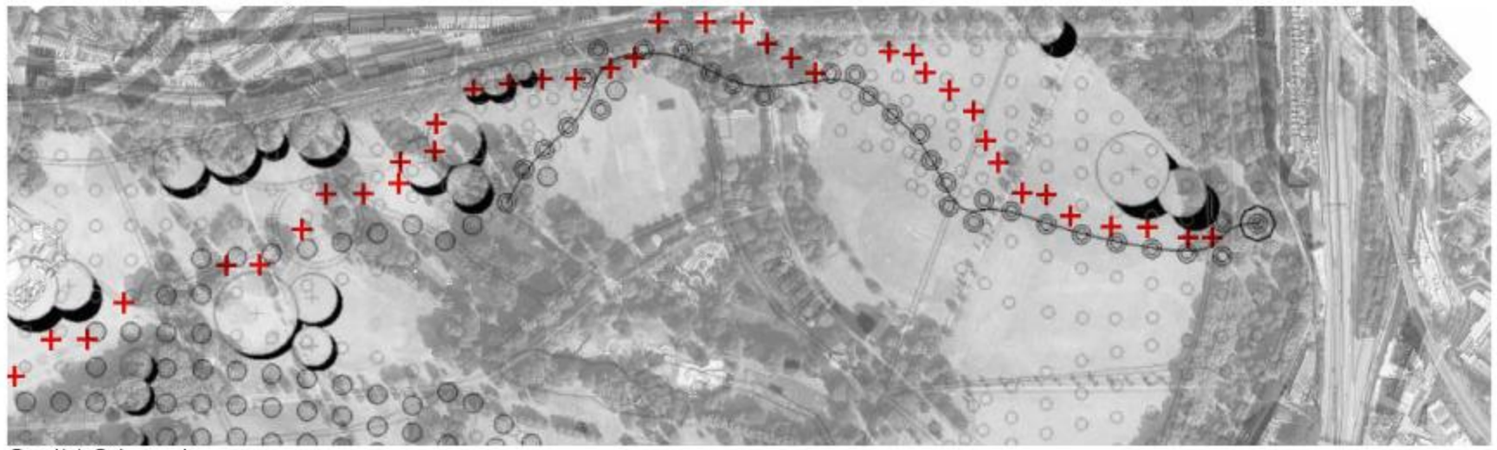
MORPHs: Genus, Species and Subsp.

a definition

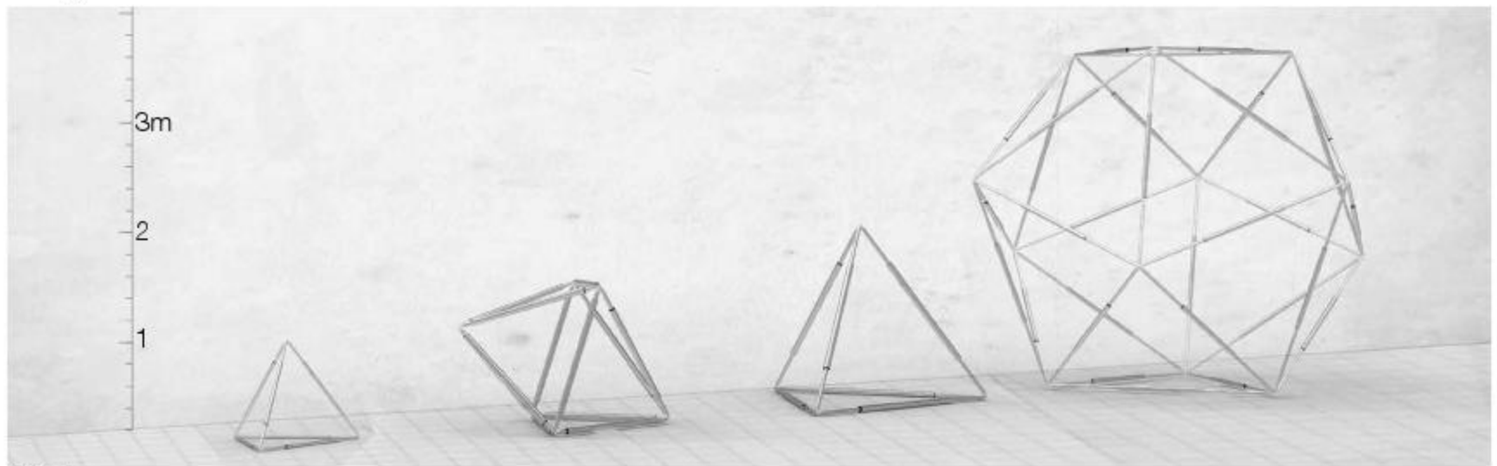




Active



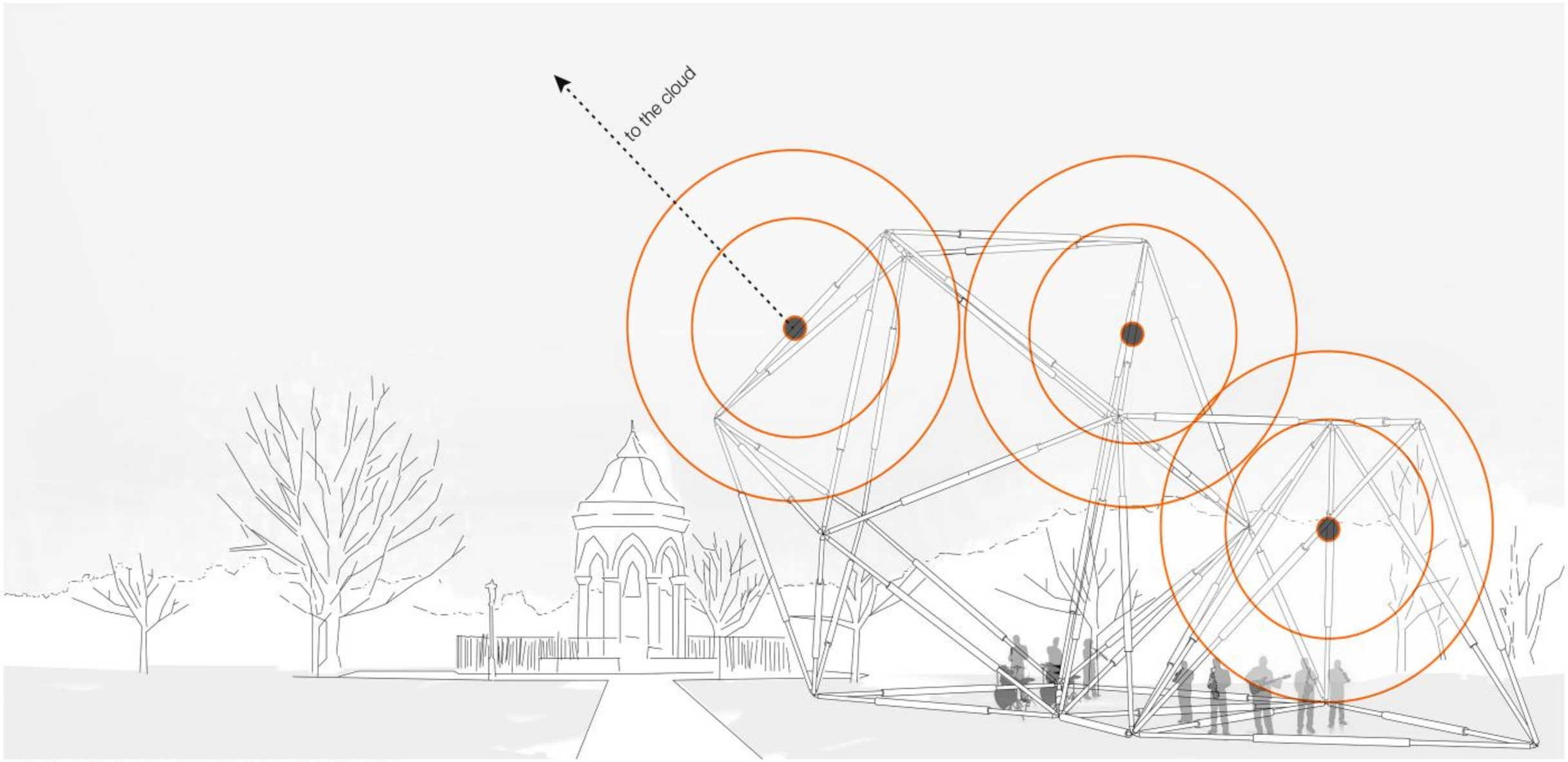
Goal(s) Oriented



Variety

Orange

Music enabled



Drawing of aggregated Morph for musical performance

Key features:

Microphones for music recording and streaming

Wi-fi enabled for live streaming

Reconfigurable nuclei

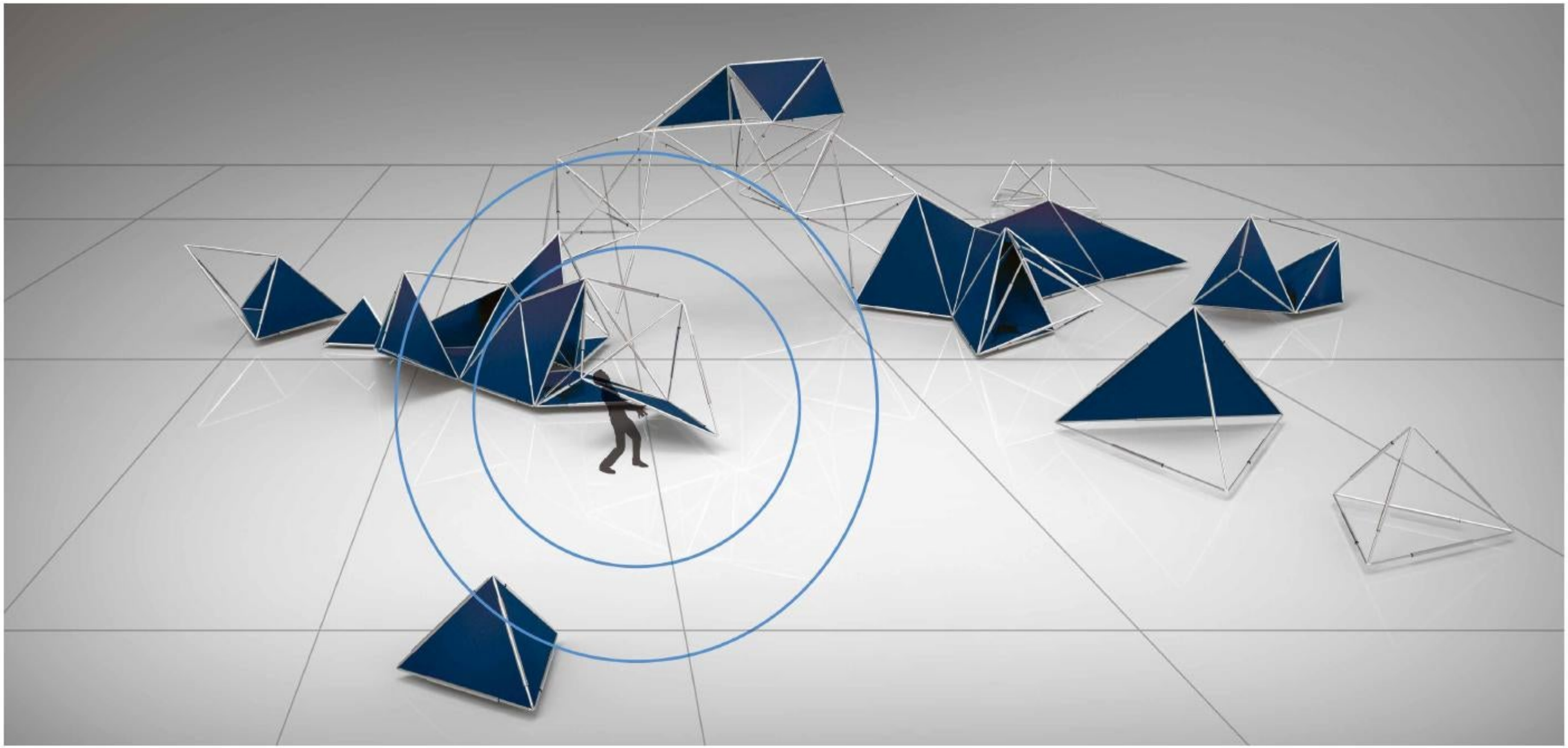
Medium speed extension

Quick release interlocking mechanism

Plug and play

Blue

Sculpture and Architecture



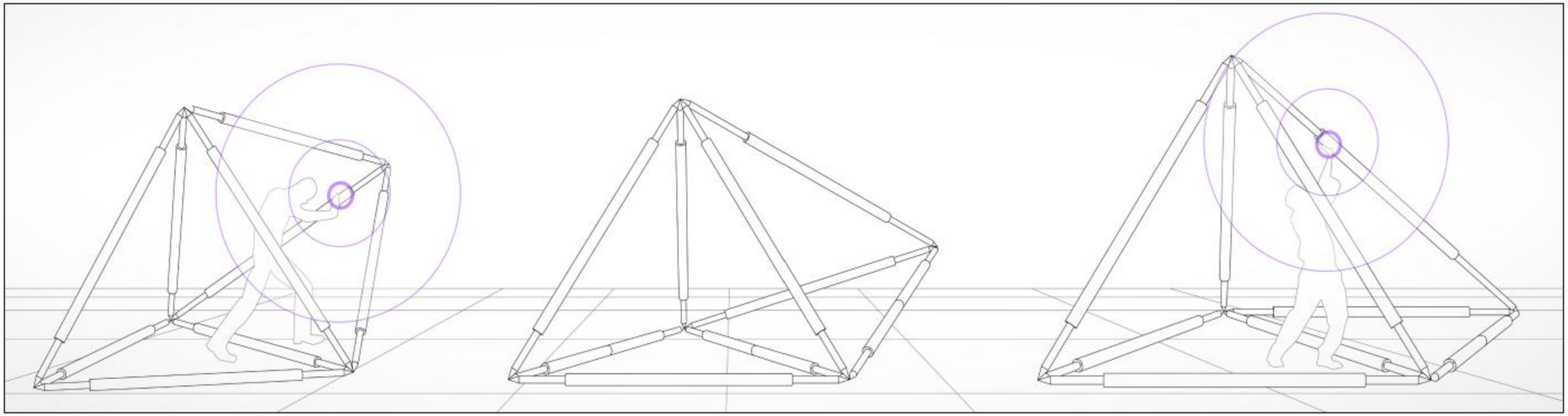
Drawing of aggregated Morph for architectural assembly - aggregation based on random selection of faces

Key features:

Structural components	Medium range communication	Slow speed extension rate
Reprogrammble behaviour	Light weight	
Range of default behaviours (shading, walking)	Slow speed extension	

Purple

Dance and Theatre



Dancer teaching a routine to a purple nucleus

Key features:

Prediction and learning

Immediate response to push/pull

Learn and play back geometries [choreography]

Fast extension rate

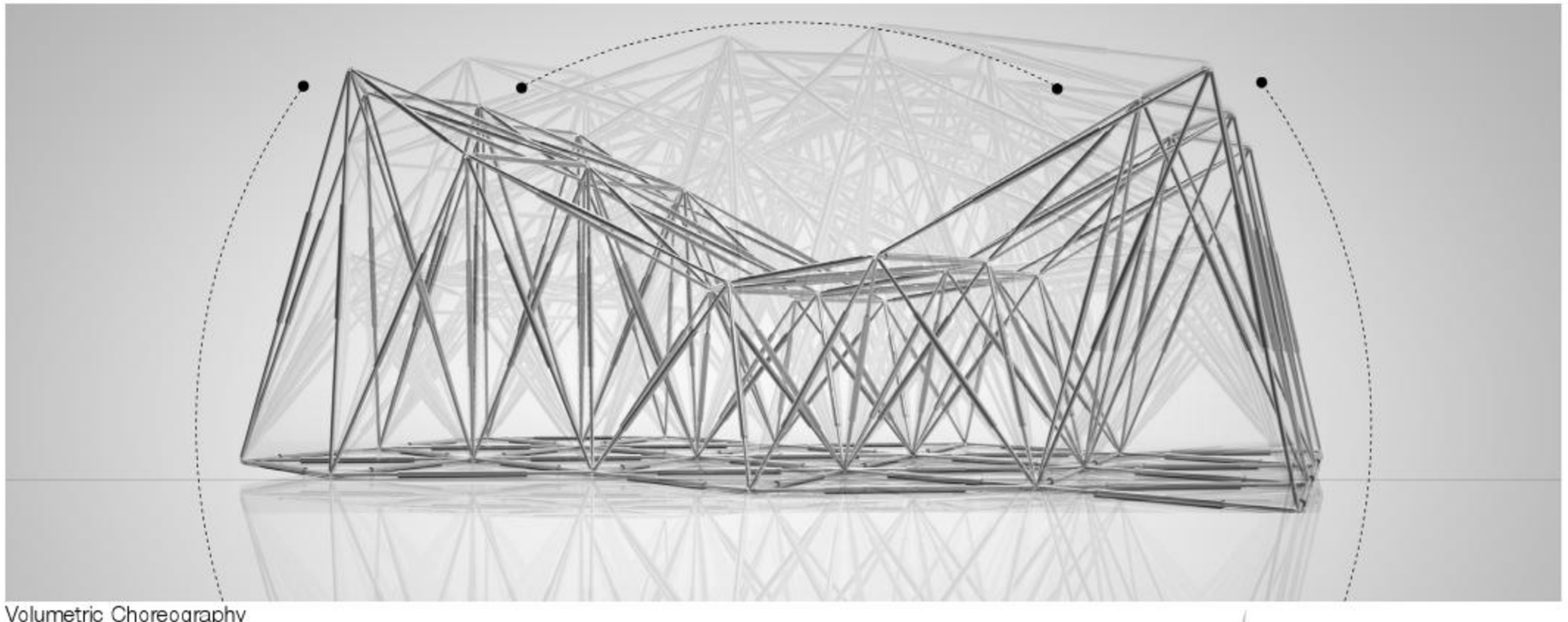
Quick release interlocking mechanism

Short range communication

Choreography can be applied to multiple units simultaneously

Collective memory

Embedded lights



Volumetric Choreography

Black

Development/ Educational

Key features:

Fully Reprogramable

Variable speeds

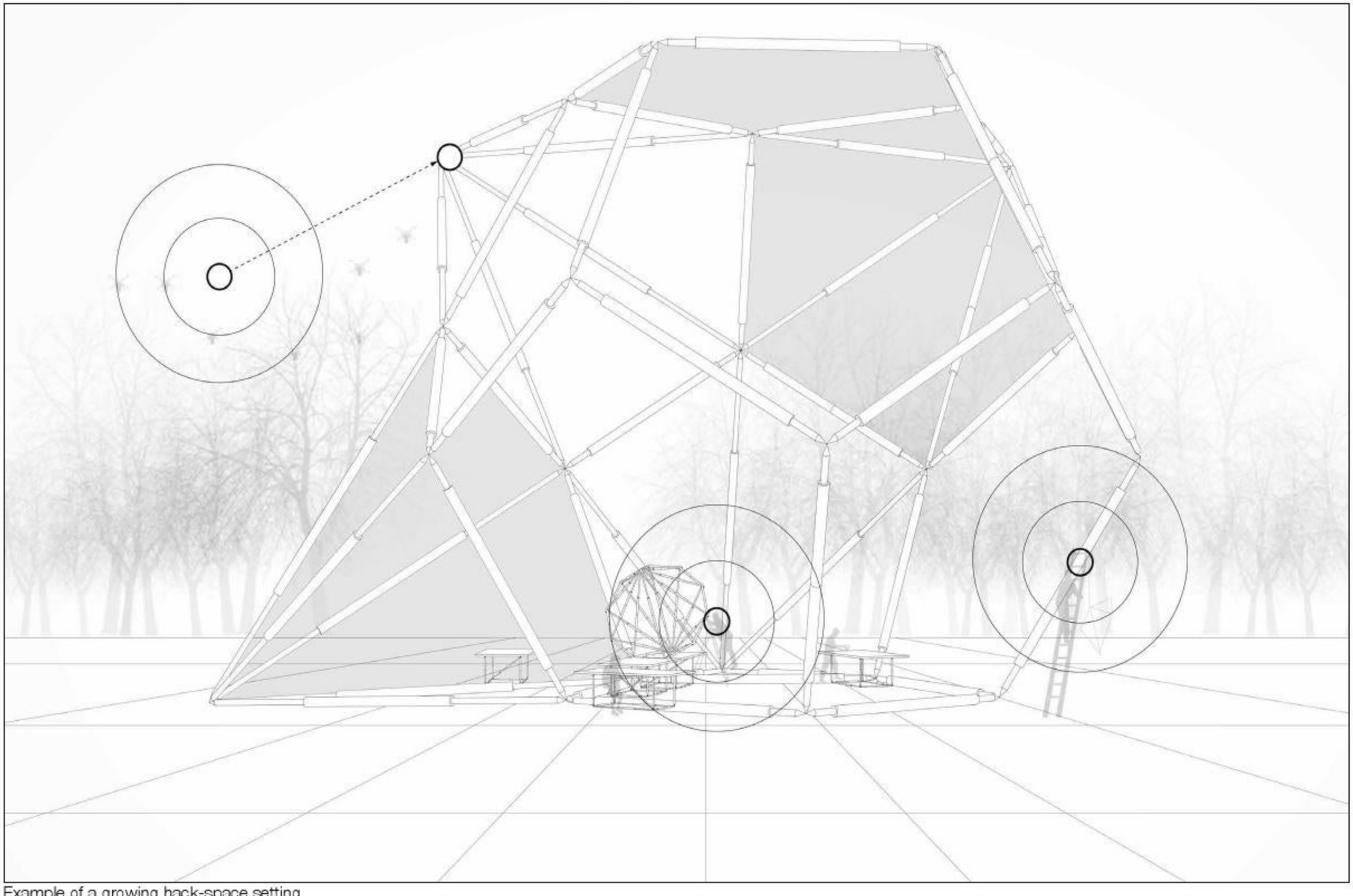
Need to be manned when operational

Variable scales

Quick release interlocking mechanism

Accepts “shields”

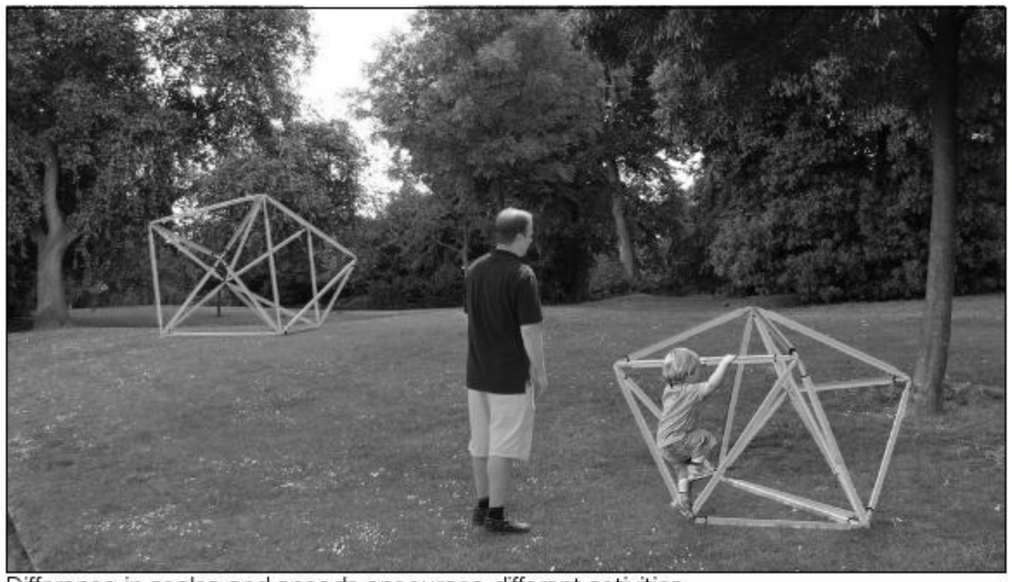
Intelligent joints



Example of a growing hack-space setting

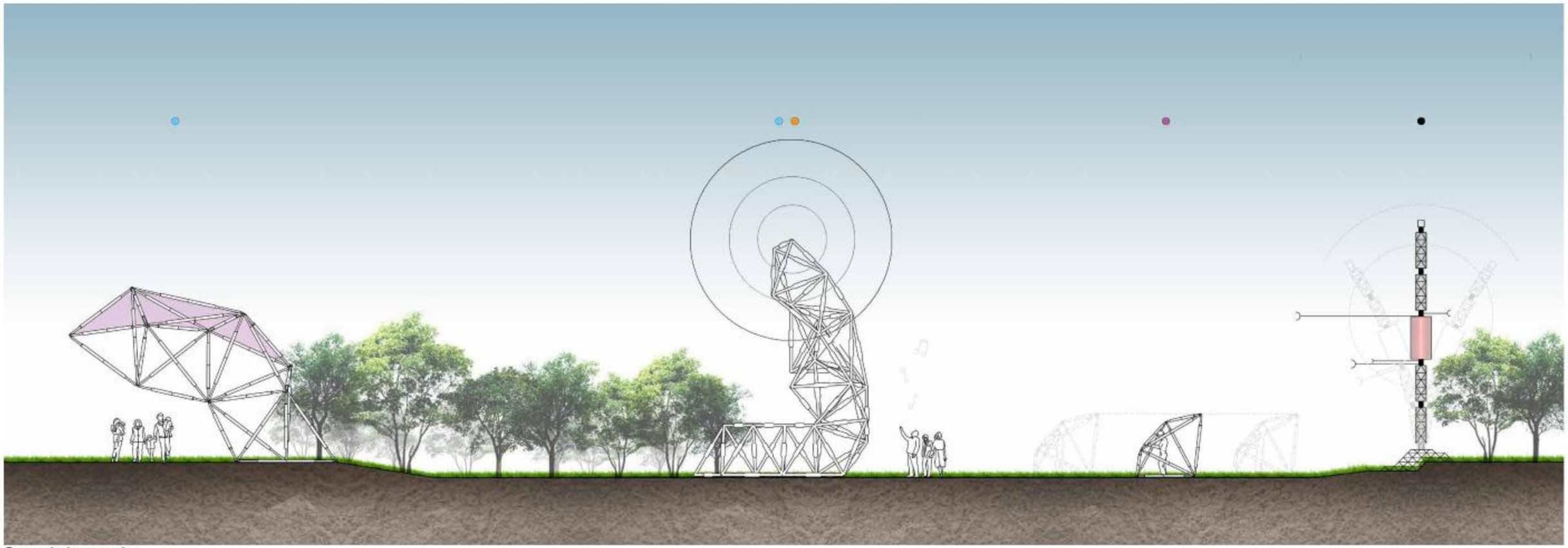
Performative Geometries

Multiple interactions



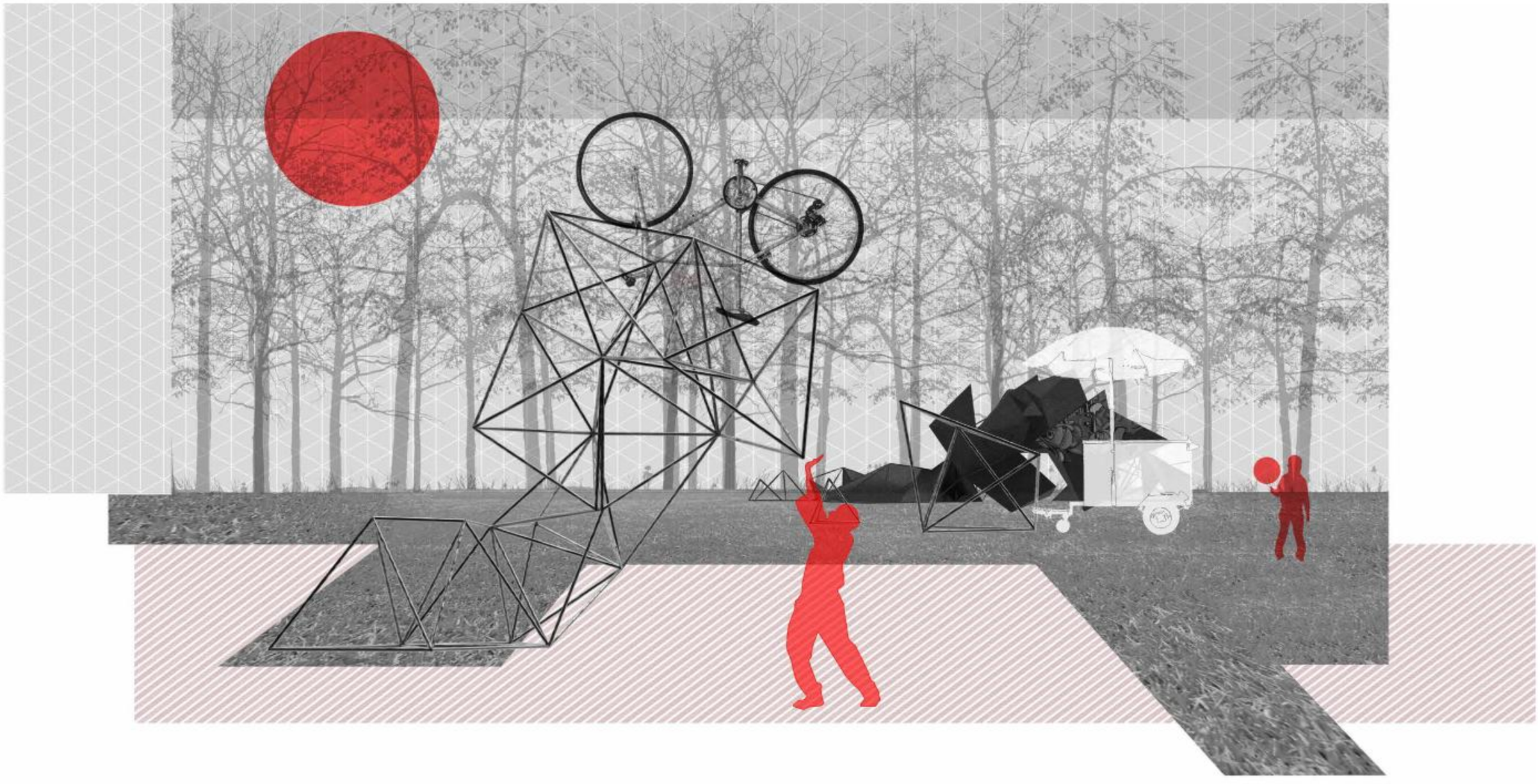
Difference in scales and speeds encourage different activities

Speculative multiple user activity



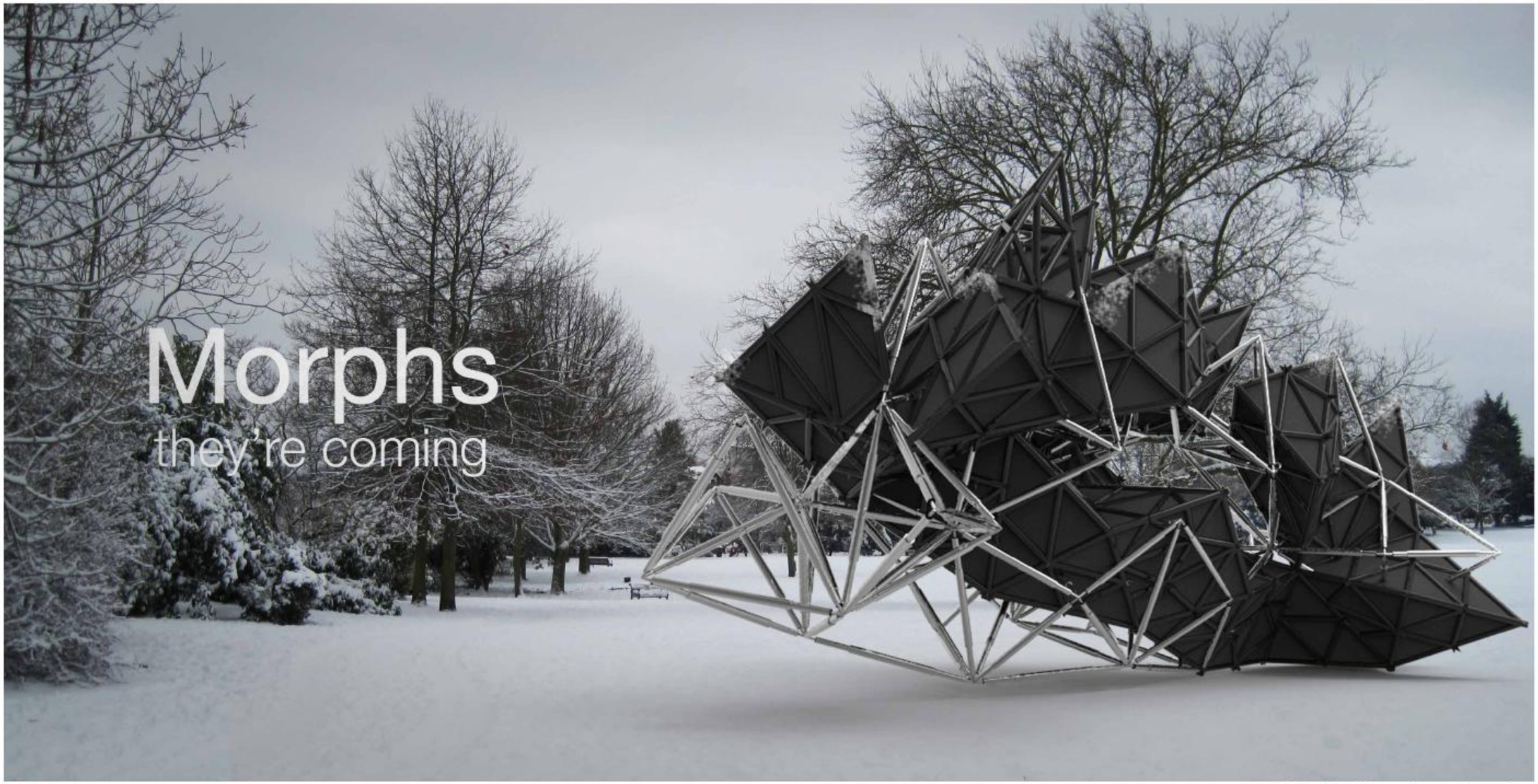
Speculative section

Use - Make - Abuse



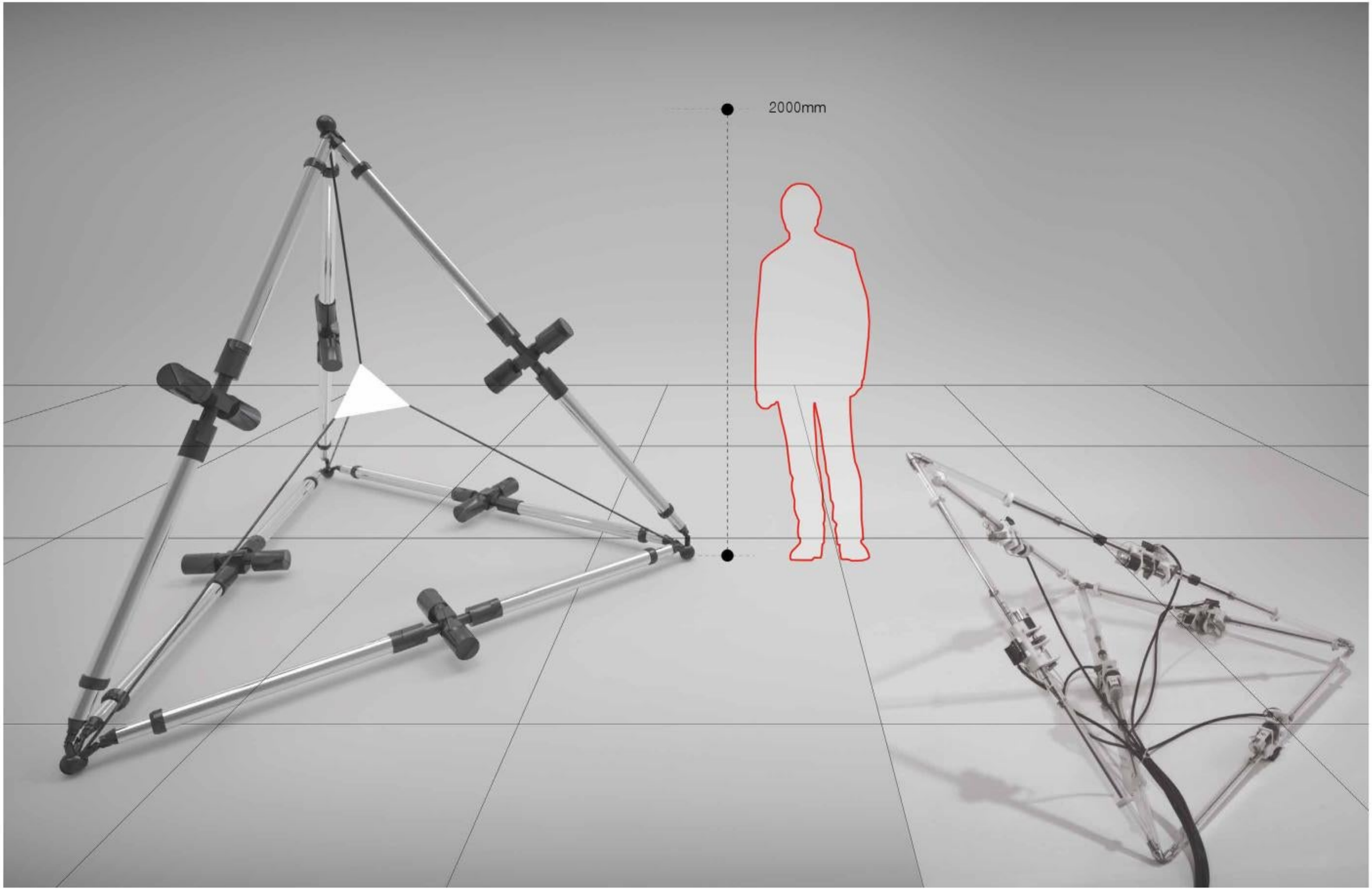
Grafiiti, clamped bikes and vandalism are expected

Walking Trusess



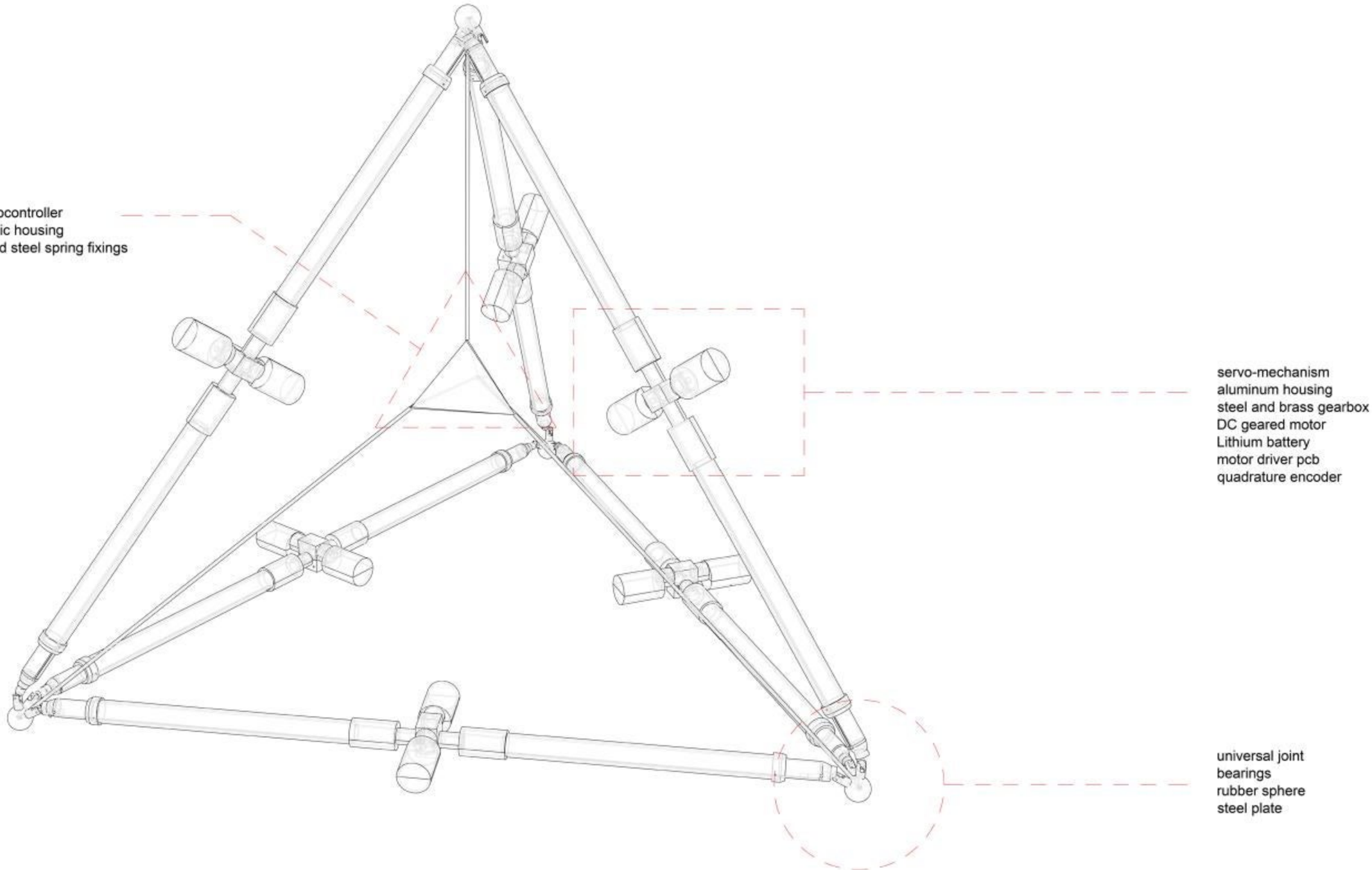
MakeUse**Abuse**Learn**Develop**

Generation 3: Architectural Scale



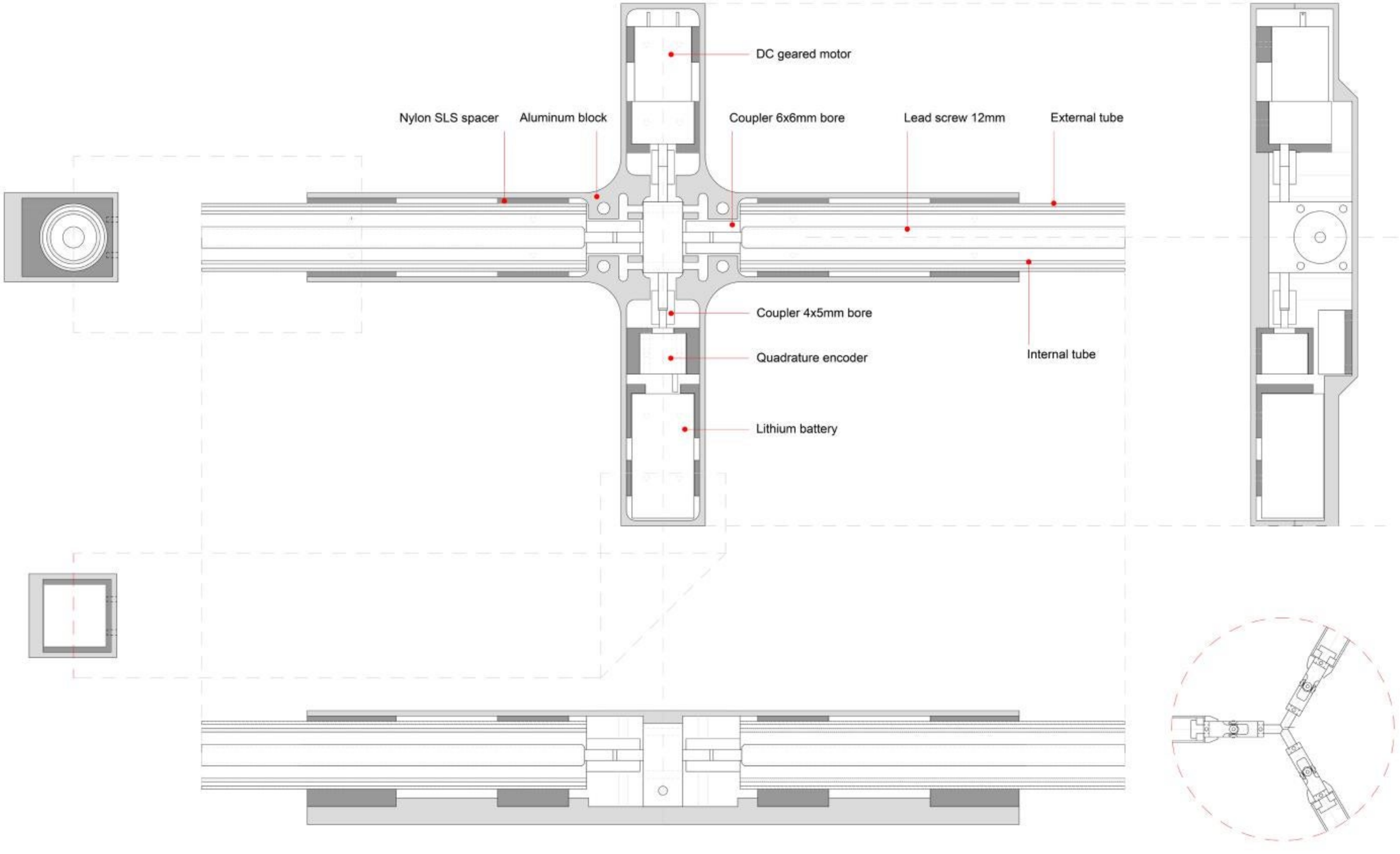
Detail Drawings

Overall Perspective



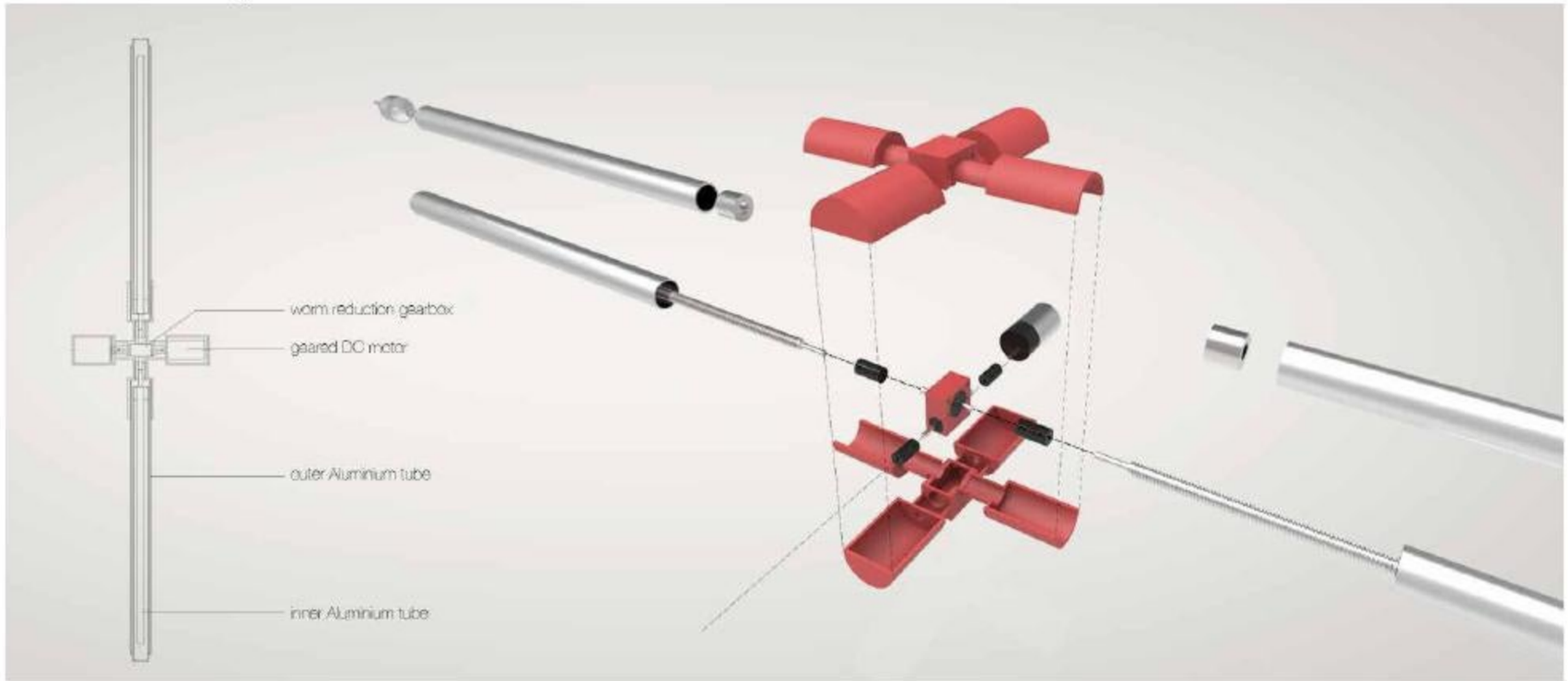
Detail Drawings

Central Block Components v.2

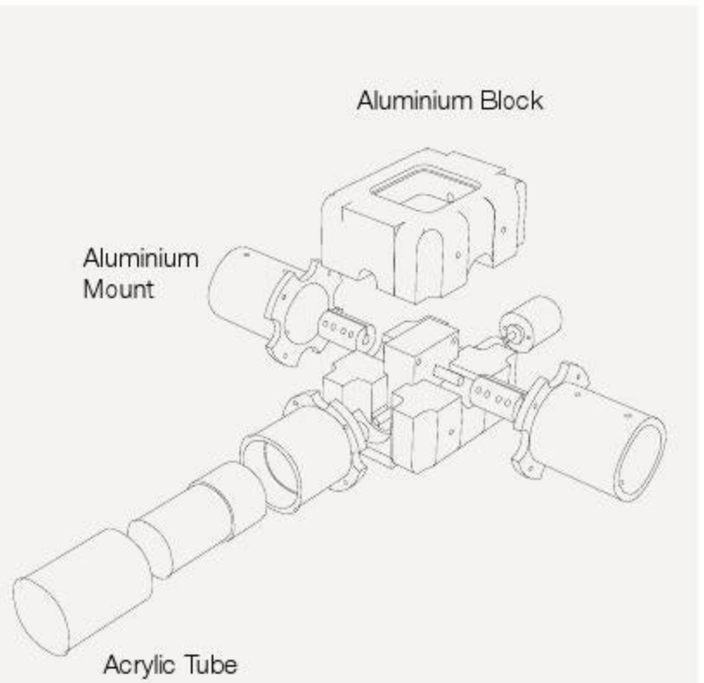


Detail Drawings

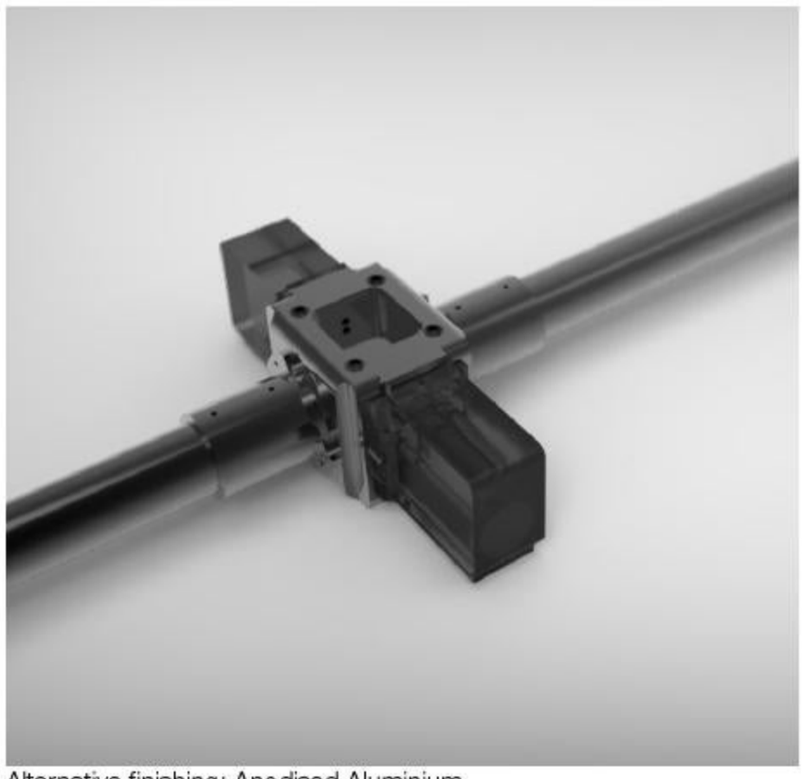
Alternative mounting solutions



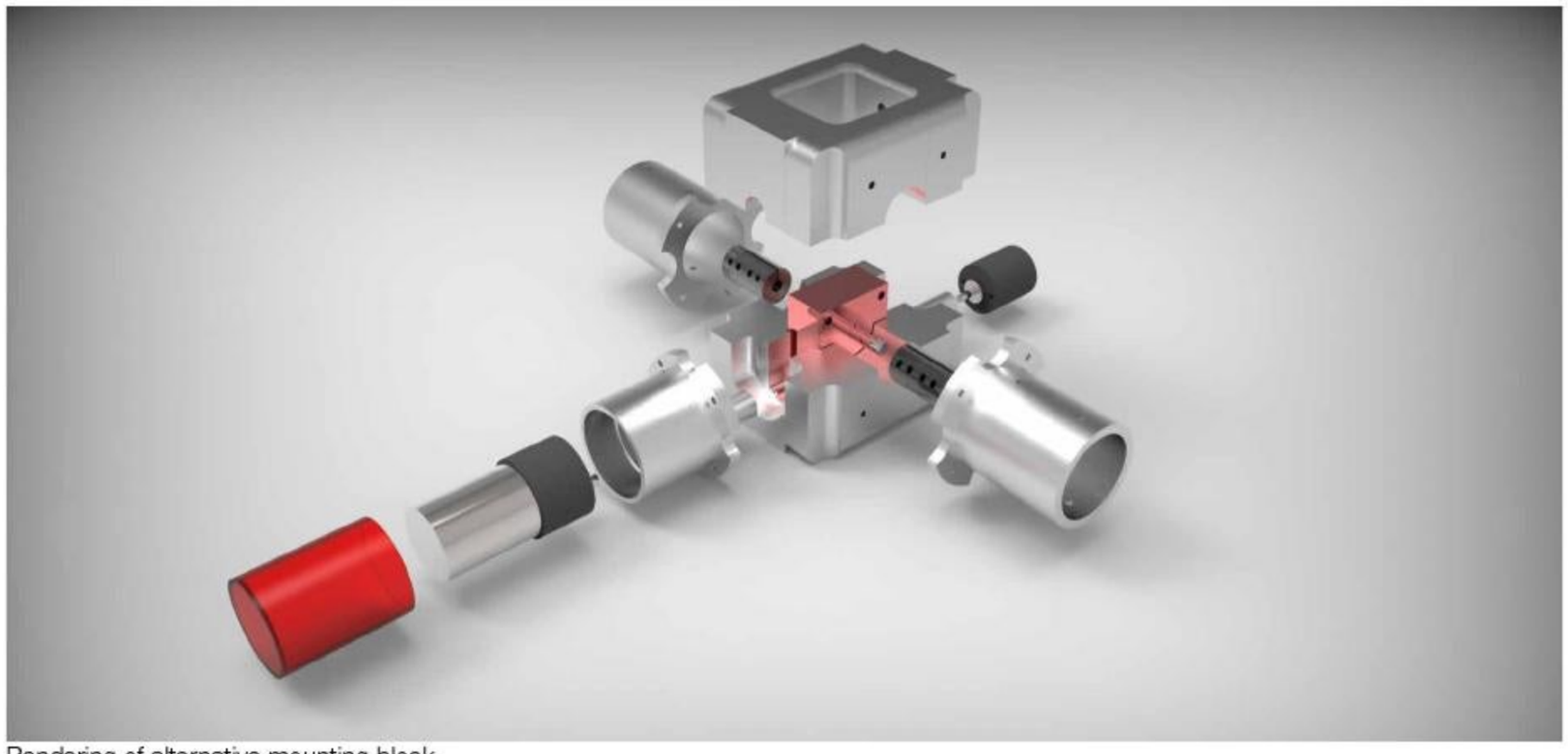
Alternative mounting detail



Alternative mounting detail



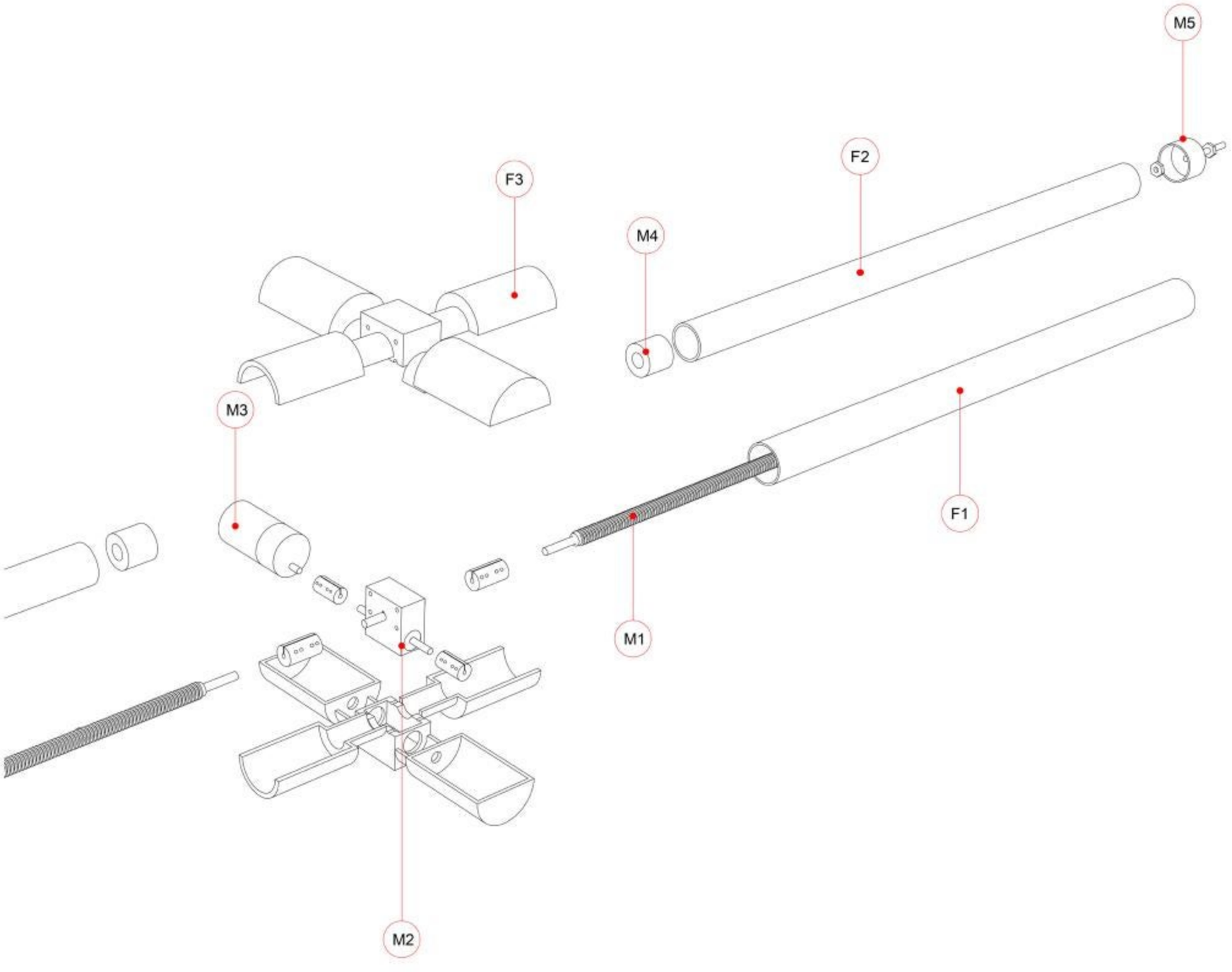
Alternative finishing: Anodised Aluminium



Rendering of alternative mounting block

Detail Drawings

Rod Components v.1



[Mx] Mechanical Components

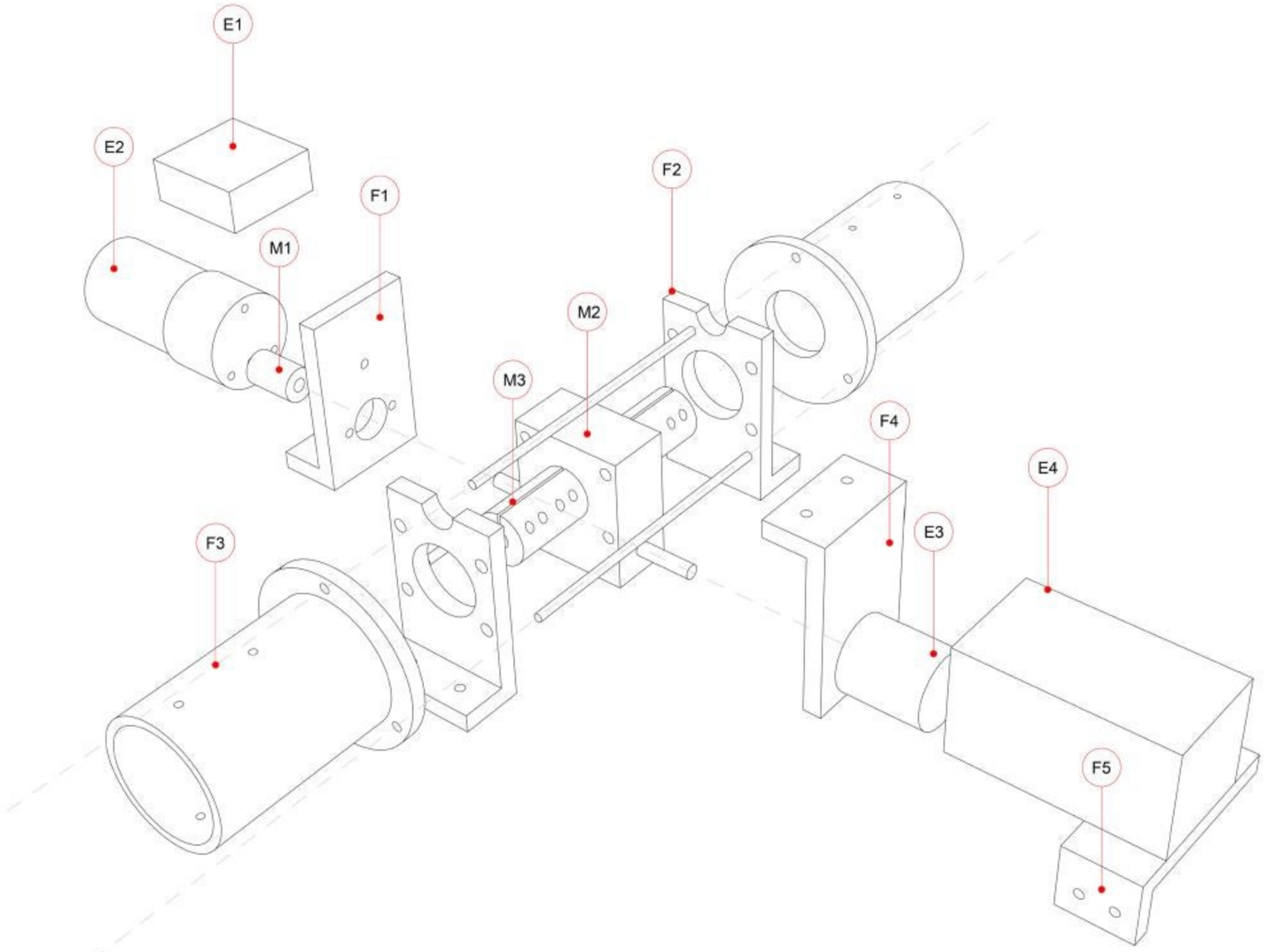
1	lead screw 12mm x 3mm pitch
2	gearbox 7:1 worm drive
3	DC geared motor 440rpm
4	lead screw nut
5	joint

[Fx] Fixings and Housing Components

1	internal 30mm Aluminum tube
2	external 38mm Aluminum tube
3	nylon SLS mounting block

Detail Drawings

Central Block Components v.3



[Mx] Mechanical Components

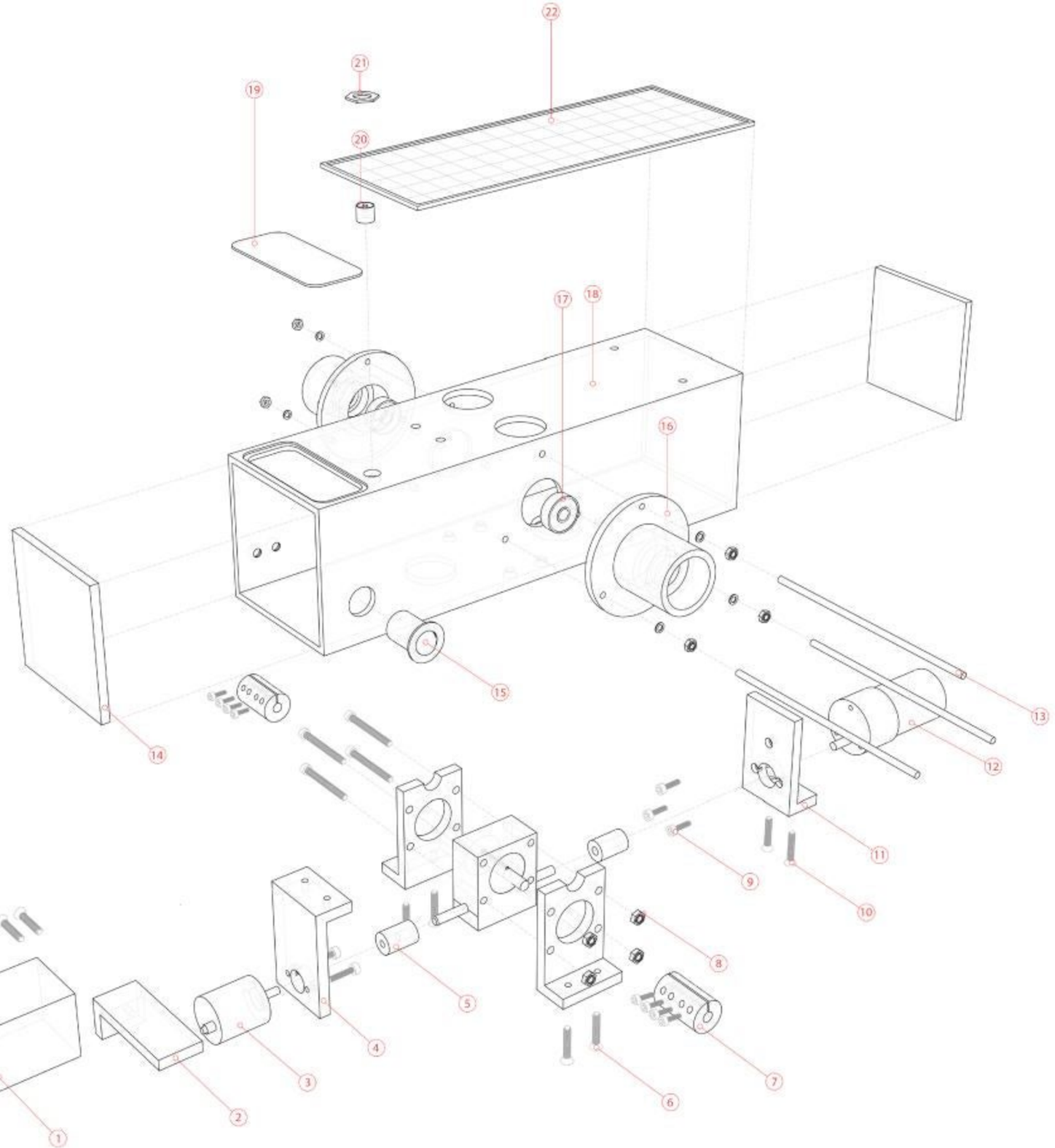
1	flexible beam coupler 5mm x 5mm bore
2	gearbox 10:1 worm drive
3	rigid coupler 6mm x 6mm bore

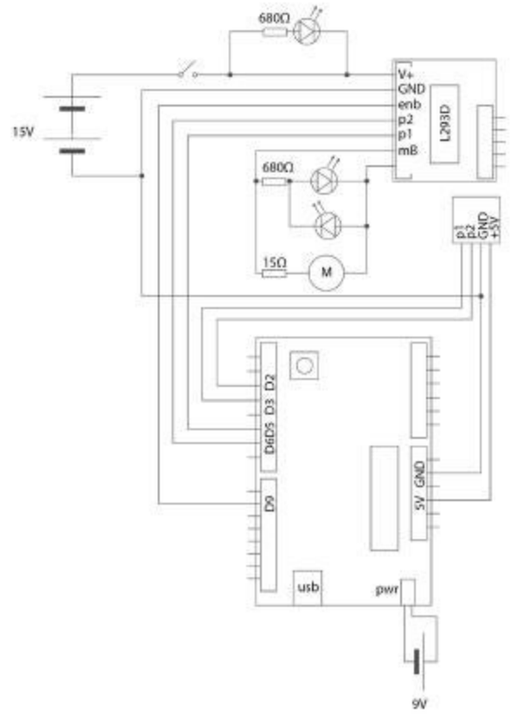
[Ex] Electrical and Electronic Components

1	H-bridge motor driver 0.6A - 1.2A
2	DC geared motor 200mA 12V 440rpm
3	quadrature encoder 200ppr
4	Lithium battery 15V 2200mAh

[Fx] Fixings and Housing Components

1	motor mounting bracket
2	gearbox mounting brackets
3	tube coupler and bracket
4	encoder mounting bracket
5	battery supporting bracket





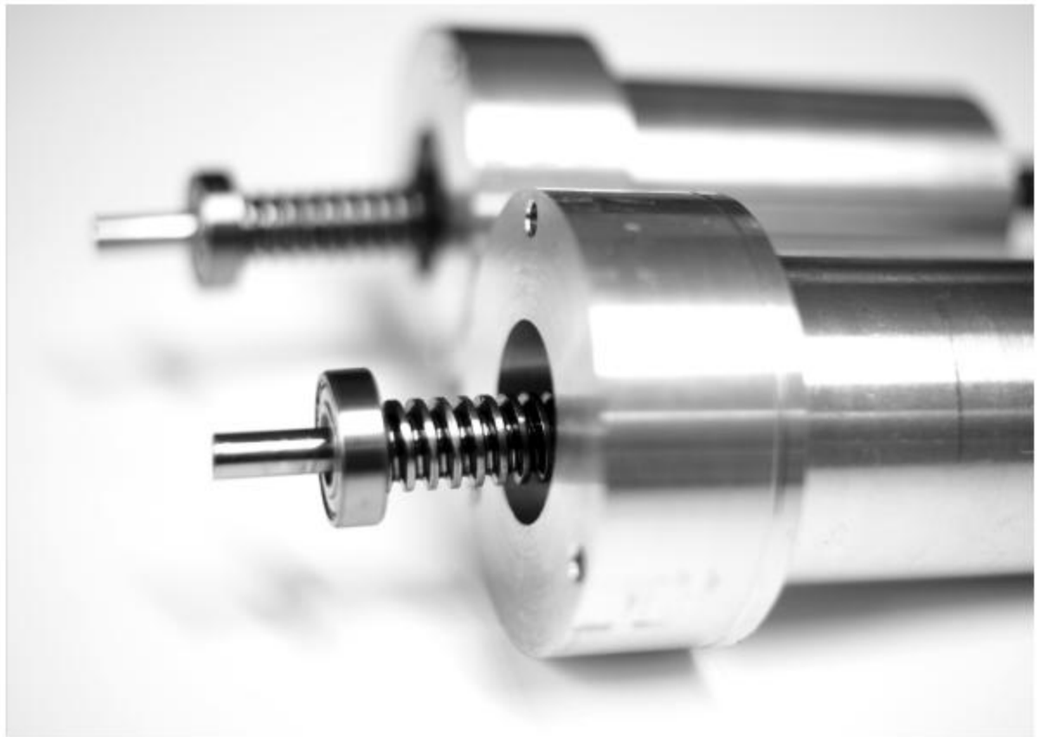
Circuit diagram showing feedback loop

1. 15V 2.2Ah Li-Ion rechargeable battery
2. Aluminium mounting bracket for battery
3. Quadrature encoder 5V 200ppr
4. Aluminium mounting bracket for encoder
5. Beam flexible coupling 4mm - 5mm bores
6. M4 16mm countersunk machine screw black oxide
7. Rigid coupling 6mm bores
8. M4 nyloc nut
9. M3 10mm hex-socket cap head black oxide
10. M4 16mm countersunk machine screw black oxide

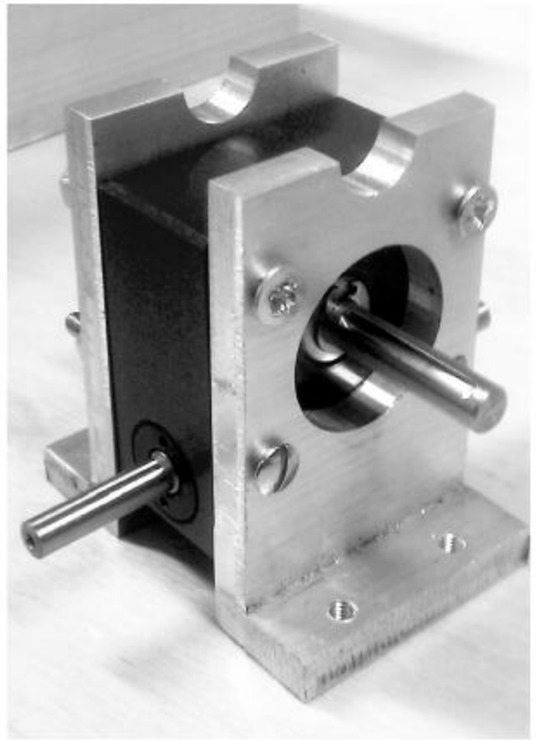
11. Aluminium mounting bracket for DC motor
12. DC 12V 200mA 440rpm geared motor
13. M3 85mm threaded rod
14. Acrylic end cap - sand blasted finish
15. Push button switch with integrated green LED
16. Aluminium mounting for tube sections and bearing housing
17. Deep groove bearing 19mm OD 6 mm bore
18. Aluminium box section finished in matt black
19. Acrylic window over LEDs - sand blasted finish
20. DC male plug
21. Hex half nut M8 for DC male plug
22. PhotoVoltaic cells

Fabrication

High precision milliing on a Haas CNC milling machine



Machined components awaiting assembly



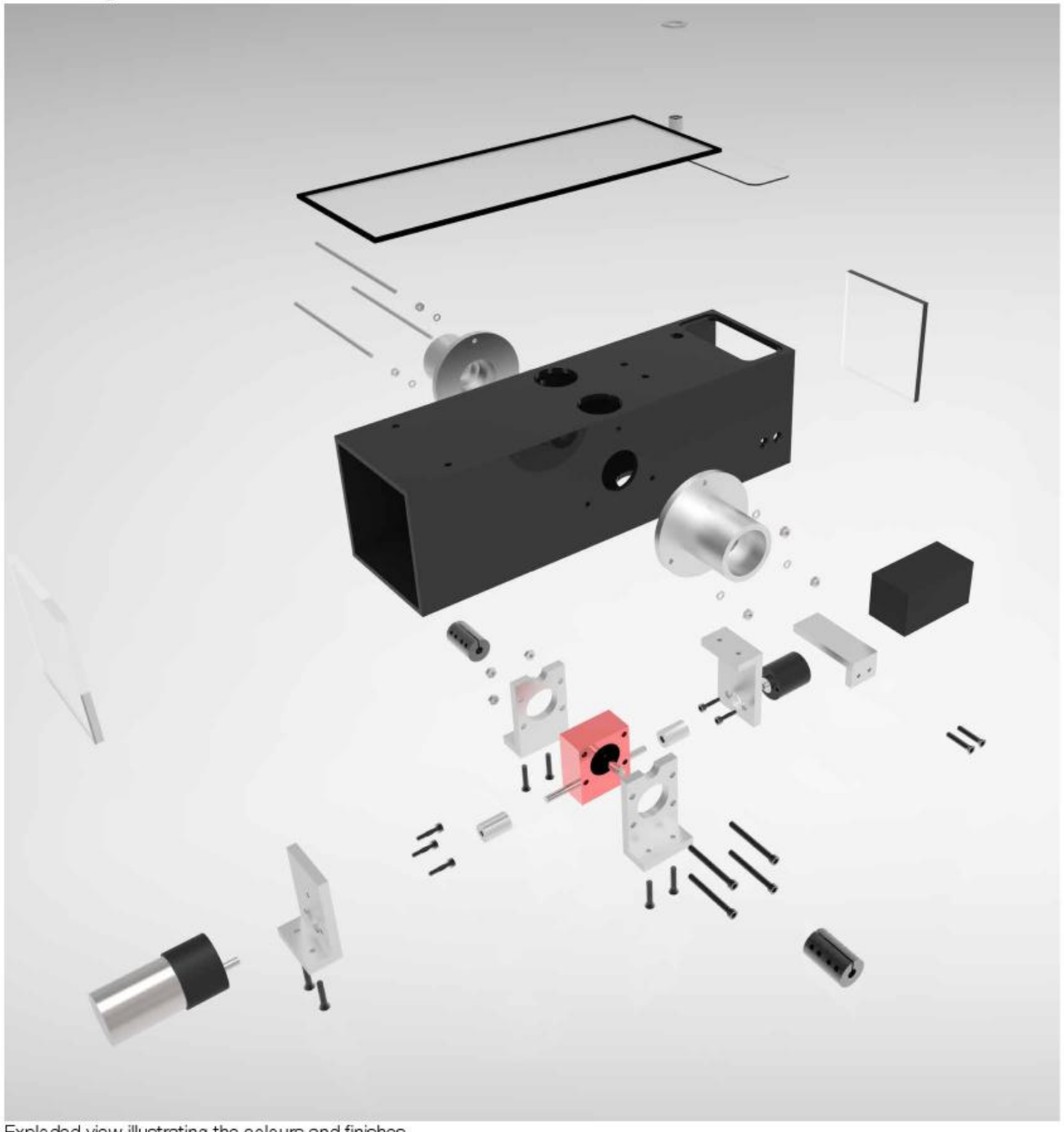
Gearbox mountings

Metal work being carried out on a manual lathe

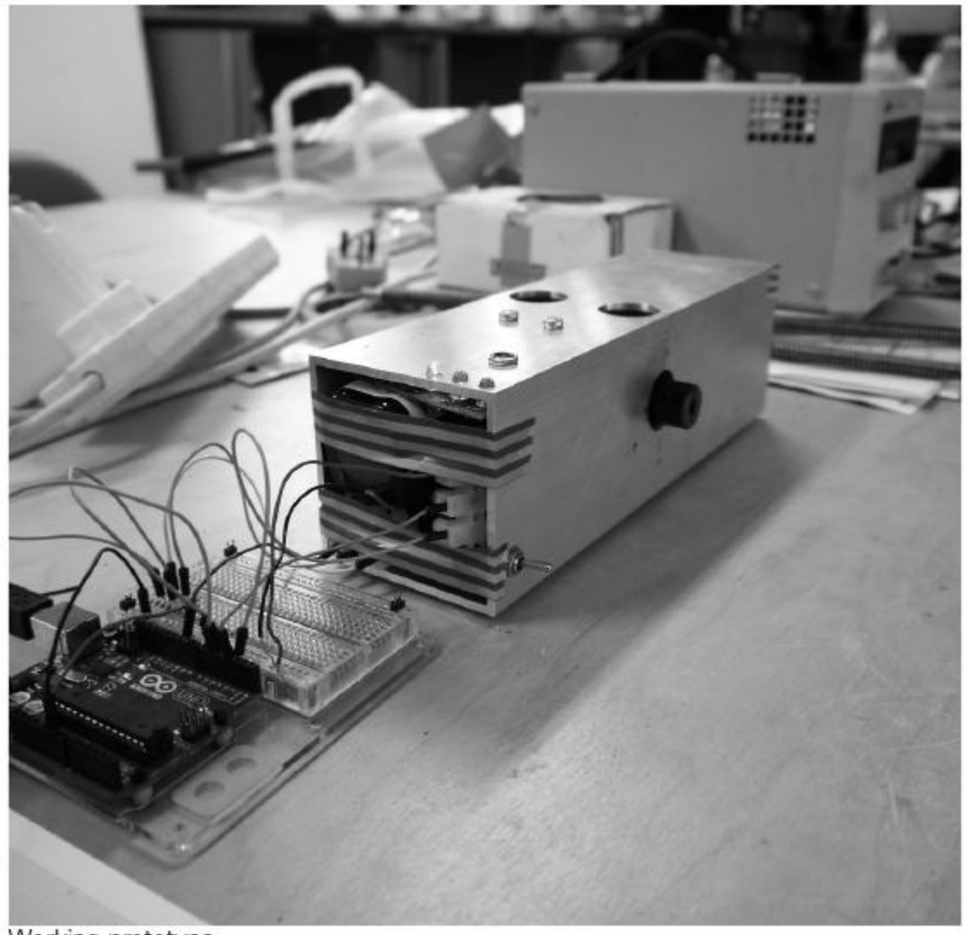
Assembly and fitting of the custom engineered servo mechanism

Detailing and Prototyping

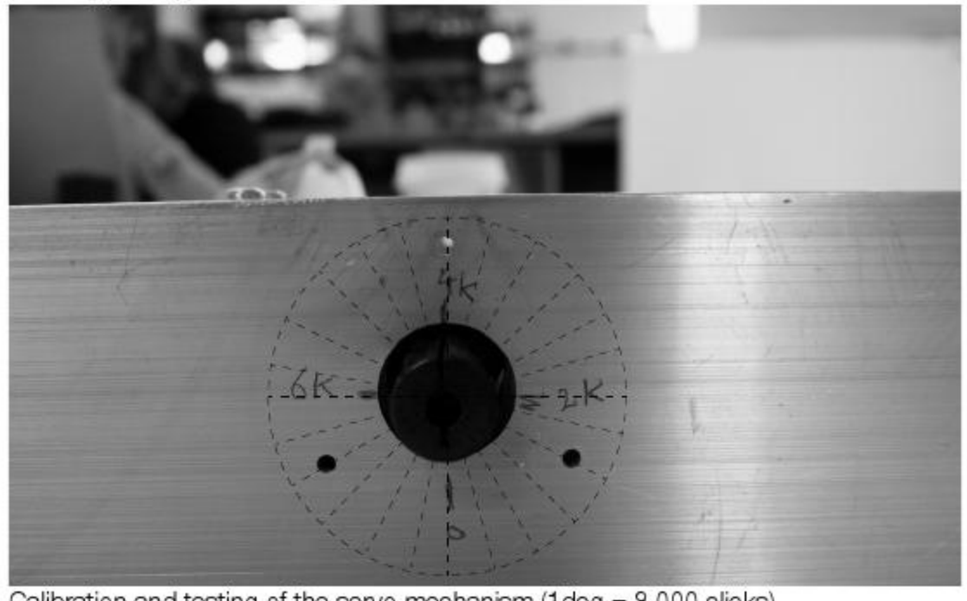
custom engineered servo mechanism



Exploded view illustrating the colours and finishes



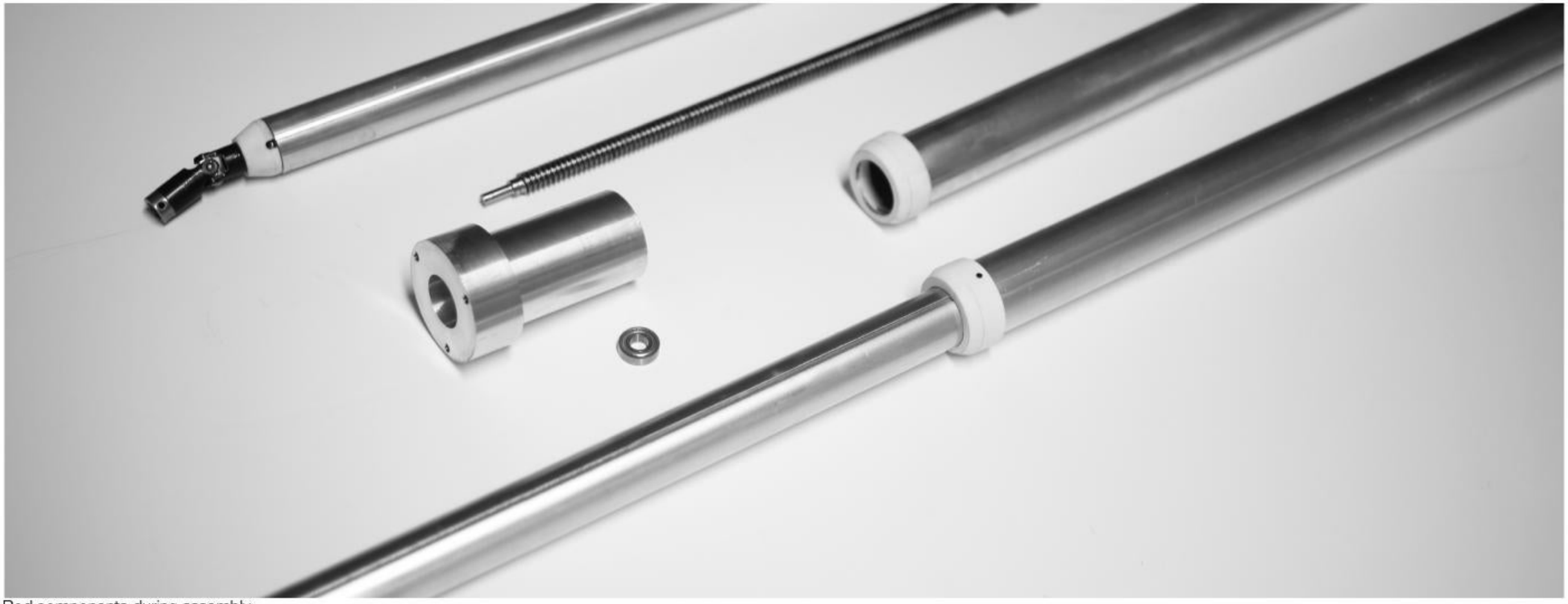
Working prototype



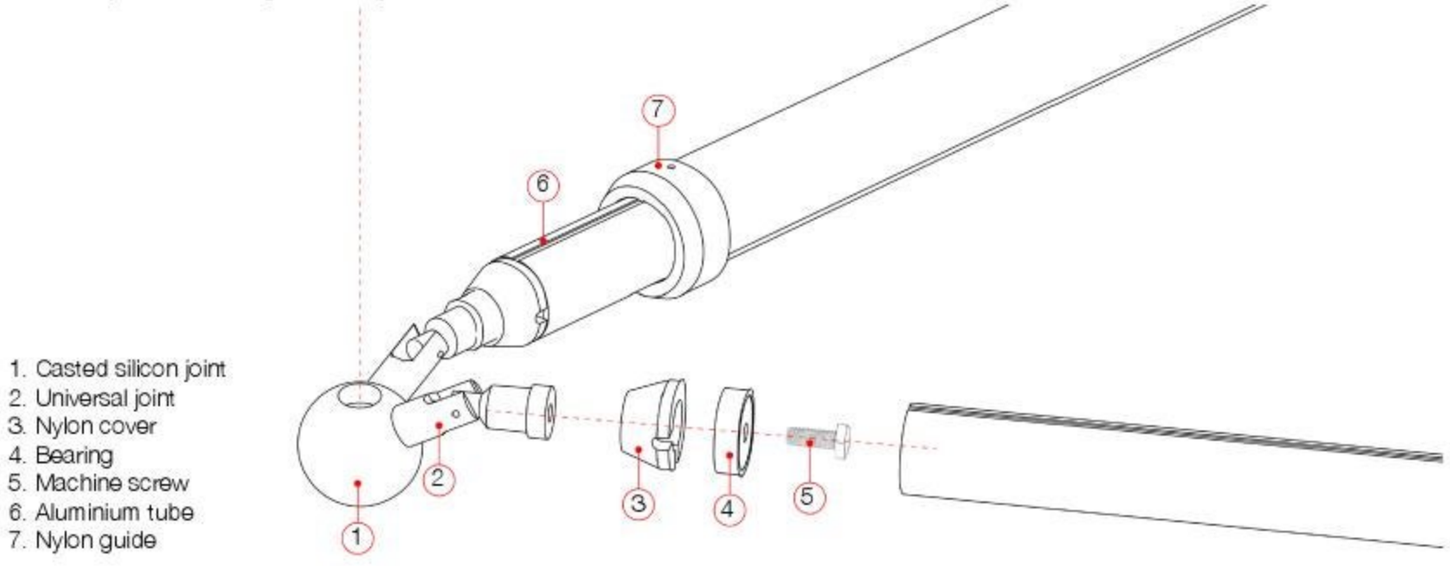
Calibration and testing of the servo mechanism (1deg = 8,000 clicks)

Detailing and Prototyping

linear actuator mechanism



Rod components during assembly



1. Casted silicon joint
2. Universal joint
3. Nylon cover
4. Bearing
5. Machine screw
6. Aluminium tube
7. Nylon guide

Exploded view of joint detail

Rendering of assembled joint

Thank You

Tutor/ Academic direction/ Technical direction	Ruairi Glynn
Tutor	Ollie Palmer
Tutor/ Academic direction	Sam McElhinney
Technical/ Technology direction	Paul Harkin
Fabrication direction	Emmanuel Vercruysse Abi Nick Richard Martin Bim Eddy Inigo