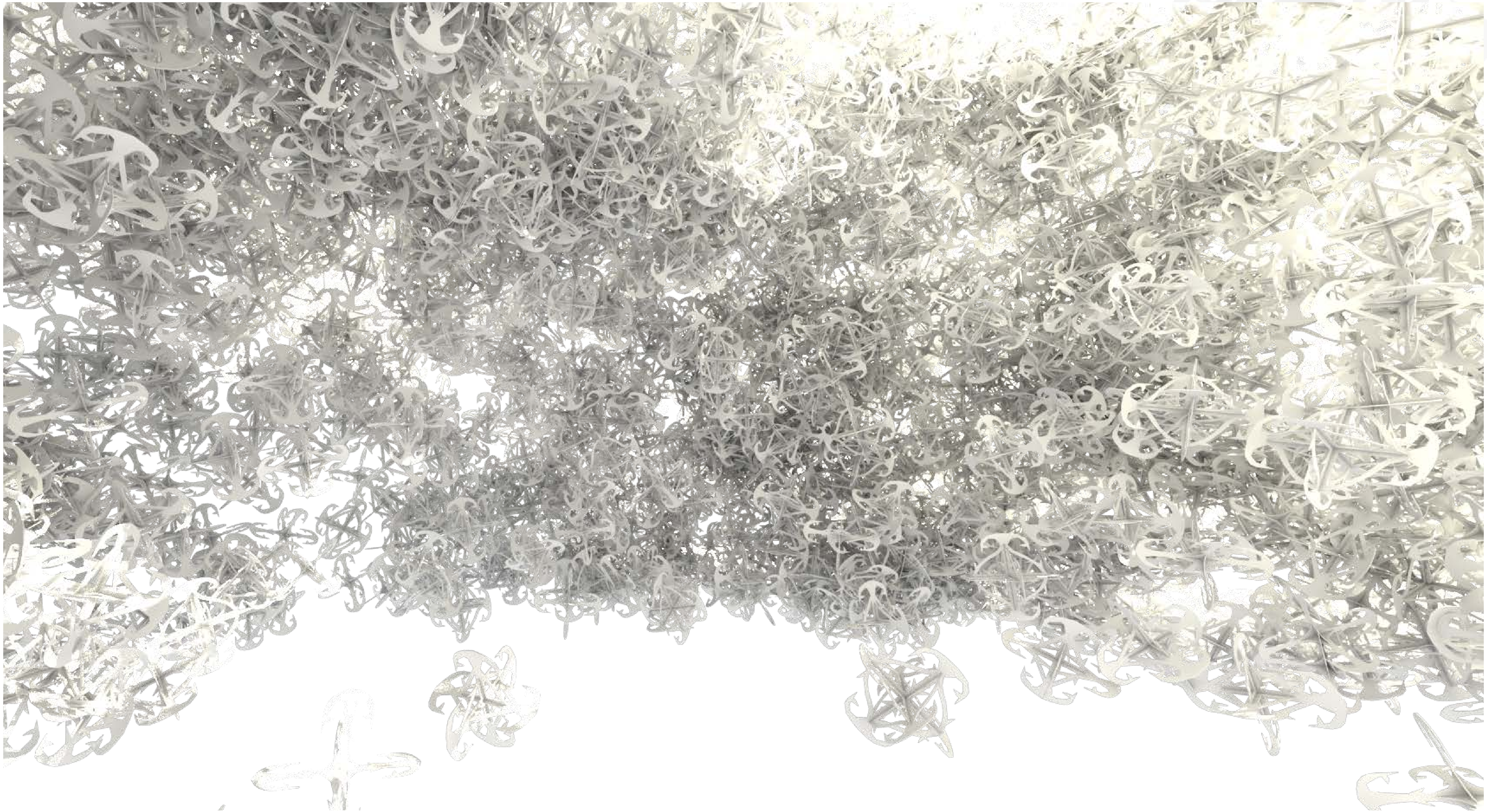
Adaptative Aggregation Based Building System

An alternative to large 3D printing



DK 2014-2015 // P8 : Oswald PFEIFFER and Mathieu VENOT
With Charles BOUYSSOU

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Dealing with unpredictability

The Newtonian paradigm places the emphasis on external forces: gravity, natural selection, the market, and so on. Taking nonlinearity into effect means we concentrate more on the system: in evolution the developmental system of the organism, in economics the nature of society and the people who make it up. It does not, as do relativity and quantum mechanics, introduce entirely new scientific principles, but it can completely alter the direction of our research all the same.[1]

- SAUNDERS Peter

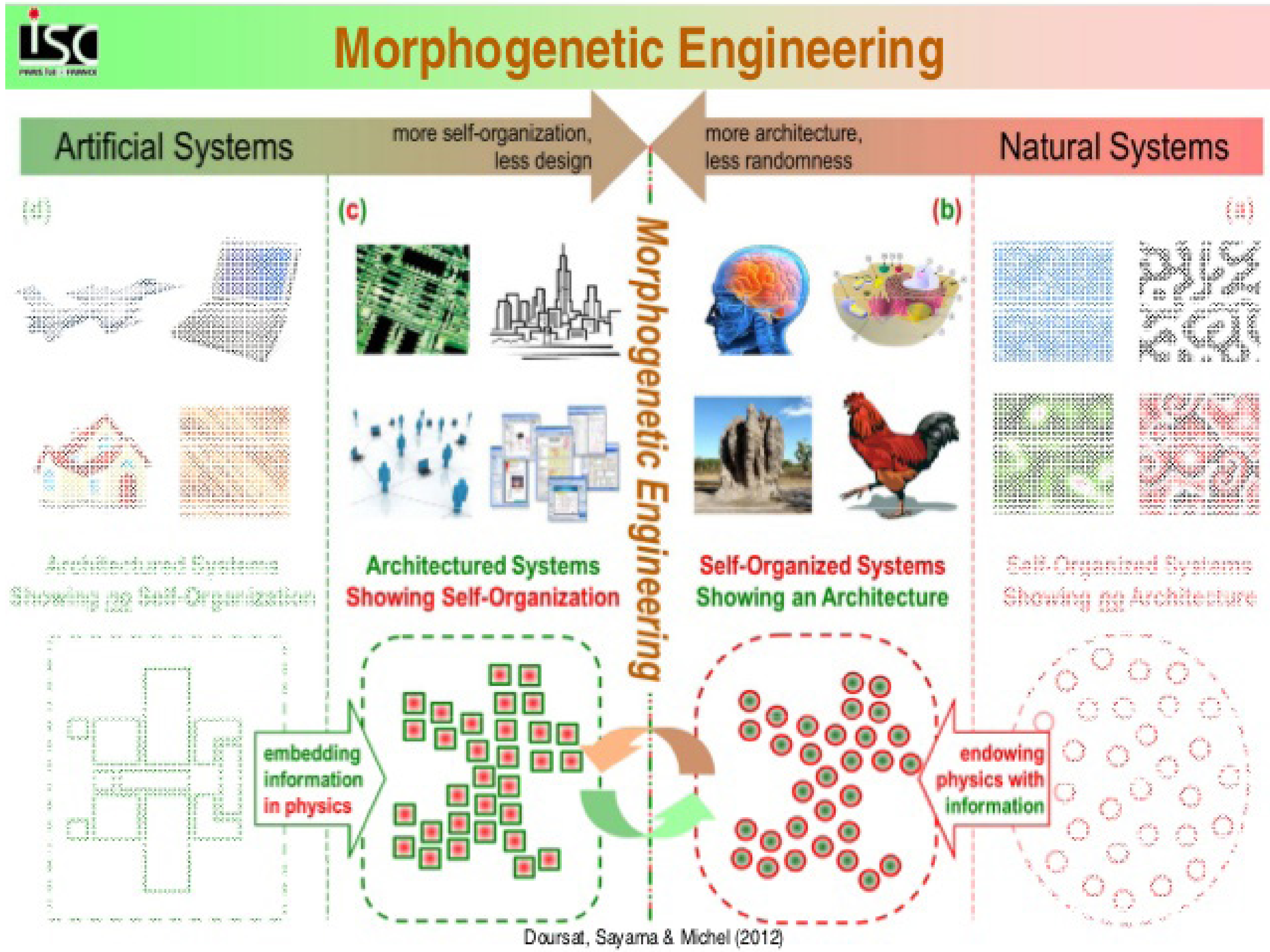
1 SAUNDERS Peter T, DI CRISTINA Giuseppa (dir), «Nonlinearity. What it is and why it matters», Chichester, AD Architecture and Science, Wiley-Academy, 2001

Dealing with unpredictability

1st reference

Meta-designers will focus on creating local mechanisms that allow small agents or components to assemble, coalesce, grow, or generate architectures by themselves.[2]

- DOURSAT René

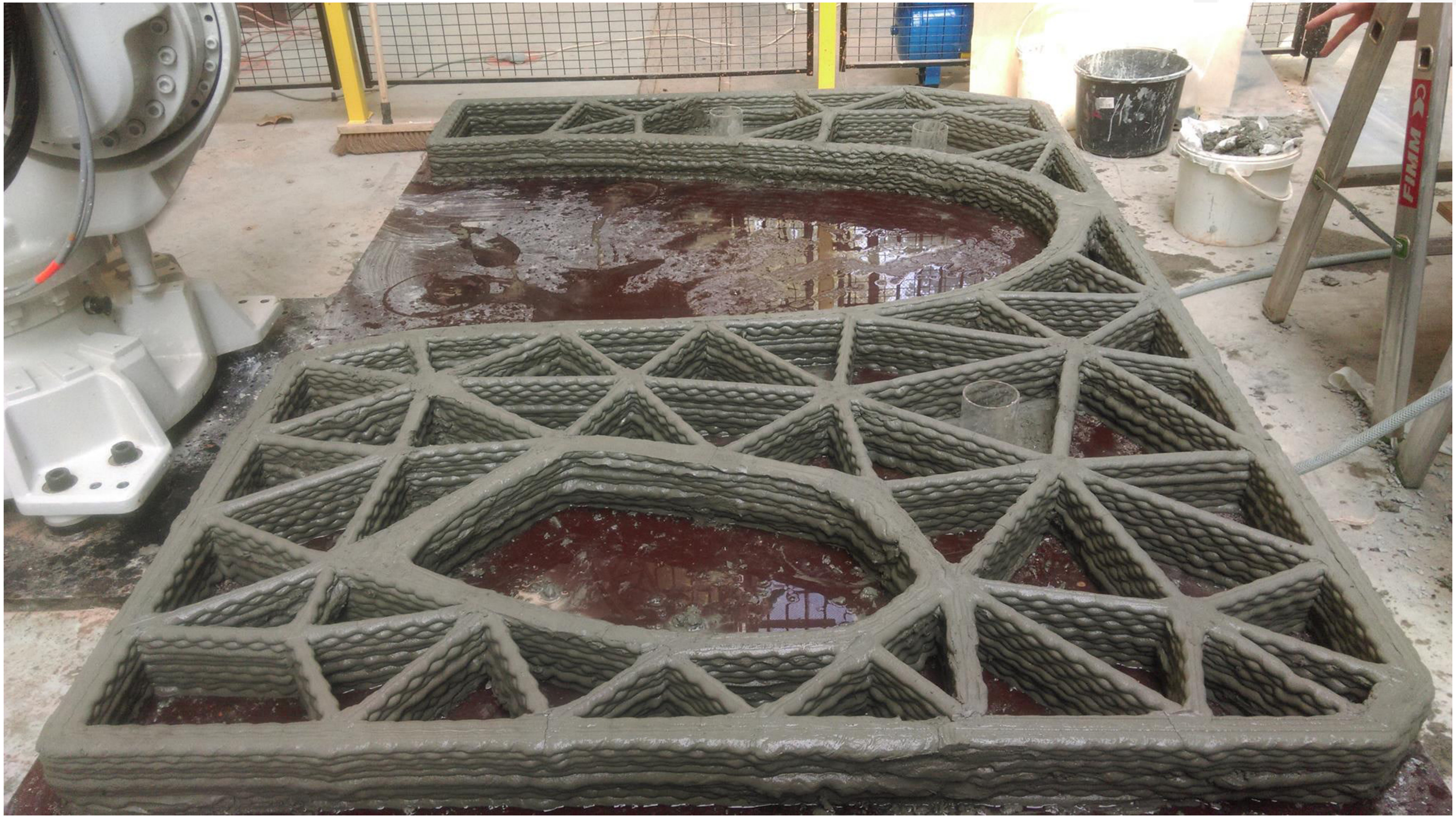


2 DOURSAT, R., SAYAMA, H. & MICHEL, O. (2013) A review of morphogenetic engineering. "Frontiers of Natural Computing" (FNC 2012) Special Issue. Lones, M., Tyrrell, A., Stepney, S. & Caves, L., eds. Natural Computing 12(2): 517-535, p.531

Dealing with unpredictability

2nd reference

Large scale 3D printing researches conducted by Romain Duballet, Clément Gosselin & Philippe Roux for DEMOCRITE. Additive process allowing the automated fabrication of large concrete shapes.



Large scale 3D printed prototype (DEMOCRITE 2015)

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Dealing with unpredictability

Purpose

Conceiving an adaptative building system that uses discontinuous and unpredictable materials in order to allow self-organization and emergence : Adaptative Aggregation-Based Building System. (AABBS).

The proposition is an additive construction process alternative to large scale 3D printing, with its own pros and cons :

	Large scale 3D printing	AABBS
Material type	Continuous	Discontinuous
Environment	Controlled (Factory)	On-site
Workable volume	Limited	Unlimited
Process type	Heavy	Light
Precision	High	Low

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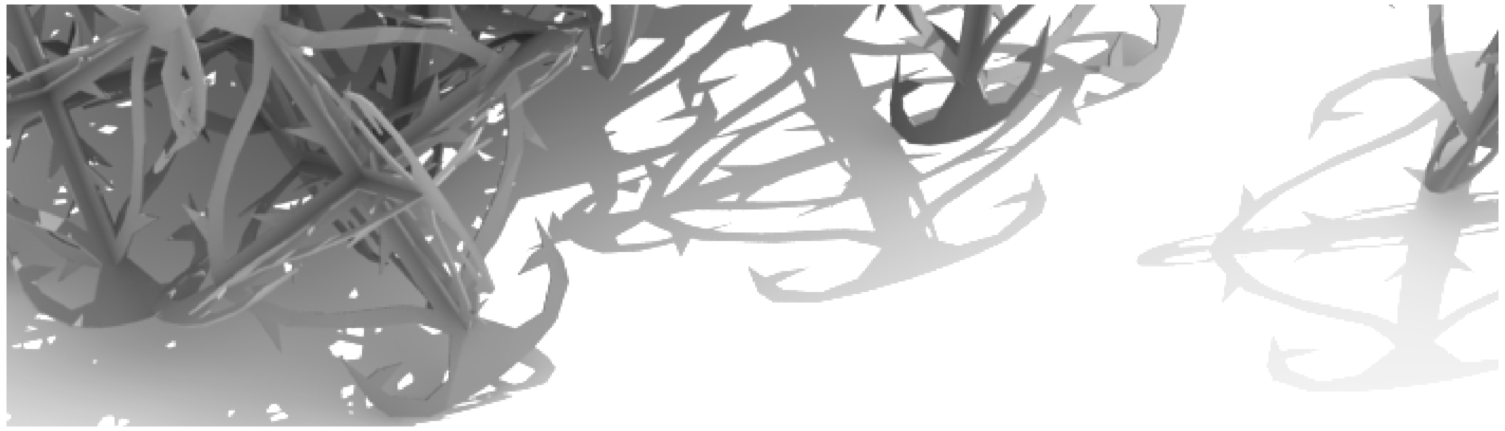
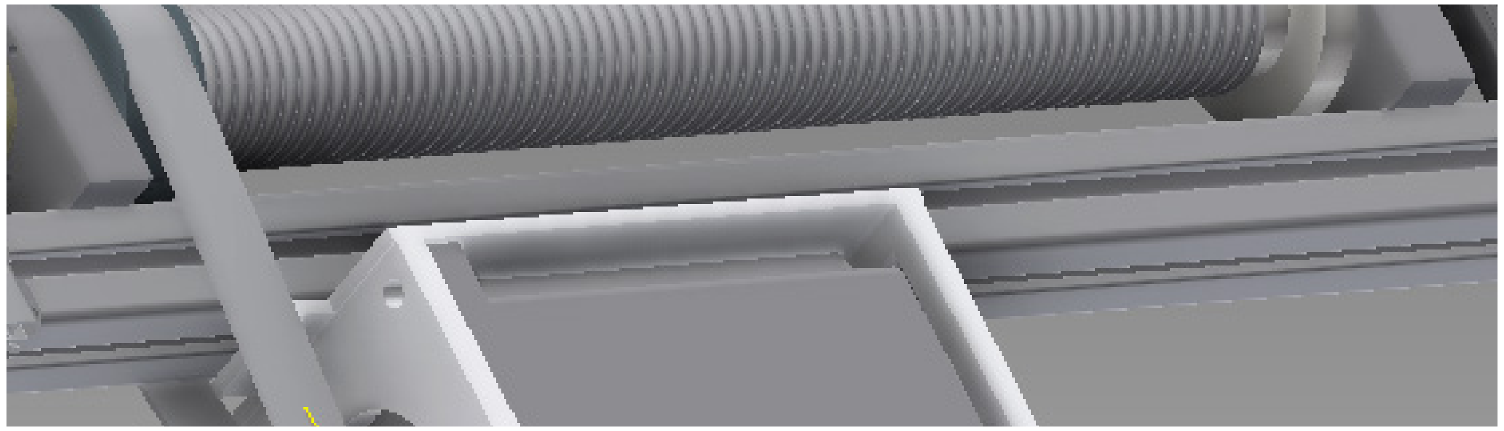
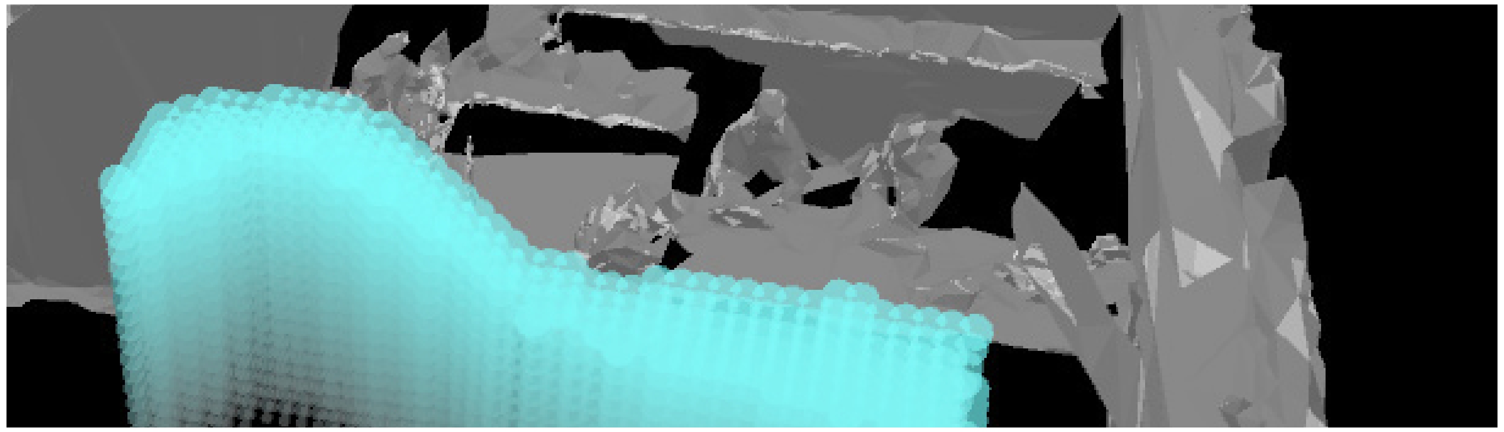
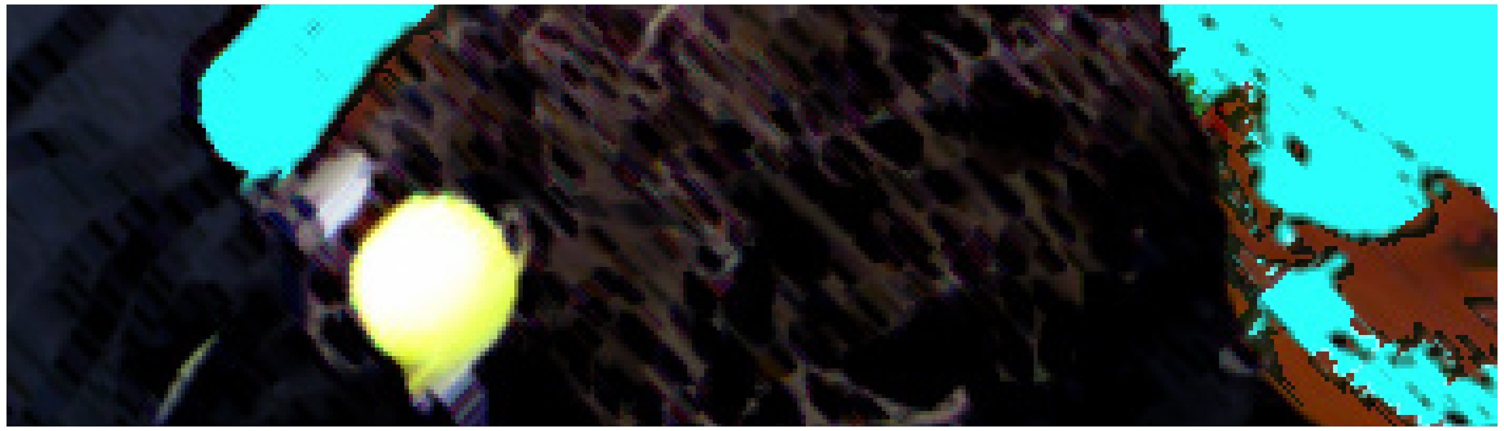
Dealing with unpredictability

Four research poles









Construction

Aggregates definition
FIRST SEMESTER WORK

Hardware

Robotic construction system
FIRST/SECOND SEMESTER WORK

Adaptability

Vision and feedback algorithm
FIRST/SECOND SEMESTER WORK

Software

Virtual/physical global communication platform : “Voxelizer”
SECOND SEMESTER WORK

Summary

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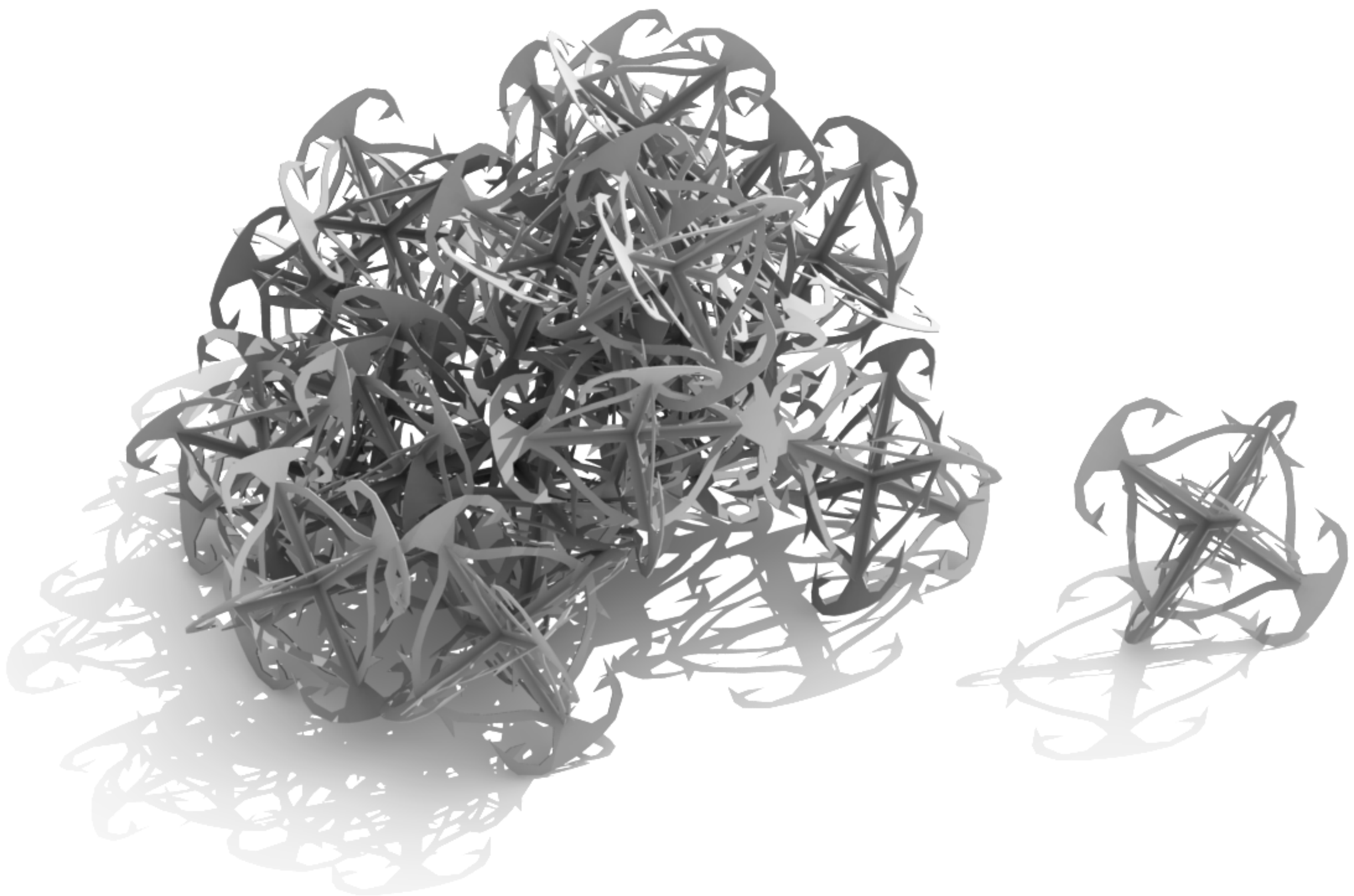
Summary



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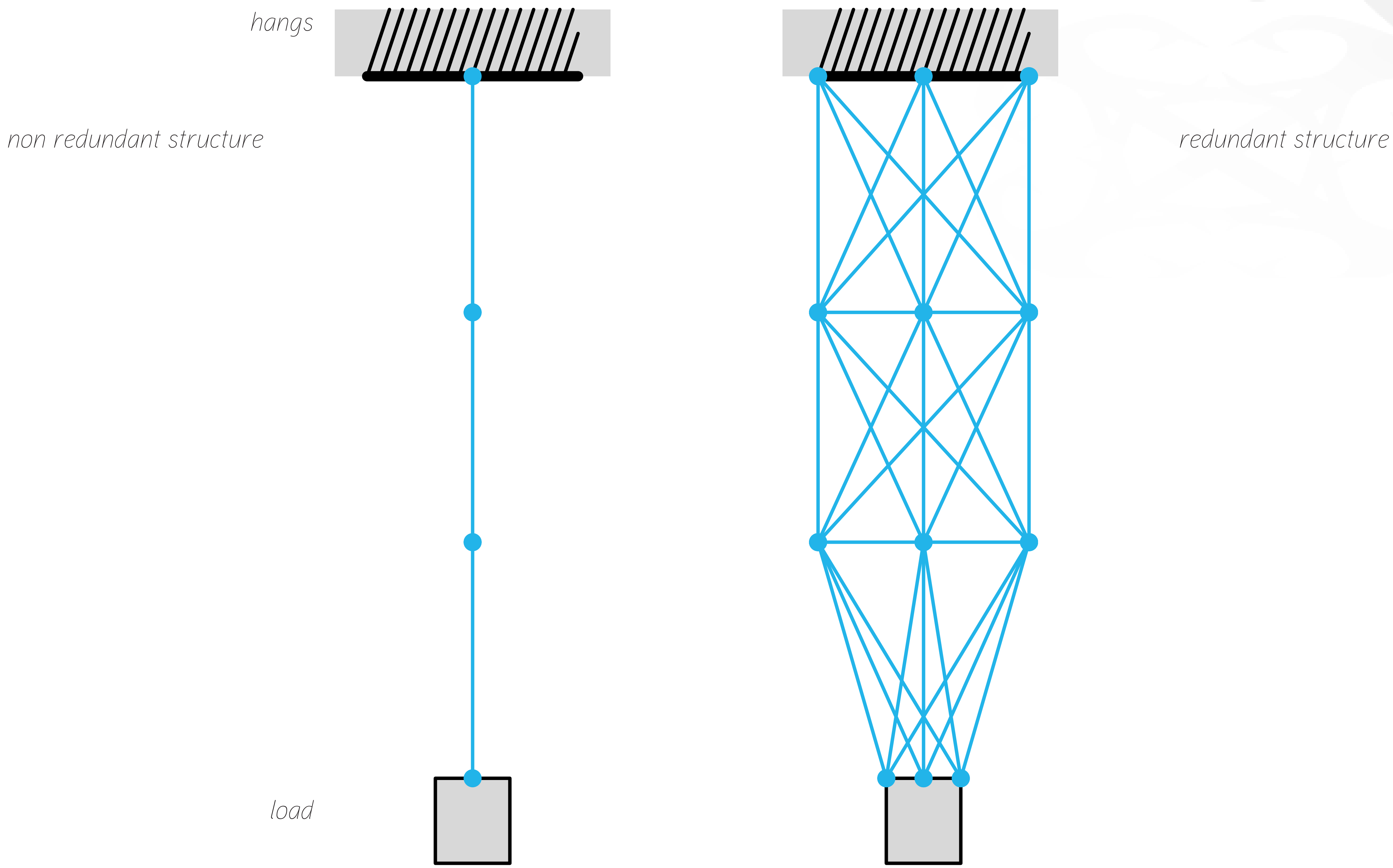
Construction (aggregation)

Purpose

To build with discontinuous material, we need to produce a high amount of aggregates in order to generate highly redundant structures.



Construction (aggregation)

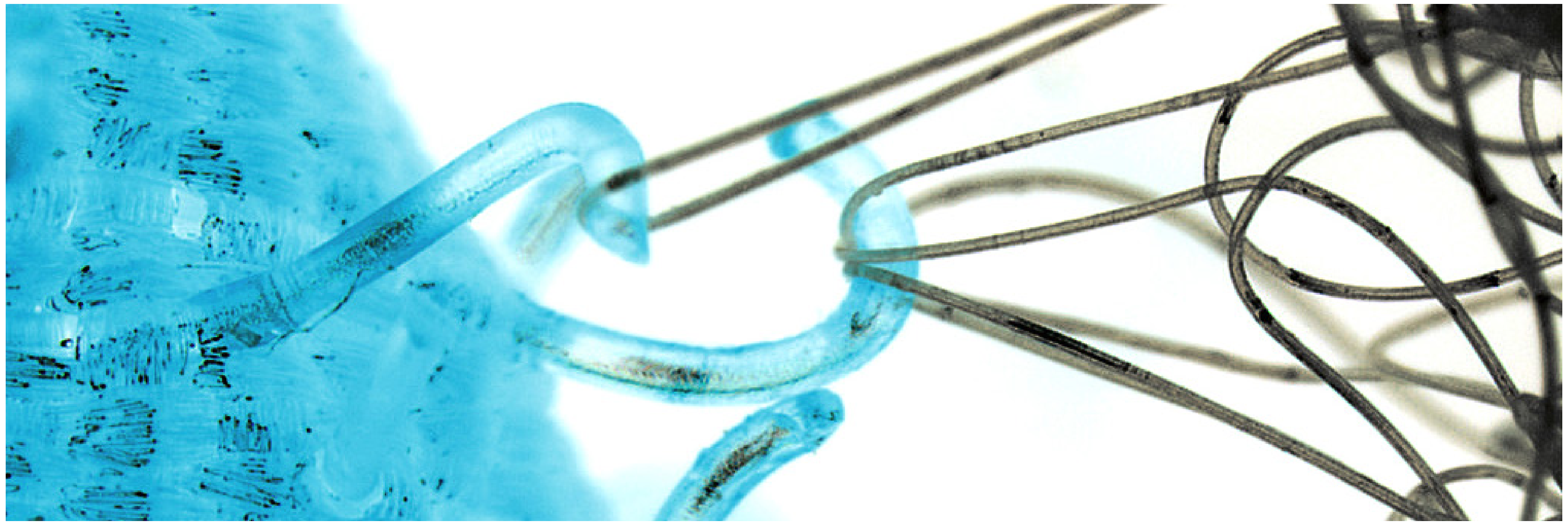
References in nature

Tumbleweed

Structural part of the above-ground anatomy of a number of species of plants.

Burdock

The prickly heads of these plants (burrs) are noted for easily catching on to fur and clothing



VELCRO system

1940s, George de Mestral, a Swiss inventor, became curious about the seeds of the burdock plant. The result of his studies was Velcro.

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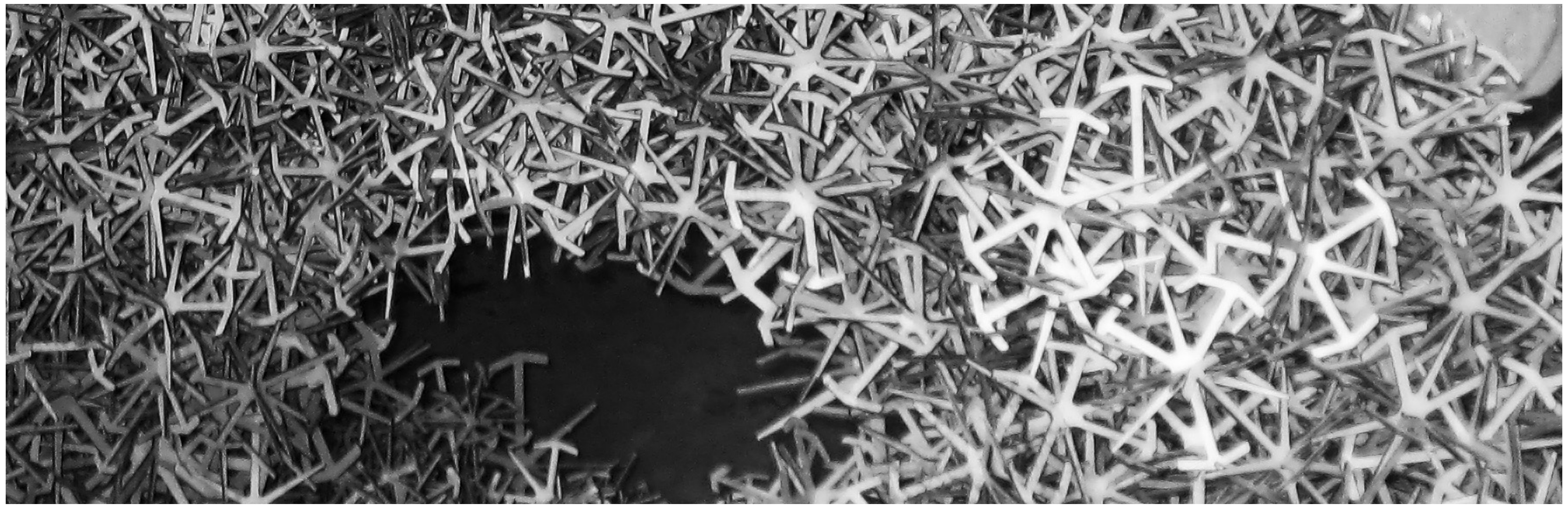
Construction (aggregation)

References in architecture

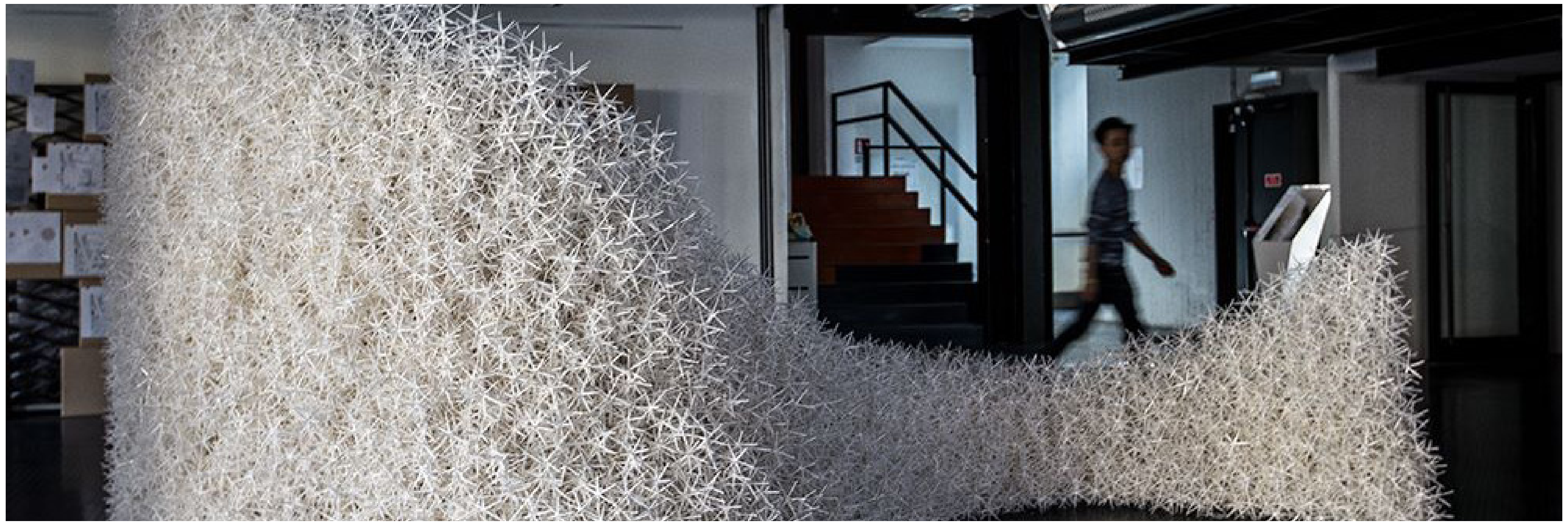


Minimaforms - Imogen Heap Stage scenography

module déposition
Module inspired Bio
Deposition by hand without control device.

Gramazio & Kohler research - Remote Material Deposition Installation

robot positioning
feedback with 3D scanning



Achim Menges & Karola Dierichs - Aggregate structures

module deposition
robot positioning
modelisation of the behavior

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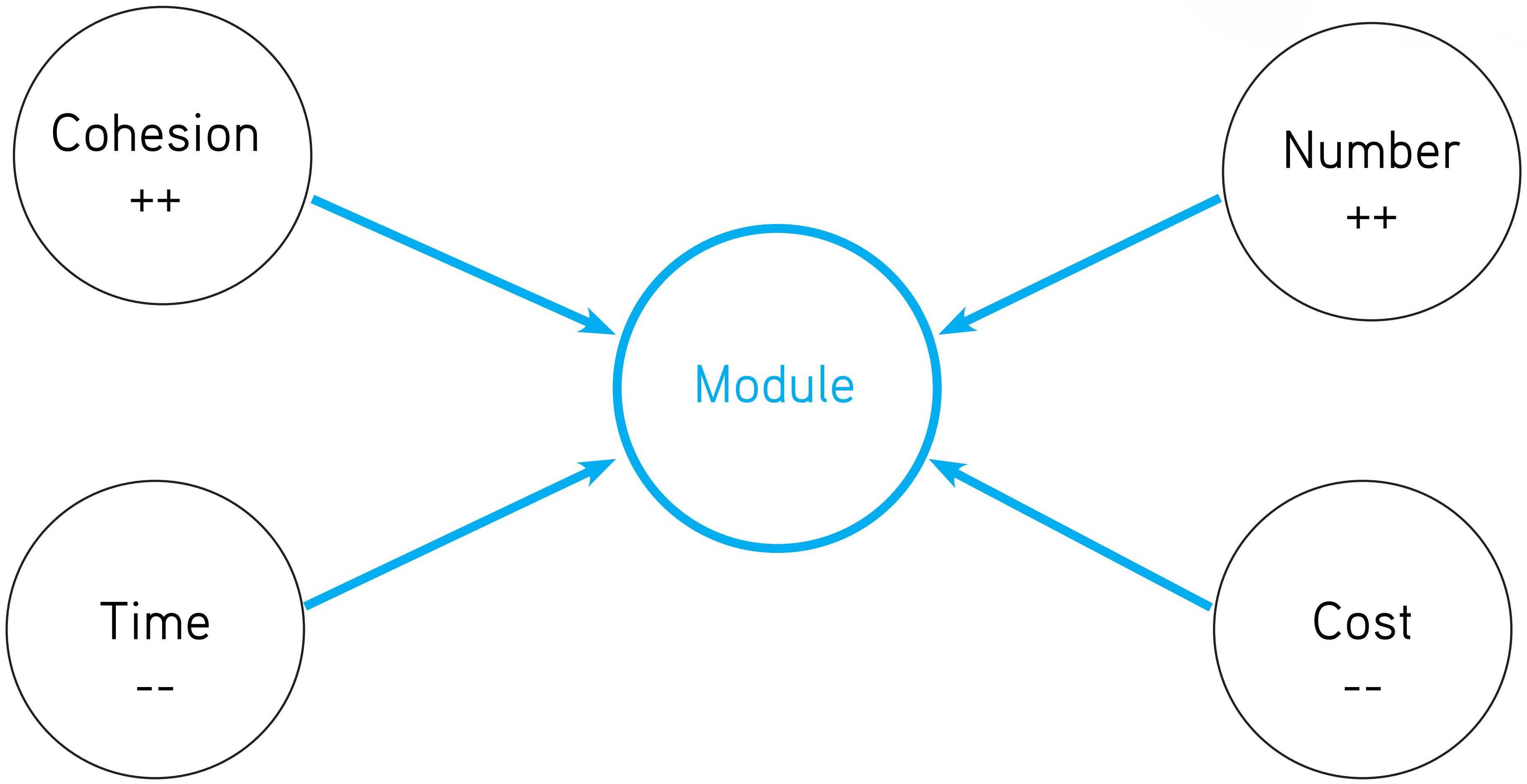
Construction (aggregation)

Aggregates proposition

The different criteria that has been taken into account for the modules generation were :
- Maximizing the mechanical cohesion between the modules
- Maximizing the number of modules produced
- Minimazing the production costs
- Minimazing the production time

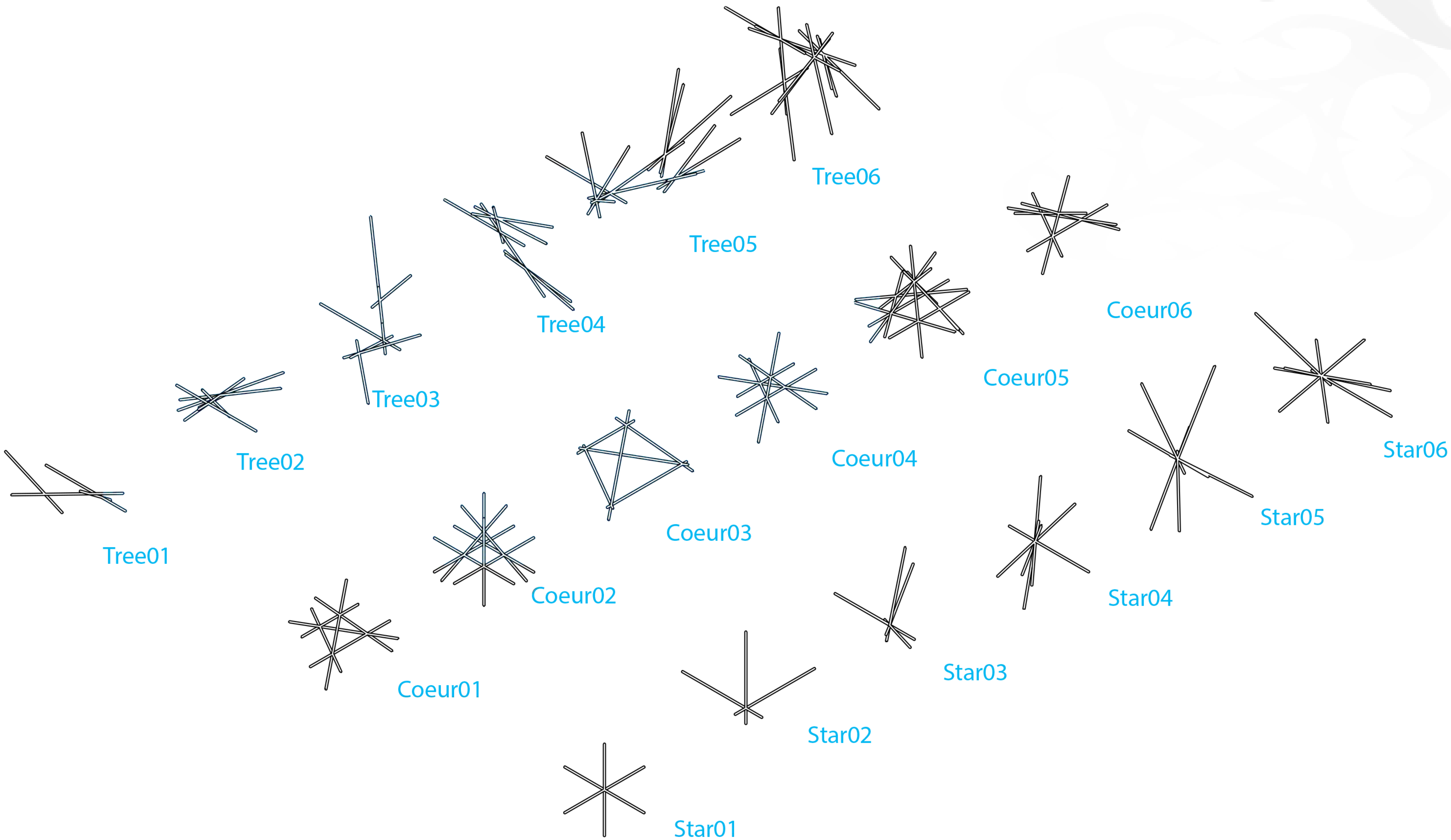
We used a high number of computer simulations to determine the best possible shape for the modules.



Construction (aggregation)

Initial shapes

In order to determine the best geometrical arrangement of the modules, we first defined 3 shapes families each declined in 6 variations. All the modules had the same rod length and diameter.



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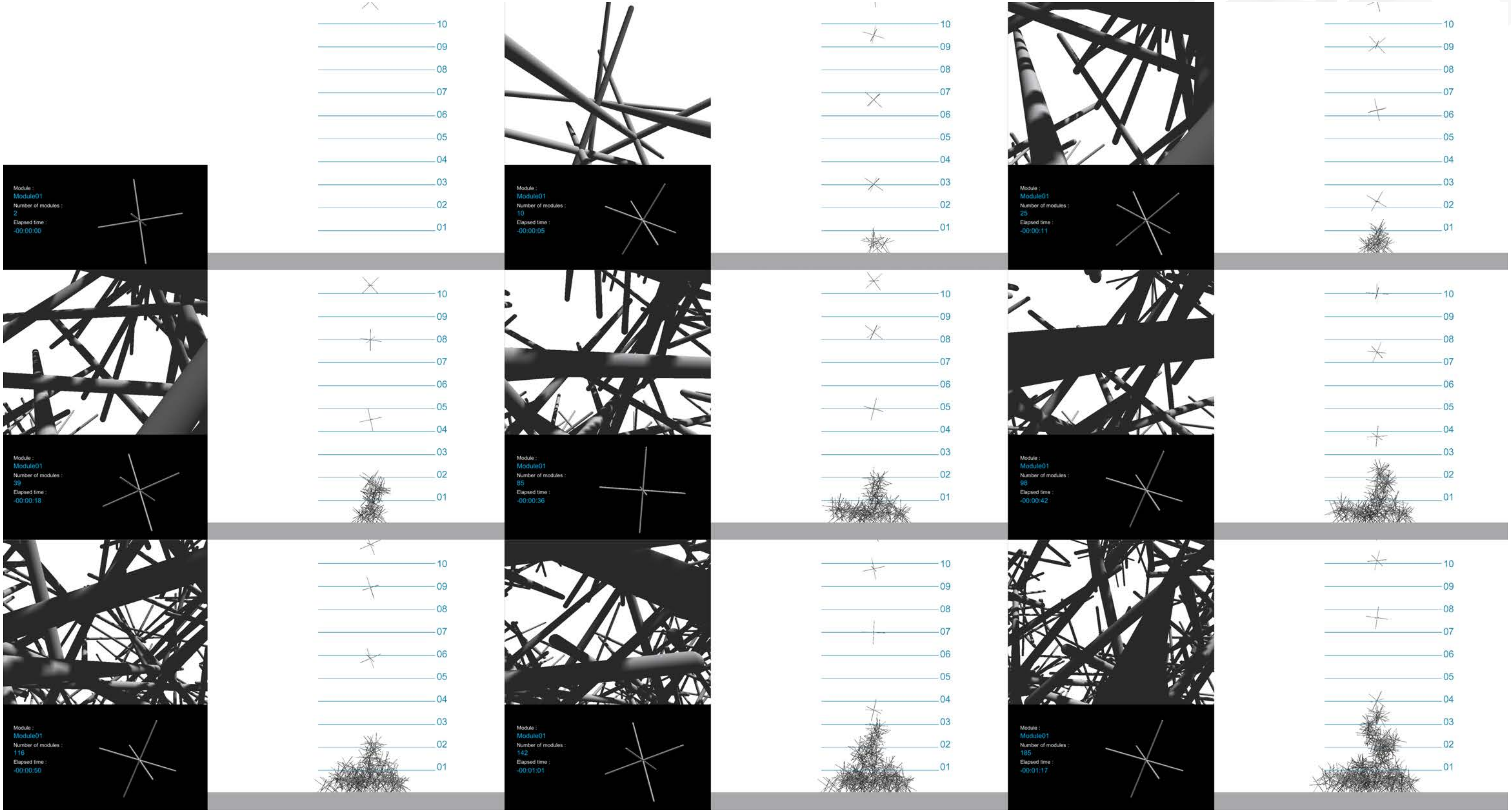
Construction (aggregation)

First set of simulations

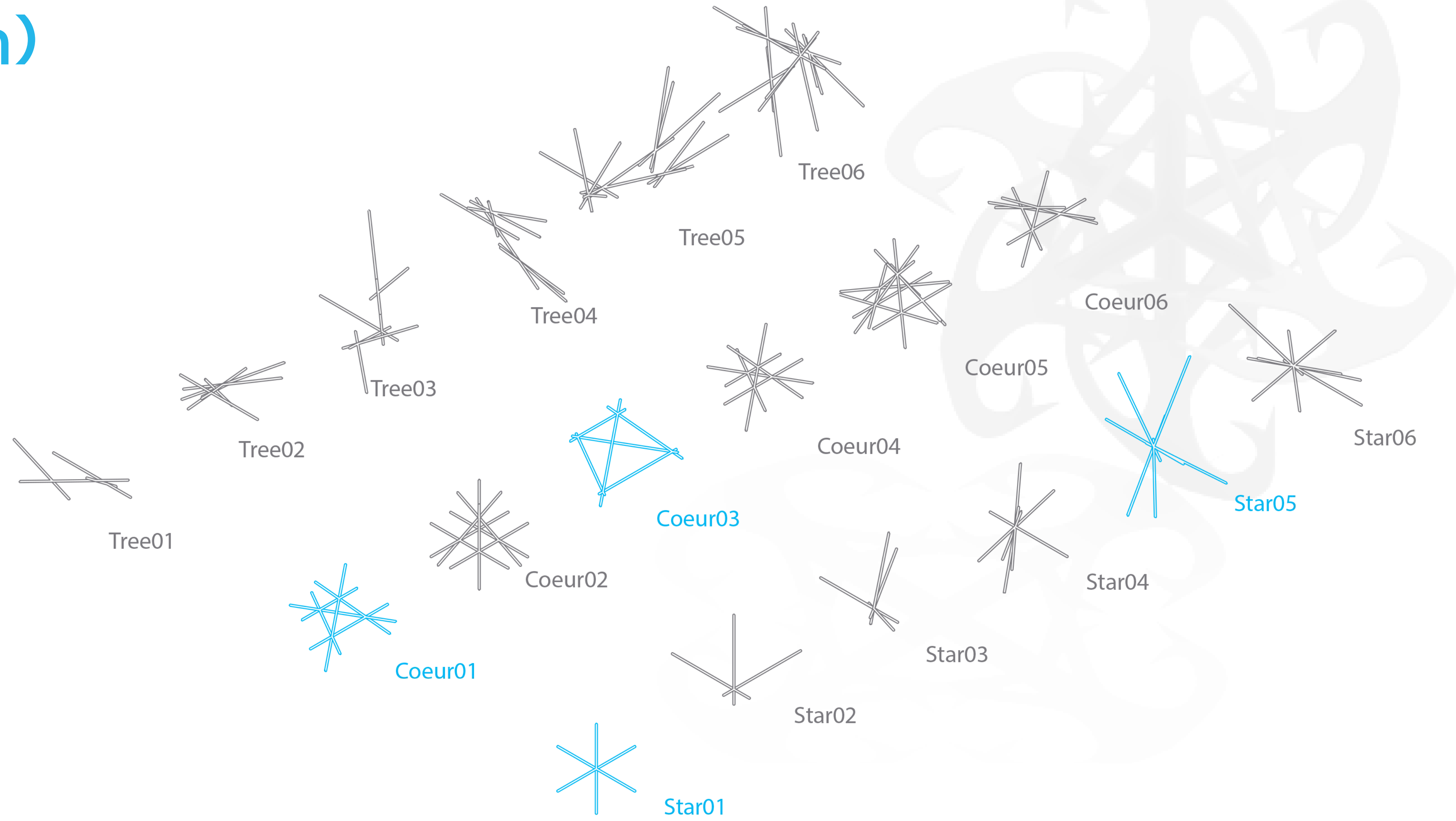
Rigid body simulations on Unity3D.
10 simulations per module / 50 modules per simulation



Construction (aggregation)

Analysis and selection

Selection of the 4 best modules from the analysis



Essai/Module	Star01	Star02	Star03	Star04	Star05	Star06	Coeur01	Coeur02	Coeur03	Coeur04	Coeur05	Coeur06	Tree01	Tree02	Tree03	Tree04	Tree05	Tree06
1	1.95	1.76	1.86	2.86	3.12	2.77	2.31	3.84	3.49	2.55	2.66	2.54	1.47	2.41	3.96	2.46	3.5	3
2	1.89	1.39	2	2.05	3.33	3.21	3.22	3.04	3.86	3.01	2.54	2.43	1.15	1.41	3.69	2.01	2.9	2.58
3	2.06	1.42	1.69	1.98	3.21	2.76	3.06	4.73	4.16	2.76	2.19	2.9	1.93	1.76	4.2	1.9	3.21	3.12
4	1.86	1.6	2.13	1.76	3.09	3.16	3.06	3.64	3.4	2.85	3.31	3.17	1.43	2.2	4.6	1.63	2.84	3.65
5	1.59	1.52	2.28	2.25	3.55	3.84	3.24	4.2	3.24	3.2	2.19	2.38	1.71	2.42	3.95	2.2	4.02	2.33
6	1.91	1.36	1.99	2.19	3.58	2.8	2.62	3.65	3.66	3.3	2.57	2.8	1.6	1.58	3.74	1.48	2.89	2.54
7	1.97	1.66	1.84	1.98	3.47	2.8	3.83	3.86	2.98	2.5	2.87	2.84	1.48	2.03	3.79	2.12	3.54	3.36
8	2.14	1.62	2.24	2.67	3.37	3.25	3.64	3.58	4.4	2.61	2.52	2.6	1.98	2.18	3.86	1.61	3.28	3.54
9	2.12	1.66	2.26	1.95	3.48	3.01	2.89	3.58	3.99	3.1	3.61	2.59	1.82	2.43	3.8	1.5	2.99	2.65
10	1.63	1.74	1.79	2.06	3.44	3.48	3.08	3.61	3.6	2.58	2.95	3.15	1.56	2.44	3.2	2.12	3	3.02
Moyenne	1.912	1.573	2.008	2.175	3.364	3.108	3.095	3.773	3.678	2.846	2.741	2.74	1.613	2.086	3.879	1.903	3.217	2.979
Valeur min	1.59	1.36	1.69	1.76	3.09	2.76	2.31	3.04	2.98	2.5	2.19	2.38	1.15	1.41	3.2	1.48	2.84	2.33
Valeur max	2.14	1.76	2.28	2.86	3.58	3.84	3.83	4.73	4.4	3.3	3.61	3.17	1.98	2.44	4.6	2.46	4.02	3.65
Écart	0.55	0.4	0.59	1.1	0.49	1.08	1.52	1.69	1.42	0.8	1.42	0.79	0.83	1.03	1.4	0.98	1.18	1.32
Barres	3	3	4	5	6	6	6	8	6	6	11	6	4	7	7	7	13	13
Moy/barre	0.64	0.52	0.50	0.44	0.56	0.52	0.52	0.47	0.61	0.47	0.25	0.46	0.40	0.30	0.55	0.27	0.25	0.23
Moy Typo	**0.52956**						**0.46344**						**0.33398**					

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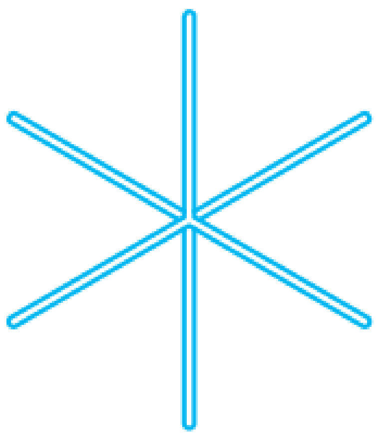
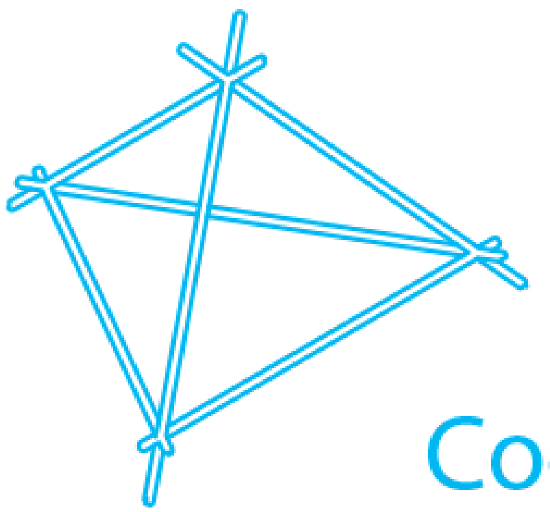
Construction (aggregation)

Second set of simulations (validation)

100 simulations per module / 50 modules per simulation
Selection of the 2 best modules from the analysis



Star01



Coeur03

	Star01	Star05	Coeur01	Coeur03
Min	1.65	2.41	2.02	2.34
Max	2.55	4.20	4.41	4.65
Ecart	0.90	1.79	2.40	2.31
Moyenne	2.10	3.20	3.03	3.45
Barres	3.00	6	6	6
Moy/barre	0.70	0.53	0.50	0.58

Test/Module	Star01	Star05	Coeur01	Coeur03
1	1.83	3.10	2.99	2.78
2	2.20	3.48	2.50	3.97
3	2.35	3.50	2.96	2.64
4	1.87	2.44	2.51	4.23
5	2.00	2.90	2.73	3.64
6	2.04	3.37	3.81	3.00
7	1.98	3.48	2.99	2.84
8	1.93	3.24	3.26	3.66
9	2.27	2.97	2.86	3.52
10	1.90	3.45	3.60	4.65
11	1.72	2.95	3.01	3.64
12	1.68	3.21	2.78	4.32
13	1.88	2.80	2.99	3.08
14	2.51	3.66	3.38	4.16
15	1.81	3.40	3.32	3.63
16	2.25	3.09	3.90	3.01
17	2.23	3.39	3.63	3.62
18	2.08	2.86	2.68	3.89
19	2.37	3.03	3.24	3.59
20	1.94	4.20	3.27	3.51
21	2.06	2.79	3.26	3.38
22	2.42	3.25	2.76	4.17
23	1.97	3.35	3.14	2.85
24	2.18	3.37	4.41	3.13
25	1.65	3.34	2.79	3.85
26	2.16	2.83	2.97	2.44
27	2.17	3.39	3.11	4.06
28	2.14	3.26	2.02	3.28
29	2.22	3.19	3.21	3.72
30	1.95	3.14	2.70	3.50
31	2.08	2.80	3.72	4.05
32	2.30	3.80	3.24	3.50
33	1.90	3.65	2.85	2.53
34	2.07	3.60	2.91	3.62
35	2.04	3.27	3.78	3.69
36	2.28	3.10	2.86	3.44
37	1.92	3.63	2.86	3.41
38	2.04	3.29	3.06	4.00
39	2.02	3.82	2.81	2.49
40	2.39	3.02	3.31	3.66
41	2.03	3.40	2.72	3.72
42	2.15	3.70	3.46	3.69
43	1.94	3.41	3.72	2.45
44	2.33	2.85	3.18	3.72
45	1.69	3.22	3.13	2.70
46	2.25	2.88	2.53	3.59
47	1.94	2.89	2.58	2.79
48	2.00	3.09	2.37	2.75
49	2.04	2.80	2.46	4.20
50	1.94	3.04	2.55	3.42
51	2.10	2.95	2.81	4.22
52	2.33	3.01	3.49	4.06
53	2.22	3.05	3.03	2.76
54	2.03	3.03	3.60	3.64
55	2.43	2.99	2.93	3.89
56	2.37	3.39	2.95	3.64
57	2.40	3.61	2.51	4.31
58	2.55	2.51	2.68	3.49
59	1.92	3.05	3.28	3.08
60	1.93	3.46	3.03	3.29
61	1.92	2.70	2.26	4.22
62	2.04	3.36	2.98	3.77
63	2.44	3.29	3.48	3.88
64	2.51	3.15	3.30	2.34
65	2.21	2.85	2.84	2.69
66	2.35	2.90	3.26	3.88
67	1.94	2.86	2.94	3.04
68	1.91	3.32	3.18	3.45
69	2.02	3.59	2.60	3.32
70	1.97	3.15	2.90	3.96
71	2.06	3.05	3.41	2.93
72	2.49	3.50	3.38	3.60
73	2.18	2.82	2.42	4.28
74	2.11	3.29	3.12	2.73
75	2.07	3.16	2.96	3.17
76	2.06	3.43	2.96	2.61
77	1.99	2.86	3.36	3.48
78	2.38	3.32	3.37	2.42
79	1.99	2.52	2.14	2.91
80	2.23	3.08	2.63	2.96
81	1.91	3.26	3.09	3.36
82	2.47	2.65	2.85	2.60
83	2.00	3.23	3.11	2.95
84	2.16	3.25	2.64	3.81
85	2.33	3.63	2.79	3.04
86	2.17	3.12	3.04	3.61
87	1.94	3.66	3.04	3.92
88	2.10	3.44	2.54	3.37
89	2.17	2.91	3.00	3.71
90	2.17	3.16	4.05	3.37
91	1.71	2.95	2.56	3.93
92	2.09	2.74	3.25	3.40
93	2.20	3.21	2.89	4.38
94	2.29	3.35	3.51	3.53
95	2.03	3.80	3.19	2.94
96	2.15	3.99	2.51	3.29
97	2.02	2.41	3.15	4.24
98	2.41	3.91	2.16	3.85
99	1.85	3.04	3.01	3.09
100	2.06	3.60	3.56	3.62
Min	1.65	2.41	2.02	2.34
Max	2.55	4.20	4.41	4.65
Ecart	0.90	1.79	2.40	2.31
Moyenne	2.10	3.20	3.03	3.45
Barres	3.00	6	6	6
Moy/barre	0.70	0.53	0.50	0.58

Construction (aggregation)

Prototyping

3 prototypes were made from the previous results and made us realized that we would need another production principle : faster and allowing more complexity.

Node:
3D assembly

hypothesis :
cutting materials (in set-wood, or other type of assembly)

Node:
Assembling added on unitary bars

hypothesis :
no standard connection 3D printing
expensive connections
low cost bars

Node:
Notch in case surfaces:

hypothesis:
lazer, water cuting depends of the material.
Low cost material.
Low cost shaping

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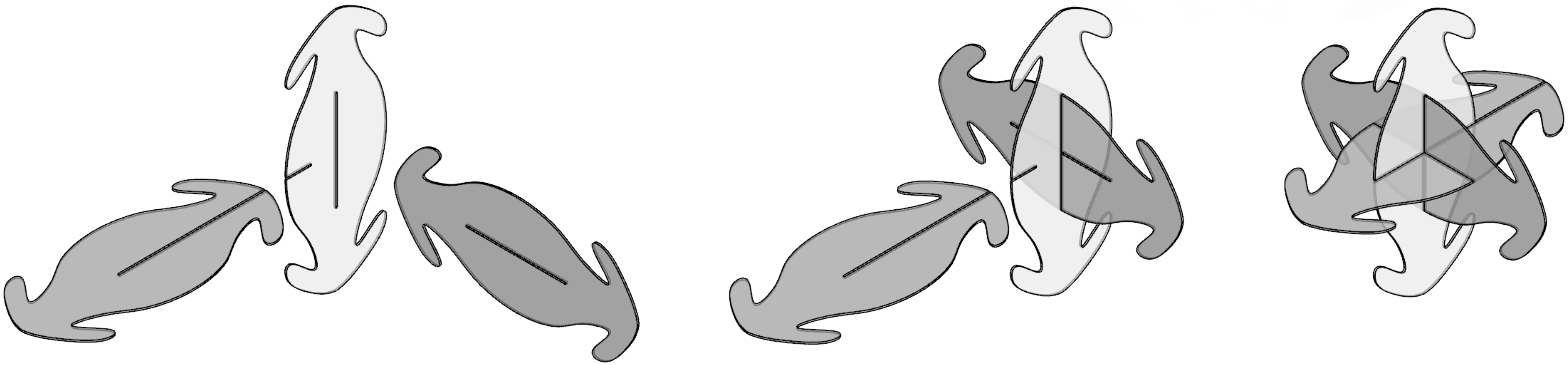
Construction (aggregation)

Prototyping

Lasercuting on cardboard and a simple assembly process.
Allows us to add more complexity, like hooks and loops.



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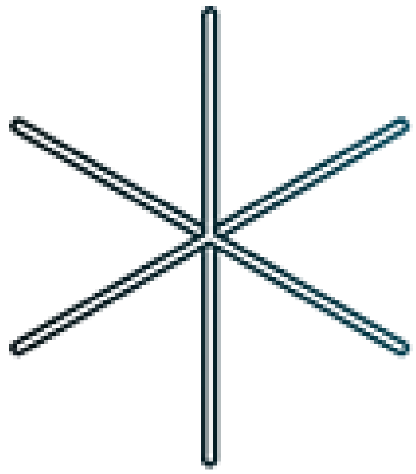
Construction (aggregation)

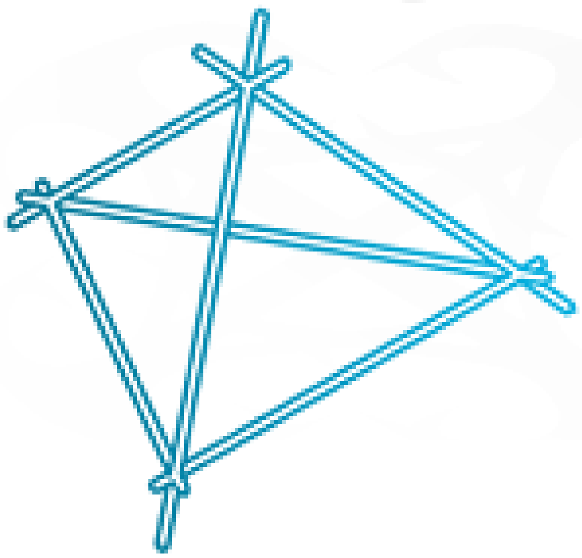
Cardboard shapes definition

Definition of 3 different morphologies corresponding to 3 densities, from the first results and the simple assembly process.

Star01



Coeur03



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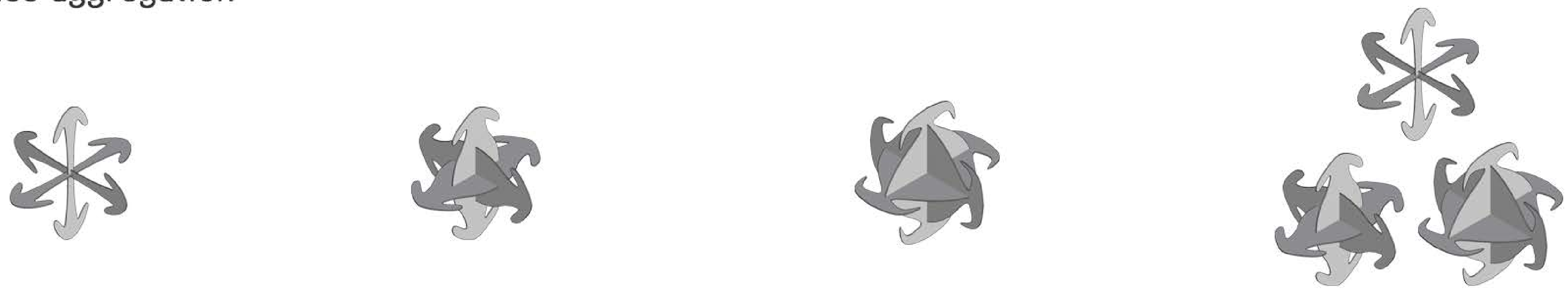
Construction (aggregation)

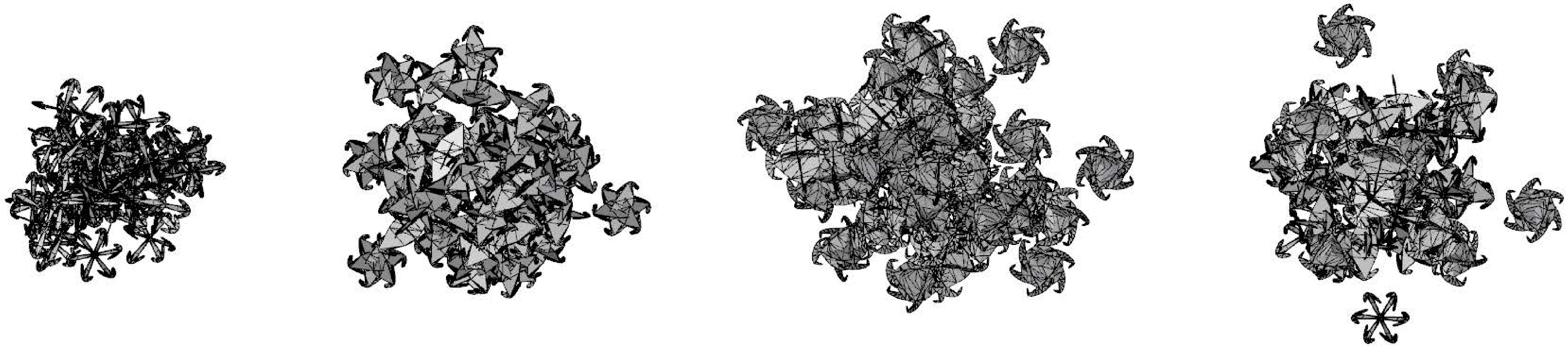
Different densities

50 Modules aggregation

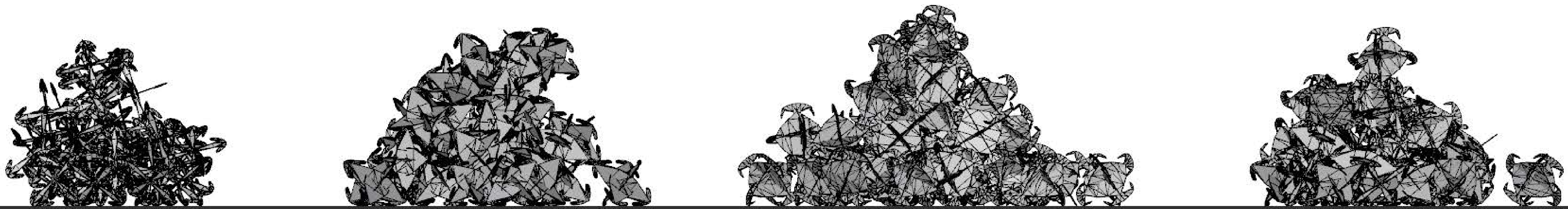
Type



Top view



Front view



Enveloppe :	0.162 m^3	0.357 m^3	0.411 m^3	0.257 m^3
Densité :	300 u/m^3	150 u/m^3	120 u/m^3	200 u/m^3

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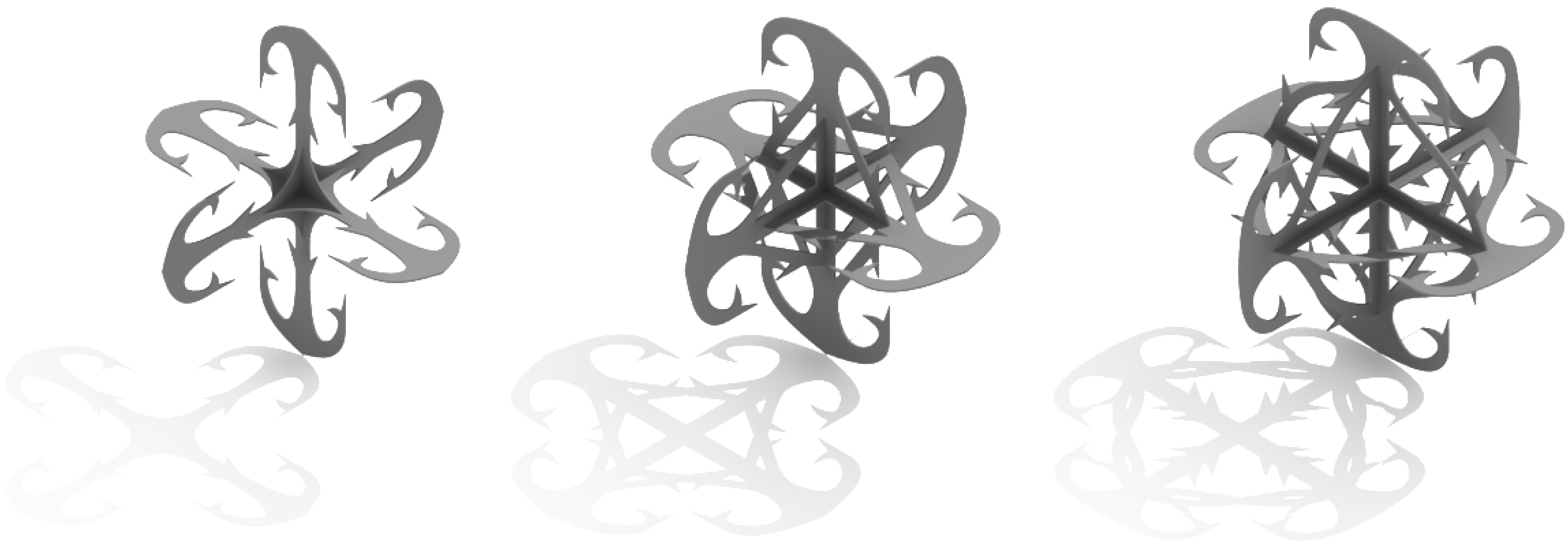
Construction (aggregation)

Last version (more hooks and loops)



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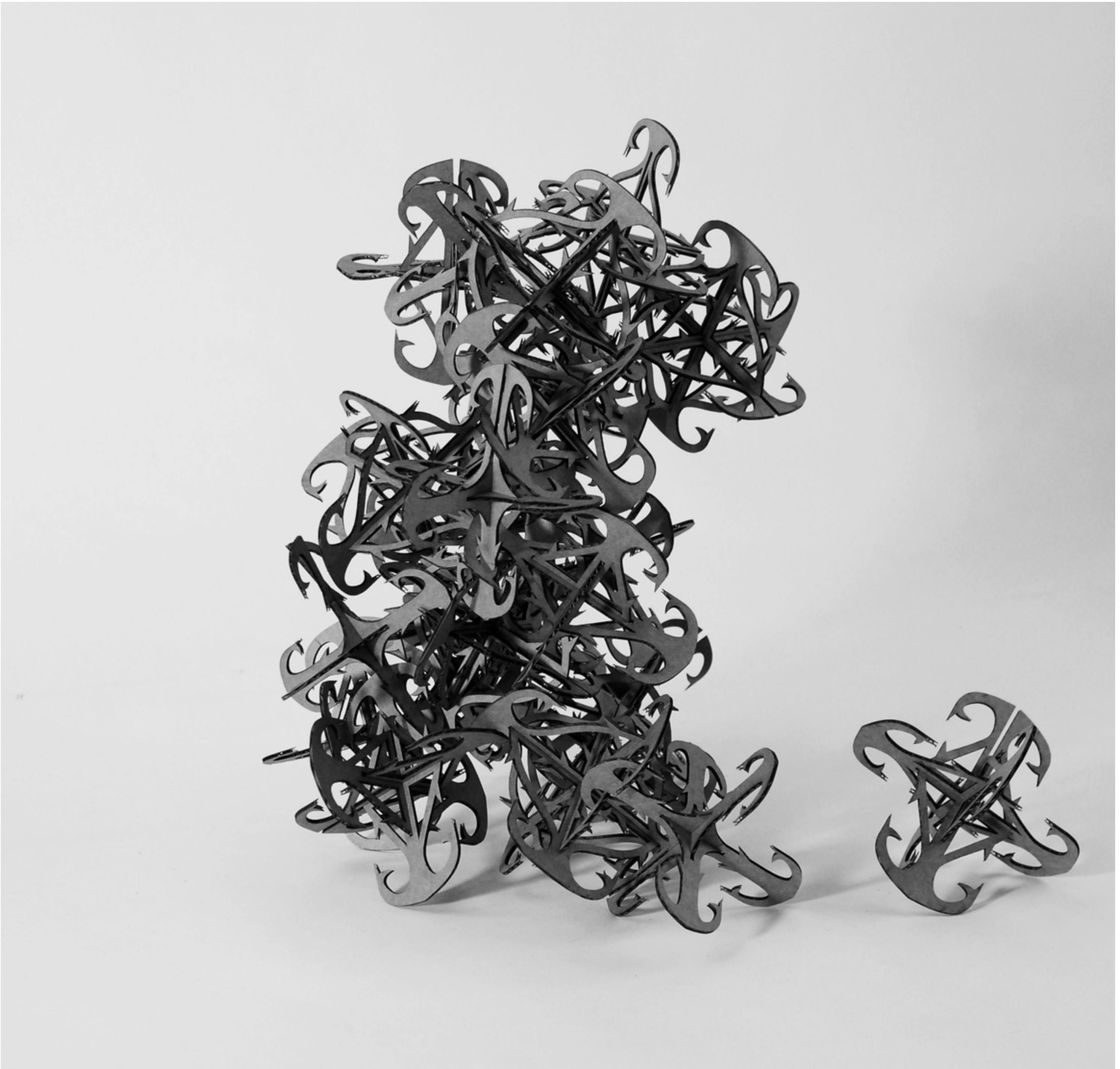
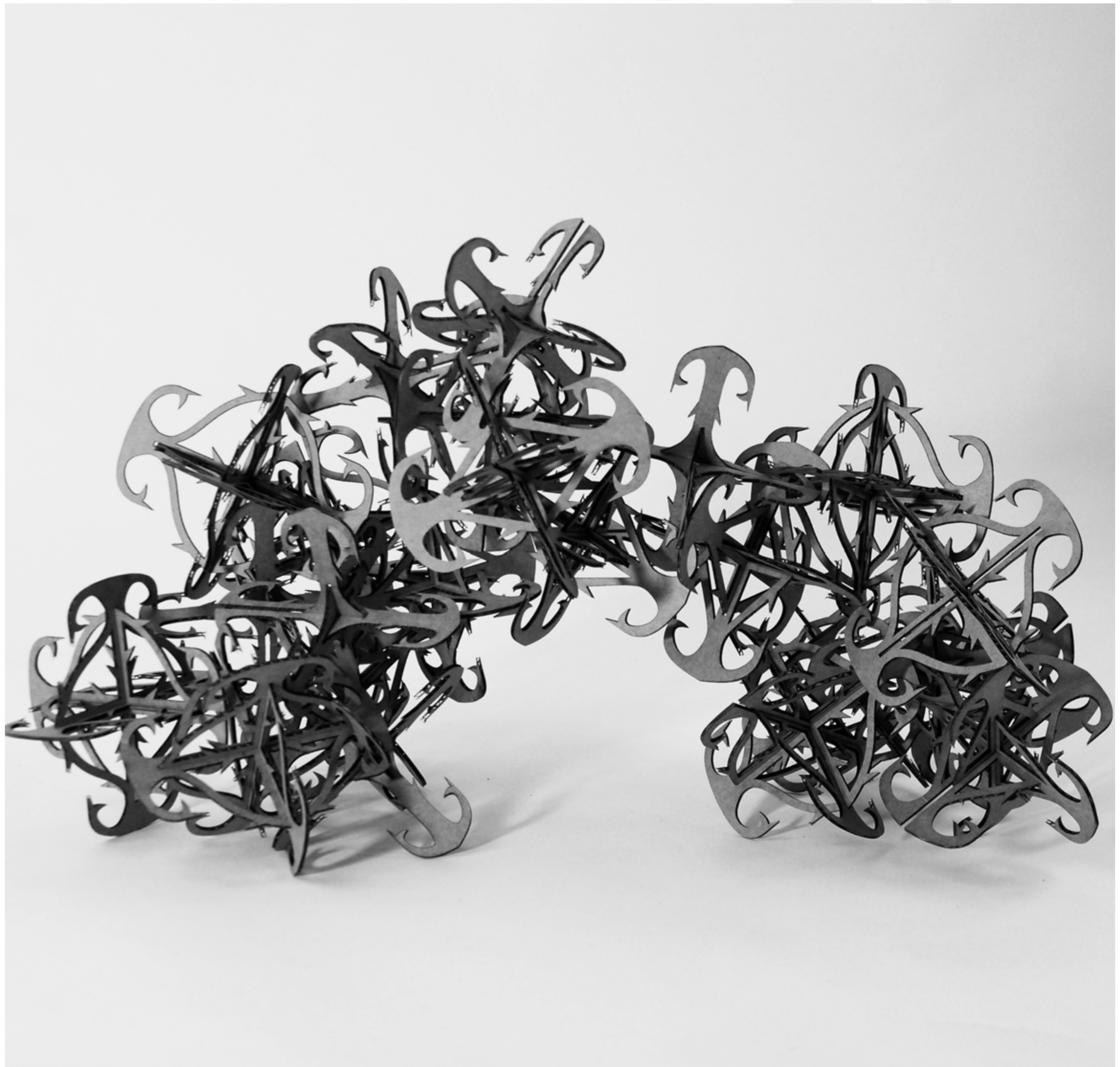
Construction (aggregation)

Final geometry

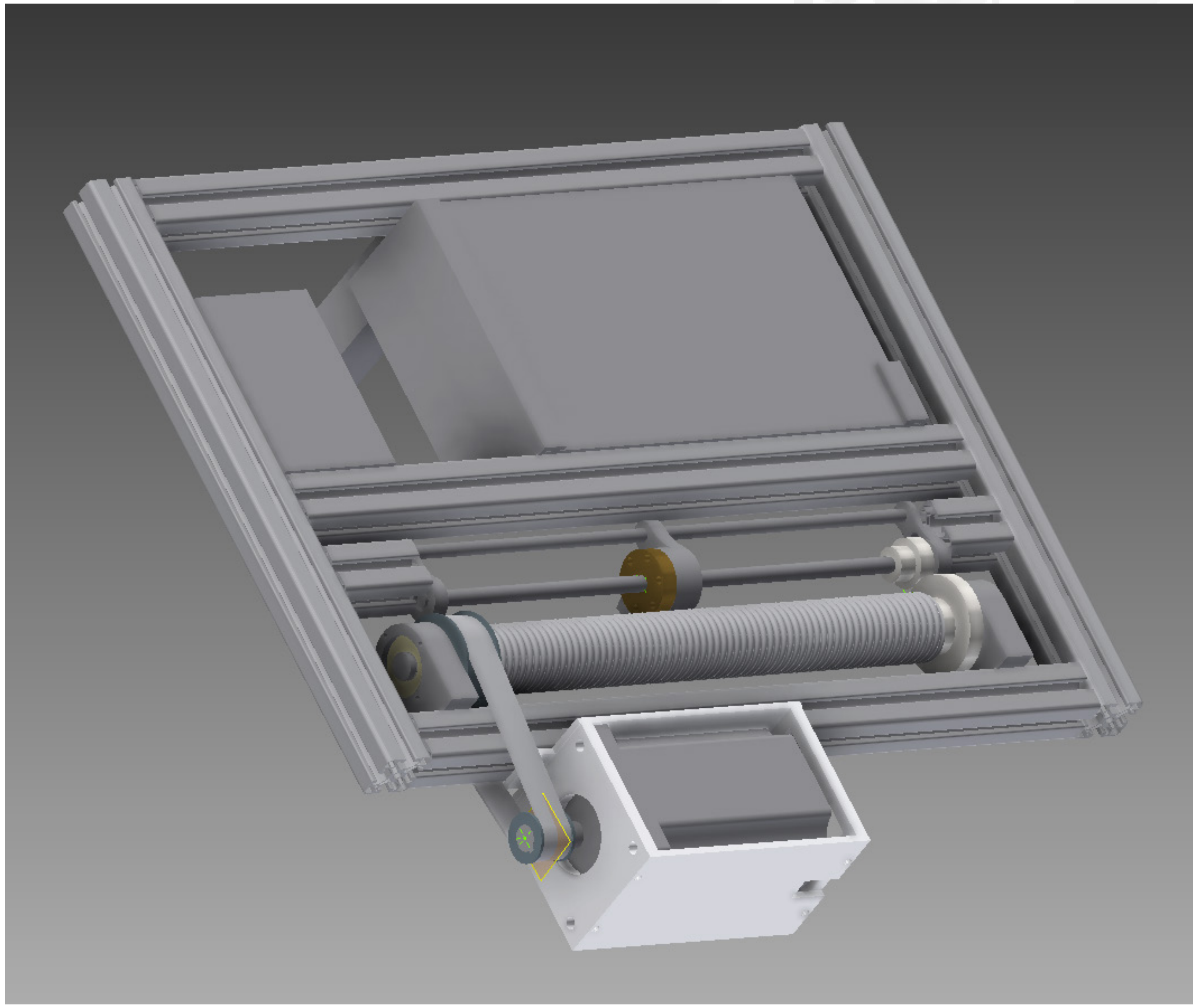
Cantilever are possible due to the hooks.
In the next physical tests we would use different sizes for each modules in order to recreate a pseudo granulometry.





Handmade aggregations

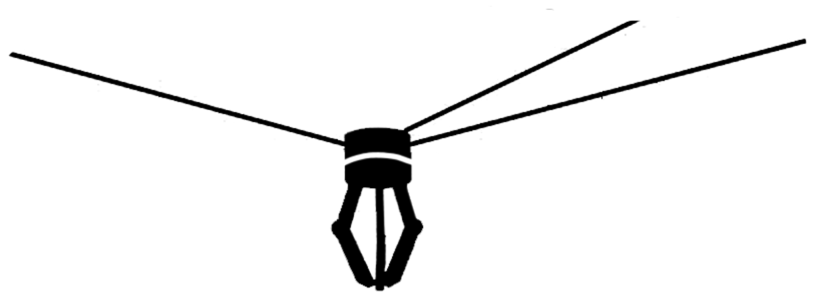
Summary



Hardware (Robotics)

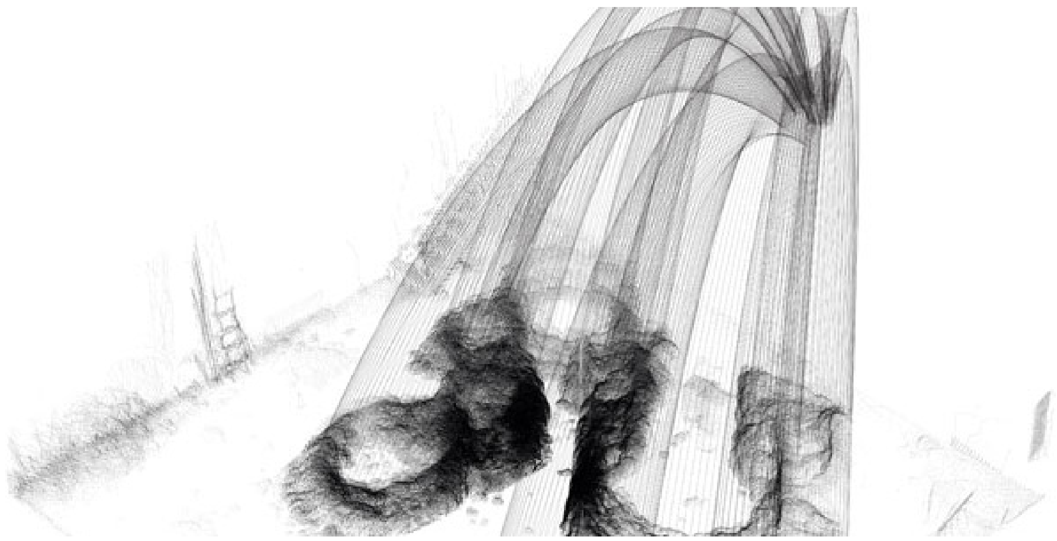
Hardware proposition

Three automated manufacturing systems were first considered:



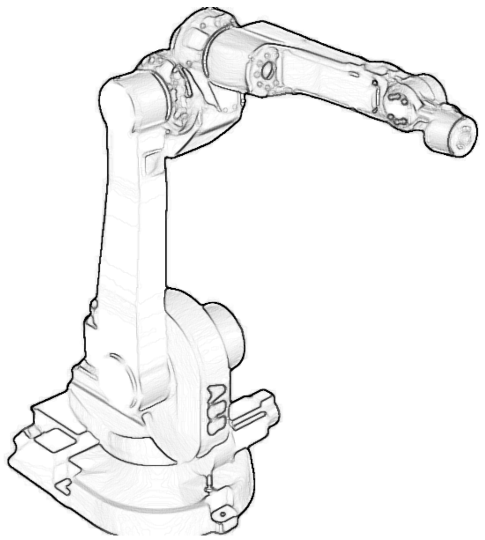
- Wirebot

reachable volume +or- 100 m^3
small spatial occupation
only works in traction



- Ballistic

reachable volume +or- 200 m^3
no spatial occupation
only works in space with high ceilings



- 6 axis robot

reachable volume +or- 20 m^3
large spatial occupation
works with high precision and strength

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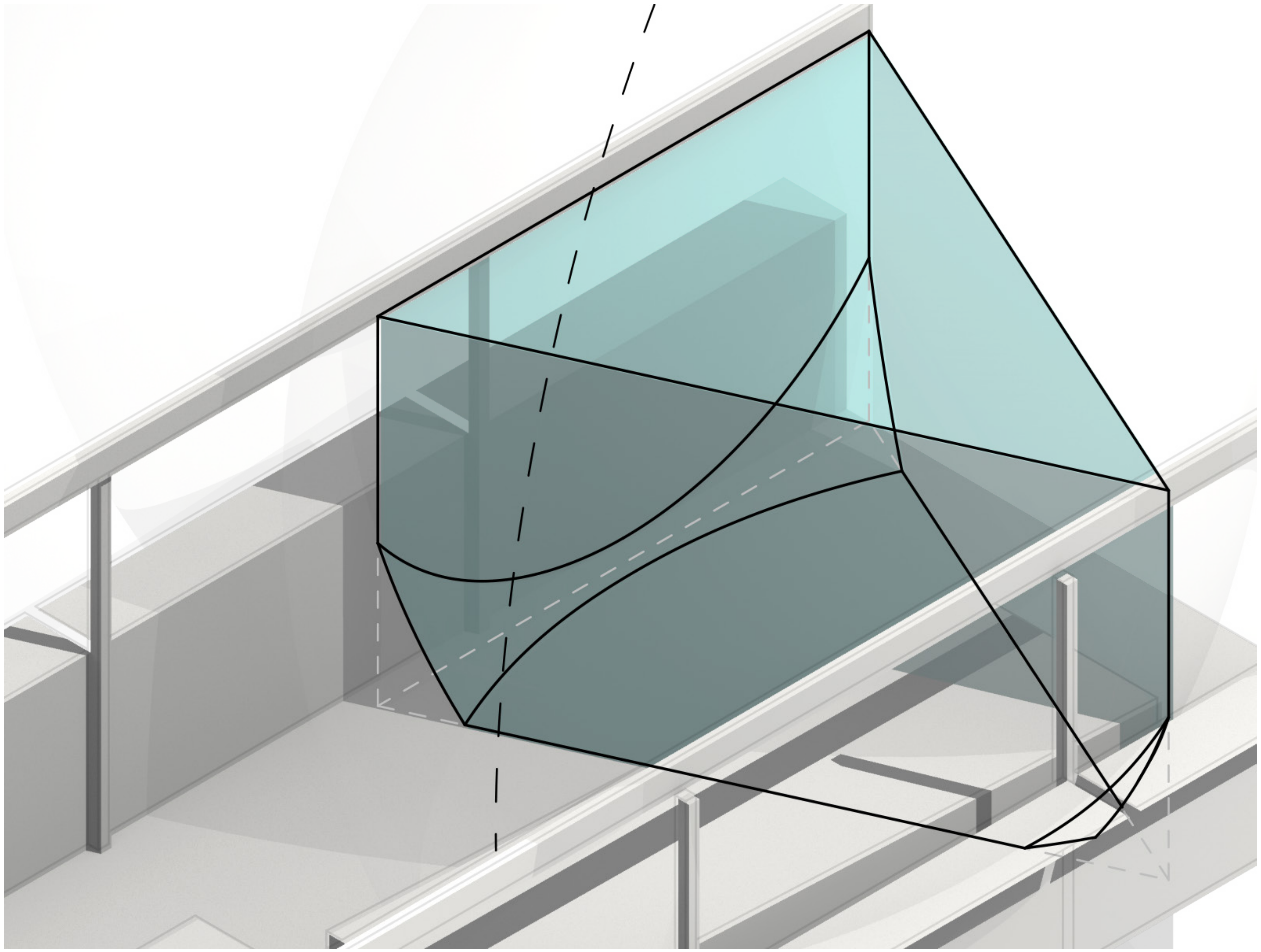
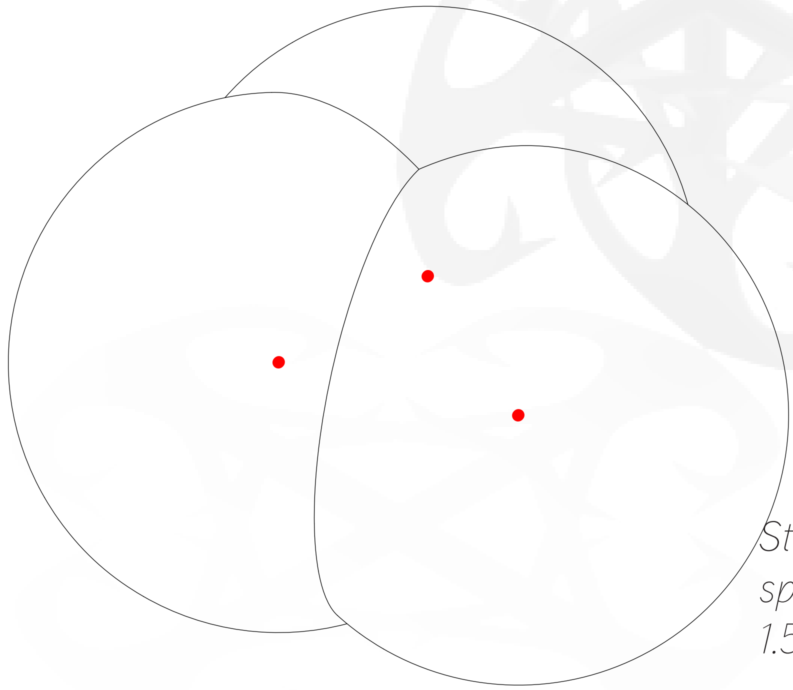
Hardware (Robotics)

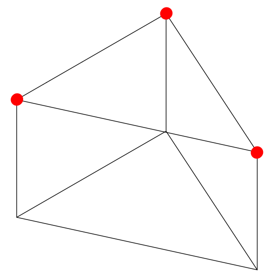
Wirebot workable area

The workable area is first defined by the length of the wires.

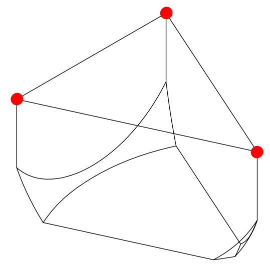




Step 1 : potential space $1.51*10^4\ m^3$



Step 2 : potential space $312\ m^3$



Step 3 : potential space $307\ m^3$

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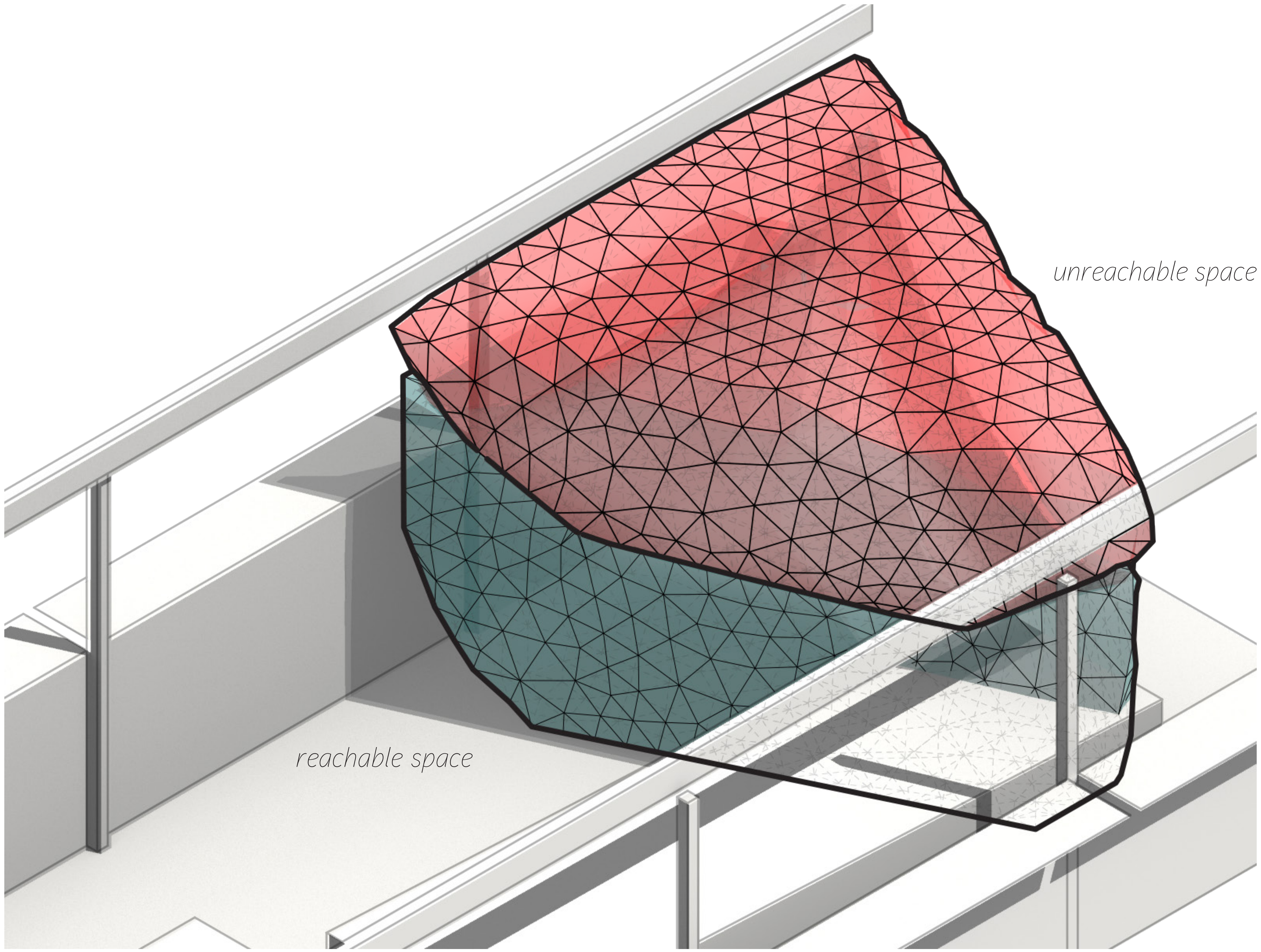
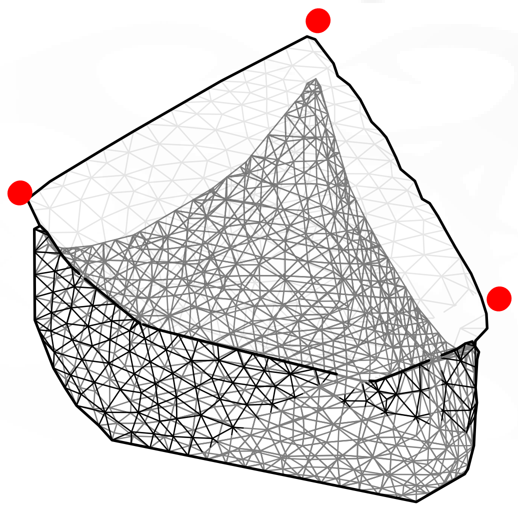
Hardware (Robotics)

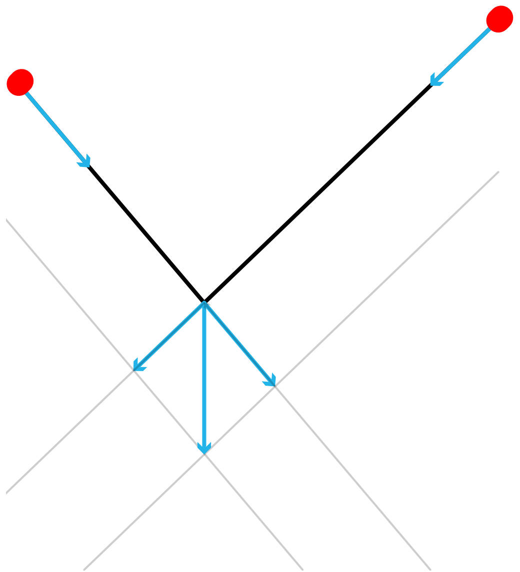
Wirebot workable area

The workable area is then defined by the wire tension.
Stochastic and concurrent forces analysis of the room in order to determine the reachable volume.





Step 4 : potential space 143 m^3



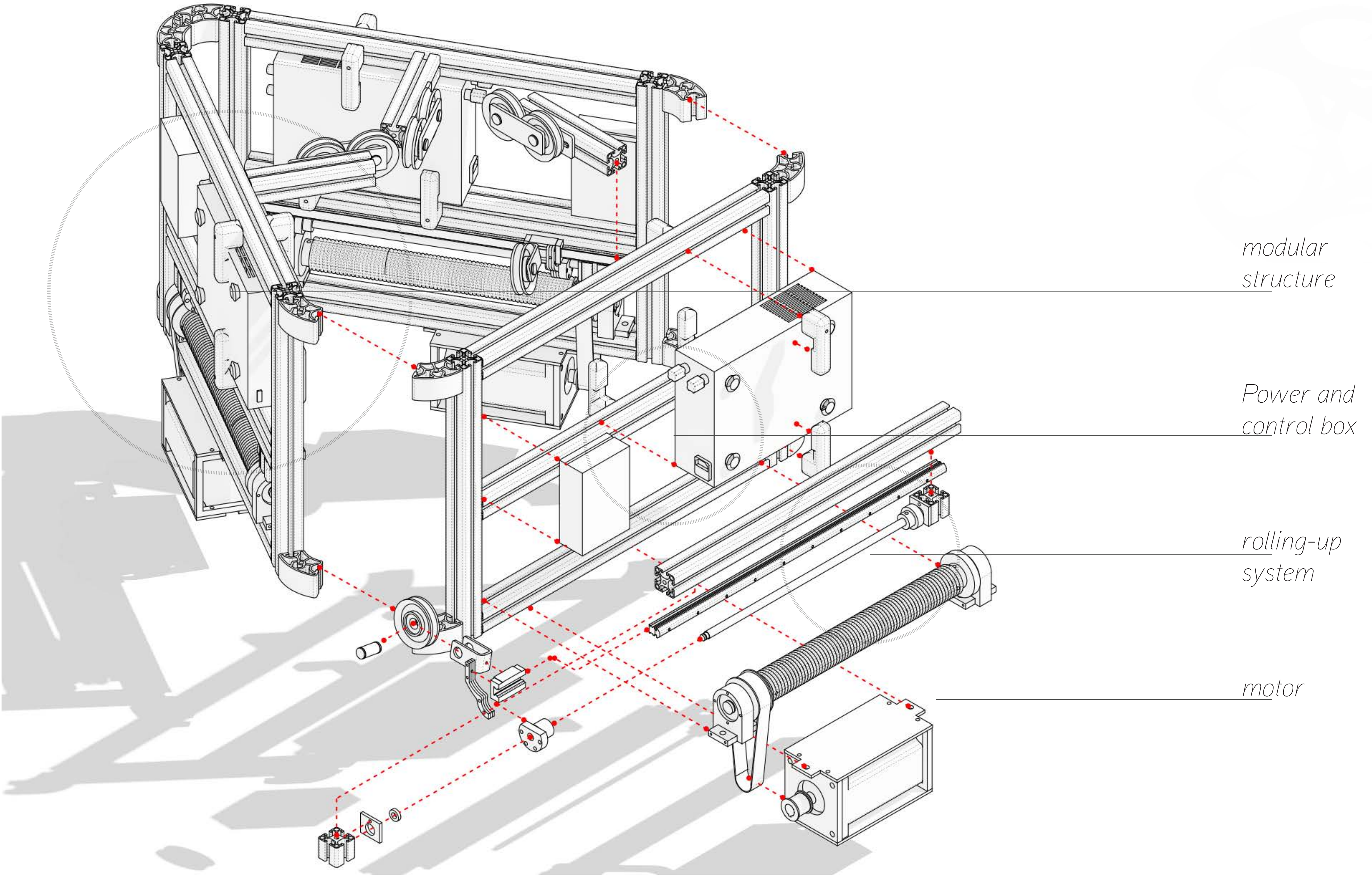
method of concurrent forces "static graphic"

Hardware (Robotics)

Exploded view

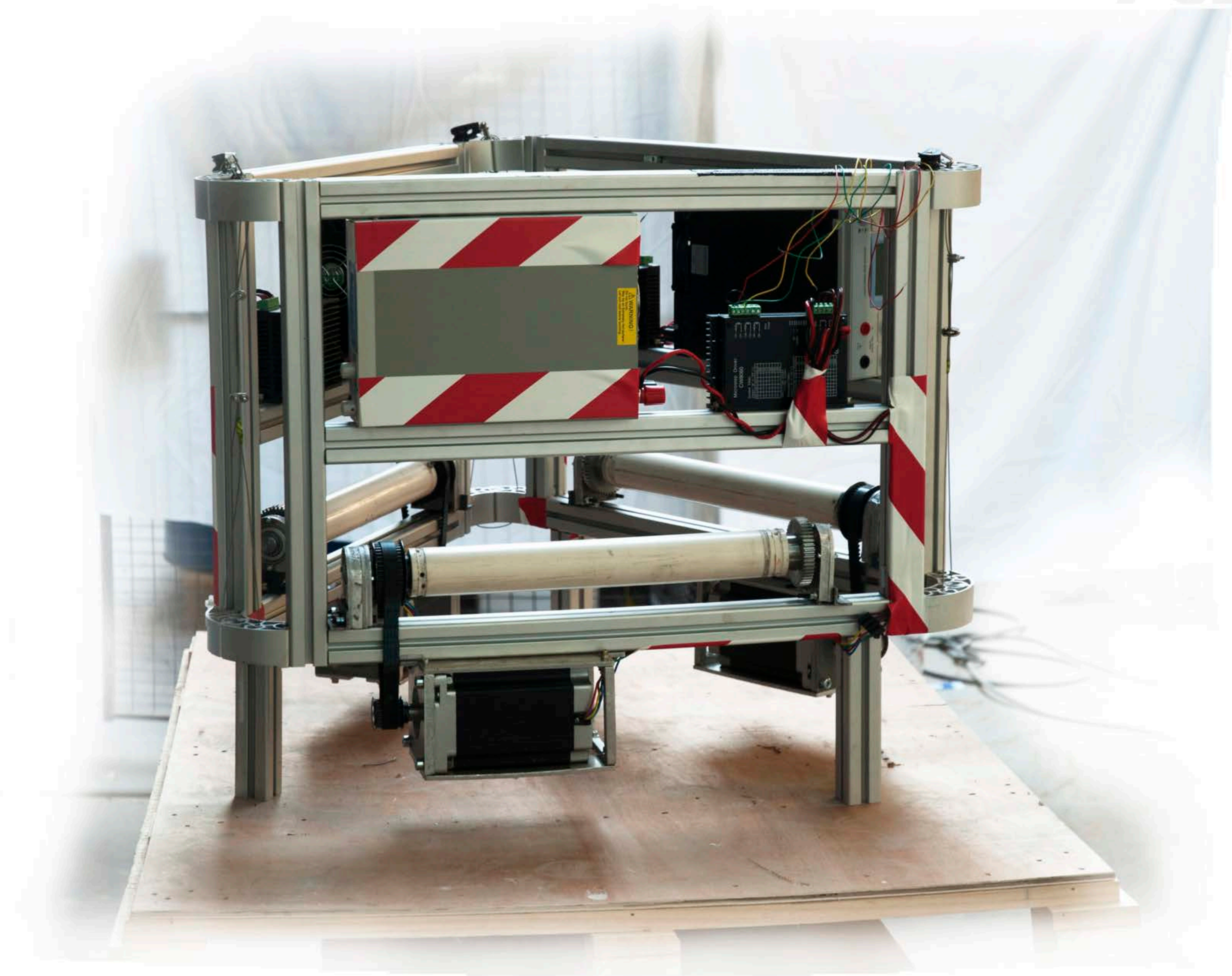
Mechanical and electronics proposal ("Standalone")

- *Arduino DUE*
- *Stepper Drivers 6A*
- *NEMA 2400 N-cm*
- *Servo*
- *ELCOM structure*
- *Cable metal*



Hardware (Robotics)

Fabrication



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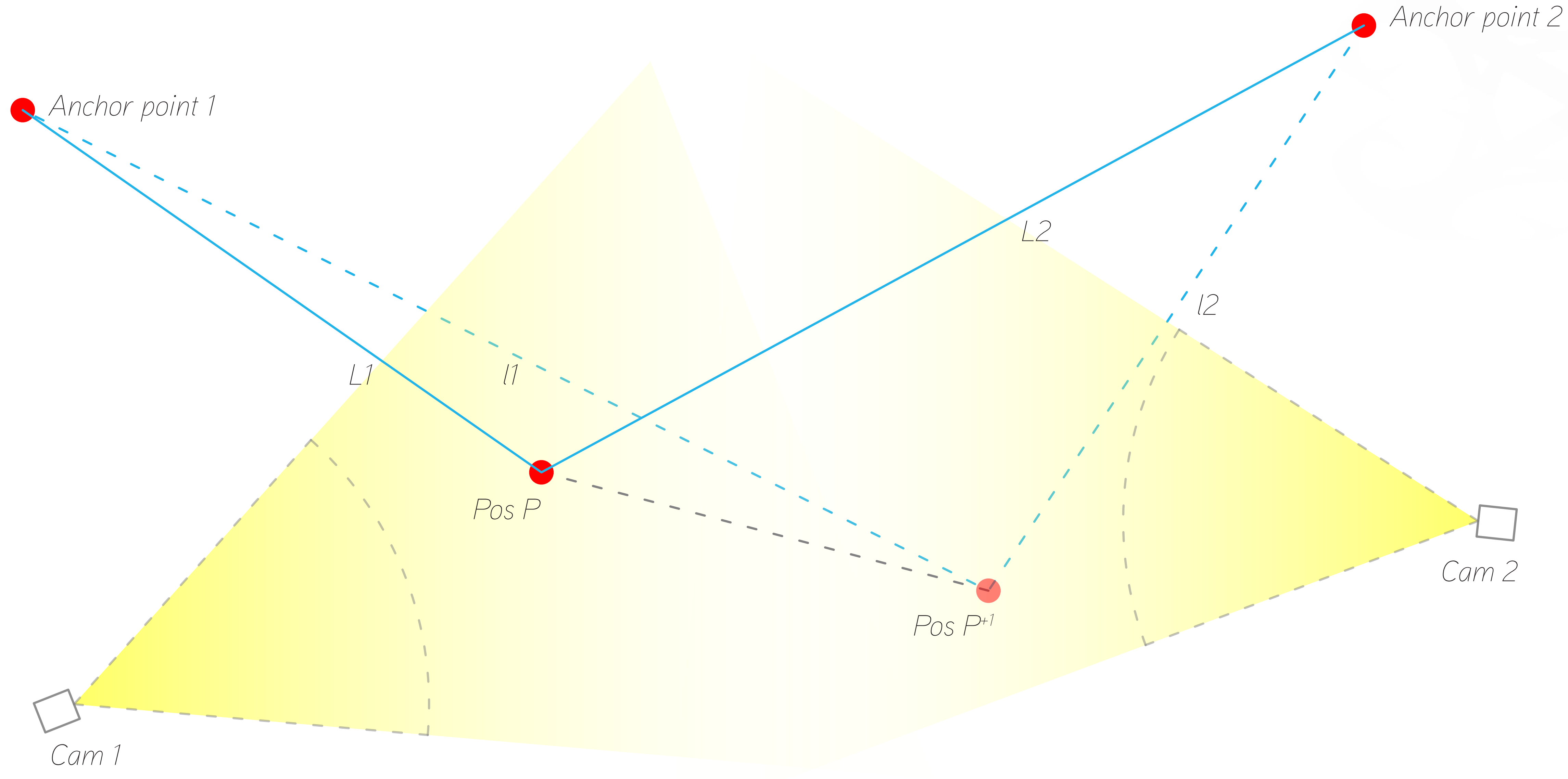
Hardware (Robotics)

Control proposal



Variables :
Vmax

Slaving relationship :
$L1 - L2 = \Delta L$
$l1 - l2 = \Delta l$

$V\Delta x = \Delta x / Vmax$
if (dist(Pos P , Pos P^{+1}) ≈ 0){
Vmax = 0
}

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Summary

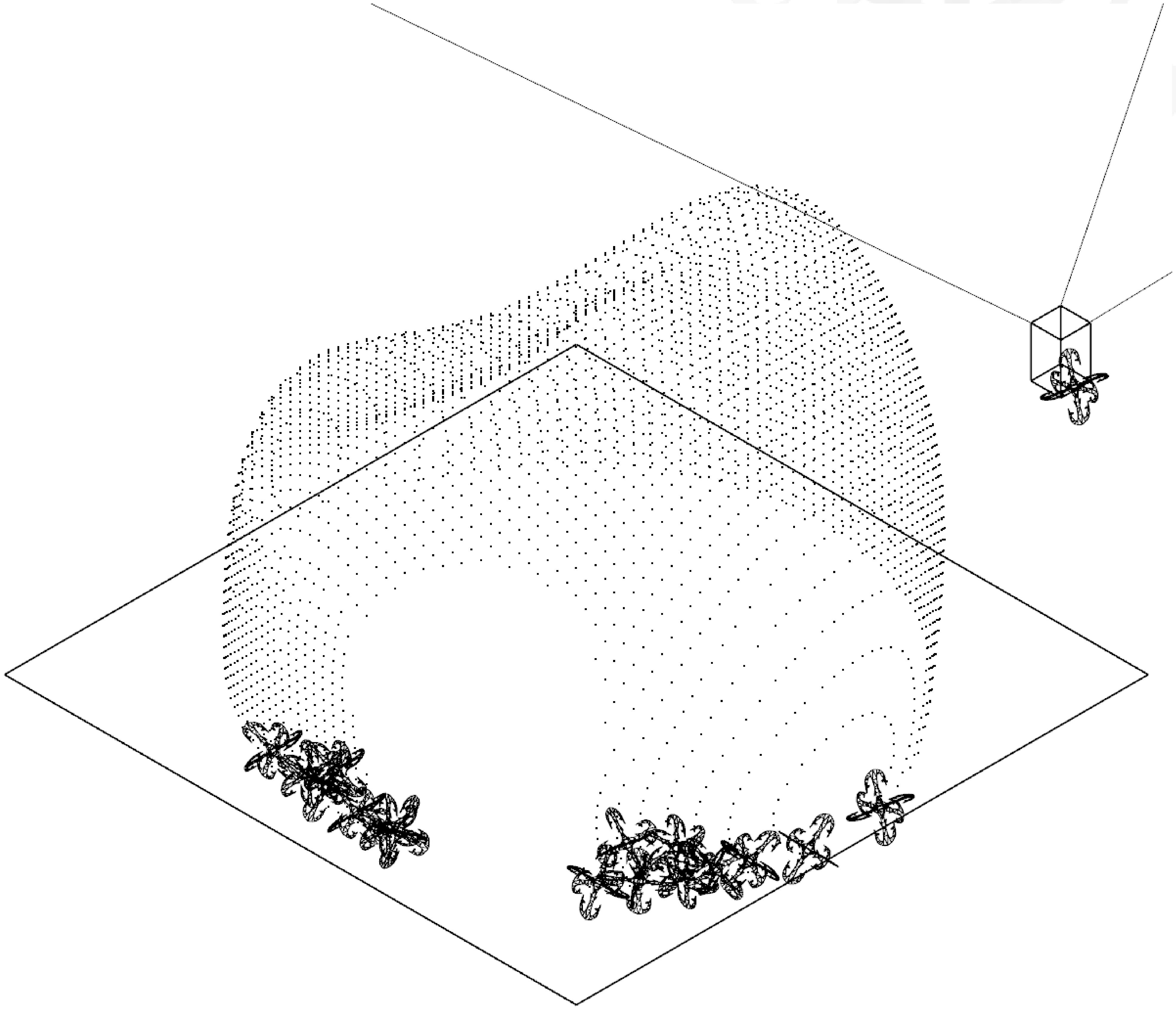
A) Dealing with unpredictability

B) System

1) Construction (Aggregation)
2) Hardware (Robotics)
3) Adaptability (Vision)
4) Software (Voxelizer)

C) Production

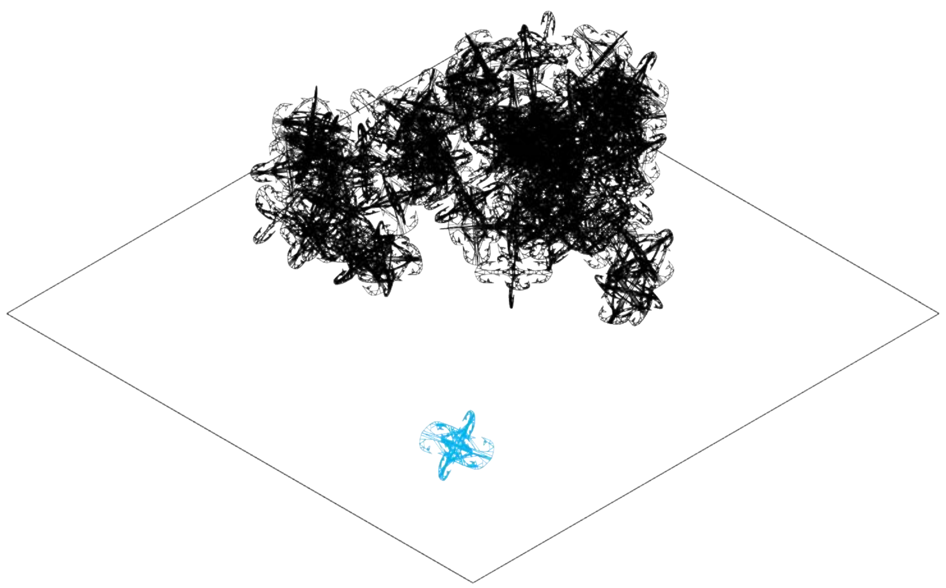
D) Development



Adaptability (Vision)

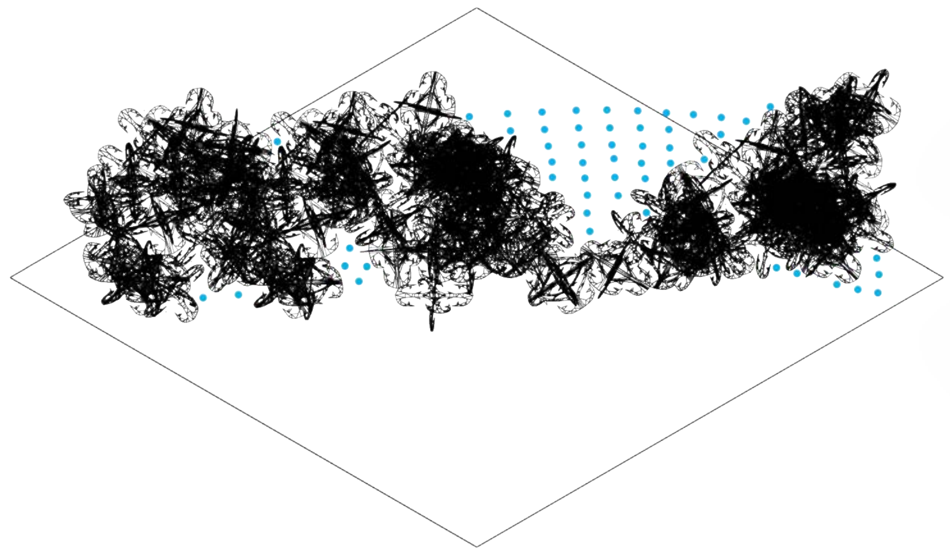
Error types

3 different error types can happen during the construction process :



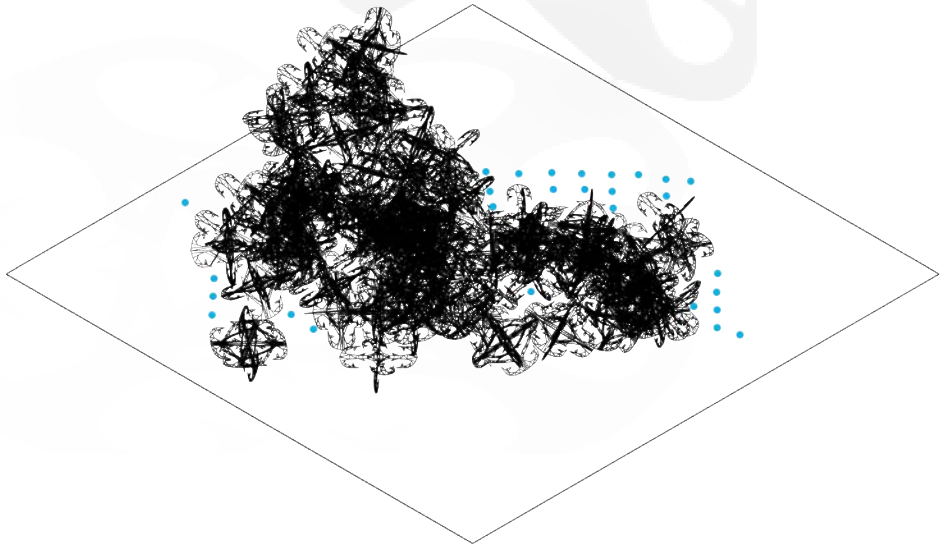
1. A module can fall, fail or rebound off its target instead of hooking on, and stay isolated on the floor.

Solution :
If the robot can reach it, reuse it.



2. One or several module can fall, or the target spacing generated by the initial shape discretization can be too wide for the chosen aggregate density, resulting in a lack of density at some points of the structure.

Solution :
Fill the gaps.



3. The targets spacing generated by the initial discretization can be too dense for the chosen aggregate density, resulting in emergent artefacts due to a veryW high amount of modules dropped at the same place.

Solution :
Ignore the targets that are already occupied.

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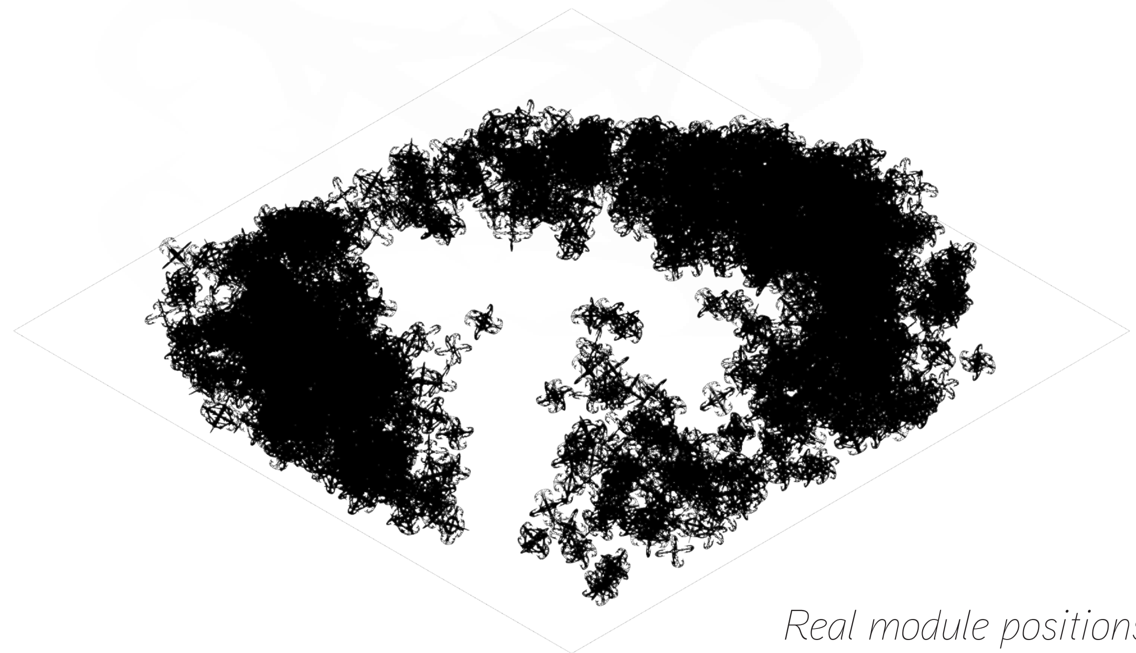
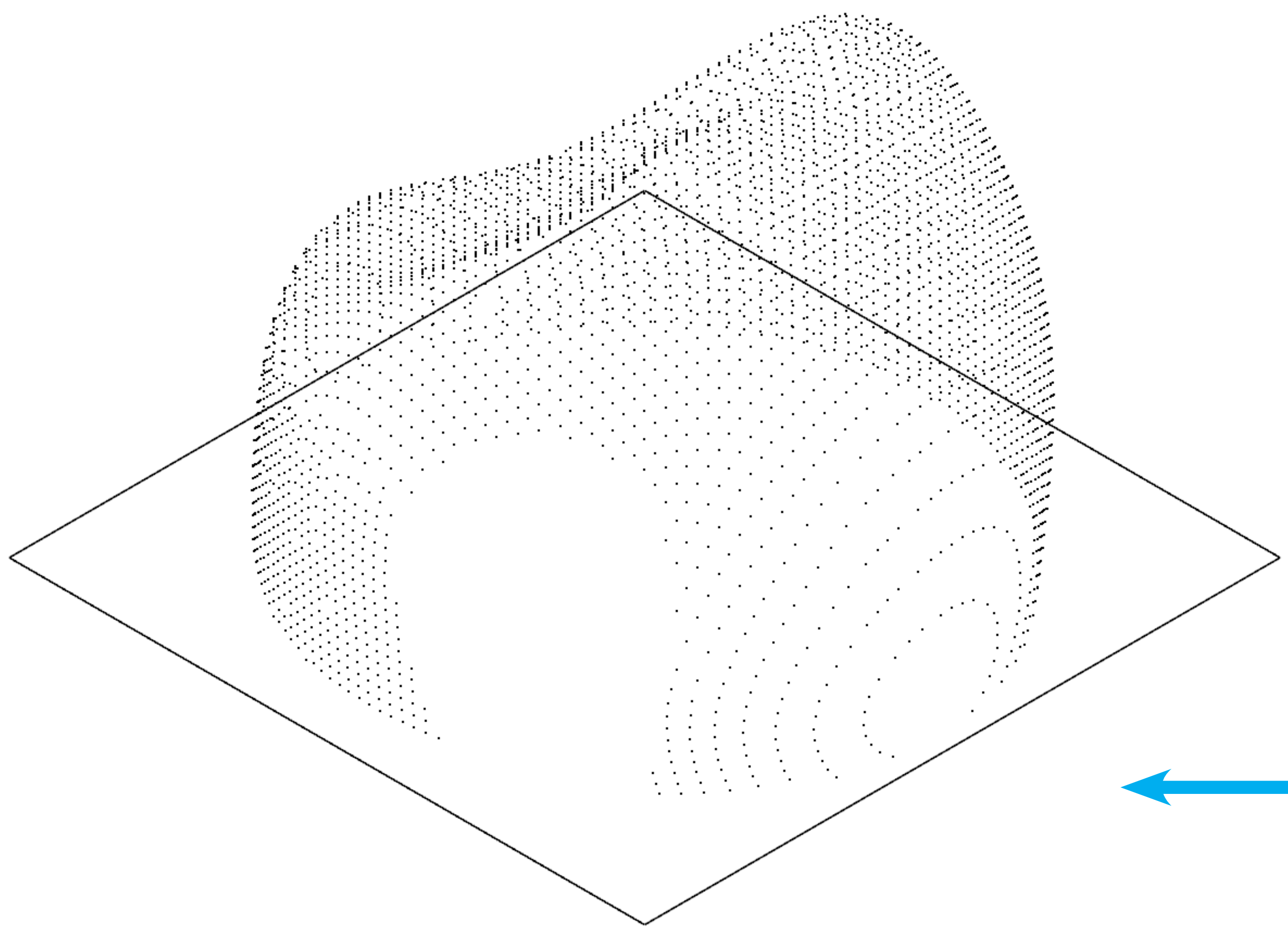
Adaptability (Vision)

Errors detection

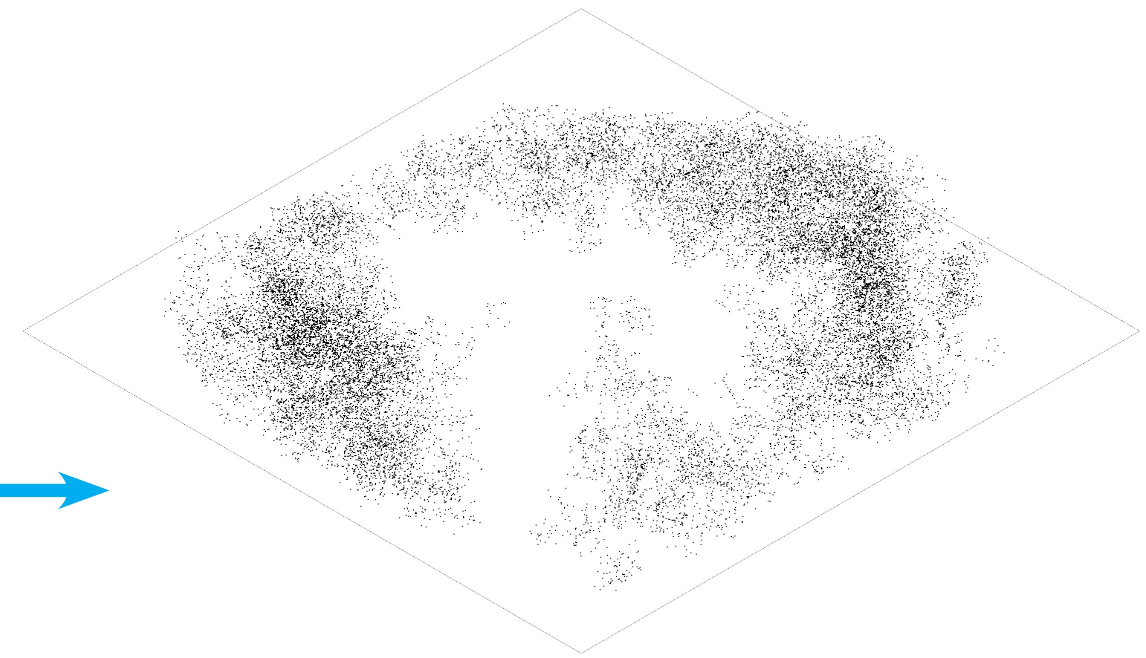
In order to detect the 3 types of error, we are scanning the construction scene using two kinects at every new module drop. Because we can't detect the position of each module precisely, we are forced to analyse the aggregate as a whole by isolating the modules with their color. We then have to compare a static points cloud (the targets), with a dynamic point cloud (the scan). We use simple "closest point" tests in order to determine if a target has correctly been filled by a module.



Real module positions



Closest point tests



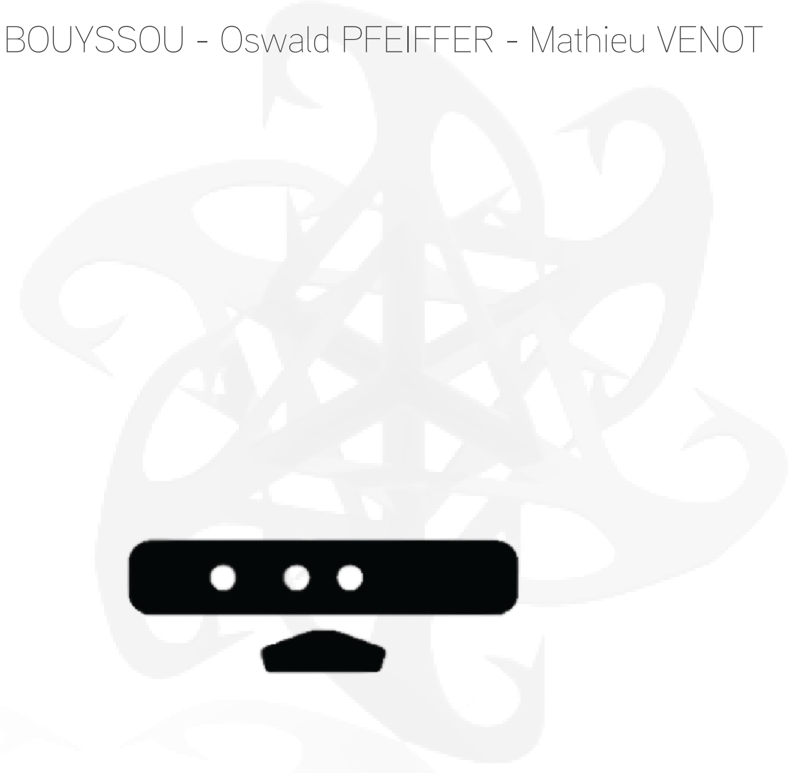
Static points cloud (targets)

Dynamic points cloud (scanned)

Adaptability (Vision)

Feedback loop

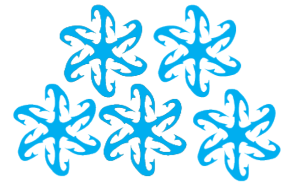
For each new drop :

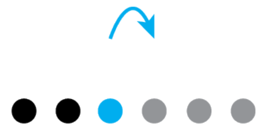


1. Scene scanning

2. IF some modules are isolated → Use fallen module

ELSE → Use stock modules





3. As long as some targets are remaining in the list :

CLOSEST POINT TEST

IF there is at least one scanned point close to the target → Target++

ELSE → **Drop a module** / Target++

4. ELSE IF there's no targets remaining in the list :

END

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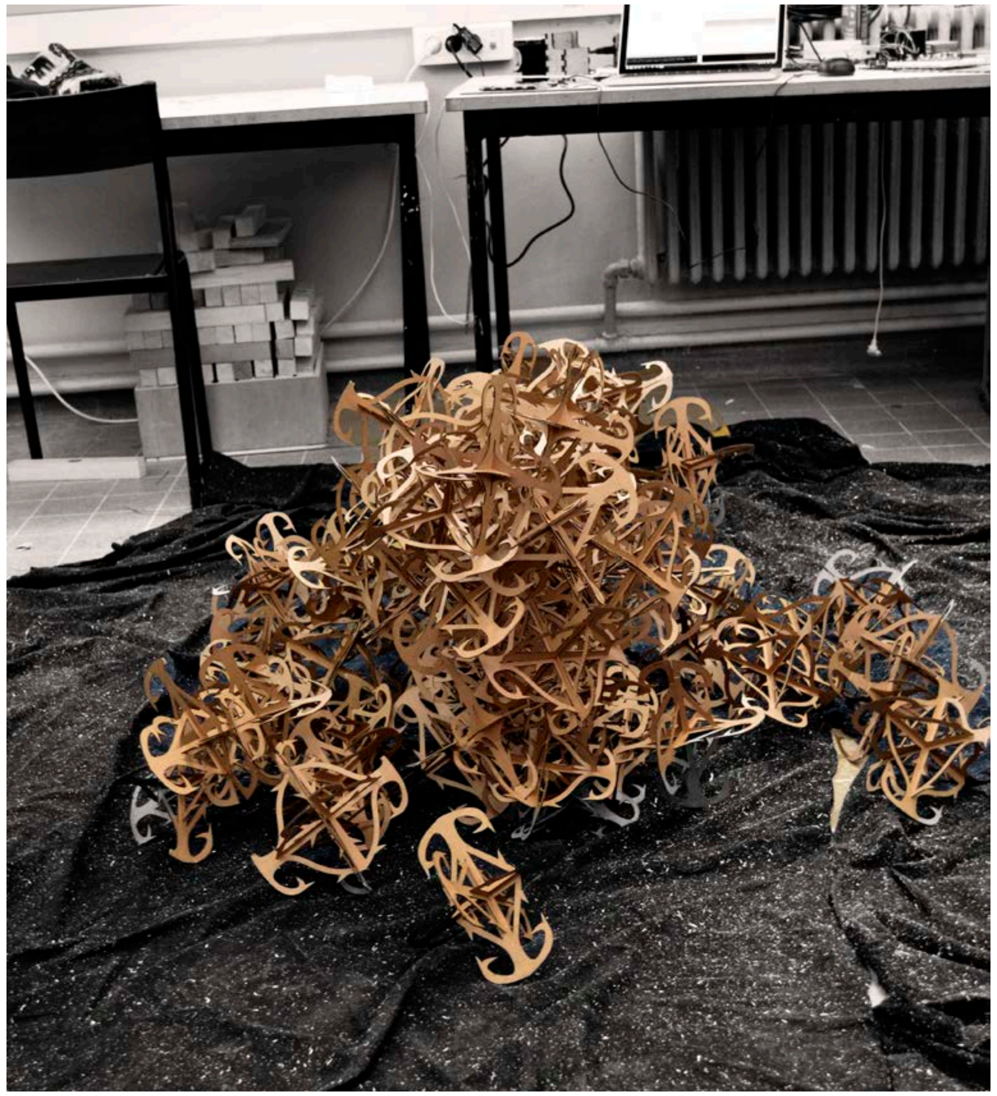
Adaptability (Vision)

Feedback loop calibration

Several physical aggregations with the variation of 1 parameter each time.
Analysis of the results in order to calibrate the different parameters of the feedback loop.

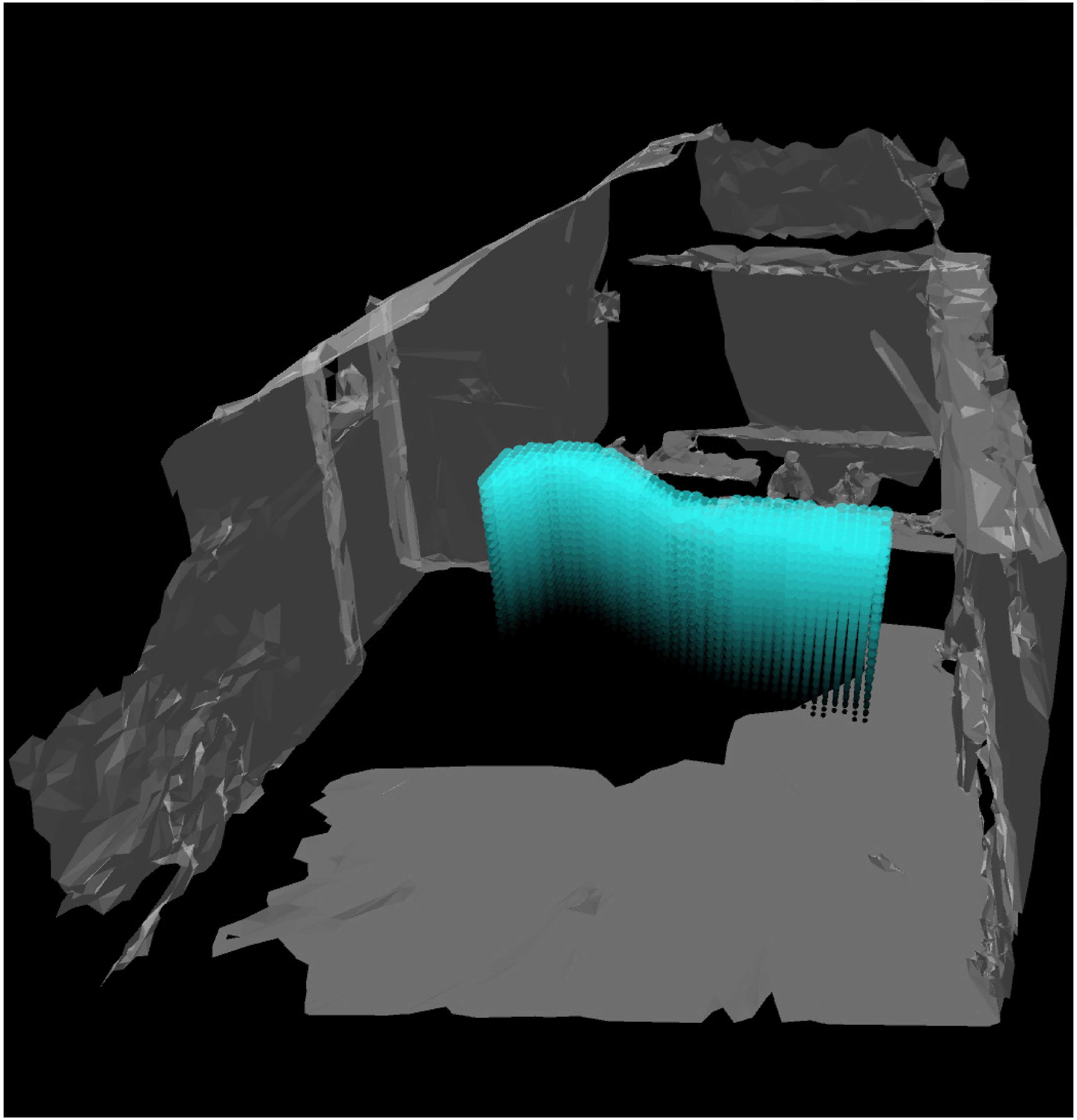


Test : 0
Nb Module : 92
CoFrequency : 5
*Dim 800*325*425*

Test : 2
Nb Module : 100
CoFrequency : 5
*Dim 600*400*500*

Test : 4
Nb Module : 124
CoFrequency : 2
*Dim 650*375*600*

Summary

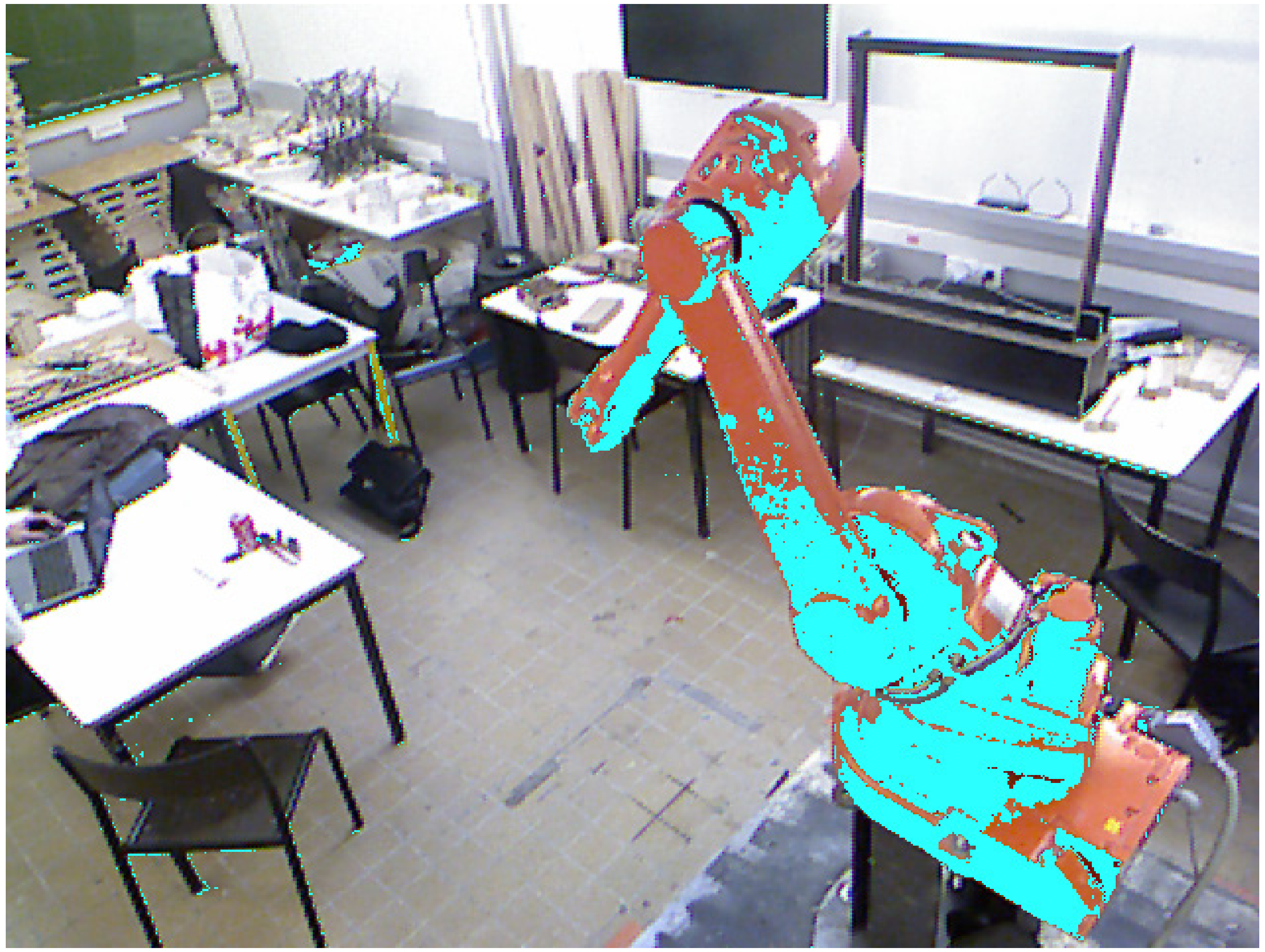


Summary

Production

Test protocol

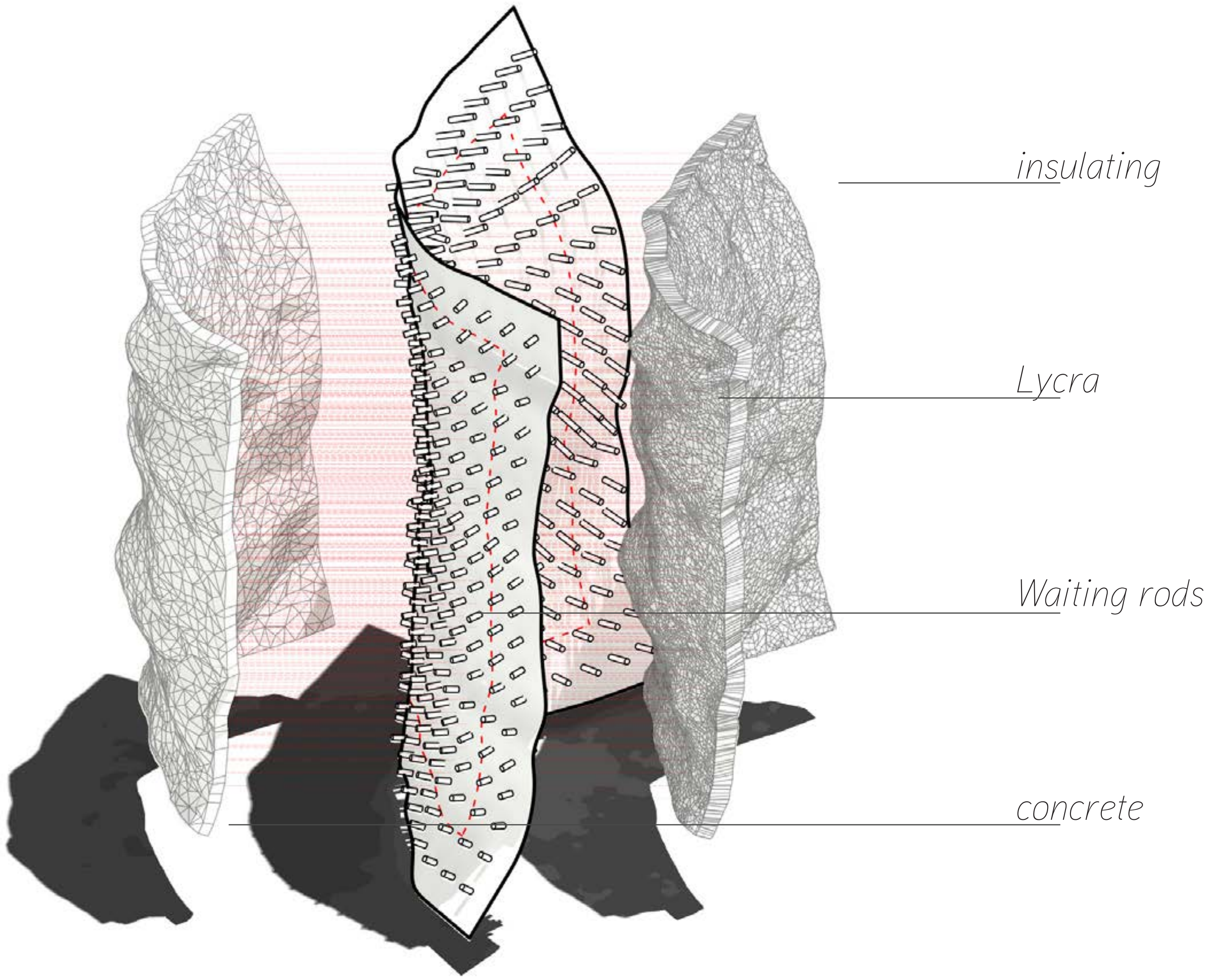
6 axis robot replacing the wirebot for time issues.
Small reachable area.



Production

Architectural scale

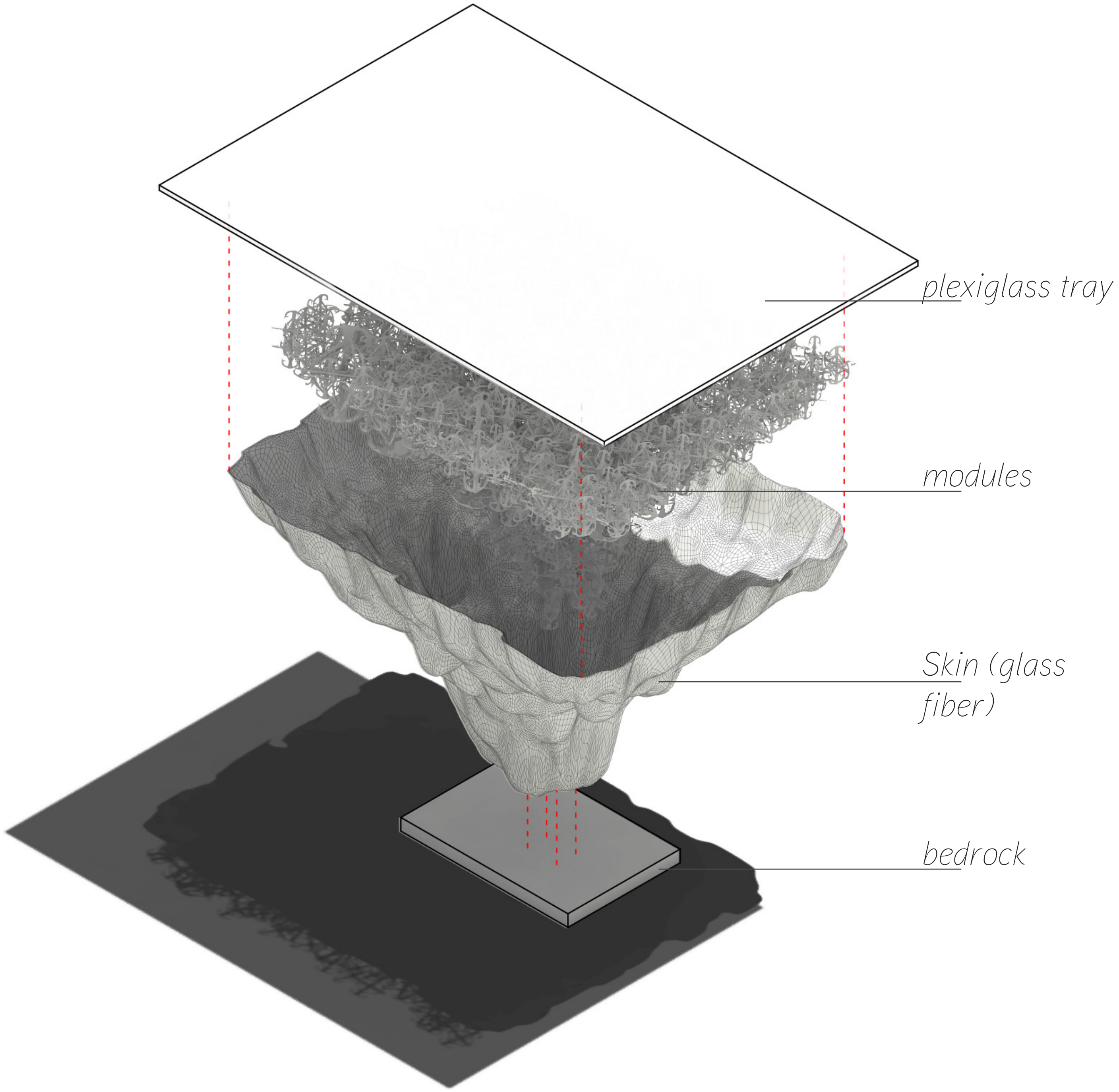
Construction of a multi layered wall using the modules aggregation as support.

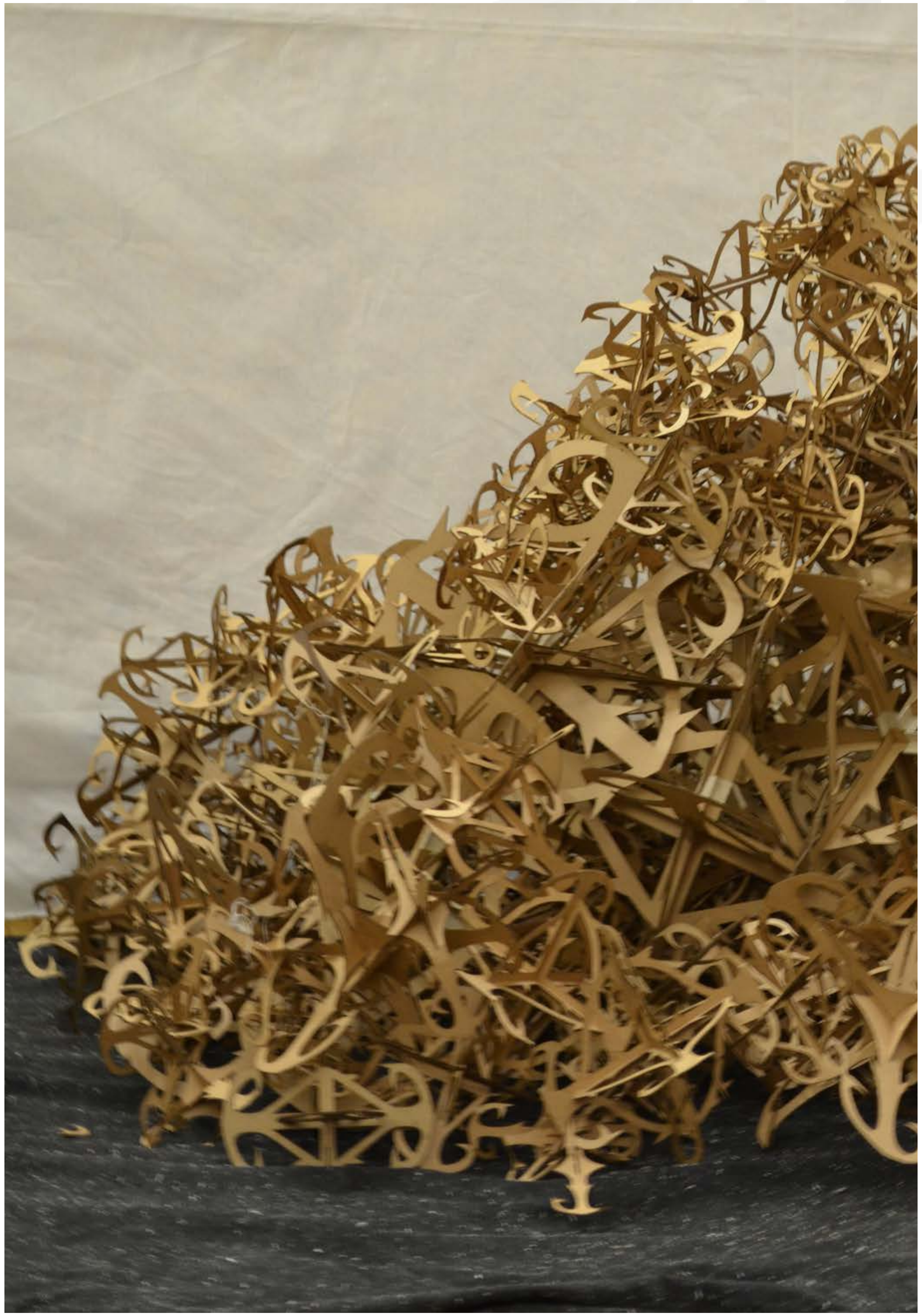


Production

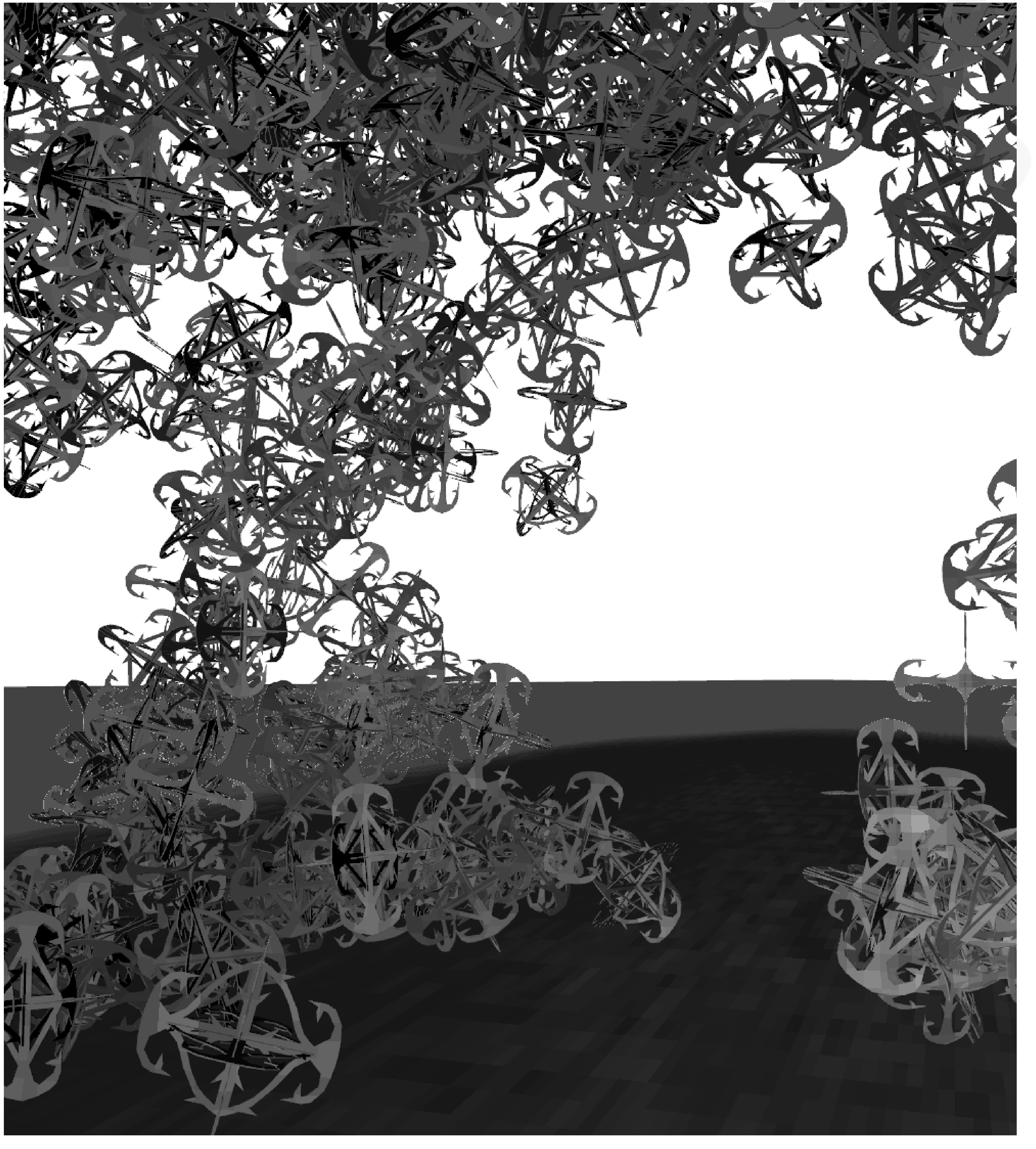
Object scale

Using the aggregation as a table support.





Summary



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Devlopement

Modules evolution

One solution was provided in order to fit the test purposes, but exploring more aggregates types would deserve a whole research on its own.

Few suggestions :
- Plastic injection
- Metallic modules for concrete reinforcement
- Bended rods
- Chemical aggregation (glue, resin..)

Gramazio Kohler Research, ETH Zurich

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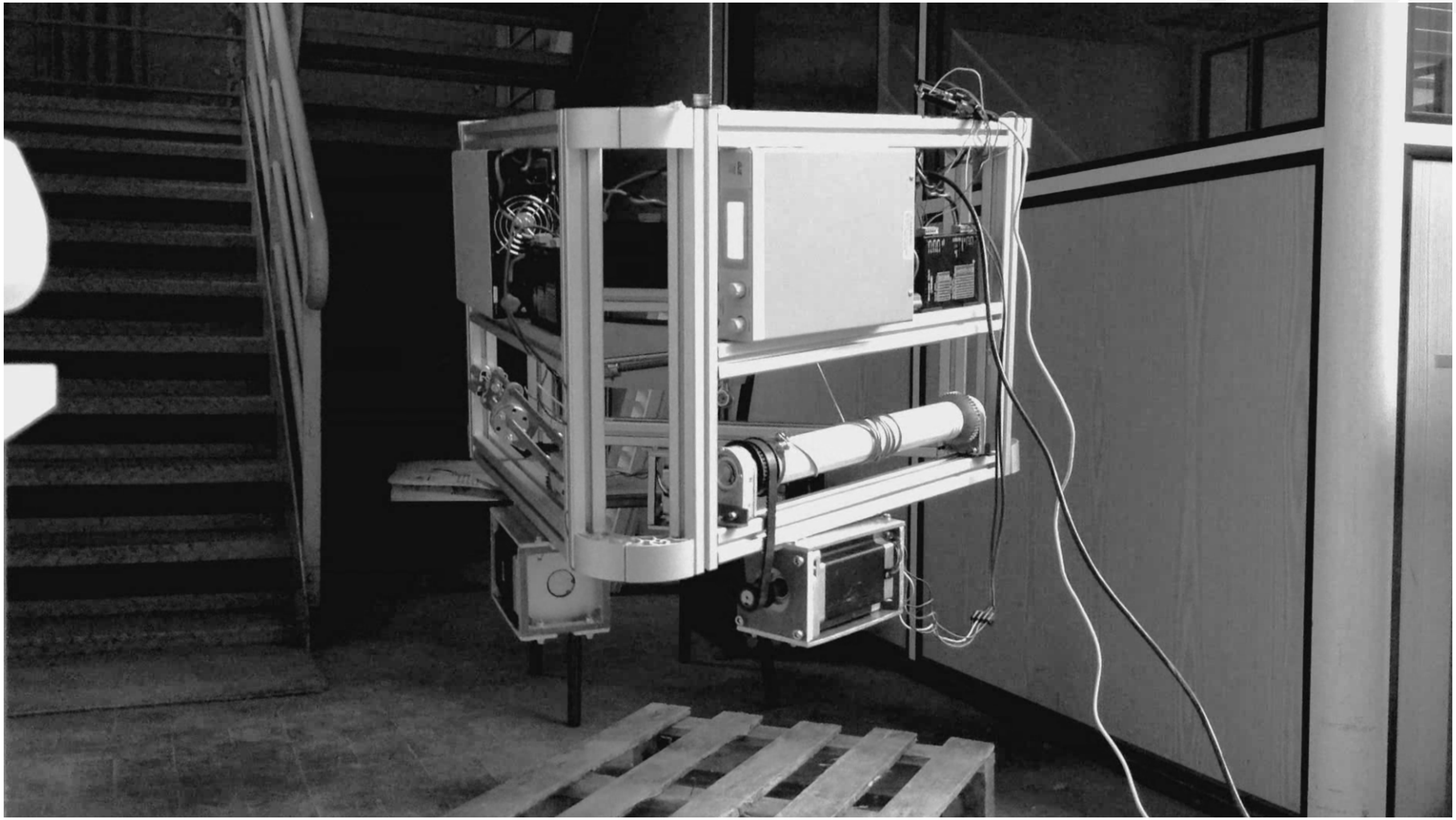
Devlopement

Wirebot setting up

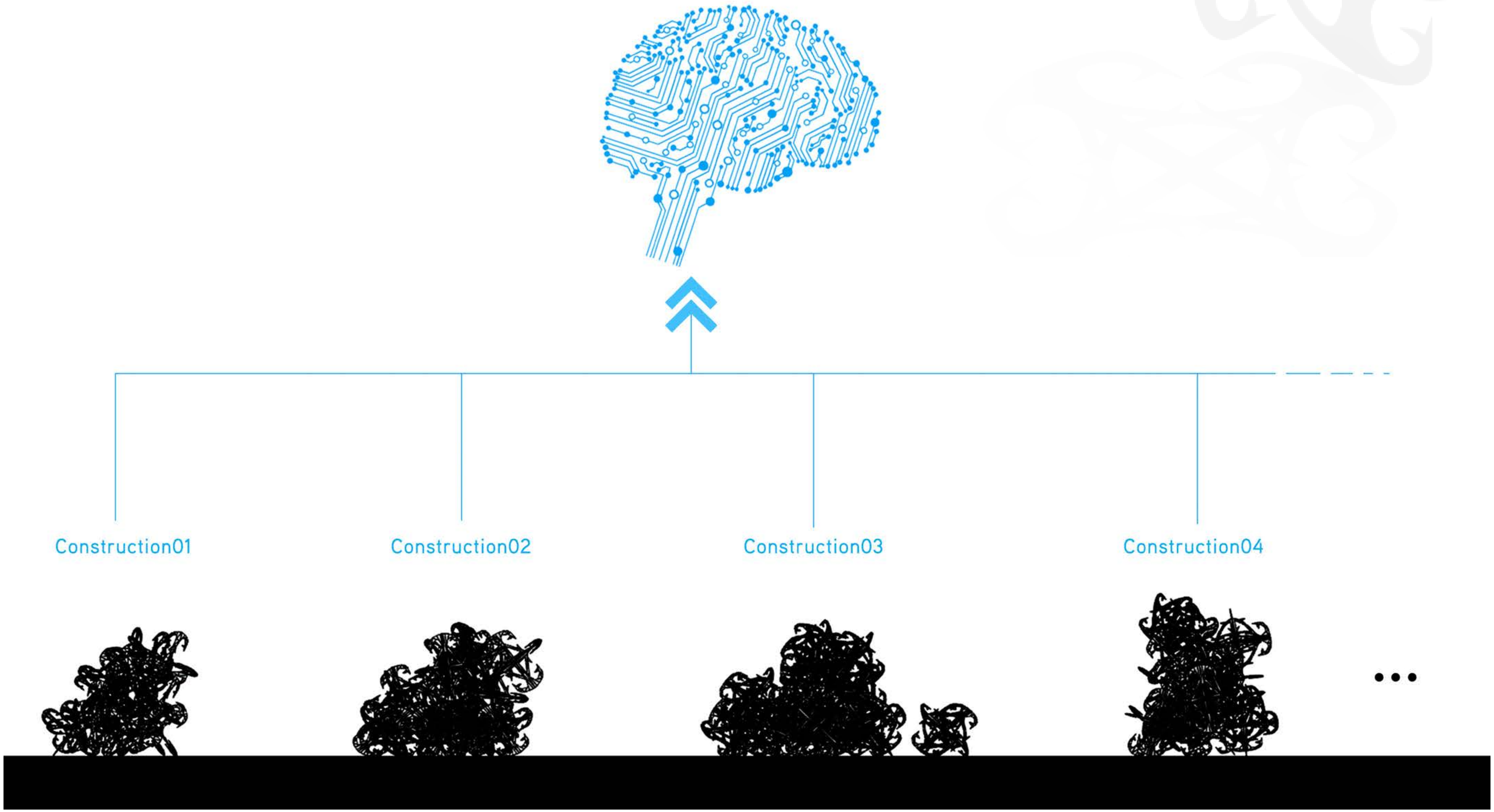
The hardware still needs some adjustments but several tests will be conducted this month.



Devlopement

Adaptability : learning algorithms implementations

The feedback loop for the construction adaptability is static for the moment. Further researches would implement learning algorithms in order to ponderate the system considering all its past experiments.



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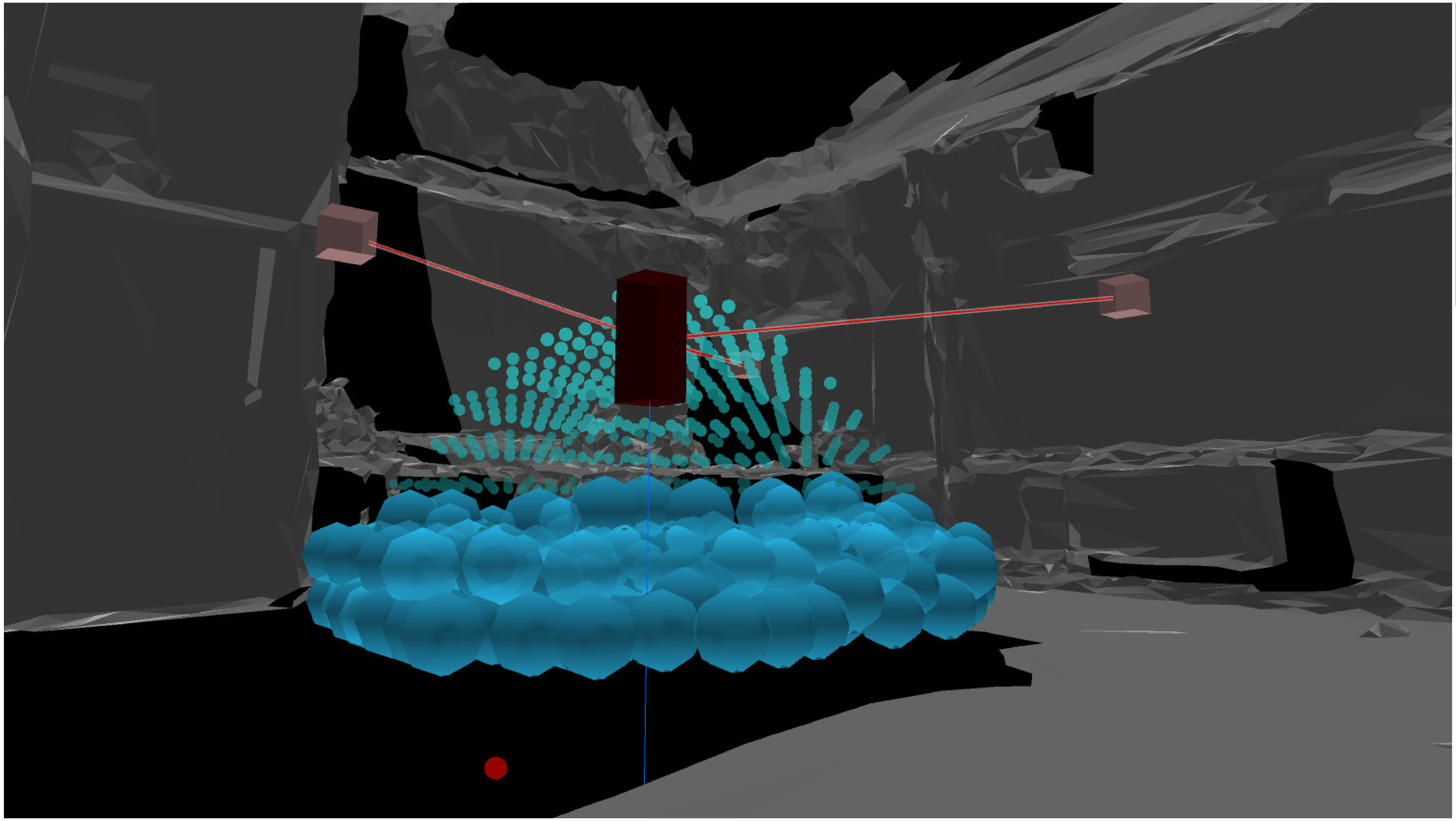
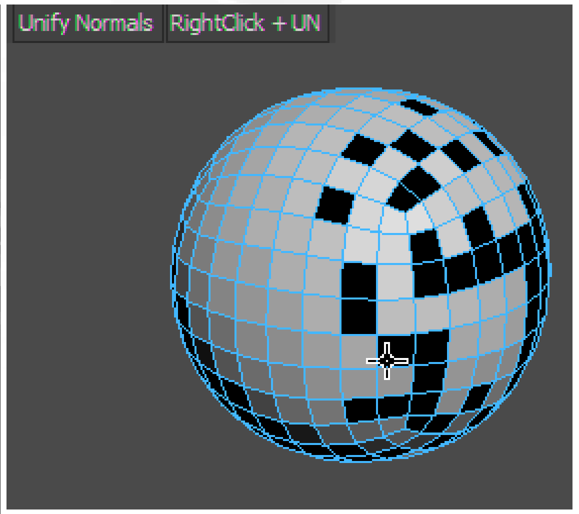
Devlopement

Software : more flexibility

Fixing last persistent bugs, adding more features, improving the modularity...





THANKS

Adaptative Aggregation Based Building System

Dealing with unpredictability

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Oswald PFEIFFER
Mathieu VENOT