

# Large-scale 3D Printing

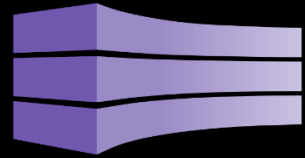
## Past, Present and Future Prospect

**Berok Khoshnevis**

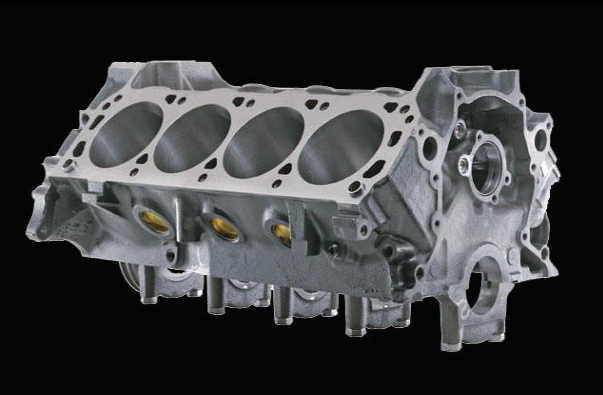
Founder CEO, Contour Crafting Corporation

Dean's Professor, University of Southern California

# Fabrication methods



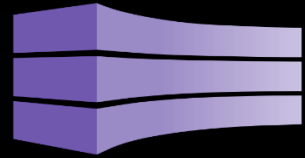
CONTOUR  
CRAFTING  
CORPORATION



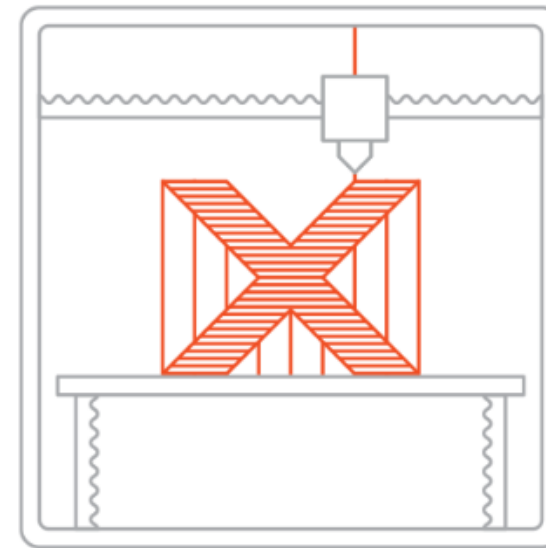
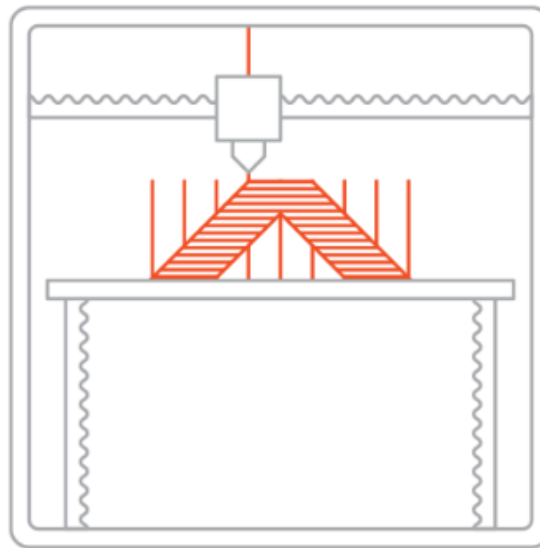
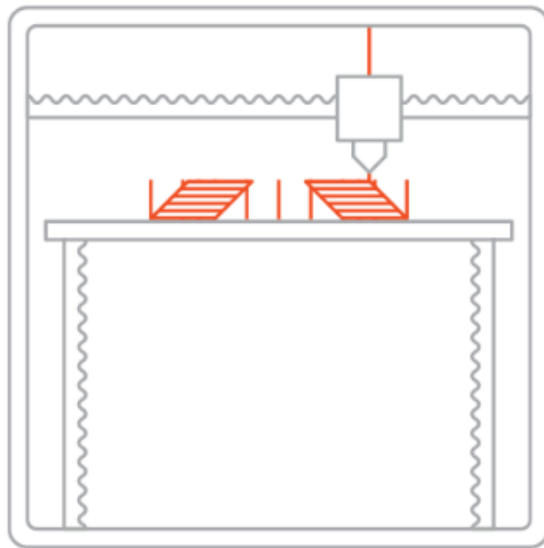
Subtractive

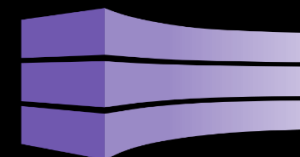
Additive

Formative

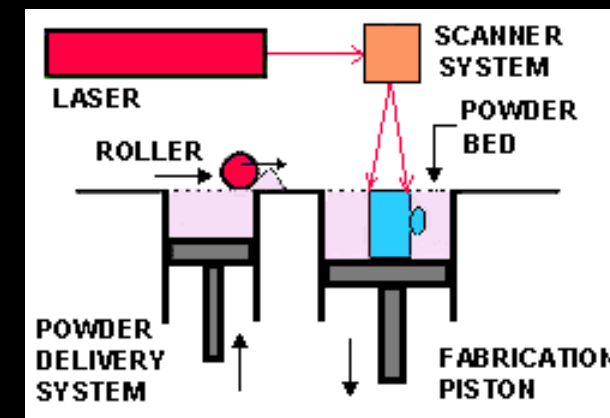
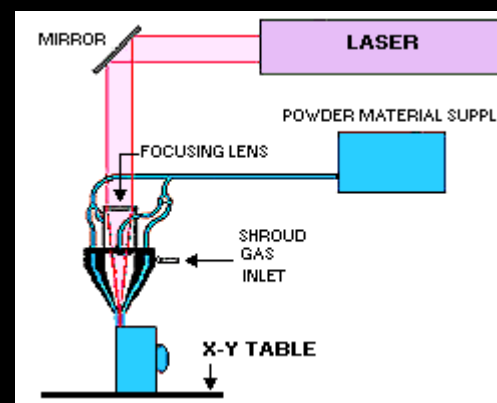
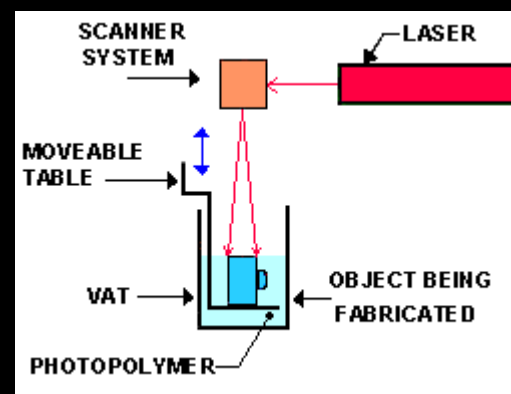
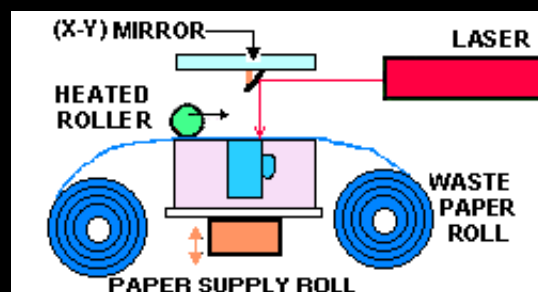
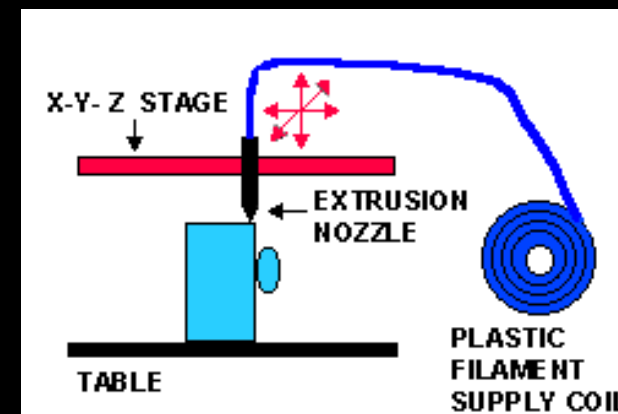
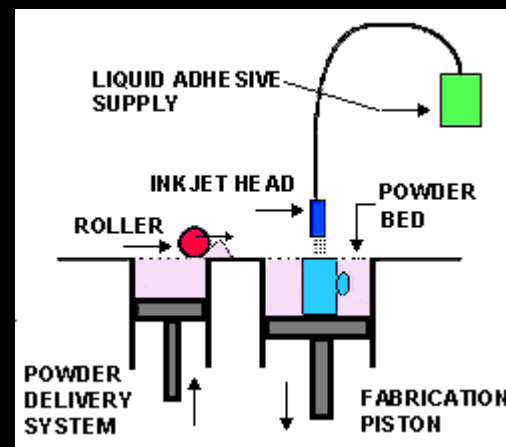
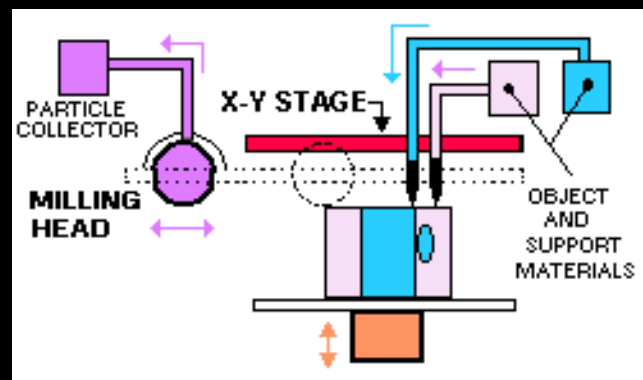


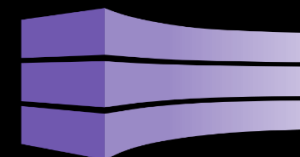
*Principle:* Add 2D layers of material one at a time to build the solid 3D part.





CONTOUR  
CRAFTING  
CORPORATION

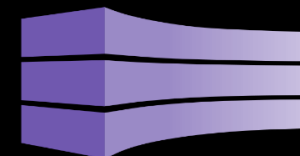




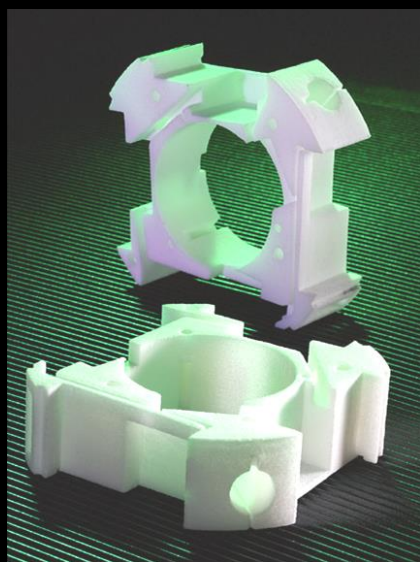
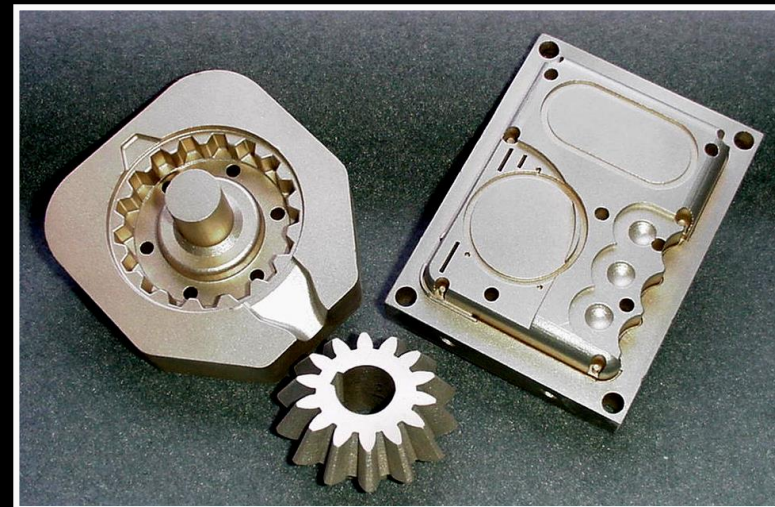
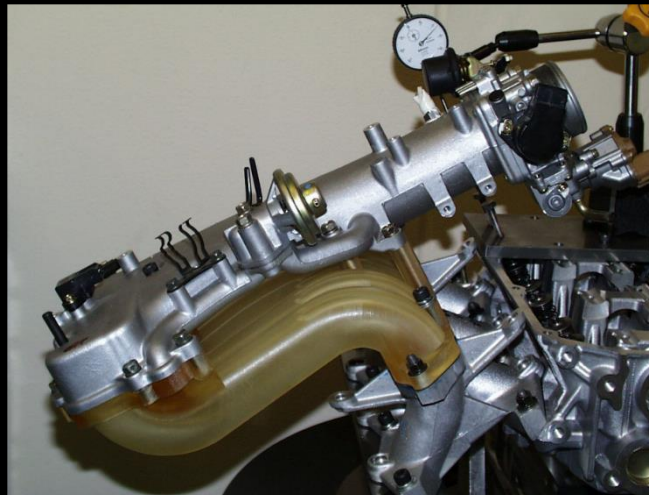
CONTOUR  
CRAFTING  
CORPORATION



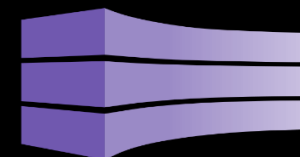




CONTOUR  
CRAFTING  
CORPORATION







CONTOUR  
CRAFTING  
CORPORATION

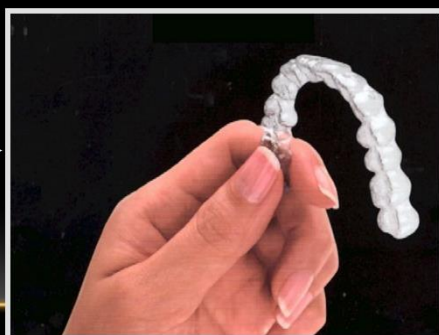
## MASS CUSTOMIZATION MOLDS



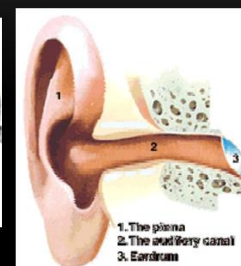
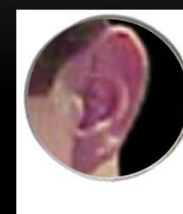
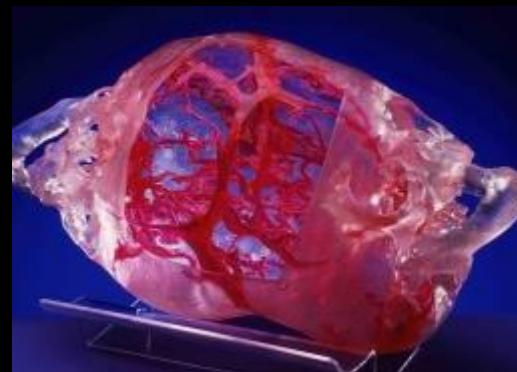
Before



After



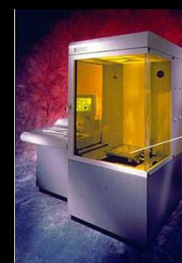
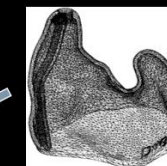
Align Technology - Invisalign



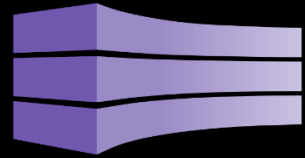
Soft  
impression



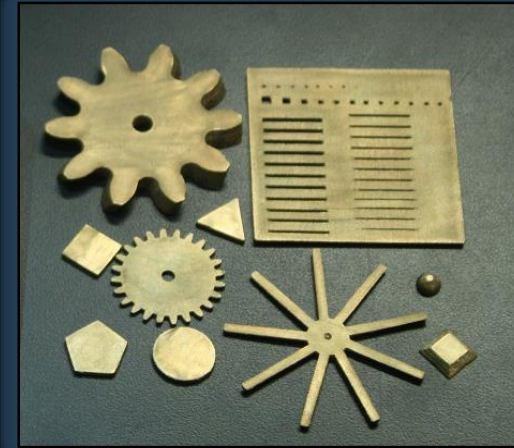
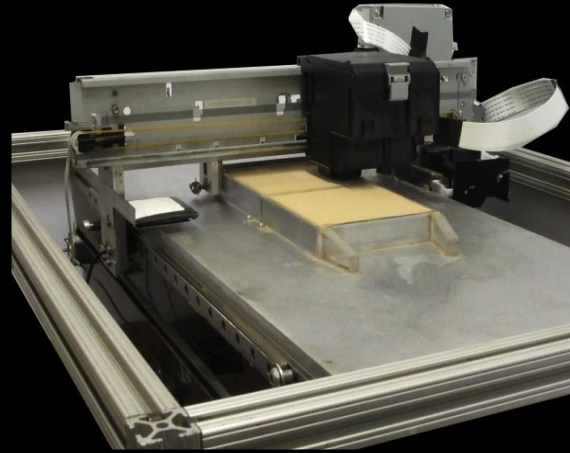
3D Scanning



# SIS family of AM technologies



CONTOUR  
CRAFTING  
CORPORATION

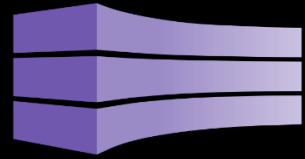


Invented by  
B. Khoshnevis



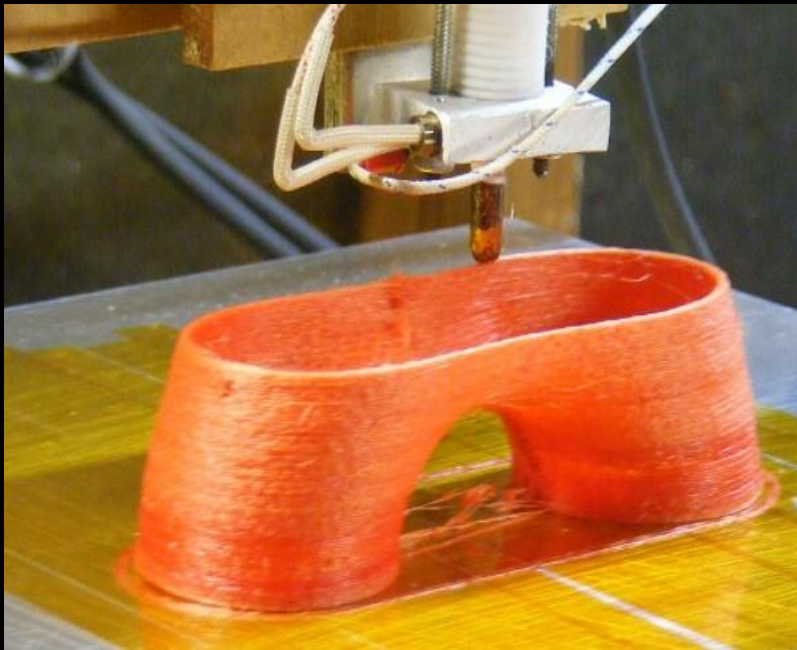
PAST

# Realizations in 1994

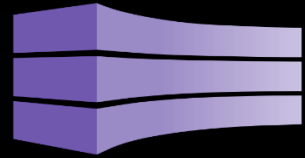


CONTOUR  
CRAFTING  
CORPORATION

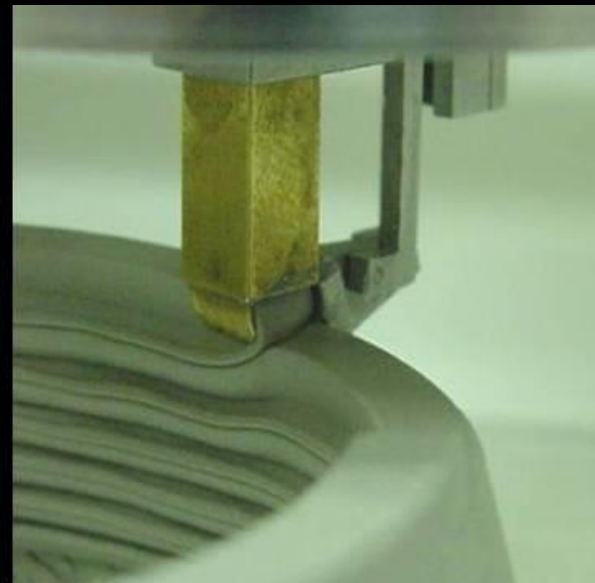
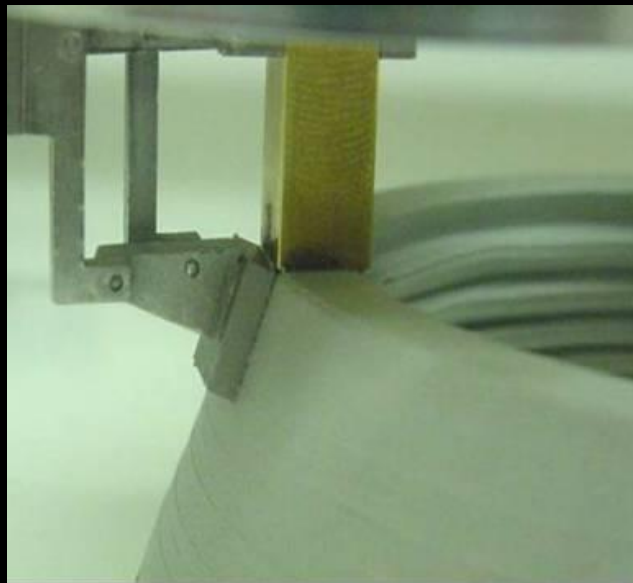
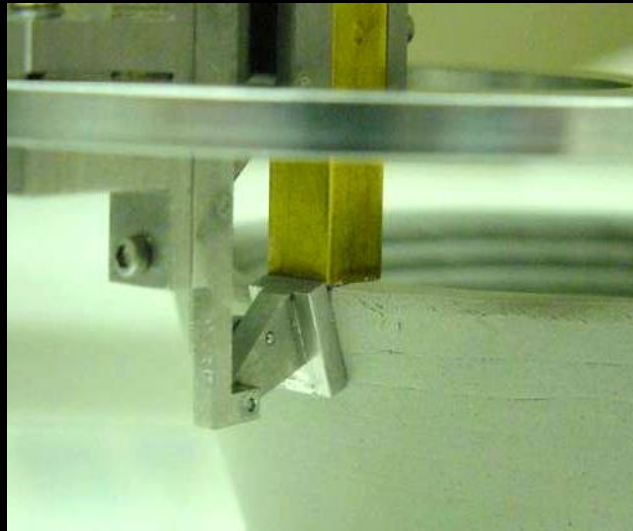
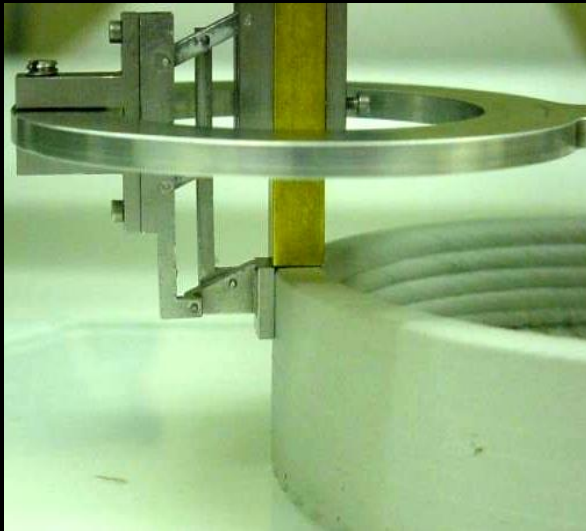
- 3D printing builds layer by layer
- We have been 3D printing for several millennia in **construction**



# Invention of Contour Crafting



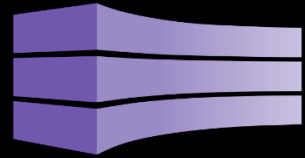
CONTOUR  
CRAFTING  
CORPORATION



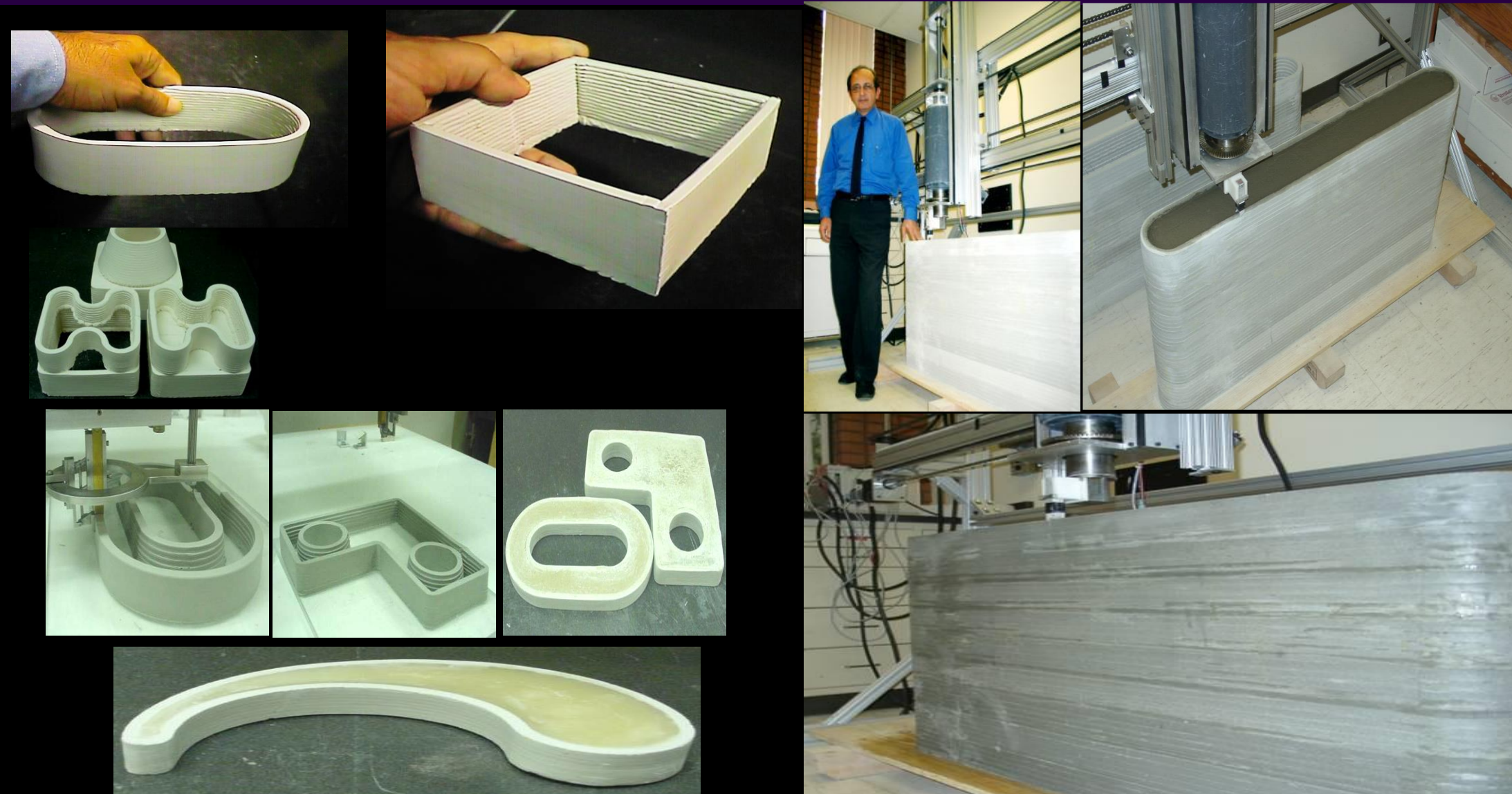
CC is an extrusion based a layered fabrication technology that builds objects with successive “thick” layers as it smooths out external surfaces



# Small-scale ceramic to large scale concrete parts

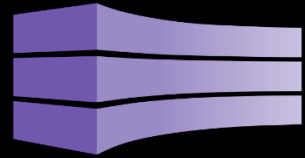


CONTOUR  
CRAFTING  
CORPORATION

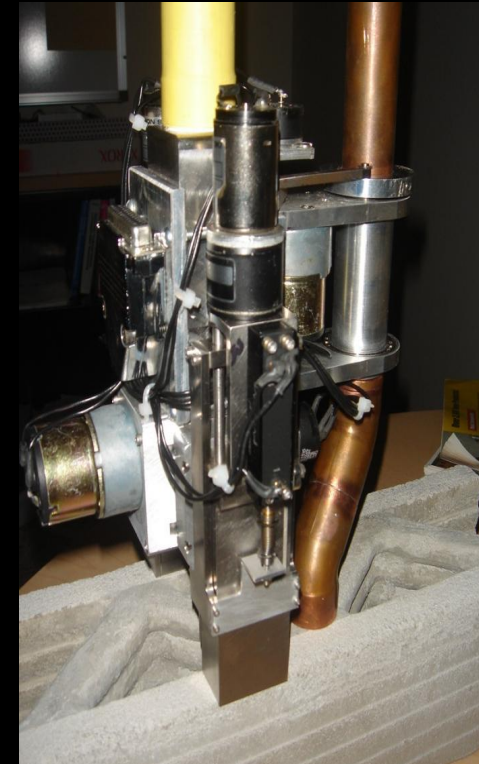




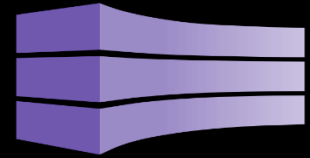
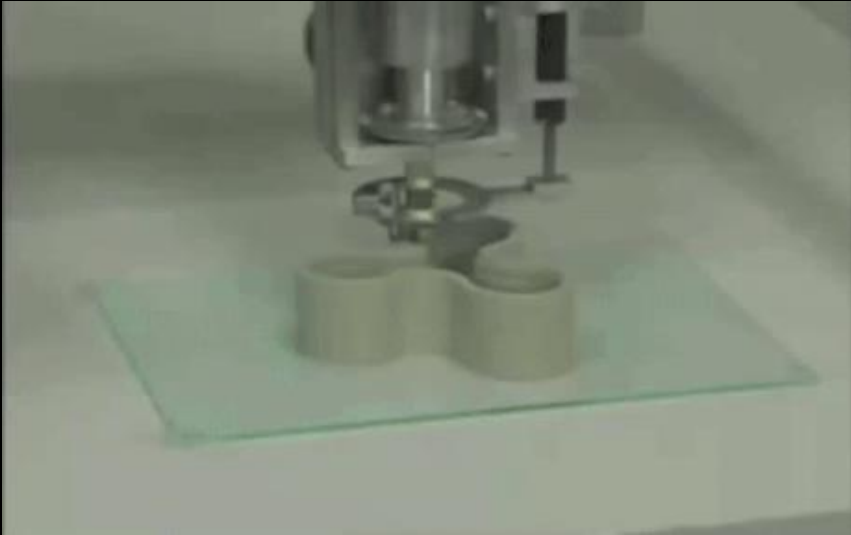
# CC Technology and its concrete structures



CONTOUR  
CRAFTING  
CORPORATION



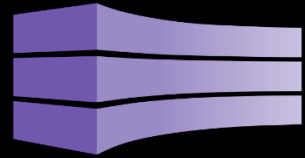
# Many modes of fabrication



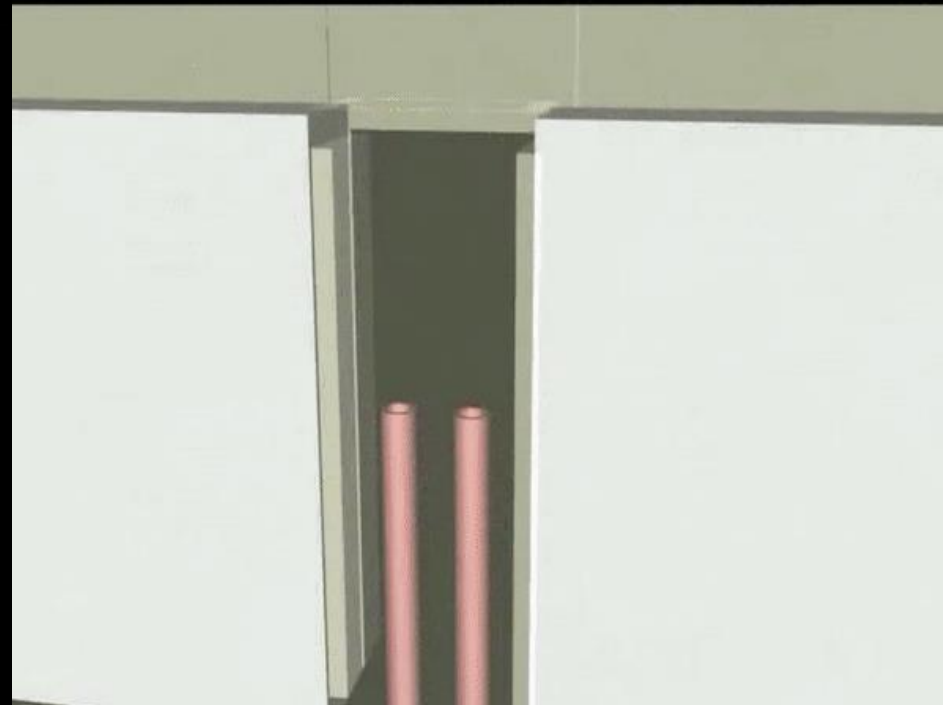
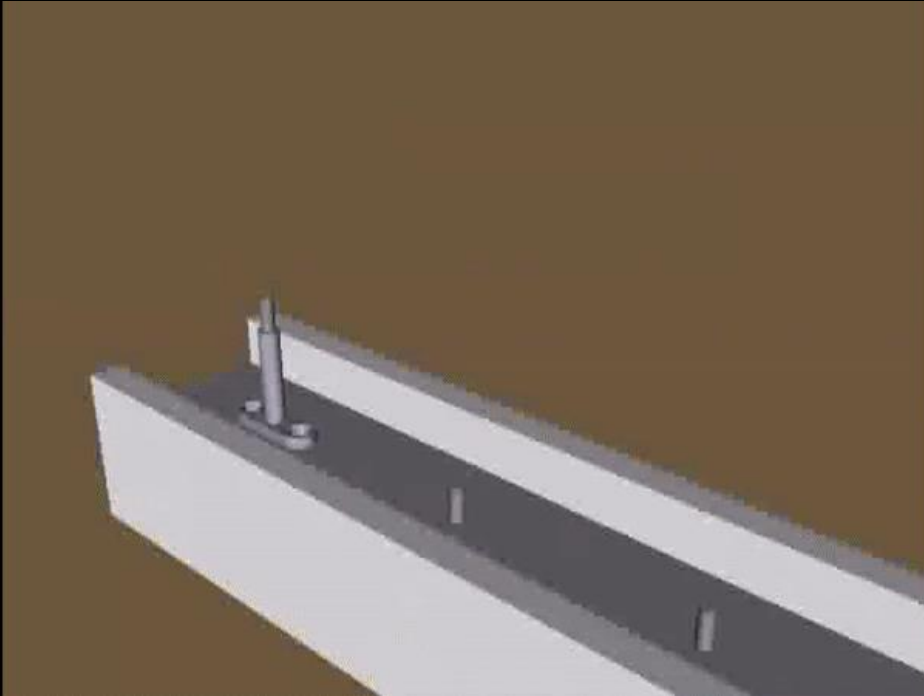
CONTOUR  
CRAFTING  
CORPORATION



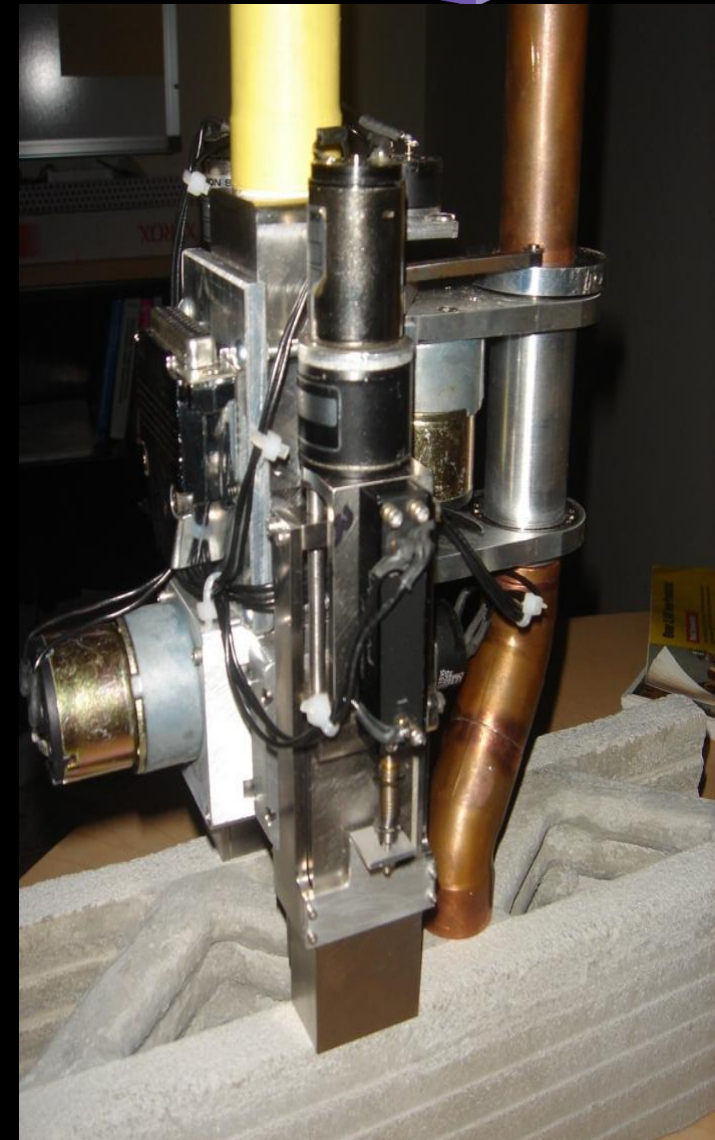
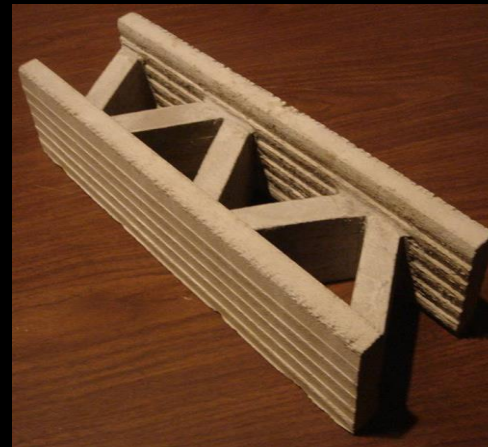
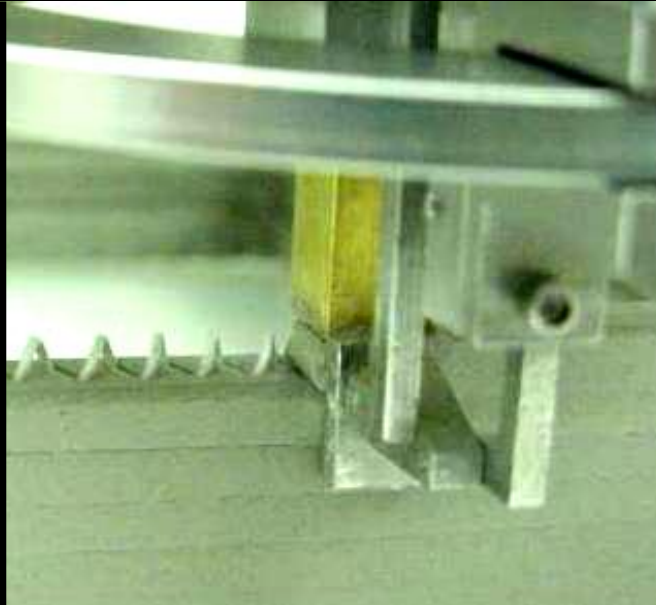
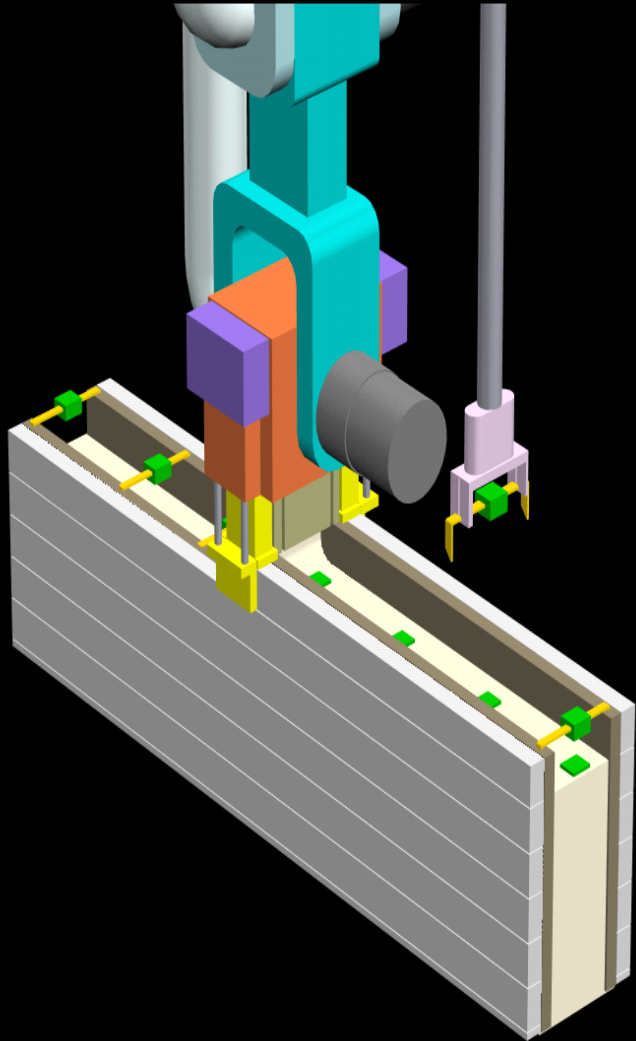
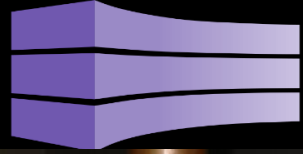
# Concurrent object imbedding



CONTOUR  
CRAFTING  
CORPORATION

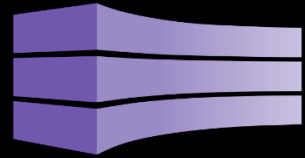


# Numerous possibilities for innovation

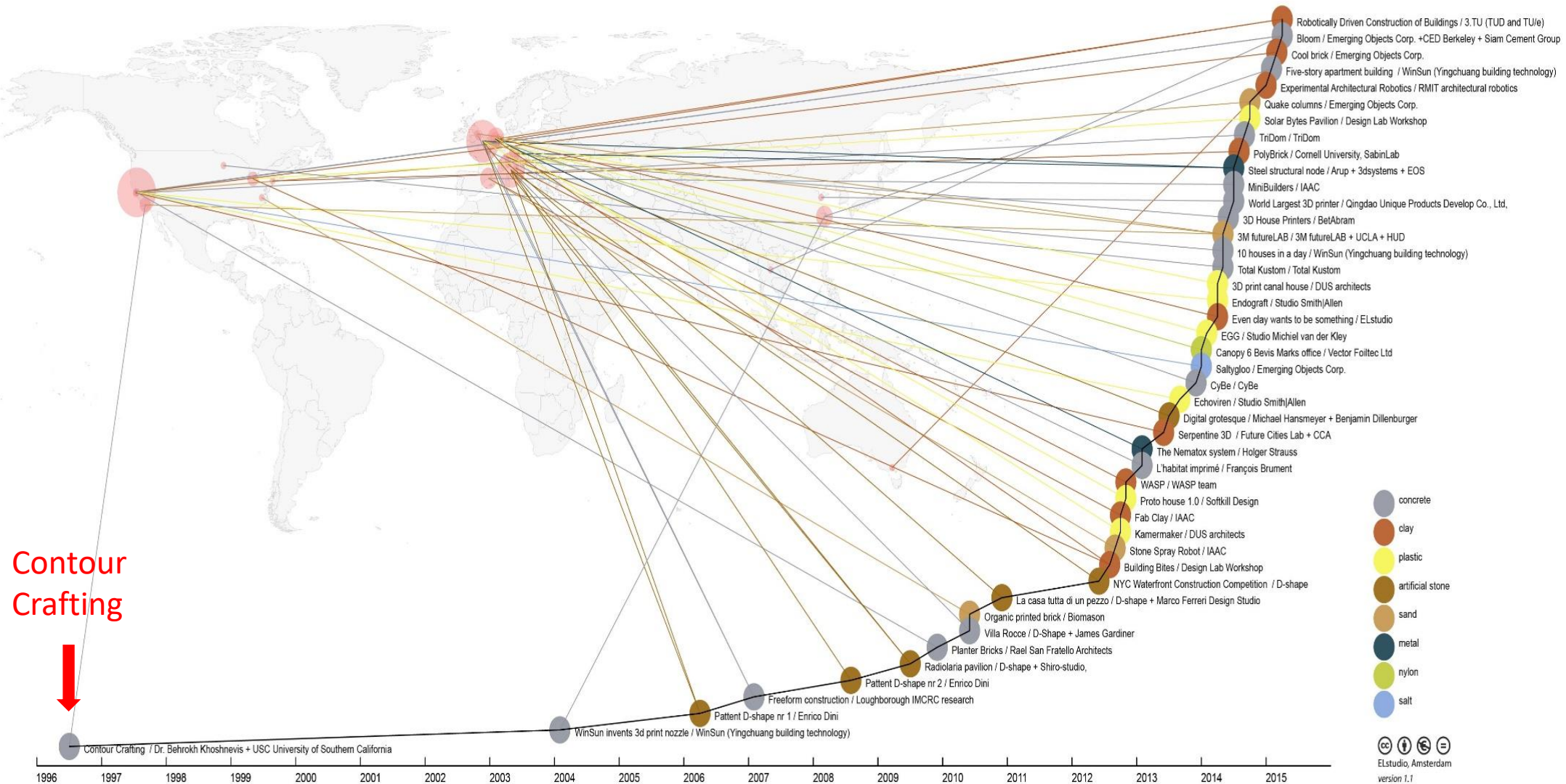




# History chart of large scale 3D printing



CONTOUR  
CRAFTING  
CORPORATION



Published by:  
**Elstudio**  
**Amsterdam, 2016**

CC BY NC ND  
Elstudio, Amsterdam  
version 1.1



PRESENT

# Current focus of construction 3D printing community is on Building Construction



## **Residential:**

- Shortage of 800 million houses worldwide (UN statistics)
- Global markets are grossly under-served
  - Nearly 2 Billion people are homeless or live in slums
  - Annually 37 million people lose housing due to war and natural disasters

## **Commercial:**

- Shortage of commercial and industrial buildings, especially in developing countries

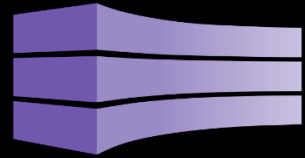
# Why construction needs a change



- Construction is the largest sector (\$5.6T/year) of almost all economies
- Labor efficiency is alarmingly low
- Skilled workforce is vanishing
- Work quality is low
- Control of the construction site is insufficient and difficult
- Accident rate at construction sites is high (> 400,000 / year in US); 60,000 fatalities/year globally
- Waste and trims are high (3 To 7 tons per average home; 40% of all materials used worldwide are for construction)
- Low income housing and emergency shelters are critical
- All other products are fabricated automatically – construction is still largely a manual task



# The Homeless, Disaster victims, Refugees

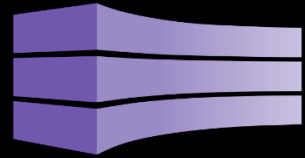


CONTOUR  
CRAFTING  
CORPORATION

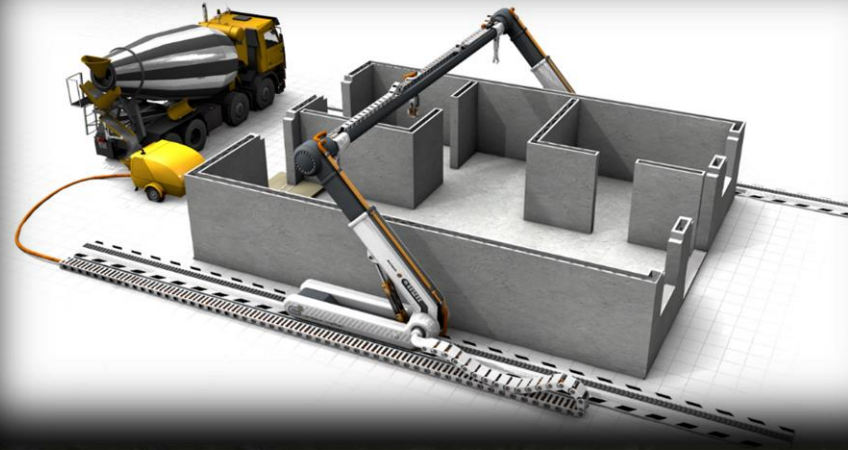
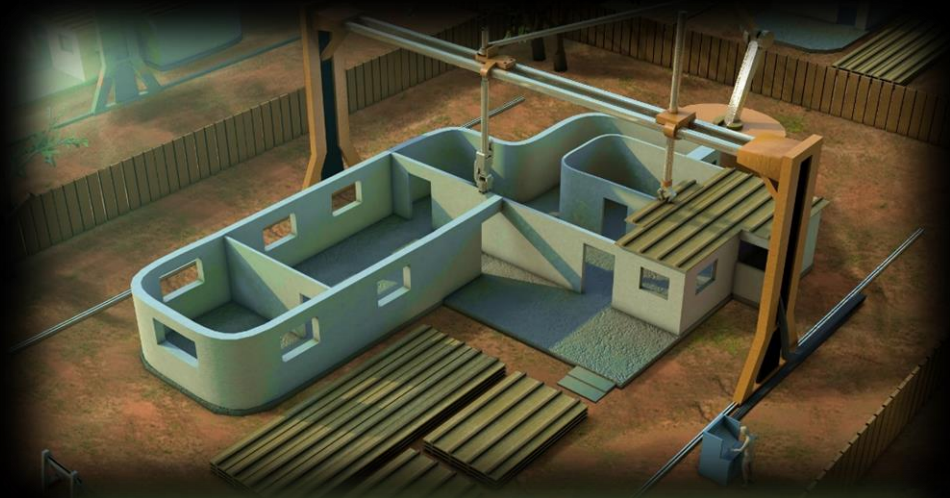


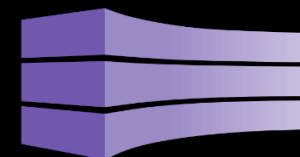


# Building construction targets of CC Corp

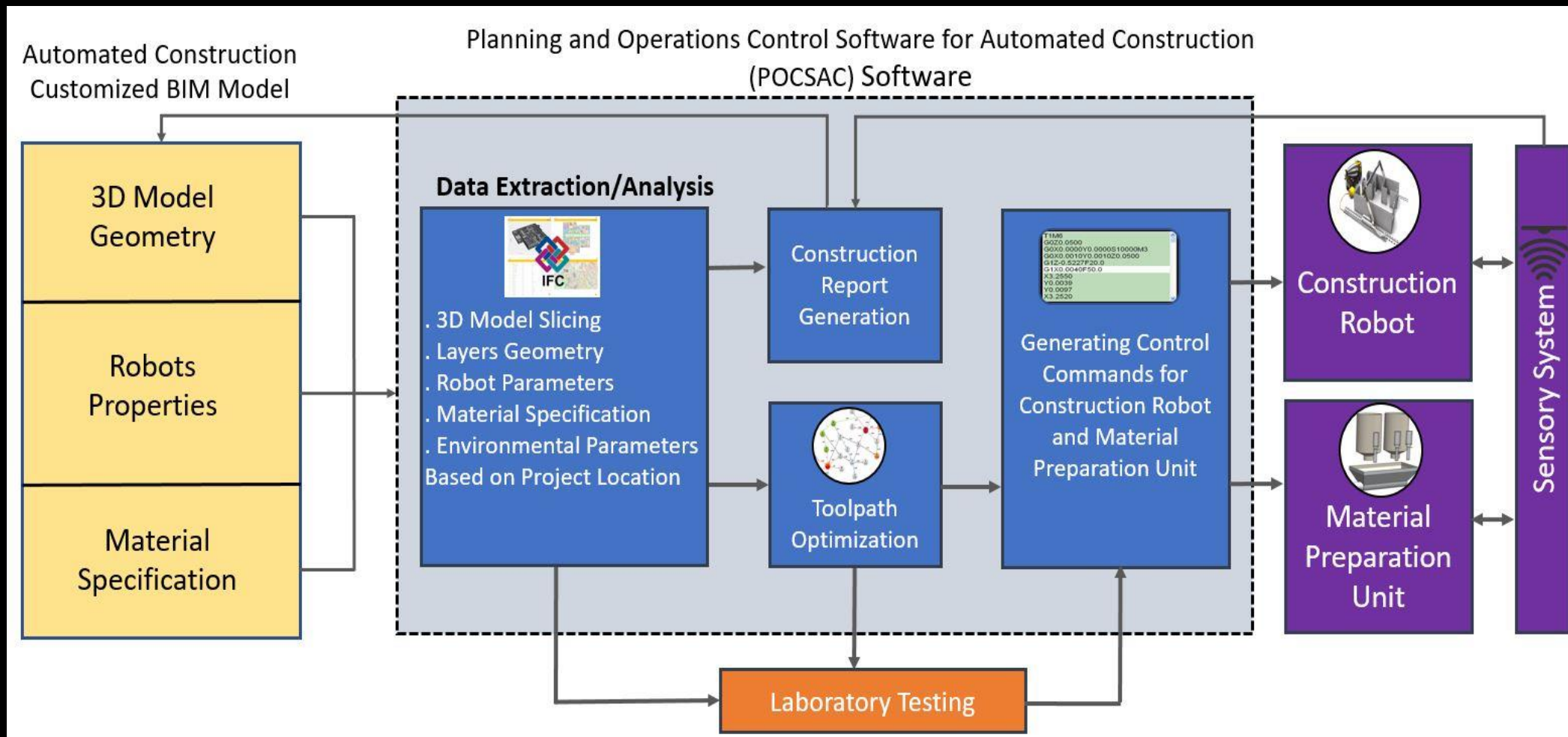


CONTOUR  
CRAFTING  
CORPORATION

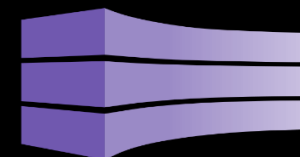




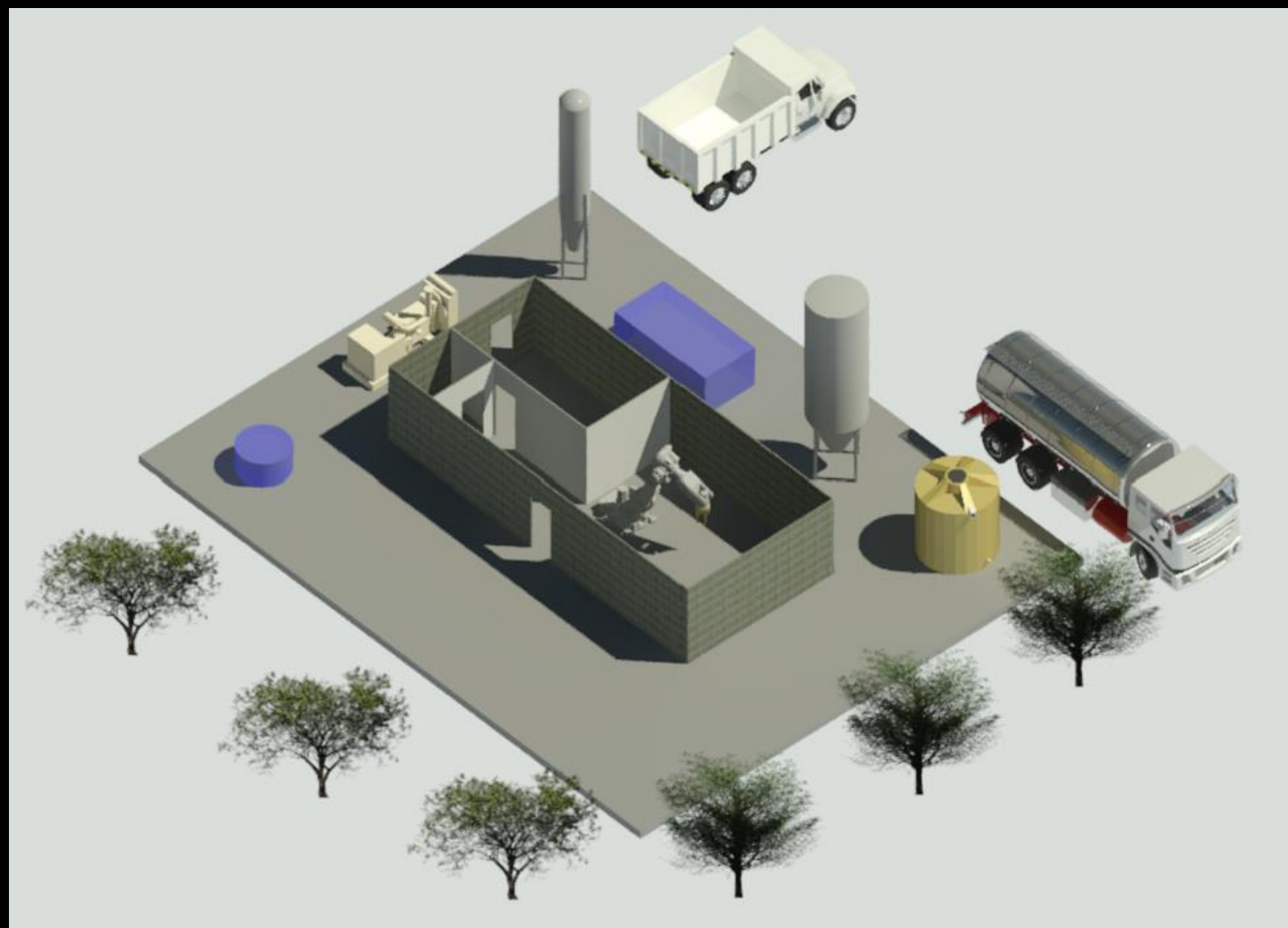
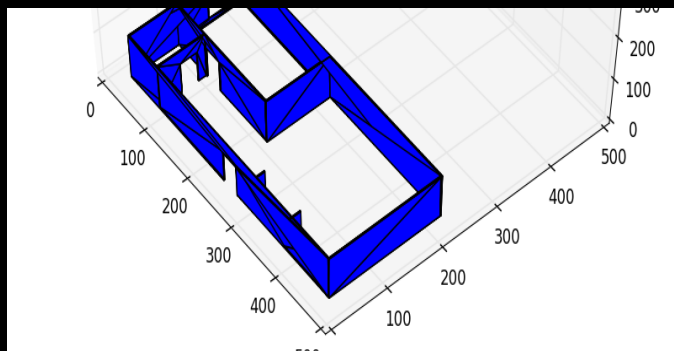
CONTOUR  
CRAFTING  
CORPORATION

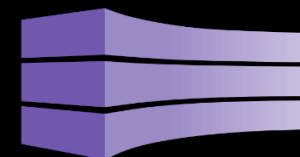




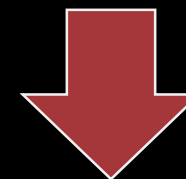
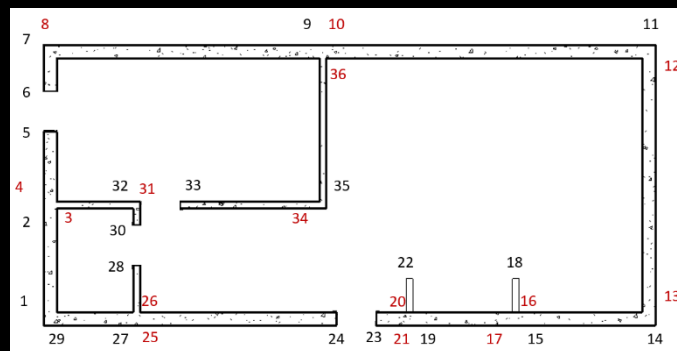
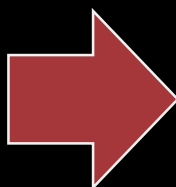
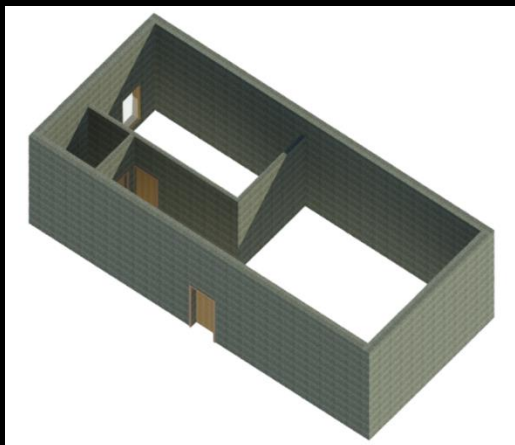


CONTOUR  
CRAFTING  
CORPORATION



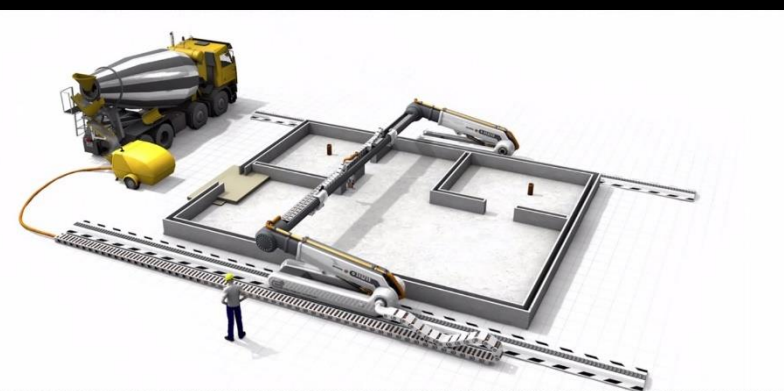


CONTOUR  
CRAFTING  
CORPORATION



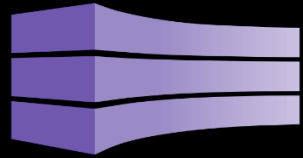
**Tool-Path Sequence - Solution**

| N1  | N2  | N3  | N4  | N5  | N6  | N7  | N8  | N9  |     |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | 2   | 3   | 32  | 31  | 30  | 28  | 26  | 4   |     |
| N10 | N11 | N12 | N13 | N14 | N15 | N16 | N17 | N18 |     |
| 5   | 6   | 7   | 8   | 9   | 36  | 35  | 34  | 33  |     |
| N19 | N20 | N21 | N22 | N23 | N24 | N25 | N26 | N27 |     |
| 10  | 11  | 12  | 13  | 14  | 15  | 16  | 18  | 17  |     |
| N28 | N29 | N30 | N31 | N32 | N33 | N34 | N35 | N36 | N37 |
| 19  | 22  | 20  | 21  | 23  | 24  | 25  | 27  | 29  | 1   |

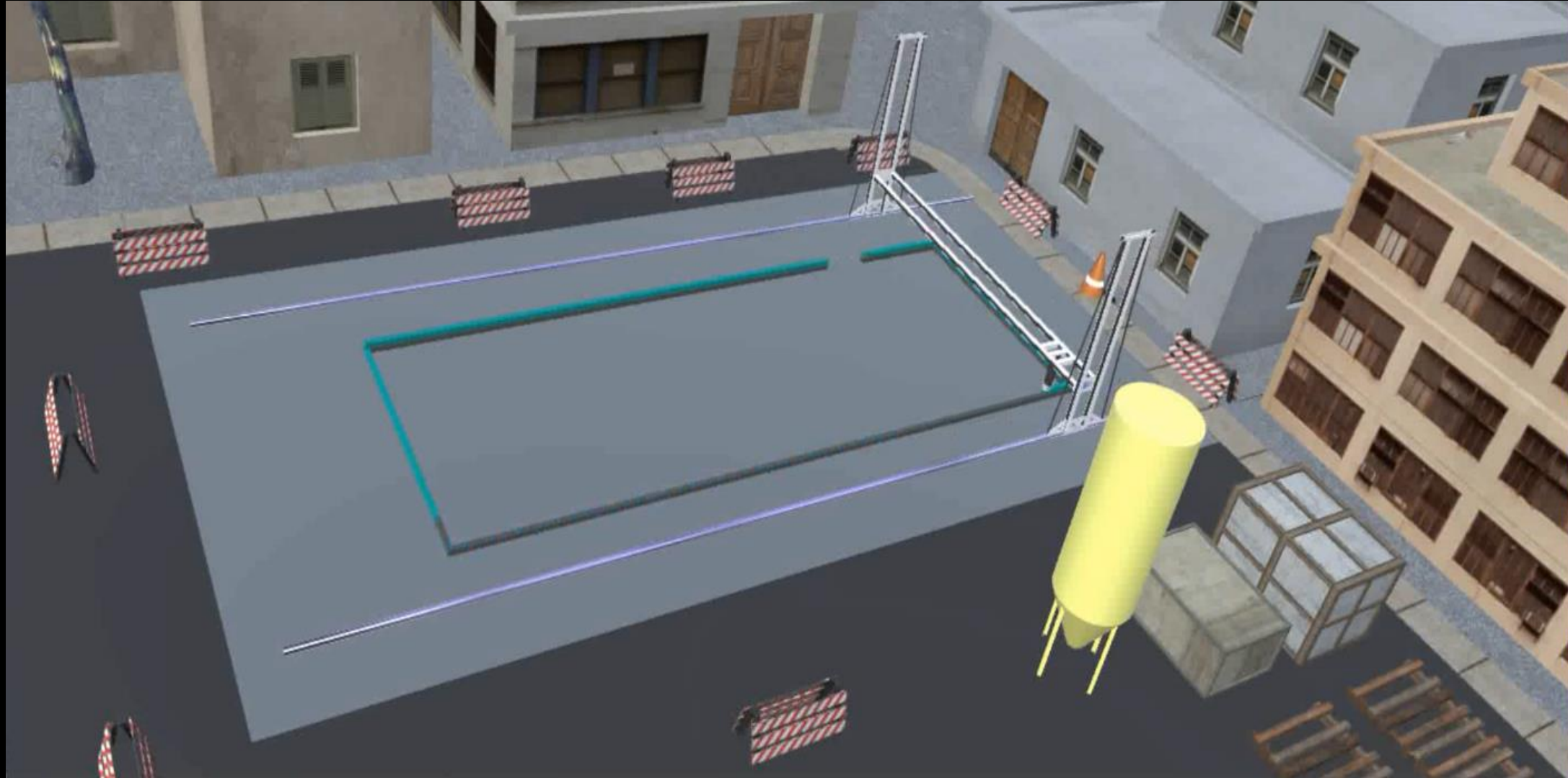


| Edge Category | Total Counts | Total Distance |
|---------------|--------------|----------------|
| Deposition    | 18           | 169            |
| Idle          | 6            | 41.7           |
| Rotation      | 11           | 22 Radian      |

# Process simulation



CONTOUR  
CRAFTING  
CORPORATION





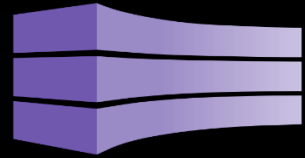
# Barriers against implementation in building sector



- Conservative industry
- Low profit margin
- Regulatory barrier
- Major paradigm change requirement with respect to inspection
- Labor unions
- At best impacts the cost of building shell only

# FUTURE

# Infrastructure Construction



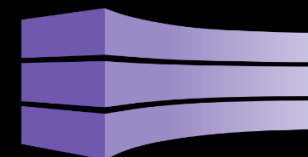
CONTOUR  
CRAFTING  
CORPORATION



Application in automated  
wind turbine tower  
construction



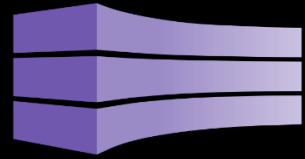




CONTOUR  
CRAFTING  
CORPORATION



# Pylon construction – Application example: *Hyperloop project*

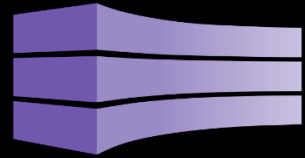


CONTOUR  
CRAFTING  
CORPORATION



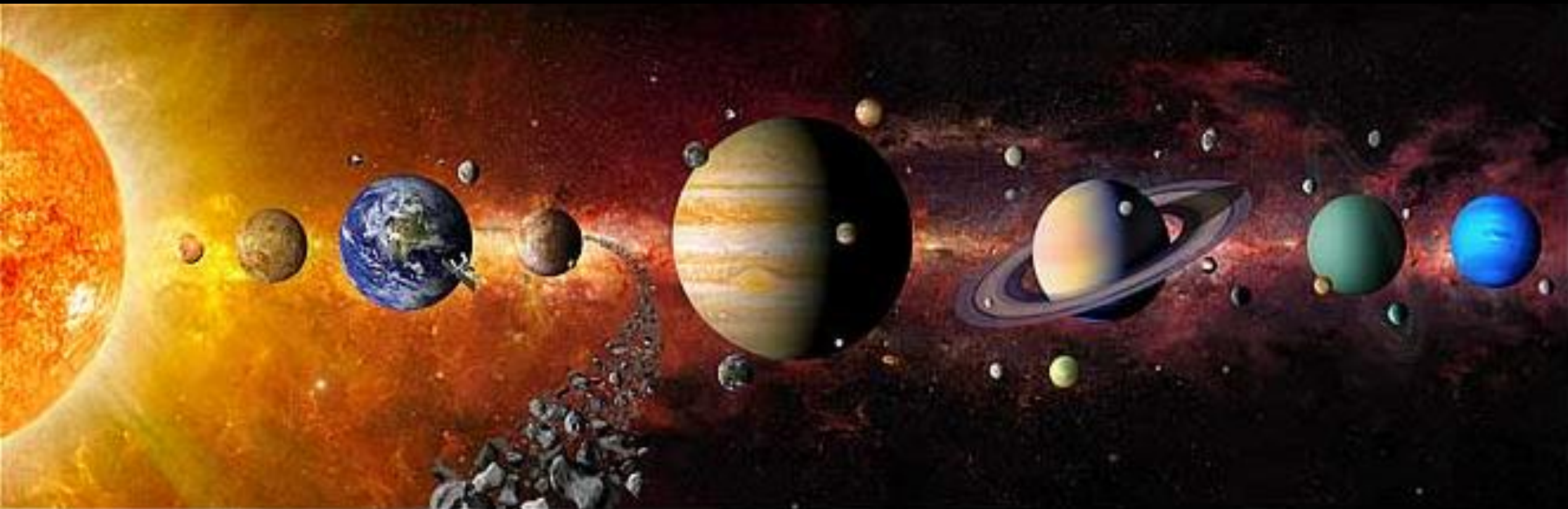


# Space Applications



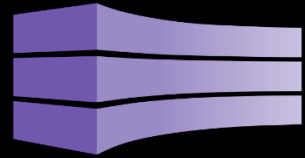
CONTOUR  
CRAFTING  
CORPORATION

The next stage after our Earth-bound civilization is the  
**Solar System Civilization** – and it is beginning





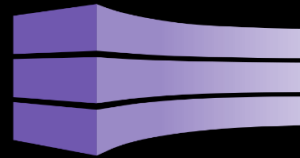
# In-space fabrication



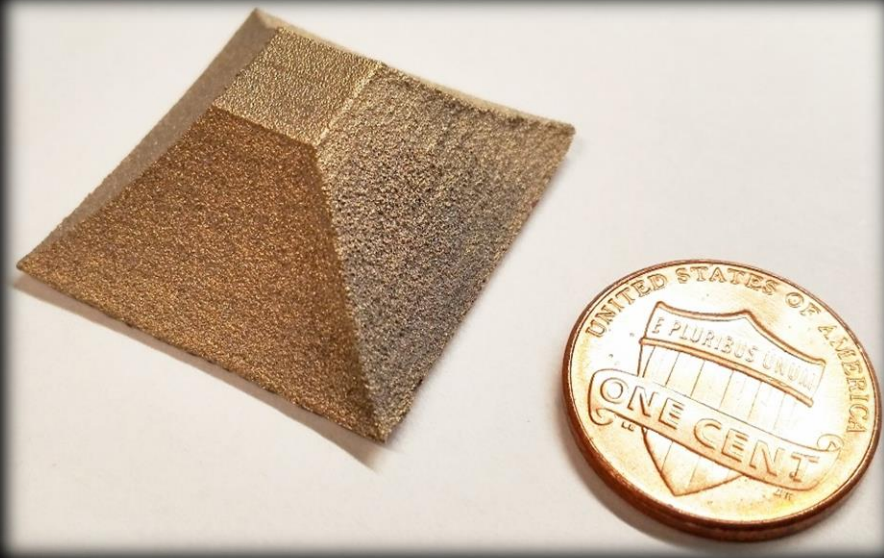
CONTOUR  
CRAFTING  
CORPORATION



# Fabrication in microgravity by SSS



CONTOUR  
CRAFTING  
CORPORATION



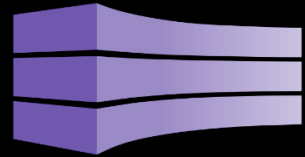
# Space mining companies



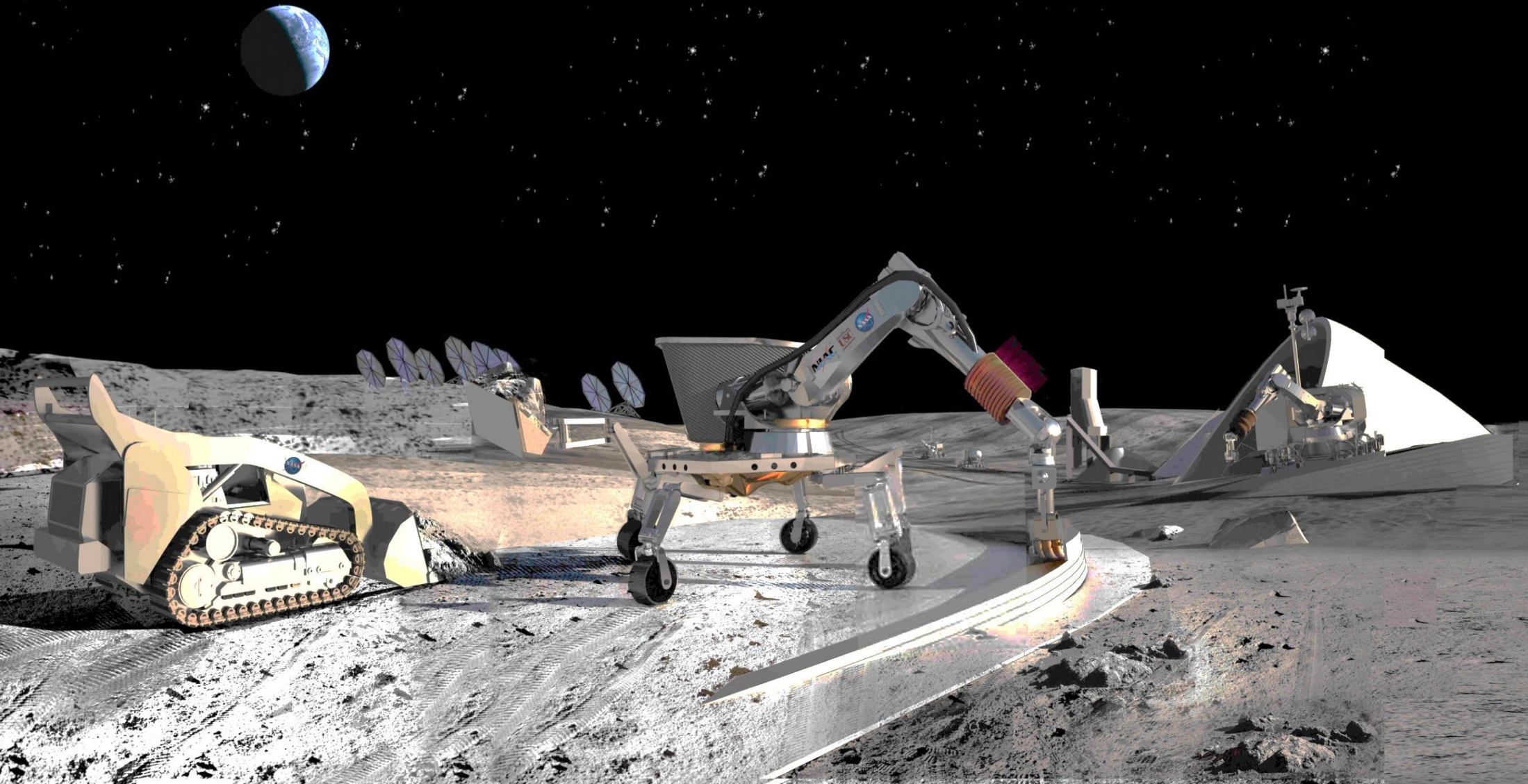
| <u>Company</u>                   | <u>Target Body</u> | <u>Objective</u> |
|----------------------------------|--------------------|------------------|
| Astrobotic Technologies          | Moon               | Water            |
| Shackleton Energy Corp.          | Moon               | Water            |
| Moon Express                     | Moon               | Metals           |
| Shamayan Innovation Partnerships | Moon/Asteroids     | Metals           |
| Planetary Resources, Inc.        | Asteroids          | Water/Metals     |
| Deep Space Industries            | Asteroids          | Manufacturing    |



# Planetary Construction by CC

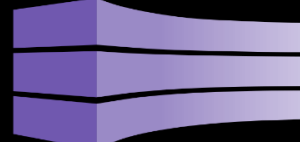


CONTOUR  
CRAFTING  
CORPORATION





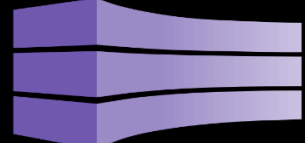
# Autonomous CC construction with **waterless** concrete



CONTOUR  
CRAFTING  
CORPORATION



# Hangar and road construction

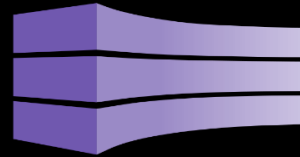


CONTOUR  
CRAFTING  
CORPORATION

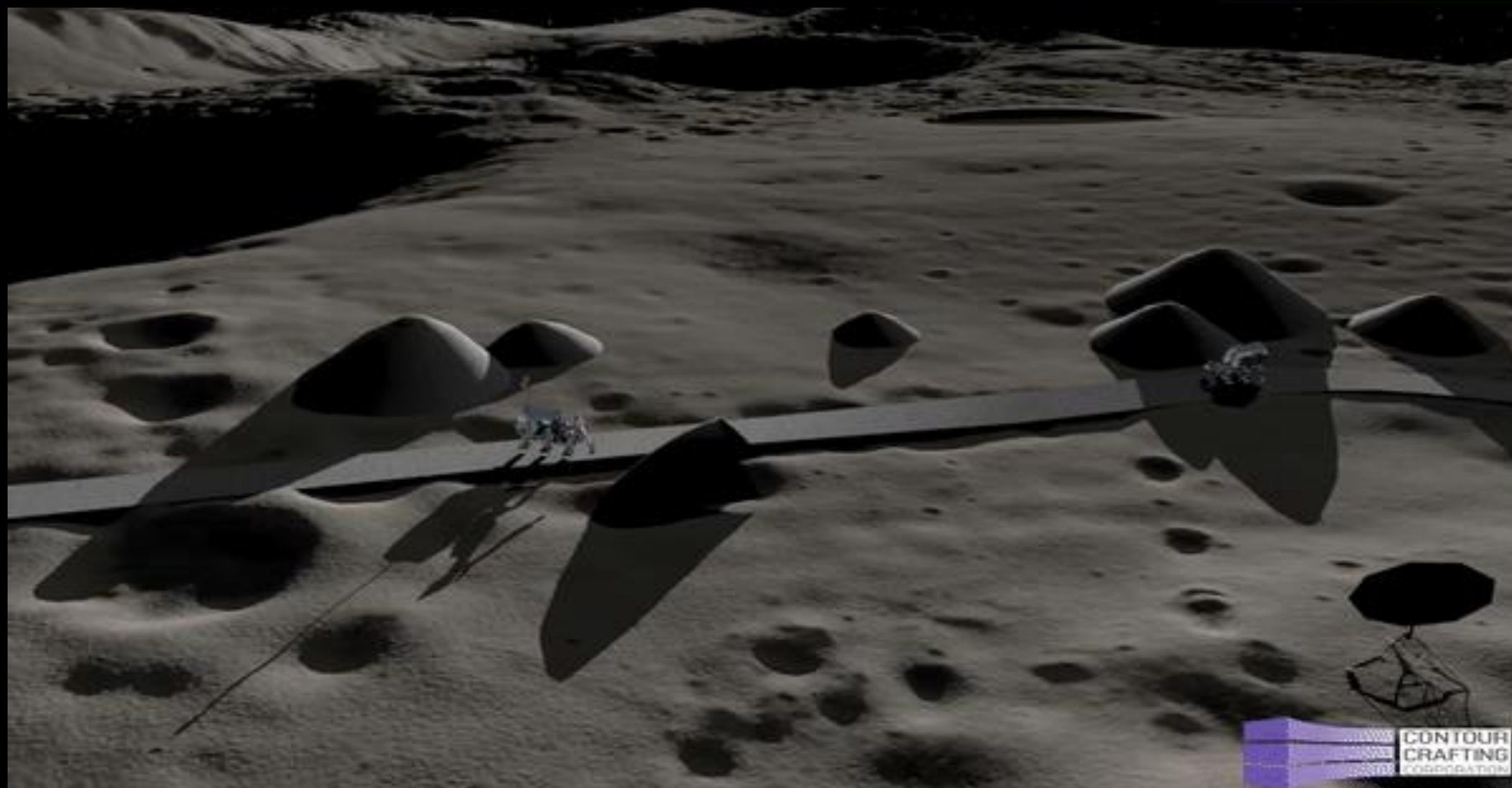


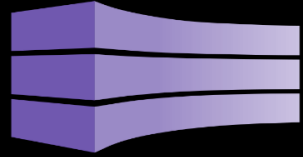


# Planetary construction using in-situ material



CONTOUR  
CRAFTING  
CORPORATION



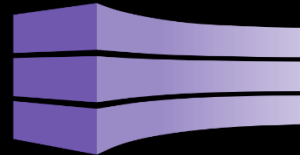


CONTOUR  
CRAFTING  
CORPORATION

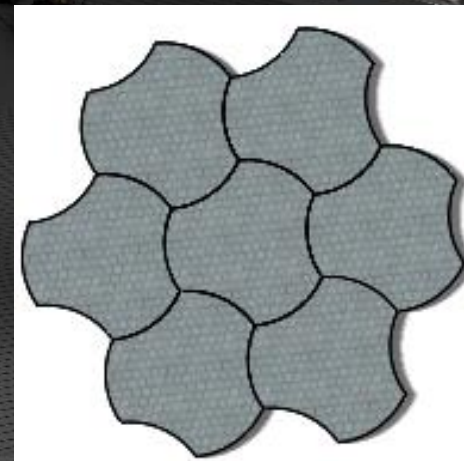
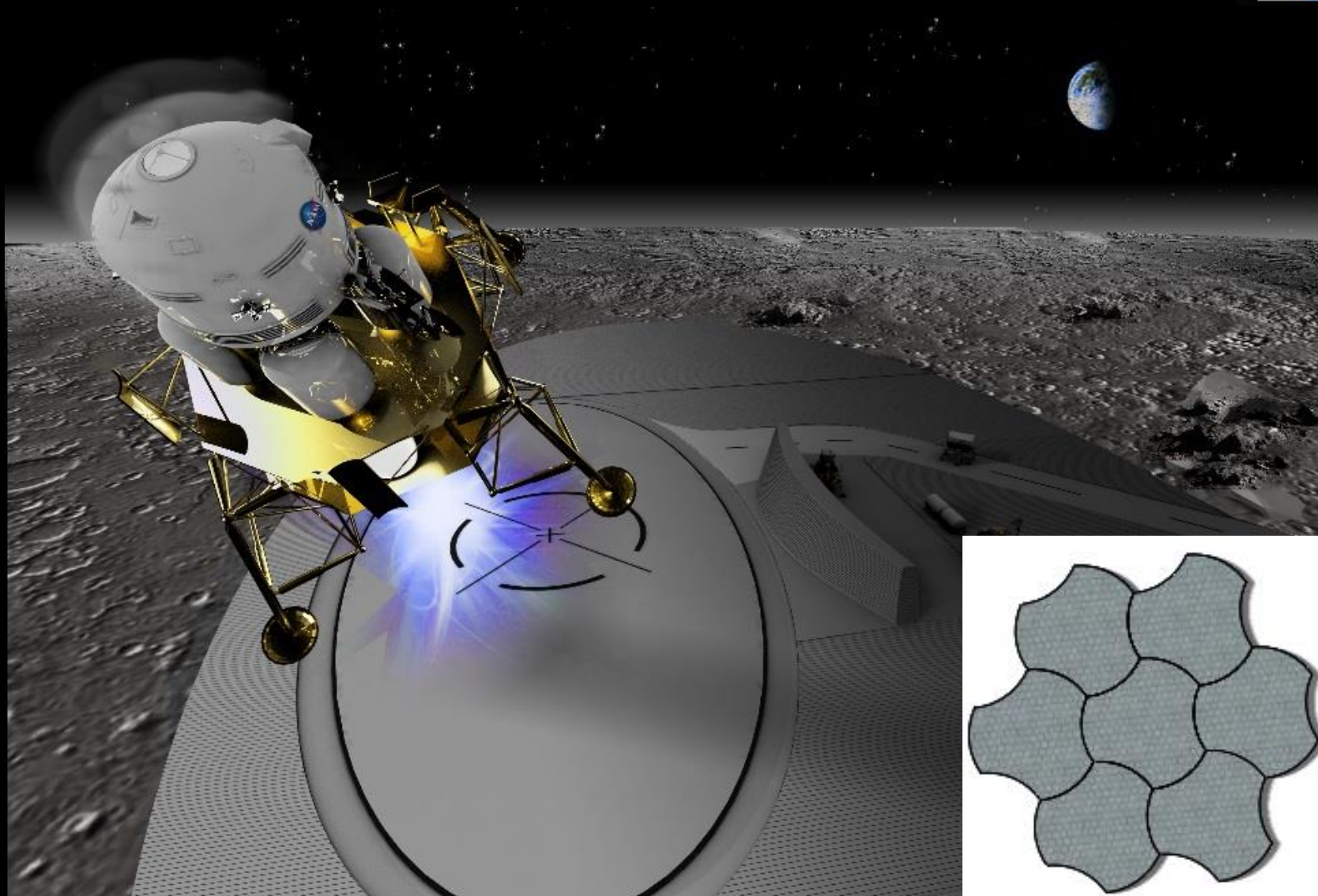
NASA awarded Contour  
Crafting the Grand Prize  
among 1000+ globally  
competing technologies in the  
*Create the Future  
Design Contest*



# Horizontal construction – Landing Pads

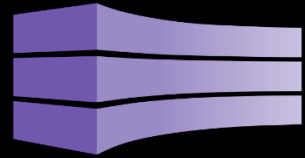


CONTOUR  
CRAFTING  
CORPORATION





# SSS- A New Large-Scale AM Process



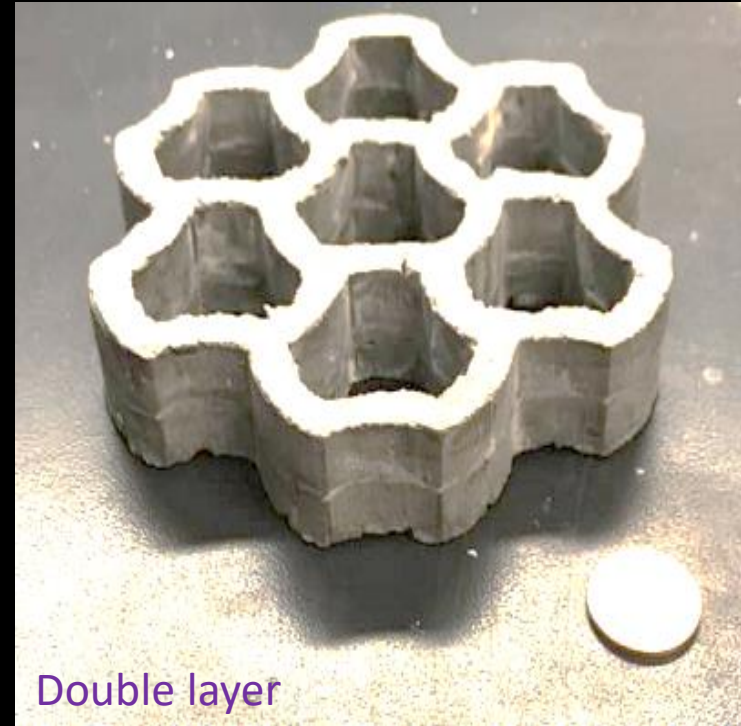
CONTOUR  
CRAFTING  
CORPORATION



Single layer

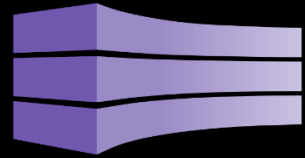


Double layer

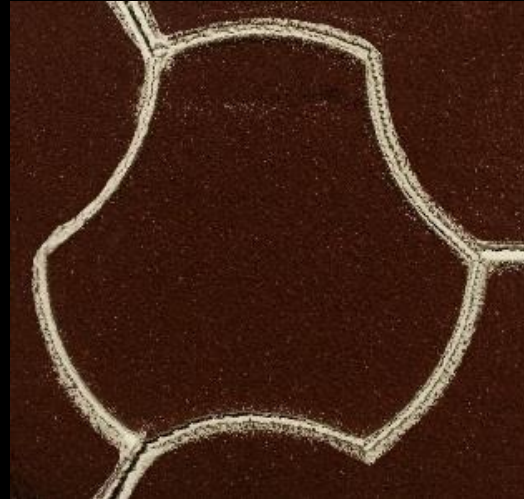


Double layer

# SSS ( Selective Separation Shaping )

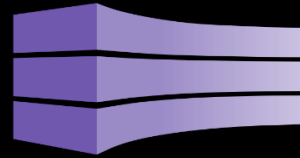


CONTOUR  
CRAFTING  
CORPORATION



A new large-scale  
powder-based 3D  
printing Technology

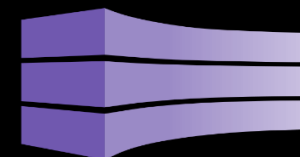
# Planetary Deployment



CONTOUR  
CRAFTING  
CORPORATION

Landing on unprepared surfaces is prone to catastrophic accidents as the redrock surface under the sand may be too slant.

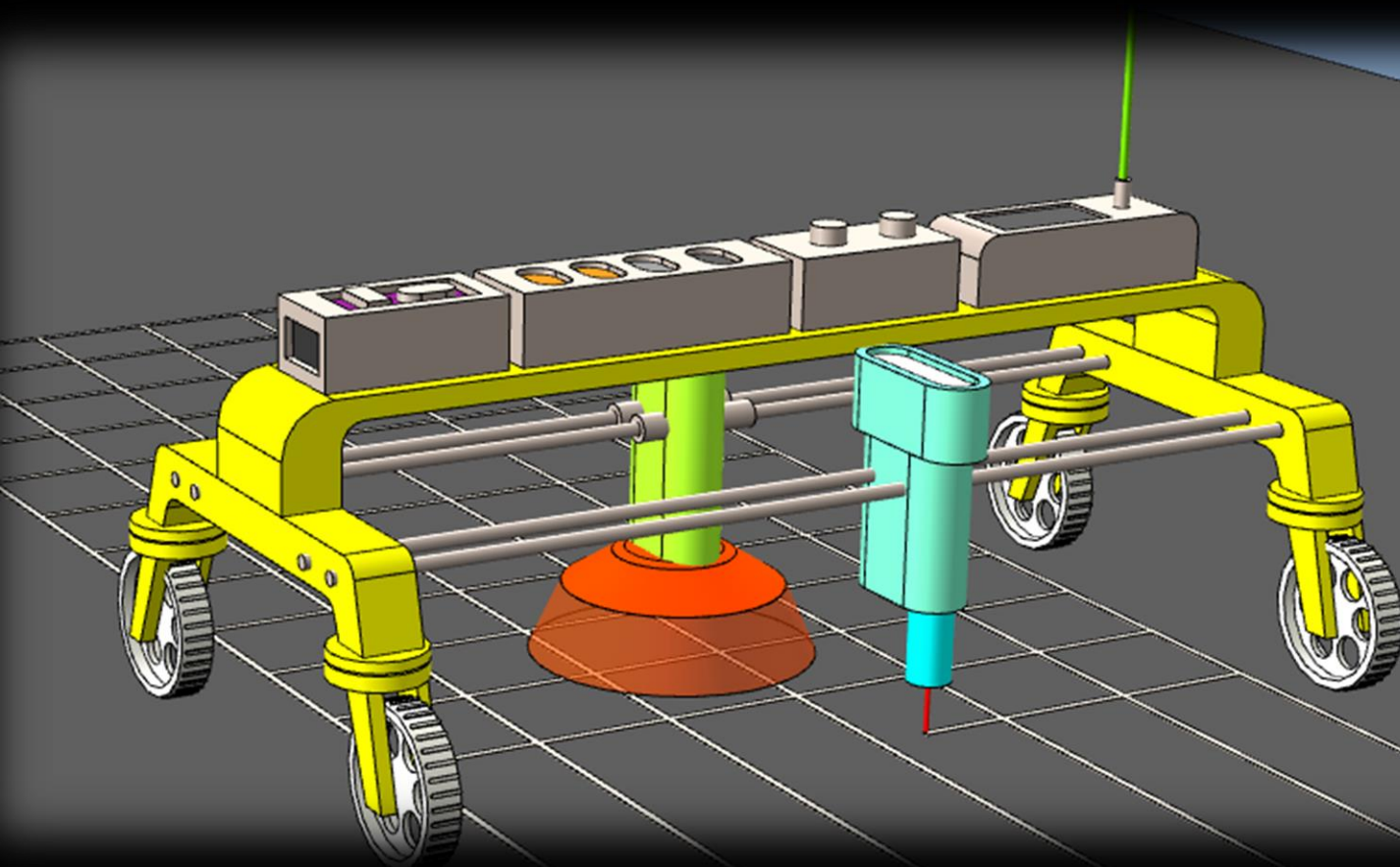




CONTOUR  
CRAFTING  
CORPORATION

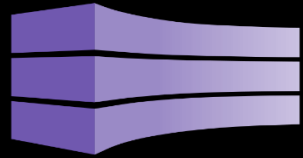


NASA awarded SSS the Grand  
Prize in the *International In-Situ  
Resource Based Fabrication  
Competition*



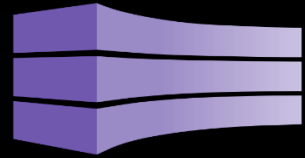
# Other research directions

- Process innovation and improvement
- Materials
- Impact on BIM and BIM integration
- IoT roles and synergies



CONTOUR  
CRAFTING  
CORPORATION

# 2017 Investment by Doka



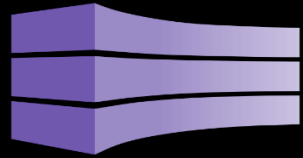
CONTOUR  
CRAFTING  
CORPORATION





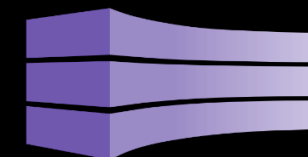
# Contour Crafting Corporation (CC Corp)

Visit: [ContourCrafting.com](http://ContourCrafting.com)



CONTOUR  
CRAFTING  
CORPORATION

*Please do not forget to fill the class survey form*



CONTOUR  
CRAFTING  
CORPORATION