



Approaches to Producing Additively Manufactured Concrete Mixtures

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MUCH ADVANCEMENT IN CONCRETE TECHNOLOGY IN TERMS OF MATERIALS AND STRUCTURAL DESIGN.

- High performance concrete
 - High strength
 - High flowability
 - High durability
 - High modulus
- Advanced structural design and analysis
- Better pumping systems



Burj Khalifa: Tallest building in the world

The process for manufacturing concrete has remained largely unchanged.



Manually mixing at site



1959, Oregon, USA



2017



Ready-mix

- ~70% in USA in 2016



Ready Mixed Concrete placing concrete along 17th Avenue in Downtown Denver, early 1950s



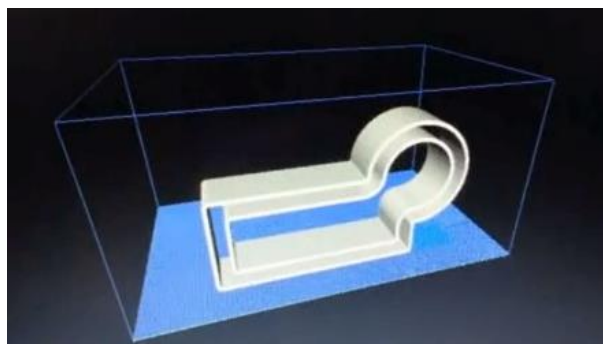
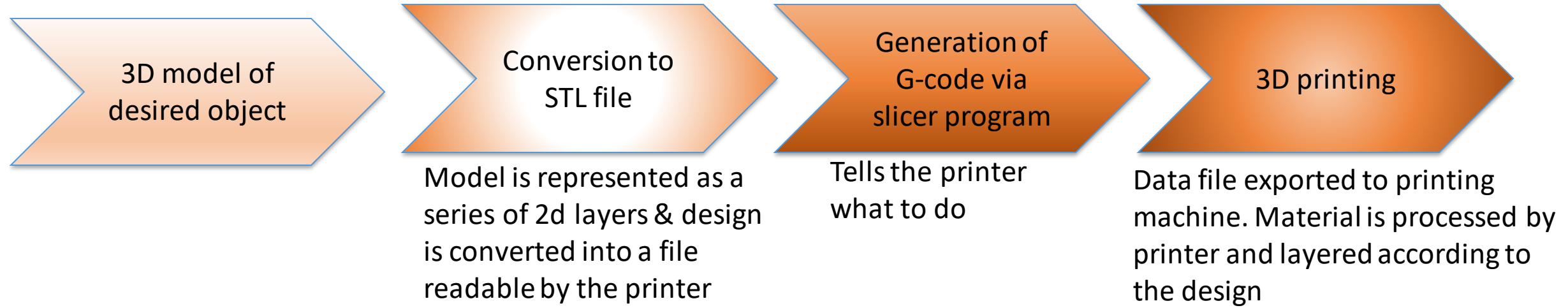
Las Vegas Mobile Mix truck pouring out ready mix concrete for utility works in Henderson, Nevada, 2018

The process for manufacturing concrete has remained largely unchanged...**but that may change with digital fabrication of concrete structures.**



Digital fabrication: the application of digital modeling and technologies to the production of custom material objects

General steps:



```

;layer 88, Z=8.79
G1 X145.31 Y41.195 F4800
M25; pause print
G1 Z8.79 F1000
G1 Z40 F1000; Height set to Z=40
G1 E0 F1800
G92 E0
  
```



Manufacturing

The third industrial revolution

The digitisation of manufacturing will transform the way goods are made—and change the politics of jobs too

Apr 21st 2012

 Timekeeper

 Like 14K

 Tweet



Brett Ryder

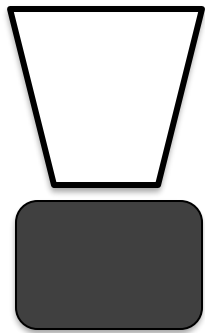


Types of digital fabrication concrete technologies

- additive manufacturing
- subtractive manufacturing

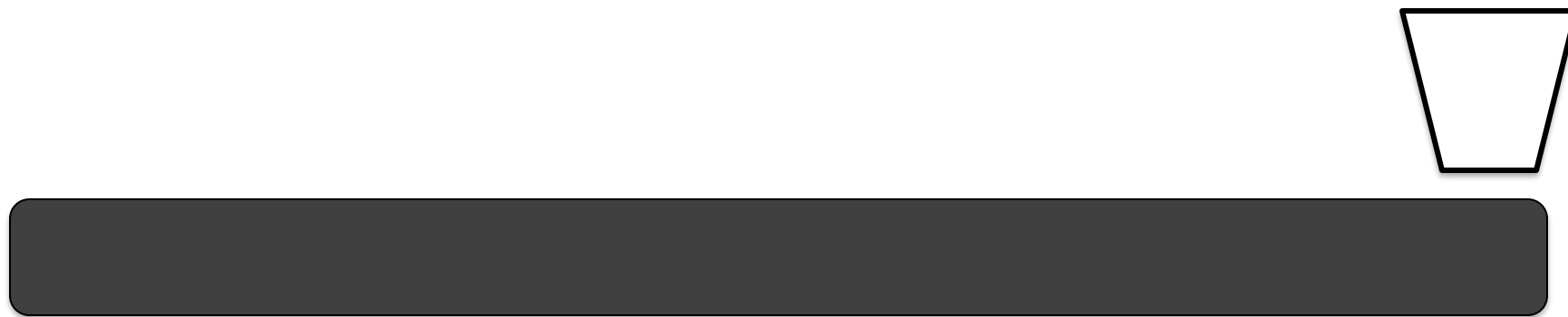


Layered extrusion-based 3D printing





Layered extrusion-based 3D printing



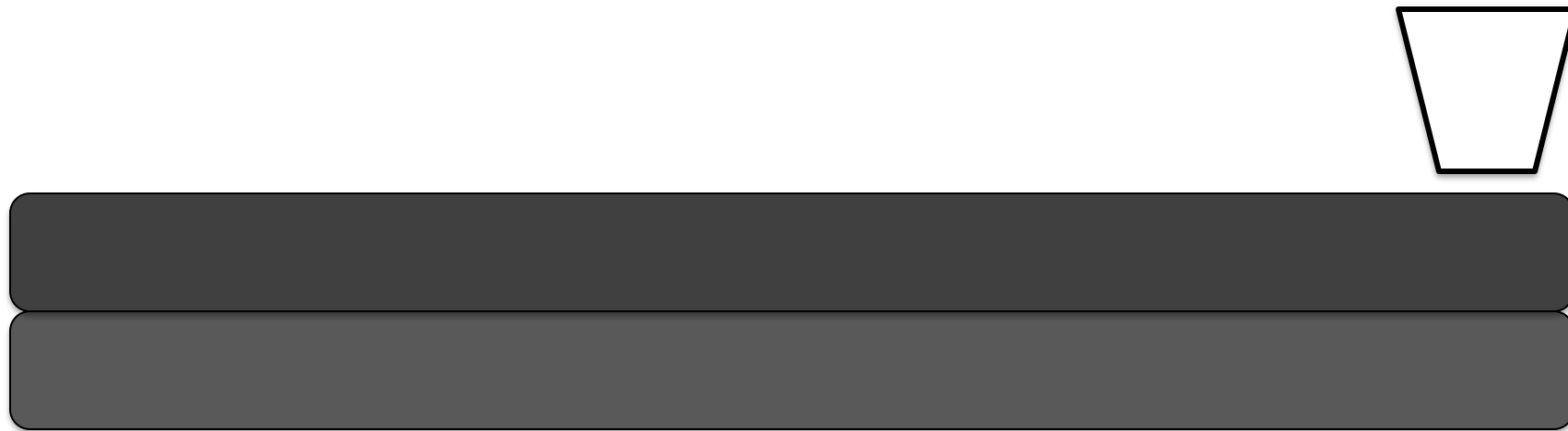


Layered extrusion-based 3D printing





Layered extrusion-based 3D printing





Layered extrusion-based 3D printing



Cement is reacting with water due to hydration and is aging over time.



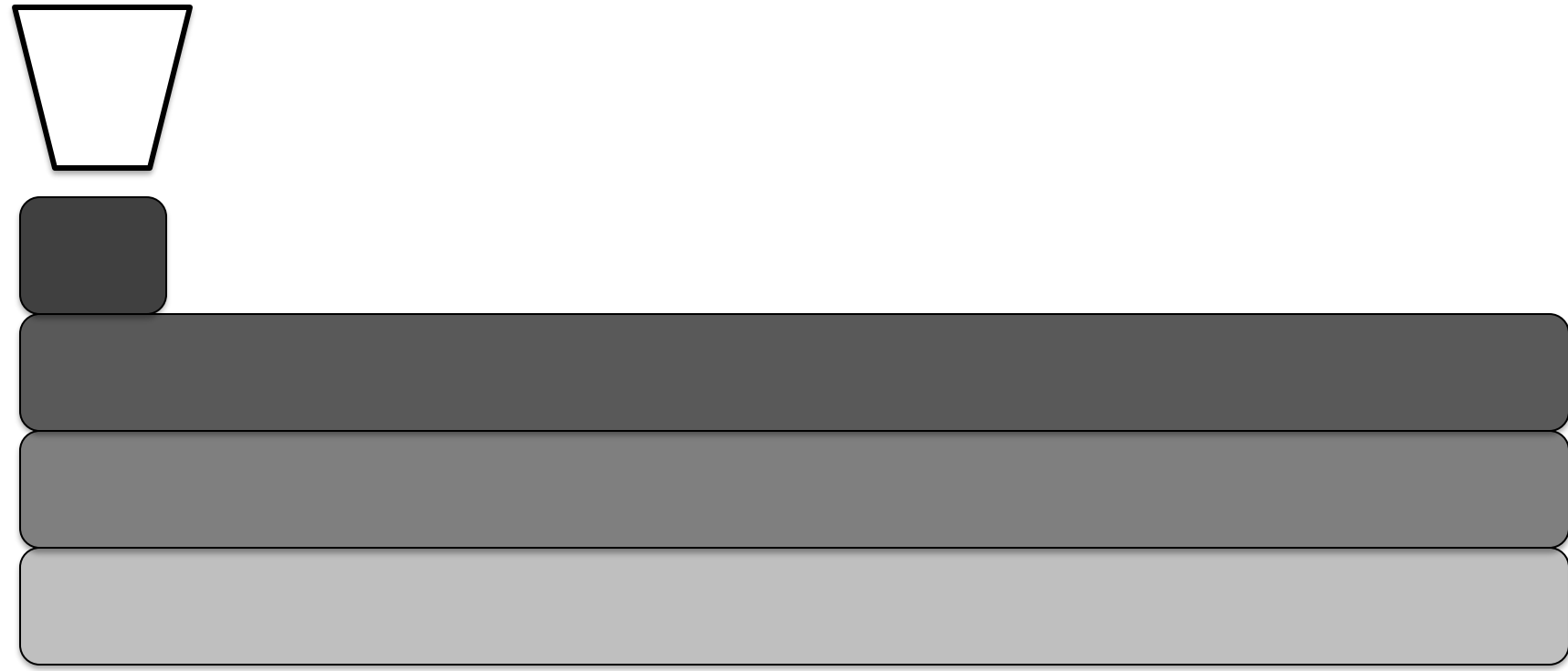
Layered extrusion-based 3D printing



Cement is reacting with water due to hydration and is aging over time.



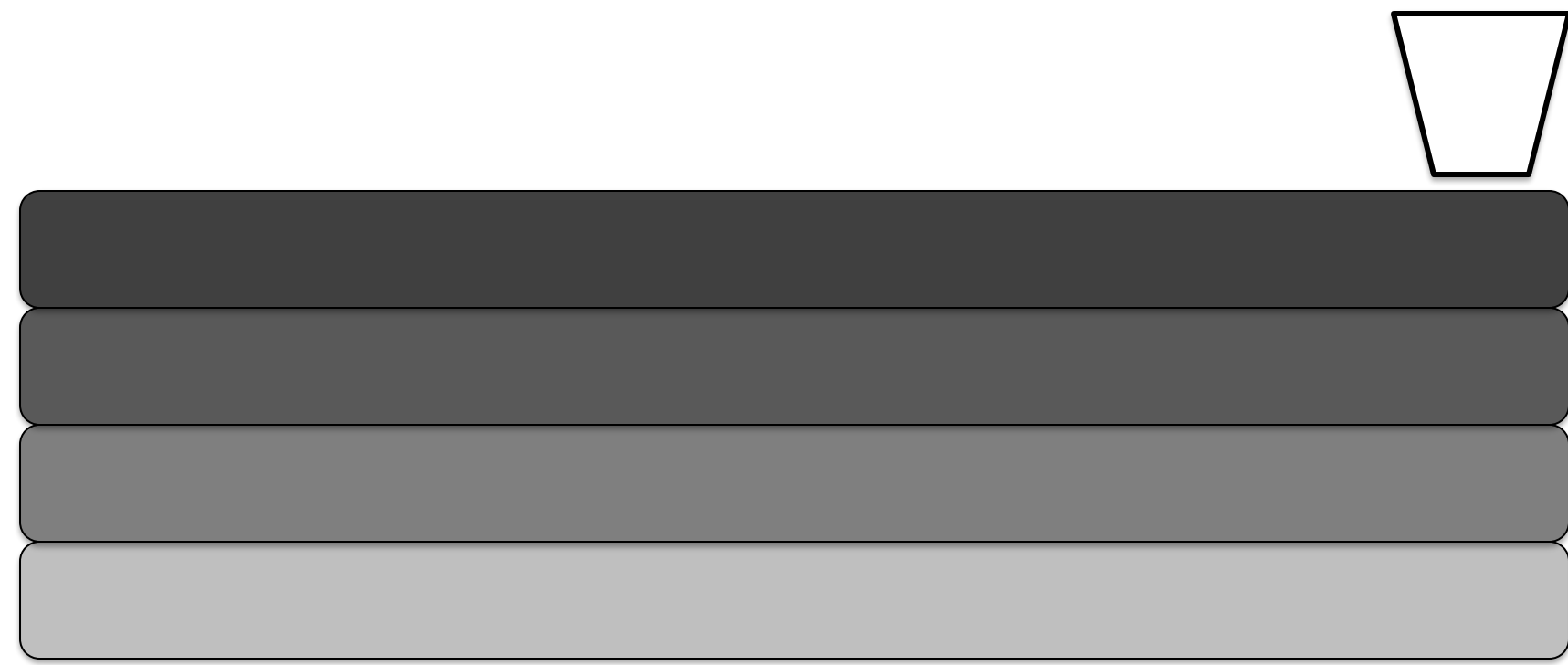
Layered extrusion-based 3D printing



Cement is reacting with water due to hydration and is aging over time.



Layered extrusion-based 3D printing



Cement is reacting with water due to hydration and is aging over time.



ICON (USA)



 **CBS THIS MORNING** Today's Rundown ▾ Politics & Power | Feat

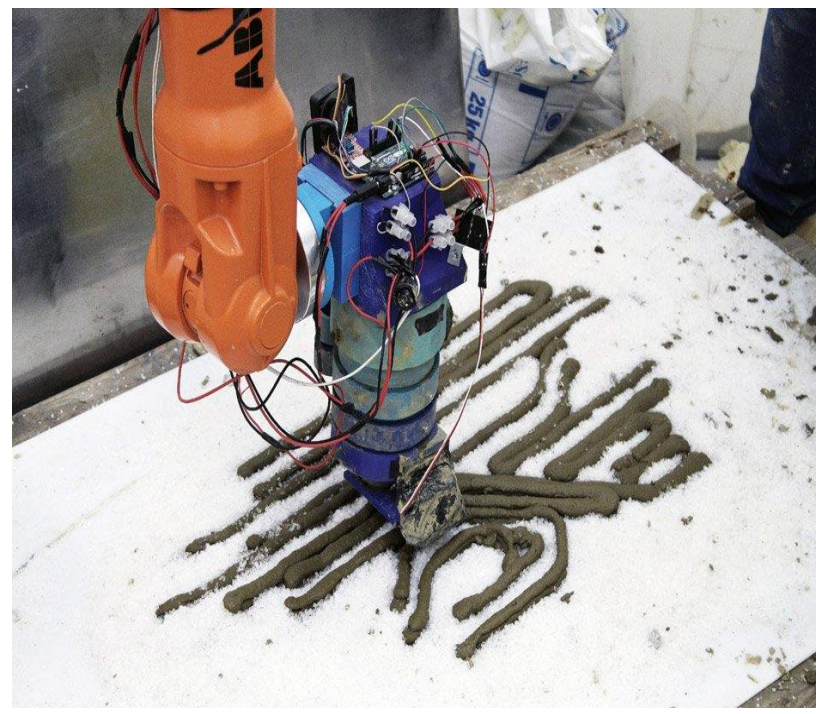


 **CBS THIS MORNING**

PRINTING YOUR PAD
3D PRINTERS COULD REVOLUTIONIZE HOME CONSTRUCTION

Binder Jetting

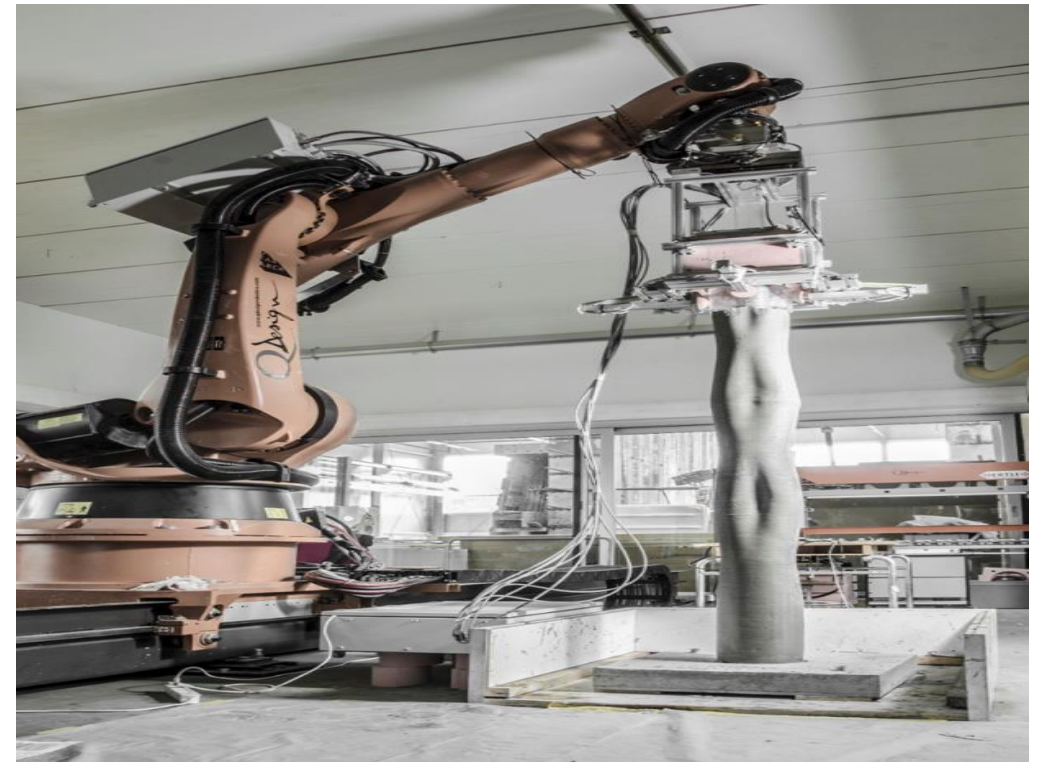
Produced by either by using cement in the powder bed and injecting water, or by injecting cement paste into an aggregate bed.



Bartlett School of Architecture (England)

Slipforming

Produces elements by robotically moving a defined formwork significantly smaller than the element produced.



Smart Dynamic Casting (SDC)- ETH Zurich (2012)

3D printing systems

■ Gantry system

- Printing on a build platform, typically smooth surface, where the extrusion point moves along x, y and z coordinates
- Space Constraint
- Labor intensive in terms of its assembly and transportation
- Orthogonal orientation – restricted curved deposition



Gantry print system, <https://thenewstack.io>



Robotic arm, UT Austin

■ Robotic arm system

- Freeform printing → Six degrees of freedom for print pathway
- Easy installation and accessibility
- More expensive than gantry system
- Additional safety measures



Large scale 3D printers

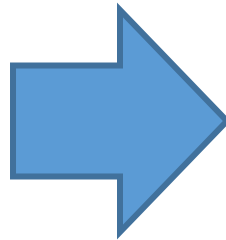
Printer	Company	Price	Printing Space (m)	Printing method	Printer Type	Country	Release date
P1	BetAbram	> \$ 250,000	16 × 8.2 × 2.5	Extrusion	Gantry	Slovenia	2017
3D Printer	Apis Cor	> \$ 250,000	8.5 × 1.6 × 1.5	Extrusion	Similar to robotic arm	Russia	2017
BigDelta Wasp 12M	WASP	\$ 100,000 – \$250,000	6 × 6 × 12	Extrusion	Gantry	Italy	2017
BIG 3D-Printer 2156	Imprimere AG	\$1,757,000	5.75× 6 × 6.25	Extrusion	Gantry	Switzerland	2017
X1	Cazza	\$480,000	3.6 × 3.4 × 0.8	Extrusion	Robotic Arm	USA	2017
3D Constructor	Machines- 3D	\$462,008	n/a	Extrusion	Robotic Arm	France	2017
S-300	AMT-SPECAVIA	> \$ 250,000	11.5 × 11 × 5.4	Extrusion	Gantry	Russia	2018
S-500	AMT-SPECAVIA	> \$ 250,000	11.5 × 11 × 15	Extrusion	Gantry	Russia	2018
BOD2	COBOD	> \$ 250,000	11.98 × 45.07 × 9.1	Extrusion	Gantry	Denmark	2018
Vulcan	ICON	n/a	6.096 x 3.353 x desired	Extrusion	Gantry	USA	n/a



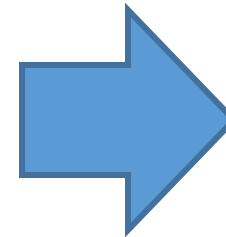
Process Approach & Key fresh state considerations

Approaches for mixture

- **Extrusion approach-** stiff mixture possess immense high structural buildup rate
- **Flowable approach-** mix should be flowable enough to be extruded out in designated patterns, yet have sufficient rheological properties to support the layers above it



- Extrudability
- Flowability
- Buildability
- Pumpability
- Thixotropy
- Open time
- Delay Time
- Printability window
- Scaleability



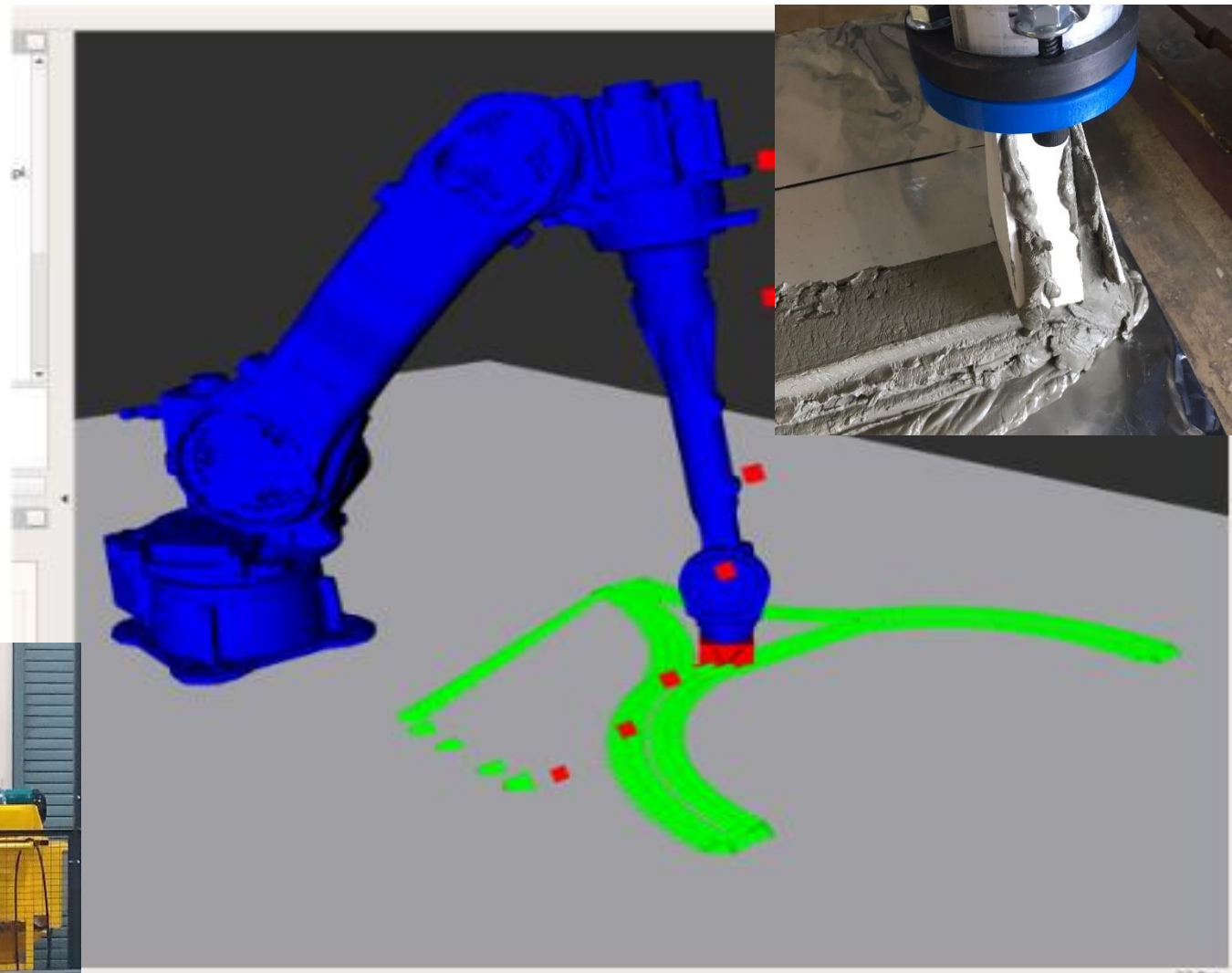
Rheology

Multi-scale printing

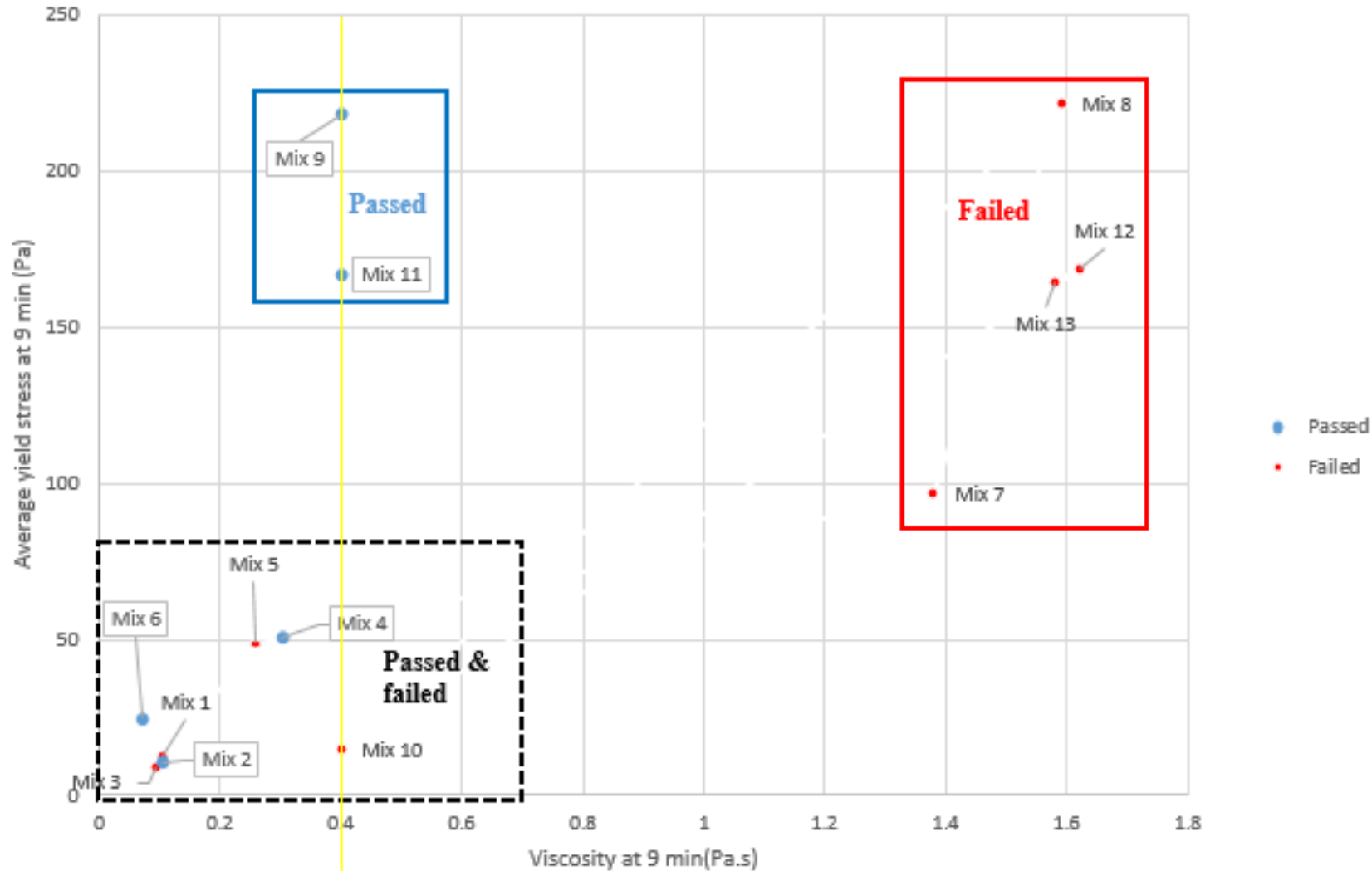
Benchtop Printer

- Dimensions: 34in x 48in ;Based on RepRap's wiring configuration (open-source)
- Softwares to be used:
 - Marlin- Computer connection & coding
 - Printrun - Printing host
 - Slic3r - 3D converter

Large scale Printer:



Key considerations for 3D-printed cementitious mixtures

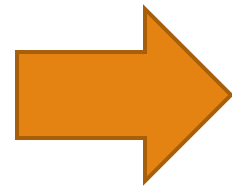


Mixture details:

- Type I/II cement
- Limestone powder @ 25% and 33.3% replacement (#30 sieve)
- Sand
- VMA
- HRWR
- Different water-to-cement ratio

Summary

- Different approaches → Layered extrusion most common
- Large-scale digital fabrication of concrete is possible and feasible.
 - Quicker construction
 - Less labor
 - Lower overall cost
 - Less material
- Better understanding of properties and performance of additively manufactured materials needed



Mass
production
customization



USACE: 3D printing of 9.5-ft-tall reinforced concrete walls for a 32-ft x 16-ft barracks

Thank You



3D printed
concrete
chair.
(Produced by Siam
Cement Group)