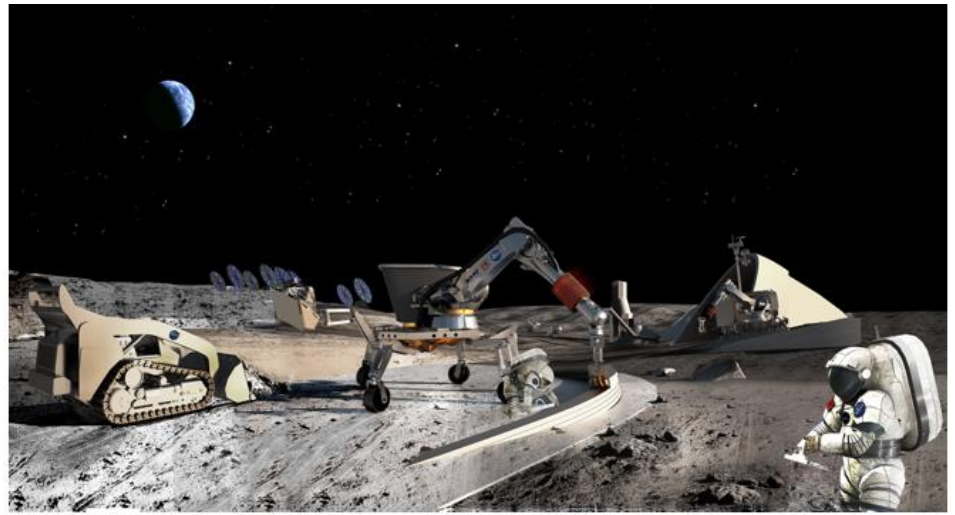




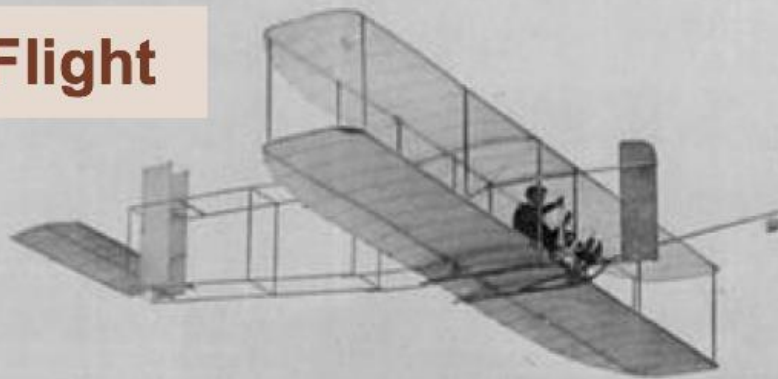
El evento del Cemento, el Concreto y los Prefabricados



## *Construcción de hábitat en el espacio - 3D Printing*

*Tony Kim  
NASA  
Estados Unidos*

# The Centennial of Flight



## The Wright "Flyer"

An aircraft built of wood, powered by hand made propellers flew at Kitty Hawk, North Carolina, on December 17, 1903, making a 12-second flight.



DC-3

1935



SR-71

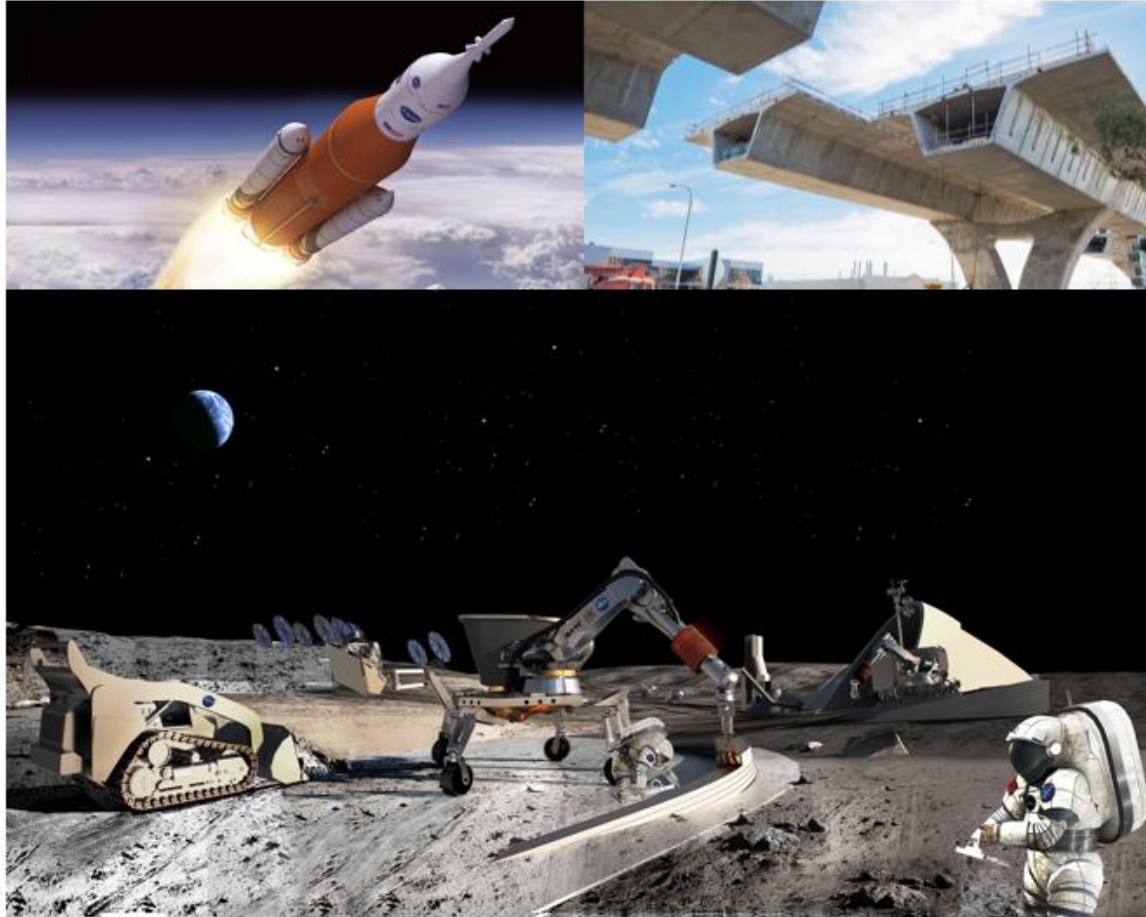
1964



F-35

present

# Why is NASA working on Concrete?





# Historical Concrete Technology Advancements

*Eddystone  
Light House*



1756  
*Portland  
cement*



1885  
*slipforming*

*Alvord Lake Bridge*



1889  
*reinforced concrete  
bridge*

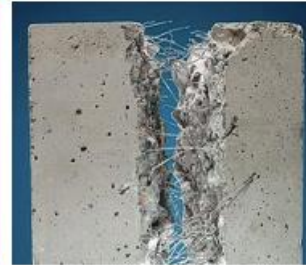
*Baltimore*



1907  
*shotcrete/gunitite*



1930  
*1<sup>st</sup> load of readymix*

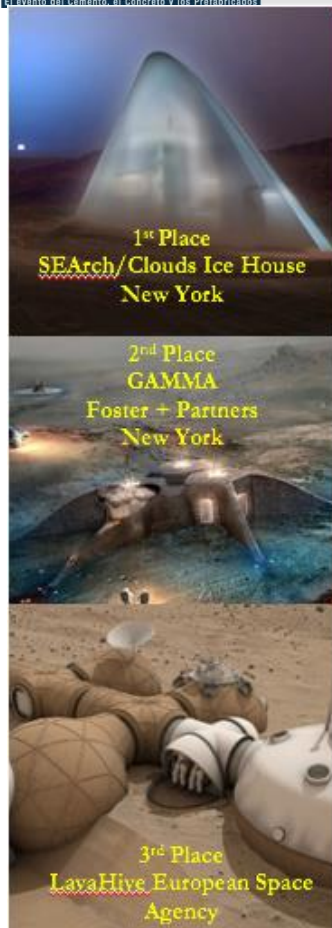


1960  
*fiber reinforcement*



*climbing concrete  
formwork*

# 3DPH Challenge: Phase 1 Design



Architectural concept  
and design approach

3D-Print  
Constructability

Habitability

Innovation

Functionality

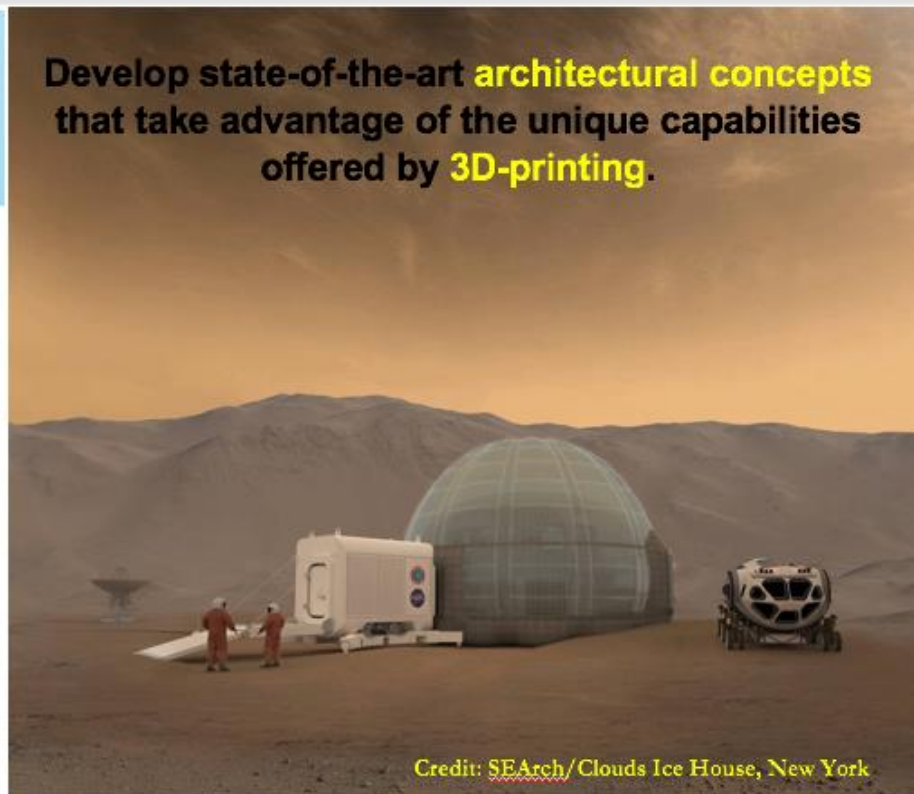
Energy Efficiency

Mars Site Selection

Documentation

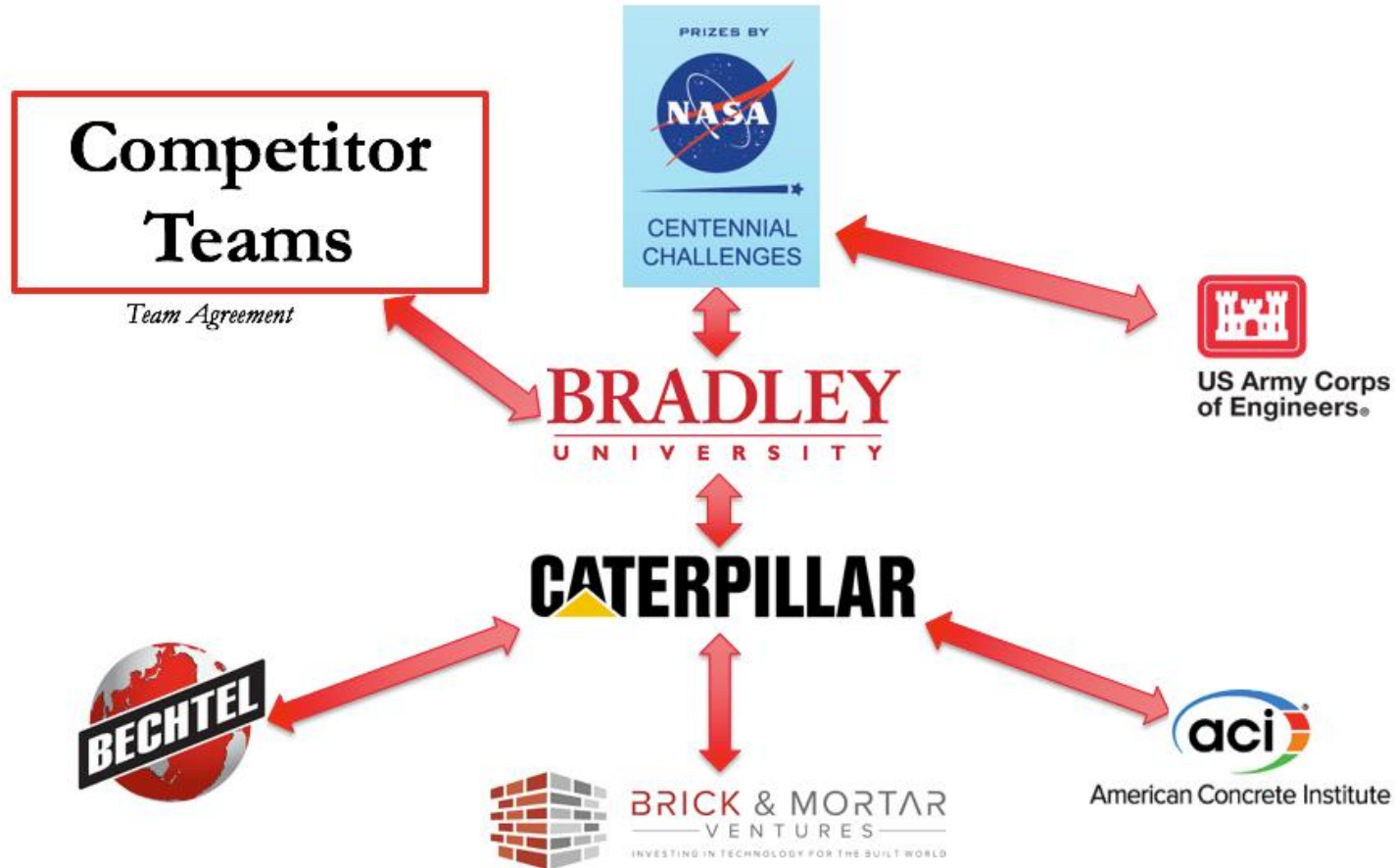
Public Appeal

Develop state-of-the-art **architectural concepts**  
that take advantage of the unique capabilities  
offered by **3D-printing**.



Started: May 16, 2015  
Completed September 27, 2015

# Teams, Partners, Sponsors, and PUBLIC





# Phase 2 Level 1: Cylinders & Cones



## Cones Slump Test

$$\frac{h_o - h_i}{h_o} < 0.15$$



Original print  
height ( $h_o$ )

Print height after 5  
minutes ( $h_i$ )



## ASTM C39 Compression Test



# Phase 2 Level 2: Beams

1<sup>st</sup> PLACE MoonX construction



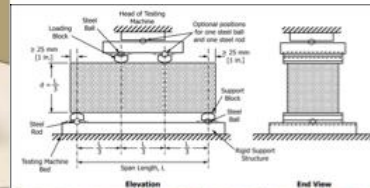
2<sup>nd</sup> PLACE FORM FORGE



3<sup>RD</sup> PLACE



Beam Flex Strength Test

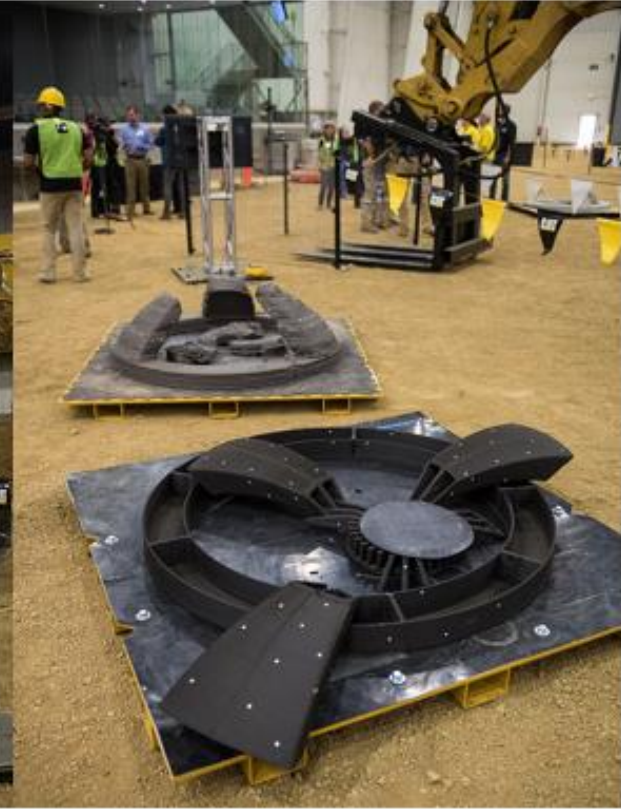


ASTM C78  
Bend Test

## Phase 2 Level 3: Dome



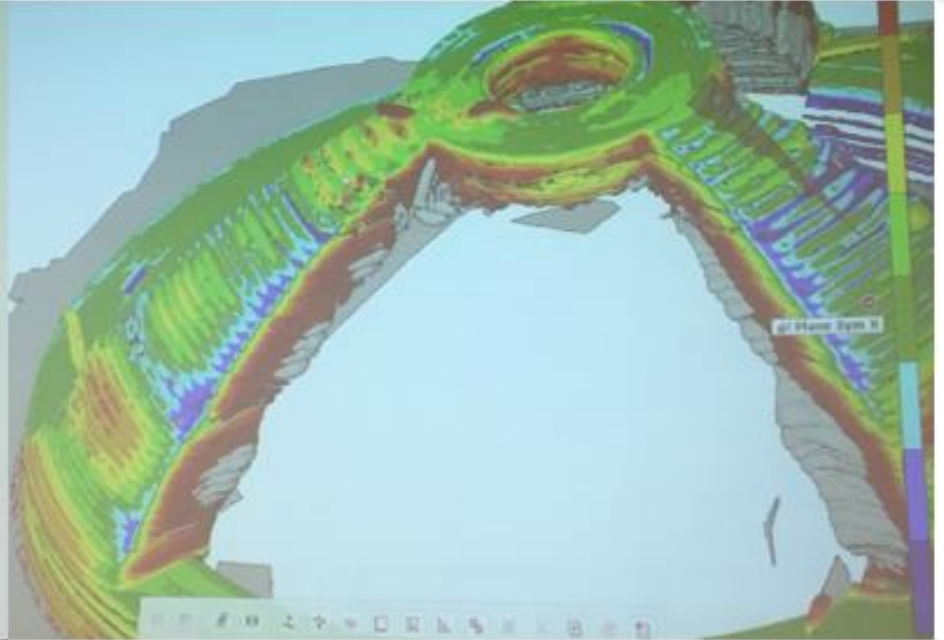
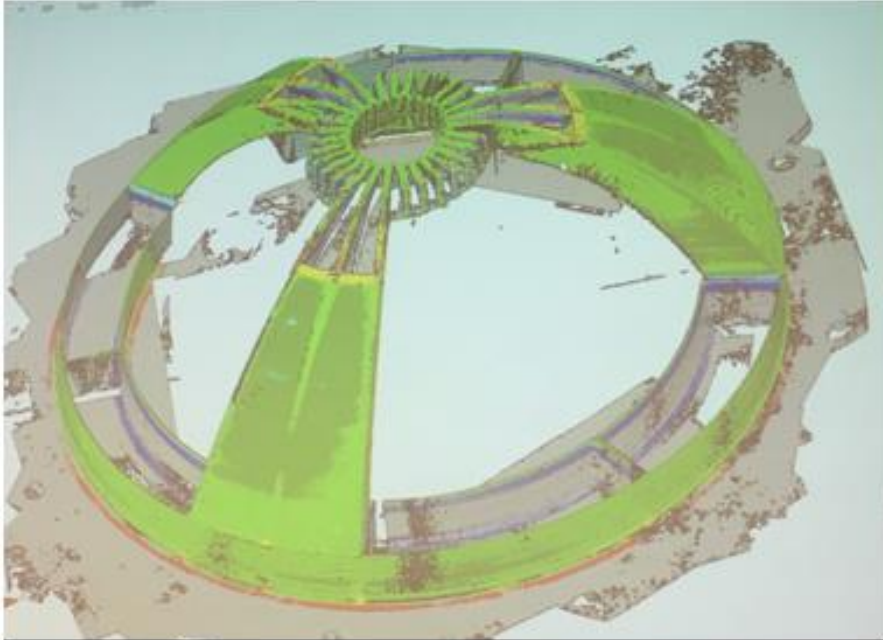
Penn State dome strength testing



Penn State and Branch Technology  
domes after testing



## Phase 2 Level 3: Dome tolerance measurements



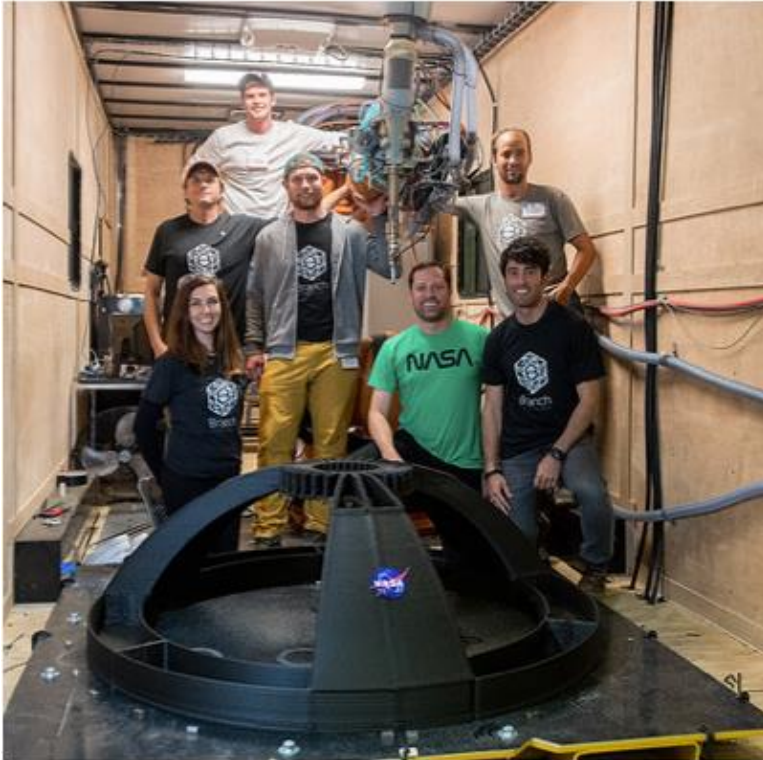
Branch  
TECHNOLOGY



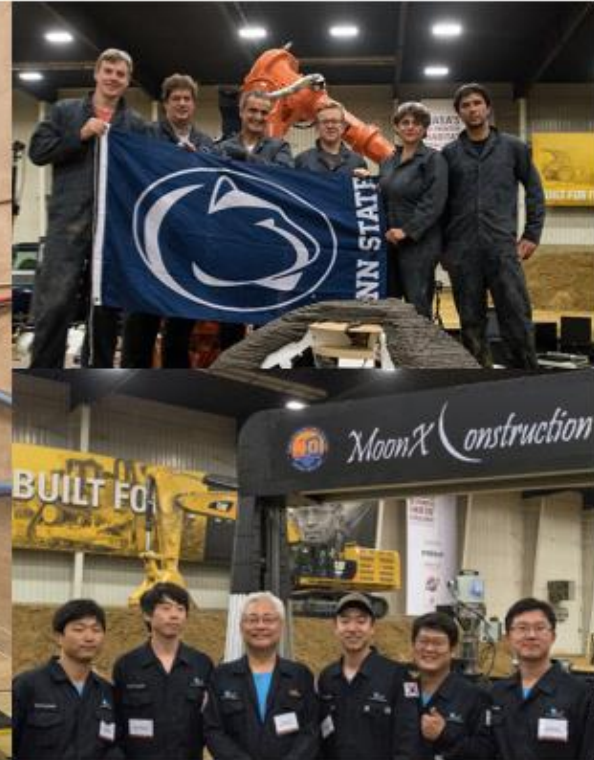
PennState

# Phase 2 Level 3: Printing Robots and Teams

## 2<sup>nd</sup> Penn State



1<sup>st</sup> Branch Technology



MoonXConstruction  
Han Yang University, Seoul S. Korea



# Phase 2 Structural Member Challenge Results

Teams	Level 1	Level 2	Level 3
Branch Technology (Tennessee)	1 <sup>st</sup> \$86k	3 <sup>rd</sup> \$64k	1 <sup>st</sup> \$250k
Univ. of Alaska Fairbanks (Alaska)	2 <sup>nd</sup> \$14k	4 <sup>th</sup> \$36k	invited
Penn State (Pennsylvania)	NC	NC	2 <sup>nd</sup> \$150k
CTL Group Mars (Illinois)	NC	5 <sup>th</sup> \$34k	invited
<u>MoonXConstruction</u> (South Korea)	NC	1 <sup>st</sup> \$0 int.	participant
<u>Robocon</u> (Singapore)	NC	6 <sup>th</sup> \$0 int.	invited
Bubble Base (North Carolina)	NC		
<u>FormForge</u> (Oregon)		2 <sup>nd</sup> \$67k	invited
Total Prize Award	\$100k	\$201k	\$400k

NC: Non-Compliant; team did not meet 70% indigenous material requirement rule

# Phase 3 On-Site Habitat Competition

## Autonomous Additive Construction System

Registration open: Nov. 7, 2017

Head-to-Head: April 29 – May 4, 2019

Total Prize Purse: \$2 million

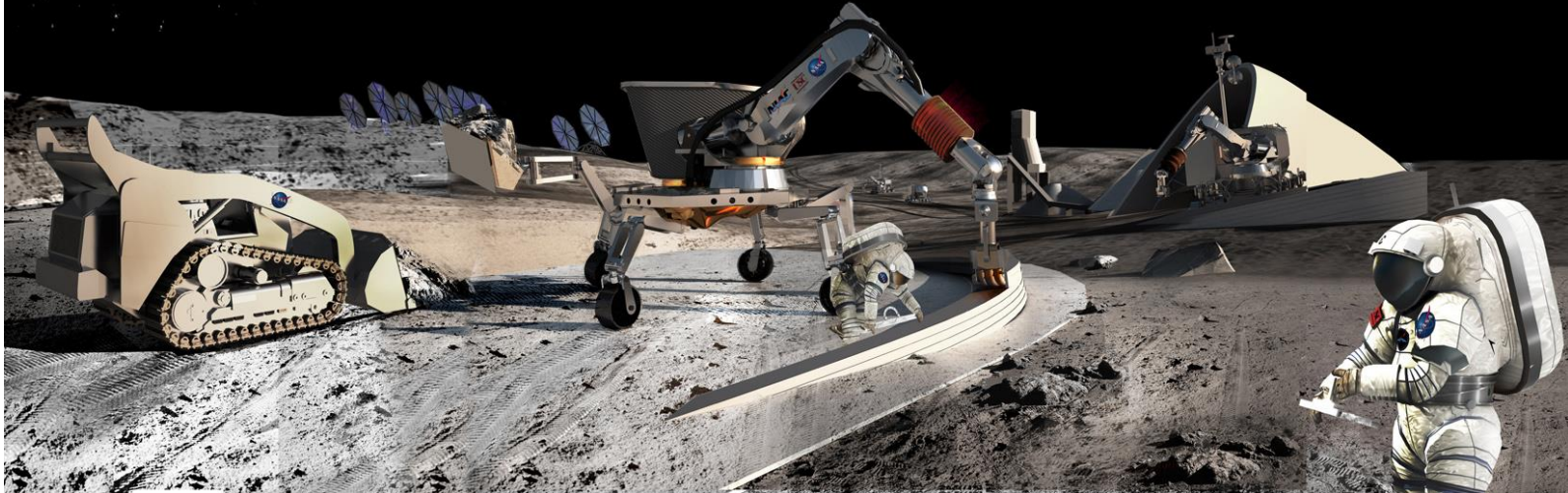
Level 1 (May 2018): Virtual Design partial

Level 2 (July 2018): Foundation

Level 3 (Dec. 2018): Sealing Test

Level 4 (Jan. 2019): Virtual Design complete

Level 5 (May 2019): Subscale Habitat



# Phase 3 Level 1 & 4 Virtual Design



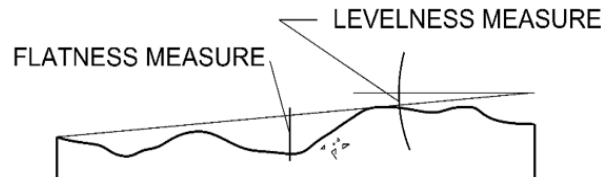
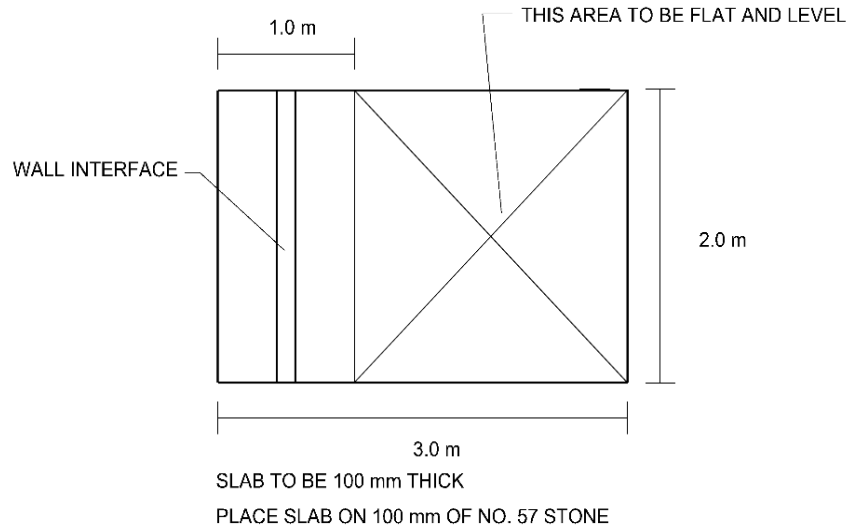
## Level 1: Virtual Design Partial

- BUILDING INFORMATION MODELING (BIM)  
Design 60%
- 1000 FT<sup>2</sup> OF LIVABLE SPACE
- THREE 46 FT<sup>3</sup> ECLSS SPACES  
(ENVIRONMENTAL CONTROL & LIFE  
SUPPORT SYSTEMS)
- STRUCTURAL AND MECHANICAL  
ELECTRICAL PLUMBING LAYOUT
- EXTERIOR WALL PENETRATION
- FUNCTIONAL FOR 4 ASTRONAUTS FOR  
ONE YEAR
- DUE MAY 16, 2018

## Level 4: Virtual Design Complete

- DESIGN 100% COMPLETE
- 4D BIM (BONUS POINTS)
- DUE JANUARY 16, 2019

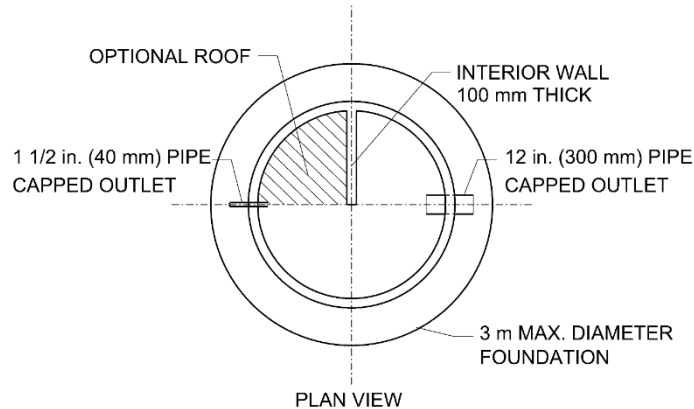
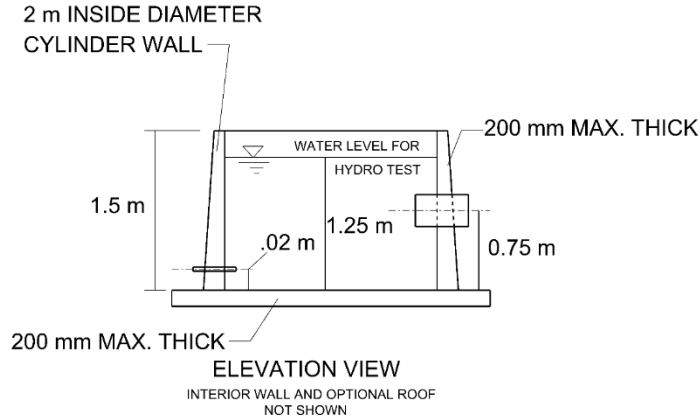
## Phase 3 Level 2: Foundation



- Team shall 3D print a 2 m by 3 m slab foundation with optional wall interface and assess it for quality (smoothness and levelness)
- Teams shall evaluate foundation durability by an impact test (drop a standard iron shotput from 5 m height)
- Team shall 3D print specimens for ASTM 666 freeze thaw testing and for ASTM C39 compression testing
- Autonomy to be scored based on number of physical and remote interventions required
- Data and Certified Test results must be provided to Bradley by July 11, 2018
- 10 teams with highest scores awarded prize proportional to score for total amount of up to \$400k



# Phase 3 Level 3: Sealing Test



- Team shall 3D print a foundation and walls with optional roof section (wall penetrations to be autonomously placed and sealed) and assess sealing via water leakage testing
- Team shall 3D print specimens for ASTM 666 freeze thaw testing and for ASTM C39 compression testing if there are changes from Construction Level 1
- Autonomy to be scored based on number of physical and remote interventions required
- Data and Certified Test results must be provided to Bradley by December 5, 2018
- 8 teams with highest scores awarded prize proportional to score for total amount of up to \$600k

# Phase 3 Level 5: Sub-Scale Habitat



- Team shall 3D print a 1:3 model of their full scale habitat design, simplified as specified in the rules
- Pre-printed parts may be autonomously placed to speed the competition
- Habitat will be subjected to a smoke test for leakage, a projectile drop test for robustness, and a crush test for ultimate strength
- Autonomy to be scored based on number of physical and remote interventions required
- Additional tests and points will be based on material properties of printed materials
- At CAT Facilities near Peoria Illinois on April 29 - May 4, 2019
- \$500k for first prize, \$200k for second prize, and \$100k for third prize

# Enabling Space Exploration





# Summary of current Challenges

Active

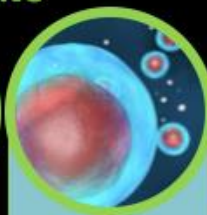
Developing



**Cube Quest**  
**\$5,000,000**



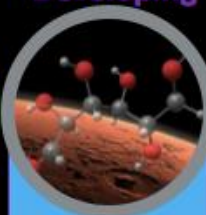
**3D-Printed Habitat**  
**\$3,150,000**



**Vascular Tissue**  
**\$500,000**



**Space Robotics**  
**\$900,000**



**CO<sub>2</sub> Conversion**  
**\$1,000,000**

**Flight-qualified**  
**CubeSats** near  
and beyond the  
moon

- \$460,000 awarded to date
- Innovative propulsion and communication systems
- 3 payload slots on SLS EM-1
- 15 U.S. teams
- NASA Lead Challenge

**Additive construction**  
technology for  
space

- \$741,024 awarded to date
- 240 teams: 167 U.S. and 73 international
- Allied Organization: Bradley Univ/ Sponsors: Caterpillar Inc., Bechtel Corp, Brick and Mortar Ventures

**Viable thick**  
tissue for  
research

- 9 U.S. teams currently registered
- Innovation in engineered tissue that can stay viable for more than 30 days
- Allied Organization: New Organ Alliance

**Advance robotics**  
software and  
autonomy

- \$555,000 awarded in Phase 1
- 92 Teams: 79 U.S. and 13 international
- Phase 2 under development
- Allied Organization: Space Center Houston/ Sponsor: Nine Sigma

**Bio-**  
manufacturing  
from in-situ  
resources

- Enable biomanu- facturing of products in space
- Announce- ment expected in FY18
- HEOMD and ER&T funding collaboration
- NASA Lead Challenge





# Questions?



<https://NSPIRE.nasaprs.com>



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/NASACC



NASAPrize



[www.nasa.gov/winit](http://www.nasa.gov/winit)