

# Structural Member Competition Rules V.5

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NASA & Bradley University

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## 1.0 Definitions

- 1.1. 3D-Printing – See Additive Manufacturing
- 1.2. Additive Construction – Additive Manufacturing on a structure scale. 3D-Printing of structures or structural members.
- 1.3. Additive Manufacturing – Synonymous with the term “3D-Printing”. Any process used to produce a three dimensional physical object by deposition of material layer by layer.
- 1.4. Automated/Autonomous – The use of machines, mechanisms, and technology to make processes or systems run without human guidance or power. The machine, mechanism, or technology is able to observe, process, and make decisions without human interaction, or other outside instructions.
- 1.5. Federally Owned Facility - Federal facilities are defined as buildings, installations, structures, land, public works, equipment, aircraft, vessels, other vehicles, and property, owned, constructed or manufactured for leasing to the Federal government.
- 1.6. Feedstock – Raw materials used as a part of the 3D-Printing process. For this competition, the feedstock may consist of indigenous, binder, water, and/or recyclable materials.
- 1.7. Indigenous – Originating in and characteristic of a particular region.
- 1.8. In-Situ Resources – Indigenous materials that pre-exist at the construction site, or recyclable materials produced from the waste stream of the mission or supply chain.
- 1.9. Prize – money, trophy, certificate, and/or award given based on technical achievements.
- 1.10. Recycled/Recyclable Materials – Used or waste materials generated during a mission that may be processed for reuse. Relevant materials are identified in [Table 1](#).
- 1.11. Semi-Autonomous – This term refers to a system which is primarily automated but may require some human interaction to perform basic functions. For instance, a semi-autonomous 3D-Printing system may require human interaction to perform certain control decisions and maintenance functions.
- 1.12. Team – an individual, or group of individuals, submitting an entry for competition. There is no limit to the number of individuals on a Team.

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- 1.13. Team Member – an Entity employee, an Entity owner, an Entity student, or an individual participant, man or woman, who is currently contributing to a Team’s entry for competition.
- 1.14. Team Leader – a Team Member acknowledged or designated by the Team as the leader or Challenge point of contact. The Team Leader must be a U.S. citizen, permanent resident, or U.S. Entity to be eligible to win NASA Prizes.
- 1.15. United States (U.S.) Entity - an Entity incorporated, chartered, or organized and maintains primary place of business in the U.S..
- 1.16. Centennial Challenge – A program initiated to incentive prizes to generate revolutionary solutions to problems of interest to NASA and the nation. It seeks innovations from diverse and non-traditional sources and engages the public in the process of advanced technology development.
- 1.17. 3D Habitat Challenge – A specific three-phase Centennial Challenge that aims to advance the additive construction technology needed to create sustainable housing solutions for Earth and beyond.
- 1.18. Structural Member Challenge – The second phase of the 3D Habitat Challenge asks teams to develop and demonstrate an additive manufacturing material system that can create structural components using terrestrial/space based materials and recyclables.
- 1.19. Compression Test Competition – The first level of the structural member challenge asks teams to 3D print and test truncated cones and ASTM C39 compression specimens. The compression specimen will be tested to failure and must withstand a minimum load of 450kg (1000 lbs).
- 1.20. Beam Member Competition – The second level of the structural member challenge asks teams to 3D print and test beam members tested per ASTM C78. Beams shall have a minimum load at failure of 750kg (1650 lbs).
- 1.21. Head to Head Competition – The third level of the structural member challenge asks teams to 3D print a dome structure and provide additional specimens for ASTM C39 and ASTM C78 tests. Teams must qualify for this event based on their performance in the previous levels of the structural member challenge and receive an invitation to compete at this level. The event will be open to the public. The majority of the monetary prizes are awarded at this event.

## 2.0 3D-Printed Habitat Challenge Overview

- 2.1. The 3D-Printed Habitat Challenge seeks to develop the fundamental technologies necessary to manufacture an off-world habitat using mission recycled materials and/or local indigenous materials. The vision includes autonomous habitat construction machines deployed to the Moon or Mars to construct shelters for human habitation.
- 2.2. On Earth, these same habitat construction capabilities could be used to produce housing wherever affordable housing is needed and access to conventional building materials and skills are limited. On Earth, it is envisioned that local indigenous materials (dirt, clay, sand, etc.) could be combined with readily available recyclable materials and used to construct semi-permanent shelters against environmental elements for human habitation.
- 2.3. The goal of the 3D-Printed Habitat Challenge is to foster the development of new technologies necessary to additively manufacture a habitat using local indigenous materials. Material formulations may include recyclable materials. The Challenge is divided into three phases described below (Figure 1). This document will focus on the requirements and rules associated with the Structural Member Competition only.
  - 2.3.1. Design Competition (Phase 1) - focused on developing innovative habitat architectural concepts that take advantage of the unique capabilities that 3D-Printing offers.
  - 2.3.2. Structural Member Competition (Phase 2) - focused on the core 3D-Printing fabrication technologies and material properties needed to manufacture structural components from indigenous materials combined with recyclables, or indigenous materials alone. (This document)
  - 2.3.3. On-Site Habitat Competition (Phase 3) - focused on 3D-Printing of a scaled habitat design, using indigenous materials combined with recyclables, or indigenous materials alone.

### Timeline for All Phases

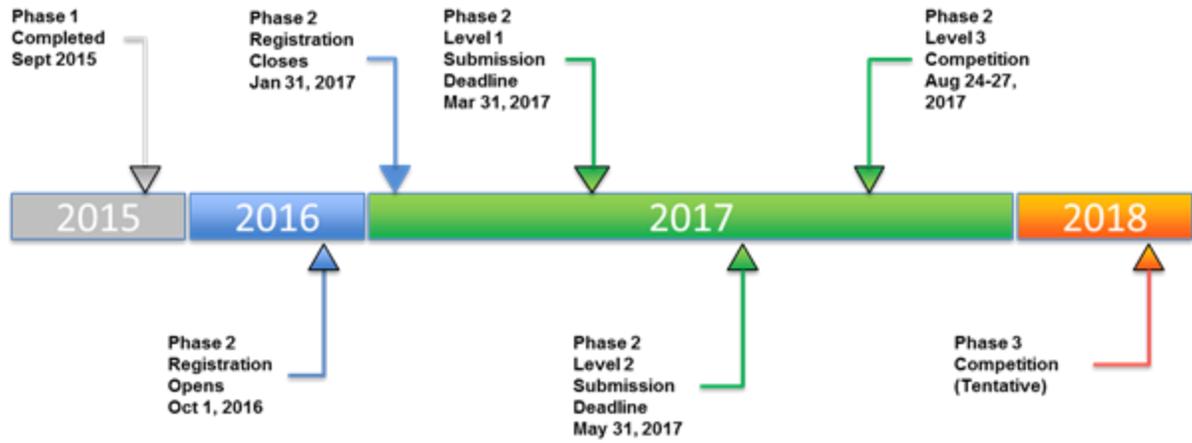


Figure 1: Overall Timetable for 3D-Printed Habitat Challenge Overview

### 3.0 Structural Member Competition Vision

- 3.1. During the Design Competition, we were introduced to our (fictional) NASA crew of four, who have been chosen for their grit, grace and intellect to be the first humans ever to step foot on Mars. As they prepare for their long journey to the red planet in 2035, they are undergoing a training program wherein they will reside in approximately 93 m<sup>2</sup> (1000 ft<sup>2</sup>) of living space for 1 year. Their new adopted home shall contain everything needed to comfortably sustain human life, including cooking areas, sleeping quarters and bathroom/hygiene facilities. Their typical jobs, such as geologists, land surveyors, prospectors, scientists, biologists, & engineers shall also be considered while creating this structure, as it will act as a terrestrial prototype for the one that they'll reside in while on Mars.
- 3.2. This Earth-based training habitat must be constructed by the Team, semi-autonomously, using 3D-Printing technologies and in-situ resources. Your mission, if you choose to accept it, is to develop the fundamental 3D-Printing technology necessary to produce a structurally sound habitat. In this competition (Figure 2), you will be required to demonstrate the capability to print structural components and test parts that will be evaluated based on criteria specified in the rules.
- 3.3. Entrepreneurs, investors, and industry professionals from fields including but not limited to architecture, engineering, manufacturing, construction, and real estate are welcome to support and participate in the 3D-Printed Habitat Challenge. The program seeks innovations from diverse sources, including industry experts who bring valuable problem-solving experience. Participation in the Challenge provides an opportunity to support the commercialization of advanced technology. Please consult the participation rules for federal employee and federal contractor limitations (section 4). Ways to get involved include spreading the word about the challenge attending the head to head events, providing sponsorship, and of course competing for the prize money.

## Phase 2 Competition Levels (Summary)



Figure 2: Structural Member Competition Levels and Summary

## 4.0 Rules

### 4.1. Eligibility to Compete and win prize(s)

- 4.1.1. In order to be eligible to win a prize, the Team Leader must be (i) a citizen or permanent resident of the United States, or (ii) an Entity that is incorporated in and maintains a primary place of business in the United States. Teams must furnish proof of eligibility (including proof of citizenship or permanent resident status, for Team Leader, and proof of incorporation and primary place of business, for a U.S. Entity) that is satisfactory to NASA in its sole discretion. A Team's failure to comply with any aspect of the foregoing requirements shall result in the Team being disqualified from winning a prize from NASA.
- 4.1.2. A Foreign National person (non-U.S. Citizen or non-U.S. Entity) may participate in the 3D-Printed Habitat Challenge as a Team Member but not as a Team Leader. All Team Members working on the Challenge must be physically located in the United States.
- 4.1.3. International teams can register and participate in Level 1, 2 and 3 Challenges. International teams are exempt from the requirements of 4.1.2 because there are not eligible for prizes. International teams need to physically attend the Level 3 competition but can participate in Levels 1 and 2 remotely. ASTM standards and specimen submission requirements remain the same for Level 1 and 2 remote participants. Customs and visa requirements pertaining to the Level 3 competition are the responsibility of the teams.
- 4.1.4. No Team Member shall be a citizen of a country on the NASA Export Control Program list of designated countries. (The current list of designated countries can be found at <http://oiiir.hq.nasa.gov/nasaecp/>).
- 4.1.5. A Federal Entity or Federal Employee may not participate in the 3D-Printed Habitat Challenge if acting within the scope of their employment. This includes any U.S. Government organization or organization principally or substantially funded by the Federal Government, including Federally Funded Research and Development Centers, Government-owned, contractor operated (GOCO) facilities, and University Affiliated Research Centers.
- 4.1.6. An Entity Employee, or Entity, contracted by the US. Government and physically located at a Federally Owned Facility may not participate if acting within the scope of the contract.

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- 4.1.7. Each Team Member shall acknowledge by their signature in the registration package that NASA shall make prize payments to the Team Leader, also indicated in the registration package. Any failure of the indicated Team Leader to make payments of any kind to Team Members is the responsibility of the Team Leader and not the responsibility of NASA or Bradley University.
- 4.2. A Team may submit a single entry per level (Level 1, 2, and 3) into competition to win prizes. Team Members can only be associated with one Team.
- 4.2.1. A Team Agreement form (provided on website) must be submitted as part of the registration package.
- 4.2.2. NASA and other federal agencies may work with and provide technical support to participating teams as long as it is done on an equitable basis. That is, similar requests are dealt with in a similar fashion, be it access to facilities, testing, scientific consultation, or other services. This does not obligate NASA or other federal agencies to provide the support.
- 4.2.3. Registration and participation in a challenge does not entitle a participant to a NASA funded prize. To be eligible to win a NASA funded prize, the competitor must register and comply with all requirements in the rules and enter into a Team agreement.
- 4.3. Safety
- 4.3.1. Teams shall review Occupational Safety and Health Administration OSHA, ([www.osha.gov](http://www.osha.gov)) policies pertinent to the Challenge.
- 4.3.2. Teams shall review the OSHA handling procedures and safety precautions for the materials they use as feedstock (see “Laboratories” and “Hazard Communication” Safety and Health Topics). Participants shall obtain and read Safety Data Sheets (SDS) for each material they use. The SDS shall be made available by the teams at the competition site for officials and public safety personnel review.
- 4.3.3. Teams shall work in a safe manner and in a safe workplace environment per OSHA requirements. (See “Construction: Concrete and Masonry,” “Personal Protective Equipment,” and “Ventilation” Safety and Health Topics. Also, see the “Silicosis Fact Sheet for Construction Workers” at [www.osha.gov](http://www.osha.gov)).
- 4.3.4. Respirators with the correct filter types shall be worn when handling material that consists of fine particles as recommended by OSHA guidelines. Respirators shall be supplied by the competitors. The design of the 3D-Printing device shall preclude excessive airborne dust. High airborne dust levels may result in a safety disqualification.

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- 4.3.5. Teams must electronically submit documentation containing a description of their 3D-printing process, its operation, potential safety hazards, MSDS for all materials, a diagram, and basic parts list by the date listed on the competition website. This documentation along with an inspection will be used to make a pass/fail safety assessment.
- 4.3.6. Any exclusion zones required for safe operation must be specified and marked. Any known safety, health, or environmental risks shall be mitigated and documented within the safety inspection review. An Emergency stop (E-stop) function must be available at all times to the 3D-Printer operator. The printer shall not be operated without the supervision of a qualified team member. The E-stop shall be used to cease operations shall a safety contingency scenario arise. The E-stop operator shall stop the 3D-Printer at any time due to safety concerns or upon request by a NASA or Bradley University official.
- 4.3.7. The team shall provide proof of insurance for team members pertaining to work and activities conducted during participation in the competition. NASA, Bradley, and partners facilitating this competition are not liable for any injury sustained by team members or loss or damage of property.
- 4.4. Each admitted Team must develop and demonstrate the core technologies necessary to semi-autonomously 3D-Print structural components.
  - 4.4.1. All structural members produced during the competition shall be produced using additive construction (a.k.a. 3D-Printed) processes.
  - 4.4.2. The 3D-Printer shall operate semi-autonomously. For example, under this Challenge's definition, an inkjet printer operates semi-autonomously. An inkjet printer receives instructions on what to print, but self-determines how to apply the ink onto paper.
- 4.5. The focus of the Structural Member portion of the Challenge is the creation of construction materials from indigenous material (could be rock, mineral, metal, or gas) and waste materials at an unspecified planetary surface. Aggregates and binders commonly used on Earth are supported in this competition, but will not be rated as highly as indigenous materials and recyclables relevant to reduction in logistics.
- 4.6. Teams must use either indigenous material, or indigenous material combined with recyclables, as feedstock. Suggested indigenous and recyclable materials are listed in [Table 1](#) below.
  - 4.6.1. Competitors shall use naturally occurring indigenous materials as a part of their 3D-Printed material.
  - 4.6.2. The indigenous materials shall consist of, but are not limited to, coarse and/or fine aggregate.

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- 4.6.3. Binders may be imported or made in-situ.
- 4.6.4. Recyclables may be used in the aggregates and/or binder materials.
- 4.6.5. Material systems shall contain a minimum of 70% indigenous materials. Failure to meet this minimum requirement will result in a zero score for that particular submission. This does not preclude competing in a future level of the competition.
- 4.6.6. Competitor's score will be determined in part based on the relevance of their feedstock material to planetary missions (Table 1). A feedstock that uses material(s) with higher relevance will result in a higher score.
- 4.6.7. Teams may adjust/modify material composition throughout the competition. The material composition used at Level 1 can be modified or improved in order to compete for the Level 2 or Level 3 competitions (see section 9.0).
- 4.6.8. Teams are required to procure their own feedstock for all levels of the competition. Sizing and grading of the feedstock prior to competition is permissible, provided it is documented. During Level 3, samples of feedstock may be requested by judges for further analysis. Likewise, specimens submitted for Levels 1 and 2 are subject to composition testing.
- 4.7. Water may be used in the binder system, but shall be minimized (refer to scoring method).
- 4.8. The 3D-Printer shall hold or receive sufficient feedstock in order to produce a required specimen.
  - 4.8.1. Teams may resupply, or refill, the feedstock into the 3D-Printer system between specimen productions.
  - 4.8.2. The 3D-Printer may hold sufficient feedstock to produce multiple specimens.
  - 4.8.3. The 3D-Printer may have multiple holding tanks or feedstock hoppers.
  - 4.8.4. Removal of any support material required for a build must be automated. Manual removal of support material is not permitted (for example: manual removal of a deposited powder bed from around the part).

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- 4.8.5. Scalability of the overall 3D printing process for operation in the space environment is a judging consideration. Traceability to a printing method that would function in an outer space environment, including a vacuum, reduced gravity, and extreme temperature thermal swings is desired. Large quantities of feedstock waste are discouraged and will negatively impact the feasibility assessment of the technology for space applications.
- 4.9. The 3D-Printer shall be self-contained, transportable, and deployable. Teams must be able to transport the system over standard Department of Transportation (DOT) roads to a central location for the Head-to-Head competition. Manual assembly at the competition site is permitted but shall be minimized to the greatest extent possible.
- 4.10. Team Members and Team Leader shall comply with all U.S. laws, regulations, and policies including those relating to export control and nonproliferation, as well as the laws of relevant state and local jurisdictions that pertain to or govern any activities conducted by competitors in connection with the Challenge.
- 4.11. On a monthly basis, Teams must provide Bradley University with a short written progress report including a total (in the form of a single amount) of the following: Team's incremental and cumulative financial, property (capital), personnel, and any other investments, and/or expenditures (direct or in-kind) made to conduct any and all activities related to or required by participation of the Team in the Challenge. This information will be shared with NASA. Neither the Bradley University nor NASA will make this information public except in aggregate form for all Teams competing in the Challenge. The data will be used to quantify financial leveraging aspects for NASA management.
- 4.12. The Centennial Challenge Program (CCP) has made significant effort to develop fair and just competition rules. In the event that the Bradley University and CCP deem it necessary, additional rules or requirements may be administered with the consultation of all currently registered Team(s). Such changes shall be documented and disseminated via the competition website. Failure to adopt or follow such additional rules or requirements shall be grounds to terminate a Team and all Team Members from the Challenge. It is the responsibility of the competitors to monitor the website and comply with all rules.
- 4.13. Bradley University and NASA also reserve the right to cancel the Challenge. All reasonable efforts will be made to avoid Challenge cancellation.

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Table 1: Feedstock Material Options

Material Applicability	Options
<b>Aggregate/ Indigenous</b>	CBI - Crushed basaltic igneous rock (SiO <sub>2</sub> weight percent less than or equal to 57) BSR - Basaltic sedimentary rocks (talus, alluvium with very little alteration/weathering, or mine tailings) GSS - Gypsum sand and siliceous sedimentary rocks (e.g., sand box sand, mudstone) CSR - Carbonaceous sedimentary rocks (e.g., limestone, dolomite) IRS - Igneous rocks with SiO <sub>2</sub> weight percent greater than 57 (e.g., granite) MR - Metamorphic rocks (e.g., slate)
<b>Recyclables</b>	LP - Low Density Polyethylene (#4 recycle code) HP - High Density Polyethylene (#2 recycle code) PT - Polyethylene Terephthalate (#1 recycle code) NY - Nylon (#7 recycle code) PP - Polypropylene (#5 recycle code) AF - Aluminum Foil or ground up aluminum parts PS - Polystyrene (#6 recycle code) VY - Vinyl (#3 recycle code)

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Table 2: Feedstock Material Weight Factors Determination

Material Applicability	Least Relevant								Most Relevant	
		MR		IRS		CSR		GSS	BSR	CBI
<b>Fine Rock Aggregate</b> ( $< \frac{1}{4}$ " mean particle diameter)		MR		IRS		CSR		GSS	BSR	CBI
<b>Coarse Rock Aggregate</b> ( $> \frac{1}{4}$ " mean particle diameter)	MR		IRS		CSR		GSS	BSR	CBI	
<b>Trash Recyclables</b>	VY	PS	AF		PP	NY		PT	HP	LP
<b>3DP Factor</b>	1	2	3	4	5	6	7	8	9	10



CBI - Crushed basaltic igneous rock (SiO<sub>2</sub> weight percent less than or equal to 57)  
 BSR - Basaltic sedimentary rocks (talus, alluvium with very little alteration/weathering, or mine tailings)  
 GSS - Gypsum sand and siliceous sedimentary rocks (e.g., sand box sand, mudstone)  
 CSR - Carbonaceous sedimentary rocks (e.g., limestone, dolomite)  
 IRS - Igneous rocks with SiO<sub>2</sub> weight percent greater than 57 (e.g., granite)  
 MR - Metamorphic rocks (e.g., slate)

LP - LDPE polyethylene (#4 recycle code)  
 HP - HDPE polyethylene (#2 recycle code)  
 PT - Polyethylene Terephthalate (#1 recycle code)  
 NY - Nylon (#7 recycle code)  
 PP - Polypropylene (#5 recycle code)  
 AF - Aluminum foil or ground up aluminum parts  
 PS - Polystyrene (#6 recycle code)  
 VY - Vinyl (#3 recycle code)

## 5.0 Level 1: Compression Test Competition

### 5.1. Compression Test Competition Overview:

The Level 1 Compression Test Competition is the first of three sub-competitions within the overall Structural Member Competition. For Level 1, teams will develop 3D printable materials, build a 3D printing machine, and print two specimens: a truncated cone and a cylinder. Tests conducted on the two test specimens will determine a Level 1 score. Teams must meet minimum criteria to qualify for Level 2. The 10 highest scores will be eligible for a Level 1 awards.

### 5.2. 3D Printing a Truncated Cone

- 5.2.1. Registrants must demonstrate that the Team's selected material combination described in their registration proposal will hold the form of a truncated cone with a maximum diameter of 200 mm and a minimum diameter of 100 mm. The original height of the cone shall be 300 mm. Computer Aided Design (CAD) model can be found on the Challenge website.
- 5.2.2. This truncated cone shall be 3D-printed, with a tolerance of +7 mm, using a viable material combination and binding process for 3D-printing.
- 5.2.3. The extruded material must maintain the printed height to within 15% for a minimum of 5 minutes (Figure 3).  $h_o$  is the original height of the printed cone. Measurement  $h_i$  is the material height five minutes after the conclusion of printing.
- 5.2.4. Teams may improve or change the material combination and/or binding process later in the competition without penalty. Teams are encouraged to evolve their material formulation as they gain knowledge through development and testing of prototypes.

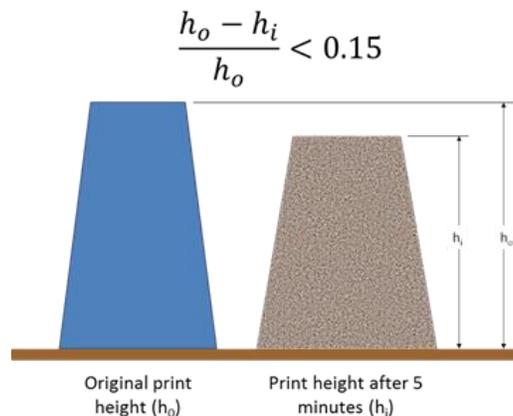


Figure 3: Truncated Cone Slump Measurements

5.3. 3D Printing and Compression Testing a Cylinder

- 5.3.1. Following a successful truncated cone printing, teams must 3D print a test specimen for an ASTM C39 Compression Test. The diameter and height of the cylinder must be 150 mm x 300 mm with a tolerance of +7 mm for height and diameter (Figure 4).

$$h_0 - h_1 < +7\text{mm}$$

$$\phi_0 - \phi_1 < +7\text{mm}$$

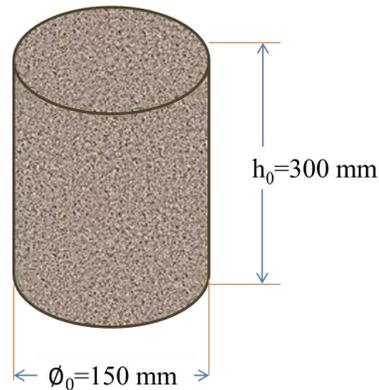


Figure 4: Compression Test Cylinder

- 5.3.2. Within 48 hours of printing, the specimen must be subjected to an ASTM C39 compression test by a certified laboratory. This test applies compressive load to the specimen until failure. Teams with access to their own certified laboratories shall seek a third party testing site to avoid conflicts of interest.
- 5.3.3. A certified laboratory is one that is accredited by a recognized third party organization such as the American Association for State Highway and Transportation Officials, International (AASHTO), Accreditation Service (IAS), etc. The laboratory must have trained personnel, controlled procedures and the calibrated equipment necessary to perform the test specified in ASTM C39.

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#### 5.4. Results Submission Requirements

- 5.4.1. A video documentary must capture the full process including, but not limited to, ingredients selected, mixing, printing, truncated cone original dimensions immediately after printing, truncated cone slump five minutes after printing, compression cylinder printing, and compression test results. A “full-length” documentary shall be 30 minutes or less in length. Separately, teams must submit a time-lapse version (30 seconds or less) that captures the same content. MP4 format is suggested. Portions of these videos may be used for promotional purposes.
- 5.4.2. Teams must submit the mix design as well as a written description of the ingredient mixing process used to print both the truncated cone and the cylinder. The mix design and process does not have to be the same for both specimens.
- 5.4.3. The truncated cone and cylinder (post-destructive testing) must be sent directly to Bradley University from the test facility. Further analysis will be conducted upon arrival at Bradley. Additionally, an ASTM C39 test report, from the certified laboratory, must accompany the compression specimen tested to failure.
- 5.4.4. The deadline for all submissions is March 31, 2017. Submissions received by Bradley University after this date will not be eligible for Level 1 prize money. To be eligible for Level 1 prize money, the complete cone and cylinder samples must be received at Bradley no later than April 14, 2017.

#### 5.5. Level 1 Scoring.

- 5.5.1. The 3D printing of a truncated Cone portion of the competition is scored as pass or fail. If the three original dimensions and the allowable slump meet the criteria outlined, the teams receive 100 points. Measurements immediately after printing and five minutes after printing must be verifiable by the video to receive points.
- 5.5.2. The 3D-printed compression specimen is scored according to the compressive load at failure and the choice of material. The maximum compressive load is derived from the ASTM C39 test conducted by the certified laboratory. This value, in kgf, is multiplied by a material weighting factor to convert the compressive load into points for scoring. The weighting is designed to encourage the use of indigenous and recyclable materials and discourage the use of water with -10 3D Printing Factor and imported materials with -20 3D Printing Factor. Refer to Tables 1 and 2 for material and 3DP factors.

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5.5.3. The formula used to calculate the Level 1 score is:

$$\frac{\%mass \times 3DP_{indig} + \%mass \times 3DP_{imp} + \%mass \times 3DP_{recyc} + \%mass \times 3DP_{water}}{1000} = DP_{factor}$$

$$Level\ 1\ Score = (DP_{factor} \times C39) + Truncated\ Cone$$

Table 3 shows an example of how the calculation is performed.

Table 3: Level 1 Score Calculation Example

Level 1 Example Score Calculation	Actual Rating	Units	3DP Factor	Weight Multipliers	Level 1 Challenge Points
Use of indigenous materials	90	% mass	5	450	
Use of imported materials	0	% mass	-20	0	
Use of recyclable materials	10	% mass	7	70	
Use of water	0	% mass	-10	0	
Measured maximum supported mass from the ASTM C39 compression specimen	20000	Kg		0.52	10,400
Truncated cone score (0 or 100)	100	points			100
Total Points					10,500

5.6. Level 1 Awards and Qualification for Level 2

- 5.6.1. In order to qualify for Level 2, teams must be register for the competition per the provisions of Section 8.1. Qualifying teams must provide a specimen that passes the truncated Cone portion, resulting in a score of 100 points. The compression test specimen must withstand at minimum load of at least 450 kgf before failure.
- 5.6.2. Awards will be based on the Level 1 scores described above. The first place award corresponds to the highest numeric score. A maximum of 10 awards will be granted. 10 teams with the highest scores awarded prize proportional to score for a total Level 1 amount of \$100,000.
- 5.6.3. Teams which did not complete Level 1 as scheduled may also qualify for Level 2 competition by completing all Level 1 requirements with satisfactory submission 2 weeks prior to the May 31<sup>st</sup> Level 2 competition submission deadline . Level 1 submissions received by Bradley University after May 17<sup>th</sup> will not be scored and teams will not be eligible to compete in Level 2.

## 6.0 Level 2: Beam Member Competition

6.1. The Level 2 Beam Member Competition is the second of three sub-competitions within the overall Structural Member Competition. For Level 2, teams will print a beam that will be tested per ASTM C78 (Figure 5). A score will be calculated based on both the material composition and the maximum load of the beam at failure. A maximum of 30 teams will qualify for Level 3. The 10 highest scores will be eligible for a Level 2 awards.

### 6.2. Beam Dimensions and Test Overview

6.2.1. The additively manufactured (3D-Printed) part shall be 65 cm long and have a 200 mm height x 100 mm width cross section. The tolerance for width and height is +7 mm. The tolerance for nominal length is +/-7 mm.

6.2.2. Flexural load testing shall be performed by a certified laboratory within 48 hours after the start of the build process. Teams with access to their own certified laboratories shall seek a third party testing site to avoid conflicts of interest.

6.2.3. A certified laboratory is one that is accredited by a recognized third party organization such as the American Association for State Highway and Transportation Officials, International (AASHTO), Accreditation Service (IAS), etc. The laboratory must have trained personnel, controlled procedures and the calibrated equipment necessary to perform the test specified in ASTM C78.

6.2.4. The part shall be tested in conformance with ASTM C78 and shall have a minimum load at failure of 750 kgf.

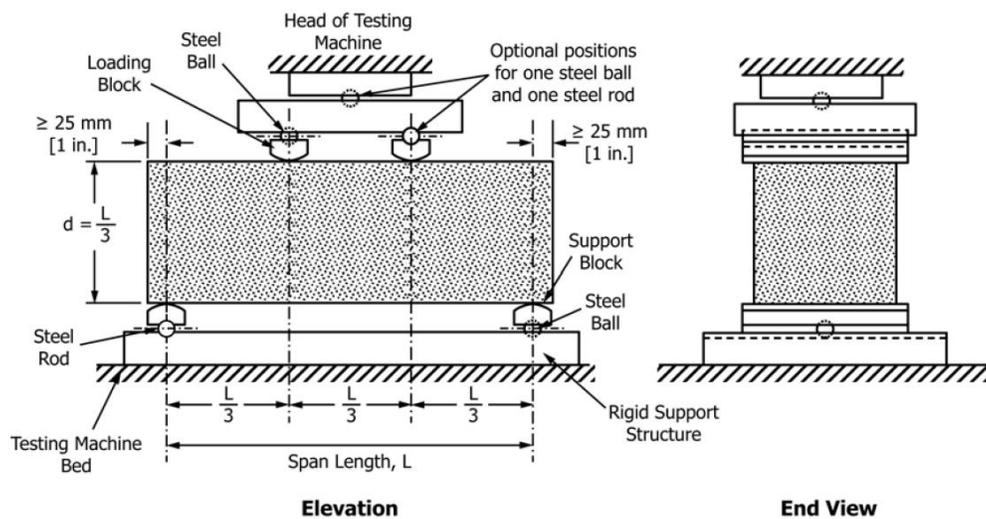


Figure 5: Flexure Test Model Diagram (taken from ASTM C78/C78M)

### 6.3. Results Submission Requirements

- 6.3.1. A video documentary, separate from the Level 1 documentary, must capture the full process including, but not limited to, ingredients selected, mixing, printing, and flexural test to failure. A “full-length” documentary shall be 30 minutes or less in length. Separately, teams must submit a time-lapse version (30 seconds or less) that captures the same content. MP4 format is suggested. Portions of these videos may be used for promotional purposes.
- 6.3.2. Teams must submit the mix design as well as a written description of the ingredient mixing process used to print the beam member. The mix design and process do not have to be the same as those used in Level 1.
- 6.3.3. Following destructive testing, the beam specimen shall be sent directly to Bradley University from the test facility. Further analysis will be conducted upon arrival at Bradley. Additionally, an ASTM C78 test report from the certified laboratory must accompany the broken pieces of the beam.
- 6.3.4. The deadline for all submissions is May 31, 2017. Submissions received by Bradley University after this date will not be eligible for Level 2 prize money. To be eligible for prize money, the complete beam sample must be received at Bradley no later than June 14, 2017.

### 6.4. Scoring for Level 2

- 6.4.1. Similar to Level 1, the beam member is scored by a combination of the flexural load at failure and the choice of material. The maximum flexural load is captured by the ASTM C78 test. This value, in kgf, is multiplied by a material weighting factor to convert the weight into points. The weighting is designed to encourage the use of indigenous and recyclable materials and discourage the use of water with -10 3D Printing Factor and imported materials with -20 3D Printing Factor. Refer to Tables 1 and 2 for material and 3DP factors.
- 6.4.2. The formula to calculate the Level 2 score is as follows:

$$\frac{\%mass \times 3DP_{indig} + \%mass \times 3DP_{imp} + \%mass \times 3DP_{recyc} + \%mass \times 3DP_{water}}{1000} = DP_{factor}$$

$$Level\ 2\ Score = DP_{factor} \times C78$$

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Table 4 example of how the calculation is performed.

Table 4: Level 2 Score Calculation Example

Level 2 Example Score Calculation	Actual Rating	Units	3DP Factor	Weight Multipliers	Level 2 Challenge Points
Use of indigenous materials	80	% mass	5	400	
Use of imported materials	15	% mass	-20	-300	
Use of recyclable materials	0	% mass	7	0	
Use of water	5	% mass	-10	-50	
Measured maximum supported mass from the ASTM C78 flexural specimen	750	kg		0.05	38
Total Points					38

### 6.5. Level 2 Awards and Qualification for Level 3

- 6.5.1. There is a limit of 30 teams for Level 3. In order to be considered for a Level 3 invitation, teams must achieve at least an ASTM C78 beam load of 750 kgf. Satisfying this minimum criteria does not guarantee admission. Admission is based on the top Level 2 submission scores of teams that meet the 750kgf minimum requirement. Level 1 scores are not used to qualify for Level 3.
- 6.5.2. Teams that achieve the 750 kgf minimum load are eligible to receive a Level 2 Award. Awards will be based on the Level 2 scoring criteria described above. The highest numeric score will receive the first place award. A maximum of 10 awards will be granted. The 10 teams with the highest scores awarded prize funds proportional to their scores. The total Level 2 prize amount to be distributed among the teams will not exceed \$500,000.
- 6.5.3. Teams may also qualify for Level 3 competition by completing all Level 1 and Level 2 requirements with satisfactory submission 4 weeks prior to the Level 3 competition held the week of August 21st. Level 2 submissions received by Bradley University after July 24th will not be scored and teams will not be eligible to compete at Level 3.

## 7.0 Level 3 Head to Head Competition

### 7.1. Head to Head Competition Overview

The Level 3 Head to Head Competition is the third of three sub-competitions within the overall Structural Member Competition. For Level 3, teams will develop 3D printable materials, build a 3D printing machine, and print three compression specimens of the elected material, three flexural specimens of the elected material, and one dome structure. Tests conducted on the specimens and the dome structure will determine Level 3 scores and awards.

### 7.2. Preliminary Schedule for the Head to Head Competition:

7.2.1. Competition start – August 24, 2017

7.2.2. Competition end – August 27, 2017

7.2.3. Check Challenge website for a detailed Level 3 Head to Head Competition schedule, including the time allotted for 3D printing of each specimen and the dome structure.

### 7.3. 3D Printing Requirements at the Heat to Head Competition

7.3.1. Each Team shall 3D print three ASTM C39 compression specimens of the elected material to be used in the construction of the dome structure (dimensions and CAD models provided on the Challenge website).

7.3.2. Each Team shall 3D print three ASTM C78 flexural specimens of the elected material to be used in the construction of the dome structure (dimensions and CAD models provided on the Challenge website).

7.3.3. Each team shall 3D print the dome structure as shown in [Figure 6](#) (dimensions and CAD models provided on the Challenge website).

7.3.4. The use of prefabricated components, built before the competition, are not permitted.

7.3.5. The ASTM C39 compression, C78 beam, and dome structure must be constructed completely semi-autonomously; thus, once the 3D printing process has started, adjustments to the material, material delivery system, and 3D printer hardware are only permissible through a software interface.

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- 7.3.6. Support structures that are fabricated during the head to head competition and/or are part of the printed geometry are permissible, but must be autonomously removed from the structure after printing is complete and prior to testing. Any modification of the dome structure (Figure 6) after 3D printing is complete will result in disqualification.
- 7.3.7. The ASTM C39 compression, ASTM C78 beam, and dome specimens shall be 3D printed in-situ at the competition location with observing judge(s) during the entire 3D printing process.



Figure 6: 3D view of the dome structure to be printed at the Head to Head Competition

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- 7.3.8. Specimens shall be printed on a platform/ pallet provided by the competition. This is to enable safe movement of specimens for testing.
- 7.3.9. There is no actual print time limit since print time and cure time will be treated as a set period. However, teams should complete printing sessions in about 4 hours because the facility will not be accessible after hours. The schedule will include additional time for setup, debugging and cleanup. The C39 and C78 will be printed during one session. The following day, the dome will be printed in another session.
- 7.4. Testing at the Head to Head Competition
- 7.4.1. The ASTM C39 compression and ASTM C78 beam specimens will be submitted to the observing judge(s) for testing after a minimum of 12 hours period.
- 7.4.2. The dome shall be loaded by a 625 kgf downward force on the top. Competition organizers will move the dome specimen from printing area to competition testing area. Detailed curing period schedule will be provided closer to Level 3 competition.
- 7.4.3. If the dome specimen passes the initial 625 kgf test, the dome shall be tested to failure by increasing the force by increments of 100 kgf until the dome collapses. The judge(s) will inspect the dome after each increment and make the determination of collapse. Each incremental load must be added within five minutes of the previously added incremental load, unless Judges are still assessing the specimen from the previous load increment. If such a case arises, incremental loading shall continue within five minutes after the Judge assessment is complete.
- 7.4.4. Alternatively, if the dome passes the 625 kgf test, the dome shall be tested to failure by increasing the force at a constant rate such that dynamic forces are minimized. Failure will be defined as the peak of the load vs. time curve.
- 7.5. Results Submission Requirements
- 7.5.1. Onsite judges will record scores. The teams will be responsible for printing and delivering specimens as the competition schedule requires.
- 7.6. Scoring for Level 3
- 7.6.1. The Level 3 scoring is similar to Levels 1 and 2 in how the material of choice is used as a multiplier of load capacity. However, Level 3 includes new C39 and C78 results that are determined during the competition.

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7.6.2. The formula to calculate the Level 3 score is as follows:

$$\frac{\%mass \times 3DP_{indig} + \%mass \times 3DP_{imp} + \%mass \times 3DP_{recyc} + \%mass \times 3DP_{water}}{1000} = DP_{factor}$$

$$Level\ 3\ Score = DP_{factor} \times \left\{ \frac{C39_{avg}}{10} + C78_{avg} + (Dome \times 10) \right\}$$

Table 5 shows a sample scoring calculation.

Table 5: Level 3 Score Calculation Example

Level 3 Example Score Calculation	Actual Rating	Units	3DP Factor & Multiplier	Weight Multipliers	Level 3 Challenge Points
Use of indigenous materials	60	% mass	10	600	
Use of imported materials	10	% mass	-20	-200	
Use of recyclable materials	30	% mass	7	210	
Use of water	0	% mass	-10	0	
Average maximum supported mass for three ASTM C39 compression specimens	20000	kg	0.1	0.61	1,220
Average maximum supported mass for three ASTM C78 flexure specimens	1500	kg		0.61	915
Maximum load for dome specimen	1800	kg	10	0.61	10,980
Total Points				Current	13,115

## 7.7. Level 3 Awards

7.7.1. Level 3 awards are based on the composite score rubric described above. A first, second, and third place prize will be awarded. Award amounts are shown in Table 6.

Table 6: Award Amounts

Place	Award
1st	\$250,000
2nd	\$150,000
3rd	\$100,000
Total	\$500,000

## 8.0 Registration and Qualification

- 8.1. The competition will be limited to qualified applicant Teams. The 3D-Printed Habitat Challenge schedule as posted on the competition website (Section 3) shall be referenced for deadlines, competition status, and closure dates. To compete for prize money and official scores at a given level of the competition, teams must formally register in advance of making their submission.
  - 8.1.1. Only those competitors who receive an invitation to compete will be admitted to the head to head competition.
  - 8.1.2. Invitations will be based on evaluation of the registration proposal (see 8.2) and successful qualification testing (see Section 5-6-7).
  - 8.1.3. There is no limit to the number of international teams that can participate in Levels 1 and 2. The 4 team limit pertains to Level 3 only. All teams that meet the minimum success criteria for Levels 1 and 2 will be ranked from highest to lowest score. The 4 highest international scores will be retained and the remaining international scores will be removed from the list. Next, the list will be resorted from highest to lowest score. The top 30 teams will be eligible for Level 3.
- 8.2. All registrants shall submit a written proposal (including graphics and technical sketches) describing a technically viable approach to producing structural components using the feedstock material options described in [Table 1](#).
  - 8.2.1. Proposals shall describe the Team's experience, credentials, and an initial concept for 3D-Printing using the materials selected.
  - 8.2.2. Proposals shall provide details about the specific combination of materials and processes to be used during printing. The information will be kept confidential by NASA and Bradley University.
  - 8.2.3. Safety Data Sheets (SDS), or equivalent, shall be provided for all proposed materials.
  - 8.2.4. Proposals shall not exceed five pages and shall follow the format and submission guidance of 10.0.

## 9.0 Award Distribution

- 9.1. Payments will be made by electronic funds transfer to the individual who is designated as the Team Leader. Each Team Member shall be aware that any failure of the designated Team Leader to make payments of any kind to Team Members is the responsibility of the Team Leader, not the responsibility of NASA or Bradley University.

## 10.0 Document Submission

### 10.1. Document Format

- 10.1.1. All Challenge document submissions shall be single sided and written in Helvetica font style with minimum 12 point font size. Arial is a suitable substitute when Helvetica font style is not available.
- 10.1.2. Document submissions shall be in Adobe portable document format (pdf).
- 10.1.3. Hand written or drawn documents shall be scanned into Adobe pdf with minimum 400x400 dots per inch (dpi) and maximum 600x600 dpi.
- 10.1.4. All documents shall be letter size (8 ½” x 11”).
- 10.1.5. Unless otherwise noted, all documents shall have a maximum of five single-sided pages. The only exception to this may be the certified test documentation.
- 10.1.6. Video submissions are described in sections 5-6.

### 10.2. Method

- 10.2.1. All Challenge submissions shall be sent to the 3D-Printed Habitat Challenge email address (Available on the Challenge Website). The subject line shall be ‘3D-Printed Habitat Challenge, Structural Member Competition’.
- 10.2.2. Submitted documents will be routed to appropriate points of contact (Judges, Subject Matter Experts, etc.). At no point will Team Intellectual Property (IP) be passed to anyone not involved with Challenge administration.

### 10.3. Submissions

- 10.3.1. Teams must submit a Team Agreement (available on the Challenge website) and a registration package in order to compete in the 3D-Printed Habitat Challenge – Structural Member Competition.
- 10.3.2. All teams shall comply with registration proposal and Qualification Verifications.
- 10.3.3. Monthly total Team investments and/or expenditures shall be provided per 4.11.
- 10.3.4. Teams eligible for Head-to-Head Prizes must submit documentation prior to Level 3 competition (Reference Challenge Website).

10.4. Challenge Correspondences

- 10.4.1. All submittals (correspondences, questions, emails, documents, videos, etc.) shall be sent to the 3D-Printed Habitat Challenge e-mail address (Reference Challenge Website Submittal Section for the e-mail address). The subject line shall be '3D-Printed Habitat Challenge Structural Member Competition'.

## 11.0 Judging

- 11.1. A panel of subject matter and industry knowledgeable experts will serve as Challenge Judges. Judges are the final arbitrators in the interpretation and enforcement of the Challenge Rules.
- 11.2. Judges may consult with NASA subject matter experts (SMEs) or industry SMEs on any matters related to the Challenge. Judges may appoint representatives to witness demonstrations. Scores and decisions will solely be determined by the jury panel.
- 11.3. This jury panel will judge the submitted entries per the scoring criteria. All jury panel decisions are considered final. Only in extraordinary circumstances can an appeal of an unfair incident be proposed. If the appeal process is chosen, the Team Leader must submit the appeal in writing to the Ombudsman within 30 minutes of the incident and prior to prizes being awarded. The final decision of the appeal will be rendered by the ombudsman before the award of prizes and shall prevail.