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ON-SITE HABITAT COMPETITION FAQ'S

NASA AND BRADLEY UNIVERSITY

VERSION 11.0



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1.0 General Participation and Rules

1.1. Is there still a way to participate in the Phase 3 competition if constructing a 3D printer is too large of a task for my team or for me as an individual competitor?

A: Yes! The competition has been structured so that participants without the resources to construct a 3D printer can participate in the BIM (Virtual Construction) Levels, which is accessible with a lower registration fee and does not require hardware procurement and physical builds. Also, via the registration link, you can request access to a forum where you may be able to align with other interested parties to form a team to participate in the full construction competition levels.

1.2. Who is eligible to participate in the competition?

A: Anyone can participate in the competition as long as they are not a citizen or an entity from a country listed on the NASA Export Control Program List of designated countries under Category 2/Column 2. (The current list of designated countries can be found at https://oiir.hq.nasa.gov/nasaecp/docs/DCList_02-15-2017.pdf)

1.3. What are the rules for teams to be eligible to win prizes?

A: To be eligible to win a prize, the Team must be mostly (50% or more) comprised of Team Members and Entity Members, as applicable, that are either:

- An individual that is a citizen or permanent resident of the United States; or
- An entity that is incorporated in and maintains a primary place of business in the United States.

1.3.1. Are there any additional considerations for prize eligibility at the head to head competition?

A: Per rule 8.14.1, initial prize order will be set based on the composite score rubric in rule 8.13.13. The rule continues on to indicate that prizes “can be awarded if Teams successfully meet the objective of 3D-printing a subscale habitat with a significant display of autonomy.” The assessment of team success vs this criteria will be carried out per the judging rules in section 12. The intent of this criteria is to ensure that teams do not receive a prize award for simply accumulating a small number of points from a few rubric categories if they are not able to produce a somewhat representative habitat at the head to head competition.

1.4. Can a person with a green card (not US citizen) participate in the competition?

A: Yes, a person with a green card that is a permanent resident of the United States may participate in the competition.

1.5. Can you participate as an individual in the competition?

A: Anyone can participate in the competition as long as they are not a citizen or an entity from a country listed on the NASA Export Control Program List of designated countries under Category 2/Column 2. (The current list of designated countries can be found at https://oir.hq.nasa.gov/nasaecp/docs/DCList_02-15-2017.pdf)

To be eligible to win prizes the individual must be either a citizen or permanent resident of the United States.

1.6. What happens if the participant is a minor (under 18 years old)?

A: If a participant is a minor, then the parent or legal guardian of the participant must sign the registration form.

1.7. Can we add additional team members after we have registered and completed the Team Registration form?

A: New team members may be added to the team after the initial registration period ends. Team members previously registered for the challenge on one team may not switch teams during the same phase of the competition unless the Team Leader submits a revised Team Roster releasing/removing that team member from the current team and that updated Agreement/Roster is accepted by Bradley University. The existing Team Leader is accountable for any decision to release team members.

1.8. When are the various submissions due? Is there additional guidance for preparing the documents and submissions required by the rules?

A: The submission due dates are found in Appendix A of the rules. Submissions are due at the end of the day listed, at midnight, US Central time (standard or daylight time as appropriate for the season). As the dates approach, additional guidance will be provided if the information already found in the rules is generating questions.

1.8.1. If I have missed the deadline for a particular level, is there still an opportunity to join the completion and compete at future levels?

A: Yes! Please refer to the eligibility information contained at the end of each section of the rules covering the preceding level.

1.9. What if I perceive a conflict between what was presented on a webinar and the rules or any other form of communication between the challenge administrators and the competing teams?

A: If you perceive a conflict please notify the challenge administrators. Mistakes can be made or statements can be taken out of context. Clarifications to the rules will be communicated to all teams to attain to the highest level of fairness and may even result in modification to the rules for clarity. The

official rules in its latest version on the Bradley 3D-Printed Habitat Challenge web-site is the super-precedent and authority for the competition.

1.10. When is the written proposal as described in rules section 9.2 due? When are the monthly reports as described in rules section 3.12 due?

A: The team's first proposal per section 9.2 is requested March 30, 2018. SDS (Safety Data Sheets) are not required for teams competing in the Virtual Construction only competition. Updated proposals (if there have been changes or additions) are due per the following schedule:

Update for Construction Level 1 – June 11, 2018

Update for Construction level 2 – November 5, 2018

Update for Virtual Construction Level 2 – December 16, 2018

Update for Construction Level 3 – March 29, 2019

A. Monthly reports per section 3.12 are due by the 10th day of each month covering the team's work in the preceding month. In addition to these submissions, each Level requires specific deliverables and documentation as outlined in the rules and Appendix C which are due per the schedule in Appendix A.

1.11. The competition rules refer to “manufacture, with 3D-printing technologies, a habitat on another planetary body”. Will scoring be more favorable toward Mars designed habitats, materials, and processes, as opposed to an entry that is designed for a lunar environment?

A: The overall goal of the competition is to develop robust ideas, concepts, and machines which could be broadly applicable to construction in a variety of environments. To execute such a competition on Earth, rules have been developed to evaluate competitor submissions against many specific criteria and tests. It is important for the competitors to focus on the rules to obtain the best score. In instances where judges must make more subjective assessments, they will use the context of a Martian environment to provide for consistency in judging.

1.12. Can you provide more information regarding radiation and shielding for Mars habitats?

A: The rules specifically do not require design for Martian environmental conditions such as cosmic radiation, reduced gravity, extreme temperatures, internal pressure within the habitat, etc – as a result, these types of specific conditions were not defined in the rules. Wall thickness is expected to be based on resistance to the test loads (dropping of shot puts) applied during the head-to-head competition; Rules 8.7 and 8.8. For more information on materials and radiation, two sites to refer to are OLTARIS (<https://oltaris.nasa.gov>) and MAPTIS (maptis.nasa.gov). Teams are encouraged to pursue a realistic Mars habitat design in all aspects but they will have to balance their efforts and focus based on the scoring metrics as defined in the rules. Teams can comment on their approach in their written submissions and/or their BIM model reviews.

1.13. Can a NASA Employee or other Federal employee/contractor be on a team?

A: Please see Rules 3.2.6, 3.2.7 & 3.2.10; And to be assured that there is no conflict, we request that the NASA Employee or other Federal employee/contractor obtain written permission from their center legal counsel which should be Standard Operating Procedure. If it is determined that there is a conflict

with the team member's participation by Bradley and NASA, the team could be disqualified from winning prize money.

2.0 International Participation

- 2.1. How can an international team compete given the requirement (4.1.2) that all teams must be physically located in the United States? What parts of the competition require international teams to be in the US? Besides, the ineligibility for prizes, what else should international teams expect?

A: International teams can register and participate in all Challenge Levels. International teams are exempt from the requirements of 3.2.1 because they are not eligible for prizes. International teams need to physically attend the Construction Level 3 competition but can participate in Construction Levels 1 and 2 and/or Virtual Construction Levels 1 and 2 remotely. Customs and visa requirements pertaining to the Level 3 competition are the responsibility of the teams.

- 2.2. If an international team(s) has a score in prize position. How is the prize money allocated?

A: If an international team scores in a prize position, their prize money (which cannot be awarded by law) is deducted from the prize purse. Detailed examples are included in the rules.

- 2.3. When does the 3 international team limit apply? How are the 3 teams chosen if more than 3 register?

A: There is no limit to the number of international teams that can participate in any level except Construction Level 3 (the on-site competition), where the 3 international team limit applies. More detail can be found in Section 9 of the rules.

3.0 Feedstocks

- 3.1. What feedstocks will be provided for the participants and how much will be allocated to each team? What are the limitations on sizing and grading of feedstock?

A: Teams are required to procure their own feedstock for all levels of the competition. Sizing and grading of the feedstock may be done ahead of the competition. Samples of feedstock may be collected by the competition organizers to verify composition.

- 3.2. How would a Martian simulant such as JSC-MARS-1A be scored on the material applicability scale?

A: JSC Mars-1A rates as 10 (Most Relevant) on material applicability sliding scale.

- 3.3. Is there a minimum quantity requirement for indigenous materials?

A: There is no specified minimum requirement. Indigenous material will generally produce higher material scores, however – refer to Appendix B of the rules.

- 3.4. What if I would like to use an indigenous material that is not on the Table of materials?

A: Creative use of all indigenous materials is encouraged; please submit your proposed material and usage for the judges to evaluate if a scoring factor can be assigned.

- 3.5. Is it legal to process the feedstock material at any point? For example, can a specimen be baked after printing?

A: Feedstock processing or curing methods which can be completed safely, in real time, including at the Construction Level 3 head-to-head event, can be pursued. At the head-to-head event, all printing and powered operations must be shut down at the end of the working day. Passive curing can continue overnight as long as any exothermic reactions do not require monitoring or active cooling to maintain safety.

- 3.6. Is it legal to extract materials out of the feedstock and use them? For example, extracting magnesium out of dolomite.

A: If material extraction will be occurring outside of the printing machine and printing activity, it must be demonstrated to the judges and approved in advance of Construction Level 1, 2 or 3 submissions which make use of extracted materials as feedstock. The process and energy required should be declared and suitable for scalable construction and it must be safe to implement.

3.7. Are we allowed to use basalt fiber powder or only basalt rock powder?

A: Yes, basalt fiber powder is also allowed.

3.8. How will materials be scored if they are not listed in the rules Appendix B?

A: Materials will be scored according to their origin and prevalence on Mars. For example, fly ash is a common additive in concrete. Fly ash is a byproduct of burning coal, and coal-burning will most likely not occur on Mars. Some geologic materials are similar in composition to fly ash; those products may be used and often will score very high as they are primarily basaltic. One major difference between the geologic and fly ash materials is grain size, which has implications for reactivity. Another example is slag. Slag is a byproduct of smelting and ore refining. This also would likely not occur on Mars (at least in the early days of settlement). However, slag can have a mineral-like composition. If this is the case, the composition of the slag would be compared to the types of minerals on Mars and scored accordingly. One more example is potassium silicate. Potassium silicate can be produced from potassium-rich minerals found primarily in sedimentary materials on Mars. Thus, potassium silicate would obtain a GST rating (see Rules Appendix B for more information on GST materials).

3.9. Are there any limitations on processing indigenous materials – can they directly use feedstocks that are derived from indigenous materials – does it all have to be done during the printing window or can it the materials be preprocessed? Are there any energy limitations imposed on material processing?

A: See FAQ 3.6 and 3.7

3.10. How will aqueous solutions be scored?

A: Aqueous solutions will be scored by breaking out the water content and scoring the water content with the appropriate 3DP factor. Even if a material is proposed to be produced in-situ, water content must be declared and each substance in the composition should be scored with the appropriate 3DP factor. The final composite 3DP factor will be determined and assigned by the judging panel.

3.11. Are we able to change the materials we choose to use throughout the competition? If yes, when will we no longer be able to switch the material that we use?

A: Please refer to rule 3.6.2. Also, please note that as described in rules sections 6 and 8 that changes in material and/or printing processes do require some tests to be repeated, driving effort and expense.

3.12. What if my team uses a single material feedstock rather than a mix? Will materials be subject to ASTM C666 testing for material durability evaluation regardless of formulation?

A: Please refer to the rules sections 2.3.3, 3.6.1, 5.5, 5.10.3, 8.5, 8.9, Appendix C and other relevant sections describing the requirements for material mixing, applicable testing, and calculation of 3DP composite factor for mixtures. Judges will be reviewing submissions and assigning points for materials related categories (such as ASTM C39 testing, ASTM C666 testing, material mix score, etc) in the context of these rules. To provide further clarity, a single material does not constitute a mix, and all

mix elements should be traceable to an appropriate waste/recycling stream and/or an in-situ mining or production process.

4.0 Printing Systems

4.1. Are support systems permissible for the dome structure? What are the limitations?

A: 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. In order to facilitate optical scanning for dimensional accuracy, all support material and/or mechanisms shall be removed before testing. Refer to rule 3.7.4.

4.1.1. Are pre-fabricated pressure-retaining membranes (such as non load-bearing inflatables to be used in tandem with load-bearing printed walls) prohibited?

A: Two rules should be consulted in this case. Under Rule 3.7.3 – such a membrane would be considered an “innovative sealing element”, and it must be autonomously placed and make up less than 2% of the structure by volume. Also, the membrane could not block any of the required penetrations in the structure or impede use of the interior space when complete.

4.2. How much time is allotted to print the 1:3 scale habitat in Construction Level 3?

A: Nominal print time for the habitat is 30 hours. Refer to rules 8.2.6 and 8.2.7 for more detail.

4.3. Is there a preferred type of printing method?

A: The intent of the competition is not to prescribe a manufacturing process solution. However, solutions should be developed with space applications in mind. Printing systems should be robust and compatible with reduced gravity environments. The printing system must also be scalable to eventually produce full scale habitats.

A: The selected 3D printing method should be able to support undercuts and overhangs in the printed structure, but manual removal of a support material is not allowed (for example: manually removing a deposited powder bed from around the part). An automated method of support removal is allowed, but the scalability of the overall 3D printing process to large structures for habitats in space and on Earth is a consideration for feasibility. Waste material is undesirable, and large quantities of wasted feedstock are highly discouraged due to the inefficiencies involved. NASA would like to use appropriate 3D additive construction processes on the Moon or Mars, so it is highly encouraged to have traceability to a method that would work in an outer space environment, including a vacuum, reduced gravity, and extreme temperature thermal swings. Any questions related to the feasibility of the selected additive construction process at large scales and in an outer space environment shall be referred to the judges’ panel for resolution. All decisions made by the judges are final and may not be appealed or contested.

4.4. What is the power source at Level 3?

A: Power will be provided at the competition site. 120V or 240V single phase power or 480V three phase power may be requested by the teams. All power provided will be 60 Hz. As the Construction Level 3 competition approaches, the teams will be asked to provide more information on their power requirements within these limitations so the facility can be prepared for competition.

4.5. << FAQ deleted – was carried over from Phase 2 and doesn’t apply to Phase 3 >>

- 4.6. Is it legal to use or modify an existing 3D printer, or use parts from an existing printer? What percentage of the printer must be manufactured by the team?

A: Yes, teams may reuse any number of components from existing products to construct a unique printing system.

- 4.7. How will the tolerances provided in the rules be enforced?

A: For tests performed as part of the Construction Levels 1 and 2, the team will be responsible for ensuring compliance with tolerance requirements. If a specimen for these tests is printed that is not within tolerance, then a new one should be prepared which meets the criteria. Specimens which do not meet the tolerance specifications will receive a score of zero, unless the rules specify other scoring and deductions for certain tolerance excursions.

- 4.8. The rule book states that "Teams may resupply, or refill, the feedstock into the 3D printer system between specimen productions." Does this mean that you cannot refill while a specimen is being produced?

A. Human intervention to resupply the printer is highly discouraged during specimen production, and will incur score reductions as called out in the rules section covering autonomy scoring. Automated refill during specimen production is allowed.

- 4.9. Can we print directly from a printer mounted on a flatbed trailer as opposed to transferring it to a new space to print; do we need to remove the printer and set it up on a given location?

A. Printing from a trailer is allowed, as long as it is safe and stable.

- 4.10. What are the requirements for tele-operation of the printer?

A. All robotic tele-operations must be performed without a direct line of sight to the printing and/or construction operations. Cameras with monitors may be used to remotely observe the printing and/or construction operations from the tele-operations station. Teams should keep in mind that autonomous operation is necessary to achieve maximum scores.

- 4.11. What are the requirements for the "electronic data log" referred to in Rules 5.10.2 and 6.10.2 and 8.3?

A. The log must be in electronic form and time stamped. A human readable capture from a control data stream which highlights operator inputs is preferred; a time stamped electronic video capture file which documents all man/machine control interactions can be acceptable and should be provided with a summary of the timestamps where interactions occurred.

- 4.12. Can we use methods which would result in disturbing the 100 mm deep bed of stone which is given as the required substrate per the rules?

A. The bed of stone must be roughly level at the beginning of the printing process. The printing process may autonomously interact with and modify the bed of stone if desired. However, the process may

not disturb the edges nor the base of the 100 mm deep bed of stone. Also, there must be a minimum stone depth of at least 25 mm under any printed elements.

- 4.13. Can we fill voids in our 1:3 scale habitat (or other competition prints) with regolith material (such as basalt) or otherwise print a structure using two or more distinct materials/mixes that remain unblended in the final print?

A. All printing materials and methods should meet Definition 1.3 for “Additive Manufacturing”. Rule 3.7.2 does specifically allow multiple print heads which may dispense particular feedstocks. With that said, the rules are built around the development of a “material mix” (Rules 5.5, 6.5, 8.5...), and this mix must be used to construct all prints for a given level of the competition (C39 and C666 samples, final products, etc). So if two or more distinct sub-mixes were to be used to construct the printed product for a given level, then all printed test samples must contain those sub-mixes in the same proportion. The only exception to this would be the use of sealing material, etc, at less than 2% of the structure material volume, which is exempt from the mix calculation/score (rule 3.7.3).

5.0 Testing/Assessments

5.1. Is there a deformation criteria for the compression cylinder or beam specimens?

A: No, just load to failure.

5.2. Can sample be trimmed and capped for cylinder test?

A. Yes, it can be trimmed and/or capped per ASTM C39 specification section 6.2; however, the as-printed dimensions must be documented in the video and be within tolerance before the ends are trimmed.

5.3. Can the test specimen be manually constructed from smaller parts or can a team print smaller test specimens (which are allowed in the standard C39 compression tests)?

A. No, the intent of the competition is not only to measure compressive or flexural strength but also to demonstrate that the teams can print samples of a certain size and meet specified tolerances autonomously.

5.4. Can the print sample be smoothed or reworked after printing before testing or evaluation?

A. Any smoothing or reworking of printed samples shall follow the same guidelines for autonomous operation as the material deposition phase of printing.

5.5. How will the vulnerable location on the structure for the impact test at the Level 3 Construction Competition be determined, and how will this will be applied consistently across teams?

A. In Construction Level 3, vulnerability to impact will be determined by dropping an Olympic size and weight shot put ball from different heights and measuring the structural response (penetration, perforation, or collapse) – Rule 8.7. The selection of the location for the application of the impact test load will be determined by structural engineers with substantial experience in impact analysis of concrete structures. Parameters that will be considered in identifying the target location include wall thickness, load paths provided by interior walls and other features, angle of impact (perpendicular impacts imparting more force than oblique impacts for the same ballistic velocity), etc. Target location will be determined on a case-by-case basis for each entry with the intent of selecting the weakest structural point (from a vertical impact) for all teams based on review of the design as well as visual inspection of the printed structure. All drop heights will be measured from the impact location identified, not necessarily from the highest point on the structure.

5.6. The C666 material durability test is time consuming. Can additional time be allotted for this testing in the competition schedule? What if teams can't get all 150 specified cycles completed by the due date? C666 specifies a 14 day curing period before testing – can a team shorten that waiting period?

A. The competition rules called attention to this as a time-consuming test to help the teams create their work plans. C666 specifies that each cycle should take between 2 and 5 hours. For 150 cycles, this is 12.5 to 31.25 days. Not all labs can run at the maximum cycling rate, so the teams may need to plan

additional time depending on their selected test lab. While C666 specifies a 14 day cure before testing, the competition rules have set 14 days as the maximum allowable curing time; teams may, at their own discretion, to reduce that cure time.

All test results and documentation must be submitted to Bradley University by the electronic submission due dates shown in Appendix A. The additional time allocated for physical sample arrival is simply to allow for reasonable shipping transit times.

If a team is unable to complete 150 cycles by the electronic submission due date, they are encouraged to submit an interim result based on the number of cycles which could be completed on-time, which the judges will review and consider for a reduced points award. The teams may keep the samples on cycle to reach the full 150 cycles at their discretion, as they may be able to use that full length test result for Construction Levels 2 and 3, if the printing method and material mix have not changed.

5.7. For Construction Level 1, does the foundation and wall interface need to be printed exactly as shown in rules and figures 5.2 and 5.4.3?

A. Per rule 5.2, the dimensions of the printed foundation shall measure 2 meters by 3 meters with a 100 mm slab thickness. As explained in rule 5.4.3, the optional wall interface design is left to the teams, but it must be at the location shown in rule 5.2. Although the wall interface shown in 5.2 is a straight wall, the wall interface can be of any profile as long as it fits in the 1 meter by 2 meter region to the left in the figure.

5.8. Do the three samples for the C666 test need to be printed individually, or can they be cut from a larger printed sample?

A. ASTM C666 allows test specimens to be cut out from larger material samples.

5.9. Can you provide additional guidance for conducting and documenting the measurements and assessments required in rule 5.6.2?

A. The crack inspection video should be supplemented with still/frozen images of 1080P quality minimum, taken from no more than 300 mm away from the crack surface, to allow for evaluation of visible cracks by the judges. To measure the permanent deformation from the impacts, use a pointed probe to determine maximum depth to the closest mm.

5.10. How much detail should be included in the 1/3 scale habitat printed at the Construction Level 3 head-to-head competition?

A. Please refer to rule 8.2 and its sub-sections, which discuss what is required for the head-to-head competition (printed scale factor, penetrations and placement, pre-printed components, etc). Any features which would affect test results should be present and correlate with the BIM model. Note also

that the as-printed habitat will be subject to testing per the head-to-head competition schedule, within 24 hours of the end of the third ten hour printing session called out in rule 8.2.7.

5.11. Will testing methods at the head to head competition deviate in any way from the descriptions provided in the rules document?

A. Unforeseen circumstances and/or safety considerations may necessitate the adjustment of planned test procedures under the governance of the challenge administrator. One specific adjustment has been identified and is communicated here. Rules section 8.7 was designed to impart three levels of impact energy to the printed structures. This was to be accomplished via releasing a 12 pound (5.44 kg) shot put 100-130 mm in diameter from approximately 4.5 m above the roof area targeted. The same shot would then be dropped from approximately 7.5 m above the roof to increase the amount of impact energy. Finally, a 16 pound (7.26 kg) shot 110 to 130 mm in diameter was to be dropped from approximately 7.5 m above the roof.

Due to the competition facility ceiling height and some taller than expected habitat designs, an alternative procedure has been developed to impart comparable impact energy. The three drops will all occur from approximately 4.5 m above the roof, and the weights will be 5.44 kg, 9.07 kg, and 12.1 kg. The largest mass diameter may be up to 150 mm due to the increased mass and desire to use iron/steel for the sphere.

5.12. Can the view port, suit hatch, and equipment hatch be placed into the habitat printed structure as a single unit?

A. No. Rules section 8.13.2 indicates that the teams conduct three independent attempts to place the three separate penetrations into the printed structure. Each independent penetration placement attempt will earn the team between 0 and 55 points, depending on the degree of success.

5.13. How is the BIM model submitted for the onsite competition different from the BIM model submitted for virtual construction?

A. The BIM model submitted for the onsite competition must represent the subscale habitat the team will construct at Caterpillar's Edwards Facility. This model will be reviewed during a 30-minute judging session where the team can present and provide a virtual walkthrough of their model. This session will be scheduled during the two days allocated for manufacturing setup (Monday, April 29 or Tuesday, April 30). Teams will be scored per the criteria indicated in Appendix C (system information, layout/efficiency, and constructability/robustness).

5.14. What documentation do I need to submit for the head to head competition?

A. Documentation requirements and scoring of documentation submitted by the team is discussed in Appendix C of the rules. While this documentation contains some of the same elements of the team proposal, it represents a separate submission. Documentation shall be submitted by noon CDT Monday April 29th, 2019. The content and scoring breakdown for the submission is summarized below:

*Document changes in printing process or materials from previous levels (30 points)

Points awarded for completeness with 6 points allocated to each subcriteria. If a team sufficiently documents that no changes were made to neither the printing process or the materials used relative to the prior level, they will be awarded 30 points in this area.

- Summarize and provide evidence of improvements in scalability, deposition rates, autonomous operations, and/or process capabilities relative to previous construction level (6 points)
- Resubmission of ASTM C666 test results and ASTM C39 test results if material mix has changed (6 points)
- Document rationale for any changes in materials (6 points)
- Detailed information on new material mix (identification of each constituent material and % weight in formulation) (6 points)
- Calculation of new 3DP factor (6 points)

*Discussion of habitat design (0-40 points) – Teams must provide rationale in habitat engineering and design, address sustainability of the habitat (scale of manufacturing processes and how processes make use of local resources, space programming and space efficiency for the habitat, logistical requirements), and how the habitat meets the top level requirements for the competition (ability to support crew of 4 for 1 year). Exterior penetrations and placement in Team’s design must be clearly indicated. Prefabricated components must also be documented. The documentation should also include a BIM file with LOD commensurate with the requirements of Virtual Construction Level 2. This BIM model represents the subscale habitat the teams will print at the onsite competition and will be reviewed by judges in a model review with the teams during one of the two setup days.

- Description of habitat and design (10 points)
- Description of setup and manufacturing sequencing -- includes discussion of exterior penetrations and placement (10 points)
- Documentation of prefabricated components (10 points)
- Discussion of habitat sustainability and use of indigenous materials (includes rationale for materials selection) (10 points)

Comment: this breakdown was not included in Appendix C originally. We wanted to break this criteria out further so it’s not just a “lump sum” bucket and judges have a better idea of how to evaluate the point total.

*Estimate of print time based on prior system development work and habitat design (5 points)

*Documentation of design and printing 3D-printed beams for test at head-to-head competition (10 points)

*evaluation of BIM Model of habitat to be constructed at head to head (0-15 points)

- System information (5 points)
- Layout/efficiency (5 points)
- Constructability/robustness (5 points)

6.0 On-Site Competition Arena and Logistics

- 6.1. We see that we have available 1-phase 240 V and 3-phase 480 V as available power. How much total power (in watts) will be available from each of these?

A. We intend to provide enough power generation resources to meet the team needs at either single phase 240 V or three phase 480 V. Please let us know how much power you would like to have available.

- 6.2. What is the height of the high bay, the height and width of the door, and total floor space we have to set up equipment?

A. The doors to the arena are 30 feet wide and 30 feet tall. While the roof is over 40 feet at the peak, we would not expect the printing equipment to exceed 30 feet in height when deployed for printing. See rules sections 8.2.5 through 8.2.10 for more detailed information.

- 6.3. Can we attach a robotic arm to the floor in that location?

A. The floor of the arena will be highly compacted soil, so nothing can be mounted to the floor; it must be free standing and self-supporting. All systems should demonstrate a factor of safety of 2:1 against overturning.

- 6.4. What are environmental conditions for material storage, printing and testing?

A: Competition will take place in a sheltered, ventilated (but not precisely air conditioned) arena with typical late April/early May environmental conditions (temperature, humidity, etc.) for Peoria, IL. Materials and equipment shipped by the teams ahead of the competition will also be stored as shipped under exterior environmental conditions (i.e. should be able to be stored outdoors).

- 6.5. Rule 8.2.8 calls out the space available for the teams and indicates the printing bed needs to be accessible from the edge of the workspace in case it needs to be moved for testing. Can you provide more information and context?

A: Teams will be provided with the required stone print bed located roughly at ground level plus 150 mm or less. Ground level printing is required to allow testing either in place or by moving the completed structures if the print bed has been provided in a “skid pan”. Movement of structures would require access to pull the bed from the edge of the team’s designated space – thus the team would need to be able to quickly remove or relocate any interfering material or equipment to allow the sample to be moved in the skid pan.

- 6.6. When will invitations to the Construction Level 3 Head-to-Head competition be sent?

A: After Construction Level 2 (Hydrostatic test) judging is complete, and the judges have reviewed the rule 9.2 proposals from the teams which competed in Construction Level 2, invitations will be sent to up to eight teams. If fewer than 8 teams qualified or accepted invitations via this criterion, additional teams may pursue an invitation as explained in rule 6.13.2, at any point up to the late qualification submission deadline of April 1, 2019. Bradley University, at its discretion, will work with the judges

to consider and evaluate these team submissions on a rolling basis from the time initial invitations are sent up to the April 1, 2019 deadline.

6.7. Can you provide more information on the schedule for the Level 3 Construction head-to-head event?

A: The following schedule based on rules 8.2.6 and 8.2.7 is subject to change but can be used for planning purposes:

April 22-26 – Team shipments of material and equipment can be received at the Caterpillar facility in Edwards, IL
April 29-30 – Teams will have two eight hour sessions to set up, prep and test printers before the competition begins
May 1-3 – Teams will have three ten hour sessions to print their habitat with additional 30 minute periods at the beginning/end of day for setup/cleanup
May 3 – Strength testing of three beam samples printed before the competition per rule 8.10
May 4 – Final evaluation of printed habitats via rules 8.4, 8.6, 8.7 and 8.8; deconstruction and removal of printers

6.8. The rules (section 8.2.7) call for three daily printing sessions of 10 hours each with 30 additional minutes at the beginning of the day to prep the machine for operation and 30 additional minutes allotted at the end of the day to properly shut down the machine. What types of activities are allowed during these 30 minute time windows?

A: The ideal competition format would be to have 30 uninterrupted hours for printing. However, due to facility limitations and safety considerations, the time was split into three days. The competition organizers realize that starting up and shutting down the printers may require special actions to prime the machine for operation and clean it out when stopping. The intent is for the machine to begin the subsequent print sessions in fundamentally the same condition and orientation as it stopped at the end of the previous printing session. “Progress” should not be made outside of the three ten hour printing windows. A few additional points:

- Rule 3.7 – feedstock – any manual feedstock additions to the hopper/printing systems once the competition begins would need to be completed during “printing windows” and would be counted as interventions
- No material may be deposited to contribute to the final structure outside of the “printing windows”
- No prefabricated components may be manipulated outside the “printing windows”
- No physical or software modifications are allowed to the printing system outside the “printing windows”
- Once the competition has started Wednesday morning, teams are responsible for executing any interventions and should be prepared to provide and safely use any equipment, material, tools, and labor to complete any such interventions (which will incur penalties per the rules). NOTE THAT THE COMPETITION FACILITY POLICY DOES NOT ALLOW FOR NON-STAFF MEMBERS TO OPERATE MOBILE EQUIPMENT (FORKLIFTS, MANLIFTS,

WHEEL LOADERS, ETC). Teams should not expect to make use of these types of equipment during the printing portion of the competition. Teams should also be aware that per rule 8.2.8, all items (equipment, printing feedstock, etc) must be set up within the 15 m x 15 m square area. Teams can submit proposals for reasonable use of facility mobile equipment and staff for the setup/teardown portions of the event.

6.9. Can you provide some insight into key activities teams should be planning for before the Construction Level 3 event and at the event?

A: All deliverables (with the exception of printing the actual structure) should be complete and submitted/presented to the judges by 12:00 PM Central Time on April 29, 2019. The exception is that rule 8.10 specifies that videos documenting the printing of the beam samples are due 30 days prior to the event (midnight, Central Time on March 30, 2019). The teams are ultimately responsible for being familiar with and fully complying with the rules. Some of the other items worth special note are:

- Consider optional pre-printed components per rule 8.2.11
- Material mix and durability test results
- Three bending test samples per rule 8.9 printed before the competition and brought for testing (videos due 3-30-19)
- Documentation for judge review per rule 8.11
- A BIM model with structural and pressure retaining elements at LOD 400 and to LOD 200 for MEP & ECLSS which corresponds to the structure that will be printed at the event submitted along with the proposal defined in rule 9.2

Please also note that the printed structure will be damaged extensively by the final test at the head to head event.

7.0 Virtual Construction Competition

7.1. If I want to compete in the Virtual Construction competition levels, so I also have to compete in the Construction competition levels?

A: No. There is a specific registration option for teams who wish to compete in the VC levels only which does not require participating in the physical construction levels.

7.2. A portion of the score for the Virtual Construction Levels is based on aesthetic representation. How will aesthetics be evaluated?

A: A portion of the judging panel for this level of the competition will be made up of architects that have been vetted by the American Institute of Architects, with many of them having experience serving on judging panels for significant and iconic structures.

7.3. A portion of the score for the 4D modeling portion of the challenge includes modeling of printing robots and equipment. Since this will require significant utilization of computing resources, is it more critical to model the details of the equipment or to model the movement of the equipment?

A: Modeling of the location and movement of equipment should be provided with greater fidelity than the details (fitting, bolts, welds, etc.) of the equipment, as this will provide a better measure of the construction sequence being evaluated.

7.4. Teams are to submit a miniature model of their habitat. Is there a size limit on this miniature?

A: Miniature models shall be of a size that is acceptable for shipment by the United States Postal Service. See <https://www.usps.com/welcome.htm> for shipping restrictions.

7.5. Should teams consider habitat layout and architectural design outside of printed elements as they create their submissions for the Virtual Construction Levels? For example, should teams consider elements such as soft goods, floor and wall coverings, color, etc. or how prefabricated structures (such as those containing ECLSS) could form part of the habitat?

A: Yes, the Virtual Construction levels include scoring parameters in the areas of functionality and aesthetics, which may be influenced by more detailed, non-printed elements and components in the BIM design which go beyond the required BIM elements. Teams are encouraged to consider autonomous solutions for the finishing and outfitting the habitat. Planning and designing components beyond structural and pressure retaining elements may also be represented in the 4D virtual

environment for the judges' review. More realistic and efficient habitat designs and components will be evaluated by the judges using the weightings assigned in rules 7.8.4 and 8.13.12.

7.6. In contrast to the Construction Level rules, no mention is made in the Virtual Construction Levels of defining the material mix. Is this not a requirement in the Virtual levels?

A: For the printed miniatures required in Virtual Construction Levels 1 and 2 (Rules 4.6.3 and 7.7.2) any material (ABS, PLA, Nylon, etc.) printed by a standard off-the-shelf 3D-printer may be used.

Material types appropriate for subscale and full-scale construction should be associated with structural and pressure retaining objects in the submitted 4D BIM model, although documentation of a specific material mix and mix process is not required. Recognizing that autonomous construction is a critical aspect of the overall challenge, the details of printer operations, placement of preprinted and/or pressure retaining components, should be considered. Reasonable, printable, structures are required as a minimum; a model of the material feed system, the simulated path for the printer head, and positioning of the robot or robots needed for placing components are also scoring considerations this aspect of the Challenge.

7.7. Can you provide additional clarity with respect to the “constructability/robustness” requirements/rubric considerations (listed in the Appendix as part of the documentation/BIM Model scoring for Level 3 Construction)?

A: The judges will assess how well the BIM model documents a practical plan of construction as well as habitat suitability for expected loads.

7.8. How will "System Information" be judged per 4.7.1? What is considered "Missing Information" in this rule?

A: System information for MEP and ECLSS may include a range of metadata such as: process description (chilled water, compressed air, etc.), and physical description (material, sizing, pressure rating, temperature rating etc.). Missing information may be judged based on either a process basis when an obvious requirement such as potable water is not included, or on a system basis when fundamental information such a pipe diameter is not included.

Design professionals with experience in terrestrial and extraterrestrial MEP and ECLSS will be part of the judging team. The team will also have access to NASA subject matter experts in MEP and ECLSS design to assist in decision making.

7.9. Can you provide more information on acceptable or preferred BIM design/viewer software and file formats?

A: Per Rule 4.6.2, the BIM model should be submitted “in a format which can be reviewed in a freely available BIM viewer software which would be accessible to the judges.” As long as this clause is met, there is no preferred file format or BIM viewer software. For reference (no endorsement of any package expressed or implied), Navisworks is a viewer that will be freely available to the judges – if a team is not able to supply a file format which carries the required BIM model information and can be

viewed by Navisworks, please contact Bradley University to propose an alternate freely available viewing option.

7.10. Are teams allowed to redesign their BIM models for the second BIM level, or will this cause point deductions?

A: It is expected that teams will learn and improve their designs throughout the competition. The Virtual Construction (BIM) Level 2 BIM submission will be judged independently from the Virtual Construction (BIM) Level 1 submission, so there would be no points deducted from the BIM Level 2 submission due to changes from the BIM Level 1 submission.

7.11. Can teams competing in the full competition (i.e. including physical construction levels) submit habitat designs for Virtual Construction (BIM) Levels 1 and 2 which do not meet the requirement from Rule 3.10.6 that the 1:3 scale habitat must fit in the 4.5 m x 4.5 m printing region available at the Level 3 Construction competition?

A: Yes, that is allowed. However, the team must also create a habitat BIM model at the Construction Level 2 – 100% Design level of detail which is compliant with rule 3.10.6 to serve as the design basis for the 1:3 scale habitat which will be printed at the Construction Level 3 competition.

7.12. Do competitors in the Virtual Only competition need to document concepts and methods for sealing penetrations through 3D printed pressure retaining elements?

A: Yes, placing and sealing penetrations through 3D printed pressure retaining elements is a key part of Phase 3 of the challenge. Teams should document their methods in their BIM models.

7.13. Do the teams' submissions for Virtual Construction Level 2 and the 3D-Printed Structure for Construction Level 3 have to match?

A: No. However, a model to the 100% design level (LOD 400 for structural and pressure retaining elements and LOD 200 for MEP and ECLSS) that does match what the teams will print at Construction Level 3 is required as the design basis for the printed structure. This increases workload on the teams. Also, it should be noted that while this provides certain design freedom for the Virtual Construction Level 2 submissions, these entries are still expected to address constructability and robustness aspects as given in the rules.

7.14. Are each of the 3 ECLSS volumes redundant, or are all 3 units required working together to make the habitat functional?

A: Please refer to rule 3.10.3, which specifies that there must be three ECLSS equipment volumes of at least 1.3 m³ included in the model. Teams may identify/define what the systems are, but there isn't a requirement to demonstrate redundancy in any particular manner or to complete detailed design of the inner workings of the ECLSS system volumes.

Revision Tracking Log

Version	Date	Summary of Changes
1.0	December 18, 2017	Initial Release
2.0	January 19, 2018	Clarified the answer to question 1.7 Removed the word “dome” from question 4.1 Added questions and answers 4.1.1, 5.5, 7.5 and 7.6
3.0	February 23, 2018	Added questions and answers 1.10, 1.11, 3.11, 4.10, 7.7 Corrected a typo in answer 3.8 which referred to “GSS” instead of the correct “GST”
4.0	April 5, 2018	Question 4.5 Deleted Added questions and answers 1.12, 7.8, 7.9 Updated answer 1.8 to specify time of day for due dates
5.0	April 30, 2018	Added questions and answers 5.6, 5.7, 7.10, 7.11
6.0	June 20, 2018	Added questions and answers 3.12, 4.11, 5.8, 6.5
7.0	August 24, 2018	Added questions and answers 1.13, 5.10, 6.6, 6.7, 7.12; Updated 3.2 and 3.12
8.0	September 24, 2018	Added questions and answers 7.13, 7.14
9.0	November 15, 2018	Added questions and answers 4.12 and 4.13
10.0	February 25, 2019	Added questions and answers 1.3.1, 5.11, 6.8 and 6.9
11.0	March 18, 2019	Added clarifications to answer 6.8, added questions and answers 5.12, 5.13 and 5.14