# ASCE Earth & Space 2020, Seattle, WA, April 21-23 2020

## 17th Biennial ASCE International Conference on Engineering, Science, Construction and Operations in Challenging Environments

# Theme: Engineering for Extreme Environments

Conference Organizer: ASCE Conferences

**General Conference Chair: Alaina Dickason Roberts, P.E., New Haven, VT** ( E-mail: alaina.d.roberts@gmail.com)
**Technical Conference Chair: Paul van Susante, Ph.D., M.ASCE, Michigan Technological University, Houghton, MI** ( E-mail: pjvansus@mtu.edu)
**Conference Local Organization Chair: John Koppelman, P.E., Boeing Co. (Retired), Seattle, WA** ( E-mail: koppelmanjohn@gmail.com)

This 17th Biennial event will explore the cutting edge in engineering, science, construction and operations for extreme environments on Earth and in Space. This conference is the premier event for sharing technical and modeling research and case studies for engineering & operations in extreme environments for the purpose of construction, mining, in-situ resource utilization on Earth and other planetary bodies such as the Moon, Mars and asteroids.

Conference includes:

- Discussions on the exploration and utilization of various planetary bodies
- The development of engineering structures, equipment and processes to be used in aerospace environments and other terrestrial applications which are subject to extreme environmental conditions
- The application of Civil Engineering concepts and technologies to aerospace environments and the application of aerospace technologies to civil engineering on Earth.
- Presentations will be made in multiple concurrent symposia over three days

Papers are solicited for the following topical areas and keywords below.

### Symposium 1: Granular Materials in Space Exploration

Chair: **Philip Metzger**, Ph.D., University of Central Florida, Orlando, FL ( E-mail: philip.metzger@ucf.edu)
**Juan Agui**, Ph.D., NASA Glenn Research Center, Cleveland, OH ( E-mail: juan.h.agui@nasa.gov>)

This symposium will focus on the science and engineering of granular materials in space exploration. When we visit a planetary body, we land on granular materials, drive on them, dig in them, extract resources from them, build with them, and study them for science. Because granular materials can rearrange on a mesoscopic scale, their emergent behaviors are difficult to predict and are the subject of intensive research by physicists, engineers, geologists, and other disciplines. Research includes experiments, computer modeling, and collection of data from planetary missions. Technologies are being developed to study granular materials on the Moon, Mars, asteroids, and beyond. Sessions in this symposium will focus on lunar regolith and dust, asteroid regolith, soil mechanics, granular flow, rocket exhaust interactions with regolith, and anything that requires or supports our understanding of granular materials in space.

### Special Session Topics:

**The Physics of Regolith: Mechanics, Heat, and Volatiles**

**Regolith Simulants**

**Instruments and Methods to Measure Regolith Mechanics**

**Modeling Methods for Regolith**

**Rocket Exhaust Interactions with Regolith**

**Trafficability of Regolith: Designing Rovers to Not Get Stuck**

**Particulate Processes under Low Gravity Environments Granular Mechanics (Otis Walton, Grainflow, CA Joseph Antony, University of Leeds, UK)**

Session Organizer: S. Joseph Antony, Ph.D, FRSC, University of Leeds, UK S.J.Antony@leeds.ac.uk a nd Otis Walton, Ph.D, Grainflow Dynamics, Inc., Livermore, CA, walton@grainflow.com

Low/micro-gravity environments strongly affect the selection of optimal processing, storage, and transport configurations of particulate materials, for example, in the design of the granular sample preparation and distribution systems (SPDS) of spacecrafts used in Lunar and Martian space exploration activities, and later for In-Situ Resource Utilization (ISRU) activities. This special session deals with the fundamental and applied research related to all aspects of processing particulate materials under low/micro-gravity environments including, but not limited to, the following: granular flows, fluidization regimes of particles, links between single-particle scale properties and bulk strength characteristics, working principles of, or replacements for: bins, hoppers, chutes, vibrating sieves, vertical fluidized beds, as well as scaling rules for mechanical or pneumatic conveying, and other solids-handling devices under reduced gravity environments.

**Keywords**

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|---|---|---|
| • anchoring in soils | • geotechnical property measurement and prediction | • regolith mechanics |
| • cratering | • knowledge gaps and how to fill them | • regolith simulants |
| • exhaust plume effects | • new findings on specific solar system soils | • numerical modeling |
| • granular flows | • terramechanics in space | • physical modeling |

## Symposium 2: Exploration and Utilization of Extra-Terrestrial Bodies

Co-Chairs: **Robert P. Mueller**, NASA Kennedy Space Center, Cape Canaveral, FL (E-Mail: rob.mueller@nasa.gov)
**Kris Zacny**, Ph.D., Honeybee Robotics, Pasadena, CA (E-Mail: kazacny@honeybeerobotics.com>

This topic will focus on methodologies, techniques, instruments, concepts, missions and system level designs associated with exploration and utilization of Solar System bodies, with emphasis on the Moon, Mars, Ocean Worlds, and Asteroids. The topic covers both robotic and human exploration. Many of the various types of civil, geological, mining, chemical and materials engineering fields are needed to sustain space exploration and space commercialization. The topic also covers legal and ethical aspects of space exploration and space mining.

Standard practices will have to be adapted, and new practices will have to be developed, to be able to rely on the natural resources of near-Earth asteroids, the Moon, and Mars to sustain human and robotic activities in space. Engineering systems and economics concepts as well as mechanical, robotic, and structural engineering solutions are needed as well. While there is always room for robust and innovative new concepts, the testing, refining, and more testing of previously proposed concepts are especially sought.

## Special Session Topics:

### Robotic Mobility in Extreme Terrain

Session Organizer(s): Colin Creager (Colin.m.creager@nasa.gov) & Kyle. Johnson (kyle.a.johnson@nasa.gov), NASA Glenn Research Center, Cleveland, OH

When exploring extra-terrestrial bodies, such as the Moon and Mars, the terrain can often be very difficult to traverse. Examples of such terrain challenges are very soft soil, sharp rocks, and steep slopes. Adding to these challenges is the fact that the terrain is often unknown before a mission, making it more difficult to plan accordingly. The desire to explore regions such as these means that unconventional methods of mobility may be necessary. This topic is focused on novel methods, tools, or technologies that serve to improve the traversability of an exploration vehicle in extreme terrain. This includes, but is not limited to, the development or use of robotic systems, components, sensors, software, or techniques. Emphasis should be on mobility improvements in the areas of efficiency, capability, or safety.

### Nature and bio-inspired concepts for Human Space Exploration

Session Organizer(s): Andrew Trunek, NASA Glenn Research Center, Cleveland, OH (E-mail; <Andrew.J.Trunek@nasa.gov>) and Vikram Shyam, Ph.D., NASA Glenn Research Center, Cleveland, OH (E-mail: Vikram.Shyam@nasa.gov)

NASA has been commissioned to establish a long-term presence on the Moon and ultimately Mars. The Moon and Mars are extreme environments; Earth can also present equally extreme environments at the depths of the ocean or in glacial caves. Extraterrestrial construction of structures to support human exploration will require new approaches due to numerous constraints. Just to name a few that will force a new approach are: limited launch mass, launch frequency, limited energy, temperature extremes, minimal atmosphere, lack of liquid water, abrasive dust, cosmic radiation and availability of other resources. Over billions of years, nature has supported the origin, evolution and continuous presence of life and its structures on Earth. Nature is similarly constrained to only the resources immediately available while minimizing the use of energy. However, nature forms magnificent structures that vary greatly in size and complexity from the Great Barrier Reef to the microscopic cyanobacteria. This session will focus on design concepts, methods and techniques of construction for human space exploration that are inspired by or that mimic nature. A few examples might be: self-assembly of materials, multifunctional materials and structures, closed-loop habitat systems, 3D printed materials, structures that are organic, passive or active and autonomous bots.

**Ocean Worlds**

Session Organizer(s): Yosi Bar-Cohen (yoseph.bar-cohen@jpl.nasa.gov) and Steve Vance (Steven.D.Vance@jpl.nasa.gov), NASA Jet Propulsion Laboratory, Pasadena, CA

Ocean Worlds are celestial bodies with substantial liquid water. This includes Earth, and potential water-rich exoplanets and moons. In the outer Solar System there are five known ocean worlds, icy moons of Jupiter and Saturn with volumes of ice-covered liquid exceeding Earth's. Similar oceans are suspected in many more places in the outer solar system. Increasingly, space exploration agencies, including NASA and ESA, are seeking to explore these bodies to assess their habitability and to look for extraterrestrial life. This special session is a forum for reporting research and technology development related to the exploration of ocean worlds.

**"Mining on the Moon and Mars" - Space Mining**

Session Organizer(s): Purushotham Tukkaraja, Ph.D., South Dakota School of Mines and Technology, Rapid City, SD (E-Mail: PT@sdsmt.edu) and Rob Mueller, NASA Kennedy Space Center, FL (E-Mail: rob.mueller@nasa.gov)

NASA envisions that In-Situ Resource Utilization (ISRU) is key to future successful sustainable space exploration, including the Moon and Mars. Successful ISRU could also extend sustained human presence to the planets and moons to enable eventual settlement. However, most of the terrestrial mining and mineral processing methods are not going to be applicable for extra-terrestrial mining, with low gravity, thermal management and vacuum being the major operational issues. This special topic deals with innovative concepts, methods, designs, research, development, and applications related to all aspects of space mining and mineral processing on the Moon and Mars. Papers are solicited on topics including, but not limited to, the following: Resource Assessment, drilling, blasting (rock fragmentation), excavation, loading, haulage, and mineral processing techniques, use of robotics, in-situ/local resource utilization, tele-operation of mining equipment, automation and remote mining.

**Resource Prospecting**

Session Organizer(s): Tony Colaprete, Ph.D., NASA Ames Research Center, Moffett Field, CA (E-Mail: Anthony.Colaprete-1@nasa.gov)

The economic evaluation of natural resources depends on the accuracy of resource distribution estimates. A frequently discussed lunar resource is water ice, however, we currently do not have a sufficient understanding of the distribution of water or its forms at the scales it would be extracted and processed. New observations and analysis approaches are needed to evaluate the distribution of water.

**In-Situ Resources: What does the Moon have to offer us?**

Session Organizer(s): Melissa Sampson, Ph.D., Ball Aerospace, Boulder, CO (E-Mail: msampson@ball.com) and Jeff Hopkins - Astrobotic Technology, Inc., Pittsburgh, PA (E-Mail: jeff.hopkins@astrobotic.com)

In order to properly build on the Moon, we need to understand what local resources we have available to us, how to find them, and where they are located. What does lunar prospecting look like and how do we use what we find to build things in the harsh lunar environment? This session presents papers on various aspects of ISRU available on planetary surfaces and beyond.

**Planetary Environment Impact on Assembly Integration and Test (AIT) Requirements for Space Systems**

Session Organizer(s): Alexander M. Jablonski, Ph.D., Canadian Space Agency, Ottawa, Canada (E-mail: <alexanderm.jablonski@canada.ca>) and Kin F. Man, Ph.D., NASA Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA, USA (E-mail: kinfung.man@jpl.nasa.gov)

Currently, many space agencies and international scientific teams are involved in planning planetary missions to terrestrial bodies such as the Moon, Mars, Venus, Mercury, and to natural moons of outer planets such as Europa, or even to near-Earth asteroids. Space systems for these missions have to operate in different or more extreme environments. Assembly Integration and Test (AIT) requirements need to be developed for more stringent qualification testing. Qualification tests could be at the assembly/subsystem level or at the full spacecraft or rover/flight system level. This session focuses on the impact of planetary environments on AIT requirements for space systems to survive the operational phase of the mission and design or mitigation techniques to improve their survival. The list of environmental conditions having impact on the planetary system operation might include: temperature, vacuum, radiation, specific planetary atmospheres, dust and soil conditions, other geophysical effects (e.g., seismic and other activities), length of the day and night; and effect of the location or of the area of operation of a specific stationary or non-stationary planetary system. This session will cover space systems for exploration of all planetary bodies, with the exception of lunar systems, which will be covered in a separate session.

**Keywords**

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| • economic geology of space | mining and processing automation | • physical and numerical testing |
| • new equipment concepts | • equipment and system capability definition | • regolith operations |
| • orbital dynamics for mine planning and scheduling | • planetary drilling and regolith excavation | • mobility and robotics systems |
| • sample handling and processing technologies | • planetary mechanisms driven by electro-active actuation materials | • dust mitigation |
| • low gravity anchoring devices and techniques | • surface stabilization | • life support systems |
| • space commercialization, policy and law | • space transportation systems | • surface habitation systems |

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| • human exploration and development of space | • in-situ resource utilization and development | • in-situ manufacturing |
| • technologies supporting space exploration | • communications and navigation | • remote sensing technologies |
| • in-situ instrumentation, sensors, site mapping and prospecting | • Assembly Integration and Test (AIT) Requirements for Space Systems | • future missions and mission concepts, and related surface mission architectures |
| • commonalities and differences in lunar, martian, and asteroidal exploitation | • planetary analogs, engineering and science and earth extreme regions | • mineral processing in low gravity/vacuum/high-energy radiation environments |
| | large, long-term terrestrial engineering projects as templates for non-terrestrial infrastructure development and financing | Robotically deployable structures |

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## Symposium 3: Advanced Materials and Designs for Aerospace and Terrestrial Structures Under Extreme Environments

Co-Chairs: **An Chen**, Ph.D., Iowa State University, Ames, IA (E-mail: <achen@iastate.edu)
**Hongyu (Nick) Zhou**, Ph.D., University of Alabama-Huntsville, Huntsville, AL (E-Mail: hongyu.zhou@uah.edu)

New techniques in experimental, computational, and analytical mechanics are expanding the understanding of the behavior of composite, smart, and other materials with applications to aerospace structures and other terrestrial structures under extreme environmental conditions. Exciting combinations of fundamental studies and practical applications by government and industry are expanding the design and analysis capabilities for aerospace structures as well as terrestrial structures to be used in extreme environments. Recent advances and studies on materials and structures as well as their design aspects in terrestrial aviation and space applications and related structures are particularly solicited.

### Special Session Topics:

**Ballistic Impact and Crashworthiness of Aerospace Structures (Justin Littell)**

Session Organizer(s): Justin Littell, Ph.D., NASA Langley Research Center, Hampton, VA ( E-Mail: Justin.d.littell@nasa.gov)

The special session is focused on high strain rate testing and simulations involving structural impacts at velocities ranging from vehicle crash events to ballistic impact. Associated impact simulations utilizing state-of-the-art nonlinear explicit transient dynamic finite element codes are desired. Impacts involving aerospace structures that are constructed of unique materials such as composites, are encouraged. Finally, the topic of vehicle crashworthiness encompasses a variety of subtopics such as human tolerance to impact, modeling of crash test dummies, seats and restraints, airbag technology, and modeling of impact surfaces including soil and water.

### Energy Efficient Structures and Habitats

Session Organizer(s): Jialai Wang, Ph.D., The University of Alabama, Tuscaloosa, AL ( E-Mail: jwang@eng.ua.edu)

The special session is focused on energy-efficient structures and habitats that are suitable for earth and space applications. The topic encompasses a range of topics including the use of emerging materials and technologies such as Phase Change Materials (PCM), high-insulation structural composites, hydronic heating and cooling, combined structural and thermal analysis and simulations, and the structural responses under elevated (or cryogenic) temperatures. In addition, submissions pertaining to the scale-up applications of additive manufacturing (e.g., 3-D printing concrete and shelters) and fast-deployable structures are encouraged.

### Advanced and Alternative Cementitious Materials

Session Organizer(s): Chris Ferraro, Ph.D., University of Florida, Gainesville, FL ( E-Mail: ferraro@ce.ufl.edu)

The use of new advanced and alternative building materials for the creation and maintenance of structures is beneficial to industry and the environment. This special session includes topics related to new and advanced concepts pertaining to green, resilient, and high-performance materials. The session includes the contributions to the behavior of alternative materials including mechanics, fatigue, fracture, durability, and resilience. Additionally, submissions that address issues in additive manufacturing, and materials applicable for terrestrial and extraterrestrial structures, are encouraged.

### Composite materials for Aerospace

Session Organizer(s): Gregory Odegard, Michigan Technological University, Houghton, MI, (E-Mail: gmodegar@mtu.edu)

Composite materials are increasingly used in aeronautical and aerospace applications because of their high specific strength and specific stiffness, as well as their insulative capabilities. However, much research still needs to be performed to improve the efficiency of processing composite structures, as well as improving the properties without sacrificing their low density. This session will focus on efforts to improve properties and processability of composites, including experimental and computational modeling approaches.

**Keywords**

- novel new structural components and systems
- structural health monitoring
- nano/micro-mechanics
- safety and health monitoring of aerospace and hydraulic structures
- impact mechanics of composites

• high-performance and sustainable materials for application in extreme environments

• materials and structures for application to space vehicles and extraterrestrial structures

• experimental, analytical and numerical techniques for composites, concrete and other aerospace structures or structures for extreme environments

• fatigue, fracture, and damage mechanics

• resilience and sustainability of materials and structures

• bioplastics and biocomposites

• 3-D printed and fast-deployable structures

• Advanced in-situ cementitious materials for use in regolith concretes

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## Symposium 4: Structures in Challenging Environments: Dynamics, Controls, Smart Structures, Health Monitoring, and Sensors

Co-Chairs: **Wei Zhang**, Ph.D., University of Connecticut, Storrs, CT (E-Mail: wzhang@uconn.edu)
**Landolf Rhode-Barbarigos**, Ph.D., University of Miami, Coral Gables, FL (E-Mail: <landolfrb@gmail.com>)
**Gangbing Song**, Ph.D., University of Houston, Houston, TX (E-Mail: GSong@Central.UH.EDU)

The technical areas of dynamics, controls, and evaluation and condition monitoring of engineering structures and systems, specially designed and built to operate in challenging environments on Earth and in space, are of extreme importance. Integration of sensors into structural and material systems enables more effective and precisely tuned performance, as well as remote evaluation and control of space and terrestrial structures systems. The design and analysis of structures in challenging environments on any planetary body need special care beyond current terrestrial practice. Space environments – on planetary surfaces or in orbit – expose systems to radiation, micro/reduced gravity, vacuum, debris/meteoroid impact, and temperature extremes. Overcoming these significant challenges is imperative to the success of any structure in space and in extreme and challenging environments on Earth. In addition, educators face challenges in using emerging technology to improve the education of the engineers of the future

### Special Session Topics:

**Title of Special Session:**

**Tensegrity – Concepts and Applications in Challenging Environments**
Session Organizer(s): Landolf Rhode-Barbarigos, Ph.D., University of Miami, Coral Gables, FL (E-Mail: <landolfrb@gmail.com>); Ju Hong Park, Ph.D., POSTECH, Pohang, Korea (E-mail: juhpark@postech.ac.kr)

Tensegrity systems are reticulated structures composed of tension and compression members in a stable self-equilibrium. They are materially efficient form-found systems that provide the possibility of designing strong yet lightweight structures as well as integrating sensors and actuators that enable structural or shape adjustments according to environmental or functional requirements. Tensegrity structures are thus excellent candidates for structures in challenging environments. In this session, topics such as physical or numerical form-finding methods, physical or virtual experiments of robotic systems and active structures, control algorithms and AI developments, smart design and fabrication systems, are of special interest.

**Structures under Extreme Environments: Theory and Applications**
Session Organizer(s): Wei Zhang, Ph.D., University of Connecticut, Storrs, CT (Email wzhang@uconn.edu)
Dong-Ho Choi, Ph.D., Hanyang University, Seoul, Korea, (Email samga@hanyang.ac.kr)

In the challenging environments, such as high wind and ocean waves for coastal infrastructures, it is necessary to design structures to respond automatically and actively to these hazardous elements that could interact actively or passively with structures. This special session deals with topics related to new and advanced concept, methods and applications on structures subjected to wind/wave hazards to improve infrastructure resilience including, but not limited to the following: wind/wave & structure interactions related vibration control and mitigation; fatigue and fracture; and structural resiliency.

**Specialized Sensors-based Structural Damage Detection and Health Monitoring**
Session Organizer(s): Gangbing Song, Ph.D. University of Houston Houston, TX (E-mail: GSong@Central.UH.EDU ) & Ramesh B. Malla, Ph.D., F. ASCE, University of Connecticut, Storrs, CT (E-mail: MallaR@engr.uconn.edu)

For durability, safety, efficient operation and functioning of structures, effective health monitoring, damage detection, and vibration control measures are necessary. This is more important for structures built to operate in harsh and hazardous environments. Special sessions are proposed that focus on (1) Piezoceramic based structural damage detection, and (2) Fiber optic sensor based structural health monitoring.

**Advanced Concepts on Renewable and Green Energy Harvesting**
Session Organizers: Ramesh B. Malla, Ph.D., F. ASCE, University of Connecticut, Storrs, CT (E-mail: MallaR@engr.uconn.edu)

To meet ever increasing demand of energy consumption world-wide in an environmentally friendly and sustainable manner, various renewable energy sources have been investigated and some already successfully used to generate electricity. This session deals with new innovative structural systems, concepts, methodologies, and their applications of harvesting green and renewable energy from wind, ocean waves, vibrations, and other sources.


**Keywords**

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| • smart and intelligent structures | • shape memory alloy actuators | • structural health and condition monitoring |
| • dynamics and controls | • modeling of intelligent structures | • fiber optic, piezoelectric, and shape memory alloy-based sensors |
| • structural vibration control via active and semi-active approaches | • nanomaterial-based and biologically inspired sensors, actuators, and structures | • tracking and control of structures in challenging environments |
| • innovative techniques/methodologies of design and analysis of structures | • structures in extreme environments on Earth, Moon, Mars, and in space | |
| • remote experiments | • other special topics related to dynamics, controls, intelligent/smart structures, and sensors | |


## Symposium 5: Space Engineering, Construction, and Architecture for Moon, Mars, and Beyond


Co-Chairs: **Ramesh B. Malla**, Ph.D., F. ASCE, University of Connecticut, Storrs, CT (E-mail: Ramesh.Malla@uconn.edu) **Melissa Sampson**, Ph.D., Ball Aerospace, Boulder, CO (msampson@ball.com); **Alexander Jablonski**, Ph.D., P.Eng, Canadian Space Agency, Ottawa, Canada (alexanderm.jablonski@canada.ca); and **Gerald (Jerry) B. Sanders**, NASA Johnson Space Center, Houston, TX (E-mail: gerald.b.sanders@nasa.gov)


There have been increased activities and interests in space activities, especially lunar and Martian exploration by the public and private sectors alike. Many national and international agencies and space industry are currently involved in the planned lunar missions. The recent United States Space Policy Directive 1 directs NASA to focus on lunar exploration with a new human return to the Moon and then manned missions to Mars. These efforts will involve both robotic and human missions. The recent landing of the Chinese lunar surface probe Chang'e-4 on the far side of the Moon has opened up a new chapter in lunar exploration with plans by several space actors for humans to follow in the late 2020's.

As the world's space community prepares to return to the Moon with humans, this time to stay, explore and then settle elsewhere in the Solar System on a long term basis, it is imperative that we continue to support the development of qualified engineering, construction and architecture concepts and guidance for these developments. On Earth, multiple new spaceports have been constructed with modernized methods and operations, providing new insights into enhanced operational efficiencies, This symposium deals with innovative concepts, methods, designs, research, development, and applications related to all aspects of human space exploration, architecture, engineering and construction, including facilities in orbit and on planetary surfaces such as the Moon, Mars, moons of Mars and asteroids, as well as terrestrial spaceports.

## Special Session Topics:

**Innovative Engineering and Construction on the Moon and Mars Utilizing and Harnessing Indigenous Geo-Environmental Resources**

Session Organizer(s): Ramesh B. Malla, Ph.D., F. ASCE, University of Connecticut, Storrs, CT ( E-Mail: Ramesh.Malla@uconn.edu) and Gerald (Jerry) B. Sanders, NASA Johnson Space Center, Houston, TX (E-mail: gerald.b.sanders@nasa.gov)

It has been long realized that long term sustainable human settlements on the Moon and Mars are only possible if the local geological and environmental resources can be utilized substantially for day to day operation. Several studies can be found dealing with the use of lunar and Martian regolith for various purposes, including habitat building material, protection against radiation and extreme temperatures, extracting oxygen, and mining. However, in-depth and exhaustive studies on the use of regolith for engineering and construction is still lacking. Moreover, new innovative methodologies for design, engineering and construction need to be developed that exclusively harness and utilize indigenous geological and environmental resources. For example, the extremely hot and cold environment on the lunar surface may someday pave a path for new engineering innovation and technologies. It might even be possible to tap the everlasting radiation on the lunar surface for certain engineering and construction purpose. How about the low gravity and vacuum that exist on the moon? These may be leveraged to come up with new and innovative design and construction technologies. This session presents papers on various aspects of innovative engineering, construction, development, and operations utilizing and harnessing local geo & environmental resources available on the Moon and Mars.

### Technical Requirements for Lunar Systems

Organizers: Alexander M. Jablonski, Ph.D., Canadian Space Agency, Ottawa, Canada (E-mail: <alexanderm.jablonski@canada.ca> ) and Kin F. Man, Ph.D., NASA Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA, USA (E-mail: kinfung.man@jpl.nasa.gov)

The Moon is Earth’s nearest celestial body. It has one of the most challenging natural environments in our solar system. They include: high vacuum, high diurnal temperature variations, super-cold temperatures in the permanently-shadowed regions, abundance of very fine and abrasive lunar dusts, a reduced gravity field (1/6 of Earth’s g), the danger of moonquakes (as high as almost 3.5 on the Richter scale), the danger of meteoroid and micrometeoroid impacts, and the duration of the lunar day. A detailed knowledge of the lunar environmental conditions is crucial for defining the technical requirements for lunar systems and structures. This session focuses on the technical requirements for lunar missions, particularly focusing on lunar system requirements associated with long surface operations, in addition to the technical requirements associated with the other typical mission phases for lunar missions: ground processing, storage, and transportation; launch; cruise; orbit insertion; and EDL (Entry, Descent and Landing). This session also covers the impact of the lunar environmental conditions on ground-based qualification testing requirements and test methodologies to survive the expected long operational life on the lunar surface, at both assembly/subsystem and system levels.

### Tensegrity Structural Systems for Moon and Mars Space Applications

Session Organizer(s): Robert Skelton, Ph.D., Texas A & M University, College Station, TX (E-mail: bobskelton@tamu.edu)

Tensegrity concepts have proved to be the minimal mass solution for many fundamental problems in Engineering and provide the possibility of designing strong yet lightweight and robust structures often with the integration of sensors and actuators. Robots made of tensegrity are lightweight yet strong compared to robot by conventional construction. Tensegrity structures have thus been proposed for planetary landing and exploration, as well as systems for space habitats and related functions. The session will deal with concepts and novel applications of tensegrity systems for space exploration including on the Moon and Mars. Papers are solicited on topics dealing with the wide-range of applications of tensegrity systems, including flexible structures, planet landers, deployable space antennas, robots, space debris collector, lunar and Martian rovers, habitats, and others.

### Architecture on the Moon and Mars: Designing for Human Space Exploration

Session Organizer(s): Valentina Sumini, Ph.D., Massachusetts Institute of Technology (MIT), Cambridge, MA (E-mail; <vsumini@mit.edu>) and Ju hong Park, Ph.D., POSTECH, Pohang, Korea (E-mail: juhpark@postech.ac.kr)

Considering the renewed interest by ESA and NASA in planning a manned mission respectively to the Moon and Mars by the next few decades and allowing for future human habitats and even cities, this session will focus on design concepts, structural analysis and construction techniques of extra-planetary architecture for human exploration of the Moon and Mars. Designing a structure on an extraterrestrial surface includes several challenges, such as internal pressurization, reduced gravity, high-velocity micrometeoroid impacts, radiation protection, severe Lunar/Martian temperature cycles, safety factors and reliability as well as ease of construction, which must be major components for space structures as they are for significant Earth structures. When designing for space habitats, creativity represents the key element for solving all these several environmental challenges in a unique integrated solution that optimizes the architectural, structural and fabrication requirements.

### Structural morphology for space structures on the Moon, Mars and other extreme environments

Session Organizer(s): Landolf Rhode-Barbarigos, Ph.D., University of Miami, Coral Gables, FL (E-Mail: Landolfrb@miami.edu); and Valentina Sumini, Ph.D., Massachusetts Institute of Technology (MIT), Cambridge, MA (E-mail; <vsumini@mit.edu>)

Structural morphology refers to the study of form and shape in structures as well as the relations between form, forces, and material. The session will focus on the relations between form, forces, and materials in structures and systems with applications in challenging environments and space exploration. Topics such as form finding, structural design, optimization, hybrid structural systems, active/deployable/smart structures, new materials and their application for structures as well as fabrication techniques are of special interest. Due to the high cost of transporting resources off of Earth's surface, new design, control, and fabrication strategies will have to be developed, to be able to rely on the in-situ resources of near-Earth asteroids, the Moon, and Mars to sustain human and robotic activities in space.

**Lunar and Martian Habitats: Design Considerations and Construction Challenges**

Session Organizer(s): Sudarshan Krishnan, Ph.D., University of Illinois at Urbana-Champaign, Urbana-Champaign, IL (E-mail: <skrishnn@illinois.edu>).

This session will provide the technical knowledge and guidance related to habitat planning and design in extreme environments of Moon and Mars. The talks will highlight the architectural and structural engineering challenges in the design of Lunar and Martian habitats. The papers will address design issues for zero-gravity and planetary surfaces, spatial planning, material and system selection, and structural design. Accompanying topics may include mechanical aspects related to deployment and construction methods such as 3D printing.

**Inflatable Structures: Habitable Applications for Space and Planetary Environments**

Session Organizer(s): Greg Muller, P.E., ILC Dover, Houston, TX; E-mail: <mulleg@ILCDover.com>; and Ramesh B. Malla, Ph.D., F. ASCE, University of Connecticut, Storrs, CT (E-mail: Ramesh.Malla@uconn.edu)

: With manned space flight missions increasing in duration to return to the Moon, and Mars, habitable volume in spacecraft and planetary structures for performing work, living, and storage for supplies must increase as well. Inflatable structures have the potential to provide the needed habitable volumes with fewer rocket launches over traditional structures. This special session will focus on deployable soft good habitat structures and both the benefits and technical challenges they provide for manned space flight and planetary environments. This topic would include: soft good materials, construction, deployment, testing and verification, launch packing, radiation protection, simulations, damage protection and repair, terrestrial analogues, planetary resource utilization.

**Strategies for Achieving Resilient Extraterrestrial Habitats**

Session Organizer(s): Amin Maghareh, Ph.D. , Purdue University, W. Lafayette, IN, (E-mail: amaghare@purdue.edu); Karen Marais, Ph.D., Purdue University, West Lafayette, IN, (kmarais@purdue.edu); and Shirley Dyke, Ph.D., Purdue University, W. Lafayette, IN, (E-Mail: sdyke@purdue.edu)

The evolution of space exploration will eventually lead to extraterrestrial settlement. Beyond the protection of Earth's atmosphere, future human settlements face new threats stemming from the lack of air pressure, extreme temperature fluctuations, meteorite impacts, high-energy galactic cosmic rays, and solar particle events. Countering these challenges and designing sustainable, long-term human settlements to provide livable conditions in Space require the highest applications of engineering and technology. This special session deals with innovative concepts, methods, designs, research, development, and applications related to achieving resilient Mars and lunar habitats.

**Innovative Construction Techniques for Lunar and Martian Environments**

Session Organizer(s): Nipesh Pradhananga, Ph.D., P.E., Florida International University, Miami, FL (E-mail: npradhan@fiu.edu)

“Out of the world” problems demand “out of the world” solutions. This special session deals with ground-breaking methods and innovative designs in extra-terrestrial construction. Papers are solicited on topics ranging from excavation and mining techniques; robotics/automated construction, maintenance and repair; infrastructure construction, assembly and advanced process monitoring ideas pertaining, but not limited to, human habitats, temporary structures, and infrastructure on the harsh lunar environments of low gravity, vacuum, radiation exposure, and extreme temperature. The session will encompass novel contribution to experimental, analytical, and computational techniques, including real-time automated construction operation analysis, construction simulation and informatics, data visualization and virtual reality, construction management, advancement in real-time monitoring and resource optimization, modular construction, lean construction, 3d printing and artificial intelligence in construction as well as material, sustainability and safety applicable to Lunar and Martian surfaces

**Robotics Development for Lunar and Martian Constructions**

Session Organizer(s): Mustafa Alsaleh, Ph.D., Caterpillar, Inc., Peoria, IL: (E-mail: Alsaleh_Mustafa_I@cat.com)

The recent literature review has clearly shown the great deal of focus on robotics development in variety of applications, including construction repair, and maintenance in the harsh space environments, in orbit and on the lunar and Martian surfaces. Robotics design, development or building is a not trivial, and often goes through many iterations to get it right, especially in the harsh, extreme and previously untested conditions that exist in space. Leveraging simulations should make this process easier to deal with as the simulation makes it possible to cut down the number of design, build and test iterations. Simulation can enable new applications and allow testing before building any physical model. Once design is finalized, less physical testing can be used to confirm the intended functioning of the robots. This special session deals with robotics development and application for space engineering and construction, especially on lunar and Martian environment. Papers dealing with various topics in these areas are solicited.

**3D Printing Applications for Lunar and Martian Construction**

Session Organizer(s): Seung Jae Lee, Ph.D., Florida International University, Miami, FL (E-mail: sjlee@fiu.edu)

In the recent efforts to enable a long-term presence on Moon, Mars, or other planets, the research community has explored the innovative concepts using 3D printing to enable the extraterrestrial human habitat, structural facilities, life support systems, etc. The 3D printing has gained popularity due to many potential advantages, e.g., inherent effectiveness of leveraging the indigenous soil for the space radiation shielding, the minimized transportation of construction resources from Earth. Furthermore, the 3D printing began to be adopted for developing the synthetic particles to experimentally study / simulate the geotechnical behavior of extraterrestrial soils in the laboratory. This special session will provide a forum for the state of knowledge on the broad topics pertaining to the recent innovations in 3D printing applications targeted at Lunar and Martian construction.

**Building Information Modeling (BIM): digital representation of physical and functional characteristics of space facilities**

Session Organizer(s): Robert Mueller, NASA Kennedy Space Center, FL (E-mail: rob.mueller@nasa.gov )

BIM use refers to the goal of delivering any multi-dimensional computer model. The BIM uses for this special session include Habitat Modeling, Site Layout Planning, Construction Equipment, Indigenous feedstocks, 3D-Printer and Autonomous Feeding System (Equipment) Flow and Virtual Prototyping.

(3D BIM) Habitat Modeling – the metadata integrated model used to depict an accurate representation of physical conditions, printing environment, and assets of the facility.

(4D BIM) Construction Sequencing – the model used to graphically represent both permanent and temporary facilities on site during multiple phases of the construction process.

(4D BIM) Equipment and Material Flow – the model used to demonstrate the movements of construction methods including, but not limited to 3D-printers, material handling, and all autonomous systems on site.

(4D BIM) Virtual Mockup – the model used to design and analyze the construction of the facility components to improve their planning and constructability.

**Terrestrial Spaceports: New Construction Projects and lessons learned**

Session Organizer(s): Robert P. Mueller, NASA Kennedy Space Center, FL, (E-mail: rob.mueller@nasa.gov) and James T. Barrett, Turner Construction, New York, NY (E-mail: jpbarrett@tcco.com)

In recent years there has been significant activity in the construction of terrestrial spaceports to support the launch and landing of space transportation vehicles, both in the USA and worldwide. The impetus for this renaissance in spaceport construction has been the entry of new actors into the space launch and landing business. Commercial entities and government entities are introducing new transportation systems with increased life cycle efficiencies, incorporating the lessons learned from the past 60 years of spaceport operations. Reusability and reduced cost have become new drivers in the spaceport design and operations. Small launch vehicles for small satellite constellations need efficient and routine launching capabilities. The military is seeking a rapid response capability. Spaceports are also expanding beyond the Earth’s surface to the Moon and Mars, where spaceports must also be constructed to support reusability and in-situ re-fueling. Lessons learned from spaceport terrestrial construction can be applied to these new extreme environments with innovative engineering and operations. Papers are sought that will communicate the construction project sequences, experiences and lessons learned from recent spaceport construction and which will identify technology advancements achieved and also those that are likely to be required in the future.

**(Panel Session) Building a viable Space Engineering and Construction Economy: How Companies Partner to Open the Final Frontier (*– panel discussion- NO papers requested*)**

Session Organizer(s): Jeff Hopkins - Astrobotic Technology, Inc., Pittsburgh, PA; E-Mail: jeff.hopkins@astrobotic.com

There are a plethora of exciting technologies and companies expanding into cislunar space. In order to build a self-sustaining economy, the space community will need to work together. This session will discuss how small and large companies and government agencies can partner and effectively execute projects related to engineering and construction for efficient, safe, economically advantageous, and peaceful exploration and development of space and extraplanetary surfaces.

**Keywords**

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| • 3D Automated Additive Construction (e.g. 3-D Printing) for human habitats in space and extraplanetary surfaces, especially using local materials | • inflatable structures for planetary habitable structures | • resilient extraterrestrial habitats |
| • assembly integration and test requirements for Human Exploration Space Systems | • lessons learned from extreme terrestrial engineering e.g. Antarctica, Arctic, Siberia, Deserts, deep sea, off-shore, etc. | • space architecture on the Moon and Mars and in zero-G environments |
| • cis-lunar engineering, construction, and operation | • lessons learned from recent new terrestrial spaceport construction and activation activities | • space and planetary surface human transportation systems |
| • innovative techniques/methodologies of design and analysis of structures | • Modular hard structures orbital and surface habitats | • technical requirements for lunar and martian human exploration systems |
| • cis-lunar engineering, construction, and operation | • NASA's Lunar Gateway station and NextSTEP habitat projects | • tensegrity systems for space applications |
| • design, analysis, and construction of human habitats, structural facilities and bases on Moon and Mars | • NASA's Lunar Gateway station and NextSTEP habitat projects | • terrestrial spaceport facilities: requirements, design, development and construction |
| • design considerations and construction challenges for lunar and Martian habitats | • novel space life support systems with AEC integration | • virtual reality as a design toolOther relevant topics dealing with architecture, engineering and construction for human space exploration |
| • effects of harsh and extreme planetary environments on built systems | • O'Neill Cylinder concepts for human habitation in space | • Electromagnetic mass drivers and non-rocket launch capabilities |

- human and robotics construction, maintenance, and repair techniques and methodologies
- Planetary body surface infrastructure for landing and launch capabilities
- human low and microgravity research, including those done in the space station
- rapid deployable space habitat structures