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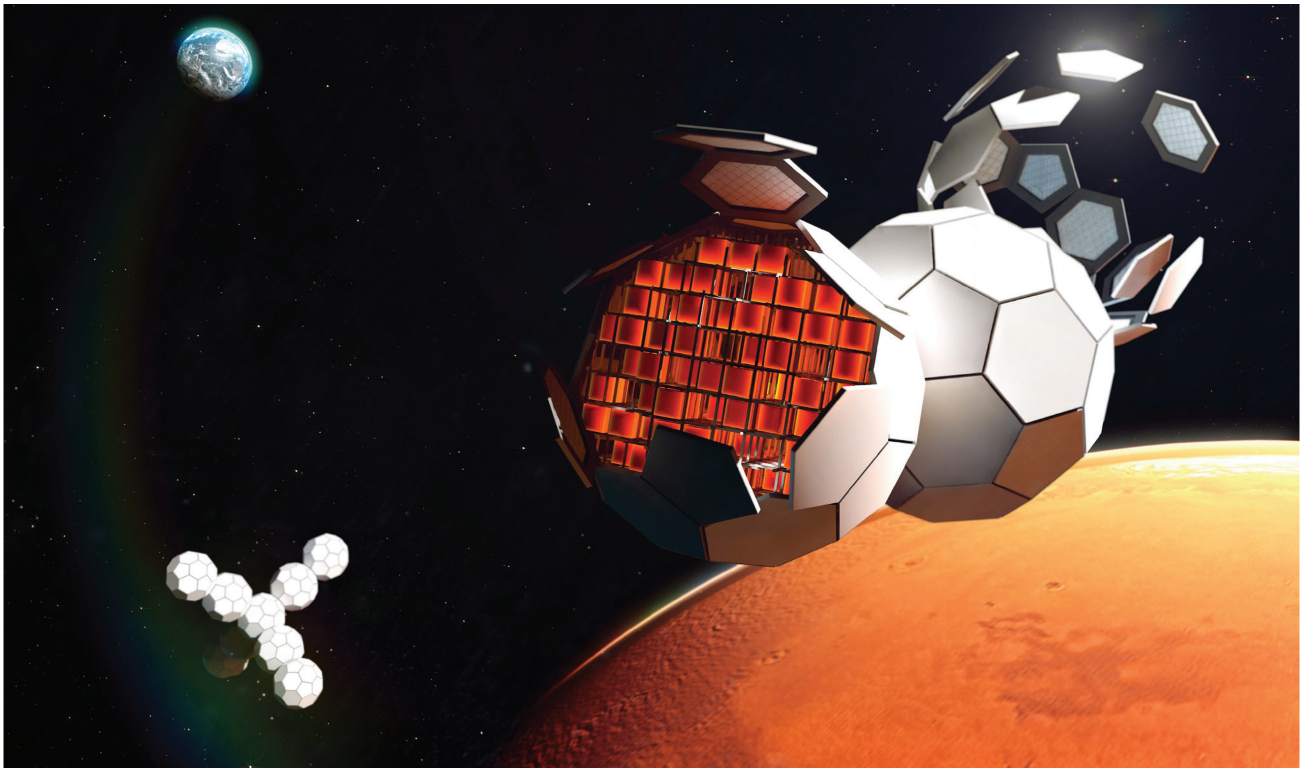


Space Architecture in Microgravity: TESSERAE Project for Large Scale Space Structures

MIT Space Exploration Initiative/ Aurelia Institute

Massachusetts Institute of Technology
Cambridge, Massachusetts

Established: 2016

Initiative Leadership:
Ariel Ekblaw (Founding Director)

Initiative Structure:
Academic Faculty: 3
Research Staff: 10
Postdoctoral Researchers: 1
Graduate Students: 15
Visiting Faculty and Students: 50+

Ariel Ekblaw
Massachusetts Institute of Technology

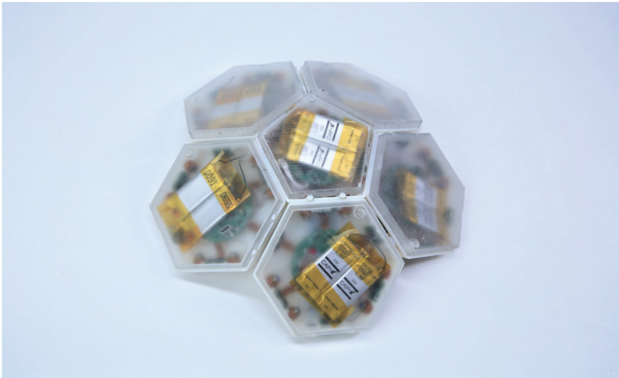
Context

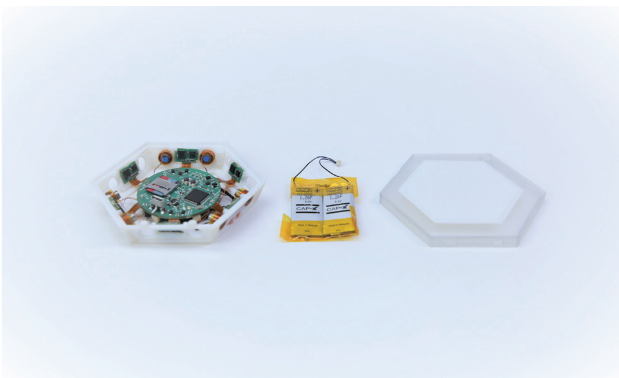
NASA and international partners are planning a crewed return to the lunar surface in this decade, with the explicit long-term goal of establishing sustainable lunar habitat infrastructure. International space agencies and several space entrepreneurs have shared plans for human missions to Mars in the 2030s. A menagerie of "new space" start-up companies is poised to support extensive activity for in-space habitation. Space exploration is entering an age of burgeoning commercial movement, fueled not only by the unique science experiments performed in microgravity but also by space tourism and a need for inhabitable next-generation space architecture.

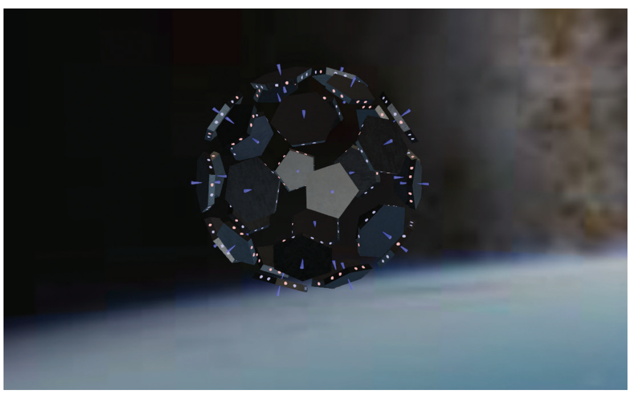
Designers such as architects, engineers, and space structure practitioners should aim to democratize access to space and challenge the prevailing paradigm of space as an exclusive and inaccessible domain. In that case, they must build space architecture that can scale to welcome, safeguard, and inspire humankind. Our space structures research program applies biomimetic principles to design modular, reconfigurable, and self-assembling space architecture. Currently, The team includes electrical and mechanical engineers, designers, a university-trained architect, and a spaceflight mission integration specialist.

Research Question

The axiom "Space is expensive, space is hard" challenged our team to develop a series of research hypotheses and in-space manufacturing tools that lower costs while increasing the robustness and resiliency of space habitats. The science of self-assembly from biology, and programmable matter approaches from the robotics and architecture fields, are applied in this







◁ Figure 1. Artist depicts the TESSERAE self-assembling space architecture in orbit around Mars. (Credit: MIT Space Exploration Initiative/TU Dortmund Fraunhofer Institute)

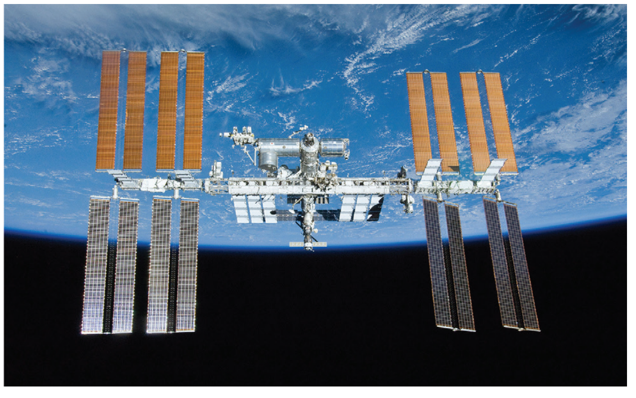
△ Figure 2. (a) TESSERAE Shell partial dome configuration and (b) TESSERAE Shell tile hardware close-up (Credit: photos courtesy of Jimmy Day, MIT Media Lab), (c) WeBots simulation of the TESSERAE Shell tiles self-assembling in orbit. (Credit: MIT Space Exploration Initiative)

work to design novel space station shell elements and nodes that indeterminately "grow" via advanced magnetic docking.[1] Through our research and iterative hypothesis development, we ask: How can quasi-stochastic self-assembly efficiently *grow* space architecture in orbit? This question requires a spiral development theory across extensive prototyping, microgravity testing, and computational design and simulation tools.

Research Methodology

The TESSERAE (Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable Adaptive Environments) project utilizes multiple research methods in our broader practice.[2] They include:

- *Fabrication of scaled electromechanical primitives*: To test assembly and construction concepts, ~1:50 scaled-down experimental hardware platforms are built in the lab. One of the most-explored geometries, a "buckyball," offers a highly efficient surface area to volume ratio, approaching that of a sphere. For space applications, maximizing volume for a given surface area is preferable, given the high cost of launching prefabricated surface cladding to orbit. These architectural primitives allow rapid prototyping, iteration, and assessment of physical and electromechanical features for structural bonding through geometry and magnetism. Specifically, dihedral bonding angles between tiles establish proper shell geometry for a buckyball or other closed shape, and magnet behavior is controlled by computational code and the power electronics in each tile. Primarily two types of primitives are built: shell tiles that self-assemble into a hollow structure, such as the pentagon and hexagon tiles of a buckyball (Figure 1); and cell nodes (i.e., plesiohedrons) that self-assemble into a space-filling design, such as the stacking of truncated octahedra. A range of 3D printing techniques is used to fabricate the shells, with a preference for light-cured photopolymer printers for more precise tolerances. The tiles are powered through a combination of batteries and supercapacitors and have a specification for 20 W pulses over two to three seconds on our latest International Space Station (ISS)-tested prototypes (Figure 2). A custom suite of electronic components, including sensors, LEDs, a central processor, and data storage, is mounted on fabricated PCBs (printed circuit boards) that run a self-assembly algorithm code in Python and C++.
- *Microgravity testing*: These miniature platforms are then tested in microgravity environments, ranging from recurring 15–20 second periods of weightlessness on a parabolic "Zero-G" flight, to three minutes of floating inside the experiment chamber of a suborbital rocket, to a multiday mission in orbit onboard the International Space Station (Figure 3). When released to float in one of these microgravity environments, the tiles record sensor data, and cameras capture footage for analysis that will inform the next iterative prototype series. These microgravity tests are crucial to a holistic understanding of self-assembly behavior at an optimized ratio of tile mass to magnetic field strength. For the ISS missions, either purely autonomous orbital tests are conducted using a confined experiment box within which tiles must self-actuate, or astronaut-tended experiments release tiles into the open aisleway for a greater volume of test space.[3] To supplement the small-scale hardware tests, we use a suite of robotics simulation software (notably WeBots from Cyberbotics) to produce mathematically rigorous models of self-assembly behavior in orbit at the human habitation scale.



△ Figure 3. (a) Dr. Ekblaw testing TESSERAE tiles on a 2019 Zero-G flight (Credit: Steve Boxall / Zero Gravity Corporation), (b) TESSERAE tiles have flown twice onboard the International Space Station for multiday missions. (Credit: NASA)

Key Research Insights

The interdisciplinary TESSERAE research program relies on integrating electromechanical engineering, architecture and design, and the physics of aerospace structures. TESSERAE is the beginning of a multiyear research and development exploration of novel in-space construction approaches. Learnings from these research methods range from identifying the optimum ratio of magnet strength to tile mass to measuring the timescale for self-assembly of a 32-tile system. These outcomes and insights are actively incorporated into building human-scale, modular habitat sets currently underway at the Aurelia Institute and Autodesk BUILD facilities in Boston. A viable path is emerging for autonomous self-assembly for space architecture through a combination of prototype and simulation work. Our research program includes exploring crossover applications for the TESSERAE modular structures in resource-constrained analog environments on Earth.

Acknowledgements

Dr. Ekblaw would like to thank present and former TESSERAE project team members for their contributions and collaboration over the years: Aswin Venkatapathy, Jamie Milliken, Sean Auffinger, Pete Dilworth, David Mansolino, Ara Knaian, and Joe Paradiso.

Notes

1. G. M. Whitesides and G. Bartosz, "Self-Assembly at All Scales," *Science* 295:5564 (2002): 2418–21; S. Goldstein, J. Campbell, T. Mowry, "Programmable Matter," *Computer* 38 (2005): 99–101, https://dl.acm.org/doi/10.1109/MC.2005.198; K. C. Cheung and N. Gershenfeld, "Reversibly Assembled Cellular Composite Materials," *Science* 341:6151 (2013): 1219–21; K. Gilpin, A. Knaian, and D. Rus, "Robot Pebbles: One-Centimeter Modules for Programmable Matter through Self-Disassembly," in *the Proceedings of the 2010 IEEE International Conference on Robotics and Automation* (*May 3-7, 2010*), 2485–92; S. Tibbits and K. Cheung, "Programmable Materials for Architectural Assembly and Automation," *Assembly Automation* 32: (2012): 216–25.
2. A. Ekblaw, A. Prosina, D. Newman, and J. Paradiso, "Space Habitat Reconfigurability: TESSERAE Platform for Self-Aware Assembly," in *the Proceedings of the 30th IAA SYMPOSIUM ON SPACE AND SOCIETY (Space Architecture: Habitats, Habitability, and Bases). Proceedings of the IAF International Astronautical Congress 2019* (October 21-25, Washington D.C.); A. Ekblaw, "Self-Aware Self-Assembly for Space Architecture: Growth Paradigms for In-Space Manufacturing" (PhD diss., MIT, 2020); "Bringing Nanoracks' BlackBox to Life with MIT Space Exploration Initiative "RIDES"" accessed Sept. 20, 2022, https://nanoracks.com/mit-blackbox-rides/.
3. https://nanoracks.com/mit-blackbox-rides/.
4. Axiom Space Signs Historic Agreement with Türkiye to Send First Turkish Astronaut to Space" accessed Sept. 20, 2022, https://www.axiomspace.com/news ax-1-research-expands-access-to-iss.
5. "TESSERAE —Self-Assembling Space Architecture" accessed Sept. 20, 2022, https://www.aureliainstitute.org/tesserae.

Ariel Ekblaw is Director of the MIT Space Exploration Initiative and CEO of the Aurelia Institute, a space architecture R&D lab. She is also a Lecturer at the Yale School of Architecture. Her work focuses on designing, prototyping, and testing technology for advanced space habitats in orbit. Her TESSERAE Ph.D. prototype research (MIT 2020) recently flew to the International Space Station on the historic Ax-1 mission.