Resilient Tensegrity Structures: Inspired by Spider Webs and Melons

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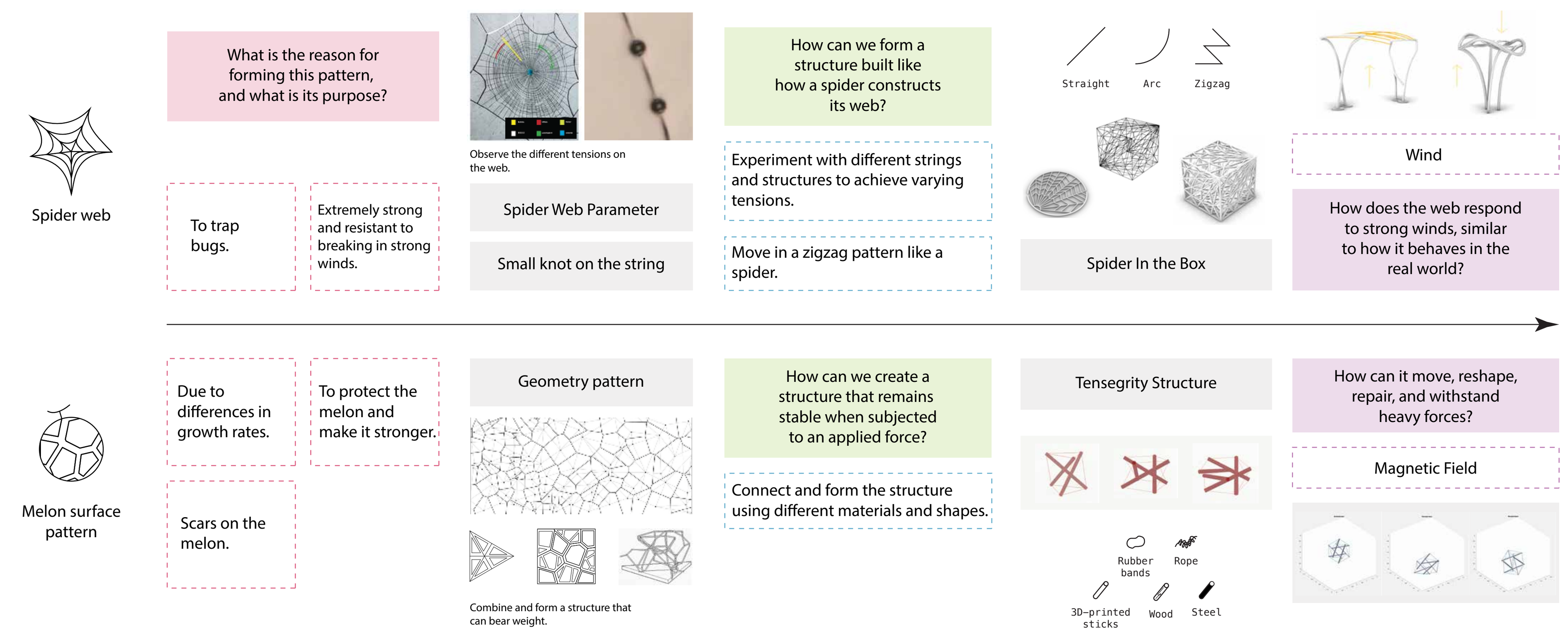
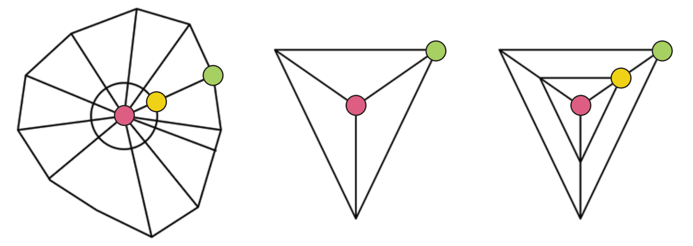
Insights from Previous Projects and the Objective of Our Design



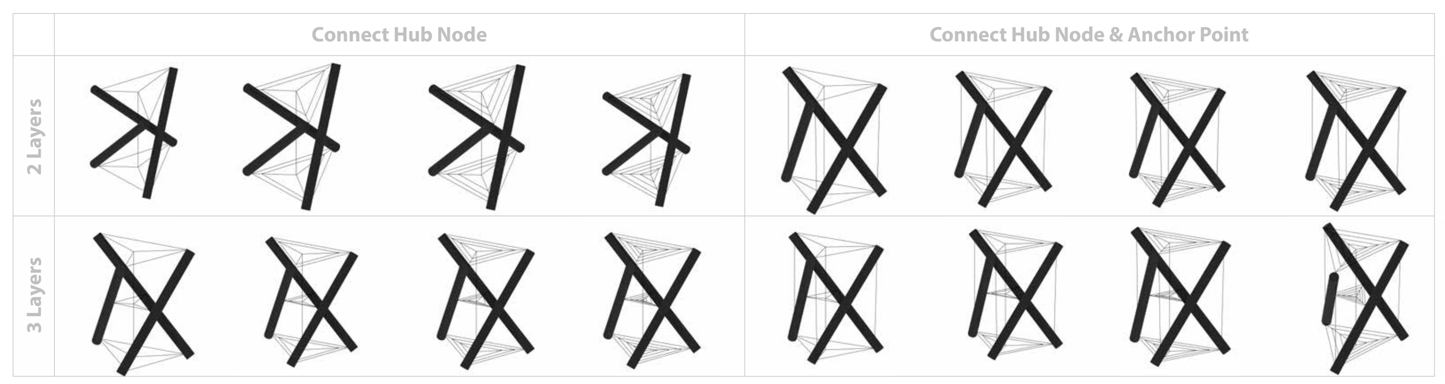
Our aim is to design a spider web- and melon-inspired Voronoi pattern to create our own tensegrity structure. This structure can be shaped into various forms and, even when subjected to different forces or when some parts are damaged, it will remain stable. This led us to the main question we want to address in this project:

How might we synthesize findings from previous projects and utilize our web tensegrity structure to introduce a new design that is both resilient and capable of moving in unknown environments, such as space?

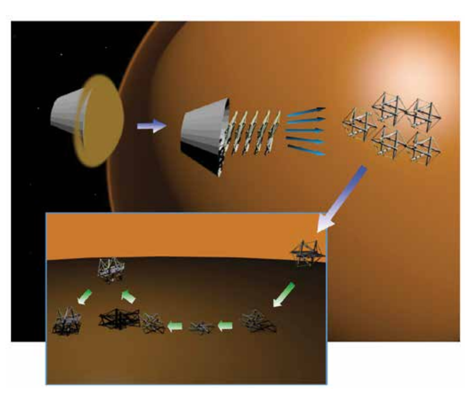
Research 1: Applying Spider Web Structures to Tensegrity Designs

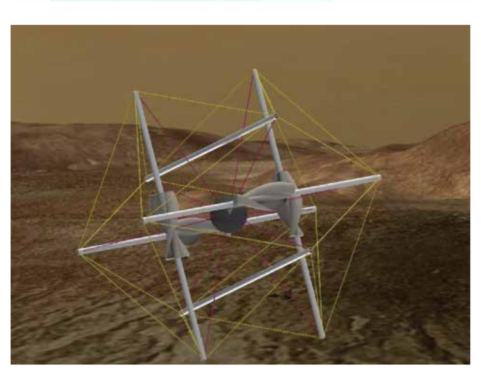


Hub Node: Distributes forces to maintain web integrity.
Radial & Spiral Node: Distribute forces along the radial and spiral lines for stability.
Anchor Node: Resists external forces and stabilizes the structure.



Research 2: NASA Superball - Advancing Tensegrity Robotics for Planetary Exploration

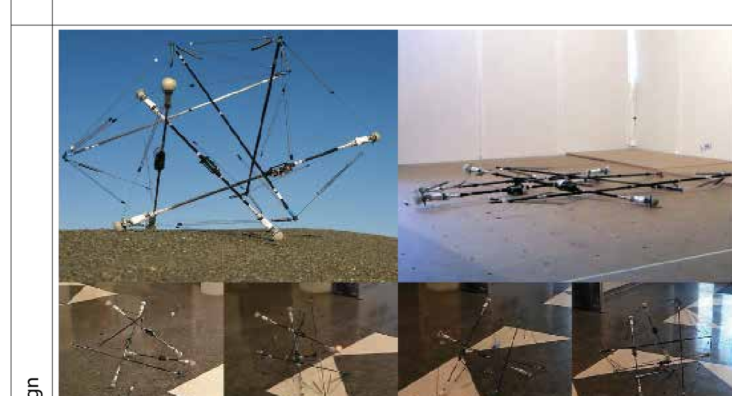
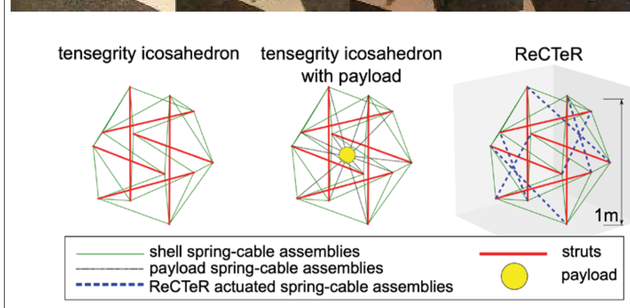
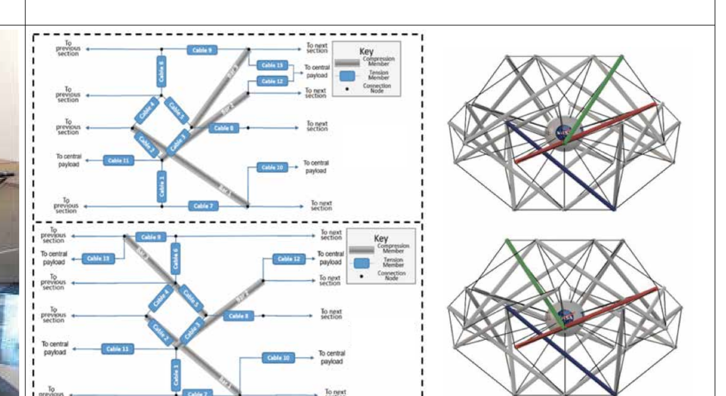
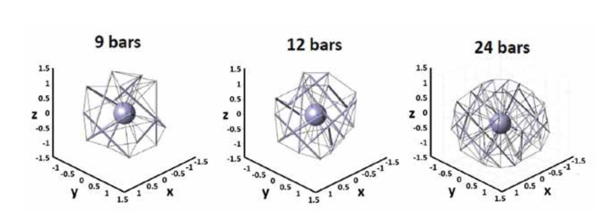




Based on NASA's papers released in 2015 and 2022, tensegrity robots have emerged as a promising concept for exploring unknown planetary environments. These robots align with NASA's goals for small, lightweight, and low-cost missions, addressing challenges posed by hazardous terrains and unstable conditions, such as those on Titan.

With their unique design of tensile and compression elements, the tensegrity structure of the robots not only facilitates planetary surface exploration but also allows the structure to fold, optimizing space and mass efficiency. Additionally, this structure acts as a buffer, preventing the robot from crashing upon landing. Moreover, incorporating extra strings enhances the resilience of the design, making it more durable and less prone to damage.

The image on the left demonstrates the structural design of the Superball and Tandem, introduced by NASA in its 2015 and 2022 research papers. The left table provides detailed designs and highlights aspects we can reference when building a tensegrity structure for space environments.

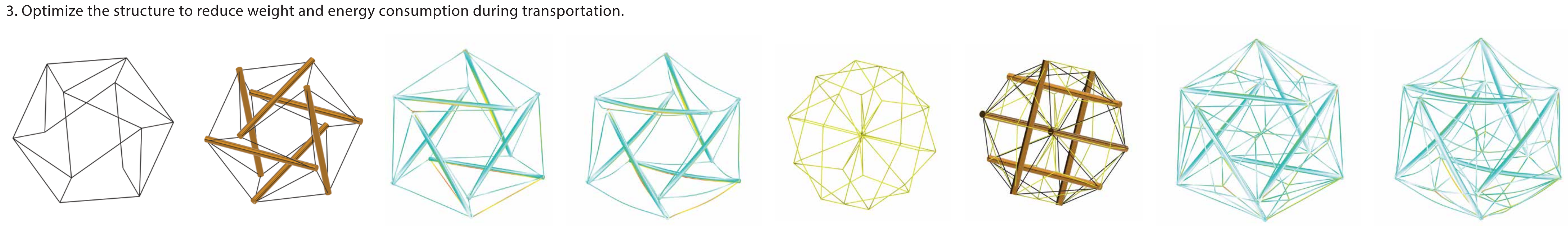
	2015 - Super Ball [1]	2022 - TANDEM [2]
Objective	Introduce the concept of designing a tensegrity robot and explain how this type of robot can operate in space environments.	Enhance the Superball design by incorporating additional structural elements, simulate how different structural designs influence the robot, and analyze how factors such as the number of struts affect the robot's properties.
Design	 	 
Key Point	When designing robots for space environments, it is crucial to prioritize reusability, redundancy, reliability, reduced mass, and cost to ensure efficient and successful missions.	The number of struts in the system significantly influences the robot's performance. A robot with fewer struts is lighter, easier to program, and more energy-efficient, reducing costs. Conversely, a robot with more struts offers greater speed, enhanced structural durability, and better protection for the central components of the robot.

[1] https://www.nasa.gov/wp-content/uploads/2015/04/niac_sunspiral_superballbot_phaseii_finalreport_tagged.pdf
[2] https://ntrs.nasa.gov/api/citations/20220014544/downloads/NASA-TM-20220014544.pdf

Design and Experiment 1: Applying Web Tensegrity Structure to the Superball

Design Goal

1. We aim to design a web-inspired tensegrity structure that ensures stability by effectively distributing loads and maintaining functionality even if some tension members break.
2. Design the structure to be easily convertible to flat geometry for efficient transportation.
3. Optimize the structure to reduce weight and energy consumption during transportation.



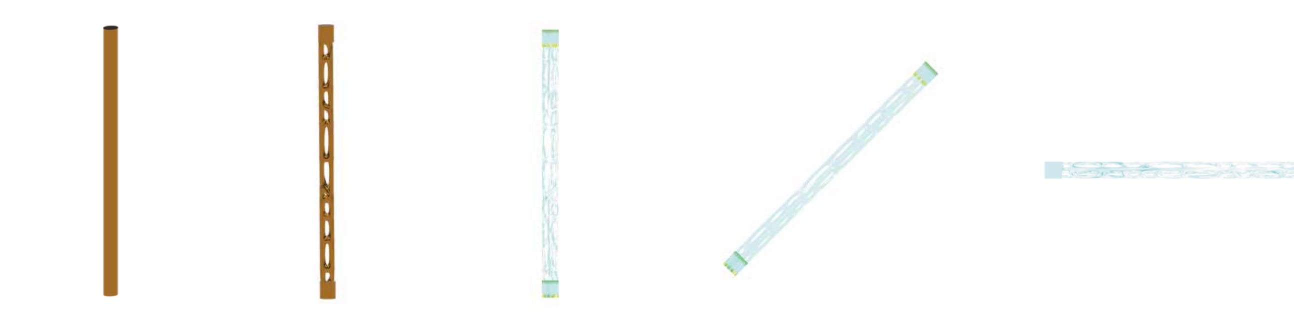
2015 - Super Ball

2024 - Web Tensegrity Super Ball (WTSB)

Research 3: Voronoi Struts Design

One of the most important considerations when designing robots for space is ensuring that the robot itself is lightweight. The Voronoi structure is lightweight while maintaining relatively good load-bearing capability. By incorporating a Voronoi design into the struts, the overall weight can be reduced, making it more suitable for space environments.

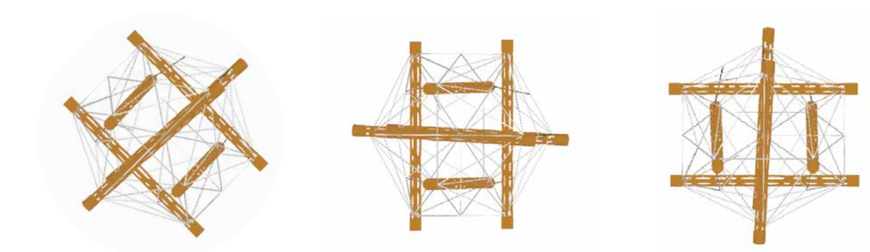
The images below illustrate the design of Voronoi struts and the stress simulation results for both basic cylindrical struts and Voronoi struts. In the simulations, red indicates areas experiencing higher stress, while blue represents areas with lower stress, meaning they can withstand greater forces. Although the basic cylindrical struts exhibit better load-bearing capability, the Voronoi struts also perform adequately.For applications where reducing the robot's weight is critical, Voronoi struts may be the better choice.

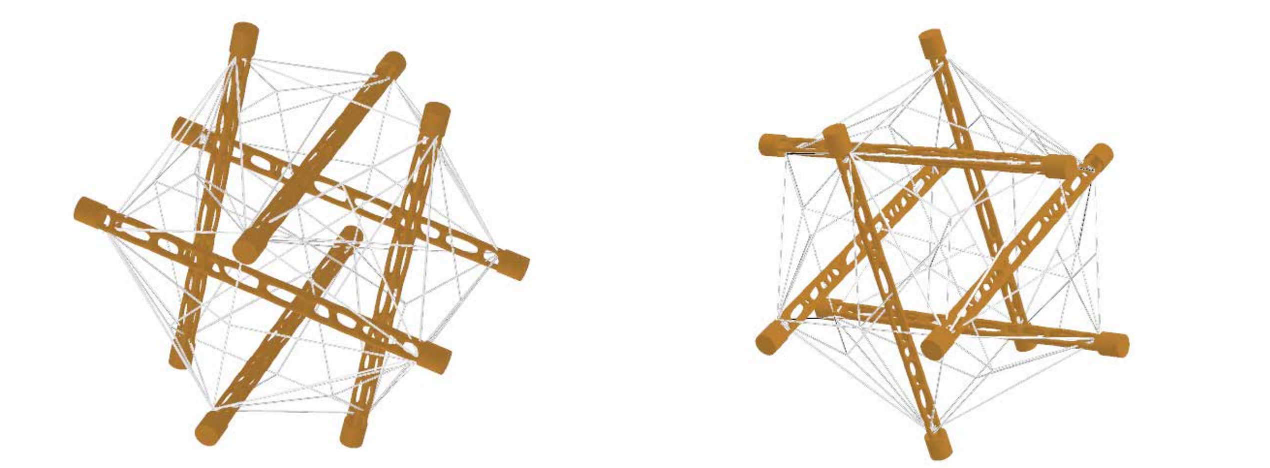


Design and Experiment 2: Applying Spider Web and Voronoi Structures to the Superball

This section explores integrating spider web and Voronoi structures into the Superball to enhance adaptability and functionality in space. Combining the tensile strength of spider webs with the lightweight efficiency of Voronoi designs improves durability and performance for planetary exploration.

Physical testing shows the WTSB (Web Tensegrity Superball) is highly potential, with added strings not affecting its ability to fold flat or move effectively.

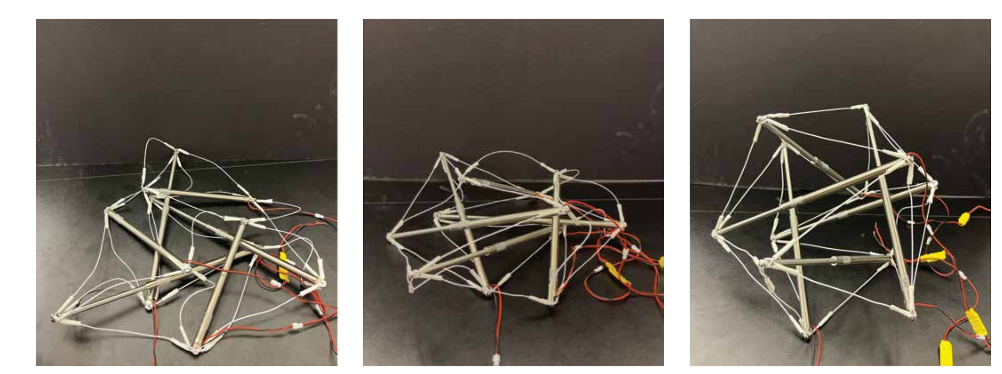


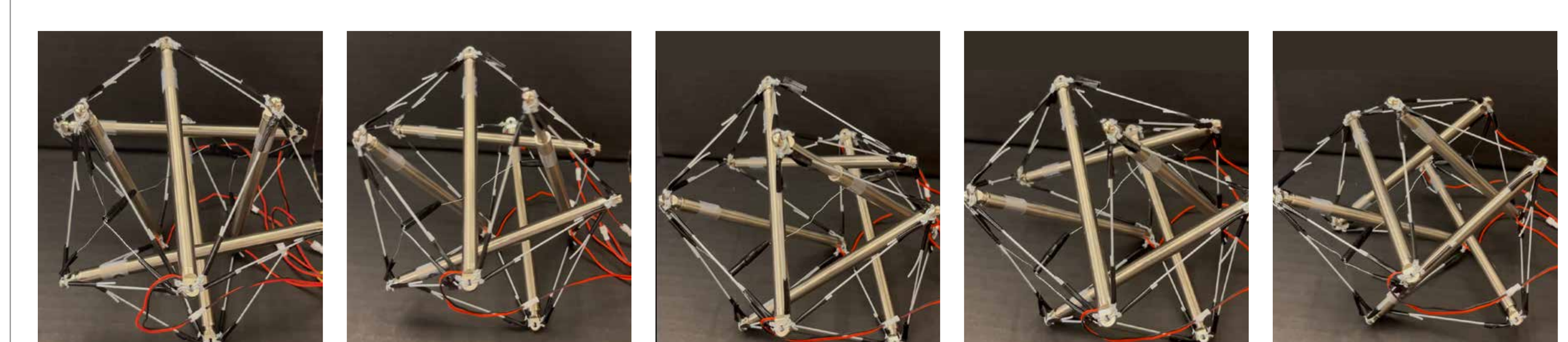


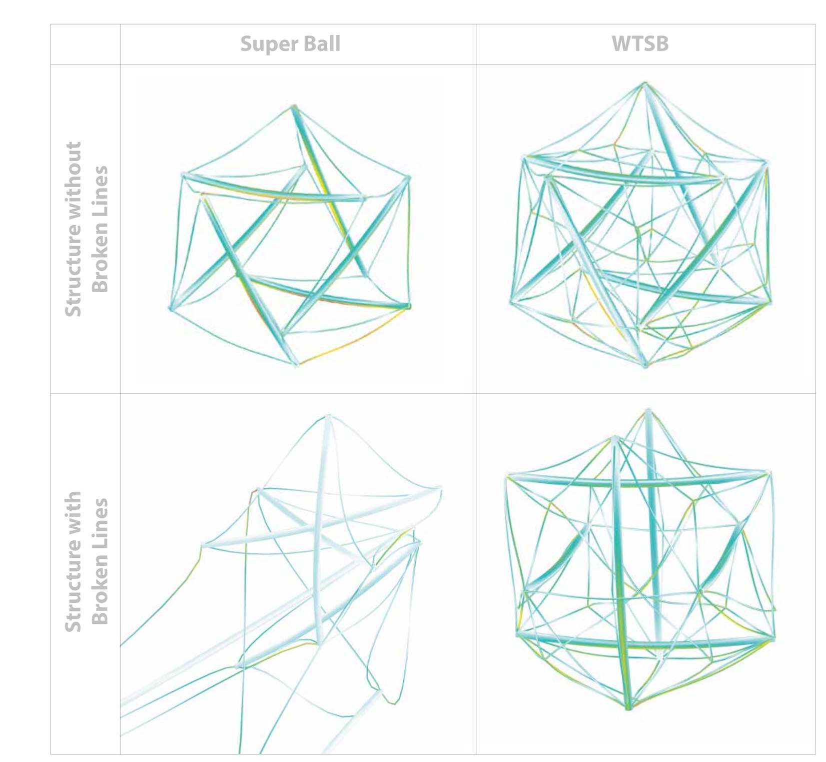
Design and Experiment 3: Testing the Structure Under Damage and Movement

In this section, we modified connections in the standard and web tensegrity Superball structures, showing the latter is more durable and robust.

For space missions, robots must be compact for transport and transition from flat to 3D configurations for effective planetary navigation. A physical model was built to demonstrate these movements.







Future Potential Applications: Building Construction on a Planet

To conclude, this project introduced a durable, resilient, and mobile structure for space exploration, inspired by NASA's Superball concept. We proposed a lighter, more robust robot, demonstrating the potential of web tensegrity and Voronoi strut designs.

In the future, these design principles could be applied to create other structures, such as domes, for various applications. The lightweight and durable design ensures structural integrity while minimizing weight, allowing rockets to transport more units into space, thereby maximizing efficiency and mission potential.