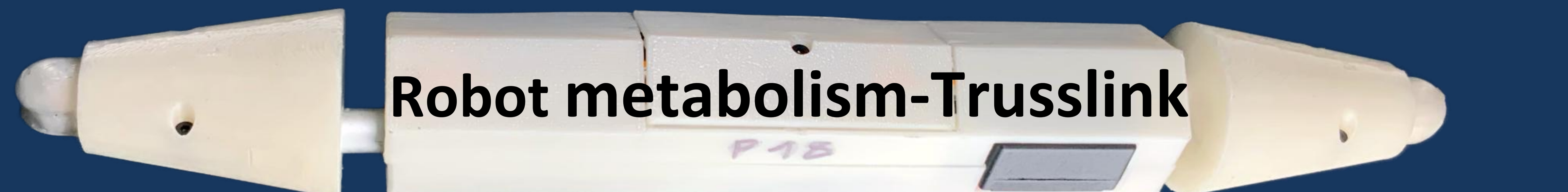

Robot metabolism-Trusslink

Towards machines that can grow by consuming other machines

Keywords: Robot metabolism - Self-assembly - Self-reconfiguration - Self-repair - Growth and adaptation - Open systems - Physical development - Machine ecology - Robot autonomy - Self-sustaining robots

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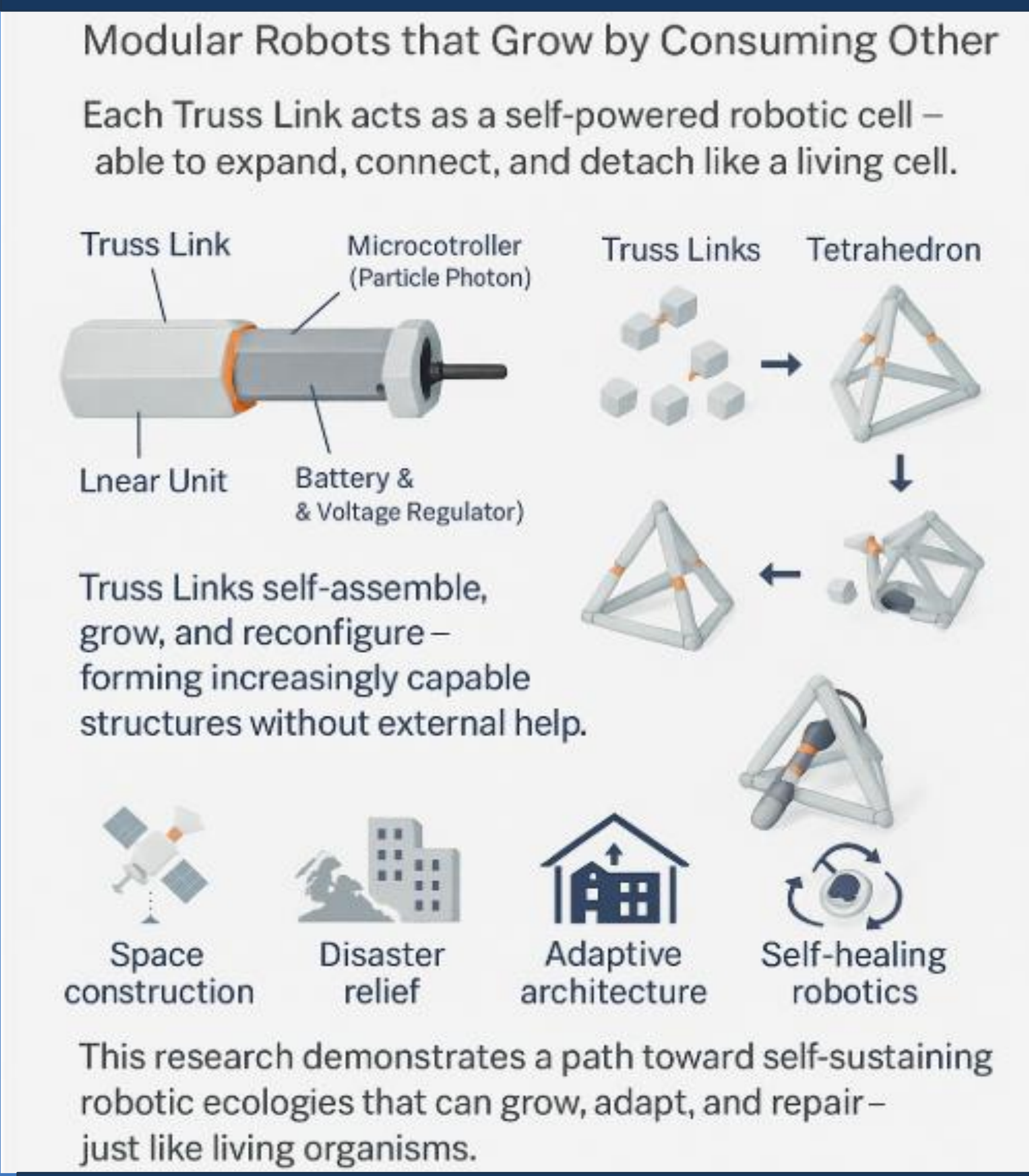
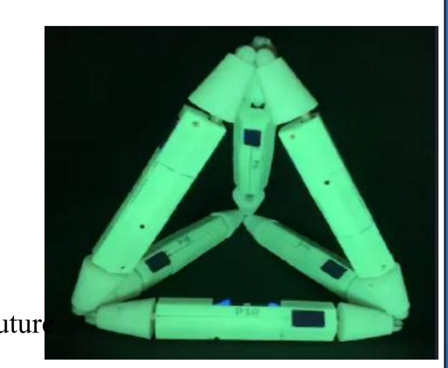
Visual abstract



Introduction

Biological lifeforms can heal, grow, adapt, and reproduce, which are abilities essential for sustained survival and development. In contrast, robots today are primarily monolithic machines with limited ability to self-repair, physically develop, or incorporate material from their environments. While robot minds rapidly evolve new behaviors through artificial intelligence, their bodies remain closed systems, unable to systematically integrate material to grow or heal. We argue that open-ended physical adaptation is only possible when robots are designed using a small repertoire of simple modules.

This allows machines to mechanically adapt by consuming parts from other machines or their surroundings and shed broken components. We demonstrate this principle on a truss modular robot platform. We show how robots can grow bigger, faster, and more capable by consuming materials from their environment and other robots.



We suggest that machine metabolic processes like those demonstrated here will be an essential part of any sustained future robot ecology.

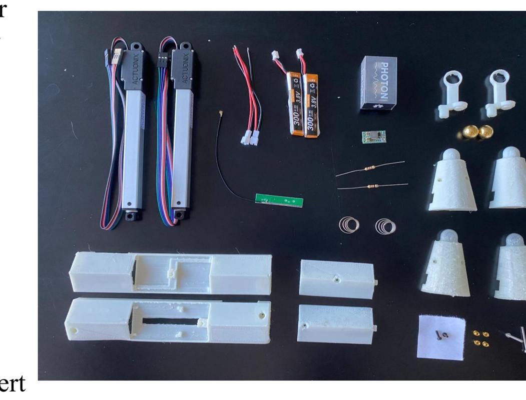
Problem Framing

The construction, deployment, and maintenance of spacecraft, satellites, and space stations are among the most expensive and challenging engineering tasks faced by humanity. Every component must be precisely designed, tested, and launched from Earth, which costs millions to billions of dollars per mission. Even minor malfunctions in orbit often require sending replacement parts or entire missions from Earth, leading to enormous financial and environmental costs. Moreover, damaged or outdated satellites frequently become space debris, creating further hazards. Developing technologies that allow autonomous or semi-autonomous repair and reconfiguration directly in space would drastically reduce these challenges. If robots or modular systems could self-assemble, self-heal, or reconfigure while in orbit, spacecraft could be repaired, upgraded, or expanded without returning to Earth. This would make space exploration more sustainable, efficient, and accessible for future missions, paving the way for adaptive architectures, robotic maintenance systems, and long-term space transportation networks.

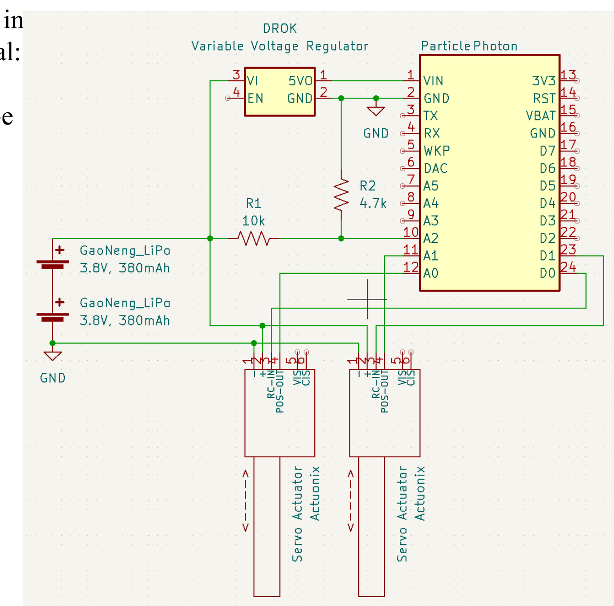
Engineering Methodology

1. Build Preparation

Partlist
Truss Link Body:
3D printed Body-Shell (Top & Bottom) and 2 x Cover
2 x Actuonix L-12I
Particle Photon
2.4GHz Mini Flexible WiFi Antenna with uFL Connector - 100mm
Drok Voltage Regulator
4.7 kOhm Resistor
10 kOhm Resistor

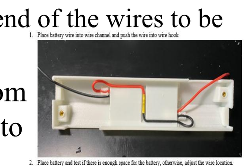


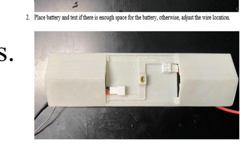
2 x JST-PH 2.0 Female harness
2 M2x20 Stainless Steel flat head screws
2 M2x8 Carbon steel flat head screws
4 x M2 heat set insert
Truss Link Connector:
2 x 3D printed Connector-Shell (Top & Bottom) and Magnet Holder
Confined-Space Conical Compression Spring 0.75" L, 0.6" x 0.375" OD
Neodymium magnet sphere 1/2" diameter
2 M2x8 Carbon steel flat head screws
2 x M2 heat set in
Support Material:
Electrical tape
Heat Shrink tube
AWG 26 Wires



2. Circuit Preparation

Actuators:
Cut green and blue wires flush with the actuator housing and save them for future use.
Separate the remaining 4 wires (black, red, white, purple).
Cut the red and black wires in half for future use.
Battery Harness:
Cut the red wire from one JST-PH 2.0 Female harness and the black wire of the other JST-PH 2.0 Female harness to 5cm in length.
Put heat shrink tubing around one end of the wires to be soldered.





Solder the shortened red wire from one JST-PH 2.0 Female harness to the shortened black wire of the other JST-PH 2.0 Female harness.
Heat the tubing so it conforms to the wires.

Voltage Divider:
Cut green wire as 100mm, red wire as 100mm and black 50mm (tolerance: ±5mm).
Solder the resistors and wires as per the circuit diagram (red wire to 10 kOhm, black wire to 4.7 kOhm and green in the middle).
Arrange the wires such that the green and black wires are on one side and the red wire is on the other.
Clip all excess wire and sharp corners to prevent puncture.
Pull heat shrink tubing over soldered resistors.
Heat the tubing so it conforms to the wires and resistors.
Voltage Regulator:
Red Wire 45mm, Black wire 110mm and Blue wire 135mm (tolerance: ±5mm).
Solder the blue wire to the VO+ port.
Solder the black wire to the GND port.
Solder the red wire to the IN+ port.
Connect the JST-PH harness to the regulator as per polarity.
Use multimeter to calibrate the output voltage to 5V.
Insulate with heat shrink tubing.
Particle Photon:
Solder black wire (100mm) on the GND port.

3. Assembly

Heat Set Insert into shell:
Increase soldering gun temperature to 300°C.
Insert heat insert into the body shell using heat gun.
Place battery wire into body shell:
Place battery wire into wire channel and adjust for fit.
Actuator into shell:
Apply electrical tape to cover the actuator gap.
Pull red and black battery wire to end of shell.
Cut servo wires as per table.
Place wires properly and secure voltage regulator and resistors with tape.
Solder connections as per the circuit diagram.
Place bushings and close the shell ensuring no interference.

Photon Placement: Solder wires to Photon as per diagram. Connect WiFi

Antenna to Photon and push inside shell.
Body Finishing:Secure the body shell with M2x20 screws.Place and test battery connection. Secure inspection window with M2x8 screws.

4. Connector Assembly

Magnet Support Bar Assembly:
Sand magnet bar faces.
Heat and snap magnet into holder.
Connector Shell Finishing:
Insert heat insert using soldering iron
Connector Assembly:
Extend servo 1–2 inches.

Screw magnet holder and center with body.
Apply hot glue between thread and actuator shaft.
Lubricate connector and magnet with graphite.
Place spring and screw connector together.

5. Firmware Installation

Server Software:
Clone *TrussLinkServer* repository and install dependencies.
Firmware Setup:
Clone *TrussLinkFirmware* repository.
Configure SERVER_IP and register links.
Flash firmware using Particle CLI.

Analysis and Results

Analysis

Robot metabolism enables modular robotic systems to replicate and self-assemble by physically consuming other robots and reusing their materials and energy. The process was analyzed through multiple growth experiments using truss link modules. Each link consists of a pair of linear actuators, a controller, and a battery enclosed within a 3D-printed shell. The metabolic process was studied by observing how links detach, transport, and integrate into growing structures. The assembly sequence showed the transformation from single truss units into higher-order configurations such as triangles, diamonds, and tetrahedrons, demonstrating structural scalability. Energy flow was monitored through the voltage feedback of the actuators and regulator components during operation, verifying that the modules could sustain growth through energy redistribution. The structural evolution and link formation were evaluated under different actuation and control conditions to determine performance stability during metabolic growth.

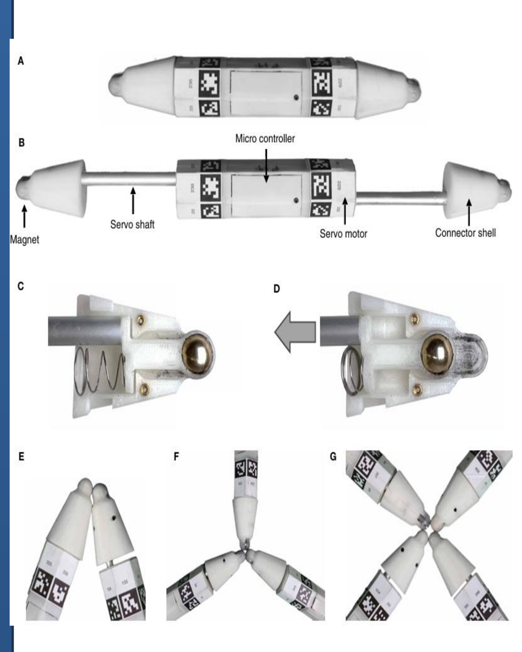


Figure 2. Overview of Truss Link structure and internal component layout. Each link is composed of two linear actuators, a Particle Photon microcontroller, a 2.4GHz antenna, and a voltage regulation circuit.

Figure 3. Stepwise assembly of truss links into progressively larger structures. The process begins with single links joining into triangular units and expands into diamonds, tetrahedrons, and complex geometric configurations demonstrating modular scalability.

Results

Experimental trials confirmed that the robotic metabolism framework allows for autonomous growth and repair. The truss robots successfully disassembled donor links and reassembled them into new configurations, demonstrating self-replication in a controlled environment. The results included quantitative measures of assembly speed, connection stability, and replication efficiency.

The system's feedback sensors provided real-time monitoring of voltage, actuator position, and link alignment, ensuring accurate reconfiguration. The structural performance was maintained across repeated assembly and disassembly cycles, confirming the durability of the mechanical and electronic systems. These findings validate the possibility of modular robots with metabolic-like properties capable of maintaining and regenerating structures without human intervention. Additional testing verified stable wireless communication among multiple truss links during synchronized actuation, allowing coordinated metabolic growth and material transfer between robots.

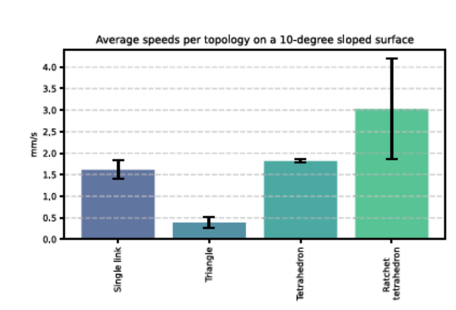


Figure 4. Experimental demonstration of robot metabolism showing donor link disassembly and integration into the growing truss.

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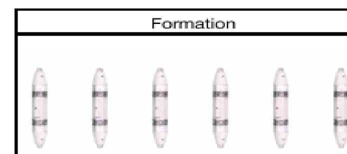
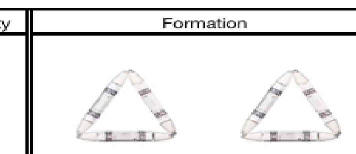
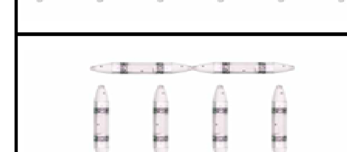
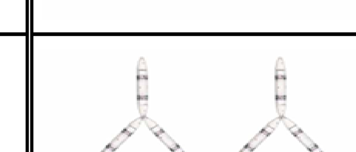
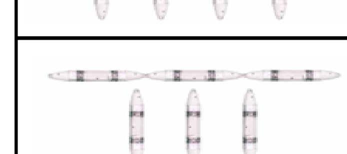
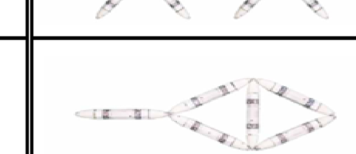
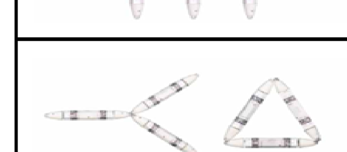
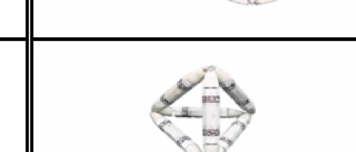
	100%		8.4%
	98.6%		64.35%
	97.6%		44.3%
	9.2%		0%

Figure 5. Growth rate and replication efficiency plotted over multiple metabolic cycles demonstrating consistent autonomous assembly.

Future work

Looking forward, this project lays the foundation for a transformative approach to space construction, maintenance, and transportation through the use of modular, self-replicating robotic systems. Currently, repairing satellites, spacecraft, and orbital infrastructure requires complex missions that cost millions of dollars and rely heavily on human intervention or Earth-based control. In contrast, future developments of this robotic metabolism system could allow for fully autonomous repair, reconstruction, and adaptation in the harsh environment of space. By enabling robots to reuse materials, transfer energy, and reorganize themselves, spacecraft maintenance could become an in-situ, continuous process rather than a scheduled, high-cost operation.

In orbit, these modular robots could repair or upgrade satellites and space stations without requiring return missions to Earth. If a component malfunctions, other modules could detach, replicate, or reconstruct the damaged part directly in space, drastically extending mission lifetimes. On the Moon and Mars, this system could serve as the foundation for self-building and self-healing infrastructure, where swarms of robotic modules assemble into protective shelters, research bases, or energy systems that automatically adapt to environmental changes such as dust storms, temperature shifts, or radiation exposure.

Additionally, robotic metabolism could revolutionize space transportation. Instead of designing one rigid spacecraft for all conditions, future vehicles could dynamically reconfigure their structure mid-mission, adjusting for thrust, weight, or atmospheric entry. This would allow more efficient launches, safer re-entries, and reusable modular fleets that evolve based on mission needs. On planetary surfaces, autonomous modular rovers could reorganize themselves to overcome challenging terrains—transforming from a wheeled system into a crawler, bridge, or climbing mechanism depending on the landscape.

Beyond space exploration, the same metabolic principles could be adapted for disaster relief and adaptive architecture on Earth, where robots could self-assemble to repair damaged bridges, reconnect power lines, or create temporary shelters in extreme environments. This convergence of robotic metabolism, artificial intelligence, and material science points toward a future where machines will not only function independently but also grow, heal, and evolve like living organisms—marking a new era of sustainable, intelligent engineering for both Earth and beyond.

conclusion

This project demonstrates a breakthrough approach to robotic design through the concept of robot metabolism, where modular robots can autonomously assemble, repair, and replicate using shared energy and materials. By combining principles of adaptability, sustainability, and decentralized control, this system represents a major step toward self-maintaining robotic networks. Its applications extend beyond Earth—enabling autonomous construction, repair, and transportation in space environments, from satellites and space stations to future missions on Mars and other planets. Ultimately, this innovation bridges biology and engineering, paving the way for a new generation of self-evolving robotic ecosystems that can support humanity's expansion beyond Earth.

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