Project Notes:

Project Title: Self-Assembling Modular Robots Enabled by an Articulated Multi-Axis Connector
Name: Xu, Chris

Note Well: There are NO SHORT-cuts to reading journal articles and taking notes from them. Comprehension is paramount. You will most likely need to read it several times, so set aside enough time in your schedule.

Contents:

Knowledge Gaps:

This list provides a brief overview of the major knowledge gaps for this project, how they were resolved and where to find the information.

Knowledge Gap	Resolved By	Information is located	Date resolved
Previous studies	Research on WPI library database	Article 5 summary	9/14/25
Origami Structure	Research on Google Scholar and communication with WPI soft robotics lab	Articles 6, 7, and Logbook	10/2/2025
3D Vision Sensing	Research on Google Scholar	Articles 17 & 18	11/11/2025
Connection Mechanism	Research & Patent Search	Articles 12, 13, 16, 20, Patent 1 & 2	12/13/2025

Literature Search Parameters:

These searches were performed between (Start Date of reading) and XX/XX/2019.
List of keywords and databases used during this project.

Database/search engine	Keywords	Summary of search
WPI Library	Soft Robotics and Swarm Robotics	Found article 5
Google Scholar	Origami in robotics	Found article 7
Google Scholar	Cagdas Onal	Found articles published by WPI Soft Robotics Lab including article 6

Tags:

Tag Name	
Mechanical Engineering	Bio-inspired
Soft robotics	Swarm robotics
Modular robotics	Origami
Pneumatic systems	Electrical and electronic engineering

Article #0 Notes: Title

Article notes should be on separate sheets

KEEP THIS BLANK AND USE AS A TEMPLATE

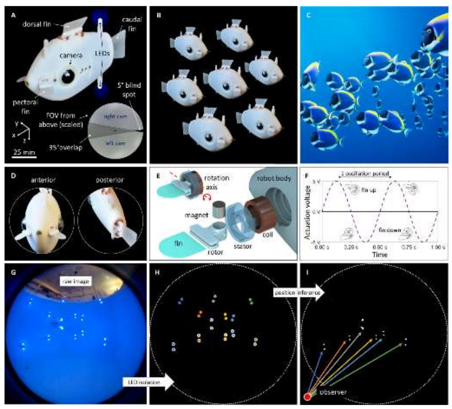
Source Title	
Source citation (APA Format)	
Original URL	
Source type	
Keywords	
#Tags	
Summary of key points + notes (include methodology)	
Research Question/Problem/ Need	
Important Figures	
VOCAB: (w/definition)	
Cited references to follow up on	
Follow up Questions	

Article #1 Notes: Implicit coordination for 3D underwater collective behaviors in a fish-inspired robot swarm

Source Title	Implicit coordination for 3D underwater collective behaviors in a fish-inspired robot swarm
Source citation (APA Format)	Berlinger, F., Gauci, M., & Nagpal, R. (2021). Implicit coordination for 3D underwater collective behaviors in a fish-inspired robot swarm. *Science Robotics.* https://www.science.org/doi/10.1126/scirobotics.abd8668
Original URL	https://www.science.org/doi/10.1126/scirobotics.abd8668
Source type	Research Article
Keywords	Swarm Robotics
#Tags	Swarm robotics
Summary of key points + notes (include methodology)	• Swarm robotics control has been used for robots on the ground and in the air, so the scientists in the study tried to make it work as well in the water • Proof of concept trying to prove the feasibility of autonomous underwater swarm technology taking part in the behaviors of social animals • To demonstrate the concept, scientists deployed fish robots, Bluebots, they designed, in a freshwater tank of size 1.78 m by 1.78 m by 1.17 m. • The scientists designed the Bluebot, a 235 cm^3 robot, roughly the size of a small schooling fish, modeled off two schooling fish species surgeonfish and damselfish • It can swim in 3 dimensions underwater using four independently controllable fins. Each Bluebot could reach speeds traveling forward at 150 mm/s, diving at 75 mm/s, and turn at radii of 65 mm • The Bluebot has two panoramic cameras for 3D perception and two LEDs acting as visual beacons. • For neighbor recognition, the cameras acted as sensors to detect its neighbors' distance and bearing. • Specifically, each LED light blinks regularly, allowing neighboring Bluebots to detect each other with cameras in order to make choices about its next move • Allows the Bluebots to coordinate movement without direct communication. Between processing of neighborhood images, the Bluebot can travel approximately 0.6 body lengths.

<table>
<tr><td></td><td>

The Bluebots could aggregate or disperse using a Lennard-Jones potential-inspired algorithm
The Bluebots could behave in a milling pattern–a phenomenon when fish can follow a circular motion around a central point–using a simple turning rule
A search and rescue function was also created which is a combination of aggregation and dispersion: first, the Bluebots had to find a red LED light in the tank, so the Bluebots first spread out in the tank; when of the bots found the light source, it would send out a special LED signal; as other Bluebots detected the signal, they would aggregate around that Bluebot that released it.

</td></tr>
<tr><td>Research Question/Problem/ Need</td><td>Demonstration of 3D coordination of underwater robots which is a new feature for robots that are used underwater</td></tr>
<tr><td>Important Figures</td><td>


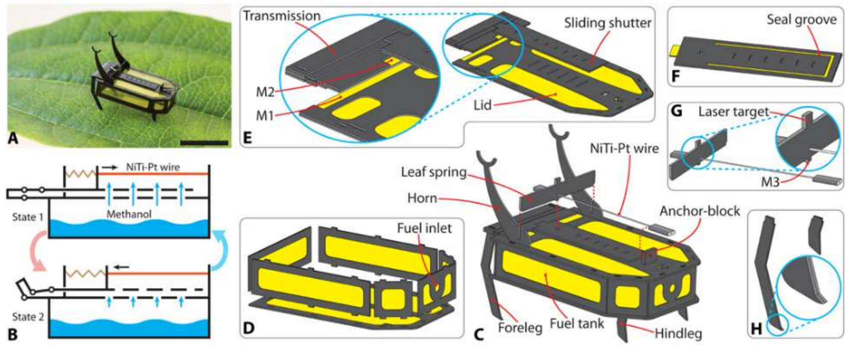
The figure is important because it highlights the key mechanical features of the Bluebot including its fins and swimming design. It also shows the raw data the robots take in when they are swimming.</td></tr>
<tr><td>VOCAB: (w/definition)</td><td>Implicit Coordination- team members working towards a shared goal by anticipating and dynamically adjusting their behaviors to each other's actions and needs without direct communication or explicit planning
Milling- Fish movement pattern where they follow a circular motion around a central point</td></tr>
<tr><td>Cited references to follow up on</td><td>Couzin, I. D., Krause, J., Franks, N. R., & Levin, S. A. (2005). Effective leadership and decision-making in animal groups on the move. Nature, 433(7025), 513–516. https://doi.org/10.1038/nature03236

Rubenstein, M., Cornejo, A., & Nagpal, R. (2014). Programmable self-assembly in a thousand-robot swarm. Science, 345(6198), 795–799. https://doi.org/10.1126/science.1254295</td></tr>
<tr><td>Follow up Questions</td><td>How scalable is the swarm method applied in this article? Is there a max number of Bluebots?
What are the real-world applications?</td></tr>
</table>

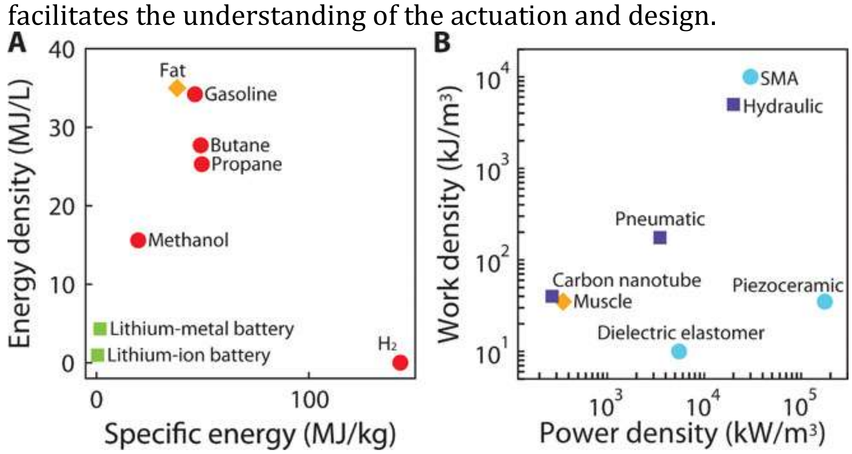
Article #2 Notes: An 88-milligram insect-scale autonomous crawling robot driven by a catalytic artificial muscle

Source Title	An 88-milligram insect-scale autonomous crawling robot driven by a catalytic artificial muscle
Source citation (APA Format)	Yang, X., Chang, L., & Perez-Arancibia, N. O. (2020). An 88-milligram insect-scale autonomous crawling robot driven by a catalytic artificial muscle. *Science Robotics*. https://www.science.org/doi/10.1126/scirobotics.aba0015#core-R13-1
Original URL	https://www.science.org/doi/10.1126/scirobotics.aba0015#core-R13-1
Source type	Research Article
Keywords	Soft Robot
#Tags	Bio-inspired, Soft robotics
Summary of key points + notes (include methodology)	• Groundbreaking microrobot called RoBeetle • First autonomous insect-sized robot powered by artificial muscles • Weighing just 88 milligrams, the robot's motion is driven by bimorph actuators fueled by hydrogen peroxide fuel and platinum catalysts, which produces heat-induced bending, in order to mimic insect–muscle–like motion • Actuators will expand and contract as a result of a chemical reaction, moving the front legs of the robot and allowing it to move forward • This design allows the RoBeetle to crawl without external power or tethers, showcasing a unique form of chemically powered, untethered transportation • RoBeetle creates new possibilities for autonomous devices in confined or inaccessible environments. • Since I am interested in combining soft robotics with swarm control for my science fair project, I think the RoBeetle provides a very intriguing source of locomotion. It is a simple form of actuation that could be potentially useful in designing several simple robots that can be applied to swarm control.
Research Question/Problem/ Need	Show autonomous mobility at an insect size and demonstrate a new breakthrough in actuation

Important Figures



This figure demonstrates the mechanical process behind RoBeetle. It facilitates the understanding of the actuation and design.



This figure shows the difference between the materials that they could have chosen from to optimize the ability of the robot which helps the audience get a better grasp of why the specific materials were used.

VOCAB: (w/definition)

Superelasticity- ability of a material, like a shape memory alloy, to undergo significant, reversible deformation under stress and then return to its original shape when the stress is removed

Nanotube- a tubular molecule composed of a large number of carbon atoms

Cited references to follow up on

Fuller, S. B. (2019). Four Wings: An Insect-Sized Aerial Robot With Steering Ability and Payload Capacity for Autonomy. *IEEE Robotics and Automation Letters*, *4*(2), 570–577. https://doi.org/10.1109/LRA.2019.2891086

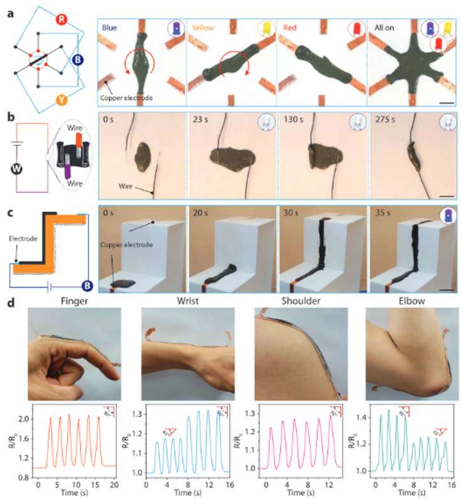
Follow up Questions

What are the potential real-world applications?

How can energy efficiency and durability be improved to allow even longer and more complex autonomous mvement?

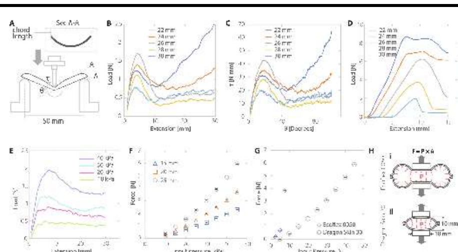
Article #3 Notes: Reconfigurable Magnetic Slime Robot: Deformation, Adaptability, and Multifunction

Source Title	Reconfigurable Magnetic Slime Robot: Deformation, Adaptability, and Multifunction
Source citation (APA Format)	Sun, M., Tian, C., Mao, L., Meng, X., Shen, X., Hao, B., Wang, X., Xie, H., & Zhang, L. (2022). Reconfigurable Magnetic Slime Robot: Deformation, Adaptability, and Multifunction. *Advanced Functional Materials—Wiley Online Library*. https://advanced.onlinelibrary.wiley.com/doi/10.1002/adfm.202112508
Original URL	https://advanced.onlinelibrary.wiley.com/doi/10.1002/adfm.202112508
Source type	Research Article
Keywords	Slime Robot, Magnetic Fields
#Tags	Soft robotics
Summary of key points + notes (include methodology)	• Slime robot that functions as both a liquid and solid • Magnetic slime which is made up of magnetic particles (NdFeB), borax, and polyvinyl alcohol (PVA) • Its composition allows external magnetic fields to control the robot's movement as the magnetic particles react and shift in response to the field's forces • By alternating the magnetic field's intensity, direction, and orientation, the magnetic slime robot can perform several basic functions: object manipulation, reconfiguration, circuit repair, chemical detection, and navigation of small environments • The robot is able to grab objects by using a tentacle-like hand, allowing it to carry small payloads and mend electrical circuits (the magnetic particles are conductive) • Can also break into smaller parts and self-heal, which is a unique function that makes the robot able to adjust its size perfectly for navigating maze-like settings and arbitrary obstacles • One main application the researchers are looking to apply the slime robot in is for surgical procedures because the robot is safe to navigate the human body after it is injected with a special biocompatible coating • Robot is very interesting because it is viscoelastic and applicable in basically any environment • It is truly a special case of soft robotics as most of the articles I have come across are still solid robots • Additionally, the function of breaking apart and self-healing is something that stood out to me, and I want to somehow incorporate that into my STEM project.

Research Question/Problem/ Need	Show design and applications of magnetic slime robot with ability to complete tasks in confined or complex environments
Important Figures	 This figure demonstrates the specific capabilities of the magnetic slime robot. It demonstrates the exact action and the amount of time concisely.
VOCAB: (w/definition)	Rheology- the branch of physics that deals with the deformation and flow of matter, especially the non-Newtonian flow of liquids and the plastic flow from solids Magnetorheological- smart materials that significantly and reversibly change their rheological (flow and deformation) properties when a magnetic field is applied
Cited references to follow up on	Jiang, J., Yang, L., & Zhang, L. (2025). An Overview of Micro/Nanorobot Swarm Control: From Fundamental Understanding to Autonomy. *IEEE/ASME Transactions on Mechatronics*, *30(3)*, 2338–2354. https://doi.org/10.1109/TMECH.2024.3449393
Follow up Questions	What challenges exist for the slime robot in a smaller scale tethered environment like a robotic arm following the slime and applying a magnetic field? How large can the slime robot be at the maximum size? Minimum size?

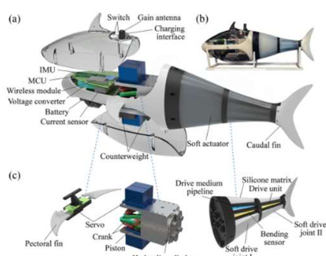
Article #4 Notes: Crawling, climbing, perching, and flying by FiBa soft robots

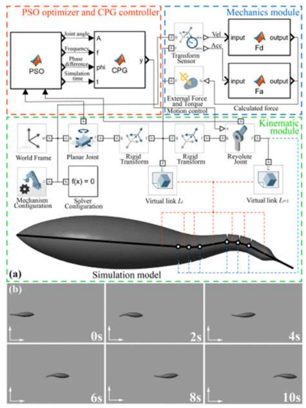
Article notes should be on separate sheets

Source Title	Crawling, climbing, perching, and flying by FiBa soft robots
Source citation (APA Format)	Ching, T., Lee, J. Z. W., Win, S. K. H., Win, L. S. T., Sufiyan, D., Lim, C. P. X., Nagaraju, N., Toh, Y.-C., Foong, S., & Hashimoto, M. (2024). Crawling, Climbing, Perching, and Flying by FiBa Soft Robots. *Science Robotics*, *9*(92). https://www.science.org/doi/10.1126/scirobotics.adk4533
Original URL	https://www.science.org/doi/10.1126/scirobotics.adk4533
Source type	Research Article
Keywords	Soft robotics
#Tags	Soft robotics, Bio-inspired
Summary of key points + notes (include methodology)	• Designed an alternative soft actuator using Fiba modules which combine thin-film polymer sheets with 3D-printed silicone balloons • These actuators are innovative in design because they significantly reduce the weight of soft robots, making untethered operation systems applicable • Up until now, many soft robots use tethered locomotion which relies on external tethers such as wires or tubes to be connected to power the robot. • Untethered locomotion gives more freedom for the robot to move • To show the applicability of these actuators, there were four different types of bio-inspired locomotion created: turtle-inspired crawling, inchworm-inspired climbing, bat-inspired perching, and ladybug-inspired flying.
Research Question/Problem/ Need	Untethering soft robotics from electrical or pneumatic power and reducing soft robot weight
Important Figures	 This figure characterizes the properties of the structures and modular balloons. It helps provide a visual to see the limitations and ability of the FiBa material.

VOCAB: (w/definition)	Tethered Locomotion- class of mobile robots characterized by a cabled connection of the robot with an anchor point, or with another robot Untethered Locomotion- robot's ability to move independently, without being physically connected to a power source or controller via wires or tubes
Cited references to follow up on	Pfeil, S., Henke, M., Katzer, K., Zimmermann, M., & Gerlach, G. (2020). A Worm-Like Biomimetic Crawling Robot Based on Cylindrical Dielectric Elastomer Actuators. *Frontiers in robotics and AI*, *7*. https://doi.org/10.3389/frobt.2020.00009 Xie, R., Su, M., Zhang, Y., Li, M., Zhu, H., & Guan, Y. (2018). PISRob: A Pneumatic Soft Robot for Locomoting Like an Inchworm. *2018 IEEE International Conference on Robotics and Automation (ICRA)*, 3448–3453. https://doi.org/10.1109/ICRA.2018.8461189
Follow up Questions	What/Is there a maximum load for FiBa materials and robots? Does it compare well to the max loads of previous soft robots? Can these FiBa robots be used to complete tasks collectively as a swarm? Are there size limits for FiBa robots' sizes if untethered locomotion is used?

Article #5 Notes: Design, Modeling, and Optimization of Hydraulically Powered Double-Joint Soft Robotic Fish

Source Title	Design, Modeling, and Optimization of Hydraulically Powered Double-Joint Soft Robotic Fish
Source citation (APA Format)	Liu, S., Liu, C., Wei, G., Ren, L., & Ren, L. (2025). Design, Modeling, and Optimization of Hydraulically Powered Double-Joint Soft Robotic Fish. *IEEE Transactions on Robotics*, *41*, 1211–1223. https://doi.org/10.1109/TRO.2025.3526087
Original URL	https://ieeexplore-ieee-org.ezpv7-web-p-u01.wpi.edu/document/10824963
Source type	Journal Article
Keywords	Robots; Actuators; Fish; Soft Robotics; Sports; Pistons; Sensors; Servomotors; Deformation; Bending; Hydraulically powered; particle swarm optimization (PSO); robotic fish; soft actuator
#Tags	Soft robotics, Swarm robotics
Summary of key points + notes (include methodology)	• Researchers designed and created HyperTuna-a fish like robot powered by soft actuators. What makes HyperTuna a soft robot is the fact that it is double-jointed, allowing it to maneuver like a real fish. • They also developed a model to incorporate the soft actuators effects in a dynamic model • Central pattern generator and PID used to accuately control swimming posture • Particle swarm optimization to tune control all of the robots to maximize their collective performance • Maximum speed improved by 3.6% or 1.12 body lengths per second • Cost of Transport decreased by up to 13.9% • Operational applicability in turning, diving/floating, and swimming in open water
Research Question/Problem/ Need	How to design/control soft robotic fish based on bio-inspired models that can swim efficiently with high maneuverability using soft actuators and remote sensing?
Important Figures	

	This figure demonstrates the mechanical building of each HyperTuna Robot. It is essential to understand the double-jointed mechanism.  This figure is what the developed simulation platform produced for the robot's movement.
VOCAB: (w/definition)	FEM (Finite Element Method)- technique to predict how an object changes (deforms, vibrates, or responds) when in the presence of forces CPG (Central Pattern Generator)-Bio-inspired math model to produce pattern-like signals (used for tail oscillations) PID (Proportional-Integral-Derivative)-Feedback control to adjust input error to keep motion controlled PSO (Particle Swarm Optimization)-Computational algorithm that has particles explore space collaboratively.
Cited references to follow up on	Chen, G. Yang, X. Xu, Y. Lu, Y. & Hu, H. (2023) Neural network-based motion modeling and control of water-actuated soft robotic fish, *IOPscience, (32)*1. https://iopscience.iop.org/article/10.1088/1361-665X/aca456/meta?casa_token=zv8YYFk2e7kAAAAA:ze4rGf6zRy64XBsfYhP0nw_UxbOGhWxZMfHKitilim2oI7kBZ4E4oKmAIZ_V-xBXJhnOBHkOPB7t5HNakhCl_MjerA
Follow up Questions	How does the performance of HyperTuna vary in different locations such as rivers, oceans, lakes, etc.? How efficient is the hydraulic control compared to other forms of control applied to soft robots?

Article #6 Notes: Salamanderbot: A soft-rigid composite continuum mobile robot to traverse complex environments

Source Title	Salamanderbot: A soft-rigid composite continuum mobile robot to traverse complex environments
Source citation (APA Format)	Sun, Y., Jiang, Y., Yang, H., Walter, L.-C., Santoso, J., Skorina, E. H., & Onal, C. (2020). Salamanderbot: A soft-rigid composite continuum mobile robot to traverse complex environments. *2020 IEEE International Conference on Robotics and Automation (ICRA)*, 2953–2959. https://doi.org/10.1109/ICRA40945.2020.9196790
Original URL	https://ieeexplore.ieee.org/document/9196790
Source type	Conference Article
Keywords	Soft Robotics, Origami
#Tags	Modular robotics, Pneumatic systems, Soft robotics, Swarm robotics
Summary of key points + notes (include methodology)	• Salamanderbot is a soft robot inspired by the Yoshimura crease pattern which allows it to deform in various ways • Drives primarily using wheels • Gear locomotion and belt locomotion • Can adapt shape based on environment to pass through • Can climb up to 60 degree slope and best driving capabilities on rug or rubber • Wheels allow it to navigate environments such as slopes that previous soft robots had difficulties with
Research Question/Problem/ Need	Design, build and test soft robot that can navigate complex environments by soft deformation and rigid locomotion. Build bridge between adaptability, power, and agility.

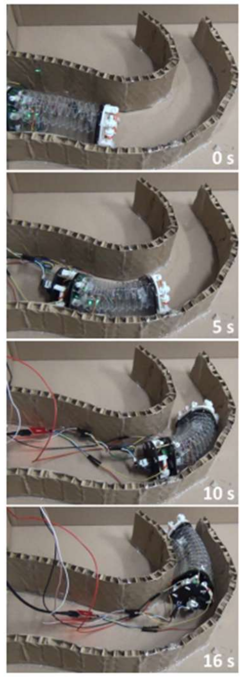
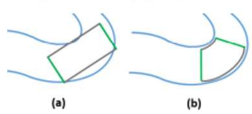
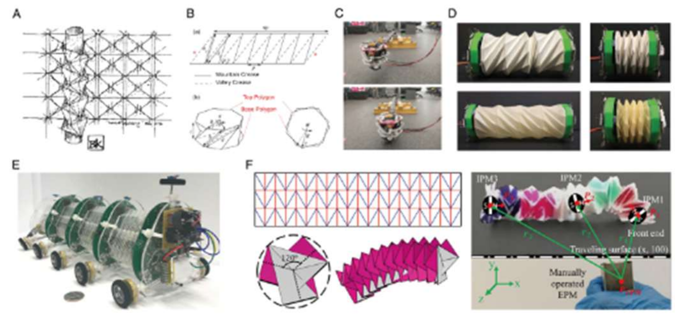
<table>
<tr><td>Important Figures</td><td>

Fig. 6. Salamanderbot going through a maze.


This figure is essential to understand how Salamanderbot can deform itself to navigate through a tight space.</td></tr>
<tr><td>VOCAB: (w/definition)</td><td>Transversal speed - speed of individual particles within a transverse wave as they oscillate up and down, perpendicular to the wave's direction of travel</td></tr>
<tr><td>Cited references to follow up on</td><td>Luo, M. Pan, Y. Skorina, E. Tao, W. Chen, F. Ozel, S. and Onal, C. (2015). Slithering towards autonomy: a self-contained soft robotic snake platform with integrated curvature sensing, Bioinspiration & Biomimetics, (10)5. https://iopscience.iop.org/article/10.1088/1748-3190/10/5/055001</td></tr>
<tr><td>Follow up Questions</td><td>If the robot became longer, how would it affect the ability to travel through complex environments?
How could many of these robots cooperate?</td></tr>
</table>

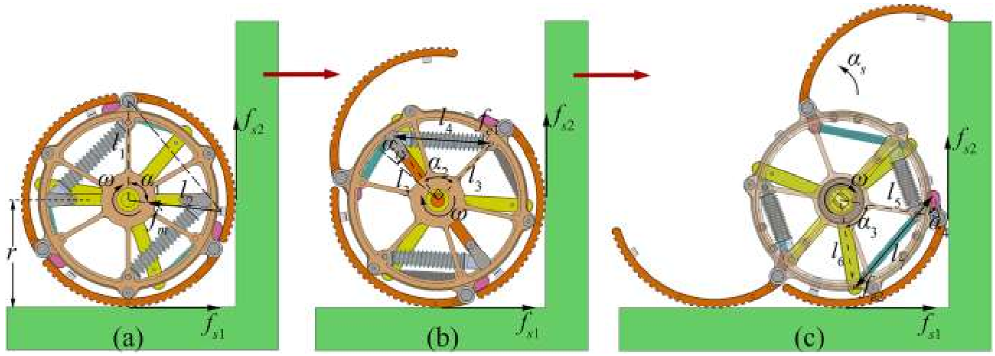
Article #7 Notes: Current Development on Origami/Kirigami-Inspired Structure of Creased Patterns toward Robotics

Source Title	Current Development on Origami/Kirigami-Inspired Structure of Creased Patterns toward Robotics
Source citation (APA Format)	Ai, C., Chen, Y., Xu, L., Li, H., Liu, C., Shang, F., Xia, Q., & Zhang, S. (2021). Current Development on Origami/Kirigami-Inspired Structure of Creased Patterns toward Robotics. *Advanced Engineering Materials*, *23*(10), 2100473. https://doi.org/10.1002/adem.202100473
Original URL	https://advanced.onlinelibrary.wiley.com/doi/10.1002/adem.202100473
Source type	Journal Article
Keywords	Origami Robotics
#Tags	Soft robotics, origami
Summary of key points + notes (include methodology)	• Analysis of different types of current folding (origami) and cut-folding (kirigami) techniques are currently used in robotics • Patterns provide a compact, light, and effective structures that can allow the robot to transform • Typical patterns include Miura-ori pattern, waterbomb pattern, Yoshimura crease, and Flasher structure • Identifies unique forms of applications for each type of folding or cut-folding pattern including robotic arms, worms, etc. • Material advances to improve durability and overall ability of origami/kirigami robots
Research Question/Problem/ Need	Bridge the gap between origami/kirigami concepts with practicable robots that can be controlled.

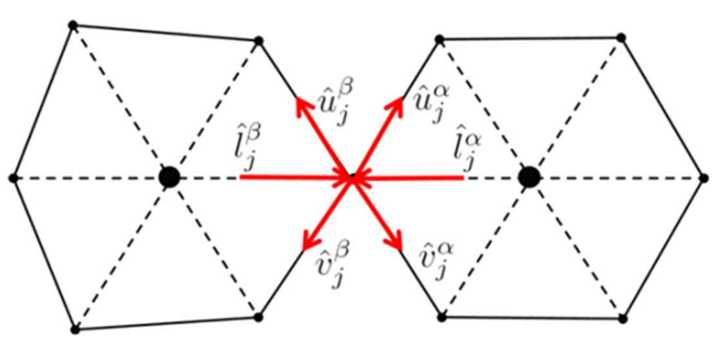
Important Figures	 Figure 4. Examples of telescopic origami cylinders: A) the sinusoidal fold lines (or the Yoshimura pattern) are similar to the kikko bamboo pattern.[96] B) The design of the generalized Kresling pattern (the creases marked with (*) are glued together to create a Kresling segment).[97] C) The hopping experiment of the origami-inspired Fore aft jumping robot from left to right, top to bottom.[136] D) Paper origami robot prototypes in the open position and closed position.[30] E) An origami snake robot based on one of the Yoshimura telescopic structures.[40] F) The triangular spring models and caterpillar-inspired biomimetic origami robot.[50] Subfigure (A) reproduced with permission.[96] Copyright 2002, Taylor & Francis Group, LLC. Subfigure (B) reproduced with permission.[97] Copyright 2019, ASME. Subfigure (C) reproduced with permission.[136] Copyright 2020, IEEE. Subfigure (D) reproduced with permission.[30] Copyright 2016, ASME. Subfigure (E) reproduced with permission.[40] Copyright 2018, IEEE. Subfigure (F) reproduced with permission.[50] Copyright 2020, ASME. This is an important figure for me specifically because this is the type of origami technique that I am considering when I am prototyping and creating my project.
VOCAB: (w/definition)	Corrugated-shaped into alternate ridges and grooves Morphological-relating to the form or structure of things
Cited references to follow up on	Yoo, S., Park, H., & Cha, Y. (2025). Design and Analysis of a Hybrid Actuator With Resilient Origami-Inspired Hinges, *IEEE Robotics and Automation Letters*, *10(3)*, 2128-2135. https://ieeexplore.ieee.org/document/10833851?utm_source=wiley&getft_integrator=wiley An, B., Miyashita, S., Ong, A., Tolley, M. T., Demaine, M. L., & Demaine, E. D. (2018). An End-to-End Approach to Self-Folding Origami Structures, *IEEE Transactions on Robotics*, *34(6)*, 1409-1424. https://ieeexplore.ieee.org/abstract/document/8558662?casa_token=iqYf9CPP1fEAAAAA:mA4_flgnLWqP5S0LdEgcllbz2ERuV6RsPz0ujta5udvvm7b8OTkpf25Yj4pVgLlyajXTQKA
Follow up Questions	Can different designs be combined so that different parts of the robot have different capabilities? How can strategies be used to extend the life-span of origami robots?

Article #8 Notes: Stability Analysis of a Wheel-Track-Leg Hybrid Mobile Robot

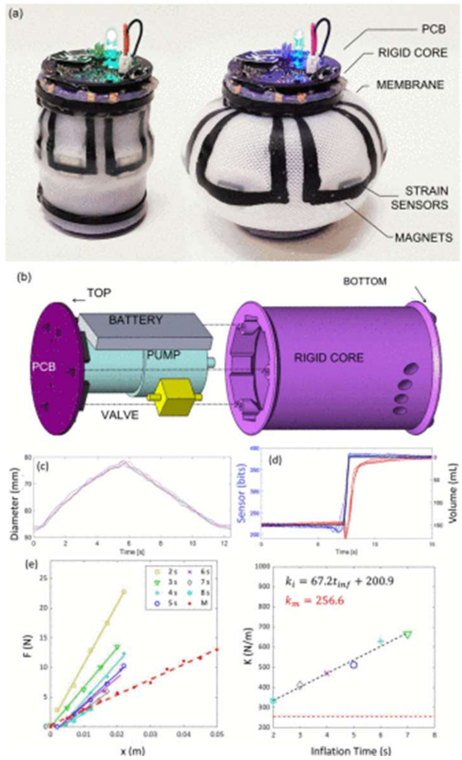
Source Title	A centipede-inspired robot with passive terrain adaptation: optimized design and performance analysis
Source citation (APA Format)	Zhang, T., Ding, C., Wang, D., Ma, T., Li, X., Li, Z., Zhang, J., & Zhu, X. (2025). A centipede-inspired robot with passive terrain adaptation: Optimized design and performance analysis. *Scientific Reports*, *15*. https://www.nature.com/articles/s41598-025-97457-7
Original URL	https://doi.org/10.1038/s41598-025-97457-7
Source type	Journal Article
Keywords	Mobile robot, Biomimicry, Transformer wheel, Flexible articulation, Optimized design, Obstacle crossing analysis
#Tags	Mechanical Engineering, Bio-inspired
Summary of key points + notes (include methodology)	• Centipede-inspired robot that can achieve stability using special wheels to leverage passive terrain adaptation • Includes multiple body segments and leg arrangements that naturally conform to uneven terrain • Compliant joints and mechanical structures that adjust to the terrain without sensors actuators for every leg • Passive deformation wheel design that has deployable swing legs to climb obstacles • Centipede robots can pass through steps and trenches • Work shows bio-inspired robots with passive mechanical design can improve terrain adaptability and reduce control complexity
Research Question/Problem/ Need	How can centipede-inspired morphology and passive mechanical design enhance terrain adaptability in multi-legged robots?

Important Figures	 The wheels by the researchers are very interesting because there are swing legs that can be deployed for the robot to climb. This figure demonstrates how the components of the wheel work together and physical analysis to make this possible.
VOCAB: (w/definition)	Passive mechanical design-physical structure and materials naturally adapt to the environment Localization-limiting something to a local place
Cited references to follow up on	Zhu, Y., Fei, Y. & Xu, H. (2018). Stability Analysis of a Wheel-Track-Leg Hybrid Mobile Robot, *Journal of Intelligent Robotic Swarms*, *91(3)*, 515–528. https://doi.org/10.1007/s10846-017-0724-1
Follow up Questions	How can origami techniques be used to make this a soft robot? Can these individual parts be separated and controlled on their own?

Article #9 Notes: Strain-Based Consensus in Soft, Inflatable Robots

Source Title	Strain-Based Consensus in Soft, Inflatable Robots
Source citation (APA Format)	Nilles, A., Ceron, S., Napp, N., & Petersen, K. (2022). Strain-Based Consensus in Soft, Inflatable Robots. *2022 IEEE 5th International Conference on Soft Robotics (RoboSoft)*, 789–794. https://doi.org/10.1109/RoboSoft54090.2022.9762180
Original URL	https://ieeexplore.ieee.org/document/9762180
Source type	Conference Article
Keywords	Robot kinematics; Computational modeling; Pneumatic systems; Soft robotics; Sensor fusion; Robot sensing systems; Sensors
#Tags	
Summary of key points + notes (include methodology)	• Soft pneumatic robot (Foambot) that can inflate and deflate to move • Proprioceptive strain sensors used to measure the deformation of each robot module • Strain sensor data acts as a proxy for robot inter-communication • Magnetic coupling for robots to physically couple • String based model that predicts steady-state configuration in 2D efficiently • Strain sensors are representation of robot perimeter/geometry • Simulation verified with sequence of 7 robots achieving motion • Consensus algorithm that takes in sensor feedback & demonstrate sensor feedback laws that rely only on measurements of relative tilt or force between robotic modules, and give proofs of convergence • Strain consensus to coordinate robots
Research Question/Problem/ Need	Validate that a group of soft inflatable robots can achieve coordinated movement and control through strain-based consensus without inter-robot communication.
Important Figures	

<table>
<tr>
<td></td>
<td>This figure explains how the simulation works to apply strain feedback from sensors into the consensus algorithm by identifying the forces.

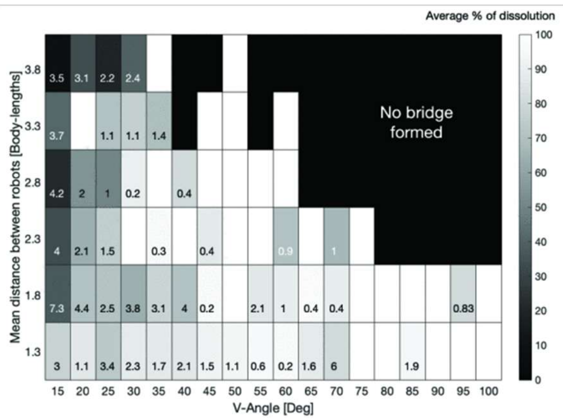


This figure depicts what parts are used in each robot and the designs for each one. It is very helpful to use the figure to actually understand what the robots are doing.</td>
</tr>
<tr>
<td>VOCAB: (w/definition)</td>
<td>Proprioceptive - the sense that allows your body to know its position and movements in space
Proxy - a figure that can be used to represent the value of something in a calculation
Coupling - a device for connecting parts of machinery</td>
</tr>
<tr>
<td>Cited references to follow up on</td>
<td>Malley, M., Haghighat, B., Houel, L., & Nagpal, R. (2020) Eciton robotica: Design and Algorithms for an Adaptive Self-Assembling Soft Robot Collective. 2020 IEEE International Conference on Robotics and Automation (ICRA), 4565-4571. https://ieeexplore.ieee.org/document/9196565</td>
</tr>
<tr>
<td>Follow up Questions</td>
<td>What are the mobility limitations of each Foambot?
Does the swarm control allow the Foambots to perform any specific functions?</td>
</tr>
</table>

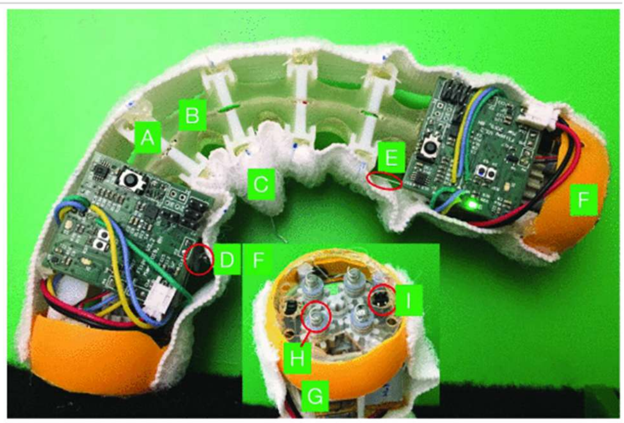
Article #10 Notes: Eciton robotica: Design and Algorithms for an Adaptive Self-Assembling Soft Robot Collective

Source Title	Eciton robotica: Design and Algorithms for an Adaptive Self-Assembling Soft Robot Collective
Source citation (APA Format)	Malley, M., Haghighat, B., Houel, L., & Nagpal, R. (2020). Eciton robotica: Design and Algorithms for an Adaptive Self-Assembling Soft Robot Collective. *2020 IEEE International Conference on Robotics and Automation (ICRA)*, 4565–4571. https://doi.org/10.1109/ICRA40945.2020.9196565
Original URL	https://ieeexplore.ieee.org/document/9196565
Source type	Journal Article
Keywords	Robot sensing systems; Bridges; Grippers; Vibrations; Self-assembly; Hardware
#Tags	Mechanical Engineering, Modular robotics, Soft robotics, Swarm robotics
Summary of key points + notes (include methodology)	• Flexible climbing robots that can climb over any velcro surface using flipping motion and grippers • Robots can act as a bridge by sensing when other robots are climbing over them • Inspired by ant-like adaptable structures • Modeled robot system using Box2D simulator • Flexible robots that can attach onto any part of each other • Individual robots are autonomous, untethered, and able to climb over complex terrain • Soft velcro body and corkscrew grippers used for attaching • Cables and DC motors withing the robot to control flipping • Max outer curvature 220 degrees & traverse angles of up to 230 degrees • Simulations model the robot’s characteristics and abilities • low traffic and easy terrains→no bridges form; high traffic and narrow terrains→ bridges form & tend to stabilize traffic
Research Question/Problem/ Need	How can soft robots physically attach and detach without centralized control and safely adapt to self-assemble?

Important Figures



This graph is essential because it analyzes when certain bridge building cases are necessary for robots when they are moving.



This figure explains the specific hardware components necessary to make the robot function. There are letter labels that correspond to ones in the caption defining each component.

VOCAB: (w/definition)

Traverse-travel across or through
Convex-having an outline or surface curved like the exterior of a circle or sphere

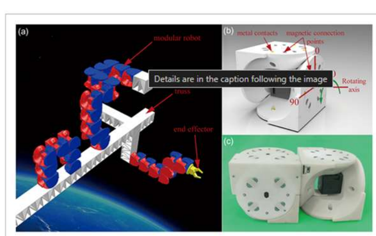
Cited references to follow up on

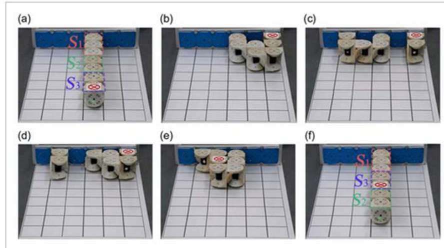
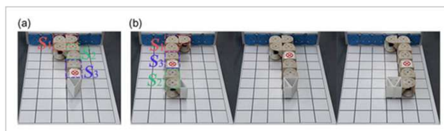
Swissler, P., & Rubenstein, M. (2018). FireAnt: A Modular Robot with Full-Body Continuous Docks. *2018 IEEE International Conference on Robotics and Automation (ICRA)*, 6812–6817. https://doi.org/10.1109/ICRA.2018.8463146

Follow up Questions

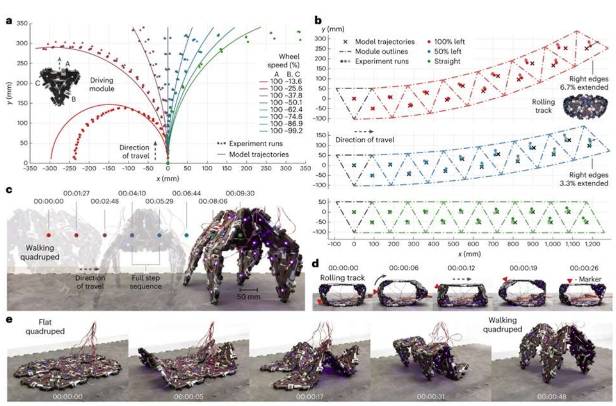
Are there any limitations to velcro?
How long can each robot last?

Article #11 Notes: A Fault-Tolerant Approach for Modular Robots through Self-Reconfiguration

Source Title	A Fault-Tolerant Approach for Modular Robots through Self-Reconfiguration
Source citation (APA Format)	Qi, J., Lai, M., Yang, Z., Zhao, N., Han, K., Sui, X., Zhao, J., & Zhu, Y. (2024). A Fault-Tolerant Approach for Modular Robots through Self-Reconfiguration. *Advanced Intelligent Systems*, *6*(7), 2300774. https://doi.org/10.1002/aisy.202300774
Original URL	https://advanced-onlinelibrary-wiley-com.ezpv7-web-p-u01.wpi.edu/doi/full/10.1002/aisy.202300774
Source type	Journal Article
Keywords	Modular Robots, Space Robots
#Tags	fault tolerance, modular robots, path planning, self-reconfiguration
Summary of key points + notes (include methodology)	• Modular chain of cubic modules connected by joints • Robot is divided into three substructures that can be disconnected • Particle swarm optimization to maximize manipulation capacity • Rapidly Exploring Random Tree algorithm plans collision-free paths • Robot rearranges to shift from positions to continue function • Dexterity of robot was measured • Effectiveness of each configuration was measured • Locked joint positions severely reduced • Relocate faulty module to better locations • Planning and docking can be executed
Research Question/Problem/ Need	Design a modular robot that can reconfigure itself and depend on healthy modules to mitigate the effects of locked joints.
Important Figures	 **Figure 1** Open in figure viewer PowerPoint a) Application scenarios of modular robots in space missions: modular robots walk on trusses, assemble trusses, and grab operation. b) The structure of the basic module. c) Two physical modules. This figure clarified what the purpose was and what they looked like.

	 **Figure 16** Open in figure viewer | PowerPoint The different phases of a fault-tolerant reconfiguration experiment (0-degree failure). The blue base is the magnetic connection surface. The module marked with a red mark is a faulty module. The substructures of the robot are $S_1 = [1, 2, 3]$, $S_2 = [4, 5]$, and $S_3 = [6, 7]$.  **Figure 17** Open in figure viewer | PowerPoint a) The robot can only reach the target position in one posture and cannot complete the assembly task. b) The robot can reach the target position in three postures and complete the assembly task after reconfiguration. This figure demonstrates the use of the fault-tolerant reconfiguration algorithm. It explains the usefulness of the fault-tolerant reconfiguration in these robots.
VOCAB: (w/definition)	Dexterity- skill in performing tasks
Cited references to follow up on	Zhao, N., Gao, L., Yang, Z., Qi, J., Han, K., Sui, X., Zhao, J., & Zhu, Y. (2023). Meta-Module Mutual Assistance: A Bioinspired Design for Self-Assembly of Modular Space Robot. *Advanced Intelligent Systems*, *5*(7), 2200450. https://doi.org/10.1002/aisy.202200450
Follow up Questions	How well does the robot system work in real-world settings?

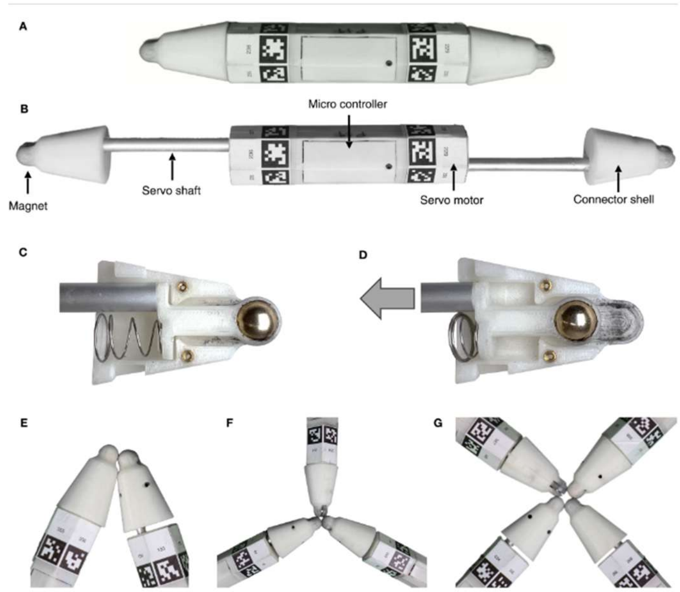
Article #12 Notes: Morphological flexibility in robotic systems through physical polygon meshing

Source Title	Morphological flexibility in robotic systems through physical polygon meshing
Source citation (APA Format)	Belke, C. H., Holdcroft, K., Sigrist, A., & Paik, J. (2023). Morphological flexibility in robotic systems through physical polygon meshing. *Nature Machine Intelligence*, *5*(6), 669–675. https://doi.org/10.1038/s42256-023-00676-8
Original URL	https://www.nature.com/articles/s42256-023-00676-8
Source type	Journal Article
Keywords	Modular Robotics, Self-Assembly
#Tags	Electrical and electronic engineering, Mechanical engineering
Summary of key points + notes (include methodology)	• Self-contained triangular polygon modules with adjustable edge lengths and connections • Triangles can join to form loops/meshes • Mesh structure determines shape that the modules take • Tested in user interaction, locomotion, and manipulation tasks • Speed and maneuverability trade offs • Rolling and walking locomotion • Robot arm using inverse kinematics • Formation of multiple complex shapes
Research Question/Problem/ Need	Create a robot system that can adapt shape to suit different functions: locomotion, interaction, manipulation, etc.
Important Figures	 This figure is important because it demonstrates how the triangle robots can combine to engage in multiple forms of locomotion. It also describes the mechanics behind it.

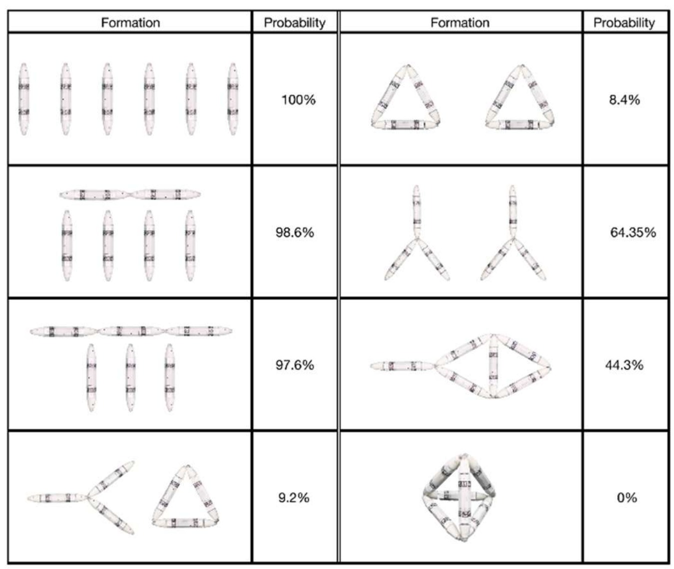
VOCAB: (w/definition)	Inverse kinematics-the process of calculating the necessary joint angles and positions for a robot's end effector (its end-point, like a hand or gripper) to reach a desired target position and orientation in space Euclidian distance positioning error-calculation errors or issues with software tools that use the Euclidean distance formula (the straight-line distance between two points in a space)
Cited references to follow up on	Garattoni, L., & Birattari, M. (2018). Autonomous task sequencing in a robot swarm. *Science Robotics*, *3*(20). https://doi.org/10.1126/scirobotics.aat0430
Follow up Questions	How can these robots be applied in the real world and how well do they do outside of laboratory environments?

Article #13 Notes: Robot metabolism: Toward machines that can grow by consuming other machines

Source Title	Robot metabolism: Toward machines that can grow by consuming other machines
Source citation (APA Format)	Wyder, P. M., Bakhda, R., Zhao, M., Booth, Q. A., Modi, M. E., Song, A., Kang, S., Wu, J., Patel, P., Kasumi, R. T., Yi, D., Garg, N. N., Jhunjhunwala, P., Bhutoria, S., Tong, E. H., Hu, Y., Goldfeder, J., Mustel, O., Kim, D., & Lipson, H. (2025). Robot metabolism: Toward machines that can grow by consuming other machines. *Science Advances*, *11*(29). https://doi.org/10.1126/sciadv.adu6897
Original URL	https://www.science.org/doi/10.1126/sciadv.adu6897
Source type	Journal Article
Keywords	Self-Assembly, Robot Systems
#Tags	Modular robotics
Summary of key points + notes (include methodology)	• Truss Link are simple robots that are shaped like bars and can expand and contract • They can work together to form more complicated 2D and 3D shapes • Truss Links can be used to build modular robots • A single Truss Link can only move in 1D and its mobility is enhanced when it combines with more • Overall, simulated speeds are greater than real-life speeds of Truss Links • Triangle shape showed some backsliding behavior • Truss Links can respond to broken connections and self-repair • Truss Links can dispose of broken segments and substitute them for working ones • Robots can self-assemble and reconfigure themselves into shapes such as triangles, ratchets, and tetrahedrons • Limitations include simplicity of Truss Links movement, cost of development
Research Question/Problem/ Need	Develop a robot system that can show robot metabolism, so robots are independent and grow, repair, and shift their bodies by consuming other robots or parts in their environment.

<table>
<tr><td>Important Figures</td><td>


This figure clearly depicts each Truss Link’s components and how multiple can interact with each other.



The figure shows the total number of configurations and the probability that are formed.
</td></tr>
<tr><td>VOCAB: (w/definition)</td><td>Prismatic-related to or having the form of a prism

Retrofit-add (a component or accessory) to something that did not have it when manufactured</td></tr>
<tr><td>Cited references to follow up on</td><td>Romanishin, J. W., Gilpin, K., Claici, S., & Rus, D. (2015). 3D M-Blocks: Self-reconfiguring robots capable of locomotion via pivoting in three dimensions. 2015 IEEE International Conference on Robotics and Automation (ICRA), 1925–1932. https://doi.org/10.1109/ICRA.2015.7139450</td></tr>
</table>

Follow up Questions	What are the major applications? What prevents harmful/selfish robotic behavior?

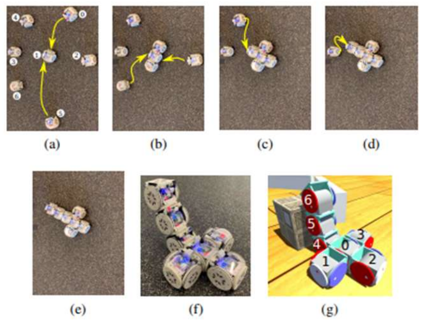
Article #14 Notes: Parallel Self-Assembly with SMORES-EP, a Modular Robot

Source Title	Parallel Self-Assembly with SMORES-EP, a Modular Robot
Source citation (APA Format)	Liu, C., Lin, Q., Kim, H., & Yim, M. (2023). SMORES-EP, a modular robot with parallel self-assembly. *Autonomous Robots*, *47*(2), 211–228. https://doi.org/10.1007/s10514-022-10078-1
Original URL	https://link-springer-com.ezpv7-web-p-u01.wpi.edu/article/10.1007/s10514-022-10078-1
Source type	Journal Article
Keywords	Cellular and modular robots, ep Distributed robot systems, Path planning for multiple mobile robots or agents, Motion control
#Tags	Soft robotics, Swarm robotics
Summary of key points + notes (include methodology)	• Cube shaped modular robots that can move independently and attach/detach with magnetic docking • Simultaneously assembly algorithm for robots into multiple target morphologies • Graphical model of robot topology configuration • Targets/final shapes are decided by algorithm for mission • Using a mathematical set containing each module and the docking positions needed, a minimum cost maximum matching algorithm calculates the “cost” related to distance, number of reorientations, and docking difficulty • Partitioned robots for multiple target configuration that can combine at the end • Robot docking affected by control, pose, and approach • Tasks such as mobile manipulator, holonomic vehicle, and rc car can be achieved
Research Question/Problem/ Need	Design a robot system that can combine into different forms in parallel, so modular robots can build multiple shapes simultaneously.

Important Figures

TABLE I
INITIAL LOCATIONS OF ALL MODULES IN TASK 1

Module	x (m)	y (m)	θ (rad)
Module 0	0.017	0.357	1.142
Module 1	0.0	0.0	0.0
Module 2	0.305	0.129	0.641
Module 3	-0.318	-0.132	0.454
Module 4	-0.318	0.158	0.823
Module 5	0.264	-0.448	-0.763
Module 6	-0.172	-0.380	-2.431



This figure shows one of the tests that the researchers did in which

VOCAB: (w/definition)

Kinematic topology - study of the arrangement and interconnection of links and joints in a mechanism

Tree topology - a hierarchical network structure where multiple star networks are connected via a bus backbone

Cited references to follow up on

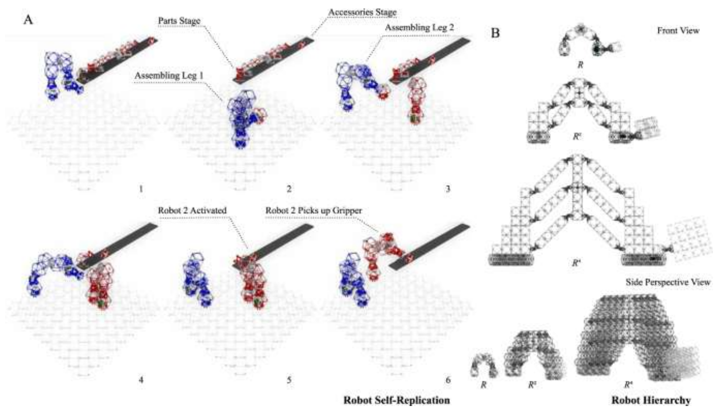
Rubenstein, M., Cornejo, A., & Nagpal, R. (2014). Programmable self-assembly in a thousand-robot swarm. Science, *345*(6198), 795–799. https://doi.org/10.1126/science.1254295

Follow up Questions

How well does this compare to similar self-assembling robots?

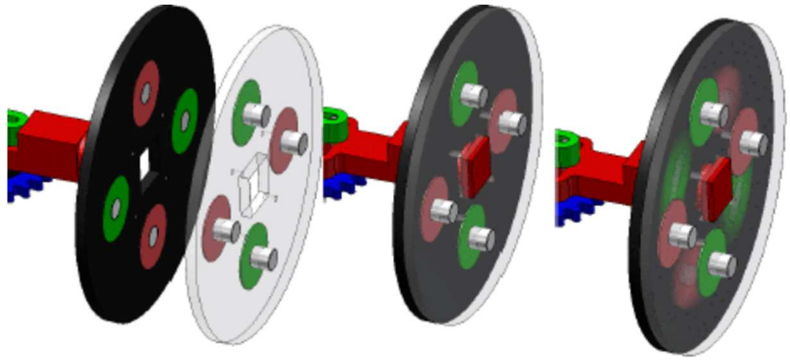
Article #15 Notes: Self-replicating hierarchical modular robotic swarms

Source Title	Self-replicating hierarchical modular robotic swarms
Source citation (APA Format)	Abdel-Rahman, A., Cameron, C., Jenett, B., Smith, M., & Gershenfeld, N. (2022). Self-replicating hierarchical modular robotic swarms. *Communications Engineering*, *1*(1), 35. https://doi.org/10.1038/s44172-022-00034-3
Original URL	https://www.nature.com/articles/s44172-022-00034-3
Source type	Journal Article
Keywords	Self-Assembly, Control System, Centralized Control
#Tags	Aerospace engineering, Computer science, Electrical and electronic engineering, Mechanical engineering
Summary of key points + notes (include methodology)	• Limitations of current modular robots: increased travel time, complex path planning, collision avoidance • Use scaling analysis to compare assembly strategies showing recursive and hierarchal assemblies provide speed advantage • Develop shape compiler to go from target shape to building blocks kind of like inverse kinematics • Demonstrate hierarchal generation growth to build larger robots composed of many voxels • Centralized for large swarms • Brings dynamic range of biological growth to robots with number and scale • Limitations use magnetic connectors which are not super strong • Future work with possible latches or fasteners to improve the connecting process • Potential in large-scale construction and remote harsh environments
Research Question/Problem/ Need	Introduce a discrete modular material-robot system that is capable of serial, recursive (making more robots), and hierarchical assembly.

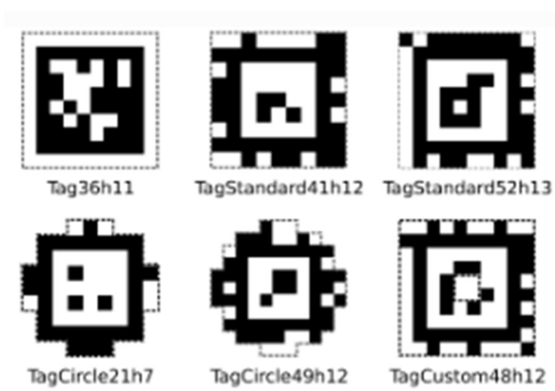
Important Figures	 This figure models the sequential order of self-replicated assembly allowing the reader to visualize the hierarchical cubical building blocks.
VOCAB: (w/definition)	Hierarchal – make larger robots Voxel-discrete unit of volume making up 3D object or grid
Cited references to follow up on	Neubert, J., & Lipson, H. (2016). Soldercubes: A self-soldering self-reconfiguring modular robot system. *Autonomous Robots*, *40*(1), 139–158. https://doi.org/10.1007/s10514-015-9441-4
Follow up Questions	How powerful are magnetic connectors? What are the minimal capabilities for each primitive robot?

Article #16 Notes: Emulating self-reconfigurable robots—Design of the SMORES system

Source Title	Emulating self-reconfigurable robots—Design of the SMORES system
Source citation (APA Format)	Davey, J., Kwok, N., & Yim, M. (2012). Emulating self-reconfigurable robots—Design of the SMORES system. *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 4464–4469. https://doi.org/10.1109/IROS.2012.6385845
Original URL	https://ieeexplore.ieee.org/document/6385845
Source type	Conference Article
Keywords	Connectors, Robot kinematics, Gears, Wheels, Mobile communication, Lattices
#Tags	
Summary of key points + notes (include methodology)	• Introduction of modular self-reconfigurable robot system designed SMORES • Identical SMORES modules that contain their own power source, computational ability, and sensing • The system focuses on versatility and emulation, meaning the same hardware can imitate multiple robot morphologies • Genderless mechanical latching system with multi-stage connection with 8 magnets and then a mechanical key • Three motorized degrees of freedom • Bending and rotation during collective motions • Robust and simplicity of reliable connections over extreme miniaturization • Locomotion, self-assembly, fault tolerance, and adaptability demonstrated in SMORES • Emulate multiple existing self-reconfigurable designs → flexible experimental platform • Testbed for studying control algorithms and swarm behaviors • “Chain systems tend to be the most capable to do useful tasks, as they can form articulated limbs. Lattice systems tend to be the best at self-reconfiguration.”
Research Question/Problem/ Need	Design a flexible and reliable experimental platform and connector for self-assembling modular robots

Important Figures	 (a) (b) (c) This figure is a locking mechanism for the SMORES EP robots. First, the magnets connect the robots, and the key stabilizes the connection. This is a design that can be compared to my connector.
VOCAB: (w/definition)	Arbitrary - based on random choice or personal whim, rather than any reason or system Predominantly – for the most part
Cited references to follow up on	Castano, A., Behar, A., & Will, P. M. (2002). The Conro modules for reconfigurable robots. *IEEE/ASME Transactions on Mechatronics*, *7*(4), 403–409. https://doi.org/10.1109/TMECH.2002.806233
Follow up Questions	How well does this compare to other designs? How can different materials impact the force?

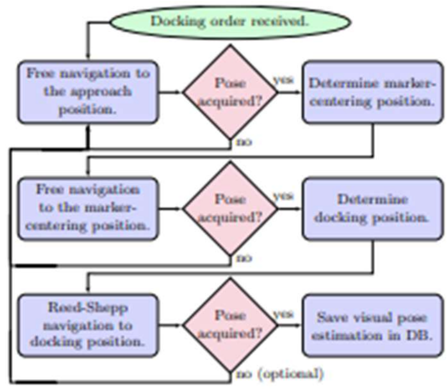
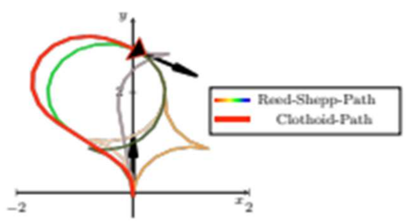
Article #17 Notes: AprilTag Introduction

Source Title	AprilTag Introduction
Source citation (APA Format)	*AprilTag Introduction—FIRST Tech Challenge Docs 0.3 documentation*. (n.d.). Retrieved November 7, 2025, from https://ftc-docs.firstinspires.org/en/latest/apriltag/vision_portal/apriltag_intro/apriltag-intro.html
Original URL	https://ftc-docs.firstinspires.org/en/latest/apriltag/vision_portal/apriltag_intro/apriltag-intro.html
Source type	Webpage
Keywords	n/a
#Tags	n/a
Summary of key points + notes (include methodology)	• AprilTag is a type of computer vision developed at University of Michigan to identify and pose from a camera looking at tag • Covers specific tag family in FTC robotics • When tag is detected, the SDK returns real world distances from the tag based on a defined coordinate system • Robots can use pose data for navigation towards tags • Usage considerations: resolution and frame rate trade-offs, camera calibration, multiple cameras, tuning cameras
Research Question/Problem/ Need	How do AprilTags work?
Important Figures	 This figure describes all of the different AprilTag families, and allows the audience to visualize what the tag actually looks like
VOCAB: (w/definition)	Bandwidth - a range of frequencies within a given band, in particular that used for

	transmitting a signal
Cited references to follow up on	n/a
Follow up Questions	Is there a minimum size an AprilTag must be for detection? What are the advantages of different AprilTags?

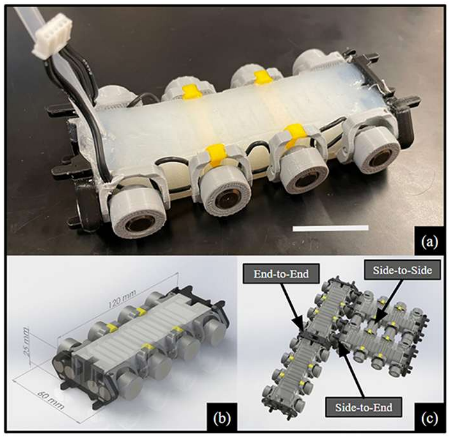
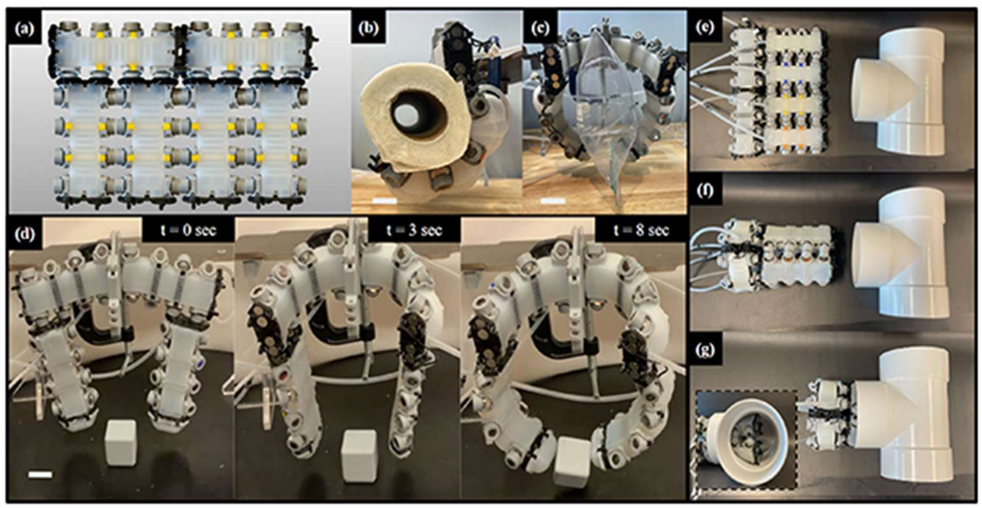
Article #18 Notes: Advanced Edge Detection of AprilTags for Precise Docking Maneuvers of Mobile Robots

Source Title	Advanced Edge Detection of AprilTags for Precise Docking Maneuvers of Mobile Robots
Source citation (APA Format)	Richter, J., Bohlig, D., Nüchter, A., & Schilling, K. (2022). Advanced Edge Detection of AprilTags for Precise Docking Maneuvers of Mobile Robots. *IFAC-PapersOnLine*, *55*(8), 117–123. https://doi.org/10.1016/j.ifacol.2022.08.020
Original URL	https://www.sciencedirect.com/science/article/pii/S2405896322010989
Source type	Journal Article
Keywords	Industry 4.0, Cyber Physical Systems (CPS), Cloud robotics
#Tags	Cloud robotics, Cyber Physical Systems (CPS), Industry 4.0
Summary of key points + notes (include methodology)	• Mobile robots often need to dock accurately, and April Tags are popular for providing visual cues for positioning and alignment • Tag pose estimation limited by accuracy of edges that can be detected in the image • Propose advanced edge detecting algorithm for AprilTags which focuses on tag contour and improving corner localization • Integrates improved routines into server-based control • Approach evaluated in terms of how much docking error is reduced when using the improved edge detection • Edge detection gives better pose stability and accuracy • Marker detection significantly impacts docking precision which is necessary for autonomous loading, recharging, or cooperation • Limitations in tag distance, extreme lighting, etc. • Reliance on centralized processing • Achieved measurable gains in high precision docking for mobile robots
Research Question/Problem/ Need	Improve AprilTag detection by using edges as a detection method.

Important Figures	 Fig. 2. Flowchart of the docking routine. This figure is important because it is a flowchart that the system takes for AprilTag scanning.  This figure shows the pathways that are visualized by the robot.
VOCAB: (w/definition)	Fiducial - (especially of a point or line) assumed as a fixed basis of comparison Odometry - a method used by robots and autonomous vehicles to estimate their position and orientation by using motion sensor data, such as wheel encoders or IMUs
Cited references to follow up on	Alijani, F. (2017). Autonomous vision-based docking of a mobile robot with four omnidirectional wheels. https://lutpub.lut.fi/handle/10024/133754
Follow up Questions	Does lens quality (causing distortion) influence edge detection of apriltags? What is the minimum acceptable size of tag per distance?

Article #19 Notes: Reconfigurable modular soft robots with modulating stiffness and versatile task capabilities

Source Title	Reconfigurable modular soft robots with modulating stiffness and versatile task capabilities
Source citation (APA Format)	Knospler, J., Xue, W., & Trkov, M. (2024). Reconfigurable modular soft robots with modulating stiffness and versatile task capabilities. *Smart Materials and Structures*, *33*(6), 065040. https://doi.org/10.1088/1361-665X/ad4d35
Original URL	https://iopscience.iop.org/article/10.1088/1361-665X/ad4d35
Source type	Journal Article
Keywords	Soft Robots, Self-Assembly, Material Science
#Tags	Modular robotics, Self-assembly, Soft robotics
Summary of key points + notes (include methodology)	• Limitation in soft robotics are the compliant structures limiting the variety of tasks that can be performed • Modular reconfigurable robot system proposed where each module is a soft pneumatic actuation unit • Built from elemental soft actuator units and pneumatically driven • Attachable and detachable components with magnetic connecting mechanism • By adjusting the current level, the induced magnetic field is controlled and flexible • Robots can reconfigure into several shapes each for separate functions connecting both in series and in parallel • ManusBot is a particular hand-like feature tat can be actuated individually • ManusBot can change how stiff each part is • Handle objects of different payloads and sizes • Rearranging modules demonstrate different structural shapes capable of a variety of tasks
Research Question/Problem/ Need	Increase soft robotic task versatility by enabling stiffness control and incorporating modular components

Important Figures	 This figure is important because it demonstrate the core pneumatic actuator that is applied in modular orientation as shown in part c.  This figure highlights ManusBot and how it can reconfigure to work in multiple different orientations to accomplish different tasks.
VOCAB: (w/definition)	Ampere's Law - the line integral of the magnetic field around a closed loop is equal to the magnetic permeability of free space multiplied by the total electric current enclosed by the loop
Cited references to follow up on	Zhang, C., Zhu, P., Lin, Y., Jiao, Z., & Zou, J. (2020). Modular Soft Robotics: Modular Units, Connection Mechanisms, and Applications. *Advanced Intelligent Systems*, *2*(6), 1900166. https://doi.org/10.1002/aisy.201900166
Follow up Questions	How does magnetic connection compare in strength, speed, and other modular connection mechanisms? Are there limits of scalability? How autonomous can reconfiguration be made?

Article #20 Notes: A Flexible Connector for Soft Modular Robots Based on Micropatterned Intersurface Jamming

Source Title	A Flexible Connector for Soft Modular Robots Based on Micropatterned Intersurface Jamming
Source citation (APA Format)	Tse, Y. A., Liu, S., Yang, Y., & Wang, M. Y. (2020). A Flexible Connector for Soft Modular Robots Based on Micropatterned Intersurface Jamming. 2020 3rd IEEE International Conference on Soft Robotics (RoboSoft), 150–155. https://doi.org/10.1109/RoboSoft48309.2020.9115975
Original URL	https://www.semanticscholar.org/reader/84eaa5a7e907714a9a852db983e549dded30a8bc
Source type	Journal Article
Keywords	Soft Robotics, Mechanical Engineering
#Tags	Soft Robotics, Mechanical Engineering
Summary of key points + notes (include methodology)	• Soft pneumatic connector for modular robots that combines micropattern adhesive surface with intersurface jamming • Uses silicon rubber surfaces patterned with microscopic structures to increase the contact area → when the connector inflates surfaces jam against each other • Deflated parts allow the structure to unjam and be separated with little force required • Jammed state can withstand about 22 N of load which is about 83% of the body weight • Planar rotation test maintained 11 N of force before failure • Soft inflatable body allows it to bend and deform during robot motion • Emphasized potential in soft modular structures
Research Question/Problem/ Need	Create soft connector that provides high load-bearing capabilities while preserving flexibility and compliance to modular soft robots

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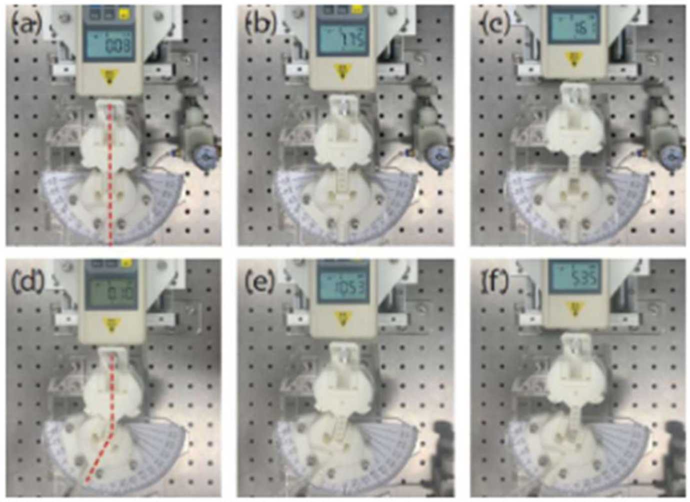
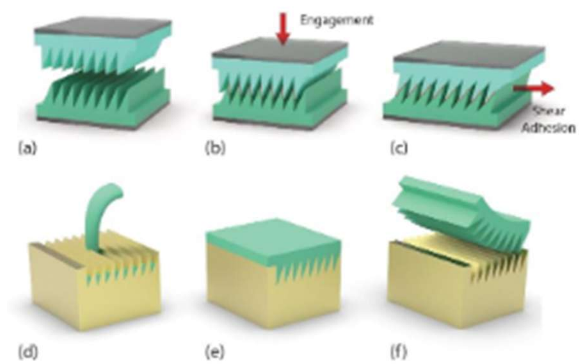
<td>Important Figures</td>
<td>


Fig. 5. Experiment process for linear (a-c) and rotational (d-f) direction. (a) Linear direction force test initial state. (b) Maximum connection force state. (c) Collapse state. (d) 30° planar rotational direction force test initial state. (e) Maximum connection force state. (f) Collapse state.
This figure shows the testing for the maximum force that the connector can hold.


This figure shows the microscopic jamming technique that the connector uses to hold in place.
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<tr>
<td>VOCAB: (w/definition)</td>
<td>Coaxial – having a common axis
Micropattern - a technique used to create precise patterns of molecules on the surface to control where and how cells can adhere and grow</td>
</tr>
<tr>
<td>Cited references to follow up on</td>
<td>Neubert, J., Rost, A., & Lipson, H. (2014). Self-Soldering Connectors for Modular Robots. IEEE Transactions on Robotics, 30(6), 1344–1357. https://doi.org/10.1109/TRO.2014.2344791</td>
</tr>
<tr>
<td>Follow up Questions</td>
<td>Does increased weight allow for greater force that can be held?
How does it compare to other connectors using similar concepts?</td>
</tr>
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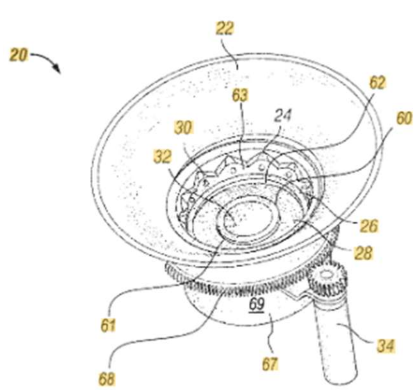
Article #21 Notes: Soft Robotic Blocks: Introducing SoBL, a Fast-Build Modularized Design Block

Source Title	Soft Robotic Blocks: Introducing SoBL, a Fast-Build Modularized Design Block
Source citation (APA Format)	Lee, J.-Y., Kim, W.-B., Choi, W.-Y., & Cho, K.-J. (2016). Soft Robotic Blocks: Introducing SoBL, a Fast-Build Modularized Design Block. *IEEE Robotics & Automation Magazine, 23*(3), 30–41. https://doi.org/10.1109/MRA.2016.2580479
Original URL	https://ieeexplore.ieee.org/document/7549069
Source type	Journal Article
Keywords	Soft robotics, Maintenance engineering, Morphological operations, Modular construction
#Tags	Maintenance engineering, Modular construction, Morphological operations, Soft robotics
Summary of key points + notes (include methodology)	• Propose modular system SoBL for soft robots which allow soft robots • Three types of pneumatically driven modules: translation block, bending block, and twisting block • Each SoBL is pneumatically actuated with air chambers • Three different connection mechanisms to attach blocks: screw-thread connections, push fitting connectors, and bistable conjunctions • Blocks fabricated using either multi-material 3D printing or silicone molding • Complex soft structures built with many capabilities • Significantly speeds up prototyping process → designers can revise the robot by swapping out blocks • Support reusability and reconfiguration
Research Question/Problem/ Need	Create fast modular platform for soft robots by developing standardized pneumatically actuated soft blocks with multiple connecting methods
Important Figures	

	This is the proposed SoBL modular design which can allow for rapid prototyping.
VOCAB: (w/definition)	Bistable Connector - designed to "snap" into one of two fixed positions Multi-material 3D printing – manufacturing procedure using multiple materials at the same time for 3D fabrication
Cited references to follow up on	Laschi, C., Cianchetti, M., Mazzolai, B., Margheri, L., Follador, M., & Dario, P. (2012). Soft Robot Arm Inspired by the Octopus. *Advanced Robotics*, *26*(7), 709–727. https://doi.org/10.1163/156855312X626343
Follow up Questions	What is the max force each connector can take? What are the limitations of the scale of SoBL blocks before pneumatics supply gets limited?

Patent #1 Notes: Magnetic capture docking mechanism US7815149B1

Source Title	Magnetic capture docking mechanism US7815149B1
Source citation (APA Format)	Howard, N., & Nguyen, H. D. (2010). *Magnetic capture docking mechanism* (United States Patent No. US7815149B1). U.S. Patent and Trademark Office. https://patents.google.com/patent/US7815149B1/en
Original URL	https://patents.google.com/patent/US7815149B1/en
Source type	Patent
Keywords	Modular Robotics, Mechanical Engineering, Aerospace Engineering, Satellites
#Tags	Aerospace, component, docking, docking mechanism, magnet
Summary of key points + notes (include methodology)	• Servicing satellites require docking mechanisms dependent on size and design • Existing docking relies on thrusters or robotic arms • Prior docking relies on harpoons, grapples, electromagnets, adjustable jaws, etc. • Goal of hybrid magnetic-mechanical docking between host vehicle and satellite • Electromagnets generate coupled magnetic field for self-centering • Shape orients the satellite to dock into the vehicle • Ball lock latch engages to make a rigid dock for capabilities in transferring power, data, or fuel • Significant initial alignment and does not require visual guidance
Research Question/Problem/ Need	How can a docking unit be designed to retrieve satellites in orbit without the need of precise alignment, complex robotic arms, or human control?
Important Figures	

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<td>This figure is important because it provides a visual of how the mechanism looks like. It features a rotatable magnet ball latching system.

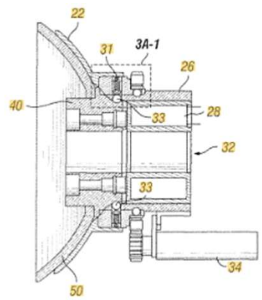

FIG. 3A

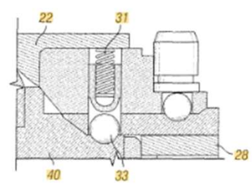

FIG. 3A-1</td>
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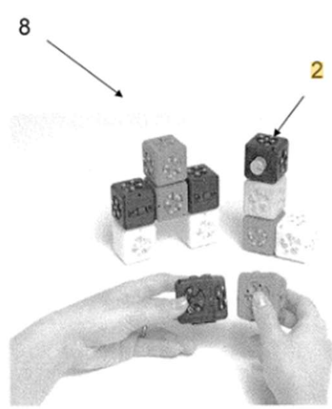
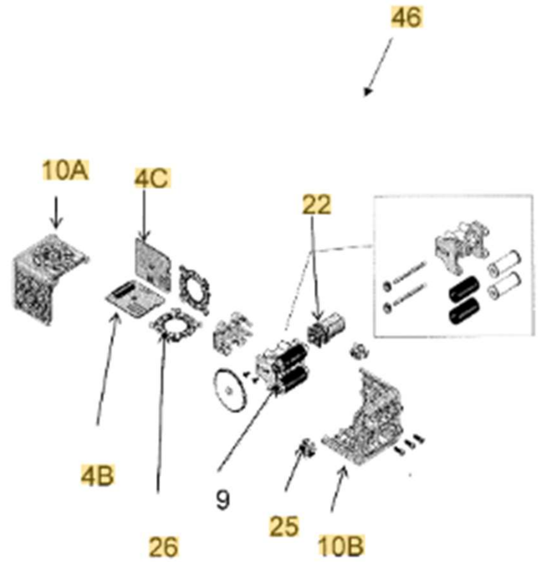
<tr>
<td>VOCAB: (w/definition)</td>
<td>Capture Envelope - spatial region in which docking forces can successfully demonstrate capture
Soft Dock - Initial contact where components are aligned but not yet mechanically locked</td>
</tr>
<tr>
<td>Cited references to follow up on</td>
<td>Barker, W. F. (1983). Magnetic docking probe for soft docking of space vehicles (United States Patent No. US4381092A). U.S. Patent and Trademark Office. https://patents.google.com/patent/US4381092A/en</td>
</tr>
<tr>
<td>Follow up Questions</td>
<td>What is the specific amount of force this connector can hold?
How well does it compare to other designs?</td>
</tr>
</table>

Patent #2 Notes: Modular Robotics US20120122059A1

Source Title	Modular Robotics US20120122059A1
Source citation (APA Format)	Schweikardt, E., & Gross, M. D. (2012). *Modular Robotics* (United States Patent No. US20120122059A1). U.S. Patent and Trademark Office. https://patents.google.com/patent/US20120122059A1/en
Original URL	https://patents.google.com/patent/US20120122059A1
Source type	Patent
Keywords	Modular Robotics, Mechanical Engineering
#Tags	Block, educational, educational construction, kit according, modular unit
Summary of key points + notes (include methodology)	• Addresses reconfiguration of modular robots that can physically and electrically connect • Traditional robotic connectors require precise alignment and gendered parts, which complicate self-assembly • Invention of hermaphroditic connector for cube-like robots • Magnets pull modules together regardless of positional and angular misalignment • Electrical contacts are integrated to transfer data when docked • Allows for multiple configurations • Low complexity attachment method • Enables robots to self-assemble, reconfigure, repair, and expand • Magnetic docking is well suited for autonomous modular systems
Research Question/Problem/ Need	Provide a simple magnetic system for simple self-aligning coupling between modular robots that enable both autonomous physical and electrical connection.
Important Figures	 This figure demonstrates how the blocks would come together and how they

	connect.  This figure explains the design format of each cube and connector.
VOCAB: (w/definition)	Hermaphroditic connector – Every module has identical connectors and can dock with any other module face
Cited references to follow up on	Milner, R. E., & Plambeck, E. D. (1992). *Chainable building blocks* (United States Patent No. US5172534A). U.S. Patent and Trademark Office. https://patents.google.com/patent/US5172534A/en
Follow up Questions	Why is this better than mechanical coupling? How is the electrical power transferred?