

# Magnetically Controlled Modular Cubes With Reconfigurable Self-Assembly and Disassembly

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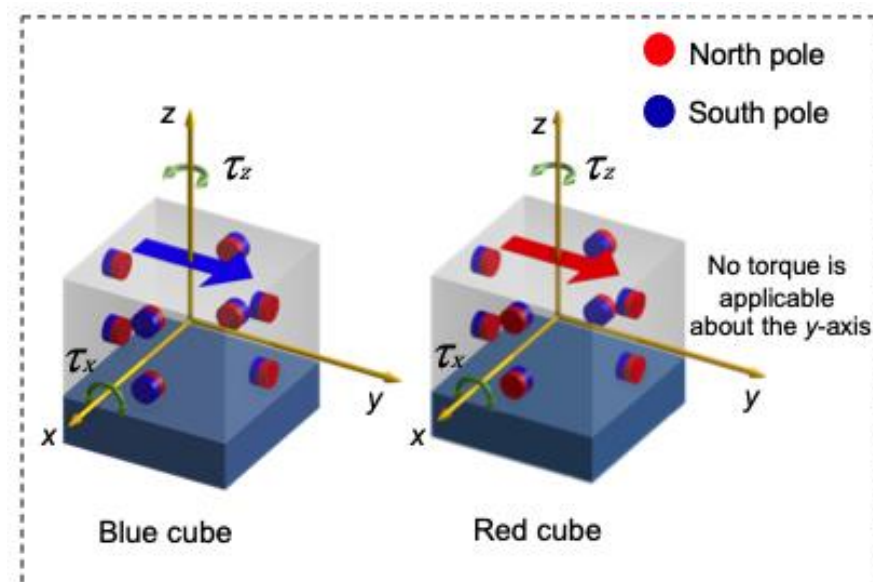
## Motivation

- Seeks a new type of meso-scale manufacturing method
- Design of a scalable modular robotic platform and techniques for controlled self-assembly, disassembly, and reassembly
- The control methods developed in this program will be applicable in other meso-scale research areas for exploring structures, dynamics, and interactions of integrated materials

## Design and Motion Modes

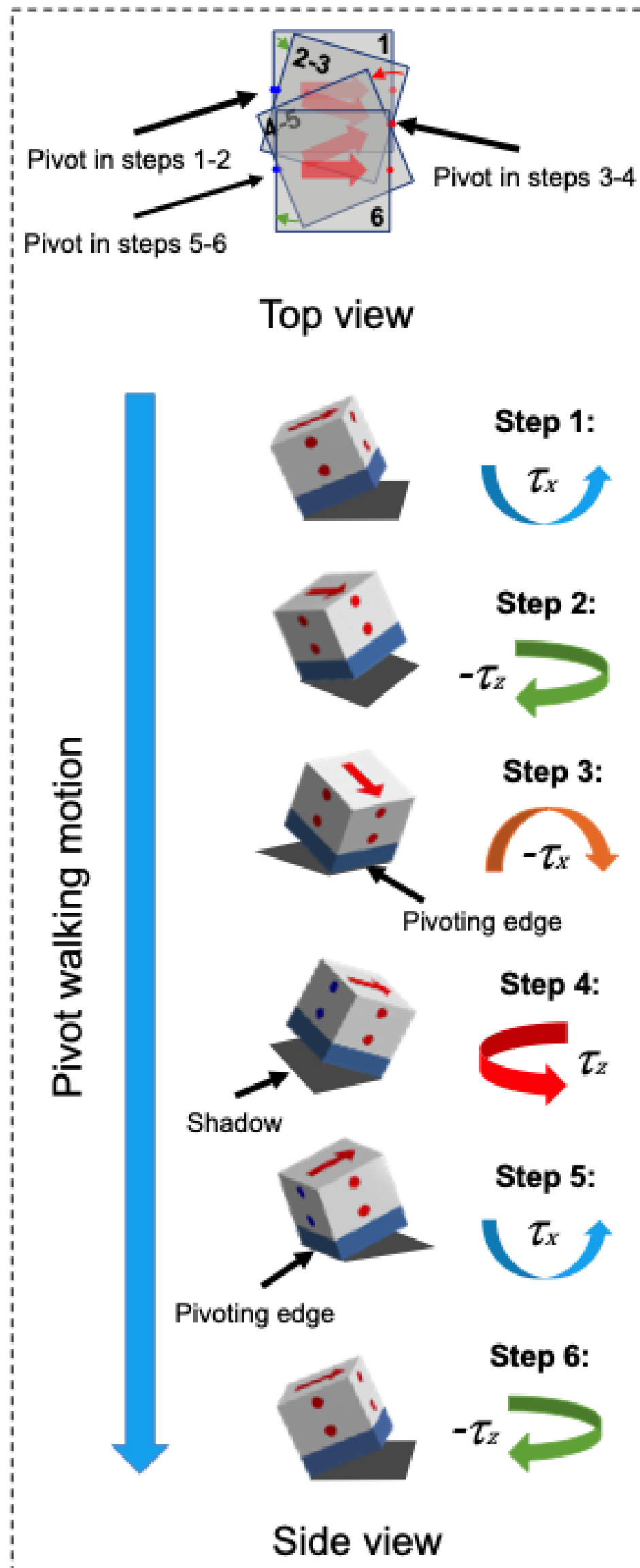
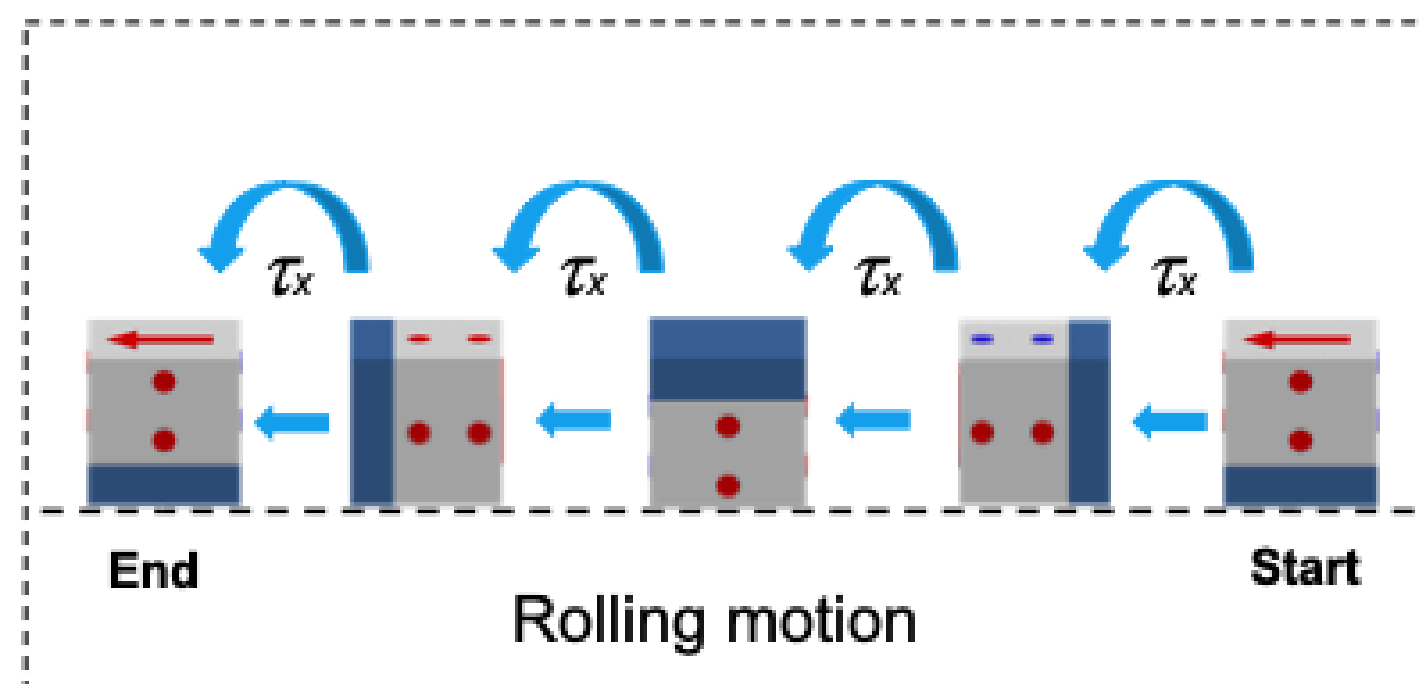
### Design:

- Two variations of the modular cubes were designed and used for conducting experiments to explore reconfigurable modular robotics
- Two cube sizes were tested: 10 mm edge lengths and 2.8 mm edge lengths



### Motion modes:

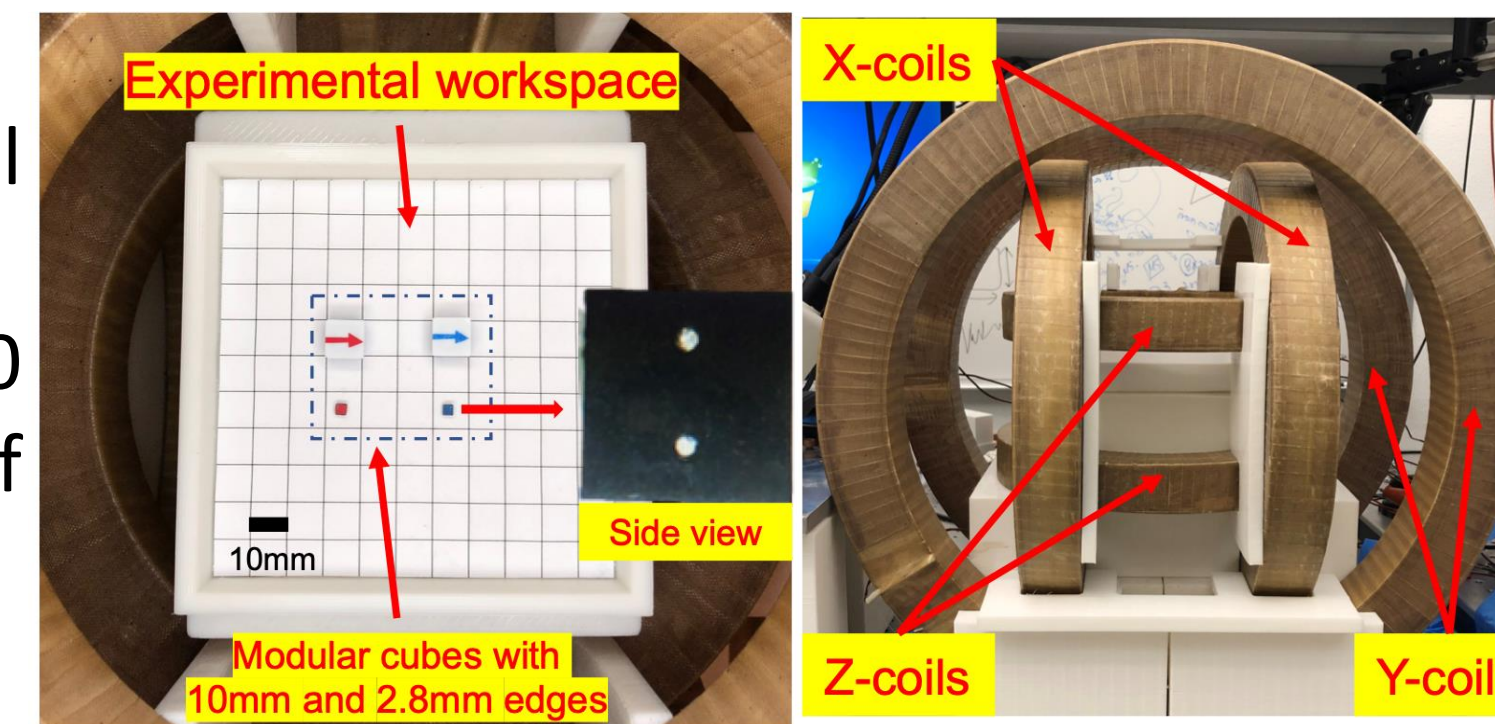
- One cycle of the rolling motion is achieved by four 90° steps of the applied magnetic torque  $\tau_x$
- One cycle of pivot walking motion is achieved by six discrete steps



## Self-assembly and Disassembly Behavior

### Experimental setup:

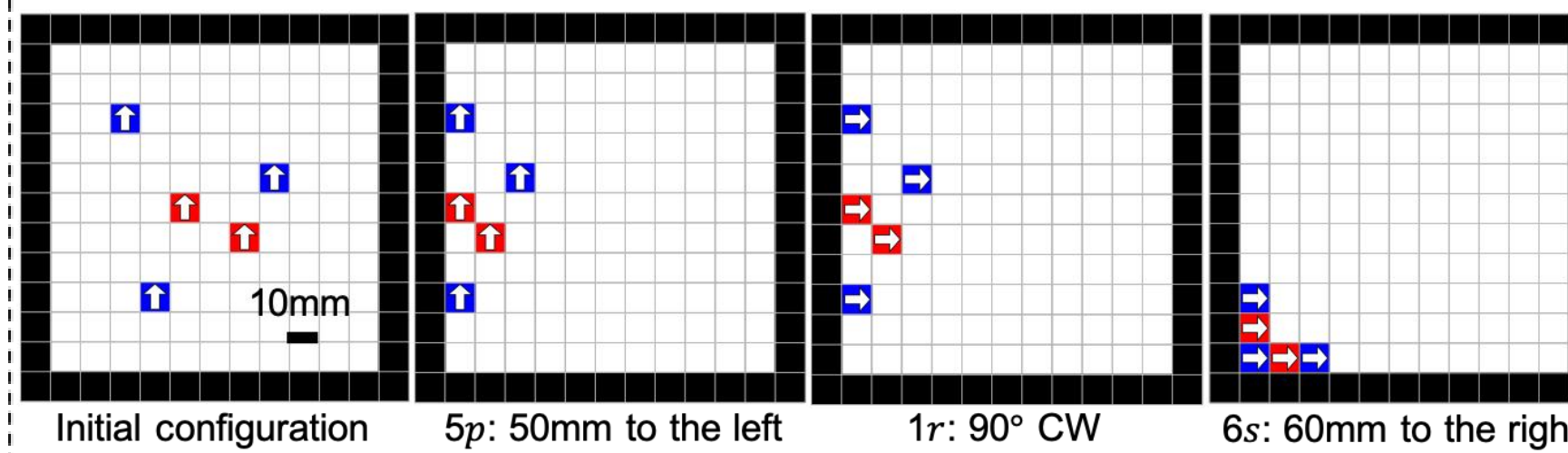
- A large-scale nested, triaxial Helmholtz coil system
- Working space of 150 × 120 × 80 mm<sup>3</sup> at the center of the coil configuration



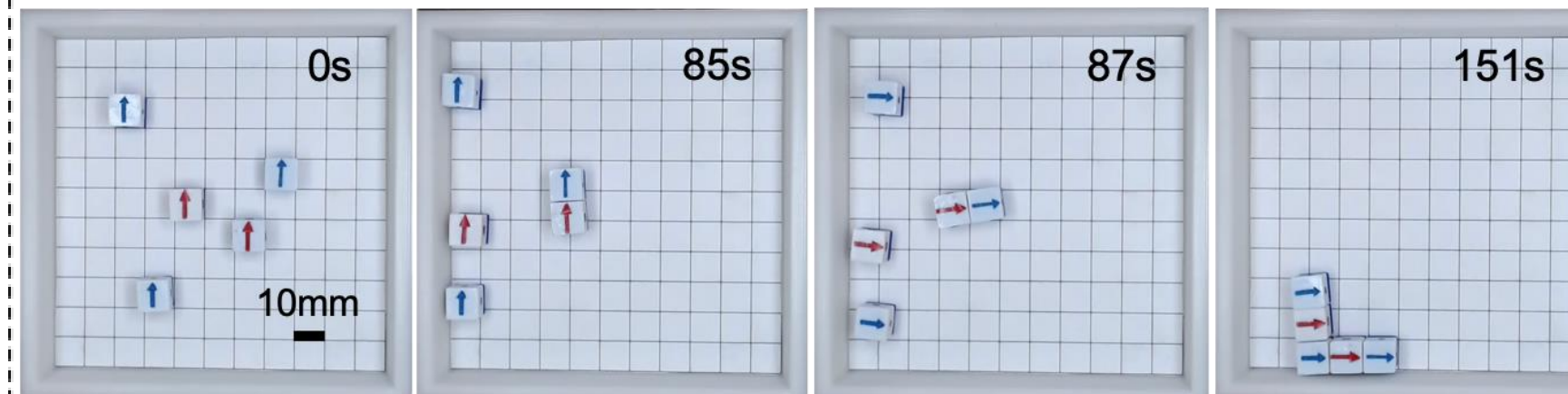
### Motion planner:

- 2D motion planner computes all reachable polyomino shapes from an arbitrary initial configuration and provides the shortest movement sequences to form each shape
- Experimental results match computational modeling, demonstrating robust and reproducible behavior of the modular robotic platform
- If the target polyomino is unreachable, we disassemble and/or scramble the cubes, and recalculate all reachable polyominoes

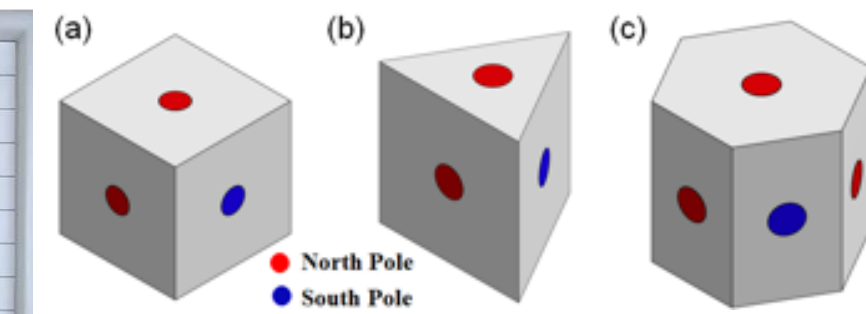
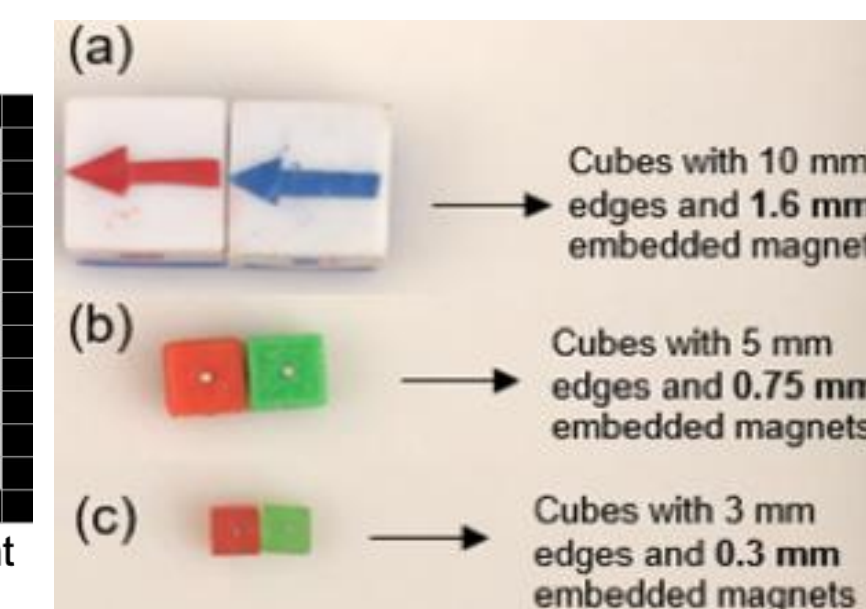
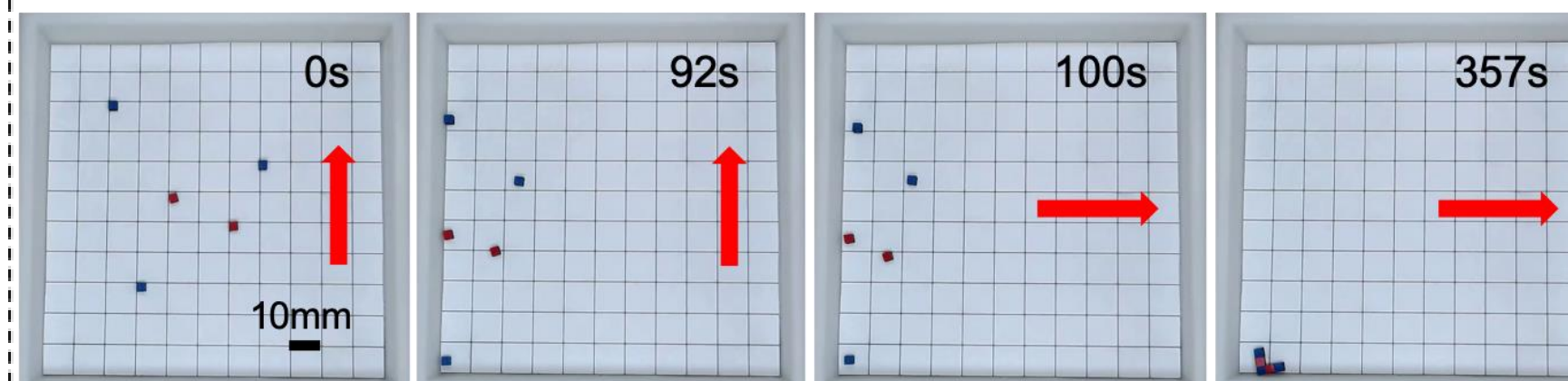
### a Details of the movements from motion-planner to form the target L-shape:



### b Experimentally verified by cubes with 10mm edge:



### c Experimentally verified by cubes with 2.8mm edge:



### Selected Publications:

- A. Bhattacharjee, Y. Lu, A. T. Becker, and M. Kim, "Magnetically-controlled modular cubes with reconfigurable self-assembly and disassembly," in *IEEE Transactions on Robotics (T-RO)*, 2021
- Y. Lu, A. Bhattacharjee, D. Biediger, M. Kim, and A. T. Becker, "Enumeration of polyominoes & polycubes composed of magnetic cubes," in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Prague, Czech Republic, Oct. 2021

## Applications

- Enables effective use of modular subunits in an intelligent meso-scale manipulation system
- Build custom shapes with many modules and quasi-repeating structures (like scaffolds) that are useful for construction
- Key novelty: the resulting structure is itself a robot

## Future works

- Making a high-fidelity simulator for motion planning
- Modeling the disassembly process, and increasing the complexity of the self-assembly/disassembly by using more cubes and by 3-D construction
- 2D/3D modular structures can be used to construct reconfigurable templates for targeted hyperthermia

