# LiftTiles: Modular and Reconfigurable Room-scale Shape Displays through Retractable Inflatable Actuators

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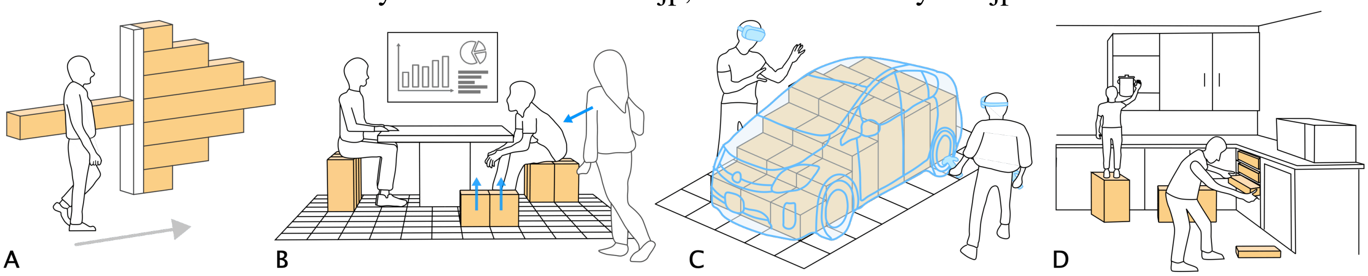


**Figure 1. A concept of a modular and reconfigurable room-scale shape display. (A) Displaying wayfinding guidance in public space. (B) Adaptive room that becomes a chair, a table, or a bed. (C) Large-scale haptics for VR and AR. (D) Modular and reconfigurable blocks for on-demand assistance.**

## ABSTRACT
This paper introduces LiftTiles, a modular and reconfigurable room-scale shape display. LiftTiles consist of an array of retractable and inflatable actuator that is compact (e.g., 15cm tall) and light (e.g., 1.8kg), while extending up to 1.5m to allow for large-scale shape transformation. Inflatable actuation also provides a robust structure that can support heavy objects (e.g., 10 kg weight). This paper describes the design and implementation of LiftTiles and explores the application space for reconfigurable room-scale shape displays.

## CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);**

## Author Keywords
shape displays, inflatables, pneumatic actuation

## INTRODUCTION
Shape display is a promising approach to general-purpose shape-changing interfaces [1]. However, most of the existing pin-based shape displays focus on interactions at the scale of a human hand [4, 3, 5, 6, 7, 8, 10] because of the following three technical challenges when trying to create a larger-size shape display: 1) **scalability**: common electromechanical linear actuators are difficult to scale to larger sizes due to cost and fabrication complexity. 2) **robustness**: in a room-scale shape display, each actuator must support heavy objects like a human body, thus it must be robust compared to smaller actuators. 3) **deployability**: existing shape-changing systems require substantial space for the mechanical actuators, which introduces difficulties in installation.

To overcome these challenges, this paper introduces LiftTiles, a room-scale shape display enabled by an array of retractable and inflatable actuators. Each actuator is compact (e.g., 15cm tall), light weight (e.g., 1.8kg), low cost (e.g., 8 USD), and strong (e.g., withstand more than 10 kg weight). It can extend up to 1.5m that allows for large-scale shape transformation. Each inflatable actuator is fabricated with a plastic tube and constant force springs. It extends when inflated and retracts with the force of its spring when deflated. By controlling the volume of internal air, the system can control the height of the actuator. Compared to similar existing reel-based pneumatic actuators [2], our proposed design utilizes constant force springs to allow for greater stability, simplified fabrication, and stronger retraction force. This enables a large actuator that expands from 15cm to 150cm, at a footprint of 30cm x 30cm.

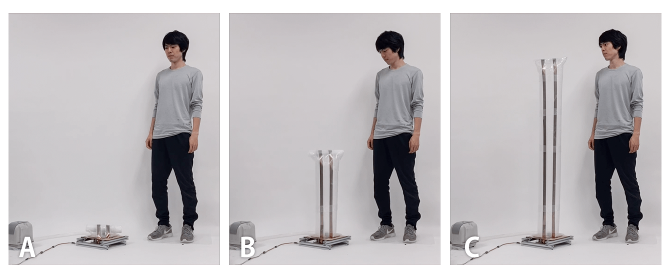


**Figure 2. A retractable inflatable actuator can extend from 15cm (A) to 150cm (C).**

## LIFTTILES: SYSTEM DESIGN
Each unit of LiftTiles consists of an inflatable plastic tube (0.15mm thickness vinyl, 20 cm in diameter when inflated) and two constant force springs (Dongguan Yongsheng Metal, 1.5 m in length, 2 cm in width, and 0.8 kgf load). One end (flat side) of the spring is fixed to the bottom plate and the other end (rolled side) is fixed to the top end of the tube (Figure 4). Laser-cut base plate (22 cm x 22 cm) has two holes for air


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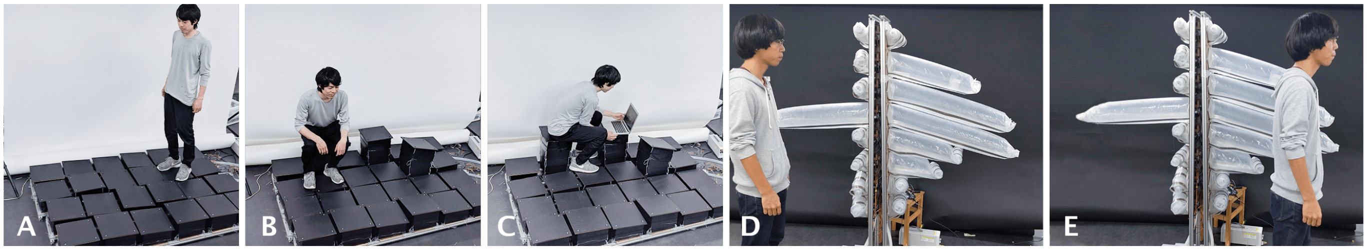

**Figure 3. LiftTiles prototype. A 5 x 5 array of actuators can reconfigure the floor and form a chair and a table (A-C). Due to the compact size and light weight, each actuator can be mounted on a column and extend horizontally to display an arrow shape to guide a user at a public space (D-E).**

supply and release respectively. The supply hole is directly connected to a solenoid valve (Ebowan Plastic Solenoid Valve DC 12V), which has 15 mm diameter. The air release hole has a T-shaped silicon tap. The silicon tap can open and close the release valve with a 3D printed rack and pinion gear mounted on a servo motor (TowerPro SG90). We mount a telescopic enclosure (30 cm x 30 cm, 18 cm in height) made of corrugated plastic sheets to enable the user to sit or step on it.

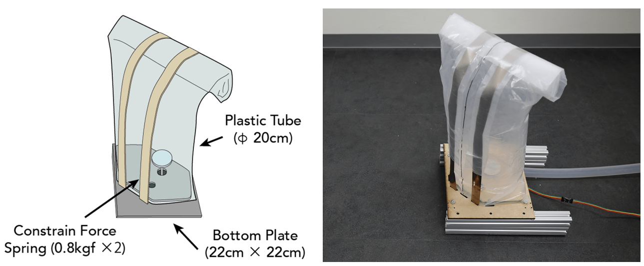


**Figure 4. Design of our retractable inflatable actuator. Each actuator consists of a plastic tube and constant force springs, which can extend from 15 cm to 1.5m when inflated and retract when deflated.**

Our actuator design is inspired by the prior reel-based pneumatic actuator [2]. However, during our prototyping process, we realized that the force of the spiral torsion springs used in [2] was too weak to retract a large sized pneumatic tube. In addition, the retractable force of the spiral springs is not constant and changes according to the length of the inflatable tube (e.g., weak spring force at shorter extension). Our design contributes to overcoming these challenges for scalable, reliable, and easy-to-fabricate actuation methods.

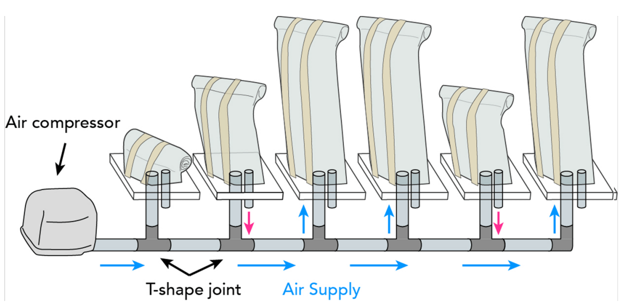


**Figure 5. Pneumatic control system for actuator arrays.**

Each individual actuator is modular and can be connected with the neighboring actuators. At the end of the solenoid air intake valve of each actuator, it is connected to a T-shaped plumbing joint. Adjacent actuators are pneumatically connected through a silicon tube between the T-shape joints. This way, an array of actuators is connected to a shared pressurized line. Multiple air compressors (Yasunaga Air Pump, AP-30P) pressurize the shared line. Each air pump provides up to 12.0kPa of pressure and supplies 30L of air volume per minute.

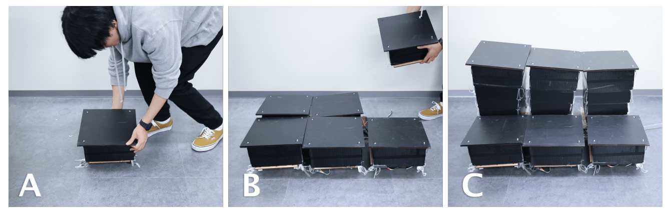

**Figure 6. Modular design of LiftTiles.**

In our prototype, the cost of each actuator is less than 8 USD, including the solenoid valve (3 USD), contact force springs (0.5 USD), the servo motor (2 USD), and other material cost. In total, we fabricated 25 units for our prototype.

## APPLICATIONS AND FUTURE WORK

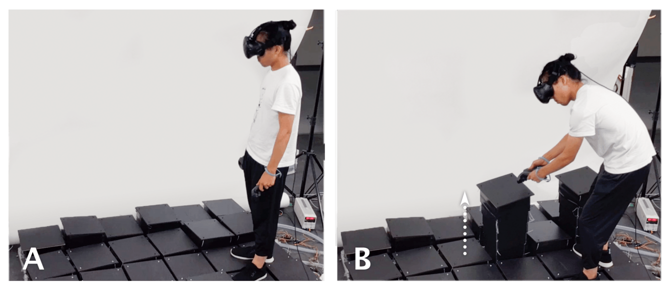

**Figure 7. Room-scale dynamic haptics for VR.**

By leveraging LiftTiles prototype, we explore possible interactions with reconfigurable room-scale shape displays and propose three high-level interaction spaces: 1) *adaption* to the user's needs and situation, 2) *display* of information or data to the user, and 3) *haptics* to provide physical feedback synchronized with visual information. For future work, we are interested in exploring other application scenarios, such as actuating large existing objects leveraging the shape displays [9, 11, 14] or adding mobility in each unit to allow an autonomous and distributed shape display [12, 13].

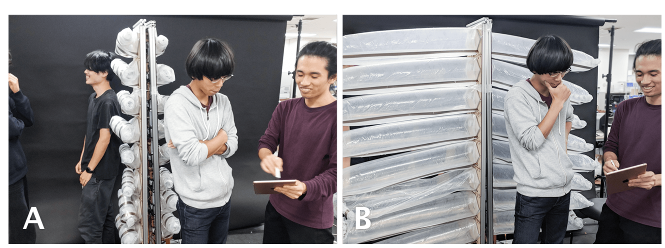

**Figure 8. Adaptive space separation. In a public working space, LiftTiles can create a temporal meeting space by separating the space.**

## REFERENCES


1. Sean Follmer, Daniel Leithinger, Alex Olwal, Akimitsu Hogge, and Hiroshi Ishii. 2013. inFORM: Dynamic Physical Affordances and Constraints Through Shape and Object Actuation. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. ACM, New York, NY, USA, 417–426. DOI: http://dx.doi.org/10.1145/2501988.2502032

2. Zachary M Hammond, Nathan S Usevitch, Elliot W Hawkes, and Sean Follmer. 2017. Pneumatic reel actuator: Design, modeling, and implementation. In *Robotics and Automation (ICRA), 2017 IEEE International Conference on*. IEEE, 626–633. DOI: http://dx.doi.org/10.1109/ICRA.2017.7989078

3. John Hardy, Christian Weichel, Faisal Taher, John Vidler, and Jason Alexander. 2015. ShapeClip: towards rapid prototyping with shape-changing displays for designers. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 19–28. DOI:http://dx.doi.org/10.1145/2702123.2702599

4. Hiroo Iwata, Hiroaki Yano, Fumitaka Nakaizumi, and Ryo Kawamura. 2001. Project FEELEX: adding haptic surface to graphics. In *Proceedings of the 28th annual conference on Computer graphics and interactive techniques*. ACM, 469–476. DOI: http://dx.doi.org/10.1145/383259.383314

5. Daniel Leithinger, Sean Follmer, Alex Olwal, Samuel Luescher, Akimitsu Hogge, Jinha Lee, and Hiroshi Ishii. 2013. Sublimate: State-changing Virtual and Physical Rendering to Augment Interaction with Shape Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 1441–1450. DOI: http://dx.doi.org/10.1145/2470654.2466191

6. Daniel Leithinger, David Lakatos, Anthony DeVincenzi, Matthew Blackshaw, and Hiroshi Ishii. 2011. Direct and Gestural Interaction with Relief: A 2.5D Shape Display. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology (UIST '11)*. ACM, New York, NY, USA, 541–548. DOI: http://dx.doi.org/10.1145/2047196.2047268

7. Ken Nakagaki, Daniel Fitzgerald, Zhiyao (John) Ma, Luke Vink, Daniel Levine, and Hiroshi Ishii. 2019. inFORCE: Bi-directional 'Force' Shape Display for Haptic Interaction. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. ACM, New York, NY, USA, 615–623. DOI: http://dx.doi.org/10.1145/3294109.3295621

8. Ivan Poupyrev, Tatsushi Nashida, Shigeaki Maruyama, Jun Rekimoto, and Yasufumi Yamaji. 2004. Lumen: Interactive Visual and Shape Display for Calm Computing. In *ACM SIGGRAPH 2004 Emerging Technologies (SIGGRAPH '04)*. ACM, New York, NY, USA, 17–. DOI: http://dx.doi.org/10.1145/1186155.1186173

9. Philipp Schoessler, Daniel Windham, Daniel Leithinger, Sean Follmer, and Hiroshi Ishii. 2015. Kinetic Blocks: Actuated Constructive Assembly for Interaction and Display. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (UIST '15)*. ACM, New York, NY, USA, 341–349. DOI: http://dx.doi.org/10.1145/2807442.2807453

10. Alexa F. Siu, Eric J. Gonzalez, Shenli Yuan, Jason B. Ginsberg, and Sean Follmer. 2018. shapeShift: 2D Spatial Manipulation and Self-Actuation of Tabletop Shape Displays for Tangible and Haptic Interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 291, 13 pages. DOI: http://dx.doi.org/10.1145/3173574.3173865

11. Ryo Suzuki, Junichi Yamaoka, Daniel Leithinger, Tom Yeh, Mark D. Gross, Yoshihiro Kawahara, and Yasuaki Kakehi. 2018. Dynablock: Dynamic 3D Printing for Instant and Reconstructable Shape Formation. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. ACM, New York, NY, USA, 99–111. DOI: http://dx.doi.org/10.1145/3242587.3242659

12. Ryo Suzuki, Clement Zheng, Yasuaki Kakehi, Tom Yeh, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2019. ShapeBots: Shape-changing Swarm Robots. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*.

13. Shohei Takei, Makoto Iida, and Takeshi Naemura. 2011. KineReels: Extension Actuators for Dynamic 3D Shape. In *ACM SIGGRAPH 2011 Posters (SIGGRAPH '11)*. ACM, New York, NY, USA, Article 84, 1 pages. DOI: http://dx.doi.org/10.1145/2037715.2037810

14. Luke Vink, Viirj Kan, Ken Nakagaki, Daniel Leithinger, Sean Follmer, Philipp Schoessler, Amit Zoran, and Hiroshi Ishii. 2015. TRANSFORM As Adaptive and Dynamic Furniture. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15)*. ACM, New York, NY, USA, 183–183. DOI: http://dx.doi.org/10.1145/2702613.2732494