Legoons: Inflatable Construction Kit for Children

Xuefei Yang
Rhode Island School of Design
2 College St. Providence, RI 02903, USA
xyang04@risd.edu

Stefania Druga
MIT Media Lab
75 Amherst St, Cambridge, MA 02139, USA
sdruga@mit.edu

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Abstract
Legoons is a ready-to-play inflatable construction kit that enables children, 6 to 12 year old, to construct characters and artifacts that can be actuated by pumping air. Our set features three types of silicone bricks with distinct behaviors when inflated, as well as various decoration bricks, connectors, and stoppers. With our design, we propose adding soft materials and organic motion to the traditionally rigid and mechanical construction kits. Our unconventional kit celebrates children's imaginations with playful and transforming materials, as well as their desire for personal expression that motivates them to tinker, experiment, and bring their creations to life. We describe our project's various design iterations, fabrication steps and discuss the lessons we learned from our initial playtests with children.

Author Keywords
Construction kit; Inflatables; Toys; Children; Tangible Interaction

CCS Concepts
•**Human-centered computing** → **Usability testing; User centered design; Interface design prototyping;** *Field studies; Sound-based input / output;* **Human computer interaction (HCI);** User studies; •**Social and professional topics** → **Children;**

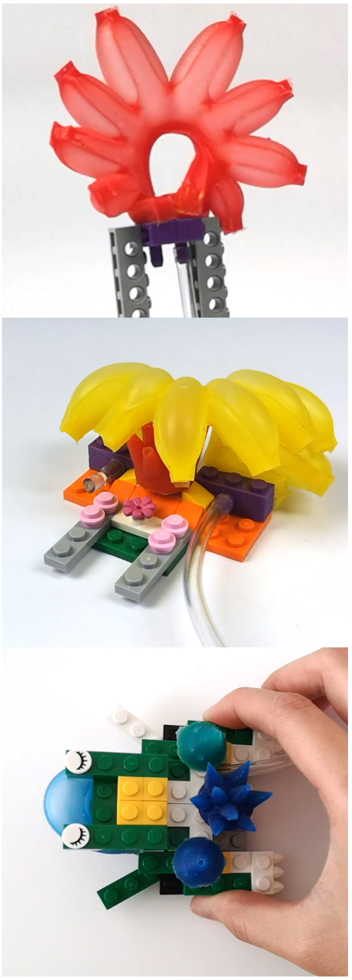

Figure 1: Various creations with Legoons: Blooming flower, Bouncy castle, Breathing Frog.

Introduction

After the development of the constructivist epistemology and constructionist learning in the last century, robotic construction kits have boomed in the past two decades [28, 19, 7]. The long tradition of working with "hard" robots has yielded commercial success for the construction toys [23] as well as rich literature analyzing children's response to them [15, 8]. Yet, followers of such toys and learning models seem to only add to the volume rather than contributing to the variety of robotic construction kits. With the inert, inorganic construction components in these kits, robotic creations remain rigid and mechanical. A greater variety of designs asks for a broader range of medium, and the robotic construction world calls for new materials and primitives [20].

On the other hand, soft robotics are becoming a prominent field of robotic engineering [1]. The air actuation and creature-like behavior [27] provide not only opportunities for new engineering possibilities [24], but also inspirations for new modes of human-robot interaction (HRI)[26]. Introducing soft robot materials into the traditionally hard robotics world might also help increase the variety of construction toys available for children, and serve as new stimuli and starting points for their creative learning.

Legoons explores the emergent field of soft robotics in children's play. In addition to existing hard robotics kits and the engineering-centric soft robots [17, 18], our kit proposes playful construction primitives that invite tinkering, character invention, and creative expression. This paper describes what Legoons is and how its design evolved during various playtests with children and fabrication iterations.

Related Works

For our design, we draw on two primary sources of inspiration: constructionist learning through playing, and soft robotics prototyping methods and inflatable kits.

Playing with Construction Kits

In the 1990s, Seymour Papert pioneered the idea of "construction" as a learning-rich activity for children to develop their knowledge by playing with technology-infused construction kits [19]. His research on LEGO with LOGO programming language highlighted new possibilities to facilitate the learning of Mathematics and other science concepts through physical play and programming [21], further inspiring generations of connected toolkits for children and youth [2]. Construction designs have expanded from traditional robotic vehicles for STEM learning towards more experimental mediums for personal interest and artistic expression, which were proven to be a valid alternative to approach science learning [16]. Recent studies foreground new potential construction mediums, such as e-textile modules [3], wearable kits [9, 14], and inflatable robot modules [10, 11, 12]. Legoons is in line with these experiments in construction kits, emphasizing the play-based learning experience. Our project hopes to enrich the constructionist learning materials and contribute to the robotics construction world by introducing a new medium for creation and new programmable behavior for the final artifacts.

Constructing Inflatables

While seeking a new medium and behavior for the construction toys world, we noticed that many modular prototyping methods have been proposed for engineering purposes in the soft robotics field [18, 17, 13, 6]. Alongside these developments, efforts have been made to offer simplified versions for children. For example, InflatiBits is a

Figure 2: Inflatable I brick, S brick, and C brick when deflated and inflated.

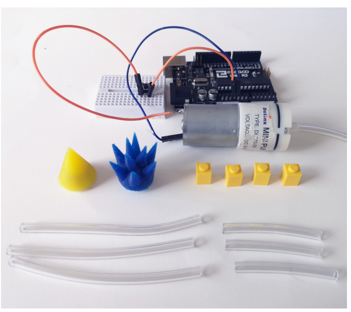

Figure 3: Other components of this kit include two types of deco bricks (Cone and Spike), tube connectors, stoppers, and an air pump.

silicone soft robot construction toy compatible with LEGO [10]. It features a white, tire-like silicone module that could be stacked or connected with tubes to perform various tasks. Similarly, Soft LEGO [12], previously SoBl [11], uses thermoplastic rubber to create small, cubic modules based on 2x2 LEGO bricks. Nevertheless, these toolkits focus more on the engineering possibility of a single module, rather than the playability and engagement of the whole construction kit. There has been a lack of ready-to-play construction kit for children to make inflatable characters for their imagination and the interaction between children and soft construction toys remains largely unexplored. We hope to bridge this gap by designing Legoons to be a children-oriented inflatable construction kit.

Legoons Construction Kit

This section describes the design and fabrication of the five components of this kit: inflatable bricks, deco bricks, connectors, stoppers, and an air pump.

Design Principles

Legoons components are compatible with LEGO bricks, enabling children to invent stories and characters with organic, life-like movements. Our project is resonant with previous efforts in creating a soft robotic construction kit for children, but it differs in several important aspects: 1) Legoons focuses on materiality and sensory experience, exploiting the satisfying tangibility of silicone to stimulate multiple senses; 2) it sparks interest with inflatables' creature-like behavior, highlighting the inflation and deflation motion; 3) it aims to inspire narratives and character invention rather than to pose engineering challenges. These design principles accentuate on playability and interaction, which are manifested through the design of Legoons.

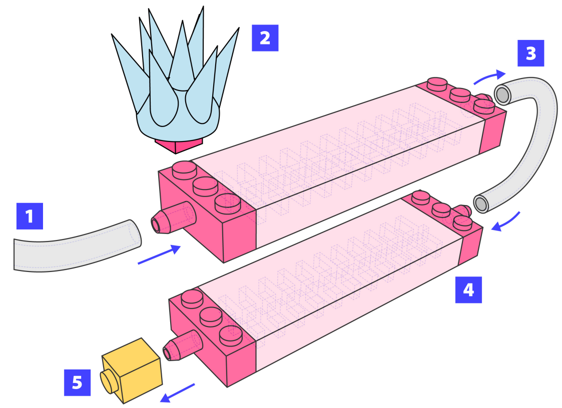

Figure 4: A simple airtight system composed with 1) Air pump tube; 2) deco bricks; 3) tube connector; 4) inflatable bricks; and 5) stopper. The arrows indicate the airflow direction.

Inflatable Bricks

The inflatable bricks are the core components of our construction set. They are shaped specifically to invite touch and play. Instead of breaking the soft robots primitives down to a single inflatable unit and providing only one shape in a construction toy like previous projects [10, 12], Legoons takes an unconventional approach to silicone modules. There are three types of inflatable bricks in Legoons: the I, the S, and the C (see Figure 2). These inflatable modules, when deflated, remain consistent with the blocky Lego shapes with straight edges measured in LEGO units [29]. When inflated, they each perform their signature action: I bricks bend in one direction into a banana shape, S bricks bend in one dimension but in two directions into an S shape, and C bricks bend in two dimensions into a round shape (see Figure 2). These three shapes are selected to represent the primary primitives of soft robots and to maximize inflation behaviour variety [25]. Because of each

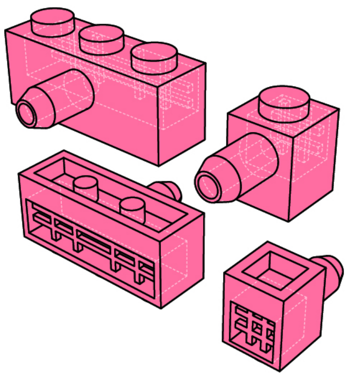

Figure 5: Modified LEGO 1x3 and 1x1 bricks with air ports.

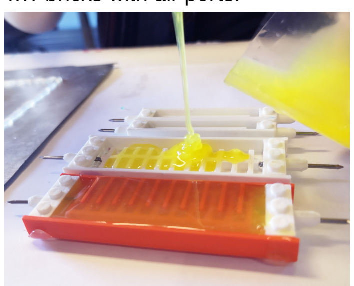

Figure 6: Pouring liquid silicone into air chamber molds for curing.

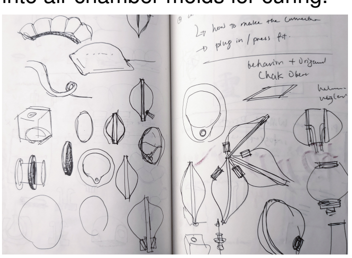

Figure 7: Initial sketches of the design

module's distinct motion, these movement primitives could be played alone or in combination to create new behavior.

Deco Bricks

Beside the inflatable modules, our kit also contains two non-inflatable components we call deco bricks. In the original LEGO collection, beside the standard cuboid building bricks, there are also modified special pieces like claws, bridges, or triangles [4]. These special pieces serve not only as decorations, but also as incentives for creations, inviting children to start building familiar imagery. Similarly, our set includes the Cone and the Spike deco bricks (see Figure 3), both intended to invite rich imagery association with various animals, plants, or buildings.

Connectors, Stoppers and Air Pump

Other supportive components in this kit include rubber tube connectors, air stoppers and an air pump (see Figure 3). The connectors and stoppers facilitate the creation of an airtight system, while the air pump controls the system inflation. The air pump keeps blowing air when the button is pressed and held; it stops immediately when the button is released. This simple device provides the basic function of inflating and deflating with the potential of being programmed with an Arduino board to have more precise control over the inflation rate and power.

Fabrication of Legoons Bricks

The inflatable bricks are made of three parts: two plastic ends and a silicone air chamber in the middle. The plastic ends are modified LEGO 1x3 and 1x1 bricks with the addition of air ports to let air into the silicone air chamber (see Figure 5). The customized brick is designed referencing the form factor of the existing Lego Pneumatic Add-on Set to maximize compatibility and familiarity. The bricks are 3D-printed with PLA on MakerBot Replicator 5 for its relevant accuracy required for snap-fit and its surface roughness required to capture silicone.

The air chambers are cast with Smooth-on Ecoflex 00-30 silicone, a skin-safe soft material that is stretchable and reversible to its original form without distortion, widely used for other toys. Though the sizes of the air chambers were designed to be 1x8 and 3x10 LEGO units [29], the silicone pieces could be stretched, squeezed, or twisted to fit different sized creations. After the modified LEGO bricks are printed, the silicone air chambers are cast with two bricks nesting inside to create one Legoons inflatable brick. Deco bricks are cast in a similar fashion with one modified LEGO 1x1 brick nested inside a solid silicone piece (see Figure 6).

Legoons Play Experience

The context and play experience of Legoons are very flexible: it could be played alone or in group; it could be used for soft robot prototyping or for creative expressions; characters could be constructed for scenes and narratives or simply for the fun of making. To increase the controllable factors, it could also be combined and matched with the motor series like LEGO Mindstorm, or programmable series like LEGO Wedo. Each Legoons brick is uniquely and purposefully shaped, inspiring a wide variety of projects: blooming flower, chubby snake, bouncy castle, air-powered spaceship, breathing bracelet, etc (see Figure 1 and 9).

To start creating a project, players need to quickly learn the rules of an airtight system: one end needs to be connected with the air pump, the other end needs to be plugged with a stopper (see Figure 4). Players are encouraged to try out how each shape performs when inflated, and then to start building their creations by snapping the inflatable bricks with deco bricks or standard LEGO bricks. They can also connect the modules with other inflatable bricks via

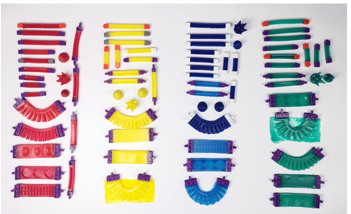

Figure 8: Older version of Legoons tested at Lexington Montessori School.

Figure 9: Players' creations. Top: A player combining two inflatable bricks. Middle: A player wearing her Legoons necklace. Bottom: Three players each making an inflatable animal, a long chain, and a sky castle.

connectors. During the building process, players are free to tinker with all the materials provided, find unexpected combinations, and modify their creations according to their shifting goals. There is no definite time duration or fixed objectives for a play session, and players are encouraged to engage with Legoons in all the ways they like to play.

Design Process

Research and Development

Legoons was initiated as part of the "Designing Smart Toys" studio [5] at the Rhode Island School of Design (RISD). After identifying the blank space of a mixed-media, expression-oriented toy in the robotic construction world, we began to formalize the idea of merging soft robotics with construction kits (see Figure 7).

After preliminary research, we started testing shapes and casting silicone with handmade wooden molds and then with more precisely 3D-printed molds. Initially, it was difficult to define a modular system that could be easily snapped on/off while keeping the system airtight. Several connection forms with silicone connectors or ready-made metal air valves were tested and dismissed. The pivotal point came when we integrated the silicone module with 3D-printed LEGO bricks. This created lots of opportunities for snap-fit constructions and provided compatibility with other construction toys. The rough surface of the 3D printed LEGO modules also provides a tighter bond between silicone air chamber and the connection pieces. This new connection system separates the snap-fit building system from the airtight system (see Figure 4). With this connection, five types of inflatable bricks and three types of deco bricks were developed (see Figure 8). We then added colors to increase the playfulness and visual stimulation.

Playtest with Children

We tested our set with a group of 65 students from Lexington Montessori School (LMS), ranging from 6-year-olds to 13-year-olds. In a science fair-like setting, LMS students wandered from station to station to play with different toys and games. On average, kids spent about 8-12 minutes at the Legoons station. Some kids left in 5 minutes, while others spent more than 15 minutes building their creations. The 6 to 8 year old participants played longer on average than older children and teens.

In general, kids reacted positively to our toy, expressing their enthusiasm with "oh slimy!" and "this is so cool". Within several minutes at our station, LMS students built and inflated various creations. When asked what they were making, kids answered from buildings like bouncy sky castle, to animals like snakes and caterpillars, from vehicles like air-powered spaceship, to wearables like inflatable bracelets and necklaces (see Figure 9). While they were building, participants learned surprisingly fast how to make an airtight system, and started to teach and help each other find pieces and check their inflatable creations. Sometimes some kids got lost building a complicated airtight system, but with a little guidance, they quickly realized how to revise and make their creations airtight.

From the playtest conversations and observations, we identified three things that attract players the most: the satisfying stretchability and squeezability of silicone, the inflation and deflation motion, as well as the endless possibility and the compatibility with LEGO that enables them to build with confidence and free imagination. The next iteration of our design will continue or augment these core features.

This workshop also allowed us to discover shortcomings of our design. The silicone-PLA bonded bricks were too

Figure 10: Legoons final version presented in paper.

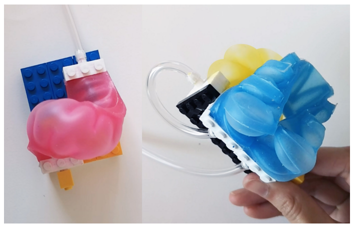

Figure 11: Unexpected twist and combination of bricks.

delicate to be stretched intensely, and kids were sometimes confused about which silicone pieces are inflatable and which are deco. In the next iteration, we strengthened the bond between the silicone air chamber and the 3D printed brick by adding more texture to the contact surface. We also reduced the variety of brick types to make each brick more distinguished and unique. This final version of the kit is presented in this paper (see Figure 10).

RISD Smart Toys Open House

The latest version of Legoons was also presented at RISD Spring studio open house. In a similar setting with the previous playtest, students, professors, and designers came to play with Legoons. Different from the children's play pattern, the adult players immediately sought ways to "hack" the silicone bricks when started playing. They squeezed, stretched, and twisted the silicone, snapping bricks together in ways impossible for traditional hard construction kit (see Figure 11). Adult players also created more complex inflation systems and combined various inflatable behaviors. The open house reveals how adults interact with Legoons and indicates the project's potential for more diverse purposes, such as robotic engineering, design prototyping, and even stress-relief fidgeting. Future iterations should leverage this inflatable kit's creative potentials and incorporate more components for a higher ceiling of creative expressions [22].

Future Directions

To further the playability and the variety of motions of Legoons bricks, more advanced controls could be incorporated into the kit, such as air valves, deflation units, an Arduino programming library, etc. On on hand, Legoons is reflective of how children and adults treat toys with soft materials differently. This exploration calls for future studies to compare how playing and building with transforming materials stimulates children's creativity and engagement differently than the traditional rigid building blocks and we plan to run comparative play sessions. On the other hand, the flexible context of playing with these mixed-media building bricks also encourages research on their applications in diverse fields, such as collaboration-training aid, rapid prototyping tool, or natural science education material.

Conclusion

Legoons reimagines the robotic construction world and play experiences by merging silicone inflatables with LEGO bricks. The introduction of these unconventional building blocks and their inflatable behavior sparks new science experiments and characters kids could build. By designing each inflatable brick to have its own behavior and characteristics, our kit invites children to start building from their imagination with these playful materials rather than tackling engineering challenges. During the playtests, we observed how each player used our set differently. Being a construction kit free of explicit objective, Legoons could be played and used by different people with different interests, for diverse contexts and goals. We hope our ready-to-play inflatable construction kit will foster and nourish youth's imagination from tangible tinkering to unique personal creations with new transformative materials.

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