Kinetic Sketchup

Motion Prototyping in the Tangible Design Process

Amanda Parkes & Hiroshi Ishii
Tangible Media Group
MIT Media Lab
20 Ames St.
Cambridge, MA 02139
{amanda, ishii}@media.mit.edu

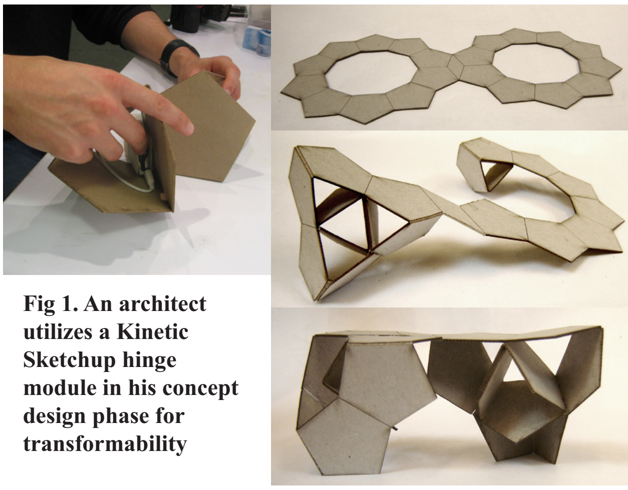


Fig 1. An architect utilizes a Kinetic Sketchup hinge module in his concept design phase for transformability

ABSTRACT
Physical malleability is emerging as an important element of interaction design as advances in material science and computational control give rise to new possibilities in actuated products and transformable environments. However, this transition also produces a new range of design problems- how do we visualize, imagine, and design the physical processes of transformation? We must create tools for intuitive motion investigation to train and develop our motions sensibilities in 3D space, moving towards interfaces that makes sketching with motion as easy as drawing with paper and pencil? This paper presents Kinetic Sketchup, an approach to a design language for motion prototyping featuring a series of actuated physically programmable modules which investigate the rich interplay of mechanical, behavioral and material design parameters which motion enables.

Author Keywords:
Tangible User Interface, Kinetic Design, Transformability, Product Design, Architecture

ACM Classification Keywords:
H.5.2 Prototyping

INTRODUCTION
At its core, the concept of Tangible User Interfaces [5] leverages the idea of using the movement of the body as an inherent part of the human side of a human-computer interaction, assuming that bodily engagement and tactile manipulation can facilitate deeper understanding and more intuitive experiences. Utilizing movement is a natural mapping for interaction, reflecting the fact that human beings possess a deeply rooted response to motion, recognizing innately in it a quality of 'being alive.' However, as an interaction principle in our era of digital design, motion construction and control is in his infancy as a design language, leaving open vast possibilities of utilizing motion's natural ability to draw our attention, provide physical feedback, and convey information through physical change. It is apparent that our relationship with movement, and its transformative properties is starting to be reconsidered and revalued.

Tangible Interfaces utilizing actuation have begin to emerge as a powerful area, from table top actuated interfaces such as PICO [7], or the shape change displays of Lumen [8], allowing the interface to play a more physically active role as a participant in the interaction conversation. In addition, technologies for physical transformability are advancing significantly, such as the reconfigurable robotics of Mark Yim [11],and moving into mainstream products and installations with kinetic behaviorm such as the Roomba, the robotic vacuum [3], or the pioneering architectural transformable structures of Chuck Hoberman [4]. With advances in material science and computational control, we are increasingly able to bring the malleability of the digital world to the physical [9], offering a new design vocabulary for TUIs as described by Poupyrev. However, as we transition to this era of transformable tangible bits, we are encountering a new range of design problems- how do

TEI 2009, February 16–18, 2009, Cambridge, UK.

we visualize, imagine, and design the physical processes of transformation? How do we 'prototype' the metamorphosis of parallel physical computational interactions through time and space? While designers have numerous techniques and tools at their disposal to explore and improve the interaction and appearance of objects, similar methods for modeling transformation through space and time are lacking. The development of physical media which breaks down the perceptual barrier between tools and materials becomes necessary. These media can supply the complexity of computational capabilities embedded in physical materials with intuitive usability. In essence, in order to create new interfaces and objects which allow for physical transformation, we must create the tools to allow designers to think through transformation in a physical medium.

This paper presents Kinetic Sketchup, a methodology for defining the variables, combinations and possibilities of an emerging motion design language and a system of physically programmable modules for motion prototyping in tangible modeling of kinetic design. We focus on the design process of architects and product designers in the belief that tangible tools for computational motion can most relevantly contribute to a new category of products and environments with kinetic behavior.

MOTION & EMOTION

The role of motion in design combines both the practical aspects of transformability, choreographing physical behavior through space and time, as well as the less utilized ideas of the ability of motion to elicit an emotion response from human beings.

It is well known that together form and function inform the product design process, but with digital products, and increasing levels of interactivity and information embedded in such products, digital interaction must also contribute intimately to early stages in the design process. The interconnectedness of form, function, and behavior should determine the development of any computational object. Frens and Djajadiningrat [2] discuss the need for a mechanism which can incorporate digital-mechanical behavior, through sensing and actuation, into the prototyping process, "Programming the behavior of interactive models goes beyond mere definition of the fact that parts of the model move. It is also about how and when they move. It is about the 'feel' of the interaction."

In the design of the 'feel' of motion, lies the power for designers to tap the emotional possibilities of motion. Valentino Braitenberg considers the conceptual significance of objects in motion from both the perspective of external perception and internal invention in his 'vehicles' [1]. He describes a series of thought experiments in which vehicles with simple internal mechanical structures behave in unexpectedly complex ways. Simple motion control mechanisms that generate behaviors that, if we did not already know the principles behind the vehicles' operation, we might call aggression, love, foresight and even optimism. Braitenberg gives this as evidence for the "law of uphill analysis and downhill invention," meaning that it is much more difficult to try to guess internal structure just from the observation of behavior than it is to create the structure that gives the behavior. This idea exemplifies an untapped opportunity for designers - to utilize and exploit the emotional effects of motion while allowing the underlying mechanisms to remain hidden. The challenge lies in the deconstruction of this craft for the designer, to abstract perceptual qualities into a vocabulary of design elements, constructed from an expanding array of new technologies to employ for behavioral transformability.

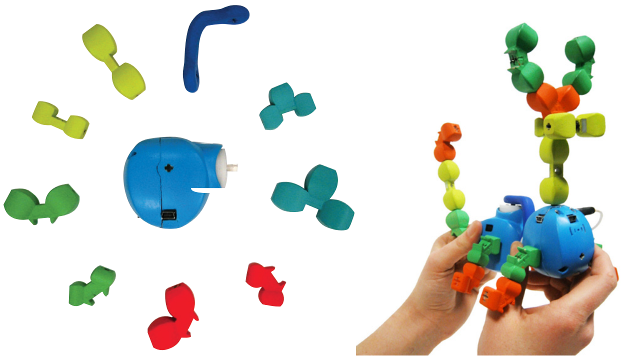


Fig 2. a) The Topobo System: an Active surrounded by Passives b) a Topobo 'moose'

MOTION PRIMITIVES & KINETIC MEMORY

The development of Kinetic Sketchup begins as an extension of the Topobo system. Topobo [10] [Fig.2] is a 3D constructive assembly system with kinetic memory, the ability to record and playback physical motion. Topobo features coincident physical input and output, where physical motion is programmed as a recording of the gestural input of the user. By snapping together a combination of Passive (static) and Active (motorized) components, people can quickly assemble dynamic biomorphic forms like animals and skeletons with Topobo, animate those forms by pushing, pulling, and twisting them, and observe the system repeatedly play back those motions. For example, a dog can be constructed and then taught to gesture and walk by twisting its body and legs. The dog will then repeat those movements and walk repeatedly. Topobo was originally designed to give children an intuitive physical experience learning dynamic physics concepts, such as torque or leverage, and allow them to deconstruct the complexities of creating walking creatures.

However, the idea of 'kinetic memory' speaks to a larger interaction concept, What is it like to sculpt with motion? Can we create tools for intuitive motion investigation to train and develop our motions sensibilities in 3D space, moving

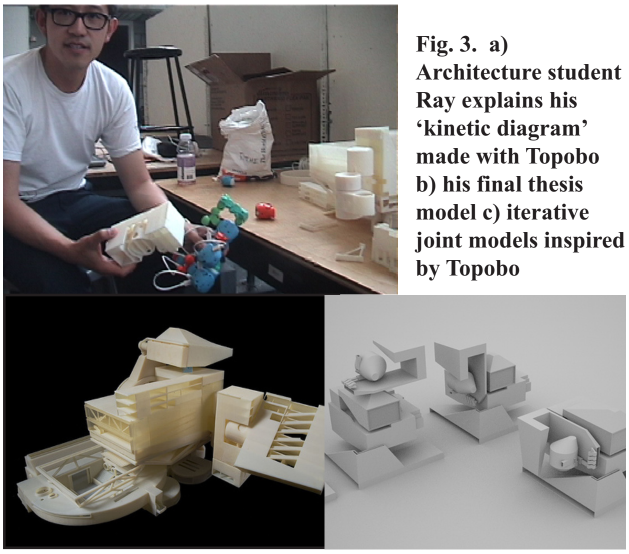


Fig. 3. a) Architecture student Ray explains his 'kinetic diagram' made with Topobo b) his final thesis model c) iterative joint models inspired by Topobo

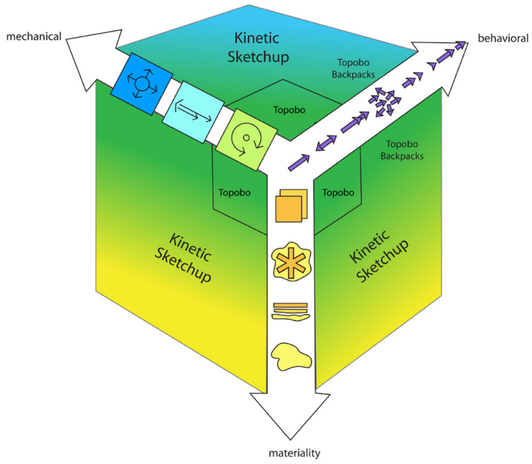


Fig. 4. The Kinetic Prototyping Space: Kinetic Sketchup expands beyond the capabilities of the Topobo Active in differing mechanics, form, mateirlaity and behavioral control

towards an interface that makes sketching with motion as easy as drawing with paper and pen? With its single button interface and gestural recording capabilities, the Topobo Active begins to embody this concept of a motion primitive, a fundamental unit of kinetic memory.

After a round of manufacturing, Topobo was deployed in an extended outreach evaluation, reaching over 100,000 users over 3 years [6]. While that outreach primarily focused on educational initiatives with children, one area focused on a broader conception of Topobo, using it with creative professionals of design, architecture, display and robotics, as a kinetic prototyping material.

Ray, a Master's student in architecture offers a particularly salient story into the potential and complexities of developing tools for motion prototyping. Ray worked with Topobo over six months, utilizing it in the design stages of his Master's thesis project. Ray's thesis work involved the design of a conceptual transformable opera house [fig 3b] which morphs between two physical states, representing two alternate realities. He used Topobo as a kinetic prototyping tool as part of the initial design phases for the project, as he describes, "Topobo was instantly these modular parts which I could bring into a kinetic state for discussion." Ray used Topobo as one medium among many in which he communicated his design, with the most useful part for Topobo being early on in the research, "getting my kinetic idea across." It helped to work with a physical kinetic material first, when thinking about what would work mechanically in space before attempting to draw it on screen.

When discussing the limitations of Topobo and why he had not continued to use it further along in his design process, Ray cited that he felt constrained by form factor and color, specifically the shape of the modules and joints being a single degree of freedom which made his kinetic model bulky and spatially more complex as he had to offset each joint. As he continued with his design, however, he cited one wing of the building's mechanical design being directly inspired by this constraint, "[this area of joints] came about when I had to keep offsetting the Topobo and I noticed that the axis of rotation could be elongated." [fig 3c]. What began as a limitation became part of his design language. He also mentioned the issue of Topobo as a 'polished kit' not offering him the flexibility of a raw material to blend into his model. Behavioral control issues also arose, he used Topobo often to discuss and explain the ideas in his models during critiques. For this, he needed the ability to advance, reverse or replay his motion easily, and on command while speaking, like stepping through the motion composition of his model.

The Topobo Active takes a first step at creating a malleable kinetic prototyping and sketching tool and showed promise as useful in the architectural context. Through interactions with Ray and other designers, however, it became clear, that more variety was needed to offer the appropriate flexibility and inspiration. Expanding the form and capabilities of the system for use in a wider variety of interactions offers the possibility of a extending the kinetic prototyping space beyond the limitations of Topobo [Fig 4] into a new range of physical attributes for quickly expressing and prototyping the language of motion in 3 dimensions.

SYSTEM DESIGN & ITERATIVE EVALUATION

Kinetic Sketchup currently consists of a series of in-progress physical modules representing a cross section of mechanical, material, and behavioral parameters, matched as logical pairings for use in transformable structures of varying scales and purposes. The development of Kinetic Sketchup has been an iterative process working in tandem with a core group of 4 designers (architects and product designers) who are developing concepts of kinetic design. By using the Kinetic Sketchup modules as part of their design process, the designers can explore motion design

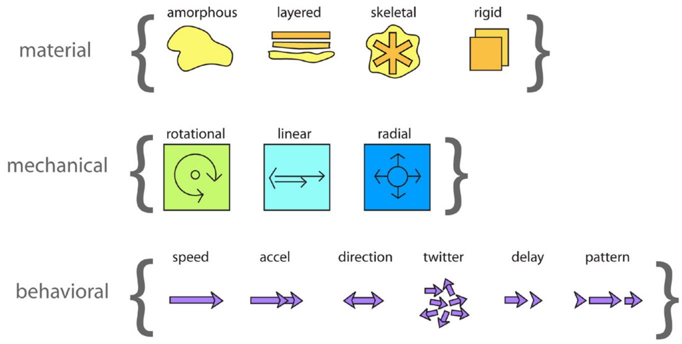


Fig. 5 Kinetic deconstruction into material, mechanical and behavioral properties

with physical intuition and material assumptions as tacit knowledge, much as the children did in the design of walking creatures with Topobo, easing and expanding the process of designing transformation. Through this process, the system continuously undergoes user evaluation in the form of implementations and documentation of the designers' projects. We hope to discover how the design process of the user is altered by use of a new physically programmable tool, in terms of functional characteristics, affordances, collaborative thinking, and the capacity for supporting a creative, expressive and inspirational user experience. In turn, this iterative process inspires, informs and evolves our own process of tool design. We believe this offers a appropriate approach to evaluation, for a system that should be constantly evolving and expanding as we look to establish functionality and usability in a base line set of tools for an emerging design paradigm.

Figure 5 shows a deconstruction of the basic motion design parameters. While many of the parameters can be created by changing/utilizing/combining with others, we have chosen to dissect them out as *perceptually* different. This is important to note as we are creating a tool to stimulate design thinking in a domain that is potentially unfamiliar. For example, presenting a designer with a rigid rotating shaft conjures up very different design possibilities than a telescoping pole or a collapsing fan, although technically they could all be created from the first. As Braitenberg suggested [1], it is important to isolate the perceptual response a motion can trigger, simplifying the mental leap and engineering knowledge necessary to arrive at a potentially new and innovative design solution.

Design Parameters:

Mechanical

Rotational - motion moving around a central axis
Linear - motion expanding outwards in a telescoping
Radial - motion expanding outward and inwards from a central axis

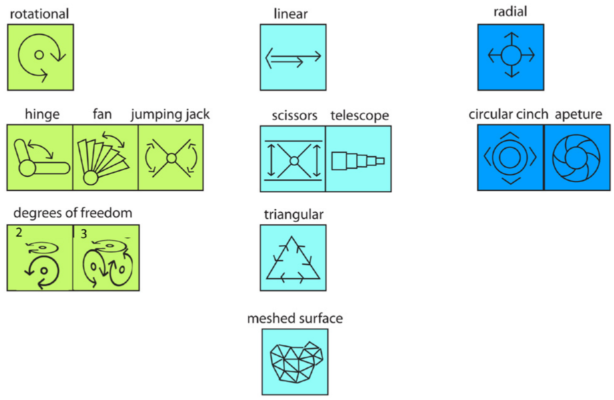


Fig. 6 Combining basic mechancial elements of rotational (left) linear (center) and radial (right) offer expansions into different base modules

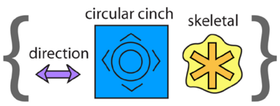
Material

Rigid - solid structural material
Layered - mixture of rigid and flexible materials
Skeletal - structure of rigid interior with malleable exterior (like the skin, muscles and bones of our bodies)
Amorphous - entirely malleable

Behavioral

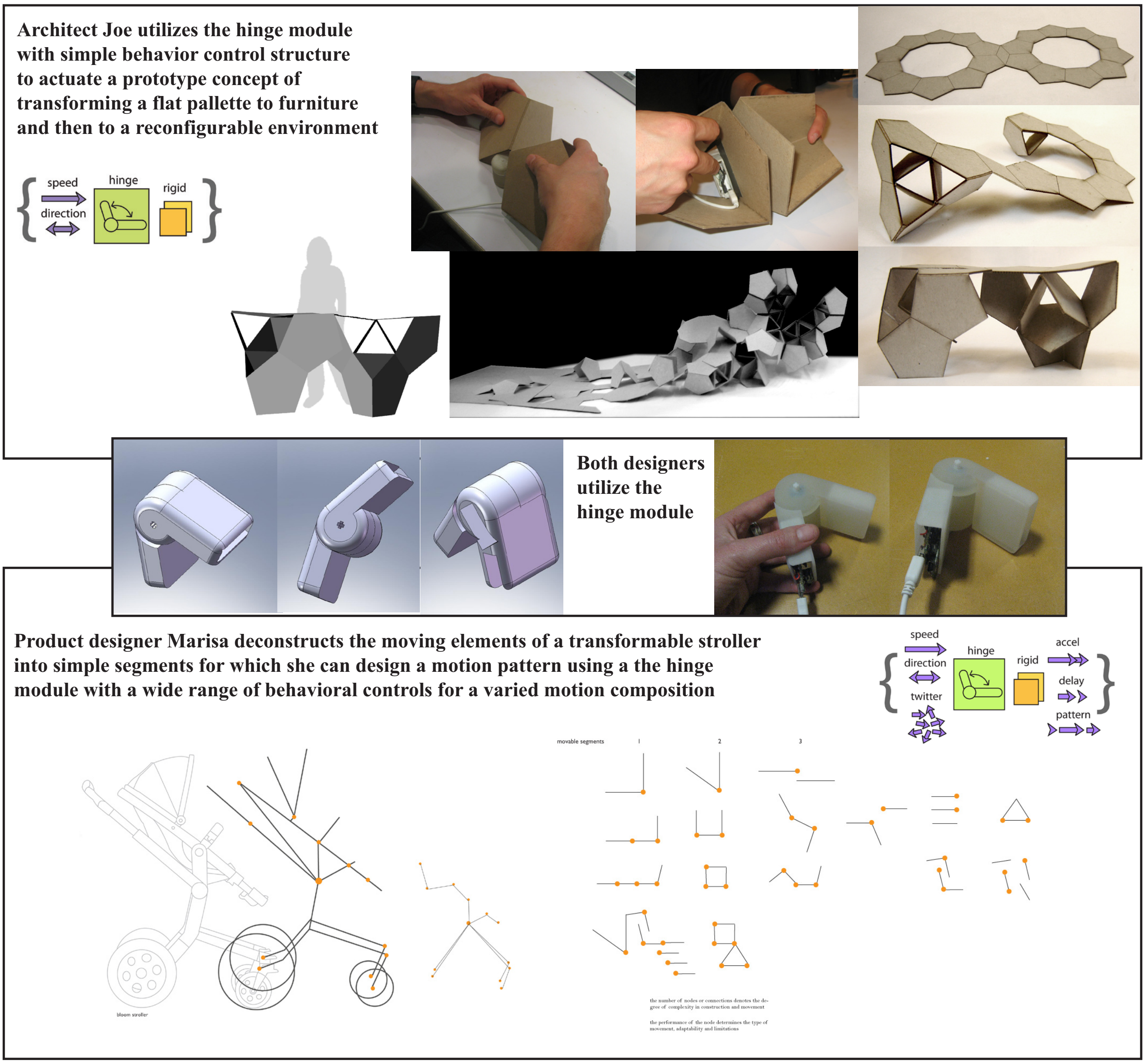
Speed - basic velocity control
Direction - basic directional control
Acceleration- increase or decrease in velocity, can be
Twitter - addition of 'noise' into the motion playback, adding a randomized variability to playpack
Delay- creates an intention pause in playback
Pattern- allowing a motion composition, of combined changes in the first 5 parameters

As a reference, each module can be seen as constructed as a 'motion phrase'. For example, following is the phrase a module of skeletal construction moving radially with simple directional control:



Like Topobo each of the modules in initially programmed to move through gestural recording, with additional playback functionality programmed as sequenced 'double clicks' through the single button interface. Technically, the current modules are built with the hardware system used in Topobo Active, including a custom PCB, custom servo motor and gears, with custom codes for varying behavior functionality. Each module is also outfitted with locations to attach additional parts and materials as necessary in a model prototype (such as threaded holes for screws on the rigid modules. The aesthetic design of each module is meant to be 'minimal', lending itself be incorporated and disappear into the design aesthetic of the structure being prototyped.

Fig 8. Designer Case Studies



Designer Case Studies

The first module to be fully implemented and utilized is the rigid rotational module offering varying levels of behavioral control. Figure 8 describes the projects of architect Joe and product designer Marisa. Joe relies on the hinge for mechanical and behavioral simplicity, bringing complexity and interest to his model through the 3 dimensional physicality he is exploring. Joe noted that earlier he had attempted to use servo motors to construct a system such as this and had difficulty envisioning the transitions of folds. Marisa deconstructed her stroller design into rotational axis points which are interconnected on a single flat plane. By isolating these elements and limiting mechanical complexity, she was able to focus on the behavioral and motion choreographing capabilities of the hinge module, setting up pattern sequences and observing the detailed differentiations which small shifts in motion design can create.

CONTINUED DEVELOPMENT

Figure 11 show two modules currently in development, the telescoping (linear) rigid module and the rigid aperture module. The next modules developed will move into material explorations of layered and skeletal material compositions, looking to explore the issues of soft mechanics. For these modules a new hardware will be implemented using bend sensors for sensing motion input and shape memory alloy (nitinol) for actuated output.

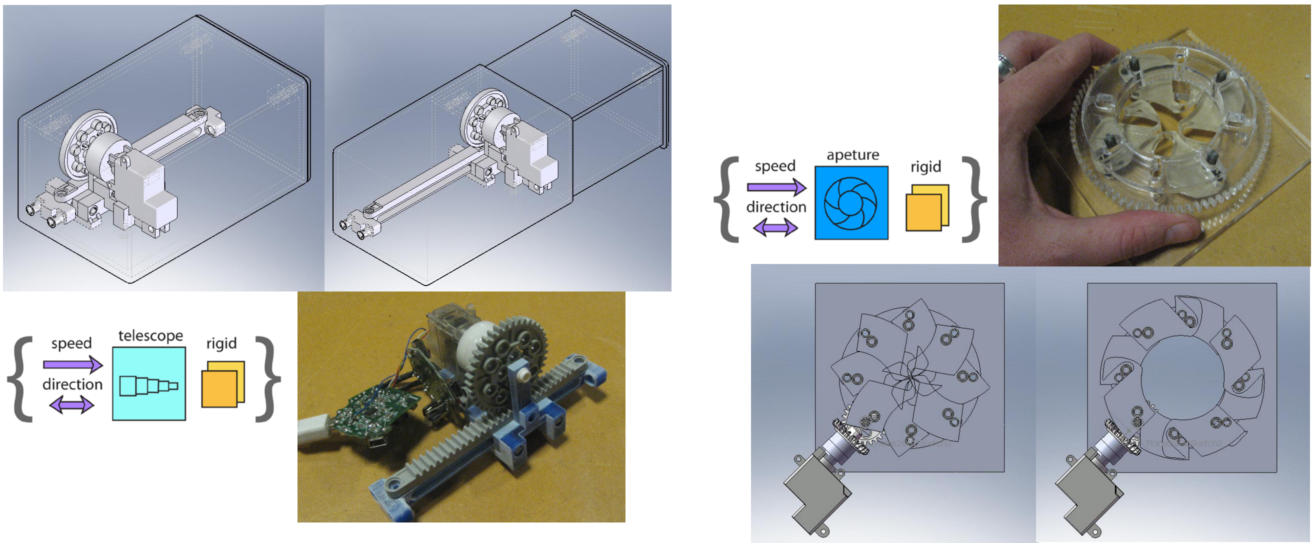


Fig 11. Mechanical design drawings and prototypes of the a) telescoping module b) aperture module

CONCLUSION

Advances in material science, actuation, nanotechnology are opening Tangible Media to new possibilities, with the power to make atoms dance with computational control, programming matter with the flexibility of programming pixels. This new genre of interface design builds on the principles of direct manipulation, engaging the hands and body fluidly and intuitively while allowing the interface to play a more physically active role as a participant in the interaction conversation. This vision predicts a future of human-computer interaction where any object, no matter how complex, dynamic or flexible its structure, can display, embody and respond to information, and a design paradigm where we think no longer of designing the interface, but think of the interface as a material itself.

In order to reach a future with an ease of physical malleability in our structures, products, and environments, we must first enable designers to develop sophisticated motions sensibilities in 3D space. The depth and richness of the perceptual and functional qualities which motion can elicit are clear, Kinetic Sketchup seeks to provide a path to visualize, imagine, design and understand the physical processes of transformation.

ACKNOWLEDGEMENTS

We would like to thank John Pugh, Kostas Terzidis, Adrian Adames, Jonathan Frazier, and Jonathan Sue-Ho and members of the Tangible Media Group.

REFERENCES

1. Braitenberg, Valentino. Vehicles: Experiments in Synthetic Psychology. Cambridge, MIT Press, 1984.
2. Frens, J. W., J. P. Djajadiningrat and Overbeeke, C. J. (2003). Form, Interaction and Function, An Exploratorium for Interactive Products. Proceedings of the Journal of the Asian International Design Conference Vol. 1, Tsukuba, Japan, CD-Rom ISSN 1348-7817.
3. Forlizzi, J. How robotic products become social products: an ethnographic study of cleaning in the home. Proceedings of HRI 2007, ACM Press, 2007.
4. Hoberman, Chuck. Emergent Surface, 2008. http://www.hoberman.com
5. Ishii, H. and Ullmer, B. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. Proceedings of CHI'97, ACM Press, (1997), 234-241.
6. Parkes, A., Raffle, H., Ishii, H. Topobo in the Wild: Longitudinal Evaluations of Educators Appropriating a Tangible Interface. Proceedings of CHI 08. ACM Press (2008).
7. Patten, J. Ishii, H. Mechanical Constraints as Computational Constrants. Proceedings of CHI 2007. ACM Press (2007).
8. Poupyrev, I., Nashida, T., Maruyama, S., Rekimoto, J., Yamaji, Y. Lumen: Interactive Visual and Shape Display for Calm Computing. SIGGRAPH 2004 Emerging Technnologies, ACM Press (2004).
9. Poupyrev, I., Nashida, T., Okabe, M. Actuation and Tangible User Interfaces: the Vaucanson Duck, Robots, and Shape Displays. Proceedings of TEI'07. 2007: ACM: pp. 205-212
10. Raffle, H. Parkes, A. Ishii, H. Topobo: A Constructive Assembly System with Kinetic Memory. Proceedings of CHI 04. ACM Press, (2004), 869-877.
11. Yim et al. Modular Self-Reconfigurable Robot Systems. Robots and Automation Magazine, March 2007. Vol. 14(1). 43-52.