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# TRANSFORM: Embodiment of “Radical Atoms” at Milano Design Week

**Hiroshi Ishii**

MIT Media Lab  
75 Amherst Street  
Cambridge, MA 02139 USA  
ishii@media.mit.edu

**Daniel Leithinger**

MIT Media Lab  
75 Amherst Street  
Cambridge, MA 02139 USA  
daniell@media.mit.edu

**Sean Follmer**

MIT Media Lab  
75 Amherst Street  
Cambridge, MA 02139 USA  
sean@media.mit.edu

**Amit Zoran**

MIT Media Lab  
75 Amherst Street  
Cambridge, MA 02139 USA  
amitz@media.mit.edu

**Philipp Schoessler**

MIT Media Lab  
75 Amherst Street  
Cambridge, MA 02139 USA  
phil\_s@media.mit.edu

**Jared Counts**

MIT Media Lab  
75 Amherst Street  
Cambridge, MA 02139 USA  
jcounts@mit.edu

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ACM 978-1-4503-3146-3/15/04...\$15.00.

<http://dx.doi.org/10.1145/2702613.2702969>

**Abstract**

TRANSFORM fuses technology and design to celebrate the transformation from a piece of static furniture to a dynamic machine driven by streams of data and energy. TRANSFORM aims to inspire viewers with unexpected transformations, as well as the aesthetics of a complex machine in motion. This paper describes the concept, engine, product, and motion design of TRANSFORM, which was first exhibited at LEXUS DESIGN AMAZING 2014 MILAN in April 2014.

**Author Keywords**

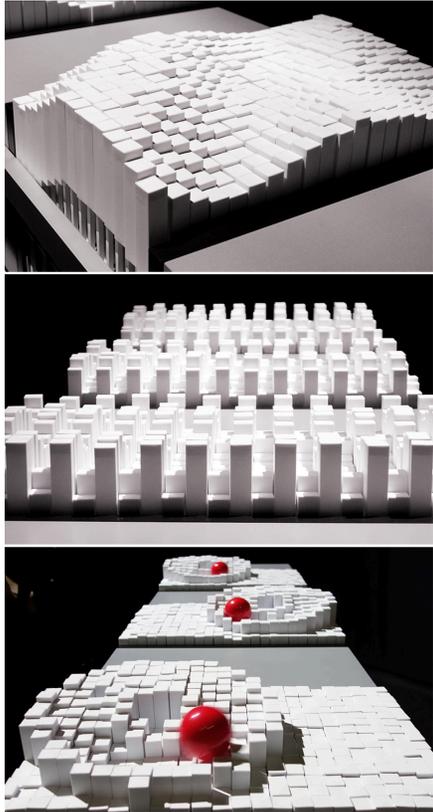
Tangible User Interfaces; Radical Atoms; Shape Display; Shape Changing Interfaces; Design.

**ACM Classification Keywords**

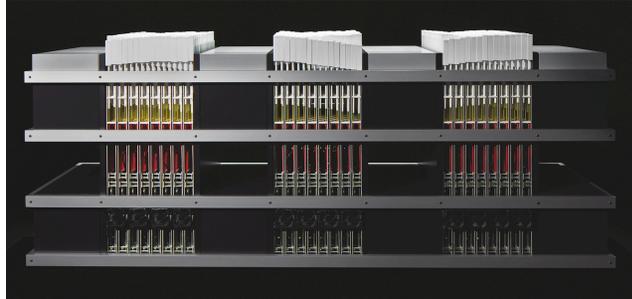
H.5.2. Information interfaces and presentation: User Interfaces.

**Introduction**

“Radical Atoms” is our vision of human interaction with dynamic, computationally reconfigurable and transformable shape-changing materials [3]. Hypothetically, these materials can reflect dynamic changes in digital information through a dynamic change in physical state. “TRANSFORM” embodies this vision through a new type of dynamic physical and computational material [2]. Exhibited at the Milano



**Figure 2.** TRANSFORM three Application Modes (from top to bottom: Wave, Machine, Escher)



**Figure 1.** TRANSFORM side view

Design Week 2014 [7], TRANSFORM was created to challenge the conventional notion of static furniture design, thus freeing designers from frozen passive materials to give dynamic form to their ideas. No longer would designers and creators need to decide between either of the following two material options:

1. inert, frozen, passive physical materials like wood, metal, glass and plastic
2. dynamic, yet virtual and intangible pixels trapped behind a 2D flat ubiquitous screen.

Radical Atoms represent a fusion of the tangible and computational, in essence a third type of material that lies at the intersection between “frozen atoms” and “dancing pixels”, which we describe as “dancing atoms.” This case study details the TRANSFORM design process for the Milano exhibit to demonstrate the potential of Radical Atoms as a new medium for design, artistic expression and storytelling. Additionally, TRANSFORM exemplifies our “Trans-Disciplinary” approach that fuses art, design, science and technology into a coherent stream in the creative process.

## Overview

TRANSFORM is comprised of three dynamic shape displays (inFORM [1][6]) that move over one thousand pins up and down in real-time to reshape the tabletop into a dynamic, tangible display. The kinetic energy of the viewers, captured by sensors, drives the wave motion represented by the dynamic pins.

TRANSFORM was featured at LEXUS DESIGN AMAZING 2014 MILAN in April 2014 [7] (during the Milano Design Week). During that time, over 5,000 people visited the venue and interacted with TRANSFORM. From observing the visitors’ interactions with both the dynamic wave and the pre-scripted narrative of “Nature and Machine,” it became clear that TRANSFORM holds immense potential as a medium for artistic expression and storytelling through the power of physicality and dynamic computation.

TRANSFORM is a custom designed table with 3 embedded inFORM shape displays. Each display provides 24 x 16 pins, for a total of 1,152 pins. Fig. 1 shows the overall structure of TRANSFORM and the three representational application modes: Wave, Machine, and Escher (Fig. 2).

1. The Wave mode allows users to interact through the motion of their hands, arms, and bodies to energize the “water.”
2. The Machine mode, which is pre-scripted, illustrates the story of “Nature and Machine.”
3. The Escher mode demonstrates “inter-material interactions” through the “dance” with inert passive materials (red balls).

This paper outlines the historical context of Radical Atoms, and describes the TRANSFORM design in four areas: Concept, Engine, Product, and Motion. Then, we discuss the implication of TRANSFORM as a new medium for expression and communication, as well as a model for vision-driven HCI research.

### From Tangible Bits toward Radical Atoms

TRANSFORM is the latest instance of Radical Atoms [3] evolved from the Tangible Bits [5] vision. Fig. 3 illustrates the trajectory of a wide variety of our projects that evolved from frozen passive tangibles (Tangible Bits) toward active and kinetic tangibles (Radical Atoms) in the past two decades.

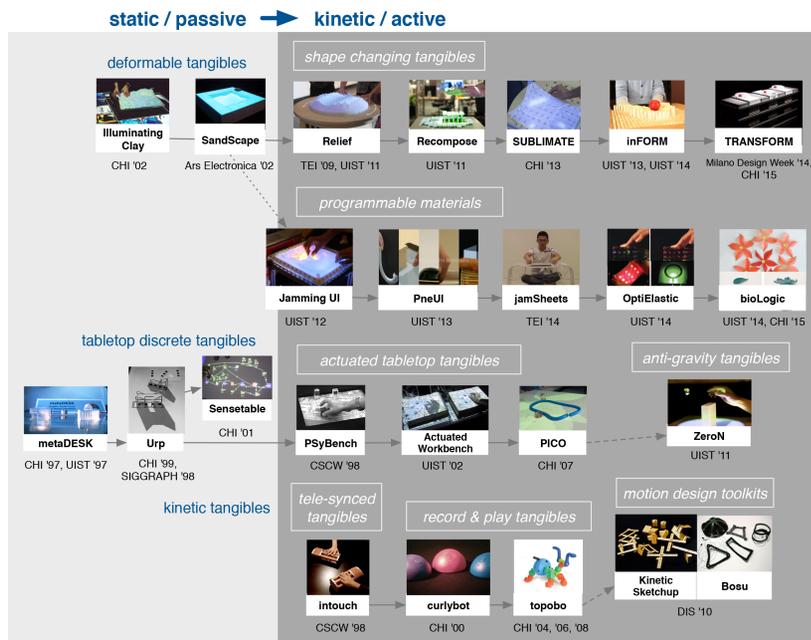


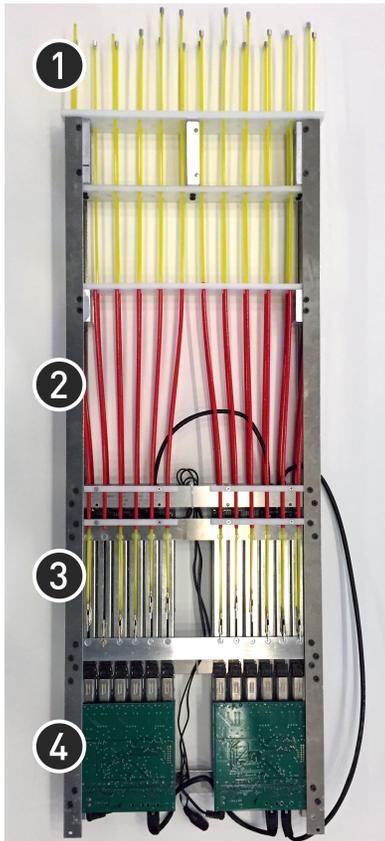
Figure 3. Evolution from Tangible Bits towards Radical Atoms

Form giving is the domain of our interests, and we designed Illuminating Clay and SandScape [4] for landscape design integrating manual sculpting and computational analysis into a single tangible media: clay and sand. While they represent the spirit of Tangible Bits, the clay and sand do not have any memory of shape nor the capability to display dynamic changes, like mountain formations or erosions. This, in turn, prompted us, to move towards the Radical Atoms projects including Relief, Recompose, inFORM, and TRANSFORM. They not only afford sculpting with our hands, but the shape can change in real-time using computation as the driving force.

### Concept Design

TRANSFORM echoes the concept of "Amazing in Motion," a core message for LEXUS International, our collaborator on this project, by fusing technology and design to celebrate its transformation from a piece of still material to a dynamic machine. In parallel with LEXUS' philosophy of "intriguing elegance through careful juxtaposition of opposing elements" [8], TRANSFORM aims to inspire viewers through its unexpected transformations and aesthetics of a complex machine in motion. To create TRANSFORM, we interpreted this philosophy as a collision of three pairs of ideas: 1) Design & Technology, 2) Stillness & Motion, and 3) Atoms & Bits.

Furniture design typically focuses on the aesthetics of the surfaces of still objects. In contrast, dynamic engines possess a beauty in the movement of the machine, which may not be compatible with the beauty of still objects. For TRANSFORM, we integrated the three inFORM engines into a table without covering any of the components to reveal the moving parts of the



**Figure 4.** Single engine module (2 x 12 pins).

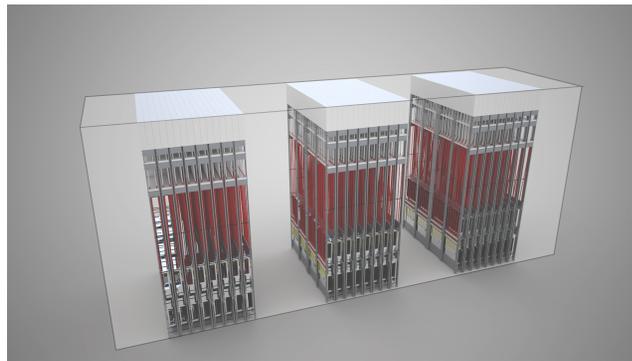
- 1) nylon rods that attach to the styrene pins
- 2) plastic housing
- 3) slide potentiometers
- 4) control boards

machine. We juxtaposed the visible pistons and wiring, that is the blood vessels of the machine's body, with the visual aesthetics of the tabletop to create tension and contrast.

We also focused on the dramatic transformation from a static state into a dynamic machine. We begin with a quiet water surface and schools of swimming fish. This then transforms into two dynamic modes: an interactive mode responding to arm and hand movement and generating waves, and another pre-scripted mode telling a dynamic story illustrated through fluid surface movements [2].

### Engine Design

The engine design was led by Daniel Leithinger and Sean Follmer, based on their experiences with inFORM's design and implementation [1][6].



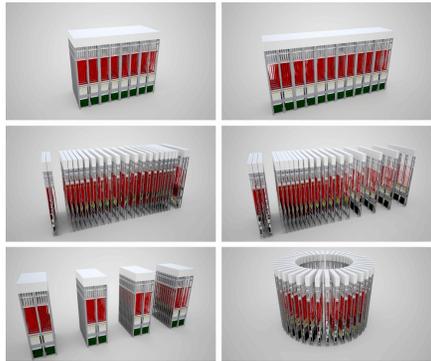
**Figure 5.** Placement drawing of the three shape changing islands

TRANSFORM is a platform based on actuator modules with 12 X 2 styrene pins covering an area of 305 X 50.8 mm, which extends up to 100 mm from the surface

(Fig. 4). The individual actuators and control boards are the same as those used in our previous inFORM System [6]. The modules can be seamlessly combined to form a larger shape display surface. We created three shape displays, 16 x 24 pins each, covering an area of 406.4 x 610 mm (Fig. 5). The shape display hardware uses custom Arduino boards that run a PID controller to sense and move the positions of 6 connected styrene pins through motorized slide potentiometers. Six slide potentiometers are then mounted onto a custom-designed PCB, powered by an Atmel ATmega 2560, and TB6612FNGCT-ND motor drivers. The linear positions are read by the 10-bit A/D converters on the microcontroller, and allow for user input, in addition to serving their position using PID control. Push-Pull rods are used to link each pin with an actuator, thus allowing for a dense pin arrangement independent of actuator size. The linkage, a nylon rod inside a plastic housing (Sullivan Gold-N-Rods), transmits bi-directional force from a motorized slide potentiometer (ALPS RSA0N11M9A07) through a bend.

The boards communicate with a PC over six RS485 buses bridged to USB. The system has a 60 Hz refresh rate, determined by the 115200 bps RS485 bus speed, the 8 byte control message, and 30 boards on each RS485 bus.

Our applications are written in C++/OpenFrameworks and support 3D models (OBJ) and grayscale images as content. The application renders a depth image, which is sent to the shape display over USB to RS485. This can be updated over 60 frames per second.



**Figure 6.** Early engine configuration renderings

## Product Design

TRANSFORM's enclosure design was led by Amit Zoran. Our design challenge was to strike a balance between two very different requirements: (1) technical constraints to house the engines composed of 1,152 actuated pins and motors, and (2) communication of our high level concepts of "collision & fusion of design & technology" through unique aesthetics.

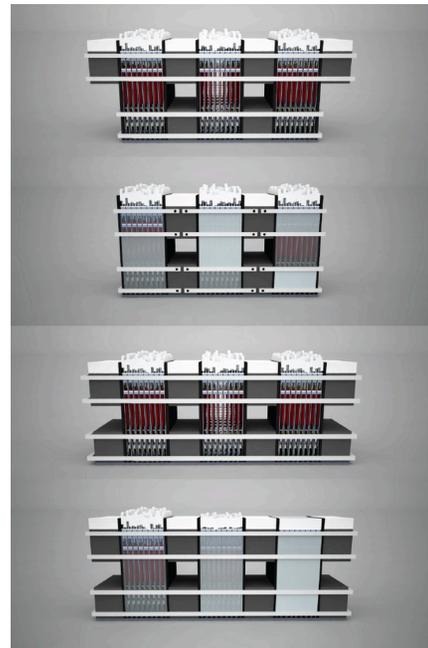
We structured our design process around three stages: (1) overall architecture of the motors and their distribution in space, (2) high-level design of TRANSFORM, and (3) detailed design for fabrication by outsourcing our illustrations to a furniture fabricator to prepare for the final fabrication of TRANSFORM itself.

### *TRANSFORM engine architecture*

The first major design decision we made centered on how to distribute and arrange approximately 1,152 pins & motors, packed into units of 24 components each.

To illustrate the visual effect of different configurations, we generated renderings using Rhino (CAD environment) and V-Ray (a rendering plug-in to Rhino), evaluating 6 different alternatives (Fig. 6).

We converged onto a triple-island architecture, which most ideally satisfied several criteria: (1) unified distance and continuous pin matrices for easier control (i.e., "islands"); (2) relatively large resolution for each independent island; and (3) a wider top surface than the amount of pins actually produced (by splitting the pins).



**Figure 7.** Early product design concept renderings

### *TRANSFORM product concept design*

After converging onto the triple-island architecture, we explored several different concept designs using Rhino and V-Ray. We considered a "conservative" design with a traditional kitchen aesthetic, a "mechanistic" design that amplifies the aesthetic of the engine qualities; a "minimalistic" design; and finally a "freeform manifold" design. Each concept highlights a different quality of TRANSFORM, all using a long horizontal structure to contrast the pins' vertical motion axis, in order to accentuate the dynamic quality of the furniture. Fig. 7 shows rendering examples produced at this stage.

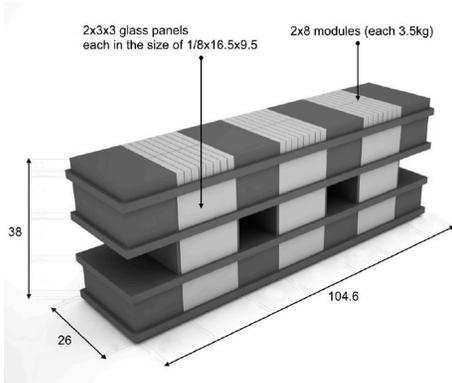
The selected design is a modification of the "minimalistic" concept, with extended top and bottom panels. We ultimately fine tuned the color selection until it converged upon the final result, thus creating a separation between the three engine sections, and aesthetically separating the top pin area from the furniture body.

### *TRANSFORM detailed design*

The detailed design by the furniture fabricator includes screw holes, connectors, material selection and assembly drawings. The final TRANSFORM construction was made from a laminated and painted MDF structure, an aluminum base and external supports, and a corian top. TRANSFORM is a modular construction that can be easily assembled and disassembled, thus hiding its structure (Fig. 8).

## Motion Design

The motion design is inspired by the metaphors of dynamic interactions among wind, water and sand in nature, Escher's representations of perpetual motion, and the attributes of sand castles built at the seashore.



**Figure 8.** TRANSFORM dimensions

Philipp Schoessler and Hiroshi Ishii took a lead on the motion design process and the narrative behind it. Jared Counts contributed to the motion design of Nature Mode including the wave and fish.

After generating many ideas on possible motions and the metaphors behind them, we narrowed the design space by clustering and organizing the best ideas into a coherent narrative. This can be illustrated by the story of the conflict between nature and machine, and their reconciliation, through the ever-changing tabletop landscape (<http://vimeo.com/98880732>).

Our design criteria were: 1) avoid overwhelming the visitor, 2) showcase interactivity, 3) showcase inter-material interaction, 4) emphasize the idea of dancing atoms, and 5) play with juxtaposing opposing elements. We developed the following three distinct modes:

#### *Nature Mode*

To embody nature, we created an interactive wave simulation on the TRANSFORM. Visitors can influence the wave amplitude and direction by waving their hands above TRANSFORM as if they were creating wind. The visitor's movements are detected using a Microsoft Kinect mounted 4 m above TRANSFORM. To emphasize the notion of TRANSFORM being a reactive piece of furniture, we also detected approaching visitors who could influence the waves' movements.

For the times when no visitors approached TRANSFORM, we implemented a school of fish simulation (idle mode). These shy creatures would appear and roam the TRANSFORM surface until someone approached the table. This would then trigger

the creatures to scatter away leaving behind ripples encouraging the visitor to further interact with the waves.

#### *Machine Mode*

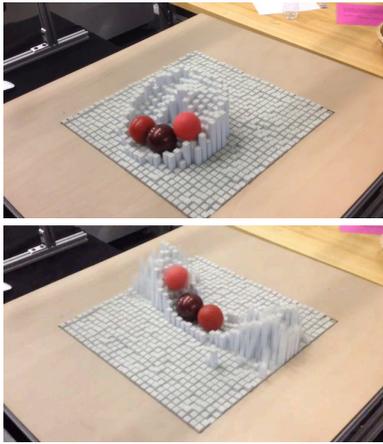
We also implemented a scripted choreography / animation that is pleasing to watch but also tells a story. Here we give a short description of the 1 min 30 sec-long choreography, its story and movements.

The animation begins by displaying pistons that start appearing out of the slowly receding water (interactivity stops). The machine tries to copy nature's waves out of jealousy for its beauty, eventually managing to recreate waves. It then starts building castles near the seashore modeled after an ancient city. The waves reclaim their right by washing away the castles as civilization declines. In the end it shows that nature is stronger than the machine and will therefore always reclaim its space.

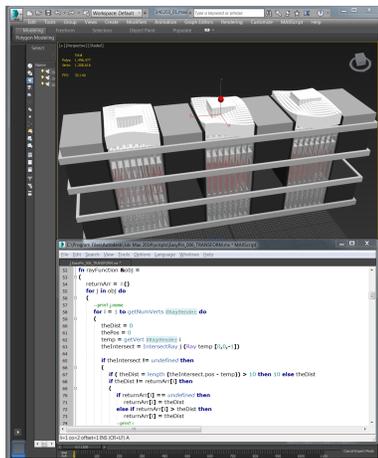
The purpose here was not to tell a literal story, but in the way a ballet tells an abstract story through the beauty of motion.

#### *Escher Mode*

We were inspired by Escher's irregular and impossible geometrical paintings and tried to recreate those concepts using kinetic movement. We created a perpetually moving circle that provides a pocket for a red ball. The red ball symbolizes our inert frozen passive materials that, with the assistance of radical atoms (pins), start to move in a controlled manner. The ball moves around the circle for one full rotation before the circle opens up only to flip and close again and



**Figure 9.** Kinetic experiments for Escher mode on the inFORM



**Figure 10.** 3D simulation environment for generating real time physical movements on the TRANSFORM

thereby reversing the balls movement and creating a kinetic perpetual loop.

### *Experiments on inFORM*

Since hardware and software had to be developed in parallel to meet tight deadlines, there was minimal time to test out ideas on the actual TRANSFORM. To ensure the ideas would work, a fair amount of ideation and testing was done using the inFORM (Fig. 9), which informed the final displayed content.

### *Software Tools*

Given the relative novelty of shape displays as an interaction medium, there are no readily available tools for quick and easy content production. This led us to develop our own software pipeline for prototyping and production.

Rendering shapes on TRANSFORM uses 102 x 24 pixel 8 bit gray-scale images, where full white will drive the pin to its highest position and black to its lowest. Although this data format allows us to easily create 2.5D shapes using 2D graphics editors (e.g. Adobe Photoshop, AfterEffects), designing 2.5D motion using only gray scale graphics proved unintuitive and thus inefficient.

As a result, we switched to 3ds Max, a professional 3D animation and rendering application, as our main content creation tool. 3ds Max provides all tools necessary to create shapes and animations and displays them on the screen in real-time. We could then render the necessary 8-bit image files by creating a special render setup that interpreted the distance of the virtual camera's height to the geometry as a value ranging from 0 - 255. Additionally, we created a tool

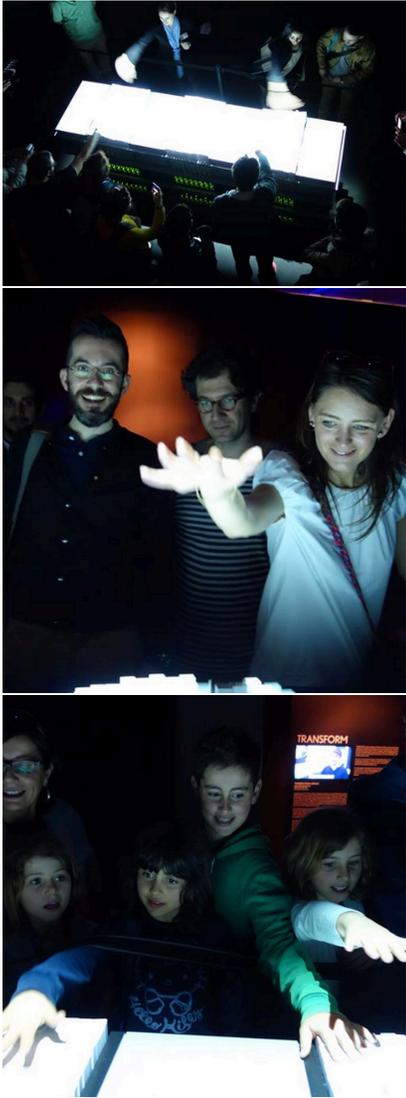
that would display the created 3d shapes on TRANSFORM in real-time using MAXScript (Fig. 10). This proved to be particularly useful, especially for fine-tuning and testing the Escher Mode.

### **Experience at the Exhibition in Milano**

We exhibited TRANSFORM at the LEXUS DESIGN AMAZING 2014 MILAN venue at Circolo Filologico Milanese, Via Clerici, 10, Milano, 20121 Milan, Italy [7]. Over the course of the exhibition (April 8th - 13th) we had the chance to observe more than five thousand visitors interacting with TRANSFORM. In general, reactions were extremely positive (Fig. 11). Since the Milano Design Week is known for static furniture design, TRANSFORM presented an entirely new experience for most of the visitors, which contributed to their enthusiastic reaction.

At the same time, we noticed that many visitors were not expecting interactivity and needed to be encouraged by a guide to step closer to interact with TRANSFORM (Wave and Fish Mode). Upon realization that they could play an active role in the furniture's transformation, visitors appeared delighted and amazed. Some talked to us about their own ideas of transformable furniture inspired by our exhibit.

TRANSFORM also demonstrated immense potential of dynamic shape changing materials for artistic expression. The Machine Mode as well as the Escher Mode were probably the most photographed and filmed parts of the scenario. The moment when the red balls started dancing on TRANSFORM particularly inspired people.



**Figure 11.** Impressions of visitors experiencing TRANSFORM in Milano

## Conclusion

We have illustrated the creation and development process for “TRANSFORM”. The goal was to demonstrate and disseminate our vision of Radical Atoms through artistic expression and storytelling in the context of the Milano exhibit. We believe that TRANSFORM is equivalent to the invention of a new medium such as the canvas and paintbrush, or the screen and pixels, that can communicate the ideas and stories through dynamic physical embodiment. The story “Nature and Machine” is one of thousands of possible stories to be told through this medium. We hope to inspire the participants who experienced TRANSFORM to begin telling their own stories using a variation of Radical Atoms in the near future.

TRANSFORM exemplifies the deep coupling of Atoms (physical materials) and Bits (digital information and computation) to materialize the vision of Radical Atoms. TRANSFORM is designed to communicate the ideas to the creators of tomorrow: “Today pixels can dance behind screens, but tomorrow, atoms will start dancing in our physical space”.

While we may need to wait decades before atom hackers (material scientists or self-organizing nano-robot engineers) invent the ideal enabling technologies for Radical Atoms, we believe the exploration of interaction design techniques driven by this future vision can begin today.

## Acknowledgements

The authors express thanks to Mr. T. Kawabe and LEXUS International for their support and sponsorship of TRANSFORM project for Milano Design Week. We would also like to thank Hakuhodo and DNP for their

help in the planning and coordination. We thank B. Tome and F. Heibeck for their design support, M. Tran Niskala for project coordination, H. Kim, P. Aguilera and J. Williams for media production, D. Doan for mechanical engineering, Patten Studio (J. Patten & J. Lusker) for PCB design and assembly, M. Miller for software development, Furniture Design Services (C. Rice & M. Atkinson) for enclosure fabrication.

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