Chapter 7:

Related Prototypes

Starting in the 1970s, a few researchers experimented with physical interfaces to CAD in the form of rigid blocks. Recent related projects have embedded computing technology into blocks, flexible plastic, flexible tape, and fabric, all of which provide a basis for further work in smart sculptural materials. New technology research points to a more fluid coupling and uncoupling of media types. Tangible and augmented reality interfaces depend a great deal on sensors, which are rapidly becoming smaller, cheaper, and more capable.

Below is a survey of prototypes that relate directly to the field of three-dimensional creative design. Many other recent interface prototypes mix computation and physical artifacts but do not relate directly to the topic of three-dimensional design, so they are not included here.

7.1 Construction Kits

Several research efforts have produced construction kits that have computational capability embedded in the components. In each case, the blocks communicate with each other to identify proximity. Using that information, with given shapes and sizes, some derive position. The first three prototypes described below (Universal Constructor, Physical Construction Kit, and ActiveCube) can be considered input devices. The last two prototypes (Programmable Brick and Triangles) can be categorized as output devices.

Starting in the late 1970s, Aish and Noakes [1] implemented a "building block system," and Frazer [2] produced a series of intelligent modeling kits for interactively representing the structural and thermal properties of buildings. Frazer's **Universal Constructor** consisted of sensor-augmented smart blocks. The sizes and shapes of these blocks were known, the sensors embedded in the blocks reported back positional information, and a real-time digital model of evolving configurations of blocks was maintained. It was used to represent abstract systems such as cellular automata.

Along a similar track, **Physical Construction Kit** [3], developed by the Mitsubishi Electronic Research Lab in 2000, is a sophisticated building block method allowing LEGO-sized blocks to be assembled into arbitrary forms. The position of the blocks in an assembly, which can be as large as 560 blocks, is sensed by the computer and displayed as a three-dimensional CAD model.

ActiveCube [4], developed at Osaba University (Japan) in 2001, is another construction kit of identical cubes, each equipped with a processor for autonomous communication between cubes. A sensor and a display/actuator output channel communicate to a desktop computer, and a virtual model of the cubes' configuration is displayed in real time. ActiveCube was designed to be a children's toy. All three of the above projects provide a physical interface to virtual model, but are significantly limited by the fixed nature of the blocks.

The Lifelong Kindergarten Group at the MIT Media Lab has developed learning construction kits that they call "digital manipulatives." [5] **Programmable Bricks,** begun in early 90s, are Lego blocks that have input ports for receiving information from light, touch, and temperature sensors, and output ports for controlling motors and lights. A computer program written in Logo can be downloaded to a "programmable brick" from a desktop computer. A newer version of Programmable Bricks, called **Crickets,** was developed in 2000. Each "cricket" contains a Microchip PIC processor capable of two-way infrared communication. Children can use Crickets to create communities of robotic creatures that interact with each other.

In a similar vein, **Triangles** [6] is a physical/digital construction kit, prototyped by the Tangible Media Group at the MIT Media Lab from 1998 to 1999. It consists of a set of identical, flat plastic triangles, each with a microprocessor inside and magnetic edge connectors. The connectors physically attach the triangles to each other, which allows data to pass from triangle to triangle. A wire connects the triangles to a desktop computer. Triangles can be programmed from the desktop computer and has been used for nonlinear storytelling games, as a configuration interface for media events, and by artists for personal expression. Triangles and Programmable Bricks are examples of embedded computation in rearrangable blocks.

7.2 Smart Sculptural Materials

Taking computer-enhanced physical materials beyond discrete, modular forms, Orth [7], in the Opera of the Future Group at the MIT Media Lab, has attempted to develop what she calls "**smart sculptural computing materials,**" which are plastic, soft, and malleable. From 1997 to 2001, she experimented extensively with fabrics to discover ways to embed them with computation. In the process of developing a number of soft fabric interfaces for musical instruments, she has developed a fabric keypad, a new conductive yarn capable of tying an electro/mechanical knot, and an advanced process for machine embroidery to create highly conductive and visually diverse electrodes.

7.3 Tangible User Interfaces

Neurosurgical Interface [8], created in 1994 by Hinckly, uses a position-tracked doll's head and knife to allow users to dissect a graphical representation of the brain. The complex three-dimensional structure of the brain can be intuitively explored by physical manipulation of the knife and the doll's head. Experiments initially used a sphere to represent the head, but a doll's head gave better tactile and visual cues about the orientation of the head.

The concept called **Graspable User Interfaces** was introduced by Fitzmaurice et al., [9] in 1995. These interfaces use physical artifacts, which they call "bricks," to directly control virtual objects. The bricks are new input devices that are tightly coupled to the virtual objects. They operate on top of a large horizontal display surface known as **ActiveDesk.**

Sinclair's **Haptic Lens** [10], developed in 1997, is a half-inch-thick elastic surface that maps deformations by pressure. For sensing, it uses a low-resolution three-dimensional surface digitizer that consists of an easily compressible elastometer bounded on one side by an opaque white deformable membrane and on the other by a clear rigid faceplate. It can be used to scan the surface of small physical objects by pressing them against the input membrane. One can also manually manipulate the membrane to directly edit virtual surfaces.

Underkoffler's **Urp** [11], ongoing since 1997, is a tangible workbench for urban planning. Part of his **Luminous Room** project at the MIT Tangible Media Group, it captures two-dimensional locations of buildings in a real-time city planning simulation. Interaction is by direct manipulation of three-dimensional architectural models that sit on a two-dimensional surface and act as representations/controls for the underlying simulation. The architectural models cast accurate shadows and reflections or divert simulated airflow in the form of two-dimensional computer graphics projected directly onto the physical model. The buildings are marked by unique colored dot patterns discernible by simple image-recognition algorithms. A video camera continuously tracks the dot-pattern positions so that the computer graphics can be accurately registered to the buildings.

Limitations of Urp include parts of the model being blocked from the viewpoint of the projector; these appear to be in shadow, and no information is projected upon them. Also, the user's hands can cast shadows onto the model. It should be possible to essentially overcome these difficulties in future versions, by using multiple cameras and projectors.

In 1999, Balakrishnan, et el., [12] introduced a **bendable strip** for inputting curves to three-dimensional modeling software.

HandSCAPE [13] is a tangible interface prototype developed in 1999 by Lee of the Tangible Media Group at the MIT Media Lab. It is an orientation-aware, digitally augmented measuring tape that can serve as a simple input device for generating digital models from straightedged physical objects. Like a traditional measuring tape, it measures length. In addition, an orientation sensor allows vector measurement.

Illuminating Clay [14] was developed by Ishii, Piper, and Ratti at the MIT Tangible Media Group from 2001 to 2002. (See section 8.1 "Description of Illuminating Clay.")

SandScape [15], developed by Wang, et al. at the MIT Tangible Media Group in 2002, builds upon URP and Illuminating Clay. The user alters a landscape model consisting of sand in a shallow box, while seeing the resulting computational analysis projected on to the surface of the sand in real time. The system works by capturing the surface geometry of the sand model, which is lit from underneath with a powerful source of infrared light. A monochrome infrared camera mounted above the model records the intensity of light passing through the sand.

7.4 Displays on Physical Materials

Shader Lamps [16], developed by Raskar et al., in 2001, provides a three-dimensional physical display by projecting non-distorted and evenly colored computer graphics directly onto the surface of an irregular physical object using multiple projectors. Some level of interactivity is provided by changing the rendered highlights on the surfaces of the physical form according the head position of the user.

CADcast [17], developed by Piper at the MIT Tangible Media Group in 2001, provides a three-dimensional template for the physical construction of building models. A sequence of perspective images created from a CAD model, and indicating the order and position of each component of a building model, is projected into the workspace and used to guide the user to construct a physical model. Although CADcast is a demonstration of how physical and digital representations can be merged in a design environment, the interface is limited to one-way interaction with the user following projected instructions from the computer. This and the above project, however, confirm that using three-dimensional physical models as display surfaces can work convincingly.

7.5 New Musical Instruments

Many new musical "instruments" have been developed with the addition of technology to a nonmusical artifact. Here I mention only two, an instrumented shoe and Musical Trinkets, because of their use of sensors. In a third project, sensors are added to a cello-like instrument.

Paradiso [18] created an **instrumented shoe** in the Responsive Environments Group at the MIT Media Lab from 1997 to 1999. Using dense wireless sensing, the shoe measures 16 different parameters at the foot, detecting essentially anything the foot does. The data is telemetered back to a remote host, leaving the shoe untethered. The data is then mapped to audio, essentially making the shoe into a musical instrument. A dancer wearing a pair of these shoes creates his or her own music.

In the Responsive Environments Group at the MIT Media Lab during 2000, Hsaio [19] used a two-dimensional sensing field to read the position and angle of wireless tags. This infrastructure supported an interface for music control called **Musical Trinkets**. Wearing finger rings with embedded tags and moving the hands within the sensing area, a user can elicit musical riffs from the system. Hsaio also developed a cubical frame incorporating Helmholtz coils to read the position and angle of wireless tags within a three-dimensional space. Although this cube was not fully operational, it is easy to imagine, with refinements to the technology, how this could be applied to traditional spatial tasks such as physical modeling.

Machover and the Opera of the Future Group at the MIT Media Lab created **Hypercello** [20][21], which began with the question: How can digital technology build on an old craft of musical instrument making without sacrificing what is valuable about traditional instruments? Hypercello uses the same physical interface of a traditional cello; you play it by stroking a bow against strings that you hold down with your fingers to form musical tones. Its shape and material, however, are different—a metal frame with many sensors attached to it, and wires going to a bank of computers. The diverse combination of sensors, custom invented and designed by Gershenfeld of the Physics and Media Group at the MIT Media Lab, gather data as the musician plays. Bow position, pressure, angle, and speed, as well as finger position, all are recorded at a data rate comparable to what is audible from a traditional instrument.

Yo-Yo Ma took part in the project and was an essential bridge between the technology and the art. He not only performed with Hypercello, he also offered advice as to what parts of his technique were relevant to measure and what parts were irrelevant. He helped Machover, who wrote the piece “Begin Again Again” especially for Hypercello, to create musical mappings that used the sensor data in ways that were artistically meaningful and that built on Yo-Yo Ma’s technique.

7.6 Computer-Generated Tactile Feedback

Phantom [22][23], developed by Massie at MIT in 1994 and now at SensAble Technologies, is a haptic interface that uses a thimble, stylus, or grip handle for interaction. It was originally developed for use with computer graphics, simulating feedback from clay and other familiar materials. Subsequently, a noncommercial plug-in to use Phantom with Alias/Wavefront's Power Animator software was developed. It has since been adapted for numerous research applications including remote-controlled surgery.

Much of the research into computer-generated tactile feedback is occurring in the field of remote-controlled surgery. These minimally invasive procedures have the advantage of inflicting only tiny incisions that limit damage to the body and help speed recovery. However surgeons struggle with receiving only visual feedback to find anomalies so that they do not exert excess pressure on delicate tissue. **Remote Palpitation Instruments** [24], being developed by Howe at Harvard's BioRobotics Laboratory, convey tactile information from inside the patient's body to the surgeon's fingertips. The "tactile display' consist of a line of ten individually activated pins that are raised against the finger-pad.

Tissue mechanics is a related research field to remote-controlled surgery that seeks to describe the non-linear behavior of body tissues. Harvard's BioRobotics Laboratory, in association with Massachusetts General Hospital's CIMIT simulation group is developing a **"tissue atlas of material properties"** [25] for use in medical simulation technology.