Chapter 3.

Physical Computing Technology: A *Future* Artistic Medium and Form

This chapter presents an overview of the goals for physical computing technology as both a future artistic *medium* and *form*, and the limitations that physical computing technology must overcome to achieve those goals. This overview provides an important conceptual framework for a deeper analysis of the process and materials of sculpting computing objects from the perspective of visual art and design practices, i.e., industrial design, decorative arts practices and sculpture, which is presented in Chapter 4.

Beyond Chips in Boxes

Over the past few years computers *have* begun to escape their neutral, beige boxes. Today, we have a myriad of *industrially designed* electronic devices,

Figure 3.1 The beige and square ancestors of today's more shapely, consumer, computing devices.

including PDA's and cell phones, programmable picture frames and the beautiful new Apple computers. Design and technology research agendas, like Ubiquitous Computing and Things-that-Think, want computers to disappear into the rich, material world around us. Sciences like MEM's and nanotechnology are promising microscopic engines, sensors that can float inside our bodies, and miniature machines that can build themselves. At the same time there is a materials revolution taking place. New visions of quantum, biological and chemical computers all promise ways to create faster and smaller computers.

Yet despite these research visions, faster and smaller materials, and ergonomic and colorful designs, most new computing objects remain no more than poor grandchildren of their neutral beige ancestors. They are still merely chips and circuits in plastic boxes. In fact, their physical form and material properties still remain a highly *superficial* reflection of their square, prefabricated guts, which may include chips, buttons, speakers, displays, wire, circuit boards and speakers. The process that creates them is also remote and industrial, leaving little room for the direct manipulation and aesthetic exploration of active, physical computing materials. Moreover, the relationship of these objects physical form to computation, or what happens inside them, is also highly superficial. And finally, the sensual and material properties of physical computing objects, are still limited in the extreme. There is only one tactile vocabulary for computing objects, square, smooth and hard. All of these artistic problems are an artifact of the square, prefabricated, physical computing materials

Figure 3.2 The typical palette of physical computing materials, including speakers, screens, IR boards, solder and batteries.

that are commonly available to most artists and designers today.

I believe that computers and computing technology have the potential to become a truly sculptural, materially rich, and directly expressive artistic medium, which will allow artists to explore more than just the relationship of a plastic housing and a circuit board. The beige computers shown in Figure 3.1 recall a time when computers were physically neutral and figuratively invisible. No one cared what they looked like or felt like. Moreover, their shape and material properties has no effect in software, (changing the shape of the monitor, or the mouse makes no difference in any application). But I believe that there can be a relationship between the physical properties of a computing object, (its shape and tactile qualities), and computation that is artistically expressive, evocative and necessary.

Software as Model for an Expressive, Computing Medium

Computer technology presents artists and designers with two types of artistic media to shape; the *physical* materials of computers (circuits, displays, buttons, silicon and plastic), and the *virtual* media of computers (light, images, and sounds.)[1] As an artistic medium,

[1] In this chapter, I use of the word medium to refer to something, like paint or film, which artists manipulate to create their message. Perhaps the most appropriate definition of *medium* in regards to computers comes from a 19th century understanding of *medium* as an "intervening or intermediate agency or substance" through which

software, and the *virtual* media it controls, (sound, images, light), have been highly successful, as can be seen by the revolution that computer graphics has created in film, computer music and much algorithmically generated art. Because of this success, software and the *virtual* media of computers provide an excellent model for what artists and designers should expect from the *physical* materials of computing technology. This may seem odd, because virtual media might be seen as the antithesis to the material and physical design practice I am advocating. But it is not. The expressiveness and directness of the virtual media of computers provide artists and designers with a level of control and intimacy that is an excellent model for the physical materials of computers.

The expressive properties of software and the virtual media it creates and controls include:

- It is highly plastic or shapeable, and therefore expressive.

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people express an idea. {Taken from: Williams, Raymond, Keywords, A Vocabulary of Culture and Society, Rev. Ed., NewYork: Oxford UP, (1983)}. In my comparison of the virtual and physical media of computers, it may seem that I have conflated the word medium with materials. I describe the virtual, untouchable, light, sound and images of computers as media, and compare them to the touchable materials of computers, screens, plastic and speakers. I think this is an appropriate comparison because the physical media of computers are indeed materials. Moreover, for my philosophy, it is essential that I use material to refer the physical medium of computers, because the material reality of this medium is what I believe is being artistically ignored.

- It allows for the direct manipulation of the *real*[2] or final materials of the thing or object being made.
- It allows for an intimate relationship between visual form, artistic process, and computation.

Plasticity, Shapeabilty and Expression

Computer artist John Maeda's description of expression is highly relevant to understanding why *the plasticity* of a medium or material is essential for artistic expression.[3]

> media: there is some external vessel that can hold the concept outside the expresser's mind, such as paper, clay, etc.
>
> tools: there is some way to shape the media in a conscious manner, such as with one's bare hands, a paintbrush, etc.
>
> skills: the expresser understands the physics and metaphysics of his media and tools, and his experience with them allows him to mold forms of superior craftsmanship. Through his experience he possesses a basic vocabulary by which he can express himself.
>
> concept: there is something that the expresser wishes to express; most importantly, he has the will to express (this can include the to express no concept at all). The expresser has an imagination within which the concept is nurtured and brought to reality with technique, tools and media.

Central to Maeda's concept of expression is the ability of the artist to convey his or her ideas by shaping and

[2] See Chapter 4 for a more thorough discussion of what I mean by the *real* medium.

[3] Maeda, J. and McGee, K., *Dynamic Form*, International Media Press, (1994).

controlling his medium. Without the ability to shape their medium an artist cannot be expressive. The visual and virtual media of computers, i.e. images on screens, are highly plastic. This is clearly demonstrated by the amazing development of special effects in film, where software has created dinosaurs, animated toys and spaceships. In HCI, the plasticity of software has allowed designers to represent information in images, icons and word. In fact, this classic and highly iconoclastic argument about how to best represent computer information, in image, icon or word, is a direct result of the shapeability of software.

Direct Manipulation of *Real* Materials

Software has also provided artists and designers with the ability to *directly* manipulate their materials. This may seem strange, as software is a *mediation* through which artists and designers can reach the images it creates. However, software allows artists and designers write a piece of code, and immediately see what it does in the *real* or *final* medium,[4] for instance the light and images on the computer screen. They do not just see some materially remote, design or facsimile of what they are making. In addition, despite compiling time, this can be a very quick of not immediate, process. Through software, artists and designers can sketch, experiment, iterate and create a final product all in the same material or medium. This fast and direct process is essential to any design process or aesthetic investigation.

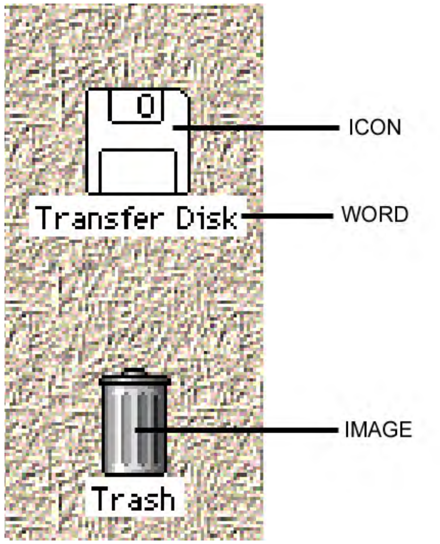


Figure 3.3 GUIs can represent ideas as images, words and icons.

[4] See Chapter 4.

An Intimate Relationship Between Form and Computation

Software and the virtual media it controls also have an intimate relationship that has allowed artists and designers to explore the artistic and aesthetic relationship of computation and visual form. This is because software is computationally active. Artists and designers working with software can ask questions like “What images do certain algorithms make?” Visual artists and designers working in software have carefully examined the expressive relationship of computation in software to the images and sounds it creates. Artists like Karl Simms (Figure 3.4) have used genetic algorithms to create a whole phylum of virtual creatures. Designers like David Small (Figure 3.5) have used software to explore new forms of text with dynamic motion. Moreover, software allows artists to create their own tools as alternatives to the pre-fabricated software tools of Photoshop and other consumer graphics programs.

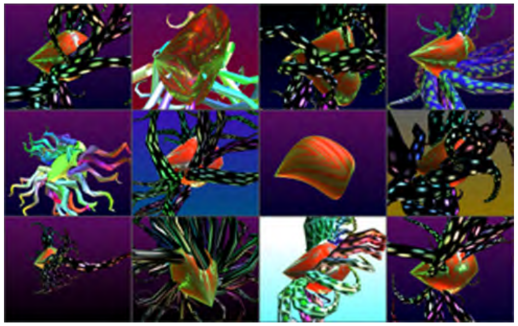


Figure 3.4 Karl Simms, *Galapagos,* 1997.

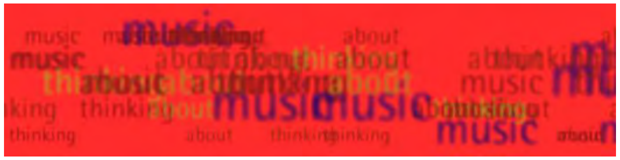


Figure 3.5 David Small, Yin Yin Wong, *Minski Melodies*, 1996.

Can Hardware Become an Expressive, Computing Medium?

Hardware, or the physical materials of computers contain no real analogue to software and the *virtual* media of computers. There are no physical computing materials that artists and designers can plastically shape, directly manipulate, and that allow them to investigate the artistic relationship of physical form and computation. This has severely limited the expressive exploration of computers and three-dimensional design and artistic practices. Without materials that are shapeable, directly manipulable and computationally active, like software, computers and computing technology will never reach their full potential as a physical and visual arts medium. Moreover, the physical materials of computers possess a property their virtual counterparts do not; they are tactile. To explore this property the physical materials of computers must become tactilely diverse and rich. Physical computing materials that are tactilely rich, shapeable and directly manipulable will also allow physical computing technology to participate in many three-dimensional, artistic and design practices that they are currently uninvolved in. Fields like the decorative and industrial arts, and certain types of "fine arts" practices, simply require these types of materials and processes. With sculptural, and active computing materials, physical computing technology also has the potential to become a truly unique future artistic form, *sculpted computational objects*.

Sculpted Computational Objects: Properties and Materials

As a potential artistic form, *sculpted computational objects* have a unique set of properties that each require a physical material. Understanding these properties and the materials that enable them will help us also understand both the artistic, practical and material challenges facing any creative person who wants to make a computational object.

I have defined computational objects as having five properties. Computational objects *must* have a unique physical form (this sets them apart from neutral computing objects like PC's and mice), be programmable, display dynamic reaction to either internal or external stimuli (be interactive), and receive some sort of power (in most cases this is electricity). Computational objects *may* also possess the ability to sense their environment and be networked.[5] Every one of these properties *requires* some sort of physical material to enable it. For anything to fulfill the three minimum properties of a computational object, (have a unique physical form, be programmable, and display dynamic reaction), it must be made from at least a physical substrate material (usually plastic), a processor, and some sort of output device. It may also have an input device and/or a network device.

I have defined all these materials as *physical computing materials* because they are what any designer must use to build a computational object. I have defined the input, output, sensing, and power related materials of computational objects as *active* because they all share and require the ultimate agency of computation, *electricity*. (I realize that new types of computation may involve active sources other than electricity, but today, it is dominate.)

To create a computational object, designers and artists usually assemble these materials together inside a CAD designed plastic shell. For the active materials of computational objects to share and exchange electricity, they must be electrically and mechanically

Properties of Computational Objects	**Enabling Materials** * necessary materials
Unique Physical Shape (required)	* **Housing Material** Like plastic
Runs Software (required)	* **Chips, Processors or Circuit Boards**
Displays Dynamic Reaction (required)	* **Output Devices**, Displays, Speakers
Can Sense (optional)	**Input Devices** Mice, buttons, etc.
Can be Networked (optional)	**Network Devices** Wired or unwired
Needs Electricity (required)	* **Power Supplies and Wires**

Figure 3.6 Abbreviated chart of the properties of computational objects and the materials necessary to enable them. An expanded chart of these properties is located at the end of the chapter.

[5] See the chart at the end of this chapter for a more detailed discussion of these properties and materials.

connected together. This usually involves using large, electrical connectors that are mechanically rigid to ensure that leads and solder joints don't break and that there is electrical continuity between the parts. (Wireless communication still cannot overcome the need for power and ground distribution between parts.)

A Closer Look at Commonly Used Computing Materials

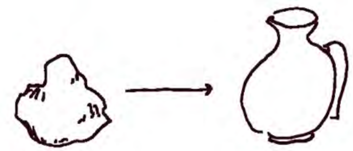
So what is so limiting about these *physical computing materials*? How do they prevent artists and designers from developing computers into an expressive, visual and physical medium? Why aren't they shapeable and directly manipulable? Why can't they be cut, bent, molded or applied like paint? And why don't they provide artists and designers a means to explore physical form and computation?

> **material** (me-tir-e-el) *n.* **1.** The substance or substances out of which a thing is or may be constructed: *"Simple ideas, the material of all our knowledge, are suggested to the mind only by sensation and reflection."* (Locke). **2.** A precursory element, such as an idea or sketch, to be refined and made or incorporated into a finished effort: *material for a comedy.*[6]

I have set up a loose classification for understanding how different types of materials are used to create objects. It divides the materials of computing objects into three categories, raw, structured and prefabricated. This system is not all encompassing, but is meant to provide a framework for understanding the limitations of current, physical computing materials.

[6] American Heritage Dictionary On-line, World Wide Web, (2000).

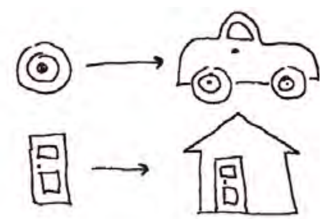
<u>Raw Materials</u>



CLAY can be molded into a VASE

Broken into smaller pieces it is still CLAY

<u>Prefabricated Materials</u>



A TIRE and a DOOR are part of a CAR and a HOUSE

Figure 3.7 Diagram of raw and prefabricated materials.

Raw Materials

Materials like clay and ink can be understood as raw materials. These materials have no pre-defined shape, and are usually highly shapeable. Moreover, their properties do not change if they are broken apart are reshaped. If you take a hunk of clay and break it in two, you still have two hunks of clay. If you shape it into a bowl, it still behaves like wet clay, until it is dried or fired. Clay, paint, ink, pencil lead, and steel are all amorphous materials. Raw materials can be easily manipulated in both an additive and subtractive manner, in other words one can easily break them apart and stick them back together. This provides a very high level of shapeablity and *plastic* control. Raw materials also provide a means for direct manipulation.

Prefabricated Materials

Prefabricated materials are precursor elements or manufactured parts that are assembled from other materials, and then used as part of a larger object. For example, a tire, a door, and a stretched canvas are prefabricated materials that can be incorporated into larger objects, like a car, a house or a painting. Because precursor elements are generally manufactured from many different other materials, they usually cannot be randomly resized or plastically reshaped without losing their fundamental material properties. Break a door in two and it is no longer a door. Bend canvas and it is no longer suitable for painting on. Of course a tire is rubbery, so you might bend it. But normally, a precursor element or prefabricated material has a structural integrity that prevents it from being radically, physically reshaped.

Structured Materials

Between the two extremes of raw materials and precursor elements are structured materials. Usually, these materials are natural or manufactured composite materials that are *sculpturally anisotropic*, or can only be shaped in a specific direction without destroying their fundamental properties. For instance, a steel beam is a manufactured, structured material that can be cut perpendicular to it length, and it will still be a beam. However, if a piece is cut out of one of its flanges, or it is cut lengthwise, it will no longer function as a beam. Paper is a structured material that is almost as shapeable as an amorphous, raw material. It can be cut, glued, folded and bent. But, it cannot be pulled out, or cut down its width, without destroying it. Textiles are also a structured material. They can be cut, bent and sewn. Structured materials, like textiles, wood and paper provide an excellent level of plastic and direct control.

Where Do Physical Computing Materials Belong?

Most physical computing materials, including almost all input and output devices, chips, circuits and network devices, are prefabricated materials that cannot be directly reshaped or cut apart without destroying their electrical properties. As a result, designers and artists looking to reshape or physically transform computing objects must usually accept the shape, size and form of prefabricated elements. This shape, size and form inevitably determines the form of their work. Thus many computing objects remain *reflections* of the square and rigid prefabricated materials from which they are made.

Of course, a designer might specify the shape of these items before manufacturing, but this is a remote, rather than, a direct process[7]. One could also imagine a prefabricated element that might be bent, but in the case of most *common* computing materials this is highly unusual because they must conduct electricity. For instance, commercial force sensors must be used on a rigid flat surface or they will crack, electrical continuity will end, and they will fail. Wires are structured materials, and as such wires can be bent and twisted fairly directly and easily. The only truly amorphous or raw physical material of computational objects that artists can freely reshape is the mechanical substrate material or housing, which is usually plastic. Designers can shape these plastic housings in CAD, have them manufactured and then integrate the active computing materials into them. But this tends to be a *remote* process that isolates the physical design from the electronic or computing design and discourages an exploration of the relationship between form and computation. Moreover, the plastic shells tend to be highly constrained by the shape of the circuits, buttons and displays they must hold.[8]

More Rigid than Stone

There are raw electronic materials, such as semiconductors, conductors, piezoelectric materials,

[7] A more detailed discussion of this is in Chapter 4.

[8] Ibid

optoelectronic materials and dielectric or insulating materials. But few people in the world can actually manipulate the raw materials of computational objects, nor is it a particularly direct or plastic process. The silicon and the other materials required to create chips are processed in clean rooms with exacting and hazardous processes that are unavailable to most people. With the exception of basic conductors (metals and wires), and basic insulators (plastic and glass), the raw electronic materials that most creative people encounter, are already built into prefabricated, precursor elements. *These elements are more rigid than stone.* If you cut them or bend them they simply stop working. This is because most raw, electronic materials have limited mechanical properties and cannot be bent or flexed or exposed to the environment without destroying their electrical properties. To preserve the electrical continuity of these materials, a complex array of other materials must usually be used. Take, for example, sensors made from an electronic piezoelectric material. For this material to be useful as a sensor it must be addressed electrically, which requires the addition of metal conductive leads to contact other materials or components. To isolate and protect the conducting and piezoelectric material, an insulator must be wrapped around it. For it to remain electrically stable, it must be placed on a rigid physical substrate. Almost immediately this raw material is a fully designed and rigid, *system* of materials, or a precursor element, that cannot be reshaped in a direct or plastic manner.

Today, we are beginning to see flexible, raw electronic materials, including conductors make their way into the market. The result of these flexible raw materials is the production some relatively flexible circuit boards, and displays. These materials are like structured materials in that they are directly flexible and bendable in some orientation. But they cannot be reshaped or resized accept through a CAD or remote design process. They generally have a finite edge or physical space that must be accepted in the process of making an object.

Fixed and Rigid, Electrical and Mechanical Connections

But the mechanical rigidity of most individual precursor elements is not the only limiting quality of the physical materials of computing objects. The fact that all these materials must be electrically and mechanically connected is ultimately incredibly limiting. Think about how a seamstress works. He or she cuts off a piece of fabric and then sews it to another piece of fabric. The two are easily joined, and the joint is strong because the two have similar mechanical properties, and no unusual physical stress (like hard meeting soft,) is introduced at the connection. In furniture making, glue can easily attach wood to wood. But what if glass is attached to fabric? When two materials with different mechanical properties, like expansion due to heat, are joined, that process becomes more complex because the materials may not be easily glued, or may damage each other with repeated contact. For instance, glass cannot be glued to wood, or sewn to fabric. It can be sewn into a fabric pocket, but if this process is not very carefully done, the hard glass will cut into or wear out the fabric. It is not that joining two different materials is impossible, just far more complex than attaching fabric to fabric.

And computing materials present more than just the need to integrate many different materials mechanically. These materials must also be electrically connected and maintain that connection. This usually necessitates that the connection between these parts be fixed and rigid. The need for fixed and rigid connections between the materials of computational objects, also means that these objects must be rigid and hard as well.

Conclusion

For *physical* computing technology to become a truly expressive medium and artistic form new computing materials must be developed. These *physical* materials must provide artists and designers with the same level of control and expressiveness that the *virtual* media of computers provide. They must give artists and designers the ability to *directly and plastically shape* their computing materials. Finally, they must provide a means to explore physical form and computation. To do this, the plastically shapeable materials of computing objects, or design materials, must become computationally active. As *real,* physical and tactile media, physical computing materials must also develop tactile and sensual qualities that virtual media do not possess. Chapter 4 will look at three-dimensional practices in the visual arts and design, and their relevance for the materials and processes that shaping computing objects.