

Chapter 6: Superimposing

In Chapter 5, I argued that physical tools and materials possess cognitive, motor, and emotional advantages over the digital medium because they provide rich sensory feedback to the designer. However, the digital medium possesses new qualities, such as mathematically defined forms, transformability, and infinite reworkability, which may enhance effectiveness and efficiency in a design process. I believe that the limitations of current CAD systems at this time are primarily at the interface level, in the transfers between physical and digital representations and in the interaction between humans and the digital medium.

6.1 My Hypothesis

6.1.1 The Problem Restated

Computer tools have proved to be invaluable to the practice of architecture—but so have pencils, pens, paper, and clay. As a result, an uneasy coupling has occurred between physical media and the digital medium. They are used, side-by-side, each one where it is most appropriate. Inherent in this side-by-side environment is the need to continually digitize and print in order to switch back and forth between physical and digital representations. More fundamentally, the GUI is limiting when it is the only interface to computation for design purposes. The root of these shortcomings is the hard division between the physical and digital realms.

6.1.2 Possible Solutions

Possible remedies to these shortcomings include the following:

1. Improve digitizing and printing capabilities.
2. Add virtual tactile feedback capabilities to the GUI.
3. Superimpose computation and physical media.

6.1.3 Superimposing Physical Media and Computation

My hypothesis is that superimposing computation and physical media will combine some of the advantages of both realms. It can bring the cognitive, motor, and emotional qualities of physical media into a computation-rich setting. It also has the practical value of reducing the need to switch between physical and digital representations. In short, superimposing computation and physical media will provide these benefits:

1. Reduce the use of command-based interfaces and cognitive overload.
2. Reduce the need for suspending workflow to print or scan.
3. Increase the cognitive, motor, and emotional qualities of interfaces by bringing these advantages from the physical realm to computer interfaces.
4. Potentially create tools that are more enabling to designers than those that currently exist.

6.1.4 Superimposing Explained

By superimposing, I mean creating smart physical media and augmented reality interfaces. This can be achieved by embedding computation using small processors, and tag and sensor systems, or by utilizing scanners and projectors on the surface of materials. A good medium combines a relevant and interesting state-space with sensory feedback that is both useful and emotionally satisfying for the designer. Digital media typically provide interesting state-spaces to explore, good visual feedback, and the capability to perform useful computations upon states. But the sensory feedback that they provide is impoverished, resulting in an experience that, over time, becomes tedious and emotionally tiresome. Superimposing physical and digital media can combine the best of both worlds by combining rich, multimodal sensory feedback with the ability to perform useful computations.

The new technology that will support this approach includes smaller, cheaper scanners, flat-screen displays, and wireless tag and sensor systems. These superimposed physical/digital tools, materials, and environments could take several forms. For instance,

a studio could have scanners embedded in the wall that scan continuously to input two-dimensional and three-dimensional data of physical drawings and models. Walls and tabletops could have large displays as output. The second approach is to focus on portability and augment existing physical tools and materials with input devices such as tiny sensors, cameras, and scanners. Output could take the form of projections directly onto materials, such as paper or physical models. Most likely, both large expensive systems and small portable systems will have a place in the design studio of the future.

Although a multiplicity of interface types is useful in a design environment, I am proposing that the most benefit can be gained by adding computation to physical media, as opposed to expanding the sensory bandwidth of the GUI by adding such things as virtual tactile abilities. These types of virtual feedback lack the verisimilitude of real senses, gaining back only a small amount of lost sensory feedback. I believe they are most appropriate to situations where real physical feedback is not possible, as when size or distance is a mediating factor.

Following is an expanded version of the table comparing qualities of physical media with those of the digital medium (Table 2). Added to it are “Digital with Tactile” (qualities of systems that have virtual tactile capabilities added to existing GUIs) and “Physical with Digital” (my proposed solution—superimposed physical media and computation). By adding up the scores it is evident that “Physical with Digital” retains the most number of qualities from both realms.

Qualities	Physical	Digital	Digital with Tactile	Physical with Digital
<i>tactile</i>	+	-	0	+
<i>olfactory</i>	+	-	-	+
<i>spatial</i>	+	-	-	+
<i>ambiguous</i>	+	-	-	+
<i>persistent</i>	+	-	-	+
<i>real-time</i>	+	0	0	+
<i>physically transformable</i>	+	-	-	+
<i>logically transformable</i>	-	+	+	-
<i>ephemeral</i>	-	+	+	-
<i>explicit</i>	0	+	+	0
<i>representative of space</i>	0	+	+	+
<i>fast</i>	0	+	+	0
<i>intelligent</i>	-	+	+	+
<i>precise</i>	0	+	+	0
<i>visual</i>	+	+	+	+
<i>aural</i>	+	+	+	+
<i>reworkable</i>	0	+	+	0
<i>copyable</i>	0	+	+	0
<i>portable</i>	0	+	+	0
<i>(totals balance out)</i>	6	6	7	9

Table 2: The ratings suggests that a quality is present (+), not present (-), or in between (0).

6.1.5 Foundations of Superimposing

Ubiquitous

Superimposing computation and physical tools and materials is consistent with the notion of “ubiquitous” computing, a new interface paradigm that turned the all-virtual paradigm inside out. In 1991, Mark Weiser, head of the Computer Science Lab of Xerox PARC, presented a new vision of specialized hardware and software connected by wires, radio waves, and infrared that would blend into the fabric of the man-made environment. In this way, Weiser suggested, computing technology would be enabling without being intrusive and overwhelming [1].

As a testament to the power of the “ubiquitous” paradigm, many researchers are now working within it. In 1994 the notion of **Graspable User Interfaces** was introduced by Fitzmaurice, Ishii, and Buxton [2]. This early example of a tangible user interface or TUI

(an acronym coined by Ishii) allowed direct control of electronic objects through physical handles for control.

TUIs

Ullmer and Ishii [3] give some insight into the complexity of issues that emerge with that mixing of physical and virtual worlds. They suggest that the abacus is a compelling prototypical example of a tangible interface. However, the abacus is not an input device. It makes no distinction between input and output; instead, the beads, rods, and frame serve as manipulatable *physical representations* for abstract numerical values and operations. Simultaneously, the components also act as *physical controls* for manipulating their underlying associations.

A GUI makes a distinction between input devices, such as a mouse, as *controls*, and output devices, such as monitors, as portals for *representations*. In contrast, tangible interfaces seamlessly integrate representations and controls, as in the tradition of the abacus.

As an example, Ullmer and Ishii discuss Urp, a tangible interface for urban planning. The interface combines a group of physical architectural models with an integrated projector/camera/computer that projects graphics onto the surface of a table where the models rest. The building models cast graphical shadows under the control of a physical clock face whose hands can be manipulated. A physical material wand binds alternate material properties to individual buildings. When a building is bound with a glass material property, it casts solar reflections as well as shadows.

In the Urp interface, physical models of buildings are representations of actual buildings. Their form, as well as their position on the Urp surface, serve both as controls and as representations of the state of the user interface. Indeed, if the projector/camera/computer were turned off, the physical representation would say something about the state of the entire system. In a GUI, a mouse holds no representational value. It acts simply like an extension of pointing, while the icons on the desktop are the representative elements. (See section 7.3 “Tangible User Interfaces” for more about Urp.)

According to Ullmer and Ishii, tangible interfaces are typically built using systems of physical artifacts. Taken together, the ensembles possess several properties. The physical artifacts are persistent—they cannot be eliminated or spontaneously created. They also carry physical state—they cannot be altered and they are tightly coupled to the digital state of the system. Tangible interfaces combine physical artifacts together in several different ways. In Urp, for example, the spatial configuration of elements is the defining parameter for the underlying system. Relational configurations are defined by sequencing and adjacencies.

More concisely, Ullmer and Ishii go on to present key characteristics of tangible interfaces [4]:

1. Physical representations are computationally coupled to underlying digital information.
2. Physical representations embody mechanisms for interactive control.
3. Physical representations are perceptually coupled to actively mediate digital representations.
4. Physical state of tangibles embodies key aspects of the digital state of a system.

What happens when the physical artifacts are not just controls but have significance whether tethered to the computation or not? This would be the case in the realm of design. Urp in fact is a rearrangeable model of downtown Boston buildings even when the computation is turned off, even though it was created custom for the Urp interface. Illuminating Clay, a recent prototype of Ishii's Tangible Media Group (and the subject of the experiments conducted for this thesis), grew out of Urp, but is not tied to any particular physical artifact the way that Urp is. (See section 8.1 "Description of Illuminating Clay" for a more thorough explanation.)

Adding tangible controls to computation, and adding computation to physical artifacts are two ways to think about TUIs. Both have validity, although in the world of three-dimensional design, adding computation to physical artifacts would have the most application. Superimposing is primarily an augmented-reality approach. However, the

most important question at this point is: What type of interface works best for the designer and the particular design problem at hand?

6.1.6 Instances of Bootstrapping Physical and Digital Media

Insight and inspiration can be gained about strategies for new interfaces by witnessing instances of bootstrapping done by designers. Bootstrapping, in the context of new technology, means adapting a system to address a different problem than it was originally designed for, or getting a faulty system to work. Of interest are instances where designers found ways to spontaneously superimpose digital and physical media to address their particular needs. Below are a few examples.

Trace paper over the computer screen

This is a fairly common technique. I have used it myself as much as 15 years ago. It is useful to trace a piece of a larger drawing to further develop that section. Once the designer “grabs” the relevant shape on paper, he or she can move the tracing to a tabletop to work. This is usually much faster and more convenient than attempting to print a section of a larger computer drawing. Similarly, I have seen designers compare a shape from one software package to another with trace paper on the screen.

Juxtaposing/collaging physical images to computer screen images

I have seen designers tape physical images or pieces of physical images to their computer screens to see if they “work” in a composition, before committing to the task of scanning the physical image.

Projecting a computer image on a wall

Within the context of a presentation, I have seen several designers gather around a projection from a computer image, tape a piece of paper within the projection, and draw and gesture on the superimposed projection/paper.

Projecting a computer image on a table

This happened in the class where the prototype Illuminating Clay was used (see section 9.5.2 “Class Log”). They had the unique advantage of having a computer connected to a video projector mounted on the ceiling and pointing down at a large table. During one

class session, the members of the class bootstrapped the Illuminating Clay projector to project Illustrator drawings onto two site models. Some students had worked out several proposed housing layouts for the site and printed them out. They attempted to lay the printouts on top of the chipboard model in correct alignment. Someone got the idea (obviously from experiences with Illuminating Clay) to project them onto the tabletop where the model was sitting. It required only a small amount of rearranging of a couple of cables from the Illuminating Clay PC to a second PC in the same room. The display from the second PC was now connected to one of the ceiling-mounted projectors. The display filled the tabletop. The chipboard model was rotated and moved to see how the housing plan might fit on the site. Some modifications were made to the drawing in Illustrator in response to seeing how the plan worked with the terrain. At times, the model was removed and trace was laid down under the projection; students explained ideas and then proposed changes to the Illustrator drawings. This bootstrapped system worked very well. The whole class could see and contribute much more easily than by looking at a small screen or even a wall projection. Everyone could easily point, gesture, and sketch. The session was intense, and it appeared that much progress was made on the housing layout.

6.2 A Vision of the Future Design Studio

I propose that the studio of the future will be the complete opposite of the 1970's vision and might instead look quite similar to the traditional studio of the past but with some seemingly magical capabilities, such as those described in my fantasy (see Preface). Clutter resulting from projects in progress will abound. This work will be evident primarily in the form of old-fashioned physical media, or at least it will look that way. The greatest evidence of the digital media will be the large displays integrated into the walls and desktops. A thin, portable notebook computer and various small handheld digitizers will also be evident. Other computer technology will be so small and embedded in physical tools and materials that it will not be noticeable.

In any future scenario, the process of converting from physical to digital representations will play a large part. Current trends in developing input devices focus on “high-level” sampling, which then requires new techniques to intelligently interpret the new forms of data. Increasingly powerful processors will enable real-time systems that capture data

continuously. This will eliminate the current interruption of the design process that's necessary to sample physical models and unlock the restriction of being in only one domain at a time, either physical or digital.

In one future vision, scanning would be ubiquitous, adaptive, iterative, and nonuniform. Imagine a studio or office with a built-in 360-degree scanner. It continuously scans the room, building up an accurate model over time. Objects that are partly or even completely hidden may be revealed temporarily. Instead of generating a complete sample and then synthesizing it, scanning and synthesizing become an ongoing process.

One might assume that high-level samplers would make the practice of computer modeling obsolete. So far, this does not seem to be the case. A possible answer, offered by Fitzmaurice, et. al. [5], is that sampled data is not always in the best form for further development by the designer. The designer's mental model of the curves and surfaces that make up the object may not correspond to the scanned object as they would have if the designer had modeled the object directly in the digital environment.

This problem may be remedied by creating smart sculptural modeling materials. If modeling materials had wireless tags embedded in them to define points, the synthesizing software could use information about the physical properties of the material to establish geometric primitives to construct three-dimensional geometric models. Tags might be located at the ends of inflexible rods (such as Tinkertoy construction sets, for example), so that they define vectors in three-dimensional wire-frame models. Similarly, tags on flexible rods could be captured as splines. If located at the vertices of a wire mesh, they could capture the surface geometry defined by that mesh. And, if distributed throughout a material like clay, they could be captured as a cloud of points. The designer might then choose a modeling material that reflects his or her own formal design vocabulary, with a new awareness of how different materials become represented in digital models [6].

Smart modeling materials could be real-time, and, as such, the most obvious way to display a digital model captured from a physical model would be on a standard monitor. This approach has the disadvantage that the designer must choose between watching the physical model or watching the screen display. With the techniques of augmented reality and the use of head-mounted stereo displays, it is possible to superimpose computer

graphics directly onto physical models. Accurate registration can be a problem, and although the hardware continues to improve, it requires users to wear awkward, expensive apparatus. At some point in the future, the physical model itself may be able to double as a display by painting tiny addressable particles onto the surfaces of the physical model.

6.2.1 Hybrid Operations

By utilizing augmented reality techniques, it would become possible to perform operations that take both physical and digital shapes as operands. For example, a solid modeler might compute the intersection of two solid shapes—one being held in the user's hand, the other existing virtually in the digital model. A screen display might show the result when the physical and virtual shapes are “pushed together,” and the line of intersection might be projected onto the surface of the physical shape. In this way, physical objects could be used as tools to sculpt virtual shapes [7].

It could also be possible to develop shapes from physically designed starting points. For example, two physical blocks might establish a spatial relationship, and the system might automatically repeat that relationship to generate a more complex form, which would then be projected back as a virtual model. Physical objects might also be arranged to specify the starting shapes and rules of a shape grammar, with the system deriving and displaying designs in the language specified by the grammar.

The results of hybrid operations could then be instantiated physically by actuators embedded in the physical model. Alternatively, output devices such as laser cutters or deposition printers could be used to produce new physical shapes to be reintroduced into the work environment. In this way, as a design develops, the designer could work with an increasingly complete and detailed physical model.

6.2.2 Linking and Unlinking

I am not suggesting that designers always need or want environments where physical and digital models are tightly coupled in real time with a consistent interface using augmented reality techniques. The freedom to vary representations as a design develops

and new issues are explored should not be undervalued or ignored. Designers usually move back and forth between different representations—whether for brainstorming, design development, communicating with others, checking earlier assumptions, or more-subtle emotional reasons—at various stages of a project [8].

Providing a setting in which designers can easily move back and forth among virtual, physical, and hybrid environments, with varying sizes, scales, and resolutions is a better solution. Also, designers should be able to introduce different types of physical models and couple or uncouple them to digital models as desired. For example, an architect might begin work with Styrofoam blocks to establish basic functional relationships among building volumes, then move to clay to begin sculpting the shapes of those volumes, then use materials like wood, cardboard, paper, or plastic to elaborate on details and explore changes in materiality.

The manner of the physical/digital coupling may also vary from stage to stage in a design process. Sometimes, it may be highly desirable to provide real-time coupling, as in *Illuminating Clay*. At other times, it may make more sense to keep digital and physical models uncoupled and employ three-dimensional scanning and rapid prototyping to translate between them as required, as in Gehry's process.

6.3 Summary

An ideal creative design environment should provide a multiplicity of physical modeling media, powerful digital media capabilities for capture and development of digital models, a setting in which physical and digital models can be linked, and convenient tools for quickly linking and unlinking as desired. Paramount should be the creative process itself, with the technology transparently supporting the thoughts and gestures of the designer—where the switching between physical and digital design modes creates the least amount of drag on creative momentum and design flow, and the least amount of confusion to bodily orientation or position.

