Tactile, Spatial Interfaces for Computer-Aided Design
Superimposing Physical Media and Computation

by
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Submitted to the Department of Architecture
in the Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Architecture:
Design and Computation

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ABSTRACT

Computer-aided design (CAD) systems have become invaluable in three-dimensional creative design fields such as architecture and landscape architecture. However, these digital tools have not replaced the use of physical tools and materials as envisioned by the early developers of CAD. Instead, most designers have added digital media to their suite of physical media, gaining the benefits of both realms and using each where it is most advantageous.

Given current CAD systems and how they are being used, two significant problems are apparent. First, the side-by-side physical/digital work environment has resulted in the need to frequently digitize and print in order to switch between physical and digital representations. This process is often time-consuming, costly, and frustrating. Second and more fundamental, the standard graphical user interface (GUI), although appropriate to some tasks, is restrictive as the only interface to CAD, because it lacks tactile and spatial qualities. Interacting with physical media such as paper, cardboard, and clay is a multisensory, spatial experience. Interacting in a GUI may be visual, but our other senses and spatial abilities remain underutilized. Recent interface design research includes embedding or augmenting physical artifacts with computation as one remedy to the limitations of the GUI.

This dissertation investigates whether superimposing physical and digital media to create new interfaces for CAD has merit. Findings are presented from experiments performed with Illuminating Clay, a prototype interface that superimposes modeling clay and topographic analysis. The objective was to discover whether these new kinds of interfaces could successfully combine the cognitive, motor, and emotional advantages of physical media with the capabilities of computation. Findings indicate that Illuminating Clay can indeed supplement a designer's eyeball analysis with more-accurate feedback while retaining the tactile and spatial advantages of working with a physical material. Salient issues pertaining to the design of tangible, and augmented-reality user interfaces were raised by these experiments: what the appropriate scale limitations should be, what the appropriate type of feedback is from computation, and whether real-time feedback is necessary.

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Cambridge, Massachusetts, USA
September 2003

To my parents, Matthew and Anne Shamonsky

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For assistance with my research, I want to thank all who volunteered to be test subjects. I also want to acknowledge the diligent work of UROPS, John Jhee, Liz Evans, and Alycia Hillman.

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PREFACE

As I worked toward this doctoral degree, I periodically received e-mail messages that began "That degree you always wanted may be closer than you think!" After a momentary glimmer of hope that a higher power was delivering me from a lot of hard work, I realized that this was spam from a place that sells college degrees. Receiving these messages was a blunt reminder that although cheap fixes can be had instantly, significant achievements of creativity, skill, and learning are the result of a long process of applied, focused effort. Fortunately, a good tool can increase efficiency to a great degree. For example, word processing enabled me to write this dissertation faster than my predecessors on typewriters, because I didn't have to retype the manuscript every time I wanted to make changes.

Ironically, with their promise of "smarter-faster-better," computers have brought confusion to ideas of efficiency, skill, achievement, and quick fixes. A couple years ago, veteran interface designer Bill Verplanck taught a week-long seminar at the MIT Media Lab on sketching for interface designers. Although I felt comfortable with my sketching skills—I spent many hours in drawing classes as an art school undergraduate—I took the class to glean some of Verplanck's wisdom. Students in the class energetically participated in the exercises, but as I chatted with some of them during breaks, I was surprised to discover how many of these students were hoping to learn a few easy techniques that would leapfrog them into becoming competent drawers or, better yet, hoping to find out what software could instantly improve the look of their drawings.

The opposite reality became evident to me as I was conducting the research for this dissertation: *Good designers design well no matter what tools or materials they have access to. Also, skilled, experienced designers use tools and materials more efficiently and effectively than novices do.* I acknowledge that this may change in the future when and if computation achieves significantly more intelligence than it has now.

I have to admit that in the past I, too, have indulged in fantasies of quick fixes, which is how I eventually came to write this dissertation. As an undergraduate sculpture major, I can recall sitting in my studio overwhelmed by the cost of materials, and exhausted by tools that weren't working properly as end-of-semester deadlines loomed. I wondered, "Wouldn't it be great if I could simply visualize a sculpture and have it materialize instantly?" I'm sure that others, tired and working late, have shared this fantasy. I wished

that I could work directly with my visualizations, as if they were shimmering life-size, three-dimensional holograms floating in space. I imagined that I could control my creation with gestures, like a conductor directing an orchestra. My baton would be a handy pointer or magical pencil. If the piece was not quite right, I would wave my wand like a wizard to rearrange the parts. Once satisfied, *poof!* The hologram would be changed into a material form.

When I first started working with computer graphics, it felt a bit like my fantasy. But my shimmering hologram of a virtual sculpture was, instead, a crude line drawing on a small screen. I could control it only by typing complicated, time-consuming commands on a keyboard. No gestures. No instant solutions. Yet I could see the potential of computer technology as well as the next person could, and became involved with digital media whole-heartedly.

What I did not see coming was how my work environment would change over the next couple of decades as computers became common design tools. I experienced what I think of as the "office-ication" of my studio. As an undergraduate, my sculpture studio was filled with natural light, texturally rich materials, and musty, invigorating smells. My tools required a variety of muscle/motor control skills and reverberated with a range of sounds, from the ping of a small hammer to the screaming of a skill saw. A decade later, working as an interface designer, my studio was considerably more sterile, with the shades pulled low and the dominant sounds being the whir of the CPU and the clicking of keys. I often would sit for hours, barely moving except for sliding the mouse around and typing. My studio had transformed from sensory-rich and playful to efficient and rote. My body—senses and muscle/motor control skills—were considerably less engaged by my new tools and materials. Although I wanted the capabilities of computation, the reality was not satisfactory.

My motivation for this dissertation is simple and comes from my experience as a designer. I want the fluid, fast, ephemeral qualities of the digital medium—something much like our thoughts—but with interfaces that are more embodied, like my old-fashioned textured tools and materials. I believe that these kinds of interfaces can better serve the needs and desires of designers.

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