Hand-Machine Conflict and the Ethics of Digital Fabrication

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INTRODUCTION

In his Princeton lecture "Machinery, Materials, and Men" Frank Lloyd Wright laments the artist's nostalgic desire for handcrafted products. He urges his contemporaries to stop squandering the creative freedom made possible by the machine.

> Why will the American artist not see that human thought in our age is stripping off its old form and donning another; why is the artist unable to see that this is his glorious opportunity to create and reap anew? [...] Come now, with me, and see examples which show that these craft engines may be the modern emancipator of the creative mind.[1]

With equal passion, William Morris voices an opposing view.

> If our houses, our clothes, our household furniture and utensils are not works of art, they are either wretched make-shifts, or what is worse, degrading shams of better things. Furthermore, if any of these things make any claim to be considered works of art, they must show obvious traces of the hand of man guided directly by his brain, without more interposition of machines than is absolutely necessary to the nature of the work done.[2]

A similar conflict tempered the early decades of the computer age. Some encouraged us to embrace the computer's creative potential, while others remained wary of a dehumanizing effect.[3] In the 1980s architects confronted computer-aided drawing and a similar conflict emerged. While some enthusiastically entered the digital frontier, a larger Resistance cautiously restricted the computer to the periphery of creative work.[4]

In recent years mature and economical digital modeling and fabrication technologies have again given architects a powerful new machine. It allows us to quickly convert a digital simulation into a material prototype. It also allows automated fabrication of full-scale building components directly from digital information. As architects put it to work, the old conflict has reemerged in a new form, fueled by an unresolved tension between machine potential and human identity.

Some architects believe this tension is healthy and others want to resolve it. Resolution is commonly sought with a design method of media integration, in which an architect oscillates between traditional and digital media – between hand and machine – attempting to reap the advantages of both.

By examining the hand-machine conflict in its current form and clarifying the cultural values at stake, this paper supports the view that technology acts as a stage for the debate of moral issues. While technology can affect the way we see the world, the primary influence is in the other direction. It also supports the need to break free of the hand-machine conflict, calling for a bolstered effort to dismantle pervasive either-or thinking. The final section of the paper describes a studio experiment that reconsiders media oscillation as a means of resolving the conflict. Although some progress has been made with the oscillation approach, further steps are needed to advance the cause of hand-machine integration.

EMBRACING THE DIGITAL

Aggressive computer advocates argue that digital model-building allows easy generation of complex curved geometry, and this provides an escape from the debilitating formal bias of conventional materials and construction methods.[5] Abstraction away from matter opens new paths of exploration, and ultimately expands our mastery over the material world. In his discussion of stereotomy, Evans[6] provides a historical example. Through a process of geometric abstraction, masons gained power over stone that seemed magical to the uninitiated. According to Lynn this is part of the natural flow of progress.

> [A]rchitects have always been, and will continue to be, mandated to operate with progressively increasing levels of abstraction in order to plan the outcome of material processes. This action at a distance on material form has been the perennial task of architects. It is in response to this necessity for abstraction that architecture's repertoire of spatial, organizational and representational techniques has developed.[7]

We are urged with a moral imperative to adopt an increasingly cerebral approach. Failing to relinquish nostalgic ties to established materials and methods will cause the built environment to stagnate, gradually losing touch with the needs of an evolving culture.

In the recent past this argument was easily dismissed as a rationalization for isolated extremism. It was often asked how this sort of architecture could occur on a large scale, given the expense and difficulty of constructing unconventional forms. Digital fabrication provides an answer. Mitchell[8] predicts that complex curved building form will eventually be as economical as orthogonal form. The prolific work of Frank Gehry seems to support his prediction. Gehry's undiluted creative vision is translated into built reality through the integral use of digitally-augmented prototyping, fabrication and assembly.

Mitchell goes beyond predicting future trends to draw out a moral implication. He suggests that the spread of digital fabrication will cause an upheaval in the way architects justify design intentions: "From a technical viewpoint, simplicity and regularity hardly matter anymore. If designers want to emphasize these qualities, they must now do so on other grounds."[9] From this point of view, leveling the economic playing field might cleanse the profession of a creativity-thwarting bias, which has put architecture at the mercy of pragmatic materialism for too long.

A future of economic equivalence is supported by lines of engineering research. For instance, Hanna and Mahdavi[10] demonstrate that with digitally augmented structural analysis and mass customization techniques, we can create optimally efficient structures. Each building component can possess a unique microstructure to serve its specific purpose, resulting in dramatically reduced material waste. By embracing abstract digital methods, we not only secure a path to creative freedom and societal progress, we emancipate ourselves from the inefficiencies of conventional construction, which undermine sustainability.

RESISTING THE DIGITAL

While there might be practical problems with this vision of the future, the Resistance stands on moral ground. Even as architects expand their use of the computer, many still see digital methods as dangerously disconnected from the human condition.[11] We experience a continuous interaction with matter through the sensory apparatus of the body. Through touch, especially, we experience ourselves as seamlessly linked to a material world, and if this link is weakened, we become alienated from the world and from our own nature.[12] This link is weakened by digital technology, since it aids us in the direct manipulation of abstract geometry rather than material. Its mathematical representations veil qualities that stimulate the senses and fuel intuitive design.[13, 14]

In defense of digital simulation, some researchers hold that real-time quantitative analysis offers superior insight into the nature of material things. For example, Bell and Vrana[15] point out that structurally efficient shapes are usually curvilinear. Aided by digital analysis, architects create structures in-tune with natural forces, analogous to plant and mineral formations. Seen from the point of view of the Resistance, however, this digital number-crunching is part of the problem. By translating sensory properties into engineering formula, we are separated from the qualitative nature of matter, which influences us in ways that defy calculation.

Digital fabrication technology seems to offer a solution to this problem, since it converts digital information directly into material product. This reduces the "experiential delay" between conceiving and making. This delay plagued older digital design methods, encouraging an architect to become enamored with a form before exploring its material consequences. Yet the abstract bias still reigns. The materials used in rapid prototyping, for example, are highly refined, homogenous substances, purposefully characterless and pliable to an extreme in order to maximize the range of allowable forms.[16,17] Materials such as starch powder and liquid resin do not behave like natural materials. Jabi[18] argues that these materials encourage the production of "appearance models" rather than models that study component assembly and other aspects of construction.

DeLanda[19] reveals the source of this digital disconnect when he describes interaction with material as a negotiation. When we build with our hands, we try to shape a material according to our goal, and the material often resists. When confronted by this challenge, we find a new way to shape it, or we adjust our goal. Through a process of give and take, we gradually enrich the idea and refine the material product. However, if a material is powerless to resist us, it cannot negotiate.

Digital fabrication cannot repair the breach between creative thinking and material exploration. Creative design requires the total interface of the body and a direct sensory awareness of the subtle qualities of a material at the moment of creative inception. This is inevitably disrupted by a computer intermediary.

MORAL DILEMMA

Embedded in this technological debate are two views of the mind and its relationship to the world.

One side believes the mind is primarily *generative*, able to produce unlimited improvement of nature. These architects want to exert their will - altering material to conform to an idea of how things ought to be. To amplify this power, we should remove the ability of material to resist us. Mechanical devices contribute to this my amplifying human muscle and computers contribute by amplifying the power of human thought.[20] Negroponte[21] argues that our culture embraces "being digital" because it is natural and right to extend the power of the mind, regardless of the consequences. In the final analysis, he states, "Being digital is different. We are not waiting on any invention. It is here. It is now. It is almost genetic in its nature, in that each generation will become more digital than the preceding one."[22]

Architects on the other side of the debate see our relationship to the world differently. They believe the mind is primarily *adaptive*. Through experience we absorb the qualities of nature, which rightfully influence the mind and shape its product. For these architects, the mind is fulfilled by reflecting upon an external content, rather than expressing an internal will. By understanding nature we reveal its inherent value - its beauty and laws. This requires sensitive and sustained contact with matter and a humble quieting of the will.[23] For Orwell, even life's dangers are vital to this process. "The truth is that many of the qualities we admire in human beings can only function in opposition to some kind of disaster, pain or difficulty; but the tendency of mechanical progress is to eliminate disaster, pain and difficulty."[24]

SEARCHING FOR RESOLUTION

Some architects see these alternatives as limiting, and they want to resolve the conflict by introducing a third alternative - one that overcomes the disadvantages inherent in an either-or approach. If we embrace digital abstraction, we lose touch with material as a source of inspiration, and if we embrace material, we become too strongly tethered to what *is* as opposed to what *might be*.

One line of research seeks to resolve the conflict by integrating hand and digital methods into a hybrid design process.[25,26,27] While varied and ingenious, these proposals share the same basic strategy: *media* *oscillation*. We are encouraged to oscillate between material and digital investigations, pursuing one for a while, then the other, and then switching back again. An architect might follow a path like this: 1) construct a cardboard study model, 2) scan the model and transform it digitally, 3) rapid prototype it and alter the prototype by hand, 4) digitally photograph the prototype and manipulate the photographs in Photoshop, and 5) print the images and sketch over them. While helpful, this seems insufficient. Oscillation between contrasting poles retains and even accentuates the poles. Oscillation is superior to the exclusive use of one medium, but it is more compromise than integration - a way to recognize the importance of both while retaining the distinction.

We might step closer to integration by using material and digital media simultaneously rather than cyclically.[28] As it becomes faster, cheaper and more responsive, digital fabrication technology will contribute to this, but as we have seen, it cannot offer a complete solution. Heightening a sense of simultaneous engagement also requires new design methods.

A design experiment was conducted to explore one possibility. In a one week exercise, students designed a screen wall system that would ultimately be constructed from a combination of off-the-shelf lumber and digitally fabricated components. The experiment required students to create an integrated composition, in which each kind of component physically attached to the other. While the lumber components are fairly static and repetitive due to standardized shapes and sizes, the fabricated components would be made from parametrically controlled geometry, which allowed mass customization. The lumber components were best studied through a simple material model, while the parametric components required a digital model. This contrast had to be resolved.

Students were required to interact with the models in a particular way. In the digital model, custom components were parametrically explored while a fixed "stand-in" was used to represent the lumber. In the material model, off-the-shelf components were explored in basswood while a fixed "stand-in" was used for the custom components. The material stand-in for custom components was achieved with 3D printing. Although the two models were altered cyclically, they were studied simultaneously, and each model implicitly contained content from the other model. No adjustment could be made to one kind of component in its favored medium without considering its direct effect on the other kind of component, explored in the other medium.

Students received no critical feedback from the instructor during the exercise. Rather than guide students toward a desired result, the goal of the experiment was to observe reactions to the given constraints.

RESULTS OF THE EXPERIMENT

Points of attachment between wood and 3D printed components mandated reciprocity. If students became enamored with one kind or the other, the final screen wall would simply not fit together. This led some students to accentuate the point of attachment, iteratively exploring the effect of one component on another and developing an articulated system of joints (Figure 1). Others resisted. They treated wood and printed components as self-sufficient systems, each with minimal influence on the other. This led to less articulated joints (Figure 2).

The experiment asked students to achieve a balance of wood and printed components. Each kind was to play an equal role in the composition. Despite this mandate, students tended to emphasize the printed components. Even where printed components are small, their figural quality dominates the composition (Figure 3). Wood members are often a neutral framework for the showcase of printed components. In extreme cases, students nearly eliminated the wood, which conveniently negated any need for reciprocity (Figure 4).

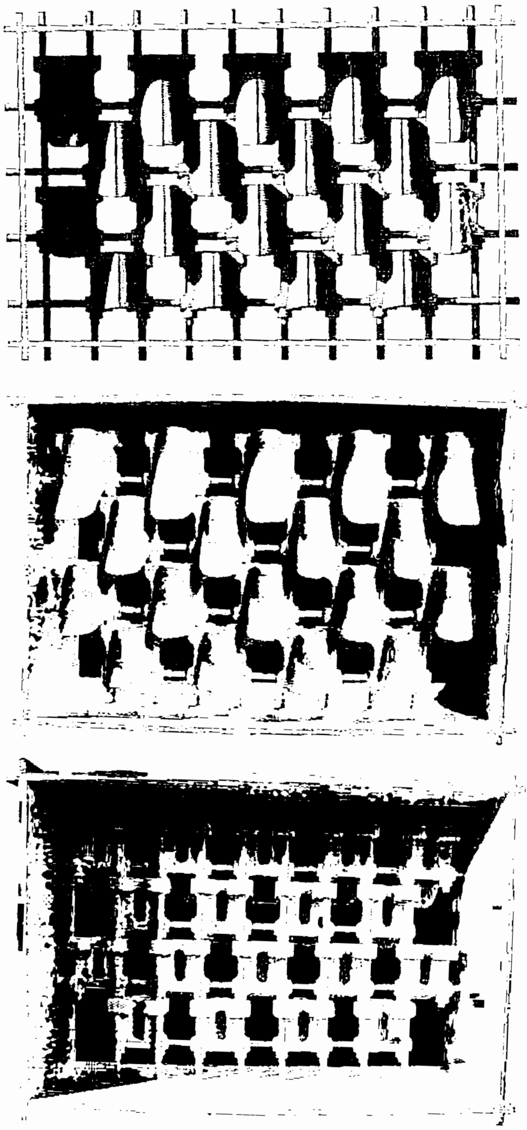

Figure 1. Dan Loomis

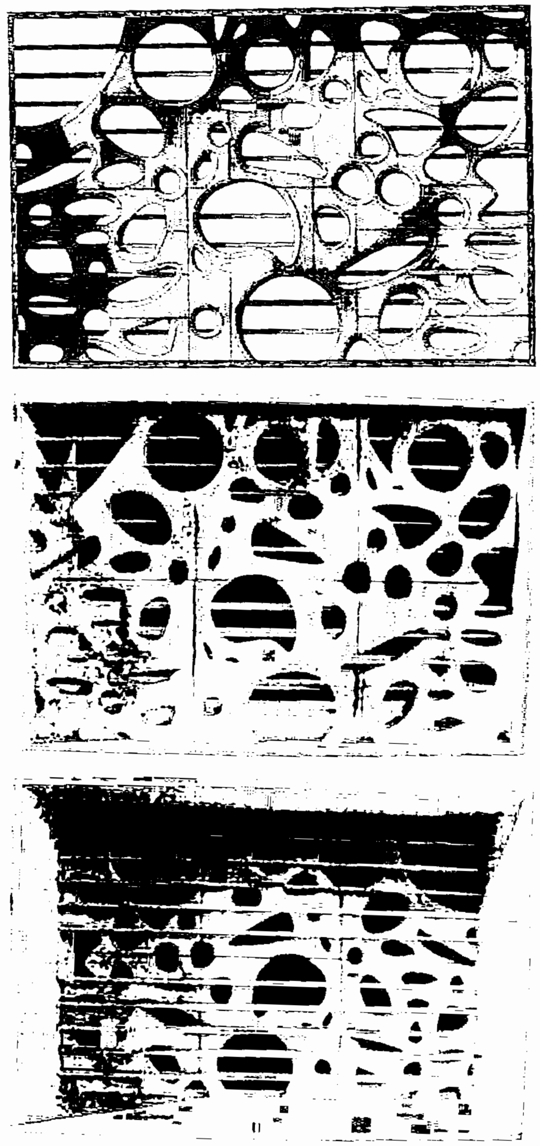

Figure 2. Max Carr

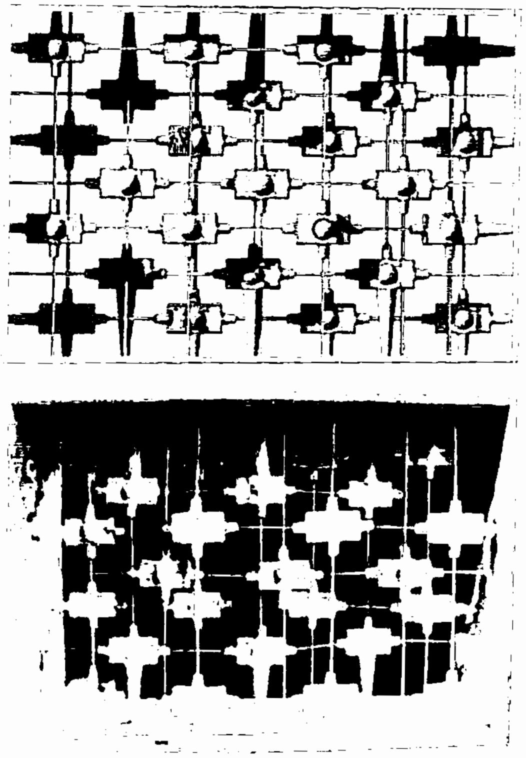

Figure 3. Anne Gustavson

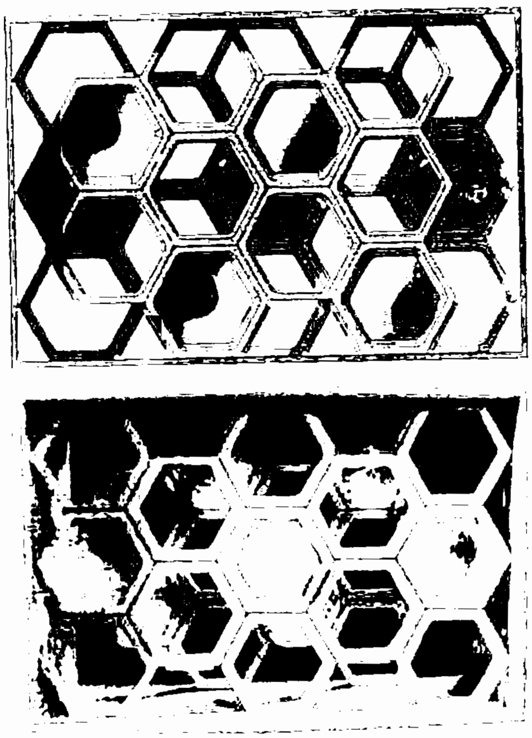

Figure 4. Maura Rogers

Despite these tendencies, some students attained a reasonable integration (Figure 5).

The experiment created an observable struggle as students altered their thinking habits in response to the assignment. Some adhered irresistibly to a monistic habit. And yet overall, the results were far from the "appearance models" normally produced with a 3D printer. No student was so fixed in his habit that he could not achieve integration to some extent, and all of the projects exhibit tectonic qualities. These results suggest that the use of concurrent and interdependent representations could help architects overcome the kind of either-or thinking still inherent in the media oscillation approach.

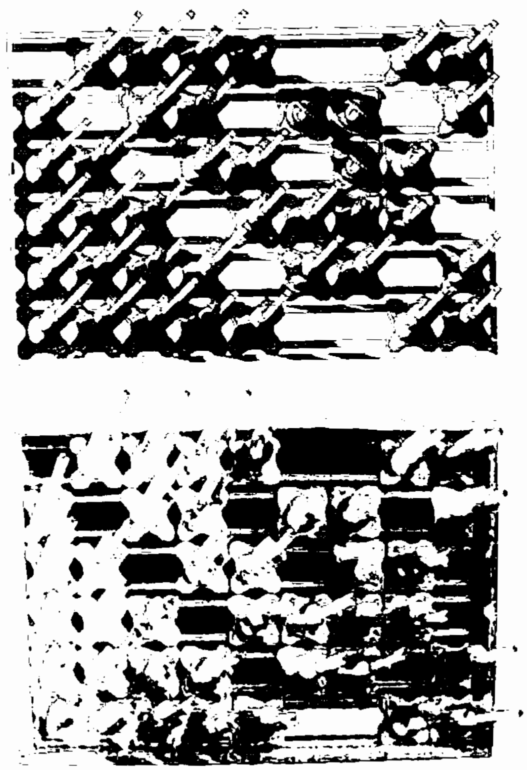

Figure 5. Jeff Davis

CONCLUSION

As computers become ubiquitous in architectural practice the Resistance appears to dwindle, but it continues from within the ranks of digitally proficient architects. Voiced with increasing force at recent computer-aided design conferences, the Resistance seems even to grow, reinvigorating the longstanding tension between hand and machine.

Digital fabrication technology provides a new stage for the debate. Despite its capacity to bridge between abstract geometry and material artifact, architects have quickly retrenched at the poles. Like a mutating strain of bacteria, the hand-machine conflict survives each technological advance. In the industrial age it polarized craft and mass production. In the digital age it first polarized hand and computer-aided drawing, and now hand and computer-controlled fabrication. It seems unlikely that any future invention can resolve a conflict with such deep moral roots. Resolving the conflict is the work of moral philosophers, but architects can uproot its polarized categories, which have become modern doctrine.[29]

We are often urged by the Resistance to harbor a healthy suspicion toward new technology,[30] but perhaps it is time to redirect this suspicion. We should become suspicious of any idea or method that perpetuates the hand-machine conflict. By uprooting design methods that reinforce its categories, we can gradually purge its influence. This applies to the media oscillation approach. Rather than providing a final solution to the conflict, media oscillation achieves only a first step in the effort to dissolve its artificial boundaries.

NOTES

1. Frank Lloyd Wright, "Machinery, Materials, and Men," in *The Future of Architecture* (New York: Meridian, 1953), 93-94.

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5. Ali Rahim, "Systemic Delay: Breaking the Mold," *Architectural Design* 70/3 (2000): 6-8.

6. Robin Evans, "Drawn Stone," in *The Projective Cast: Architecture and Its Three Geometries* (Cambridge, MIT Press, 2000), 179-239.

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8. William J. Mitchell, "Constructing Complexity," in *Proceedings of the 11th International CAAD Futures Conference*, Vienna, Austria (July 2005), 41-50.

9. William J. Mitchell, "Roll Over Euclid: How Frank Gehry Designs and Builds," in *Frank Gehry Architect*, ed. J. Fiona Ragheb (New York: Solomon R. Guggenheim Foundation, 2001), 359.

10. Sean Hanna and Siavash Haroun Mahdavi, "Modularity and Flexibility at the Small Scale: Evolving Continuous Material Variation with Stereolithography," in *Fabrication: Examining the Digital Practice of Architecture, Proceedings of the AIA/ACADIA Fabrication Conference*, Toronto, Ontario (October 2004), 76-87.

11. Malcolm McCullough, *Digital Ground: Architecture, Pervasive Computing,* and Environmental Knowing (Cambridge: MIT Press, 2004).

12. Ryszard Sliwka, "Untimely Fabrication," in *Fabrication: Examining the Digital Practice of Architecture, Proceedings of the AIA/ACADIA Fabrication Conference*, Toronto, Ontario (October 2004), 52-65.

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14. Juhani Pallasmaa, "Hapticity and Time: Notes on Fragile Architecture," *Architectural Design* 207/1239 (2000): 78-84.

15. Bradley Bell and Andrew Vrana, "Digital Tectonics: Structural Patterning of Surface Morphology," in *Fabrication: Examining the Digital Practice of Architecture, Proceedings of the AIA/ACADIA Fabrication Conference*, Toronto, Ontario (October 2004), 186-199.

16. Patrick H. Harrop, "Agents at Risk: Embedding Resistance in Architectural Production," in *Fabrication: Examining the Digital Practice of Architecture, Proceedings of the AIA/ACADIA Fabrication Conference*, Toronto, Ontario (October 2004), 66-75.

17. Sliwka, "Untimely Fabrication."

18. Wassim Jabi, "Digital Tectonics: The Intersection of the Physical and the Virtual," in *Fabrication: Examining the Digital Practice of Architecture, Proceedings of the AIA/ACADIA Fabrication Conference*, Toronto, Ontario (October 2004), 256-269.

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20. Howard Rheinhold, *Tools for Thought: The People and Ideas Behind the Next Computer Revolution* (New York: Simon & Schuster, 1985).

21. Nicholas Neogroponte, *Being Digital* (New York: Random House, 1995).

22. Ibid., 231.

23. Pallasmaa, "Hapticity and Time: Notes on Fragile Architecture," 78.

24. George Orwell, *Road to Wigan Pier* (New York: Harcourt, Brace and Company, 1958), 226.

25. Wassim Jabi, "Digital Tectonics: The Intersection of the Physical and the Virtual."

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