MATERIAL IMAGINATION IN DIGITAL CULTURE
Making Virtual

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Introduction

Only 8 years ago when I began teaching, integrating digital media in the design studio was hampered by institutional politics and lack of hardware accessibility. Now students come to my studio with dual monitors and are multitasking maniacs with a host of distractions and a subtle reluctance to explore and test ideas physically. As design culture becomes more and more a digital culture, perhaps the fact so much digital work looks the same is not only due to a fairly basic understanding of tools and skills, but a lack of material imagination. Digital fabrication in association with the virtual prototype and parametric modeling are powerful tools for design development, but the growing conventions of use can thwart the material development these tools were meant to engender. Perhaps obvious in hindsight, digital fabrication requires not only digital dexterity but a robust material sensibility that precedes digital mediation. To this end, I have focused on a materials first approach to developing digital skills to excite the material imagination.

This material imagination is more than a pragmatic means to develop digital skills, but a more epistemic way of operating - an engagement with the world. My interest is to position the material imagination as a reciprocal creative intelligence to the dominant formal imagination enabled through the fluid geometric precision in digital tools. In the end, nurturing this material imagination in concert with the formal imagination may have a strong influence on the conceptual horizon that students draw from.

The Graft: Developing a Synthetic Sensibility

In *Water and Dreams*, Gaston Bachelard focuses on the imagination through the eyes and ears of poetry.[1] In poetry he sees the aesthetic component of language derived from material causes, such as the fluidity, reflection, and depths of water. He highlights two aspects of creative inspiration: the formal cause and the material cause, or the formal imagination and the material imagination. In particular he sought a "dual participation" between the two. For Bachelard, form gives structure but material is the inspiration - the springtime. The material imagination doesn't simply describe or represent (as in realism) but it projects. Through poetry, Bachelard seeks to cultivate the projective image sprung from the material imagination.

To encourage the reciprocity between the formal and material imagination, Bachelard puts forward the materialist metaphor of the graft insisting the graft is more than simply a metaphor:

> "To me this is not simply a metaphor. The graft seems to be a concept essential for understanding human psychology. In my opinion it is the human stamp, the specifying mark of the human imagination...
> It is the graft which can truly provide the material imagination with an exuberance of forms, which can transmit the richness and density of matter to formal imagination. All metaphors aside, there needs to be a union of dream-producing and idea-forming activities for the creation of a poetic work. Art is grafted nature."[2]

According to Bachelard, the graft is a synthetic sensibility between the formal and mate-

1 I thank Kyna Leski at RISD for sharing with me the role of the "material imagination" in the core curriculum at RISD. I then came across Juhani Pallasmaa's reference to Bachelard's material imagination while, ironically, I was looking up the Korean Presbyterian Church by Lynn, McInturf, and Garofalo, and finally, too see this same Pallasmaa reference appear in the first chapter of Branko Kolarevic and Kevin Klinger's Manufacturing Material Effects.

2 Gaston Bachelard, ***Water and Dreams***, page 10.

rial imagination connects to the whole of the human psyche. Without this material imagination, ultimately our engagement with the world suffers.

While the graft develops a reciprocity between the material imagination and the formal imagination, Bachelard further decomposes the material imagination as a "paste" composed of earth and water.[3] While matter extends from the earth, the combination of water gives the paste fluidity to the substance of the earth. He describes this paste in association with the working of geometry as a kind of kneading and modeling. Like his French contemporary Henri Focillon, Bachelard is critical of the idealization of the formal imagination observed after the fact of creation, but rather seeks to look at the point of creative inception and the role of material imagination in this. Through the paste in particular, he emphasizes the experience of fluidity and pliability in creative development. In the beginner's hands, digital tools are rigid and uncompromising. On the other hand, with the pliability of NURBS based software, geometry is all too frequently kneaded without the paste of the material imagination grafted onto it. Bachelard's concepts of the graft and the paste are not simply materialist metaphors, but are concepts rooted in the understanding of creative development, and therefore an essential understanding for any design pedagogy. Materiality gives resistance to the geometrical flexibility of software, and yet material flexibility is needed to inspire the material imagination.

Pedagogical Goal: Tactics/Strategies

The reciprocity between two causes of creative development, the formal imagination and the material imagination, aligns with another great French thinker Henri Bergson, one generation Bachelard's senior. Thinking, for Bergson, is thinking through matter, in which duration cannot disassociate the "theory of knowledge" (general concepts) from the "theory of life" (action). Duration is a circular process between action and representation that "push each other on unceasingly" reciprocating between instinct and intellect in which our actions do not play out our thoughts any more than our thoughts evolve from our actions.[4] Intuition is central to Bergson's method as the go between of instinct and intellect in which instinct pulls intuition to material action, and yet, the intellect pulls intuition toward a conscious reflection of its actions. Bachelard's concept of "the graft" seems to follow closely from Bergson's interrelation between general concepts and material action, and furthermore Bachelard's concept of "the paste" within the material imagination aligns with Bergson's intuition. The fluidity of water gives material its pliability exciting the image from within the material imagination. This image is not simply a reflection of reality, but a projection that "opens eyes which hold new types of visions."[5] For Bachelard, this projected vision is not a passive view but is actively formed from the material imagination necessarily preceding the formal imagination.

Some 40 years after Bachelard's *Water and Dreams* (but in fact coincident with its english translation in the 1980's) the developmental psychologist James J. Gibson demonstrates that *action precedes cognition*.[6] Gibson's theory of active perception is coupled to his theory of affordances. In short, affordances direct attention toward particular actions while concealing others and therefore the theory of affordances represent certain opportunities for action with respect to an individual in an environment. My research has focused on the affordances of digital fabrication in design education, but pedagogies have affordances too - they direct attention to certain aspects while concealing others. To focus only on the affordances of tools and technology leaves too much instrumentality on the part of technology without the pedagogical social-conveyance of the importance, that is the intention of these affordances in the context of a practice.[7]

3 ibid, page 13.

4 Henri Bergson, *Creative Evolution*, page xiii. At the NCBDS Intersections conference, 2006, in my paper "Technique as Method" I went into more detail on Bergson and see this paper as a further development of some of the ideas in that paper.

5 Bachelard, ibid, page 16.

6 James J. Gibson, *The Ecological Approach to Visual Perception*.

7 Harry Heft, "Affordances and the Body: An Intentional Analysis of Gibson's Ecological Approach to Visual Perception".

My intent in bringing in this philosophical frame is not as a kind of philosophical buttressing, but to suggest our inherited cognitive models of constructing knowledge privilege formal/linguistic knowledge leaving intuition and the material imagination by the wayside. This becomes manifest in curricula and design pedagogies in which "skills" become isolated events and courses outside of what might otherwise be considered content. At the same time, this is not to glorify or substantiate skill-based pedagogies. Rather, the success of any skill-based learning is how it can connect back to the context of a practice.[8] Rather than a technological *push* with the expectation and hope that it will do more, this technological skill-based development can be *pulled* through content interrelating action and intention. My interest in digital fabrication developed from my material sensibility nurtured in my undergraduate education long before digital fabrication was commonplace. After several years of my own tool-driven research in digital fabrication and teaching focused studios and seminars on digital fabrication, I have come to the realization, perhaps naively, that digital fabrication is not a substitute for the material imagination, but rather sits at the opposite end of a spectrum, if not a totally different analytical and intellectual faculty that must be grafted onto the material imagination (Figure 1).

This grafting requires translation that is at once both a projection and an abstraction of the material imagination. Perhaps the weakest conventions with digital fabrication are because there is so little translation, so little abstraction is involved.

Digital/Material Sensibility

For this reason I take a material's first approach to developing digital skills. Below I present two approaches, one beginning with the physical basswood spline and the other with the constraints of sheet material. Rather than simply the development of digital skills, as if skills were isolated from the development of content, my approach is to cultivate a digital/material sensibility. After all, what is sensibility but sense plus ability? The development of skills, that is ability, should be taught in relationship to the senses they cultivate. As Malcolm McCullough has observed, "usability, identity, desire, and intent tend to relate."[9] No doubt the formal image has dominated digital discourse due to the geometric structure and screen-based interface of digital media. Through the inseparability between identity and skill, it should be no surprise that architecture has become so focused on visual imagery, and likewise, the identity of the design student as the image-maker. In beginning with materials first, my intentions are to cultivate a material sensibility enabled through the precision and geometric development in NURBS-based tools.

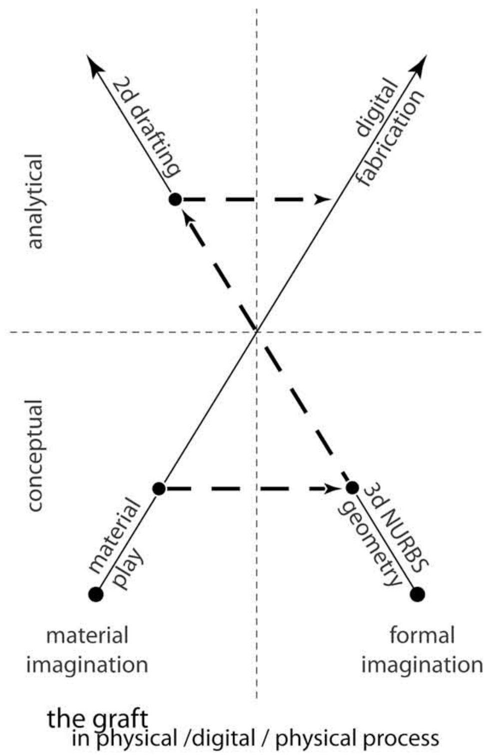

FIGURE 1: The intersection of two modes of development, the material imagination and the formal imagination, illustrating path of development from conceptual to analytical and the translation from material imagination to formal imagination.

Material Primitives: the Forming of Form

In the 18th Century, splines were drawn analogous to the material resistance of wood planks

8 See Lave and Wenger, Situated Learning.

9 Malcom McCullough, D*igital Ground: Architecture, Pervasive Computing, and Environmental Knowing*, page 160.

in ship building.[10] In other words, the tools developed were in relation to material properties. In the 1960's, mathematicians such as Pierre Bezier abstracted the geometry from these material splines but abstracted out the material properties. Bezier's intentions were not to develop a more efficient means of existing methods, but to create a bi-directional link between design and manufacture.[11] Despite these intentions, ironically these material constraints must be brought back in by the designer.

The first approach emphasizes a physical-digital-physical cycle. I begin with the literal basswood spline discussing its capacity and tendency to take shape.[12] The *capacity* of materials includes its material composition, for example how the higher grain density in basswood is superior to the looser grain structure of balsa. In discussion with my students, many have already experienced how balsa will snap somewhat unpredictably. The *tendency* of material to bend a certain way has to do with a material's geometric cross section, such as the weak and strong bending axis (bi-axial versus uni-axial), which students can identify with from their structures courses.

Students are asked to create a simple structure from a minimum of 12 basswood splines developing the most spatial variation with the least number of basswood splines. The structure must past two tests, the fist test and the finger test. The fist test requires that a closed fist should be able to get into the majority of spaces created. The finger test tests the behavior when pressing on one stick effects the others, thus requiring the sticks to be assembled in a network like fashion rather than discrete individual sticks. (Weaving is prohibited due to the difficulty of translating this in a digital model.) From this material primitive, a number of principles of NURBS based geometry can be introduced including degree of curvature, surface development, and surface panelization through ruled surfaces completing the cycle from material primitive, to 3d form, to 2d cut files.

10 Farin, Gerald E. *Curves and Surfaces for Computer-Aided Geometric Design: A Practical Guide*.

11 Pierre Bezier, "A View of the CAD/CAM Development Period."

12 See Manuel Delanda, "Material Complexity".

Degree of Curvature

The technical understanding of curvature degree (1st, 2nd, and 3rd) is important as students begin to transcribe their physical sketch models into digital splines. At first students have a raster mentality thinking the more points they transcribe the more accurate their model will be. In fact, the opposite is true. Students begin to develop a vector mentality understanding that a minimum of points creates a smoother curve. A grid can be drawn to plot these points or the use of a 3d-digitzer greatly streamlines this process. As digital tools become more parametric, this vector mentality is essential.

Surface Development

Many students are already familiar with lofting. This quickly becomes a bad habit generating random surfaces from random curves with little understanding of neither how they got there nor where to go from there. Flexible form becomes rigid. Based on the network arrangement of their physical splines, lofting doesn't work. Instead, students have to work into selectively skinning the model introducing a range of surface modeling approaches from lofting, railing, from boundary curves etc. The principal point in this is to understand the surface as a jig. That is, they can construct a preliminary surface from which they can extract isocurves to then develop a new surface, discarding or hiding the original surface. Using the surface like a jig is akin to the kneading of geometry that Bachelard referred to working and reworking their geometry such that their skills become fluid, not just the form.

Surface Panelization

From these digital surfaces, surface panelization through ruled surfaces is introduced to come full-circle from physical input, digital development, to physical fabrication. Rationalizing these surfaces through degree reduction requires a judgment call on the amount of surface subdivision - the more subdivisions the more accurate the surface but the complexity and time in fabrication. Although rudimentary, the real world material and time constraints of fabricating complex shapes balances their idealized non-material digital surfaces. Students also quickly realize that at each surface seam a back-up structure is required from which surface normal is introduced to develop structural ribs from the surface panels.

While clearly a skill-oriented approach for a digital fabrication seminar, beginning with the material spline allows the students in the first four weeks of this seminar to develop exceptional digital skills while developing a flexible translation process from physical input, to digital development, to developed physical fabrication from the original input model (Figure 2). As their mid-term project, students have both a refined physical model and are asked to project a larger image of their structure through developing skills in digital representation.

Material Organization: Epigenetic Landscapes

I have employed a less technical basswood spline approach in my design studio using 2d basswood material organizations rather than 3d form based approaches. Developed through a tryptic of 2d drawings with basswood splines, a physical vocabulary of bunching, pinching, bifurcating, is intuitively discovered (Figure 2).

These also follow the same requirement of a simple structure with complex behavior tested through the finger test encouraging the interrelation between splines, not simply isolated graphic lines, thus becoming a performative rather than graphic model. Through a vector then raster approach, students digitize these models then develop graphic hierarchy of line-weights in Illustrator, and then apply raster blurring techniques to create a smooth gradient. This linear spline based gradient is brought back into Rhino and developed as a height field 3d topography which are then milled in foam or MDF as their studio sites. In this one-week charrette, students are introduced to a basic material system through which the interoperability between a more familiar software, the Adobe suite, helps them with a completely new software, Rhino, and the CNC router. While less technically oriented than the previous process, this project has deeper conceptual roots as epigenetic landscapes in which the site conditions the evolution of forms set upon it.[13] The site is presented as a large distributed network of water retention swales bringing ecology into the discussion through a series of what would be massive earth works projects or constructed wetlands. With the majority of students having no previous 3d skills, this materials first process pulls them through an interoperable digital workflow while maintaining the studio discussion around waterflow and the relationship between landscape and the concept of nature.

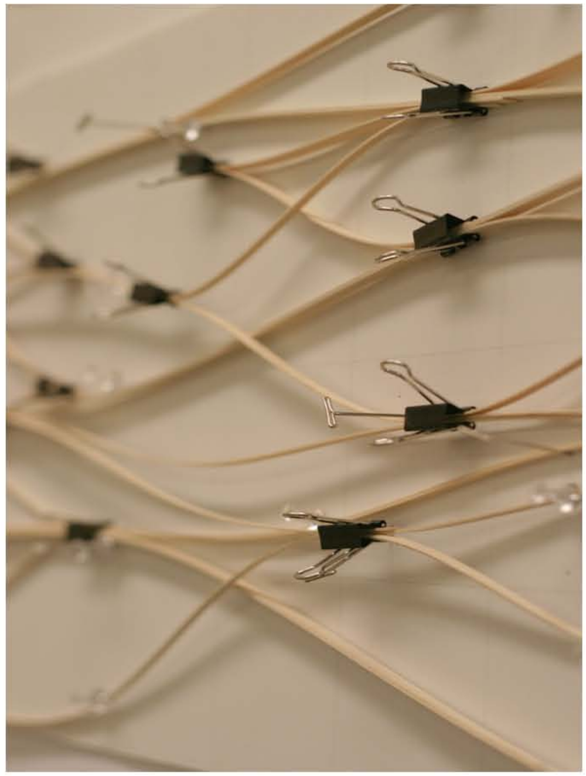

FIGURE 2: From physical basswood splines, a performative material system is developed from which digital splines are digitized and developed as topographical landscapes.

Material Constraint: Economy of Means

While the pliability of the basswood spline is an excellent introduction to the paste of the material imagination, in the previous examples the material imagination is not required for their surface panelization or actual fabrication. While effective introductory tools, there is inherently a great deal of material waste in their fabrication. Most digital fabrication develops from sheet goods. Despite the flexibility of form enabled through digital fabrication, little if any attention is paid to the sheet as a material in and of itself. Developed in the course of several studios from Spring 2006 to Spring

13 Sanford Kwinter, "Landscapes of Change: Boccioni's Stati d'animo as a General Theory of Models."

FIGURE 3: Full-scale installations require abstraction and translation from initial material play while allowing students to situate themselves in their collective work.

2009 (Figure 3), these examples explicitly focus on an economy of means through full-scale installations. By beginning with flexible paper, focus is placed on developing a material system from sheet goods minimizing or eliminating off-cuts. Through this explicit criteria the material constraints of sheet material become operative through cutting, scoring, and folding. Three approaches are given to direct this material play: expanding pattern, folding, and pattern tessellation. Pattern tessellation packs specific geometric objects on a sheet eliminating the margin and therefore material waste. While known to work for example through Philip Beesely's installations,[14] this approach has been less effective thus far.

Like expanded lath, the expanding pattern develops from a simple pattern of staggered cut lines allowing flat material to stretch and even develop three-dimensional shapes. This approach can be seen from SANAA's aluminum rainscreen for the New Museum of Contemporary Art[15] or Reiser and Umemoto's Vector Wall for the MoMA's Home Delivery Show. Folding as an approach needs little explanation but the goal to eliminate waste all together focuses this familiar approach.

Both approaches begin with zerox paper to allow the material imagination to play. This play is developed in brief one hour charrettes as a form of common materials research allowing students to borrow from each others' techniques. The incremental shift toward slightly more rigid materials such as manila file folders, index cards, and bristol board allow this material play to slowly work into material constraints. Developed toward full-scale installations, this initial material play required a scalar shift which also necessitated more rigid material such as a cardboard. Both the shift in more rigid materials and the shift in scale require a translation from the initial material studies. I have previously presented the role of scale in these installations.[16]

14 See Philip Beesley, *Hylozoic Soil*.

15 See Irina Verona, "Engineered Surfaces: Toward a Technology of Image," in *Praxis* 9: Expanding Surface.

Material Systems: Design for Assembly

In looking back to the paste within Bachelard's material imagination, it would seem that something more literal like clay would be most akin to NURBS-based development. On the contrary, this only extends the formal imagination. Based on the scale of architecture, as distinct for example from the fluid geometry of small scale sculptures or industrial design objects, the material imagination in architecture continues through the rigorous configuration of material systems. Toward this end, material constraints focus the material imagination. In these installations, it was the constraints of these basic material operations along with the criteria to eliminate waste altogether that excited the material imagination. Constraints are operative for the material imagination not imposing upon some presumed if mythical unfettered imagination. Even the capacity and tendency of the basswood spline includes material constraints. In these assignments, the development of a material system requires translation and abstraction from the initial material studies. The availability of sheet sizes along with their associated means of fabrication are criteria incorporated into the design development. Along with these material and fabrication constraints, focus is placed on the joint and the assembly process. Students must anticipate the fabrication and assembly of the piece through their design. Although straightforward criteria, focusing the material imagination on these criteria requires both a fluid and flexible material process as well as very physical and explicit constraints.

For example, the expanding pattern installation employed the laser cutter focusing

16 Mark Cabrinha, "Life-Size: Environmental Knowing through Full-Scale Installations."

the basic unit size on the 18"x30" bed size using an inexpensive and somewhat flexible white poster board. On the other hand, using the same technique of expanding pattern for a moveable feast, the rigidity of cardboard required a scale translation while the 4'x8' bed size of a CNC tangential knife cutter established the unit size. At the same time, these inexpensive, temporary, and very quick two week installation projects can extend into more permanent and rigid materials such as aluminum or steel, as illustrated in a 4'x10' full scale mock-up of the expanding pattern technique from water-jet cut aluminum (Figure 4). Regardless of the fabrication tool (laser cutter, CNC tangential knife, or abrasive water jet), what preceded the technology was the cultivation of the material imagination through the flexibility of material and focused constraints. This requires translation and abstraction from the initial material play to the design of material systems enabled by the precision of digital fabrication. Simply put, digital fabrication is not a substitute for the material imagination, nor necessarily does it inspire it. The material imagination is cultivated through the fluidity of material play and focused through constraints. Through a rigorous process of translation and abstraction, digital fabrication enables the development of material systems which may be derived from the material imagination. This process of translation and abstraction is a pedagogical opportunity to connect the material imagination with a disciplinary development of material systems.

Desire: Economy of Intent

Bachelard captures the "image" within the imagination focusing on the material imagination as a connection back to material experience. This image is not simply a reflection of how things appear, but a projection into the depths of experience. Ultimately, the material imagination is to cultivate projective images that are in touch with human experience. If developing a young designer's sensibility is the combination of sense and ability, skills then should not be isolated from the senses they engender. The geometrical structure of digital modeling tools effectively biases form rather than a more critical question of what informs form. Taking a material's first approach biases the material imagination as a projective method requiring translation and abstraction as this material experience is grafted onto the formal imagination. Even while encouraging the fluidity of material play, material constraints focus this material imagination. Through the graft between the material imagination and the formal imagination, my larger interest is how developing an economy of means might lead to an economy of intent. Design "concepts" are not developed as abstract ideas, but rather develop from material experience as contemporary studies in embodied cognition show.[17] As design culture inevitable becomes more of a digital culture, a more robust model of design conception must be paired with the develop-

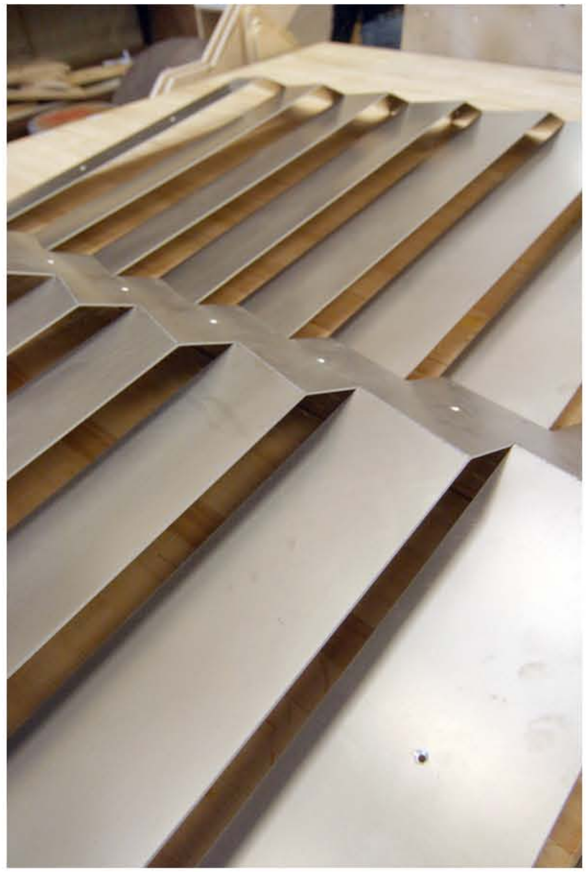

FIGURE 4: Material imagination writ large: from material play with index cards to full-scale aluminum prototype through an incremental development from conceptual technique to material system.

17 Vittoria Gallese and George Lakoff, "The Brain's Concepts: The Role of the Sensory-Motor System in Conceptual Knowledge," in *Cognitive Neuropsychology* 2005, Vol. 21.

ing parametric sophistication in digital tools. Sophisticated tools must be met with a more sophisticated model of design conception. The graft between the material imagination and the formal imagination is just such a model, and moreover, introduces a bias from which the projective image springs from the material imagination. Developing a designer's sensibility is, in part, a graft between the material senses pulled through the development of digital skills through a process of translation and abstraction at the core of architectural thinking.

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