This paper expands the discourse surrounding digital forms of making by scrutinizing the role of materials within computation, ultimately proposing a speculative working model that charts new territory. The growing importance of materials within technological research makes this an appropriate time to consider the nuance of their role within it. Currently, material innovation is happening along two central tracks: the customized cutting, sculpting, and forming of conventional materials with Computer Numerically Controlled (CNC) fabrication equipment and the development of new materials through innovations in material science. Both tracks rely on a limited set of material protocols which enable process-based control and eliminate the intrusion of any unpredictable material variable. Although efficient, such an approach limits architecture’s ability to procure novel material engagements.

A few designers are developing an alternative model where computational codes are coupled with eccentric materials to produce unusual results. Digital materiallurgy, as I have called it, is part technique and part attitude; it relies on intentionally ceding limited design control to unpredictable matter—thus capitalizing on matter’s innate ability to produce unexpected formal and material complexity. Digital materiallurgy identifies the intersection of computation and eccentric materiality as a departure point for architectural innovation. By purposefully inserting material heterogeneity and inconsistency into computational means and methods, this work pries apart the apparently seamless relationship between digital design and physical production. By blurring the distinction between physical material and digital form, this work offers an integrated aesthetic experience, one that fetishizes neither the virtual nor the vintage but fuses both into a richer, wilder present.
1 Introduction

The current moment in architectural production is marked by an unprecedented level of technological sophistication. At top schools around the world, crude experimentation with digital form has developed into highly sophisticated formal expertise. Professionally, the adoption and extension of computation in construction and engineering is realizing the future of building faster than most can imagine it. Advances in material science are creating the thinnest, strongest, most dynamic materials our field has ever seen. Although these are mostly positive developments, these innovations also bring with them the burden of defining what comes next for computation and material production within the context of speculative research. As novelty turns formulaic, experimentation evolves into expertise, and theoretical research drifts into mainstream practice, pressure is placed on the discipline to develop broader discourses and constructive new tangents.

The arguments to follow contribute to this general effort by scrutinizing the role of materials within computation, ultimately proposing a speculative working model that charts new territory. The growing importance of materials within technological research makes this an appropriate time to consider the nuance of their role within it. Currently, material innovation is happening along two central tracks: the customized cutting, sculpting, and forming of conventional materials with Computer Numerically Controlled (CNC) fabrication equipment and the development of new materials through innovations in material science. Both tracks rely on a limited set of material protocols that enable process-based control and eliminate the intrusion of any unpredictable material variable. Although efficient, such an approach limits architecture’s ability to procure novel material engagements.

A few designers are forecasting an alternative model where computational codes are coupled with eccentric materials to produce unusual results. Their approach is part technique and part attitude; it relies on intentionally ceding limited design control to unpredictable matter—thus capitalizing on matter’s innate ability to produce unexpected formal and material complexity. While mainly peripheral to dominant trends, these projects may offer productive digressions. In this essay I will attempt to theorize and situate this work by distinguishing it from prevailing attitudes of material agency in digital fabrication. I will then describe initial attempts I have taken to integrate these concepts into my teaching. Ultimately, these contributions are not meant to stand as an alternative to current research, but rather as an attempt at projecting its limits.

2 Digital Materiality

The importance of materials within digital production has increased with the shift from the exclusively software-based formal experiments of the early years, which took place in the immaterial, virtual platforms of design software, to the prototyping of physical artifacts which, by necessity, account for real material constraints. Increased access to CNC fabrication equipment has provided designers the means to test and develop methods of working where digital codes cycle through physical construction sequences. The work of Zurich-based architects Fabio Gramazio and Matthias Kohler has gone far in developing the possibilities and thinking behind this type of work. Their experiments with robots as an aid for construction illustrate the kind of cyclical process involved in the digital coding of material assemblies (Figure 1). “Digital Materiality,” as they have called it, defines architecture as the design of dynamic rule-based processes that govern both digital patterning and physical assembly (Gramazio and Kohler 2008). This open-ended operation allows for parameters to be changed throughout the process, triggering the other variables to respond and dynamically update the whole. Although the breadth of Gramazio and Kohler’s work is impressive and surely aids the development of new possibilities in digitally-enhanced construction techniques, the role actual materials play in their work is limited and, in fact, reflects the dominant trend in digital fabrication.

Conventionally, material choices within digital fabrication are governed by technical specifications—a limited set of physical characteristics that determine how a material
will interface with a specific machine. Two-dimensional cutting with a laser or abrasive water jet requires sheet materials with precise, uniform thickness. Thermo-forming, often used to form plastic over CNC fabricated molds, requires materials made of consistent chemical compounds that melt evenly under specific temperatures. CNC routing and milling require monolithic, moldable materials that can be systematically carved by machining tools. In this world, tolerance governs everything—and that tolerance leaves no room for material eccentricities.

This limited material scope is derived, in part, from the standard protocols of CNC machining, but it also reflects the dominant goal of most digital fabrication: to produce physical artifacts that resemble, as closely as possible, the computer models from which they originate. Within such a schema, materials are cast as inert matter waiting to be formed, relegated to a position of subservience to digital patterns. To counter this position I will put forth a model of working that is based on an intentional looseness, a productive slack between materials—including their textures, shapes, and colors—and digital form. I call this method of working digital materiallurgy; a play on the ancient craft of metallurgy.

3 Digital Materiallurgy

Medieval metallurgy is a process by which crude human actions guide the formation of animate metal. The internal workings of actual molecular formation remained a mystery for centuries, necessitating the development of techniques that work the material from the outside. The blacksmith, in other words, simply guides metallic development, knowing all the while that she can only manage such a volatile material. The actual process of forming a sword, for example, involves cold working the steel—hammering its hard edge while cold and solid—then annealing it by heating the sword to just below the steel’s melting point and slowly cooling it. Through such operations, a blacksmith is able to control the performance capabilities of the sword, making the edge hard enough to maintain its sharpness, and the body ductile enough to absorb the impact of other objects. Contemporary metallurgy, however, has abandoned these ancient techniques, working instead on actual molecular formation.

Manuel de Landa, in a recent essay, explains the molecular process of metallurgy and how it is informing contemporary research in the field (De Landa 2006). To summarize, as metal hardens after being heated to a molten state it starts to crystallize. The crystallization begins at localized moments in the metal and as these zones expand they meet and form small boundaries between them. As adjacent patches crystallize at slightly different angles they are unable to fully adhere along these connective lines, ultimately creating linear defects where the steel is most likely to fail. Current research is attempting to minimize the effects of these imperfections, distributing them in systematic ways throughout the body of the metal by guiding their molecular formations (De Landa 2006). The hammer, in other words, is long gone.

Taken as an analog for the evolution of architectural design, this example presents an interesting choice. Do we, as designers, follow the example of the contemporary molecular metallurgists and work our material formations from the atoms up, or do we work as the ancient metallurgists did, allowing matter to form itself, shaping it through expedient means? Although technological progress tends toward the former, I advocate a turn toward the latter for a few simple reasons. Firstly, regarding materials as dynamic agents in digital fabrication encourages novel treatments of conventional materials, which are too often guided by tolerances and not novelty or expressivity. Additionally, attitudes that seek to activate matter point us towards materials that are typically overlooked, ultimately allowing us to tap more fertile material ground. Finally, combining digital techniques with animate materials often supersedes the possibilities afforded by either total technical control or material purity. By increasing sensitivity to the unique capacities of computation and materiality designers are more able to craft pragmatic design solutions that utilize the unique capacities of both.

Giving materials space to unfold naturally allows one to harness their innate capacities. Materials have always possessed a default agency in establishing architecture’s qualitative dimension. They denote the territory where our bodies
engage architecture's physicality—a zone of interaction that can engender a broad range of human experiences, some that stimulate the retina, some that prod the skin, and some that set the mood. Materials provoke references and associations that connect architecture to other domains of cultural production. When materials are stamped into preexisting forms, however, they lose their innate expressivity in order to take on the characteristics of the mold. I am advocating for a degree of intentional chaos; a discrete lack of control which affords materials space to do what they do on their own, with little to no technical intervention.

This line of thinking finds support in the writing of Sanford Kwinter, who, elaborating on the work of Rem Koolhaas, puts forth one of the most poetic accounts of architectural materialism to date (Kwinter 1996). In his essay “Flying the Bullet, or When did the Future Begin?” he establishes an approach to design which relies on an engagement with an active, vital matter:

“...this radical view of materiality is a perfectly active, fluid and mobile one: it describes a materiality that actually moves and changes as it is worked, one that envelops and releases its own spontaneous properties or traits, carries its own capacities to express itself in form—all beyond the arbitrary reach of external control” (Kwinter 1996: 69).

Material formations, in other words, need not be determined by the techniques and types that make up the canon of one’s discipline; rather, they extend from the productive coupling of those techniques with the animate properties of matter. Designers must seize these productive capacities to produce novel arrangements. Modern technical paradigms advocate an approach that shies away from material collaboration for an “arid continuum of numbers,” where it is more important to abstract material processes into a set of equations than it is to tap its potential (Kwinter 1996: 70). Such an attitude reduces the complexity of material morphology by reducing it to predictable models that are then substantiated in some new medium. The approach advocated by Kwinter is more dynamic—using it, one intuitively senses the feral forces of matter, and guides them with whatever means possible. As Kwinter writes:

“To follow the movements of matter, to seize the prodigious blooms of ‘work’ that emerge ‘for free’ at certain critical moments in matter’s free and irregular flow, is to collaborate with, and actually develop, the unfolding of a vitalist universe, to tap both its powerful inevitability and its vast, though subtle, potential; to merge with that fluid universe, to both guide and be guided by its unchallengeable, inexhaustible, but fully intuitable efficacy (Kwinter 1996: 70).”

Before I enlist Kwinter as a supporter of the arguments put forth in this essay, I should make clear that the kind of materiality Kwinter is describing is much broader than the one being described here. He and Koolhaas are more concerned with the flow of actual historical conditions as their working materiality. However, the poetics and the attitude put forth by Kwinter are entirely translatable to the more modest scale of physical prototyping and architectural building materials. Perhaps the “free work” that Kwinter alludes to may be redefined, in the current context, as the affective potential of material properties or the cultural associations offered by a particular palette. Whatever the case, it can be said that materials do work; and part of our job as designers is sometimes simply to let them do it, all the while attempting to support, extend, and guide them.

3.1 DIGITAL MATERIALURGY AT WORK

A small group of designers is developing this approach through a close collaboration between technology and materials. Their work deploys deep codes, which I define as orders and patterns that are at work somewhere in the structure of a thing, but are often covered up by some form of messy materiality. Computation is fully enabled, but in support of the physical, textural qualities of the eventual materialization. By being buried, something happens on the way up to the “surface”—a productive coupling of the chaotic and the controlled, which determines the physical characteristics of the final assembly, the specificities of which cannot be predicted a priori.
P-Wall, a project by Andrew Kudless of Matsys, displays characteristics of digital materialurgy (Figure 2). Reminiscent of Miguel Fisac’s experiments with flexible concrete formwork, Kudless’ P_Wall combines digitally-aided elastic formwork and common plaster. A computer-generated pattern of points is translated into supports for the elastic fabric. Liquid plaster is then poured into the formwork, causing the fabric to expand under its weight. The plaster bulges irregularly, following the pattern of supports by sagging wider and deeper in areas of less constraint. Through very simple techniques Kudless is able to provide an arena for plaster to behave as plaster, while guiding its formation through subtle pressure points. Perceptually, the piece reveals a fluctuating visibility of the two systems—when viewed frontally, the imposed order of the gridded panels and the support points are visible; when viewed obliquely those patterns dissolve into a landscape of sensuous lumps.

Another project that exploits the gap between computation and material realization is Red Sea, a project by SOFTlab in collaboration with artist Michael Somoroff (Figure 3). For this large-scale sculpture, made of a frenzied mass of roughhewn wood sticks, SOFTlab created a parametric computer model where irregular pieces of wood are abstracted into lines and arrayed perpendicular to an undulating surface. A random function further varies the orientation of the lines to the surface, making the model progressively more chaotic and furry. The digital model also aids the actual construction, where the abstract lines are translated into assembly points for the wood members. The final result is a thick pile of jagged wood, spiraling upward in patterns that are ordered just enough to not appear random.

In both SOFTlab’s Red Sea and Kudless’ P_Wall unpredictable outcomes occur in the act of construction. A project that curiously slows down the process of digital materialurgy to the pace of natural decay is Raspberry Fields by Jason Payne of Hirsuta (Figures 4, 5). In addition, this project extends the current discussion which, up until this point, has pertained mostly to process into the realm of aesthetics. The project is a renovation of an old one-room schoolhouse in Utah. Due to its orientation in an open field, one side of the building gets exposed to the weather more than the other. When visiting the schoolhouse, Payne noticed that the wood-slat siding on the exposed side had dried out and curled up, producing a distinct texture. Instead of devising a solution to resist the effects of weathering, Payne started to think about ways to embrace and amplify it. His solution was to deliberately misuse wood shingles. He does this in two ways: first, he changes the proportions from wide to thin and second, he changes the orientation of the grain to encourage the curl that happens naturally from the weathering process. Over time, the façade goes from taut and ordered to shaggy and wild. As such, he redefines the protocols of common shingling—an intentional misapplication of a standard building material. What would be considered a failure in the context of utility, or poetic in the context of material entropy, is pushed toward something else, something more enigmatic.

Payne’s essay “Hair and Makeup,” offers some insight into the peculiar qualities of his work (Payne 2009). For Payne, materials and their superficial alterations are used as instruments to swing a building’s affective posture, similar to the way that hair and makeup enhance a musician’s sound in order to construct a total image. Far from superfluous, cosmetic enhancements are vital to the positioning of a project—establishing links to unexpected contexts, affiliations, and audiences. With this in mind, the motivations behind Payne’s subsequent material operations become clearer. On the backside of the shingles is a vibrant color field of purple, yellow, and orange, which is initially hidden but over time is revealed with the aged curling of the wood; thus producing an ever-changing array of vibrantly-toned yet simultaneously-decaying color. Further, the global pattern of curl is guided by the curvature of the underlying surface, which Payne digitally sculpts in order to encourage extra tangle in its crevices.

These final refinements aesthetically charge the rich textures produced by digital materialurgy. Taking a function of a natural material process—the weathering of wood—and digitally altering and amplifying it, Payne is able to produce an odd
mixture of seemingly incompatible sensibilities: the cosmetic and the entropic. What would be poetically preserved, framed, and displayed as an inevitable, natural occurrence in the work of more romantic architects, is here exploited, perverted, and bent toward new affective and associative terrain—including Payne’s career-long interest in hair. Interestingly, this fascination is not limited to actual hairy materials (although he uses those in other projects); rather, the hirsute, as a material property, and hair-styling, as an overt form of expression, are instantiated in the most ordinary of materials. In Raspberry Fields, Payne surfs the entropy of the aging wood, capitalizing on the "work for free" alluded to by Kwinter. Standard materials and protocols are extended through a mixture of geometric calibration and overt, stylistic manipulations, expanding their capacity to procure novel associations and generate exotic textures. His work is as much cultural as it is natural, as much aesthetic as it is morphogenetic.

3.2 DIGITAL MATERIALURGY AT PLAY

I first attempted to fold digital materialurgy into an academic setting in a course co-taught with Ellie Abrons at the University of Michigan’s Taubman College of Architecture and Urban Planning. The Material Fringe, as it was titled, sought to expand the discourse around materials and computation by combining digital techniques with material exploration. The course focused initially on hands-on, physical experimentation with various kinds of "fringe matter"—generally byproducts of manufacturing streams or recycled building materials gathered locally. The materials, either irregular cast-offs of regular materials or non-modular materials with no visible logic of construction, all required some degree of nonstandard development. Working in groups, the students were assigned a specific material and charged with the task of translating it into a viable architectural material. Methods of assembly were developed through rigorous studies of material behavior. Tendencies were quickly identified: particulate materials were likely to bunch and...
pile while blocks and sticks often stacked, fibrous materials were woven and bundled while surfaces were draped. Crude experiments led to the development of refined techniques, culminating in a catalogue of working material operations for each group.

Our introduction of digital techniques was strategic and measured. Instead of imposing ideal geometries onto the materials from the "outside," the digital work focused on extending the capabilities of the materials themselves, enabling them to aggregate in ways they could not otherwise. Students identified material limitations that could be mediated by digitally produced, extrinsic systems. Particulate materials, for example, had no way of building up substantial mass and required artificial support. Flexible surface materials needed to drape over a substrate in order to cover larger areas. Problems such as these defined the context in which the digital was deployed.

Two projects typify the work of the seminar. The first group used cullet, a mixture of various sizes of broken glass left over from float glass manufacturing (Figure 6). The major challenge with this material is adhering individual shards together to form larger surfaces. After numerous failed attempts at bonding single pieces, the students turned to casting, a common technique for incorporating particulate materials into composites. At this point, digital techniques were incorporated as a means to surpass the possibilities of standard casting, which treats matter as inert fill for standardized molds, thereby producing identical building blocks that predictably stack or fasten. Rejecting this approach, the students treated their mold as a live surface—a dynamic template that produced a fluctuating relationship between mold and matter. Material techniques were then developed to play off the curvature of the undulating, CNC-routed mold, producing variability in translucency, texture, and thickness. The distribution of cullet within the mold varied—sometimes following the geometry by pooling in depressions and thinning at peaks, and at other times generating its own patterns that washed over the mold in unpredictable ways. At points, the cullet rose above the lip of the mold, exposing its jagged edges above the surface of the final resin cast. The layered nature of the process produced a cast with two qualitatively different sides. One side took the shape of the mold, masking material changes behind smooth curvature and distorting silhouettes through fluid changes of translucency, texture, and color, while the other side appeared only faintly more ordered than a pile of broken glass. Thus, the traces of the digital were only visible in the curvature of the smooth side, while the rough side buried those traces beneath a thick irregular texture.

A second project illustrates a different approach within the course where novel possibilities were developed out of experiments with standard materials—in this case recycled asphalt shingles (Figure 7). Since this material came equipped with its own logic of assembly, the challenge was finding other logics that were latent in the material and could be brought about by alternative use or artificial support. Students began by rethinking the patterning of typical shingling, testing options with thinner pieces cut from their irregular stock. Eventually, the identical repetition of standard shingling was abandoned for variable patterns that bordered on stochastic. The experiments also modified the overall section of the surface: piling up to create a thick mass or hanging from above as thin strips. The shingles were supported by a doubly-curved substructure comprised of ribs with small slots to hold the shingles. Each slot was carved at a different angle relative to the rib, altering the orientation of the shingles to the surface below. The support structure’s carefully calibrated points were negotiated by the eccentric properties of the shingles, which simultaneously conformed to them and obscured their exactitude through a welcomed messy materiality.

Overall, the seminar provided an opportunity to think about the complex relationship between novelty and technical expertise. The relationship is a challenging one to navigate—while focus and specificity beget expertise they can also discourage more experimental approaches to research. In this course, material experimentation provided a context for novelty to emerge through an unscripted set of initial investigations that were only eventually aided by digital techniques. Computational
expertise was not an end in itself, but rather a means of extending the results of some other form of experimental practice—in this case, material innovation. Thus, the work avoided a reactionary position of picking matter over (digital) form by insisting on the productivity of both.

4 Conclusion

These projects, and others like them, forecast a future where the control resulting from conventional technological processes is intentionally relaxed in order to mine the gap between the coded and the chaotic. I present them, not as a call to abandon other forms of technological research, but as a means of exploring new speculative ground. Certainly, innovations in material science, advanced engineering, and environmentally responsive systems are necessary—and our best chance at truly sustainable practices. In the broad name of research however, we must constantly seek out projective terrain that opens up novel tangents. I offer digital materiallurgy as one such trajectory.

Digital materiallurgy identifies the intersection of computation and eccentric materiality as a departure point for architectural innovation. The purposeful and directed insertion of material heterogeneity and inconsistency into computational means and methods can serve to pry apart the apparently seamless relationship between digital design and physical production. Ultimately, by blurring the distinction between physical material and digital form, architecture can offer a more integrated, startling, aesthetic experience, one that fetishizes neither the virtual nor the vintage but fuses both into a richer, wilder present.

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