Considering the next tile prototype, the introduction of phase-change materials as micropellets into the ceramic material will significantly increase the thermal storage capacity and hence the leveling factor of the thermal mass. Vollen and Clifford's ecoceramic facades (2012) provide an example of how ceramic vessels filled with phase-change material can be sculpted to work with specific sun angles for passive environmental benefit.

5.2 Future Toolsets

A feedback loop is cyclic by nature: between a simulation model based on material characteristics, the actual material composition of the piece, and the material behavior in a specific context (Figure 25), measured with a sensory array which then inputs behavior data into the model.

In this project, the use of handheld instrumentation (spot thermometer, hygrometer) informed the haptic aspects of making, and to some extent helped quantify material characteristics comparative to a priori knowledge. The sensory array delivered data that was useful toward verifying this knowledge and is a basis for further modeling assembly behavior. Performance modeling such as the flownet is a useful starting point toward a simulation of a dynamically balancing system, based on leveling effects of temperature and moisture (Figure 26), which can effectively accommodate human comfort.

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WORK IN PROGRESS

MATERIAL INTENSITIES

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ABSTRACT

For many years now, two distinct strains of inquiry have preoccupied both theoreticians and critical practitioners in the field of architecture: first, the adoption of computation as both an analytical and a generative tool, and second, concern with performance of the actual—how real materials and systems perform in the environment. The dialogue between the two has tended toward a result wherein one process subjugates the other as a means of qualification and verification, and rarely have we seen instances of designers allowing a level of parity in inquiry between these two strains. However, in the format and staging of the 2012 Smartgeometry Conference (sg2012), this question of parity in the inquiry between computation and the world of performance and material was explicitly staged. The challenge was designed with the aim of using as a productive resistance the notion of material intensity—described below—as both a foil to and a measure of current concepts of simulation and intensive modeling in architectural computation. The holding of sg2012 aimed to stage this resistance in the form of workshops, roundtable discussions, lectures, and symposia, with the outcome attempting to define a new synthetic notion of material intensities in modes of architectural production. This paper aims to form the basis of a continued exploration and development of this work. In summary, we focused on:

> *Intensive thinking as derived from the material sciences as an actual and philosophical framework that emphasizes qualitative attributes, which is likened to behavior, simulation, and dynamic modeling. Extensive attributes lead to analytical, representational, and static modeling.*
>
> *Material practices can also be formed as a result of this method of thinking. As demonstrated by the glasswork of Evan Douglis and "paintings" by Perry Hall, the managed complexity possible by working with materials during intensive states of change allows for scalar, morphological, and performative shifts according to a designer's criteria.*

Although both are necessary and actually complement each other, architects need to "catch up" to intensive thinking in process and modeling strategies. Our methods rely on static modeling that yield often complicated frameworks and results, wherein accepting methods of dynamic modeling suggests the capacity to propose complex and nuanced relationships and frameworks.

figure 1

MATERIAL INTENSITIES

"Materials influence design in every way imaginable. Design assemblies driven and executed with material logics through computation have radically expanded our design paradigms. The question though is whether computational design is truly taking advantage of all that materials have to offer us? Whether in the space of nano-designing the geometry and characteristics of an element at its molecular level to prejudice its final aggregated form and performance, or in the space of simulating material properties in easily accessible 3D modeling programs, it is true that computation has engaged research, material, systems, and assembly like never before. However, these modes of work have not had the forum to cross-pollinate and enter into dialogue with each other before. We have the opportunity to shift the paradigm in favor of a multi-scalar material intelligence within the discipline of architecture creating radical new potentials for our ecosphere." (Comodromos and Ellinger 2012.)

As suggested above, computation's dominance in the discourse and practice of architecture in the last two decades has unquestionably tended toward advancing modes of control over geometry, translation of "drawing" and "models" to methods of fabrication, the possibility of staging a full simulation—wholly virtual—of a building being constructed and completed, and aspects of building information management during the design phases and post construction. What is in question, however, if these methods and modes of production are in fact harnessing the scalar and complex potentials presented by simulation and dynamic modeling as understood by other disciplines, particularly the sciences? Furthermore, can these models simulate the level of response and complexity that our discipline's own historical simulations such as the (analogical) models of Gaudí, Isler, and Otto were able to produce? These models—dependent on material to *compute both form and performance*—move well beyond typical digital simulations that are designed to imitate rather than simulate. Finally, can new practices, and not just techniques or technologies for design, focus on ecological and synthetic methods of dynamic modeling that use the intensive thinking grounded in analogical modeling, with methods used for centuries in "the sciences"? These questions were formulated and synthesized by the authors as an accepted proposal for a conference held recently on the nature of material intensity and computation in architecture. The questions formed the basis for that conference's challenge, wherein feedback loops between design, computation, material practice, and morphology could be tested and proven in workshop format. And since the conference, the work and lectures provide a resounding yes to the question of whether or not these practices are possible, and more importantly, whether or not they have value to the discipline and its intervention to the world at large. As such, this paper proposes to establish with more specificity the theoretical and critical basis used by that conference while also aiming to project these concepts further to the practice of our discipline and engagement with the built environment at large.

"The ... challenge, Material Intensities, is intended to dissolve our notion of the built environment as inert constructions enclosing physically sealed spaces. Spaces and boundaries are abundant with vibration, fluctuating intensities, shifting gradients, and flows. The materials that define them are in a continual state of becoming: a dance of energy and information." (Smartgeometry Conference 2012.)

Perhaps the key term in the challenge's title that modifies our traditional notion of the first term, "material," is *intensities*. *Intensities* reference explicitly what are the intensive properties of materials: those aspects of a material that are qualitative, intrinsic, and indivisible as opposed to the extensive properties—which rely on quantity, measure, and proportion. As such we begin to understand materiality not in terms of metrics and tables, but instead through key relationships that affect the performance and conditions of materials such as temperature, pressure, density. This helps us frame the argument further, in perhaps more familiar terms; whereas *intensive thinking* speaks to the topological, *extensive thinking* speaks to the topographic. Even further, we can analogize "intensive vs. extensive" to the familiar terms "simulation vs. representation."

figure 1

Opening day of sg2012 at Rensselaer's Experimental Media and Performing Arts Center.

"As biological organisms and social agents we live our lives within spaces delimited by natural and artificial *extensive boundaries*, that is, within zones that extend in space up to a limit marked by a frontier. Whether we are talking about the frontiers of a country, a city, a neighborhood, or an ecosystem; or about the defining boundaries of our own bodies—our skin, our organ's outer surfaces, the membranes of our cells—inhabiting these extensive spaces is part of what defines our social and biological identities. We also inhabit other spaces, *zones of intensity*, the boundaries of which are not defined by spatial limits but by critical thresholds: the zones of high pressure explored by deep sea divers, the zones of low gravity explored by astronauts, the zones of high speed traversed by test pilots. These are all, of course, rare professions, but we all populate these intensive zones even if at more moderate intensities." (DeLanda 2010.)

To paraphrase above, we experience the world primarily within space as defined by extensive limits, but we also inhabit other spaces, spaces that are described here as zones of intensity. These spaces are not defined by limits but rather by critical thresholds; importantly, it is the intensive that gives rise to the extensive.

This manner of thinking permeates all manners of scale, structure, and configuration. The dynamics of state change mean that a critical increase or decrease of energy into or out of a system means a reordering and reconfiguring of structure. In thermodynamics this occurs as a change in state—solid, liquid, gas, etc. In kinetics of bodies, it is the walk, to the gait or trot, to the run (each state determined through a triggering of different muscle sets of the body). In urban models, it is how behaviors become identified as the individual agent, the institution, and the state. The question therein lies: how do we understand architecture as being differentiated when crossing critical intensive thresholds? Element, component, assembly? Component, system, assembly? In these questions about the nature of modeling, scales of assembly, flows, and the structure of phases and states of materials as systems lie the questions of material intensity.

"Using these concepts we can define the sense in which the metric *(extensive)* space we inhabit emerges from a nonmetric *(intensive)* continuum ... the idea would be to view this genesis not as an abstract process but as a concrete physical (material) process in which an undifferentiated intensive space (that is, a space defined by continuous intensive properties) progressively differentiates, eventually giving rise to extensive structures (discontinuous structures with definite metric properties)" (DeLanda 2002).

Until recently, architectural design traditions have been built almost exclusively on deep explorations of extensive boundaries. Whereas most of the sciences have adapted their traditions in response to understandings of the intensive properties that give rise to the extensive, such as described here, architecture has largely continued to explore the realms of the extensive. That is to say, architecture is one of the last remaining disciplines that conceptually understands a "model" as a static representation; whereas, fundamentally, other disciplines have shifted their thinking and now conceptualize models as simulations of dynamic (intensive) processes that then, in turn, give way to their extensive relations.

figure 2

figure 2

Manta, by the Responsive Acoustic Environments cluster, sg2012.

There is a core group of architects and designers around the world engaging in design research exploring this very thesis, exploring what amounts to a paradigm shift in modes of critical thought that reconsiders the architectural model as a dynamic one—constructed to negotiate intensive differences for the production of an emergent extensive boundary that operates within the flows, forces, and potentials (intensive properties) of its context, however you may define it.

Most clearly, what is percolating amongst these like-minded architects, designers, and researchers is the suggestion that the exchange between energy and the built environment must be better understood, in every sense of both. At their most primitive, both energy and built environment are seamlessly, perhaps effortlessly, integrated; at their extreme, the recent tendencies have been to segregate and isolate systems of energy resolution (structural, environmental enclosure, mechanical delivery, etc.) into more and more *complicated* assemblies of discrete layered components within the built construct. However, if one is to truly develop architectural solutions that work with the environment, then the operative systems must be understood as *complex* assemblies. As Paul Cilliers so clearly illustrates, "I have heard it said ... that a jumbo-jet is complicated, but that a mayonnaise is complex" (Cilliers 1998). As mayonnaise relies on process and technique to transform few additives into something with radically different performance, so too must the built environment. Unfortunately, building design tends toward the jumbo-jet model where additives are not introduced in ways so that they work cooperatively to produce more productive performative responses. We are at a critical period in the digital age within the trajectory of the architectural design engines, when looking toward some of the ways in which the sciences have begun to use advanced computation to understand energy flows would be more suitable for our discipline. With access to incredible computing capacities, the sciences have developed incredible resolutions of "multiscalar modeling, leading to radical material advances, including a new understanding of the relationship between material behaviors and 'bioclimatic' energy flows in the environment. The 'Bioenergetic Information Model,' rather than 'Building Information Model,' proposes an inclusive basis to manage the complexity of fluctuating ambient energy flows and fluctuating programmatic demands as they concern the building life-cycle, which extends urbanistically and infrastructurally beyond the conventional understanding of a building" (Dyson, Vollen, and Ngai).

Specifically, the work of the conference shows how the *concept of material intensity can operate at multiple scales* and as both process and method. In *Manta*, the Reactive Acoustic Environments cluster set up an active feedback loop between the morphology of an acoustically reflective ceiling (by crimping the seams of the panels, which were hung by a CNC winch system) and the number of inhabitants in a space and their relative proximity to each other. The parametrics of the design—wherein a more intimate gathering precipitates a more severe crimping of the surface to allow for quieter conversation—creates a logic and flow of cause and effect that in behavior simulates the kind of resistance embedded in material systems. Immediately in the research of the cluster, both the programmers and the passive participants became *active agents* in trying to induce state changes and identify thresholds wherein the morphology of the ceiling surface would undergo a rapid or unexpected change due to the rate of increase of one of the inputs. Conversely, the *Transgranular Perspiration* group worked on designing actual material to embody and control state change and ultimately the responsiveness and performance of a given material (in this case, clay fired into ceramic tiles) by altering and creating continuous difference within the material and eventually the component. These examples—2 of 11 different investigations—indicate the power of material intensity as a method of inquiry and framework for architectural research and practical methodology.

Capitalizing on the intellect of our partner disciplines is nothing new for architecture, which is only fair since many of these disciplines are born out of architecture's legacy. In 1917, D'Arcy Thompson wrote in On Growth and Form, as "... we reach through mathematical analysis to mathematical synthesis ... we pass quickly and easily from the mathematical concept of form in its static aspect to form in its dynamical relations: we rise from the conception of form to an understanding of the forces which gave rise to it" (Thompson 1917). Le Corbusier often referenced Thompson for other purposes, but perhaps what was missing from Corbusier's time was the ability to use Thompson's suggestion through creation of dynamic models of design synthesis. As other sciences have begun to use computational methods to model complex energy for the advancement of their disciplines, so too must ours. Specifically, material and energy systems can be simulated with advanced computation, and this is the way in which architecture can literally redefine the building paradigm—one in which material and energy flows work together rather than as resistive propositions. Material intensity seeks the grounds of design where flows are captured, transformed, and redistributed through the building material matrix seemingly effortlessly, negotiating the complexities of these systems through a reliance on behaviors rather than resistances.

figure 3

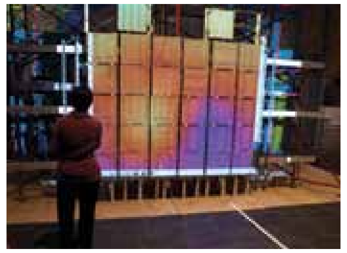

figure 4

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Thompson, D. W. (1917). On Growth and Form, 270.

figure 3

Work of the Bioresponsive Building Envelopes cluster, sg2012.

figure 4

Work of the Transgranular Perspiration cluster.