The Weather Inside: Thermodynamic Flows and Architectural Entropy

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1 MOVING WEATHER

In the sweltering days before the Beijing Olympics last year, the Chinese government invented a novel approach to climate control on a grand scale. Worried that the storm clouds gathering on the horizon would turn the Olympics' opening day into a downpour, the China Weather Modification Office fired 1,000 rain-dispersal rockets filled with silver iodide into the clouds—which broke apart and drifted away over a matter of hours. This was geo-engineering writ large, as if the atmosphere itself were a programmable piece of stage scenery. The project was a temporary success. As a Chinese representative said, "under such a weather condition, a small bubble in the cloud would have triggered rainfall, let alone lightning."[1] However, by the following day, the rains were back in force, along with electrical storms. Most of the later outdoor events, from archery to tennis to cycling, were conducted in a torrent.

Meanwhile, a number of gigantic infrastructural buildings were under construction across Beijing's horizon. These buildings were, for the most part, intended to seal one kind of weather *outside* the building (hot, muggy, polluted) and another kind *inside* the building (cool, dry, clean.) If the geoengineering of the clouds around Beijing didn't work, then at least Beijing's habitable spaces would be protected against inclement weather through layers of curtainwall and structure. As a deflating coda, a few months later Rem Koolhaas's TVCC tower, companion to the more famous CCTV loop, caught fire just weeks before it was to open. The windows were blown out, the inside gutted by flame, at a cost of perhaps $500 million dollars. Some cynical commentators regarded the disaster as the metaphorical denouement of the heroic cultural ambition manifested in China's Olympics.

These interlinked episodes demonstrate a continuum in our thinking about climate, both inside and outside of buildings. Traditionally, we have imagined buildings as closed systems, to use the language of thermodynamics, when they are in fact open systems in a constant sensory flow. Our historically bivalent image of inside/outside is beginning to give way to one in which interior and exterior systems are dynamically intertwined. Flows extend into invisible dimensions composed of particulates, energy and even data. We exist as vectors or clusters conveying not only physical matter in its varied forms, but information and signals. This way of thinking draws on non-equilibrium thermodynamics filtered through a number of other mediums: from its origins in physics, it spun off into economics (Nicholas Georgescu-Roegen, Kenneth Boulding), ecology (Howard Odum, Fritjof Capra), cybernetics (Norbert Wiener, John Von Neumann), and even into the "soft" domains of anthropology, sociology, and political science. These approaches are based on the notion that most natural systems are not in equilibrium, but are in a perpetual exchange of material, energy, people, capital and information. In fact, as the thermo-economist Nicholas Georgescu-Roegen once said, "if we set aside the case of the whole universe, isolated systems are set up…only in laboratories."[2] Looking at the models in these varied fields, we often see what might be called a *productive disequilibrium*, meaning that the interactions of two systems with differing qualities creates a flow from one to the other, like two eddies forcing one another to spin, generating a third dynamic condition of overlap and commingling. This third condition is productive in the sense that it can create new energies or transformative states.

Yet over the last forty years, architecture has had a tentative relationship with issues of thermodynamics. Our profession, even today, is largely deterministic and almost classical in its regard for order and process, with a few exceptional outliers. We continue to envision buildings as sealed boxes with doors and gaskets to "trap the air in"—we persist in the idea that architecture is a more or less closed system. There was a moment in the 1960s when architecture seemed primed to take a thermodynamic turn: cybernetic concepts were everywhere; firms like Superstudio, Archigram, Cedric Price, and the Smithsons theorized an idea of urbanism that was decentered, unstable, and evolving; Reyner Banham raised questions of atmosphere and environmental systems in his visionary 1967 book, *The Architecture of the Well-Tempered Environment*.[3] At the time, Banham's ideas had potential to act as a counter-history to techno-formalist readings of Modernism, such as Giedion's *Space, Time and Architecture*. But this broad ecological theorization was quickly dissolved in the prevailing attitude, a Postmodern preoccupation with type and semantics that characterized the 1970s and 1980s. Environmental thinking was thus relegated to the sidelines of architectural debate for thirty years, even as the larger culture entered a phase that Lewis Mumford forecast as *biotechnics*.[4] We might say that our current era is thoroughly biotechnical, with strange new hybrids being created in genetic laboratories every day: glowing rabbits, cloned sheep, and transgenic ears grown on the backs of mice.[5] But Mumford's biotechnics also owes its existence to an awareness of the climate crisis, with its attendant local effects such as rising sea levels, fluctuating temperatures, melting glaciers and so on. These trends no longer signal some dark future, but rather the outlines of an anxious present.

In this situation, architecture could not escape its own eventual biological turn. But architecture's engagement with dynamic systems has been tentative at best. Until now, even "green" firms have approached these issues cautiously, applying sustainable technology as grafts upon fairly traditional armatures. In certain *au courant* practices, such as UNArchitects or Foreign Office Architects, an algorithmic or genetic view of design has often resulted in static morphological forms that do not always engage dynamic systems in active and ongoing ways. That may soon change, as practices like R&Sie, Phillipe Rahm, Lacaton & Vassal, and many others begin to create architecture not of rigid boundaries, but of literally interacting dynamic systems. The results may not remind us of architectures that we have confronted in the past, where the exterior limits of the building were readily perceptible in the form of an envelope—indeed, in the case of some of this recent work, the notion of "building" has completely dissolved, replaced by a gradient from outdoors to indoors (see, for instance, R&Sie's house in Nimes, France called *Spidernethewood*.)

If architecture sits at the confluence of ecology, capital, and information, then the evolutions in these disciplines *should* impact the very nature of architecture itself. But recent developments in these overlapping modes are illustrative of what architecture lacks: a syncretic idea of itself in relation to the world. Philosopher Peter Sloterdijk, in his essay "The Operable Man: On the Ethical State of Gene Technology," describes how our perspective on technological culture has been bivalent for a long time: culture vs. nature, man vs. machine, mind vs. matter, being vs. non-being.[6] This perspective has created a situation in which technologies and machines are seen as oppositional to our humanness—*there is a man, and he governs a machine, and therefore controls some small aspect of nature*. But, Sloterdijk argues, our relationship to technology is at least trivalent, if not ambi-valent. It exists as an almost infinite series of gradations of technology as an extension of our humanness. In an era of Lasik surgery, cochlear implants, pacemakers, prosthetics, genetic sequencing, multi-touch screens and so on, we might argue that the merging of biology and technology foreshadowed by Mumford is complete. As Antoine Picon has remarked, the image of our age is not the Renaissance's humanist subject, nor even Le Corbusier's Modulor, but the cyborg, which Picon says is "not a utopian figure, but the result of the full use of existing technologies."[7] Even as our definitions of the limits of the human shift, our engagements with building technology are changing as well. It remains to be seen, however, whether architecture will respond with hybridized models of interaction of its own.

2 IMMUNIZED SPACE

> The cosmologists had predicted an eventual heat-death for the universe …the meteorologists, day-to-day, staved it off by contradicting with a reassuring array of varied temperatures. Thomas Pynchon, *Entropy*[8]

These words are spoken by the protagonist Callisto in Thomas Pynchon's early story "Entropy". Castillo lives in a hermetically sealed apartment, fretting about entropy while his downstairs neighbors throw a riotous party. He reacts against the universe's "eventual heat-death" by attempting to hold it at bay outside the apartment, where the temperature has been lingering at a fixed 37º Fahrenheit for days. The story ends when Castillo's live-in girlfriend, Aubade, smashes the windows in Castillo's apartment in order to break it open and allow the air from the outside to invade this closed ecosystem, which normalizes to the outside at 37º, "the final absence of all motion."[9]

Pynchon's story speaks to certain tendencies in the architectural profession to treat buildings as airtight objects sitting more or less inert in the landscape. In the traditional view, buildings act as almost climato-militaristic fortresses attempting to prevent the outside weather from getting in. Think of Peter Sloterdijk's image of architecture as a kind of foam, in which individuals occupy contemporaneous, touching cells (or apartments) that nonetheless do not overlap.[10] They have precise limits, a boundary, an edge that encompasses an interior. In that sense, buildings have long been one method for "normalizing" the weather, abolishing those conditions we find unpleasant, creating a meteorological stasis, a sort of immunological space.

Since the advent of air conditioning by Willis Carrier in 1902 (and conceptually stretching back to the first prehistoric fire lit inside a cave,) our interior climates have been manipulable through technology. Beginning in the 19th century, new structural and environmental technologies allowed architects to reinvent their approaches to building, but created complexities that fell outside of the traditional boundaries of the discipline. As a result, a series of branch economies were spawned to deal with new technological conditions. Infrastructural issues were subcontracted out to civil engineers; structural issues to structural engineers; landscape questions to landscape architects; issues of ventilation and climate to mechanical engineers. The building was reduced to an agglomeration of disparate systems that in the best instances formed an uneasy whole, and in the worst tended to operate at odds with each other. The architect was left with a kind of universalized aesthetic wrapper enclosing a set of tangled systems. During the modern period, even as buildings became more transparent, their ability to isolate climate increased through new barriers such as curtain walls, insulation, thermal breaks, and so on.[11] Drafty buildings were sealed, R-values went up. In the 20th century, this trend manifested as a concern for prismatic modernist forms and a glassy transparency, with the envelope as a mediator between the interior and exterior. Thus, influential works such as Mies Van Der Rohe's Seagram Building or the Lever House by SOM were fundamentally about sealing spaces off almost hyperbarically. Huge HVAC systems regulated the interior environment. Air conditioning was piped in, the windows were siliconed shut, the inside ceased to interact with the outside. In later and more totalizing variants of this aesthetic, the windows were even mirrored on the outside, so that no visual contact was possible (in my city, Houston, these reflective rectangular megastructures populate the edges of highways, mirroring the always-encroaching weather systems, and yet evince nothing of what goes on inside. Like sensory-deprivation tanks, they seal inhabitants off from surroundings.) Building envelopes and HVAC systems have become effective at *immunizing* interior conditions,[12] which means that our understanding of a building's relationship to its surroundings is increasingly a function of envelope and mechanical performance. The architect trusts in a brute force methodology often used by mechanical engineers—ramming ducts through interstitial spaces, using a machine logic to generate constant airflow and regulate temperature.

As a result, architecture has had a primarily *reactive* relationship with environmental technologies. Under pressure from performance criteria like LEED, architects have begun to imagine buildings as aggregates of individual technologies, each of which grant a certain number of points—once these points are totaled, a building might achieve a silver, gold, or platinum certification. Many architects concerned with sustainability find themselves acting as techno-specialists rather than designers, implementing a by-the-book understanding of individual techniques (solar panels, for instance, or low-VOC materials) and performance benchmarks.

Buildings risk becoming mere frames for performance-tested materials, shades, glazing systems. And architecture as a profession, responding to this zero-sum measure, threatens to mistake environmental performance for architectural quality and thought. In many lectures in recent years, we've heard architects tout their buildings as having achieved "LEED platinum," an honor that occasionally has the ability to whitewash deficiencies in the design. The trend may be transforming the historic role of architects, as we surrender the generalist advantages of a discipline that cross-fertilizes and hybridizes thought, for the narrow specializations of engineering or even specifications writing.

I would like to contrast a performance-oriented practice with a different methodology. Through the work of the firms I mentioned above, R&Sie, Phillipe Rahm, Lacaton et Vassal, and others, the age of Goethe's "frozen music" may be passing away. In its place we are hopefully seeing a deep ecological design evolving along with its surroundings: architecture as a transistor in a series of flows, a kind of semiconductive medium in the ongoing motions of people and climates. I'm referring here not simply to the formalized notion of flow represented in some recent *morphological* architecture—complex topographical systems of ramps and linkages that are fundamentally about a formalist perception of space via the eye, and which do not, in fact, flow, even as their curvilinear shapes are suggestive of a neo-Baroque simulation of flow. In many of these projects, the architects use elaborate definitions to describe the work as evolutionary, when in fact it is merely morphological: that is, having to do with form, shape, color, and pattern. In some of this work, an algorithmic process of feeding data and variables into computers in order to generate a composite is halted when the algorithm has cooked long enough, or, as Alejandro Zaera-Polo writes about FOA's method on the Yokohama Ferry Terminal: "[the project was] surprising us at every moment with how the technical requirements were organizing themselves into arrangements."[13] In other words, the designers watch a magically evolving image on the screen, before choosing the moment at which to hit *return* and freeze the arrangement, somehow abdicating responsibility for the process to a virtuality, a microprocessor, and a script. The conceit has been that this process is genetic, in the same way that the evolution of a species over millennia is genetic, creating a series of unprecedented architectural phenotypes, almost like creatures in a petri dish. But, as Jorge Silvetti has written, "nobody involved in these attempts seems to want to be responsible for the outcome and its authorship insofar as *form* is concerned…They all relegate the architect to the role of intermediary—the midwife."[14] Though morphological models have value, they can appear somewhat passive and uncritical in the face of very legitimate social and ecological forces that are influencing them—emphasizing arrangement s rather than interactions with evolving consequences. In some sense, they amount to a new kind of techno-determinism, in which the algorithm becomes a generator of results, and is seen as, if not infallible, then at least objective. Yet one has to wonder if this appropriation of biological language in architecture is largely metaphorical or analogical, providing easy cover for architects to experiment with new forms without having to be accused of a "meaningless" formalism. As Greg Lynn writes in a telling moment, these approaches "simulate the appearance of life."[15]

A potentially richer way of pursuing flow in architecture is through thermodynamics, not form. Inherent in ecological thinking, for instance, is a sense of thermodynamic processes that evolve over time, allowing for both entropy and positive growth. In this sense, architects could learn much from their compatriots in landscape architecture. When landscape architects discuss issues such as flow and transformation, they speak not in metaphors or analogies, but in terms of real matter. As James Corner writes, "Landscape architects tend to view the specificity of a given site—its environment, culture, politics, and economies—as a program unto itself, a program that has an innate tendency or propensity with regard to future potentials."[16] One might also cite the diagrammatic thinking that rose out of Rem Koolhaas or Bernard Tschumi's early projects, in that it reworked architecture as a field of potential, a staged event, a programmatic system in two senses of the word: both a use and a script. But if their preoccupation has been with program as a generator of social activity, thermodynamics has the expanded opportunity to create buildings that are wholly ecological—as opposed to simulations of the biological—interacting with climate, matter, and demographics simultaneously. This might be considered a kind of phenomenological realism, where science serves the real needs of architecture rather than its merely formal demands.

3 ENTROPY GARDENS

The high modernist idea, rooted in a kind of aesthetic classicism, was of a building as an inert object in a landscape, yet also divorced from that landscape. Yet, as I've noted above, buildings are actually in a state of perpetual exchange of air, people, matter (both new and spent), data, and many other elements. The physicist Ilya Prigogine called these *dissipative structures*,[17] and argued that living processes "follow from the laws of physics appropriate to specific nonlinear interactions and to conditions far from equilibrium." He continues that social structures are "both influenced by and act upon their environment."[18] The same might also be said of buildings: that they are ultimately massive dissipative structures both influenced by and acting upon the environment. In other words, a building is not a vacuum, it is a sponge.[19] One of the fallacies of a visual culture is that we sometimes ignore the molecular, invisible, long-duration aspects of our creations. Because in reality WYS *isn't* WYG: what you see is not what you get. What you see is only a part of the equation—a network of invisible effects flow around and through our buildings, in the form of weather, migratory pathways, germs, dust particles, electricity, data, flows of capital and cash in its digitized form. Though these elements seem to represent the "virtual" life of a building (illusory qualities that manifest only on computer screens), they are real and have somatic effects.

A new aesthetic would deal explicitly with these quasi-invisible phenomena. The first step is to acknowledge the role of entropy in architecture. In every system in the world, degradation and transformation inexorably occur. Buildings weather, patina, and erode. As the thermo-economist Nicholas Georgescu-Roegen wrote, "all over the material world there is rubbing by friction, cracking and splitting by changes in temperature or evaporation, there is clogging of pipes and membranes, there is metal fatigue and spontaneous combustion. Matter is continuously displaced, altered, and scattered to the four corners of the world."[20] Buildings were never meant to stand unchanged in one spot for eternity; they were meant to evolve, to grow and shrink and find new uses.[21] I was disappointed to hear a few years ago that Villa Savoye had been renovated, the weeds removed, the cats chased out, the chipped paint repaired. In its decay, it had been a fitting memorial to a certain moment in our architectural history—and ruins have a special ontological power that new buildings simply do not. But our building culture is always trying to hold decay and entropy at bay. We repaint, we repair, we prop up our old idols on new stilts, trying to engineer some sort of equilibrium out of broken parts. The Japanese architect Kengo Kuma makes reference to this idea of an entropic architecture by way of gardening, discussing the gardener as the ideal archetype for how architects might regard themselves in the future: "[the gardener] is forever occupied with watering, ridding plants of bugs, weeding and replanting, and the garden would cease to exist if he stopped….There is no temporal *point* where a goal is reached and completion is achieved. There is no completion for a garden."[22]

In this respect, the work of Piet Oudolf, a Dutch landscape architect, is instructive. Oudolf plans gardens based on the entire life-cycle of plants, from birth and bloom through death and decay. Oudolf takes an entropic view of how gardens work, not trying to sustain them in perfect bloom year round but allowing for plants to fade and grey. Often, the spathes and bulbs in his gardens appear to be dead, but they are in fact merely dormant, waiting for the seasons to change. Oudolf frees himself from what landscape critic Charles Waldheim calls "the soft pornography of the flower."[23] In the realm of architecture, a recent proposal from OMA for the Hermitage in St. Petersburg takes a similar approach: treating matter as transitory, entropic, allowing the dust and rubble of the old museum to remain in place with minimal interventions. As OMA writes of its project, "Does every museum need to be modernized? …Do all museums have to be extended and updated, or can a certain amount of inaction, a certain resistance to change, actually be instrumental in maintaining a degree of the authenticity so frequently erased during the process of modernization?"[24] The OMA plan conveys a new methodology for building rehabilitation, one that allows the ruin to continue to exist as a marker of time. One could imagine a future architecture that embraced entropy, or even made use of the constant dissipation of heat and structure to reconfigure buildings—perhaps in a kind of *controlled* entropy.

4 THE SURROUNDED SUBJECT

By the 1960s, conceptual artists were already working with ideas about thermodynamics and open systems. Beginning with artists like Hans Haacke and Robert Smithson in the 1960s, and progressing into the contemporary period of Olafur Eliasson, Carsten Höller, Wolfgang Laib, and others, this art deals with the phenomenological state of a body inhabiting and sensing an environment. The pieces engage with transitory conditions as a form of the beautiful (as an example, Eliasson's simply named *Beauty*, in which a fine mist of water is illuminated in a darkened gallery, creating rainbows in constant flux.) Indeed, this art calls into question our assumptions about the very notion of beauty, as often related to an aesthetics of touch or time as of the eye.

Drawing on this conceptual art and on phenomenologists such as Merleau-Ponty and Heidegger (channeled through Christian Norberg-Schulz), many recent writers have discussed an architecture of five senses. But the issue is not simply human subjectivity in its somatic experience of a specific building (nor an eye moving through a space, as in so many raytraced architectural animations.) When Juhani Palaasma talks about *hapticity* in architecture, he isn't merely referring to immediate sensory effects: he is referring to how architecture interacts with us both thermodynamically and entropically. Palaasma writes, "the architecture of the modern era aspires to evoke an air of ageless youth and of a perpetual present. The ideals of perfection and completeness further detach the architectural object from the reality of time and the traces of use….Instead of offering positive qualities of vintage and authority, time and use attack our buildings destructively."[25] A different way of looking at architecture might allow us to escape from the static and totalizing qualities of earlier modernist thought (Le Corbusier's "X-ray of beauty, a permanent court of judgment, the eye of truth."[26]) However, it would be both too limited and too self-centered to imagine a somatic architecture simply in terms of the aesthetic effect it has upon an individualized sensing subject (what does the building do to *me?)* Rather, architecture has a life separate from the individual: it opens up for flows of masses and crowds, over/against the individual. Material is drawn into a building, first through construction, and then through the constant application of electricity, heat, cooling, data; material is drawn out again in the form of waste products of all kinds (biohazard waste, common garbage, etc.) as well as in escaped heat and cold, carbon dioxide, oxygen and so on. In other words, atmosphere and perceptual aesthetics are not the whole of the issue. Architecture is really about interdependence and interaction. As the landscape urbanist Alan Berger writes in "Drosscape,": "cities are not static objects, but active arenas marked by continuous energy flows and transformations of which landscapes and buildings and other hard parts are not permanent structures but transitional manifestations. Like a biological organism, the urbanized landscape is an open system, whose planned complexity always entails unplanned dross in accord with the dictates of thermodynamics."[27]

A new thermodynamic architecture will require a rethinking of how architects have traditionally imagined design. A recent project at the University of Guelph-Humber in Ontario illustrates this. Rather than construct a network of ducts forcing air through various mechanical apparatuses to condition the air, researchers erected a giant Biofilter Wall, a 21 by 51 foot high screen of oxygenating plants. Air cools as it passes through the wall; the plants trap and metabolize pollutants such as formaldehyde, toluene and trichloroethylene that have gathered within the building.[28] This is a natural, open solution to a problem that fifty or even five years ago would have been solved entirely mechanically, using resource-heavy technologies and generating substantial waste.

Many other firms explore these interfaces between architecture and invisible flows. The Living, a New York-based firm, designed what they call *Living Glass*, a transparent silicon sheet with apertures that flex open in the presence of carbon dioxide (i.e. a breath.) [29] Jurgen Mayer H. created a theoretical house covered in thermographic paint whose envelope changes color according to surface temperature. And Phillipe Rahm's works are radically thermodynamic. In one project, called *House Dilation*, Rahm breaks the house apart and spreads it across a number of different ecologies, all situated on a large property. The objective of the design is to give each individual room its own climate. He likens the project to a comment by novelist Georges Perec, who wanted his house distributed throughout Paris, "his living room in the Latin Quarter, his study close to the Champs-Élysées, his bedroom in Montmartre and his bathroom on the Île de la Cité," a kind of discontinuous (or even Situationist) house-structure occupying the entire city. In the same way, Rahm proposes an architecture spanning multiple biomes at once, taking advantage of the unique climatic qualities of each.

The firm R&Sie have been constructing thermodynamic environments for a number of years. In a museum proposal for the city of Bangkok, R&Sie envisioned an almost schizoid structure that would gather pollutants: they designed an antiseptic white building surrounded by an electrostatic mesh drawing pollution from out of the Bangkok sky. The mesh becomes a filter between sterile white space of the museum and the surrounding environment—pollution itself becomes the façade of the building, even as the building scrubs the air. Another example is the courtyard house called *Lost in Paris*, enveloped in a net of 1200 prehistoric ferns, a species called *Dryopteris filix-mas*, each of which is fed bacterial nutrients and water from a series of blown-glass bottles. These ampules act as an external organ to the house, sustaining its envelope over time and processing the natural elements back into the house in the form of cleansed water.

What these examples show is that architecture, at its outer limits, offers a potential for addressing our relationship to technology, a relationship that has barely been theorized even as its penetrations into the biological and into our daily life increase. Architects tend to regard technology as a mere tool, an appliqué, without realizing that we are bound up in its evolution. When we switch on a computer, we are opening a channel between the synapse and the circuit; when we drive a car, we are subcontracting out the core function of our legs. Architecture is a world-prosthetic, as Peter Sloterdijk says[30], and a mediator between dwelling and technology. Like a body, it takes in matter, energy, and ideas, and expels them too. Though the dimensions of the invisible that daily penetrate and flow through our architecture are not haptic and cannot really be formalized except in the most reductive terms, we must acknowledge these thermodynamic realities as a way of regenerating architecture for the future.

ENDNOTES

1. "China Disperses Rain to Dry Olympic Night." *China View*, August 9, 2008. Text available online at http://news.xinhuanet.com/english/2008-08/09/content_9079637.htm
2. Georgescu-Roegen, Nicholas. "The steady-state and ecological salvation." *Bioscience* 27, 1977. P. 267. Incidentally, thermoeconomics was the branch of economics that he created, applying thermodynamic principals to economic systems. His work, for many years disregarded, has gained new admiration since the foundering of the global economic markets last year.
3. Banham, Reyner. *The Architecture of the Well-Tempered Environment.* London: Architectural Press, 1969.
4. See Mumford, Lewis. *The Pentagon of Power: The Myth of the Machine Volume 2.* New York: Harvest Books, 1974.
5. Interestingly, each of these animals has a name: Alba was a genetically modified rabbit created by French geneticist Louis-Marie Houdebine; Dolly was the first mammal cloned from an adult somatic cell at the Roslin Institute in Scotland; and Vacanti was a mouse whose back had been seeded with cow cartilage in order to grow an ear in a UMass laboratory.
6. Sloterdijk, Peter. "The Operable Man: On the Ethical State of Gene Technology." Lecture at the UCLA conference *Enhancing the Human*, May 21st, 2000. Text available online at http://www.petersloterdijk.net/international/texts/en_texts/en_texts_PS_operable_man.html
7. Picon, Antoine. "Architecture, Science, Technology and the Virtual Realm." In Picon, Antoine and Alessandra Ponte, eds. *Architecture and the Sciences*. Princeton, NJ: Princeton Architectural Press, 2003. p. 310.
8. Pynchon, Thomas. "Entropy," in *Slow Learner: Early Stories.* New York: Little Brown and Company, 1984. P. 85.
9. Pynchon, however, got the equation wrong. By smashing the apartment window and opening it up to other weathers, other systems, Aubade was actually generating a thermodynamic flow, a cycle of heat and cold from inside to outside. Incidentally, Pynchon states in the introduction to *Slow Learner* that the story was incorrect and that the older he gets, the less he seems to know about thermodynamics.
10. Sloterdijk, Peter. "Sphere Theory: Talking to Myself About the Poetics of Space." *Harvard Design Journal.* 30. Spring/summer 2009. P. 134.
11. For an historical account of how architecture was transformed by mechanical systems in the modern period, see Banham. 1969.
12. The Department of Energy, the U.S. Green Building Council, and other organizations are primarily dedicated to understanding and regulating what it means to apply these technologies correctly, leading to a set of performance criteria that architects in America are encouraged to meet.
13. Zaera-Polo, Alejandro. "A Scientific Autobiography, 1982-2004." In Saunders, William, ed. *The New Architectural Pragmatism.* Minneapolis: University of Minnesota Press, 2007. p. 13.
14. Silvetti, Jorge. "The Muses Are Not Amused: Pandemonium in the House of Architecture." In Saunders, William, ed. *The New Architectural Pragmatism.* Minneapolis: University of Minnesota Press, 2007. p. 177.
15. Lynn, Greg, 1995, http://www.basilisk.com/aspace/formview.html
16. Corner, James. "Not Unlike Life Itself: Landscape Strategy Now." In In Saunders, William, ed. *The New Architectural Pragmatism.* Minneapolis: University of Minnesota Press, 2007. p. 91.

17. Interestingly, Prigogine spent his life attempting to forge a connection between natural and social sciences, contributing to fluid-dynamic studies of traffic flows in cities and other research.
18. Prigogine, Ilya, and *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations.* London: John Wiley and Sons, 1977. Pp. 18-19.
19. The metaphor of a sponge has been used before, by Steven Holl and others, but in an almost purely geometric or formal context. Here, I am referring to a sponge thermodynamically, as an object continually absorbing and then desorbing the byproducts of neighboring systems.
20. Georgescu-Roegen, N. "Energy Analysis and Economic Valuation." In *Southern Economic Journal.* Issue 45. P. 1034.
21. This is an argument that Mohsen Mosastavi and David Leatherbarrow also make, eloquently and at some length, in their book *On Weathering*. Cambridge: MIT Press, 1993.
22. Kuma, Kengo. "Gardening vs. Architecture." *Lotus International* 97, June 1998, p. 49.
23. In McGrane, Sally. "A Landscape in Winter, Dying Heroically." New York Times, January 31, 2008.
24. See www.oma.nl.
25. See Palaasma, Juhani. "Hapticity and Time: Notes on Fragile Architecture." *The Architectural Review.* May, 2000.
26. Le Corbusier. *The Decorative Art of Today.* Cambridge, MA: MIT Press, 1987. P. 190.
27. Berger, Alan. "Drosscape." In *The Landscape Urbanism Reader*. Charles Waldheim, ed. New York: Princeton Architectural Press, 2006. P. 203.
28. This is somewhat different from the pretty landscaped walls of Patrick Le Blanc, which may serve an implicit biological function, but are conceived more as living tapestries than biofilters.
29. See Benjamin, David and Soo-In Yang. *Life Size*. New York: Columbia University GSAPP, 2007.
30. Sloterdijk. 'Sphere Theory," 2009. P. 134.