Energetic Ecologies
Industry, Adaptation, & The Thermodynamic Paradigm

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ENERGETIC ECOCOLOGIES: INDUSTRY, ADAPTATION, & THE THERMODYNAMIC PARADIGM

The sustained abandonment of post-industrial sites poses significant public health, safety, and ecological risks for urban areas—hazards that disproportionately affect low-income populations and people of color. Addressing the persistent socioeconomic and environmental challenges of post-industrial decay is imperative as residents and policy makers strive for safer, healthier, and more equitable cities.

This M.Arch thesis details the development and testing of a novel approach to post-industrial adaptation and renewal. In the first section, a careful reappraisal of America’s post-industrial heritage reveals the cultural, ecological, and energetic potential of industrial ruins, reframing these sites in terms of opportunity rather than liability. The second section focuses on energetic potential, using the development of a conceptual project to propose a methodology for re-engaging post-industrial sites from the perspective of thermodynamics. The final section analyzes the performance of the project and synthesizes these findings into a series of conclusions and proposals for future study.
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Adaptive Reuse – the process of reusing an existing site, building, or infrastructure that has lost the function it was designed for, by adapting it to new requirements and uses with minimal yet transformative means (Robeglo 2017)

Atmosphere – a gaseous envelope containing a mass of air within a localized area or environment

Biofiltration Swale – a shallow, gently sloping vegetated conveyance channel that holds and filters stormwater; removes sediment and particle-bound pollutants from urban runoff

British Thermal Unit (BTU) – a unit of heat; the amount of heat needed to raise one pound of water at maximum density through one degree Fahrenheit

Computational Fluid Dynamics (CFD) – a branch of fluid mechanics that simulates fluid motion and heat transfer using numerical analysis and data structures

Conduction – the process by which heat or electricity is directly transmitted through a substance when there is a difference of temperature or of electrical potential between adjoining regions, without material movement

Construction Ecology – a subset of Industrial Ecology focusing on the sustainable design and construction; the concept links major human energy and materials flows to the dynamics of natural systems

Convective – heat transfer due to bulk movement of molecules within a fluid; hotter, less dense material rises, while cooler, denser material sinks due to gravity

Deindustrialization – a process of social and economic change caused by removal or reduction of industrial capacity or activity, especially heavy industry or manufacturing

Energetic Ecology – a systems approach to design, development, and operation of human systems; aims to create a sustainable transition to a world in which economic activities respect the limit of global and local carrying capacity; attempts to design human systems using dynamics from natural ecosystem behavior

Intensive Properties – physical properties that do not depend on the amount of matter present (i.e. pressure, density, velocity, turbulence)

Laminar Flow – fluid dynamics, a type of flow in which fluid travels smoothly in regular paths with little or no mixing; contrast with turbulence

Life Cycle Assessment – a methodology for assessing environmental impacts associated with every stage of a product’s life from material processing, manufacture, distribution, and use

Material Flow Analysis – the quantification of the flow of raw materials, parts, components, and integrated objects into and out of systems for the purpose of understanding economic, social, and environmental impacts of material extraction, processing, use, and disposal

Macrolimate – the overall climate of a region; usually a large geographic area

Microclimate – the local climate of a small site or habitat based on airflow, temperature, humidity, solar radiation, and the ambient thermodynamic characteristics of the natural and/or built environment

Non-Isolated Thermodynamic Systems – energetic systems that exchange matter and energy with their surroundings; human bodies, buildings, cities, and natural ecosystems are all non-isolated thermodynamic systems, like most systems in the universe. Also referred to as Open Systems

Operational Energy – the energy consumed by a building to meet demands for heating, cooling, hot water, ventilation, lighting, and appliances

Pressure (atmospheric) – the force exerted on a surface by the air above it as gravity pulls it to the earth

Radiation – the emission or transmission of energy in particles or waves through space or a natural medium

Systems Ecology – a holistic approach to the study of ecological systems; applies general systems theory to ecological study

Thermal Mass – the ability of a material to absorb and store heat energy, providing inertia against temperature fluctuations; when (typically high-density) materials require a high amount of heat energy to change the temperature of the material, they are said to have "high thermal mass"

Thermodynamics – the branch of physical science that deals with heat, work, and temperature, and their relation to energy, radiation, and the physical properties of matter

Thermodynamic Spolia – material harvested from ruined structures, repurposed for new construction or adapted to new uses based on the material’s inherent thermodynamic properties

Turbulence – in fluid dynamics, fluid motion characterized by chaotic changes in pressure and flow velocity; contrast with laminar flow

Vernacular – architecture concerned with the domestic and functional; a built response to the cultural, socio-economic, and climatic environments of a specific region, people, or era

Vorticity – in continuum mechanics, a pseudovector field that describes local spinning motion, or tendency to rotate, in relation to a specific point traveling along a flow
PROLOGUE //

THE LEGACY OF DEINDUSTRIALIZATION

During the latter half of the twentieth century, industrial regions throughout the United States experienced a dramatic transformation as industrial production rapidly declined, decentralized, and migrated away from population centers. Precipitated by the global energy crisis of 1973 and the end of unrestrained post-World War II consumerism and economic optimism, this sudden industrial shift left thousands of abandoned factories, mills, warehouses, and ancillary structures to deteriorate in densely populated areas.1

Because these massive industrial relics were predominantly constructed of steel, reinforced concrete, or masonry, and often occupy contaminated brownfield sites, the costs of demolition and remediation can exceed property values. Consequently, a considerable number of these structures were “mothballed” and have remained uninhabited for decades.2 The sustained abandonment of post-industrial sites poses significant public health, safety, and ecological risks for urban areas—hazards that disproportionately affect low-income populations and people of color.3

Rapid deindustrialization revealed a problematic legacy of twentieth-century functionalism—pervasive misalignment between the life cycles of function and material. Bereft of purpose, but stubbornly monumental, the ruins of America’s industrial heritage have become a constant in the continually evolving collage of post-industrial urbanism. After decades of neglect, many of these ruins have been reclaimed by the natural environment, creating moments of urban wilderness that highlight the ongoing tension between natural ecosystems and the built environment endemic to post-industrial cities.

2 Ibid., 201.
Addressing the persistent socioeconomic and environmental challenges of post-industrial decay is imperative as residents and policy makers strive for safer, healthier, and more equitable cities. The sheer quantity of industrial ruins and their lingering presence in America’s urban condition suggest that current methods of evaluating and intervening in these sites are insufficient; we need a new way of thinking about the problem itself.

The following sections detail the development and testing of an alternative approach to post-industrial adaptation and renewal. In the first section, a careful reappraisal of America’s post-industrial heritage reveals the cultural, ecological, and energetic potential of industrial ruins, reframing these sites in terms of opportunity rather than liability. The second section focuses on energetic potential, using the development of a conceptual project to propose a methodology for re-engaging post-industrial sites from the perspective of thermodynamics. The final section analyzes the performance of the project and synthesizes these findings into a series of conclusions and proposals for future study.
EXTRACTING VALUE FROM POST-INDUSTRIAL DECAY

The perception of value is a key hurdle to the renewal and redevelopment of post-industrial sites. Developer-driven economic models that result in decades of abandonment and neglect are problematic, not least because they overlook the cultural, ecological, and energetic value of these sites. Although these types of value may be difficult to quantify, qualitative value is equally important to a site’s relationship to the surrounding urban condition.

In Karl Popper’s seminal 1965 lecture, Of Clouds and Clocks: An Approach to the Problem of Rationality and the Freedom of Man, Popper argued that despite our best efforts to understand the universe as a “clock,” both natural and anthropogenic systems tend to behave more like “clouds” – dynamic, irregular, and unpredictable. The overly-reductive economic valuations that sustain post-industrial abandonment are relics of physical determinism, an Enlightenment-era doctrine that asserts, in Popper’s terms, “all clouds are clocks” and can be precisely measured. The fundamental weakness of physical determinism is that even the best “clocks” involve some measure of “cloudiness” – the inevitability of variables that cannot be precisely measured. Nevertheless, the lure of “certainty” provided by physical determinism can easily become convention, and that convention eventually mistaken for “truth.”

As Matteo Robiglio (2020) noted, mistaking convention for truth is a common theme in architectural history; he points to the work of Viollet-le-Duc, whose idealized notions of Classical orders in the 19th century were proposed as historically “correct” though they never actually existed in antiquity. By disregarding value that is not easily quantifiable, prevailing economic conventions tell us industrial ruins are essentially worthless. But to mistake these conventions for “truth” neglects the immense cultural, ecological, and energetic significance of post-industrial spaces within America’s urban environments.

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America’s industrial past is fundamental to the nation’s cultural heritage. Though initially decried as ‘machines in the garden’ that threatened the romanticized pastoral innocence of rural America, immense engineering projects and heavy industry became a symbol of the United States’ technological prowess and economic might during the late 19th and early 20th centuries.  

Combined with the nation’s scarcity of culturally significant buildings compared to other highly industrialized regions, like northern Europe, the soaring industrial architecture that emerged during this period became a tangible source of national pride and a symbol of the United States’ cultural identity. Europe had its cathedrals; the United States had its cathedrals of industry.

David E. Nye argues in American Technological Sublime that America’s multicultural society achieved shared notions of the sublime not through religion, as in Europe, but through the products, mechanisms, and structures of industry. During the peak of America’s mechanization of production, vast industrial landscapes demanded the same type of sublime reverence formerly reserved for the natural environment.

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Yet, for such important symbols of America’s cultural identity, the ruins of this mighty industrial heritage—but for a few notable buildings—have not enjoyed protection or idealization. In contrast to Gandy’s romanticized paintings of Soane’s Bank of England, industrial ruins are treated with a kind of macabre fascination immortalized in “ruin porn” – a contemporary genre of photography devoted to architectural decay in which post-industrial urban America features prominently.\(^9\)

Though unlikely to be considered “high art” in the sense of Gandy’s paintings, ruins photography is not as sensationalist as its crude moniker would suggest; on the contrary, these photographs read as quiet and often deeply personal introspections, the result of a ground-up, pluralist movement of photographers documenting a fading cultural heritage in the decaying remains of forgotten places. In this sense, the practice is as much a reflection of its contemporary social and political environment as Gandy’s romantic paintings were for early 19th-century England. The emergence and growing popularity of ruins photography suggests widespread interest in maintaining a tangible connection to the industrial past, particularly within the United States.

Because industrial production typically occupied the path of least resistance for the transportation of raw materials and manufactured goods, post-industrial ruins often inhabit the boundaries between urban and natural ecosystems—frequently along waterways.

Though these industrial edges were originally established along the outer fringes of American cities, urban growth and demand for increased industrial capacity drove industry within population centers. Following deindustrialization, this resulted in vital inner-city pockets—or in cases like Detroit, vast swaths—of American cities becoming uninhabitable areas of contamination and urban blight.

Neglecting these sites and their unique positioning within cities disregards their enormous potential to re-establish urban connectivity between the built condition and the natural environment. Likewise, the ecological value of remediating these sites cannot be overstated—treating site contamination is critical to the long-term health of city residents, wildlife, and ecosystems.

In recent years, Life Cycle Assessment has drawn attention to the shortcomings of traditional ex-situ soil excavation and disposal, while advances in in-situ nanoremediation and biosorption have significantly lowered remediation barriers by reducing the economic and energetic costs of site cleanup.\(^{10}\)

Perhaps the most promising value inherent to post-industrial sites is their latent energetic potential. Examining industrial ruins through the lens of energy reveals immense thermodynamic vitality; far from being composed of “dead” material with little functional use, the energy embedded within industrial pre-existences can be re-engaged and deployed in a variety of ways.

Reinforced concrete and masonry contain significant thermal inertia, while steel is an excellent conductor. The monumental size and formal qualities of post-industrial structures create their own microclimates, which can be calibrated with site features and new interventions to create atmospheric zoning. In some cases, soil excavated during construction can be manufactured into site-harvested building material for new structures. Geophysical and biological processes on site can be tapped for passive thermal conditioning.

Studies show that energy expended during material production, building construction, and maintenance far exceeds the total operational energy consumed by a building during its lifetime. This underlines the importance of embracing adaptation over demolition and new construction, and it suggests that architects should not neglect material geographies, constructability, longevity and ease of maintenance in their energy optimization efforts.

Extracting energetic potential to renew and rehabilitate post-industrial sites can dramatically reduce the economic and energetic costs of conventional methods of demolition, remediation, and new construction. But this process demands more from architects than typical building projects. As David Benjamin writes in *Embodied Energy and Design*, architects must expand their purview and learn to “design the material, the factory, the building, and even new building typologies at the same time.”

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Non-isolated energy modeling is more challenging to quantify, but it reveals valuable insight into a structure’s cumulative, long-term energy footprint and provides guidance to help architects make material, siting, design, and construction decisions that minimize the total energy expenditures of their projects.

However, these models do not address the performative aspects of thermodynamic processes, nor do they connect these processes to the physiological effects of energetic exchange. Recent publications by architects like Javier García-Germán, Iñaki Ábalos, Kiel Moe, and Philippe Rahm explore this relatively uncharted territory.

Clearly the inherent value of post-industrial sites cannot be measured by economics alone. Proponents of adaptive reuse have long recognized the cultural significance and ecological benefits of re-engaging industrial relics; but identifying the energetic potential embedded within buildings is a more recent phenomenon that is still very much in its infancy.

Originating from breakthroughs in quantitative economic modeling and systems ecology during the 1960s, non-isolated energy models like Embodied Energy, Life Cycle Assessment, Material Flows, and Energy Analysis have become part of the architectural lexicon during the last 30 years. These concepts assert that buildings, like most systems in nature, are open thermodynamic systems that continually exchange matter and energy with their surroundings. This argument pushes against traditional energy models—in widespread use today—that assume buildings are isolated thermodynamic systems to simplify energy calculations. Popper’s Of Clouds and Clocks discussion is equally relevant here.

Fig. 12 (left) Energy Model of a Typical Building, Adapted from Srinivasan & Moe (2015)
Fig. 13 (above) Self-organized Convection Cells, Marrakesh, from Architecture Without Architects, Bernard Rudofsky (1964)

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By advocating for the cultural, ecological, and energetic value of America’s industrial heritage, architects can reframe these neglected sites as urban opportunities rather than liabilities. Instead of waiting decades for decaying industrial sites to be scraped clean for new construction, we should be asking how these sites can be co-opted as social, cultural, economic, environmental, and energetic assets for cities.

The thermodynamic paradigm is particularly promising for the adaptation and renewal of post-industrial sites. By integrating non-isolated energy modeling, lessons from systems ecology, and modern analysis tools, this methodology can not only transform how we conceive of site-specific design solutions for industrial ruins, it has widespread implications for architectural practice.

Making the leap from theoretical to practical, the following section identifies a specific post-industrial site in Houston, Texas, and considers how the site’s energetic pre-existences can guide a design process that spans material, structure, construction, performance, and typology.
Deindustrialization affected Houston, Texas, quite differently from other industrial regions in the United States. Because of Houston’s heavy investment in the oil industry, rising oil prices following the 1973 energy crisis stimulated the city’s economy during the global recession; in the mid-1970s, employment in goods-producing industries grew in Houston by 18% while dropping nationwide.  

The city’s insulation from recession did not last long, however; Houston’s economic diversification plummeted as allied bankers increasingly invested in oil at the expense of other non-oil industries.  

The decline of manufacturing firms without direct connections to the oil and gas industry soon began to mirror the deindustrialization of other US cities.  

Much of Houston’s industrial heritage is located along Buffalo Bayou, which flows through the center of the city to the gulf coast, becoming the Houston Shipping Channel four miles east of downtown. Today, the shores of Buffalo Bayou between downtown Houston and the shipping channel are littered with brownfield sites and the decaying ruins of abandoned industry. Although several urban development projects are planned for this area, it will take years, if not decades, to fully rehabilitate this neglected part of Houston’s industrial past.

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21 Ibid., 1220.
Along the southern shore of Buffalo Bayou, just east of downtown Houston, are the remains of an industrial complex that originally manufactured building materials. Much of the original complex has been demolished, but four monumental concrete gravel silos continue to tower over the site.

The area is overgrown with vegetation and intermittently occupied by the city’s homeless, who take refuge among the ruined concrete walls of the former buildings. Large trees have taken root within the silos themselves, suggesting a lengthy period of abandonment. To the north, a hike and bike trail runs along the site’s steep bayou shore; to the south and west, newly constructed townhomes—evidence of the area’s growing gentrification—define the site’s urban edge.

By re-engaging this post-industrial site through the lens of energy, this conceptual project examines how the practical application of thermodynamic principles can shape the process of adaptation and urban renewal. In developing a low-cost, low-embodied energy public space with high social and ecological value, this project also considers the implications of biasing the ambient, sensorial properties of energetic exchange in architectural design.

Conceived as an overlapping network of passively-conditioned public spaces, programming is not pre-determined, but evolves as a function of atmospheric diversity. The formal expression of the project emerges as a synthesis of the material, structural, atmospheric, and energetic pre-existences of the site and its industrial relics.
The design process begins with an identification of the site’s energetic pre-existences and the establishment of a boundary condition for the project. Energetic boundaries are not physical boundaries; they are dynamic, soft conditions defined by gradients, hierarchies, and flows that can reach far beyond a site border or a building’s physical envelope.

In this case, the project’s boundary condition is defined by the site’s energetic pre-existences and its hierarchy of thermodynamic potential. This hierarchy is a simplified input-output model, in which energetic outputs from one level become the inputs of the next, and so on. At each level, a new energetic pre-existence is added to the legacy input, driving the design process and increasing the project’s material, formal, structural, and energetic complexity. Since this project ultimately aims to showcase the performative and physiological effects of energetic exchange, the generation of atmospheric zoning is the final output of this hierarchy. Note that this hierarchy represents an iterative, but non-linear design process; it is not intended to show the feedback loops, exergy flows, and entropy outputs of a more complex emergy diagram.

By adjusting the hierarchy order, number of levels, or pre-existences chosen, dramatically different building typologies can be achieved. This makes the methodology incredibly flexible, both in achieving site-specific goals and in adapting to meet the requirements of vastly different contexts, industrial types, and pre-existing materials.

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Fig. 19 (above) Diagram. Hierarchy of Energetic Pre-existences and Thermodynamic Potential
Fig. 20 (right top) Imagery. Site location, Houston, TX (Google Earth, 2020)
Fig. 21 (right) Analysis. Mapping the Energetic Pre-existences of the Site
Site Ecology (input). There is significant energetic potential embedded within the site’s ecology; this project focuses on the bayou ecosystem and the geology of the site. An analysis of topographical surveys from the last 100 years shows the evolution of Buffalo Bayou from a more natural waterway to a manufactured shipping channel (left). The bayou was dredged, the banks were widened, and some sections of the bank—including this industrial site—were armored and shored up with pilings.

Studies show this type of bayou channeling, once thought to improve flood mitigation, actually makes flooding worse by increasing stormwater conveyance and removing natural wetlands. A visualization of Buffalo Bayou’s flood cycles shows the site borders the 100-year flood zone (above).


Fig. 22 (left) Analysis. Site Topography - Bayou Evolution
Fig. 23 (above) Illustration. Bayou Flood Cycles - Floodway, 100-Year Floodplain, 500-Year Floodplain
By transforming the site’s steep armored shore into a series of terraced biofiltration swales, a closer and more controlled connection is established between the city and the bayou (right). Rather than barricading against floodwaters at the expense of residents and businesses downstream, inviting flooding onto the site simulates the effect of natural wetlands, slowing stormwater conveyance and providing wildlife habitat while controlling erosion.

The swales incorporate organic media filters to remove urban contaminants and purify stormwater runoff, increasing the overall health of the bayou ecosystem (above). Installation of a bayou boardwalk and seating along the terraces further enhances urban connectivity to the bayou (see pp. 58 & 112).

Excavating the terraces produces tons of clay, a high-performance building material with excellent thermal and humidity-regulating properties. Testing would determine if this soil is suitable for building material or if it requires remediation.

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Industrial Ruins. The industrial ruins on site are almost entirely reinforced concrete, a material with high thermal mass. At 60’ tall, 32’ in diameter and one foot thick, each of the silos contains approximately 11,875 cubic feet of reinforced concrete and can store approximately 375,000 BTUs of heat energy before changing temperature 1 degree F. With another 20,000 cubic feet of reinforced concrete in the adjacent ruins, the combined site material can store over 2,000,000 BTUs of heat energy per degree of temperature delta. The thermal mass present on site is immense.

Because the inherent thermodynamic properties of reinforced concrete are embedded within the material itself, the thermal mass is not lost if the concrete is re-used for other purposes. This means the energetic potential of the silos and adjacent ruins can be activated in place, or disassembled, mobilized, and reconfigured for a variety of uses. In this case study, both approaches are taken: two silos are left in place, while the other two silos and the surrounding concrete ruins are disassembled for specific structural and thermodynamic uses.
Building Material (thermodynamic potential). The primary energetic outputs, or thermodynamic potential, extracted from the site’s ecology and industrial ruins are the site-harvested building materials—clay and reinforced concrete—that are reinvested into the thermodynamic hierarchy as legacy inputs for the next level.

Secondary outputs—outputs that are not directly reinvested into the local thermodynamic hierarchy—should not be disregarded, however, as they become valuable inputs to the larger urban (eco)system. Secondary outputs from site terracing include urban connectivity, flood mitigation, wildlife habitat, erosion control, runoff purification, and bayou health.
Macroclimate (input). Climate data (left) shows Houston’s prevailing wind direction during the majority of the year is from the S/SE with an average velocity of 8mph, only changing during winter months when the wind alternates between S/SE and N. Daily averages show wind coming from the S/SE during the majority of the day, switching to N during coolest hours of night. Diurnal temperature range is 20 degrees year-round, with highs in the mid 90s F in summer and low 60s F in winter.

In Houston’s hot and humid climate, passive structures must pay careful attention to solar shading and ventilation. Vernacular architecture from similar climate zones (above)—regardless of geographic location—show a tendency toward roof articulation and wall dematerialization to vent warm, buoyant air and allow breezes to pass through freely.

Fig. 31 (left top) Analysis (Ladybug/DIVA). Prevailing Wind Direction & Speed, Annual / Daily - Houston, TX
Fig. 32 (left) Analysis (Ladybug/DIVA). Dry Bulb Temperature & Humidity - Houston, TX
Fig. 33 (above) Imagery. Hot/Humid Climate Vernaculars (clockwise from top left: Vietnam, Indonesia (Sunda Islands), Japan, Indonesia (Sulawesi), Cameroon, Malaysia)
Structural System (thermodynamic potential). Extracting thermodynamic potential from the combined inputs of building material and macroclimate led to the selection of Timbrel, or Catalan, vaulting for the project’s structural system. This system is a reinterpretation of the hot/humid climate zone vernaculars that favor roof articulation and wall dematerialization, adapted to take advantage of site-harvested clay and concrete building material.

Timbrel vaulting is a low-cost, low-emergy system that uses multiple layers of thin brick tiles and fast-setting mortar to span long distances with minimal construction time, material, and labor (right). Reinforced concrete from the industrial ruins can be incorporated into plinths and piers that support the legs of the vault, while a tile yard constructed onsite can produce compressed clay brick tiles. Using a manual brick press, an 11-person team can create around 1,000 compressed clay bricks per day. If structural requirements specify brick tiles must be fired, a pre-existing kiln is located less than 1 mile from the site.

Since timbrel vaults are self-supporting, formwork is necessary to achieve specific curvatures but not for support; this means that formwork can be a lightweight, recyclable system—bamboo, cardboard, wire mesh, or tensile—with minimal impact on the ground conditions of the site.

Several projects have demonstrated that even timbrel vaults with complex curvature can be constructed quickly by small teams of unskilled labor with minimal instruction (left). This means that nearby residents can potentially be involved in the project’s construction, cultivating a sense of agency and ownership of the project among the local community. According to David Benjamin (2017), “embodied energy is a social issue as well as a technical one,” and Matteo Robiglio (2020) notes that “making [something] together incorporates it into the collective identity of the group,” strengthening community bonds.26 27

Microclimate (input). Although climate-zone vernaculars took centuries to develop, modern analysis tools allow architects to compress the process of thermodynamic discovery and develop specific solutions to highly localized microclimatic conditions in a fraction of the time.

By importing climate data and a digital model of the site into Computational Fluid Dynamics (CFD) software (SimScale) and conducting a series of Incompressible Fluid Flow simulations, intensive thermodynamic properties like wind velocity, vorticity, turbulence, and pressure can be visualized on the site.

Each of these thermodynamic properties tells a part of the microclimatic story. Velocity mapping shows the direction, magnitude, and vorticity of passive airflow through the site (left). Turbulence (k-epsilon) analysis indicates laminar airflow and moments of volatility (center), while Pressure gradients reveal how and why airflow is pushed and pulled around the site (right).

Because airflow significantly affects other atmospheric properties, like temperature and humidity, these analyses are critical to an overall understanding of the site’s microclimate.

Fig. 42 (above) Analysis (SimScale). CFD Analysis of Site Wind Velocity & Vorticity
Fig. 43 (middle) Analysis (SimScale). CFD Analysis of Site Turbulence
Fig. 44 (right) Analysis (SimScale). CFD Analysis of Site Pressure Gradients
Atmospheric Generation (thermodynamic potential). Because the support conditions of Timbre vaults are quite adaptable, the size, location, and orientation of vault supports can be adjusted to actively calibrate how airflow moves through the site.

By intervening within the site’s primary laminar airflow (top), the vault’s legs direct passive ventilation in specific ways, similar to changing a wing’s orientation in flight (above) or directing the flow of water in a stream. The vault supports work together to modulate airflow velocity, direction, and vorticity, creating the basis for atmospheric zoning using the site’s pre-existing microclimate.

CFD analyses (right) show how these interventions can leverage formal permeability to generate atmospheric diversity: a stable vortex creates a moment of calm in the open air, while continuous, low-velocity airflow is driven to a specific area.

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Fig. 45 (left) Diagram. Progression of Vault Support Placements in Primary Laminar Airflow of Site
Fig. 46 (above) Imagery. Wind Tunnel Analysis of Aerials Orientation, from Babinsky (2003)
Fig. 47 (right top) Analysis (SimScale). CFD Analysis of Pressure Gradients at Ground Level - Stable Vortex Creation
Fig. 48 (right) Analysis (SimScale). CFD Analysis of Velocity & Vorticity at Ground Level - Stable Vortex Creation
The final vault form is derived using Rhinovault software, developed by the Block Research Group at ETH Zurich.

Starting with the support locations defined by CFD analysis in the previous step, the vault’s legs are refined into circular chords (1), while boundaries (openings) become conic sections/ellipses (2). Connecting supports and boundaries (3) leads to the generation of a triangulated mesh form diagram (4). Software-based mesh anomalies are noted. Horizontal equilibrium is achieved on the force diagram after several iterations (5). Vertical equilibrium is then calculated to generate a thrust diagram with maximum height of 25 feet (6). Finally, equilibriums are recalculated to account for elevated plinths and perforations (7). The final vault form is shown below right.

Fig. 49 (above) Analysis (Rhinovault). Derivation of Vault Form & Analysis of Structural Performance
Fig. 50 (right) Model Visualization, Final Vault Form Showing Plinths & Perforations
The final step in atmospheric generation involves linking the site’s microclimate to the remaining silos, now integrated within the project’s vaulted structural system. By reinterpretting Iranian vernacular (top right) and conducting CFD and Particle Trace analyses, a strategy was developed to transform the silos into wind catchers. Capturing cooler, higher velocity airflow from 60 feet overhead and routing it along the silos’ internal thermal mass greatly improves the performance of ground-level passive ventilation.

Vernacular windcatchers typically use orthogonal forms to break up laminar airflow and drive ventilation inside the towers to be released below. Cylindrical forms disrupt airflow less efficiently, so they are rarely used for wind-catching. However, contrary to vernacular convention—because cylinders compress and increase the velocity of airflow moving around them, they can actually be quite effective at wind-catching if they are modified to generate turbulence along their vertical edges (right).

Fig. 51 (above) Diagram. Thermodynamic Hierarchy: Atmosphere Output
Fig. 52 (right top) Imagery. Vernacular Wind Catchers, Yazd, Iran (Unknown, n.d.)
Fig. 53 (right) Diagram. Silo Section Showing Airflow Capture & Release
Fig. 54 (far right) Illustration. Silo Exterior with Detail of Cut Geometries
Following removal of the silos’ internal hoppers, a series of stereotomic cuts creates localized turbulence along the silos’ exterior walls; the geometry of the cuts directs airflow within and downward, where a reversal of the cuts below the vault’s roofline releases airflow at ground level. Because the geometry of these cuts is material dependent, tolerance would have to be tested; this represents an ideal scenario.

CFD analysis shows how exterior geometry creates localized turbulence (top right). Sectional analysis illustrates internal flow performance (center right) and pressure gradients (below right).

Particle Trace analysis of the silos before and after modification (above, from rear) demonstrates the efficacy of this wind-catching strategy.
Calibrating energetic exchange between the project’s structural system and microclimate establishes three distinct but overlapping atmospheric zones underneath the vault. The moments where these atmospheres interact become a kind of thermodynamic poché that is embedded with circulation and performative site features. CFD analysis guides the final thermodynamic articulation of the atmospheric zones, including placement of an evaporative cooling pond, solar screens, vegetation, and a perforation in the vault’s roof above Atmosphere 01.

The ground level plan suggests a hybrid condition between architecture and landscape and shows how the project engages pedestrians, celebrates the bayou connection, and begins to blur boundaries between urban, industrial, and natural ecologies.
Fig. 61 Model Visualization - Final Project Perspective - Northwest
In Atmosphere 01, a stable vortex creates constant, single-direction, low-velocity airflow over the evaporative cooling pond and the seating area. At the vortex’s center, a moment of stillness is created along the water’s edge. Ground-linked thermal mass and a sunken gravel pavilion cool visitors on warm days through radiation and conduction. Stagnant hot air is vented through a perforation in the vault along the direction of the vortex and low-lying vegetation reinforces ground-level airflow at the vortex edges.

Potential uses of the space could be intimate musical performances, community meetings, or outdoor learning. This zone is cool in the mornings and warmer in the late afternoon and evening.
In Atmosphere 02, variable airflow direction and velocity creates a breezy area well suited for active pursuits. A tall ceiling sheds warmed air and ground-linked thermal mass seating provides a welcome respite from the heat.

Reinforced concrete from the industrial ruins is re-used for its structural, spatial, and thermodynamic performance as the vault’s support pedestals; curved sections from the former silos allow natural light to filter into the passively-cooled seating nooks.

A warm spot in the mornings, this zone is temperate/breezy in the afternoons and cooler in the evening.
Atmosphere 03 contains significant atmospheric diversity. Stereotomic cuts transform the silos into giant heat exchangers, catching high velocity wind from above and releasing it at ground level, while simultaneously venting warmed interior air from their open tops and leeward sides. The silos operate in every wind direction, allowing them to purge stored daytime heat by catching cool night air from the north.

Seating areas are integrated within the silos’ interiors. These areas are cool & calm on the silos’ windward sides & breezy on their leeward sides. Solar screens harvested from vault formwork help protect the silos’ lower thermal mass from solar radiation while allowing cross breezes to pass through.
CFD analysis of the project’s performance relative to the surrounding buildings (right) shows that windspeed, vorticity, turbulence, and pressure gradients are dramatically improved by the vault shell. Shear stress on the vault is also significantly lower than the surrounding buildings (above).

The vault does not simply perform better than its neighboring buildings; it acts to stabilize the highly volatile and turbulent wake coming over and around these buildings, improving pedestrian comfort.
CONCLUSIONS

Architecture does not exist in a vacuum. How buildings interact with their surrounding thermodynamic context has dramatic effects on the natural and built environment hundreds of meters or more beyond a building’s physical envelope. In urban environments, these effects stack together, affecting wind speed and direction, temperature, and air quality. By incorporating thermodynamics into the design process, architects can develop more controlled, nuanced interactions between their projects and the surrounding microclimate, vastly improving passive thermal conditioning and activating space in entirely new ways.

Thinking in terms of energetic boundaries can have a transformative effect on project development. The immaterial properties that govern energetic exchange are equally relevant to architectural design as the extensive properties like length, mass, and volume that architects typically bias. With a thorough understanding of a site’s microclimate, intensive properties like pressure, density, turbulence, and velocity can be calibrated to define space using atmospheric zoning, reducing architecture’s reliance on tectonic solutions. This creates opportunities for architects to soften boundaries between interior and exterior, embracing porosity and atmospheric diversity over insulation and atmospheric homogeneity.
This conceptual project is constructed almost entirely from pre-existing material extracted from the site and its industrial ruins. In essence, the visualizations show what was already there—thermodynamic spolia processed into material assemblies and redistributed into new types of space and experience. Allowing site-specific materials, ecosystems, and microclimates to guide the design process can result in an incredible diversity of project types that are fundamentally tied to their context, both physically and energetically.

Program flexibility can help ensure that projects evolve to meet changing needs over time and do not fall in the trap of hyper-functionalist dereliction; however, this flexibility must include a boundary condition—something to “charge” the space, add tension, or create definition. These boundaries need not be physical; energetic boundaries have direct physiological effects, and architects can cultivate these effects using the intensive properties of the ambient, immaterial world. So much of our surroundings are defined by what is felt but not seen; with modern analysis tools and an understanding of thermodynamic principles, architects can actively design that elusive, sensorial space.

When programming is linked to atmospheric diversity, function becomes a dynamic, self-organizing system. Though it may not always be practical to remove walls and allow programming to conform only to atmospheric qualities, the thermodynamic paradigm accommodates this potential—especially when paired with analysis tools that encourage the reinterpretation and adaptation of vernacular principles at much smaller scales than the climate zone.
By identifying and extracting energetic potential from pre-existing materials, processes, and systems and applying thermodynamic principles to the design, construction, and operation of inhabitable atmospheres, architects can cultivate the energetic ecologies of cities into new types of architecture and urbanism.

Ultimately, this thesis only scratches the surface of this methodology’s true potential; not only does the thermodynamic paradigm offer promising alternatives to the challenges posed by industrial ruins, it has the capacity to fundamentally change how architects design and build projects in our increasingly energy-conscious societies.

Fig. 75 Visualization: Project Entrance - Southwest


APPENDIX A-01

SITE ANALYSIS

Fig. 76  Land Use in Houston's Second Ward

Green Space (including undeveloped land & former industrial sites)
Public
Single-Family Housing
Multi-Family Housing
Industrial / Commercial
APPENDIX A-02

SITE ANALYSIS

Fig. 77  Topography, Flood Zones, & Pre-Existing Structures (100-Year Flood Zone in White, 500-Year Flood Zone in Red)
Fig. 80 Visualization of USGS LiDAR Data Set (NW)
Fig. 81 Visualization of USGS LiDAR Data Set (S)
Fig. 82  CFD Analysis (SimScale) of Site Airflow Velocity with 5 m/s Input Velocity
Fig. 83  CFD Analysis (SimScale) of Site Turbulence (k-epsilon) with 5 m/s Input Velocity
Fig. 84     CFD Analysis (SimScale) of Site Atmospheric Pressure (Pa) with 5 m/s Input Velocity
APPENDIX C-01

SUNLIGHT & RADIATION ANALYSIS OF SILOS (LADYBUG / DIVA)
APPENDIX D-01

PRECEDENT ANALYSIS - COMPRESSION VAULTS (RHINOVAULT)
APPENDIX E-01

SITE ADAPTATION PROCESS
APPENDIX E-02

SITE ADAPTATION PROCESS
Fig. 98  09. Construction of Vault Plinths & Pedestals using Site-Harvested Concrete

Fig. 99  10. Construction of Vault Formwork (note: formwork type is flexible and should be recyclable with minimal impact on ground condition)

Fig. 100  11. Vault Construction

Fig. 101  12. Vault Construction

APPENDIX E-03

SITE ADAPTATION PROCESS
APPENDIX E-04

SITE ADAPTATION PROCESS
Fig. 106    Complete Project Perspective - Southwest
Thank You.