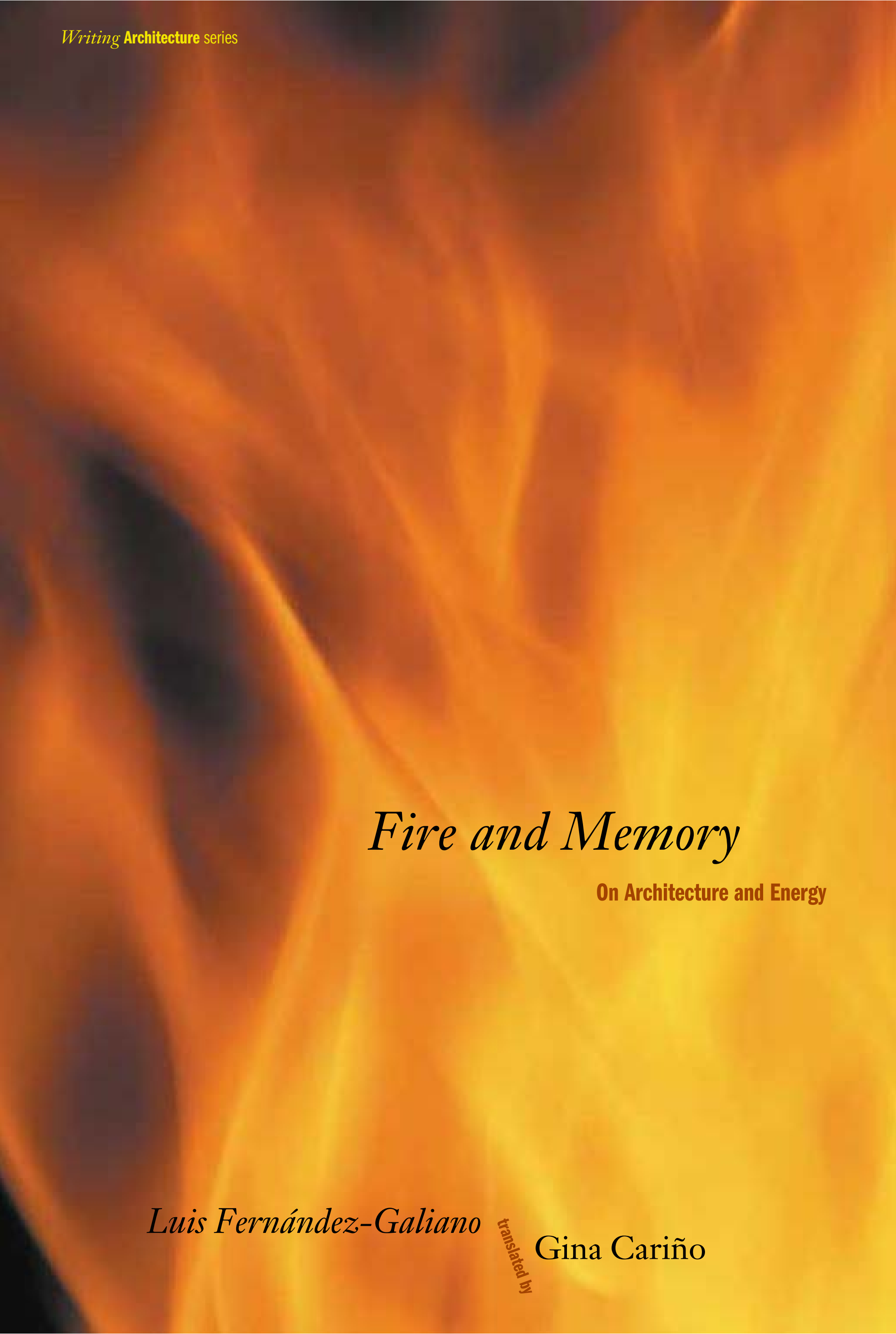

Writing **Architecture** series

Fire and Memory

On Architecture and Energy

Luis Fernández-Galiano

translated by Gina Cariño

Fire and Memory

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Fire and Memory

On Architecture and Energy

Luis Fernández-Galiano
translated by Gina Cariño

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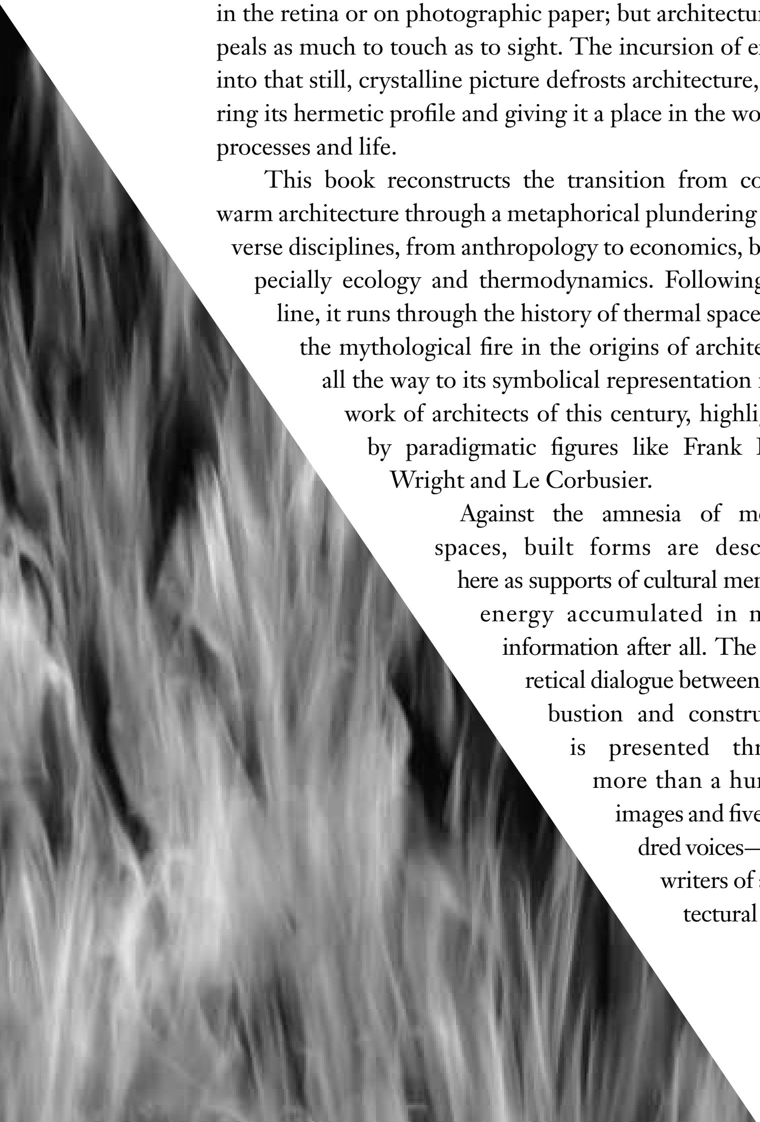
To my parents

Preface

From the eye to the skin: such is the architectural itinerary proposed here. We tend to think of buildings as forms frozen in the retina or on photographic paper; but architecture appeals as much to touch as to sight. The incursion of energy into that still, crystalline picture defrosts architecture, blurring its hermetic profile and giving it a place in the world of processes and life.

This book reconstructs the transition from cold to warm architecture through a metaphorical plundering of diverse disciplines, from anthropology to economics, but especially ecology and thermodynamics. Following that line, it runs through the history of thermal space from the mythological fire in the origins of architecture all the way to its symbolical representation in the work of architects of this century, highlighted by paradigmatic figures like Frank Lloyd Wright and Le Corbusier.

Against the amnesia of modern spaces, built forms are described here as supports of cultural memory: energy accumulated in matter, information after all. The theoretical dialogue between combustion and construction is presented through more than a hundred images and five hundred voices—from writers of architectural trea-



tises to contemporary philosophers and scientists—engaged in a conversation between ideas and forms that focuses on mechanical and organic analogies, on the relationship between time and entropy, or on the paramount importance of chance.

With the exception of the last chapter, which came a year later, I wrote this book during the summer of 1982. For final Spanish publication in 1991 I added half a dozen notes, as well as the illustration captions, but the original text remained unaltered. This English edition has omitted one of the eight chapters of the Spanish version and one third of the images, hoping to make the book leaner and better balanced.

Any work so extended in time leaves the author indebted to so many that it would be difficult to compile a list without significant omissions. For this reason I prefer to send a generic thanks to my colleagues of Madrid's School of Architecture, to those who have shared my editorial endeavors at *AV/Arquitectura Viva*, *CAU*, and Hermann Blume, and of course to my family, who have put up with my dedication to these themes more than I can ever compensate for. Nevertheless I must mention a number of friends who, though not actually belonging to the architectural world (a world we all too often encapsulate ourselves in), took a special interest in this work and offered me support and stimulus. At different points Ivan Illich, Emilio Lledó, Juan Antonio Ramírez, and the late Manuel Sacristán read all or parts of the text and gave me valuable insights. And this English edition would not have happened without the enthusiasm and encouragement of Cynthia Davidson, the meticulous translation of Gina Cariño, and the intelligent editing of Paul Henninger and Matthew Abbate.

Luis Fernández-Galiano

Fire and Memory

one

Architecture Discovers Fire

Construction and Combustion in the Oven and the Hearth

On matter and energy
architecture between mud and breath

Architecture does not exist as an object of knowledge outside of what physicists call *intermediate* dimensions. At the scale of the very big or the very small, one may speak of the architecture of the cosmos or the intimate architecture of matter, but this involves a metaphorical use of the term. The architecture we refer to here has the scale of the building or the city. It shares with man and his other artifacts an intermediate dimension in which one can rightly speak of matter and energy as different concepts. Of course the distinction would not easily hold in situations belonging to another dimensional field: in high-energy physics, for example, scientists routinely measure the mass of particles in energy units; and, after all, the relativity equation expressing the equivalence between mass and energy is surely the most popular in the history of science. What is important here is that in our immediate environment, in that part of reality that a contemporary of Galileo would have called the sublunar world, the distinction between matter and energy is epistemologically and phenomenologically valid.[1]

An important fact about our intermediate world separates matter from energy. Without energy, the movement of matter is reduced to locomotion, trajectories, and elastic collisions; without energy there are no processes or transformations; without it there is no life, which requires a constant flow of energy.[2] It is precisely this link between energy and life that connects energy theories to vitalistic or animistic philosophies.

Through time, matter and energy are opposed to one another in the same way as the inanimate and the animate, or that which possesses *animus*. In the book of Genesis, matter acquires life—it is animated—through the gust that fills it with spirit, producing the duality between mud and breath that is best expressed by the Cartesian distinction between *res extensa* and *res cogitans.* When Napoleon wonders about God's place in Laplace's World System and the latter replies "Je n'ai pas besoin de cette hypothèse," we know that it is not only God who is banished from his Celestial Machine: with him go the spirit, final Aristotelian causes; life and energy depart from the material, ordered, and immutable world of trajectories. And it comes as no surprise that the nineteenth century's most radical ideological attempt to place energy at the center of an explanation for the world, Wilhelm Ostwald's theory, clashed head on with the mechanistic reductionism of scientific materialism.[3]

Thus, energy injects life, processes, and transformations into the inanimate world of matter, and thus into the world of architecture. We are accustomed to thinking of the latter exclusively in terms of physical, mute, immutable objects; architects themselves like to photograph their buildings unfinished, silent and empty. It could be said that architecture is concerned solely with material forms, cold and intangible, situated beyond time.

Partly responsible for this *vision* of architecture, this *image* of it that we conserve (and language and its polysemy betray us here), is precisely the dictatorship of the eye over other organs of perception. But another, perhaps more important factor is the scandalous absence of energy considerations in architectural analysis and criticism.

The irruption of energy in the universe of architecture smashes its crystalline images, shakes its mute silhouette, and gives it a definitive place in the field of processes and life. Architecture can then be thought of as a transformation of the material environment by changing living beings, an artifact continuously altered by use and circumstance, in constant degradation and repair before the aggression of time, permanently perishing and renewing itself.

The building as an exosomatic artifact
a process containing processes

Architecture can be understood as a *material* organization that regulates and brings order to *energy* flows; and, simultaneously and inseparably, as an *energetic* organization that stabilizes and maintains *material* forms.[4]

This leads to a first metaphorical bifurcation: architecture, as an artifact of the human environment, regulates natural energy flows and channels the energy accumulated in combustible substances for the benefit of the living beings who inhabit it; and architecture, as organized matter, is subject to permanent deterioration and needs a continuous supply of materials and energy to enable it to reconstruct its form.

The building accommodates processes but is in itself a process, and both circumstances call for the presence of energy. Thus energy is installed in the heart of architecture in two ways: through the energy consumption of buildings (or more accurately, of the building's users) in thermal regulation, water heating, lighting, etc., and through the energy needed to organize, modify, and repair the built domain. In other words: through the energy consumed by the processes that the building houses, and through the energy consumed by the process that the building itself is. We shall call the former an energy of *maintenance*, and the latter an energy of *construction*.[5]

We must stress the importance of the latter term, often overlooked when energy issues in architecture are tackled. Only through it can we understand the strong bonds that link the degradation of energy to the degradation of matter. Matter and energy, though dichotomized for the sake of methodological convenience,[6] are as inextricably connected as the warp and the weft.

The building, in effect, as von Bertalanffy wrote of the living cell and the organism, "is not a static organization or a structure resembling a machine made of more or less permanent 'construction materials' in which 'energetic materials' provided by nutrition decompose to supply the energy needs of vital processes. It is a continuous process in which both construction materials and energetic substances [the *Bau-* and *Betriebsstoffe* of classical physiology] decompose and regenerate."[7]

How well this description of the organism suits architecture! It might be said to apply only as a biological analogy, but in this case as well as others the metaphor translates into stark reality, revealing some hidden connections that are often more enlightening than mere phenomenological description.

I have mentioned that energy injects life into the world of architecture. More correctly, it is the link between life and architecture—the fact that architecture is created by human beings—that injects energy into the core of architectural practice.

Therefore, architecture can be thought of as an *exosomatic* artifact of man, existing outside of the body,[8] and the energy used in the building and maintenance of the environment must be included within the general concept of external or exosomatic energy, defined by Margalef as that "which helps maintain life and the organization of ecosystems, but which neither flows through nor gets debased in the channels of somatic metabolism." He adds: "In today's human life this label applies to all energy used in heating, transport, food preparation, air conditioning, the building and maintenance of dwellings, and information dissemination."[9]

At this point a pause and some clarifications are in order. Endosomatic energy—energy that feeds the internal metabolism of organisms—has limited thresholds of variation. The ratio of its biologically possible maximum and minimum rate of use can never exceed two to one.[10] Not so in the case of exosomatic energy, where the range of variation is virtually limitless, from cultures like the Eskimo tribes, which practically use only endometabolic energy, to the use, by certain groups of individuals in industrial countries, of quantities of exosomatic energy a thousand or more times greater than the metabolic energy they consume in their organisms.[11]

Hence it is precisely within this latter framework of exosomatic energy, so dramatically and spectacularly variable, that we must present the energetic panorama of architecture.[12] But first we must remember that the *biological* conditioning of endosomatic consumption is one thing, while the *cultural* consumption of exosomatic energy is another. The biological realm of necessity and the cultural realm of choice complement and oppose one another: the fact that architecture belongs to the cultural domain ought to serve as a warning against biologistic reductionisms, always tempted as they are to formulate the sort of organic analogies that are otherwise enlightening and stimulating on their own terms.

The hut and the bonfire

built order, combustible disorder

A parable attributed to Reyner Banham can be used to illustrate some of the ideas so far presented.[13] The tale tells of a primitive tribe that has just come across a clearing in the wood where it plans to spend the night—an archetypal tribe that, as the author reminds us, has so many antecedents in architectural criticism, from Laugier to Le Corbusier. There are fallen branches and some wood in the clearing. The tribe has a dilemma: whether to use the wood to build a small shelter or as firewood for a bonfire. An entire theory of architecture is encapsulated in this simple question.

Wood is, of course, a material for both construction and combustion. As such, it meets the potential conditions of both matter and energy and illustrates the close relation between them. The tribe regards the wood, just as the builder regards a natural resource (material or energetic), and considers the two basic strategies of environmental intervention: regulating natural energy flows through the creation of material structures (the hut), or exploiting the energy accumulated in combustible substances (fire); using the climate's free energy through construction, or using its accumulated energies through combustion. Construction is nourished by flows, combustion by deposits. One feeds on our profits, the other on our thermodynamic capital. The two strategies are perfectly differentiated, yet one excludes the other only when they compete for the same resources.

So when faced with our tribe's dilemma, both strategies are feasible. Both present themselves in most cultures and both deserve to be called architecture. Indeed, the thermal space of the bonfire is no less architectural than the visual space of the hut. Only an obstinate fetishism for icons or an object-oriented, hieratic conception of architecture can deny the bonfire the status of *ab ovo* architecture so easily assigned to the hut. What is a house but a hearth?

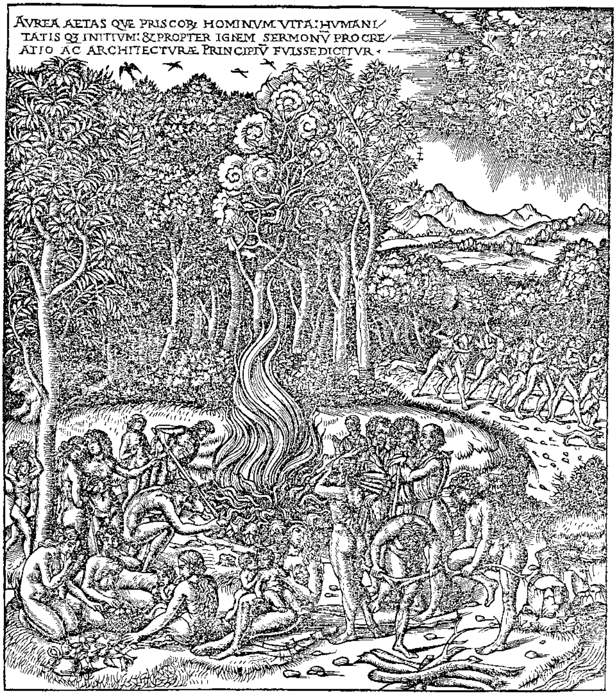
Moreover, hut and fire, construction and combustion, are inextricably linked in the history of habitation, a unique combination of constructed order and combustible disorder. Energy brings architecture into the world of processes and life. But it also bestows architecture with consumption, fugacity, and irreversible time. Architecture brings together fire and hut, chaos and organization.

The close bond between construction and fire is clearly reflected when architecture is reduced to its most elemental and primitive form: on one hand, in stories about the origin of architecture and the rituals of urban foundation; on the other, in the infantile perception and the psychoanalysis of the house. In all beginnings or origins, in myths and rituals as well as in the preconscious or unconscious mind, construction and fire are intermingled and intertwined.[14]

Fire in the childhood of architecture
myths of origin, foundation rites

In what are probably the two paradigmatic treatises on architecture, *De architectura* and *De re aedificatoria*, Vitruvius and Alberti offer symmetrical and significantly opposed accounts of the origin of architecture. In the Roman's colorist narrative about "the beginning of buildings" (book II, chapter I), it is the discovery of fire that gives rise to human society ("the collaboration between men, the communal life and coincidence of many in one place"), and with it, the construction of the first shelters and huts. This explanation by Vitruvius comes from the Epicurean evolutionism crystallized by Lucretius. The idea is not original: the Greek Hephaestus—and later the Roman Vulcan—represented the *ignis elementatus*, the civilizing physical fire that counters the symbolical fire of knowledge in Prometheus; and, starting with Homer, the God of Fire is acknowledged as Arch-artisan and Master of Humanity, who teaches the crafts to men who had lived "in caves like wild beasts."[15] It is this same expression—*ut ferae*, like wild beasts—that Vitruvius uses to describe the life of man before the discovery of fire, the subsequent formation of human society, and the beginning of architecture.

In contrast, Leon Battista Alberti, early on in his prologue, is convinced that "a roof and walls" mark the beginning of the congregation of men, and not, as "some have said," water or fire. Yet a few pages onward, at the start of chapter II of book I, the hearth precedes ceilings and walls in the story of the origin of the house: "In the beginning, men



1.1.

Fire has a privileged place in myths about the origin of architecture, the same leading role it plays in the foundation rites of the city or the house. Combustion precedes and accompanies construction.

1.1. *The discovery of fire in Cesariano's Vitruvius (1521).*

1.2. *The building of the first shelters and huts in the same edition of Vitruvius.*

1.2.

sought a place of rest in some region safe from danger; having found a place both suitable and agreeable, they settled down and took possession of the site. Not wishing to have all their household and private affairs conducted in the same place, they set aside one space for sleeping, another for the hearth, and allocated other spaces to different uses. After this men began to consider how to build a roof, as a shelter from the sun and the rain. For this purpose they built walls on which a roof could be laid."[16] As we see, early on in what Alberti calls his *partitio* (the distribution of uses in the plan), fire is part and parcel of architecture.

Whether we put emphasis on the structural similarities of the narratives, as Joseph Rykwert has done,[17] or on the differences in their textual organization, for which Françoise Choay has exhaustively argued,[18] fire is intimately associated with construction in the myths of origin; the same is true in the rites of urban or domestic foundation.

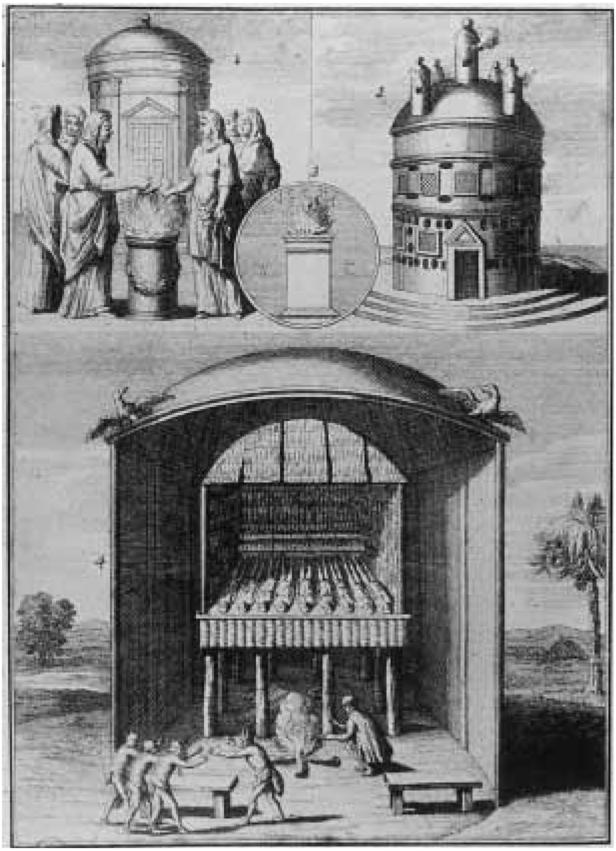
In the classical world, for example, fire was of utmost importance in the rites having to do with the city or the house. We must remember that, for both Greeks and Romans, the sacred fire of the city was "its prime altar, the origin of its identity and the fount of religious life." Hestia, the Greek goddess of the hearth, was "the 'focus' of the internal space of the city . . . the 'home you start from.'"[19] Her fire burned in the *prytaneion*, the communal palace-temple, seat of citizen power.[20] The Roman Vesta, in turn, "ruled both the household fire of the individual family and the civic hearth of the city. Hers was the fire which warmed and nourished, a benign and fertilizing power."[21] It is significant to note that the names of both goddesses derived from a common Indo-European root, "perhaps . . . **wes*-, to live in, to occupy, but more probably **deu*, to burn."[22]

Thus when Rome was erected, its founders—after leaping over the purifying bonfires[23]—dug a *mundus* (a round hole representing the mouth of the underworld) in what was to be the heart of the city, placed a stone altar over it, and over the altar lighted a fire: this fire—writes Rykwert—is "the 'focus' of the town. At this point the city may also have received its name."[24] This original fire was taken from one city to another, never abandoned; when a colony was founded, the fire came from the original city of the settlers; when the vestal virgins fled from the approaching Gauls, they transported the sacred fire with them in a vessel.

The key presence of fire in foundation rites is of course not exclusive to Greco-Roman culture. Rykwert himself, and others like Frazer or Raglan, have described similar ceremonies—wherein house, fire, and city are associated with one another—in primitive Eastern, African, Amerindian, and European cultures. From the role of the sacred Vedic fire in the founding of Hindu temples to fire's generative function, as a seed, that always links it to habitational implantation in animistic cultures, construction and combustion are bound together in a close and permanently renewed relation, as occurs in the feast of the new fire among America's Natchez, described by Chateaubriand: "Pieces of oak bark are kindled upon the altar, and this new fire then gives a new seed to the extinguished hearths of the village."[25] The same conception of fire as a fertile beginning is present in nuptial ceremonies, as in ancient Greece, with the mother of the bride carrying fire to the new house to signify the continuance of the domestic cult, or in India, where the newlyweds brought to their new home a part of the sacred fire that had witnessed their marriage, to be used in the future in all domestic ceremonies, according to Raglan.[26]

Fire is thus associated with the house and the city in foundation rites—the establishment of the city, the creation of the home—and in subsequent civic and domestic ceremonies requiring the continuity of the flame, but it is so by virtue of its role as an image of fertility and a metaphor of life. This identification between fire and life, notoriously present among alchemists,[27] comes as no surprise. As Lisa Heschong points out, "The fire was certainly the most lifelike element of the house: it consumed food and left behind waste; it could grow and move seemingly by its own will; and it could exhaust itself and die. And most important it was warm, one of the most fundamental qualities that we associate with our own lives. When the fire dies, its remains become cold, just as the body becomes cold when a person dies. Drawing a parallel to the concept of the soul that animates the physical body of the person, the fire, then, is the animating spirit for the body of the house."[28]

Matter and energy, architecture and fire, construction and combustion are once again placed in relation to one



1.3. *The cult of Vesta and of the sacred fire compared with a similar cult of fire at the temple of Louisiana's Natchez Indians. Joseph-François Lafitau,* Moeurs des sauvages américains comparées aux moeurs des premiers temps *(Paris, 1724).*

another through the thin thread of life, processes, and transformation, which links them together in an inextricable tangle.

Fire in the architecture of childhood
nostalgias and dreams

The house and fire come together and complement each other also in the mind of the child and the poet, in the state of consciousness at the moment of awaking and in that which inhabits the threshold of sleep. Children's drawings and poetry weave the part of the subconscious that ties together the cave and the bonfire, the fireplace and the house.

Gaston Bachelard, who knows that "the house, even more than a landscape, is a 'psychic state,'" has described studies that have been carried out on children's drawings of houses: "In certain drawings, quite obviously, to quote Mme. Balif, 'it is warm indoors, and there is a fire burning, such a big fire, in fact, that it can be seen coming out of the chimney.' When the house is happy, soft smoke rises in gay rings above the roof. If the child is unhappy, however, the house bears traces of his distress. In this connection, Françoise Minkowska organized an unusually moving exhibition of drawings by Polish and Jewish children who had suffered the cruelties of the German occupation during the last war. One child, who had been hidden in a closet every time there was an alert, continued to draw narrow, cold, closed houses."[29]

The warm house, like the maternal womb, expresses the joy of the protective shelter; the more inclement the season, the more intense the joy; the colder it is outside, the more intimate the warmth becomes. This identity between the mother and the house has been expressed by Milosz in two tense lines:

I say Mother. And my thoughts are of you, oh, House.
House of the lovely dark summers of my childhood.[30]

The nostalgia of childhood, the protective nostalgia of the mother, and the melancholic nostalgia of the house are fused and lost into one another.

Kent C. Bloomer and Charles W. Moore have recalled the old association between the cave and the womb of Mother Earth,[31] but failed to mention that in it fire represents the fecund masculine beginning. Without this sexualized fire described by Bachelard,[32] the cave is a barren womb. The cave needs fire as much as the child's house needs the smoky chimney. Only then do they express and contain life, only then do they become a desirable architecture.

The nostalgia of the primitive gesture of inhabitation is a tepid, round nostalgia for the womb and the nest. This is not a merely spatial sentiment; it is also—and above all—a thermal sentiment.

There is a beautiful fragment from Bachelard that illustrates this admirably, through a page of Henri Bachelin. Bachelin writes in *Le serviteur:* "I delighted in imagining (although I kept my feelings to myself) that we were living in the heart of the woods, in the well-heated hut of charcoal-burners; I even hoped to hear wolves sharpening their claws on the heavy granite slab that formed our doorstep. But our house replaced the hut for me, it sheltered me from hunger and cold; and if I shivered, it was merely from well-being." Bachelard comments: "Bachelin is more fortunate than dreamers of distant escape, in that he finds the root of the hut dream in the house itself. He has only to give a few touches to the spectacle of the family sitting-room, only to listen to the stove roaring in the evening stillness, while an icy wind blows against the house, to know that at the house's center, in the circle of light shed by the lamp, he is living in the round house, the primitive hut, of prehistoric man."[33]

As in the primitive hut of treatise writers, fire is present in the hut imagined by the child Bachelin. In both the writer's text and the philosopher's commentary, thermal sensations come before others. The dream of the "well-heated hut . . . sheltered from cold" is inspired by "the stove roaring in the evening stillness, while an icy wind blows against the house." The only spatial definition of the hut is provided by a sheaf of light, and the feeling of comfort is manifested by a shiver.

The primitive hut and the primitive fire are revealed to be inseparable. The protoarchitectural fire of the treatise writers, the sacred flame of the city and the house, and the smoky chimney of the child's drawing all show the close identity of house and fire in the luminous furnace that is the origin, the singular and unrepeatable moment, in which architecture is born in myth, in rite, or in consciousness. The warm hut of the imagination manifests this in the even more far-reaching moment in which architecture is reborn in dream.

Besides the fire that dwells in buildings, the fire that builds the dwelling

The story of the primitive tribe confronted with the dilemma of the hut and the bonfire has led us to review other origins that eloquently speak of the link between construction and fire. But there is more to it than the mere beneficent presence of energy in the building, by which it is rendered habitable or sacred, intimate or joyful; to stop here would be to limit the matter to what we have called energy of *maintenance*, that which feeds the processes contained by the building. More than the energy that nourishes the *processes of the building*, it is important to consider the energy that nourishes the actual *building as process*, which we have named energy of *construction*.

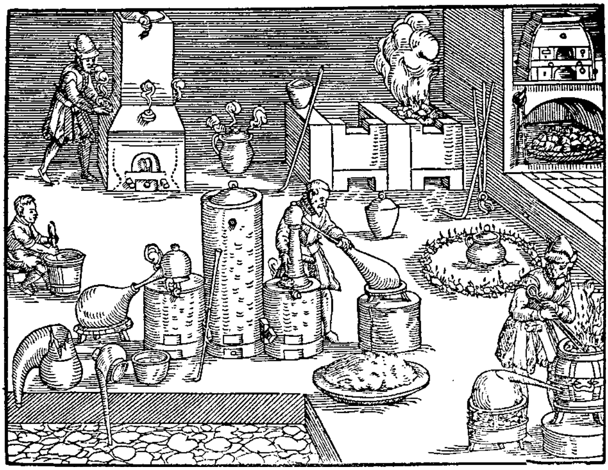
With night about to fall, our undecided tribe could well decide to follow both strategies of environmental intervention put forward earlier: use part of the wood to build a small shelter and light a fire with the rest of it. Up to this point we have been thinking only in terms of the complementary relationship between the primitive hut and the primitive fire: a material component and an energetic one forming an inhabitable environment. But the tribe could also choose to build a larger hut with all the wood available, or to do away with a hut altogether and surrender the wood to the flames. In the first case the strategy of environmental intervention is exclusively material; in the second, exclusively energetic.

There is a certain commutability between matter and energy that resides in the fact that wood is potentially as much a construction material as a combustible substance. This is precisely our concern now. If previously the emphasis was on the *complementarity* and *simultaneity* of the material and energetic strategies, now emphasis goes to the *commutability* and *interchangeability* of the two. Construction and fire, matter and energy are complementary *and* interchangeable.

Energy comes from the combustion of a material, and the material can be expressed in energy units: in such permeability rests the possibility of comparing the two by reducing them to a common denominator. Thus so much emphasis on the fact that if the processes of the building need maintenance energy, the building as a process needs construction energy.

In the case of the tribe, this energy is accumulated in the material itself, wood, in which solar radiation has gathered and concentrated; metabolic energy will be needed to transport, prepare, and assemble it. In our society, energy is similarly accumulated in materials, formed in the heat of ovens for ceramics, glass, cement, or metal; mechanical and metabolic energy will have to be used in order to transport them to and install them in the building site.

Energy, present in the principle and foundation of every process, is present as well in the process—of construction, of



1.4

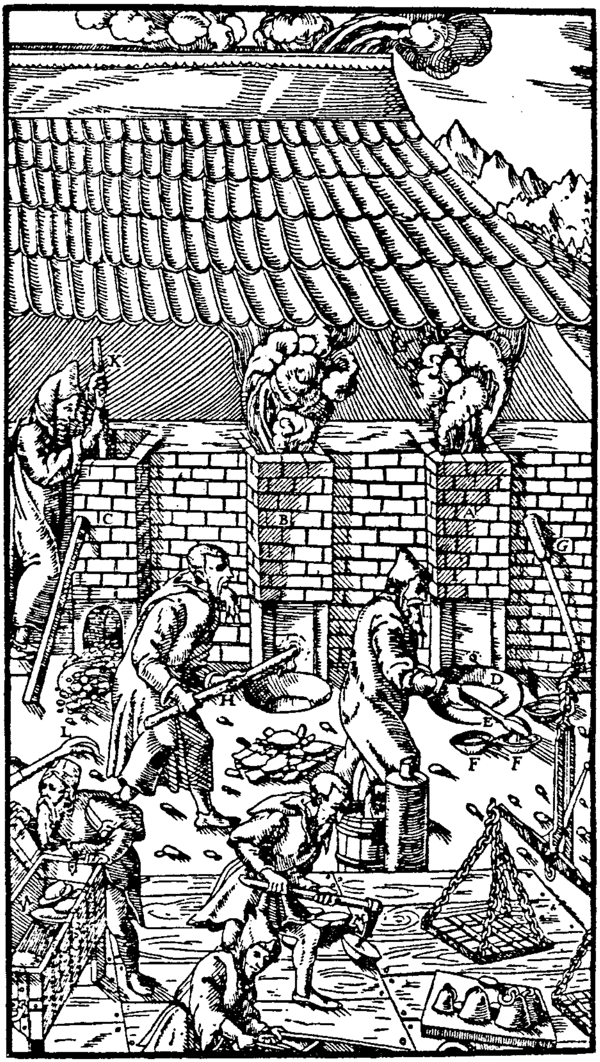
The fire of the hearth dwells in the building; the fires of the oven build up the dwelling. The energy necessary to maintain a house is as important as the energy needed to build it: architecture and fire are linked to one another as much by the hearth as by the ovens that produce brick, glass, and metal.

1.4. *Assaying laboratory. Lazarus Ercker,* Beschreibung allerfurnemisten mineralischen Ertzt und Berckwercksarten *(Prague, 1574).*

1.5. *A glass-blowing workshop. Agricola,* De re metallica *(1556).*

1.6. *Ovens for refining copper ore. Agricola,* De re metallica *(1556).*

1.5.



1.6.

repair—that constitutes building. There is no transformation, irreversible change, or mutation without energy; without it there is neither construction nor destruction, neither animation nor time. Only energy transforms matter; only fire transforms material. As the insignia of old chemists said, *ignis mutat res*. Fire creates alterations and metamorphoses in the furnace of the blacksmith and the crucible of the alchemist; in the oven of the manufacturer, fire converts mineral into material. Fire bakes clay, generates metal, makes glass. In the hearth, fire dwells in the building; in the oven, fire builds the dwelling.

The clockwork sun and the unpredictable fire

cosmologies and cosmogonies

The two basic methods of environmental intervention have already been presented: on one hand is the regulation of free energy[34] through construction; on the other is the exploitation of accumulated energy[35] through combustion. We have seen how construction needs energy in order to be carried out; combustion, in turn, tends to need the help of material contrivances (fireplaces, stoves, boilers, tanks) which in themselves are manufactured with energy. Both methods thus require energy, but in very different amounts and consumed through time in very different proportions; and though they tend to be presented together, each has a very separate identity. Between the two strategies lies a broad conceptual and philosophical void.

Construction involves a passive availing of the orderly world of trajectories; fire, an active availing of the chaotic world of combustion. Constructed order is opposed to combustible disorder, celestial mechanics to terrestrial thermodynamics, the clockwork sun to the unpredictable fire.

This formidable ontological and existential opposition between sun and fire, which feeds and devours our entire culture—and which is also present, as we shall later see, in our architectural culture—has been admirably described by Michel Serres in a paper about Zola's work.

The century that was ending when the novel appeared had begun under the ruling stability of the solar system, but now, with the implacable degradations of fire, it was possessed by anguish. Thus the dilemma, positive and savage: a perfect cycle, without residues, reversible, eternal and revalorized, the cosmology of the sun; or a frustrated cycle, which loses its difference, irreversible, historic and devalued, a cosmogony, a thermogony of fire that must be extinguished or destroyed, and inevitably so.[36]

The confrontation between the cosmogony of fire and the cosmology of the sun, between Chaos and Logos, between the Heraclitan fire and the regularity of the trajectories that filled Kant's heart with reverence, is an opposition but equally a hidden identity. After all, the universe as we know it today is a gigantic combustion, a multiple, catastrophic, historic fire, whereas fire, for all its aleatory agitation, is a creator of order, a Hesiodic, genetic, constructive fire. As Edgar Morin has shown, there is an essential link between the star-sun, the *arch-machine*, and the earthly fire, the *wild engine*, which brings together disorder and organization, Chaos and Logos.[37]

Despite this link, or perhaps precisely by virtue of this subterranean identity, the opposition of sun and fire provides a wonderful metaphor through which to interpret some architectural polarities in the field of environmental intervention. These will be discussed in the terms of a philosophical architecture and two architectural philosophies.

A philosophical building and two building philosophies
Solar Le Corbusier, igneous Wright

The philosophical building, appropriately, is in itself a metaphor, since Robert Misrahi fabricates a *Treatise of Happiness* through the story of the building of an imaginary castle. Here are but two quotes from it that can exemplify the solar conception and the igneous conception of architecture.

> The visible must be built in such a way that, with the rising sun and summer solstice, the sun invades the tallest and longest room in all its splendor, and this room shall therefore be at once the center of the building and its most elevated place.[38]

> The central foyer . . . like the fire that is at once punctual and cosmic, from which all these movements and all these beginnings emanate, will be created by reflection, that is, the optic and reflective interaction that the visitors work out among and in themselves, nourished as they will be by their respective, common and mutual affirmation.[39]

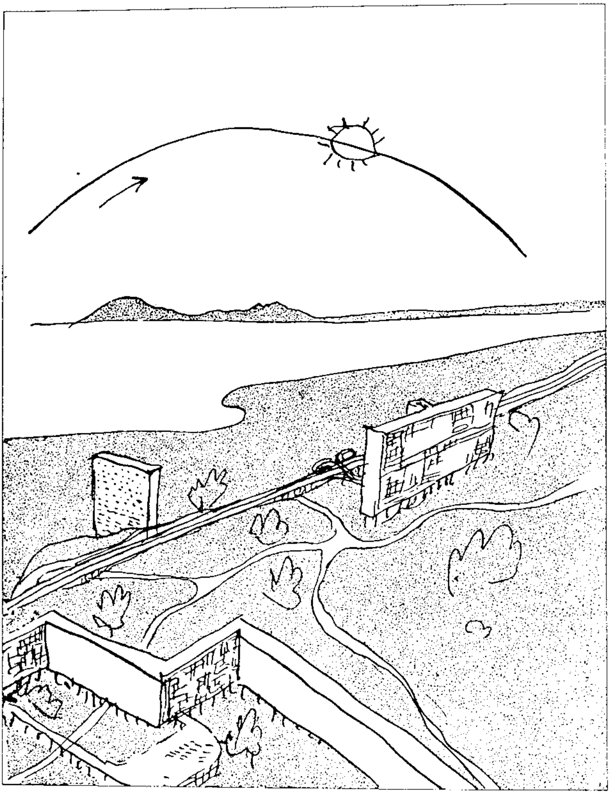
Observe how the solar and astronomic references situate architecture in the orderly world of trajectories, of necessary and predictable occurrences, whereas the mention of fire introduces agitation and interchange, movements and beginnings, interaction and unpredictability. The rising sun, removed from the world of men and changes, in its full splendor more luminous than warm, is opposed to fire, the source of transformations, made up of the reflection of the subjects.

This same opposition of sun and fire can be found in the works and writings of two architects of the century, perhaps the two greatest, definitely among the most controversial and passionate interpreters of the role and function of architecture. They are Le Corbusier and Frank Lloyd Wright.

Le Corbusier is, indeed, a splendid example of the necessary and orderly, Apollonian, solar conception of architecture. His sun is a perfect cycle, logical and closed, and a testimony to this is the obsessive omnipresence in his notebooks of the sinusoidal curve representing the 24 solar hours, "événement fondamental qui rythme la vie des hommes." His is a sun of mathematical trajectories, of certitude and precision, of equinoxes and solstices: a Cartesian, Laplacian, indispensable sun. His *brise-soleil,* as at the *unité* of Briey-en-Forêt, are designed in such a way that no ray of sun touches the glass during the warmest hours of the day, "between the spring equinox and the autumn equinox." In the huge hyperboloid of the assembly hall at Chandigarh, the lighting of the ceiling "rejects the summer sun, receives the winter sun and sends the equinox sun over the interior edges of the hyperboloid."[40] The sun designs the architecture, univocally and obligatorily, through the regular and orderly cycles of its daily rotation and annual revolution. Below the drawing of the solar cycle (the cycle that runs from *un soleil se lève* to *un soleil se lève à nouveau),* Le Corbusier writes: "If not all the necessary and sufficient conditions are achieved, the result is disequilibrium, insufficiency—disgrace all day and . . . all one's life!"[41]

Happiness is the perfect and serene equilibrium under the logical empire of the solar cycle. Environmental design rests in submission to the immutable and necessary laws of the movement of the stars.

Wright, in contrast, represents the igneous, organic, agitated, and emotive view that is diametrically opposed to solar rationalism. Even when he does refer to the sun, he does so in terms having little to do with Le Corbusier's clocklike star. Cosmic laws are not the laws of trajectories but the laws of change (which "sing in unison with cosmic law"). Rhythm does not reside in orbital cycles, but "dances in sentient



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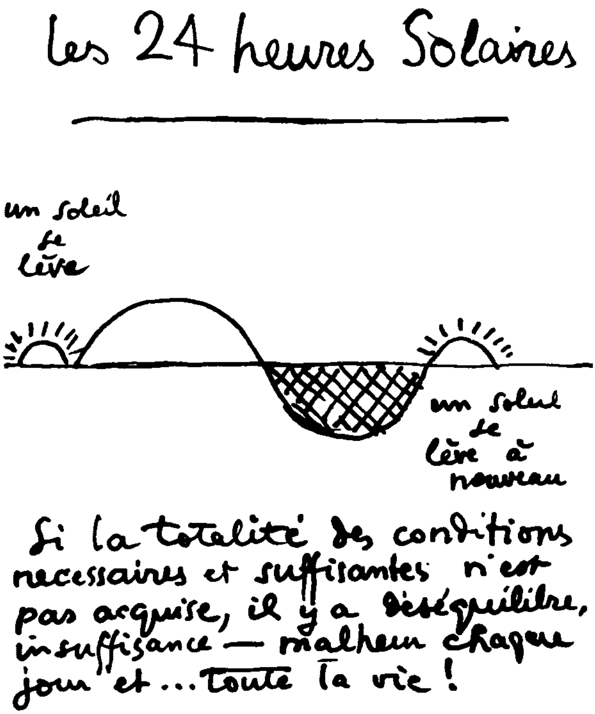

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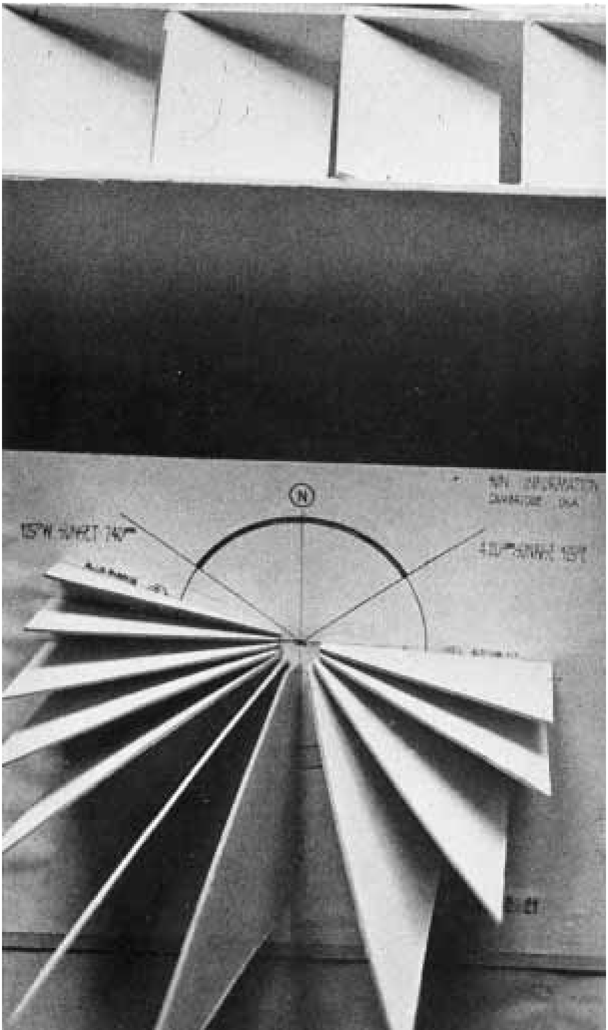
Le Corbusier under the empire of the orbits: the sun designs architecture, which is subjected to the logic of the cardinal points and the inexorable law of astral movement.

1.7. *The law of the place, Le Corbusier, 1946.*

1.8. *The solar cycle, Le Corbusier, 1954.*

1.9. Brise-soleil *of the Carpenter Center, Le Corbusier, 1961.*



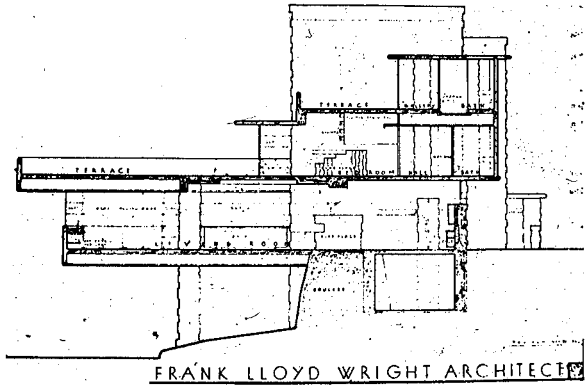
1.9.

beings." And the sun, more than a celestial body, is the beginning of life and growth, impeller of changes, seed of the earth, which "becomes more and more the creative creature of the sun. It is a womb quickened by the passions of the master sun."[42]

To Le Corbusier, the sun is a luminous and regular sign that normalizes and organizes the life of human beings. To Wright, the sun is heat more than it is light, a beginning more than a regulator, a factor of change rather than of stability. His is a warm, chaotic, igneous sun: a cosmic fire.

And fire is precisely where the keystone of Wright's environmental vision resides. Remember his Prairie Houses and the leading role played in them by the hearth, the thermal and compositional focus around which the architectural space and the life of its inhabitants is elaborated. The architect described his intentions in a revealing statement: "At that time a real fireplace was very rare. In its place were 'mantels'. A 'mantel' was a marble frame for a few pieces of coal, or a wooden furniture with tiles and a grille, attached to the wall. The 'mantel' was an insult to comfort, but the *integral* fireplace became an important part of the building itself in the houses I got to build on the prairie. I found it refreshing to see a fire burning deep in the masonry of the house itself."[43]

The link between construction and fire goes beyond the conventional association between the *hearth* and the *heart* of the house. The fire is not only present in the center of the house, but burns "deep in the masonry of the house itself." In Fallingwater, his most famous house and one of the fetish images of this century's architecture, the fireplace rises precisely over the large rock on which the building sits, so that it has been said to be, more than a house over a cascade, a fire over a rock.[44] It might be more than mere irony



1.10.

1.11.

that the rock, before its igneous consecration by Wright, was the client E. J. Kaufmann's favorite place for sunbathing.

Needless to say, in the case of both Le Corbusier and Wright, the use of sun or fire is more symbolic than functional. Behind the *brise-soleil* and around the fireplaces are sophisticated climate control systems; nevertheless the role of *signifying* climate control is attributed to the screen and the hearth, most likely because they fall within the range of wider symbolic systems.

Thus, the careful astronomical determination of their inclinations links Le Corbusier's *brise-soleil* to a respectable architectural tradition of buildings governed by the stars, a tradition ranging from megalithic alignments to the Arc de Triomphe in Paris, the pyramid of Cheops, the Chartres cathedral, and the monastery of the Escorial. In all of these the calendar of the stars has left a mark. And there is little doubt that Wright's chimneys invoke a no less archaic tradition in which fire is the soul of the house and the city, a symbol of fertility and life, a sacred and beneficent flame.

In the prologue to his eighth book, Vitruvius writes that "the sun and the fire, meant to be fostered naturally, make life more secure." If the examples cited are convincing, then to

Frank Lloyd Wright at the service of fire: the hearth is the heart of the home, and the ceremonies of domestic life are celebrated around its sacred and changing flame.

1.10. *Fallingwater, a fire on a rock, Frank Lloyd Wright, 1935.*

1.11. *Interior of the second Jacobs House, Frank Lloyd Wright, 1946.*

the Roman's narrow interpretation of *utilitas* we would have to add that sun and fire *also* make life more significant. In this way we would better understand the double role—functional and symbolic—played by sun and fire, the world of orbits and that of combustion, celestial mechanics and terrestrial thermodynamics, which constitutes the axis of the relation between architecture and energy.

two

The Heating of the World, from Newton to Carnot

From Celestial Mechanics to Earthly Thermodynamics

The mechanistic paradigm and thermodynamics
trajectories and processes

The opposition between the world of trajectories and that of combustion does not appear in architecture in a casual way. On the contrary, it arrives there through a process of material and ideological diffusion resulting from knowledge of the physical world and the ensuing technological development, as well as from a conception of nature and the concomitant cultural *Weltbild*. Artifacts and ideas both intervene in the building of architecture, and it is this double presence that lies at the base of the functional-symbolic duality referred to at the end of the previous chapter. Technique and ideology come together in the scientific realm, which interacts manifestly with both, and thus the interest in exploring the parallelisms and correlations that can be established between science and architecture.

It is in this sense enlightening to trace the polarization of scientific knowledge, through the course of the nineteenth century, into what we could call the mechanistic paradigm on one hand and thermodynamics on the other, a process that continues into the current century and still contributes to the terms of epistemological debate.

Though the mechanistic paradigm has its roots in the works of Bacon and Descartes in the seventeenth century and has its most representative figure in Isaac Newton, who at the start of the Age of Enlightenment established a hegemony that remained undisputed throughout it, the most thorough and eloquent expression of the mechanistic conception of the world must be attributed to Pierre-Simon, marquis de Laplace. By the end of the eighteenth century, Laplace had finished the first two volumes of his *Treatise of Celestial Mechanics*, the most formidable conceptual monument to a mathematical interpretation of nature, and the nineteenth century began under the omnipresent sign of the mechanism. Nevertheless, despite such splendid presages, the century that was to witness the final triumph of the mechanistic paradigm would also see the emergence of a rival paradigm and the beginnings of a confrontation between them that was to take up much of the second half of the century and continue, in diverse forms, to present times.

Sadi Carnot published *Réflexions sur la puissance motrice du feu* in 1824, only a year before the publication of the fourth and fifth volumes of Laplace's work; the first cracks in the gigantic building of mechanicism began to appear even before it was completed. A quarter of a century later, in 1850, James Joule published *On the Mechanical Equivalent of Heat*, and Rudolf Clausius *Über die bewegende Kraft der Wärme*. With them came modern thermodynamics, which in time would give rise to a conception of the world that was markedly different from, and in many ways incompatible with, that of Newtonian mechanicism.

The task of undermining the foundations of the Newtonian world has of course not been a simple one. Thomas Kuhn has described the extraordinary inertia and resistance to change of scientific paradigms, which leave the scene only as a result of true interpretive and predictive catastrophes, and this case is no exception. Moreover, as Prigogine and Stengers point out, there is the additional problem that "Kantian criticism has in general identified the scientific object with the Newtonian object; it has thus defined as impossible any opposition to mechanicism that is not also opposed to science itself. This is Kant's philosophical elaboration of the mythical discourse of modern science."[1]

Such "mythical discourse" has proven, in any case, to be singularly resistant. "Few occurrences have been announced in the history of the sciences as frequently as the end of the mechanistic conception of the world. This implies that few resurrections have been repeated as often as those of the mechanistic Phoenix."[2] The voice of Engels, proclaiming the death of mechanicism in his *Dialectic of Nature*, is but one of many that have been raised since 1850, all drawing attention to the conflict that pits thermodynamic irreversibility and the historical character of nature (as revealed by Darwin and Lamarck) against reversible and historyless mechanicism. Notwithstanding, the latter has managed to reemerge time and again.[3]

Perhaps the most spectacular of resurrections was that put forward by Ludwig Boltzmann, who undertook the formidable tour de force of reestablishing mechanics at the very heart of thermodynamics by expressing the laws of the latter in terms of statistical mechanics.[4] It is hence not surprising that Boltzmann himself, in a lecture delivered in 1886, should have maintained that the nineteenth century must not be remembered as the century of iron, steam, and electricity but as the century of the "mechanical vision of nature" and (paradoxically) of "Darwin's evolutionism."[5]

When Boltzmann made these affirmations, the "mechanical vision of nature" was already engaged in a crucial war of attrition, but only well into the twentieth century did developments in physics, the biological sciences, and cosmology relegate it to an obscure secondary role. The world of processes began to collect its debt from the world of trajectories.

Today it is possible and even obligatory to acknowledge what Morin calls the need to change the world. "The universe inherited from Kepler, Galileo, Copernicus, Newton, Laplace was a cold, frozen universe of celestial spheres, perpetual movements, implacable order, measurement, balance. It is necessary to exchange it for a warm universe with a burning cloud, balls of fire, irreversible movements, order mixed with disorder, waste, imbalance."[6] Such a change in our understanding of the world is necessarily accompanied by a parallel change in the world of understanding: "The universe of fire, in replacing the classical universe of ice, makes the wind of madness blow over classical rationality, under which the ideas of simplicity, functionality, and economy were united."[7] Exactly the same ideas were at the base of the modern movement in architecture, and are today being blown away by a wind of change resembling the one that has devastated mechanistic dogma in contemporary science.

Newtonian architectures

cenotaph and Panopticon, symbol and function of mechanism

It is curious to note how architectural historians like Giedion, Benevolo, Rykwert, Collins, and Hitchcock situate the origins of the modern movement in the second half of the eighteenth century, since it was precisely then that the mechanistic paradigm was at its peak. Newton had died in 1727, basking in a popularity so immense as to earn him a regal funeral, and his mighty figure continued to dominate the century. Shortly before it ended, two buildings associated with his name were proposed. They admirably exemplified the symbolic and functional reductionism on which modern architecture is founded.

Expressive simplicity, identified with Platonic solids, rotund volumes, and smooth surfaces, is perfectly reflected in Boullée's 1784 project for a cenotaph for Newton. In its cold and orderly balance, the huge sphere makes a splendid image—no less eloquent for being literal—of the conceptual mechanistic world.

Barely three years later, Jeremy Bentham, known during his time as "the Newton of legislation," wrote his *Panopticon*, which recommended the use of panoptic buildings for prisons, schools, hospices, and factories. The modern ideals of functionality and economy are adequately materialized in the transparency of these machine-buildings, at the service of a state in the process of building an institutional "machinery" of a complexity and rigor heretofore unknown.

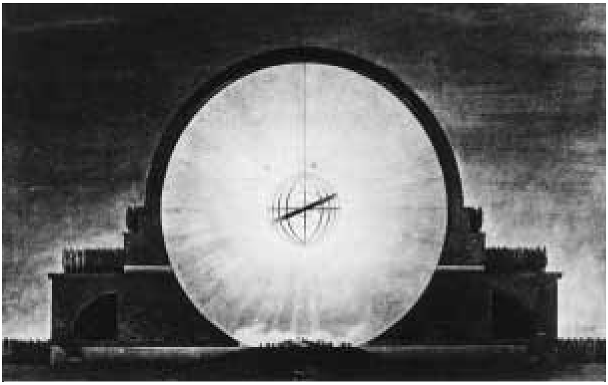
In the symbolic and functional realm, Newton's cenotaph and the Panopticon express the absolutism of reason and the totalitarian character of mechanism. They are therefore worthy spatial manifestations of the material and cultural universe of Newton and the Enlightenment and notorious precedents of the physical and conceptual world in which modern architecture emerges.

It might not be merely coincidental that the most important building linked to the name of the physicist who in our century was to demolish Newton's space-time conception, the Einstein observation tower in Potsdam, should have adopted a language totally removed from the orderly, exact, and machinelike simplicity of functionalism. Mendelsohn's tower, whose interior complexity has nevertheless been compared to a Swiss watch, chooses to express such complexity through a poetic that Einstein himself deemed to be organic. To be sure, it was a poetic permanently on the margins of the mainstream of modern architecture, which unfalteringly circulates through the symbolic channels of mechanism that Newton and Laplace had placed at the center of science and culture.

The challenge of a strange science

necessity and chance in the face of fire and orbits

The theory of relativity and quantum mechanics have played a key role in the revision of the concepts of space, time, continuity, and causality, concepts that formed the epistemological warp of the mechanistic paradigm. Nevertheless, in this entire process of radically transforming our conception of the world, the leading role must rightly be attributed to



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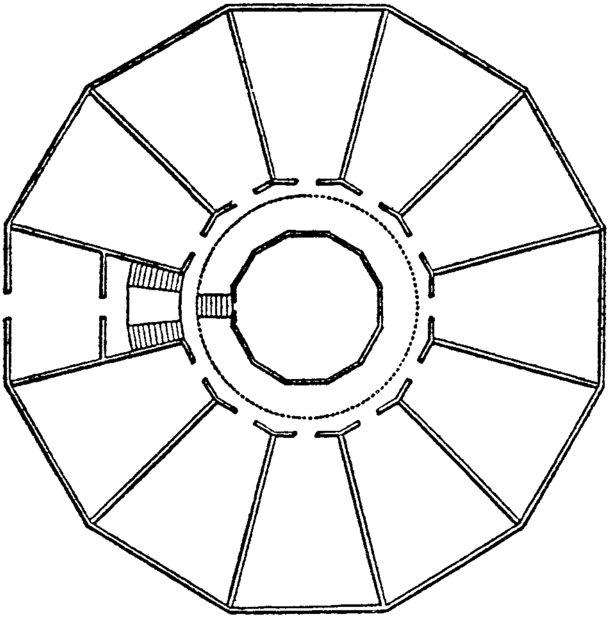


2.2.

thermodynamics, which a century and a half ago initiated the task of weaving an alternative view of the world and, through developments like the thermodynamics of open systems, remains splendidly fertile in its approaches.

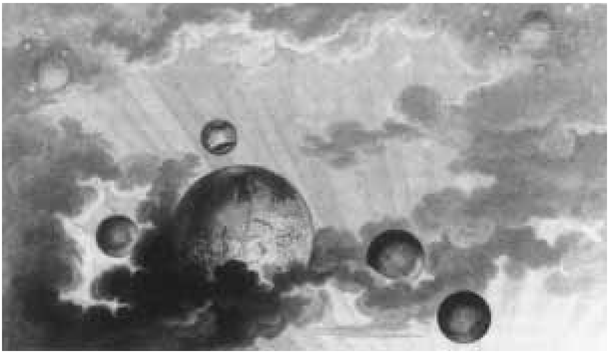
This is surely a singular theory. Cesare Maffioli calls it "a strange science" in the title of the book he dedicates to it. Formidably general, the theory joins the beauty of its conceptual construction to the seduction of the human echo that one finds in it. Albert Einstein himself succumbed to its magic, and explained his motives thus:

> A theory is more impressive the greater the simplicity of its premises, the more difficult the kinds of things it relates, and the more extended its range of applicability. Thus the deep impression that classical thermodynamics made on me. It is the only physical theory of universal content which I am convinced, within the framework of applicability of its basic concepts, will never be overthrown.[8]

Boullée's cenotaph to Newton and the Panopticon proposed by Jeremy Bentham well exemplify the reductionism of modern architecture in both the symbolic and the functional fields, by compactly representing the absolutism of reason and the totalitarian dimension of the mechanism. In their emphatic clarity Boullée and Bentham are something more than premodern or protomodern; these drawn buildings, products of an inexorable logic, are really exacerbations of the modern, modern in excess, hypermodern.

2.1. *Cenotaph to Newton, Etienne-Louis Boullée, 1784.*

2.2. *Floor plan of Jeremy Bentham's Panopticon, 1791.*



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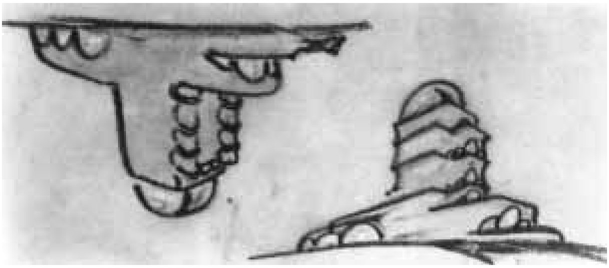

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Indeed, the coherence of the logical construction of classical thermodynamics is such that it has been said to be as harmonious and complete as Euclidean geometry, and it is surely the only contemporary theory that has deserved that comparison.[9]

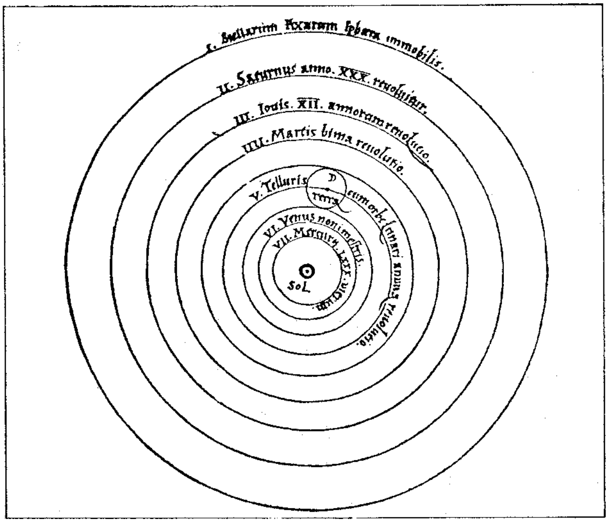
In any case, its special intellectual attraction is not independent of its historical and epistemological peculiarities, which have endowed it with those anthropomorphic qualities—for example, the qualitative distinction between available and nonavailable energy[10]—that cause some to deny it the status of a legitimate science of nature.[11] It is to these qualities that the Nobel laureate P. W. Bridgman attributed the uneasiness of most physicists with regard to thermodynamics, partial as they are to the statistical mechanics approach, which focuses on "the details of those microscopic processes which in their larger aggregates constitute the subject matter of thermodynamics." He adds: "It must be admitted, I think, that the laws of thermodynamics have a different feel from most of the other laws of the physicist." They contain, he would say, "something more palpably verbal . . . they smell more of their human origin."[12]

At this point we must remember something that was briefly stated in chapter 1. What makes thermodynamics so different from other scientific theories, what accounts for its extreme originality and marks its break from the mechanistic conception, resides precisely in the idea of *entropy* established by the second principle. The first principle, that of *energy* conservation, does not create—as was once thought—any conflict with the laws of classical mechanics.

Cosmological architectures, from Newton to Einstein: Ledoux's engraving—significantly titled "elevation of the cemetery of the village of Chaux"—expresses the symbolic relationship between the harmony of the spheres and the Rousseauian harmony of the ideal community; Mendelsohn's sketches for the Einstein tower manifest the architect's desire to give spatial expression to the new concepts of physics.

2.3. *Cemetery of Chaux, Claude-Nicolas Ledoux, 1804.*

2.4. *Einsteinturm in Potsdam, Erich Mendelsohn, 1917–1921.*



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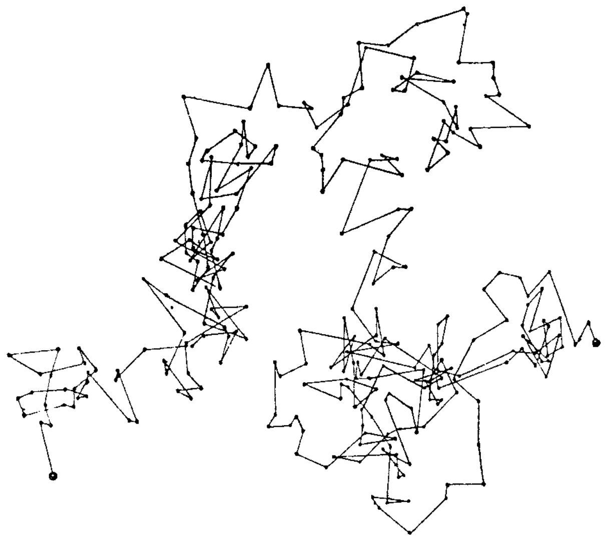
Two ideograms of the world: necessity associated with orbits in the Copernican model of the universe, and the random movement of particles in fluids in Perrin's classical representation of Brownian motion. The gulf between the two epistemological paradigms is graphically expressed in the contrast between the fatal regularity of the heavenly body and the aleatory unpredictability of the earthly particle, between circular trajectories and fractal itineraries.

2.5. *Model of the universe. Copernicus,* De revolutionibus *(1543).*

2.6. *Brownian movement of a colloidal particle. Jean Perrin,* Les atomes *(1913).*



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Arthur Eddington thus refers specifically to entropy when he notes the challenge that the science of heat has meant for mechanistic reductionism: “From the viewpoint of the philosophy of science the conception associated with entropy must, in my opinion, be considered the twentieth century’s great contribution to scientific thought. It showed a reaction to the idea that all that which science must concern itself with is discovered through the microscopic dissection of objects.”[13]

This same microscopic dissection—the reduction of the whole into the sum of the parts, so dear to mechanicism—was undertaken by Boltzmann on thermal phenomena, by which he established the statistical mechanics that proved so comforting to Bridgman’s colleagues, in contrast to the disturbing qualitative and cosmological expression of the second principle. Nevertheless, the introduction of chance through statistics had the effect of placing a time bomb at the epistemological heart of mechanicism, while leaving intact both the radical and irreducible uniqueness of entropy and its character as an alternative paradigm to that of the Newtonian universe.

Evidently the confrontation between the worlds of trajectories and processes, between being and becoming, necessity and chance, does not take place only in the more general context of the opposition between mechanics and thermodynamics, but also in the very bosom of the latter. Energy and entropy simultaneously represent the two conceptual pillars on which it rests and the two epistemological poles between which it oscillates.

At once complementary and opposed, the quantitative/conservational principle of energy and the qualitative/evolutionary principle of entropy now give rise to the same dialectic that existed during the time of Newton, between the science of gravitation and the science of fire, between the physics of repeated and exact orbits on one hand and the chemistry of irreversible mutations on the other. Yet even then, the sciences of gravitation and fire were judged to be matters that, though opposed, were not incompatible, and proof of this is Newton's simultaneous dedication to the cultivation of both.

In any case Newton goes down in history not for his alchemical investigations but for the Law of Universal Gravitation. From that moment on, and as a result, among other things, of his own work, trajectories moved fire out of the center of the scene,[14] and the "mechanical view of nature" discussed by Boltzmann acquired hegemony as a paradigm for the duration of the Age of Enlightenment, remaining dominant, albeit contested, through the course of the century after.

As an anecdote illustrating this hegemony of the mechanical view, it is worth noting the case of one of the first manuals on fireplace construction, which introduced—among other innovations—the use of "caliducts," pipes through which air warmed in a chamber behind the hearth was conducted to other parts of the building. Its author, the Frenchman Nicolas Gauger (pseudonym for Cardinal Polignac), as early as 1713 gave it the singular title of *La mécanique du feu.* Already during Newton's lifetime fire was being regarded in mechanical terms!

Thermodynamics of the first principle
Joule and the culture of energy

The cultural and theoretical hegemony of mechanicism was to hold, without major challenges, up to the mid-nineteenth century. Carnot's *Réflexions* were in fact published in 1824, but they went unnoticed and their influence on the scientific community was scarce. Only in 1850 would there be a first rupture. As noted above, this year saw the publication of the two works by Joule and Clausius that marked the birth of modern thermodynamics. In the context of the new theory, these two men would also represent the two poles of interpretive emphasis. Joule, in continuity with the mechanistic tradition, stood firm on the conservation of energy; Clausius, in open rupture with that tradition, attached his name to the idea of increasing entropy.

Joule's formulation of the first principle entailed the confirmation of the dynamic theory of heat, and the definitive abandonment of the "caloric fluid" that had played so vital a role in the works of Lavoisier, Laplace (including the famous *Mémoire sur la chaleur* of 1870, written by both), Poisson, and others. In this field, an invaluable precedent was the famous experiment performed in 1798, before the

Royal Society, by Benjamin Thompson, adventurer and scientist commonly known as Count Rumford. Thompson (who like Gauger was an innovator in the design of fireplaces, where he introduced the use of refractory bricks) showed how the mere mechanical movement of a drilling machine could boil the water of the bath in which the perforating head was immersed.

Half a century later, the determination of the "mechanical equivalent of heat"[15] was to lead to the use of energy as a unit of measurement for all natural phenomena. Though proposed as early as 1811 by Hachette, only now did it become feasible. Such a conception of energy as a "coin of physics" led in turn to the successive "energetic theories" inaugurated in 1855 by W. M. Rankine's *Outlines of the Science of Energetics*. In all of them, the emphasis was on the interchangeability and equivalence of the different forms and manifestations of energy, and this obscured the fact that certain conversions are accompanied by losses, a consequence of their irreversible character. Joule's own formulation, "mechanical equivalent of heat," later sanctioned through application, was ambiguous, since it actually referred to the "calorific equivalence of mechanical work," which he measured in the famous experiment of the blade wheel, repeated by high school students throughout the world. Its original expression, nevertheless, suggests a nonexistent reversibility.

Up to this point we have discussed the methods and limitations of the "thermodynamics of the first principle," which, as repeatedly pointed out, is kept within the conceptual framework of mechanicism. The rupture came with the second principle. Nevertheless we must note from the beginning that a rigorous formulation necessarily starts with the principle of the conservation of energy. As Maffioli has written, "only by understanding what was being conserved was it possible to determine, in turn, what other thing was being irreversibly modified."[16]

Thermodynamics of the second principle

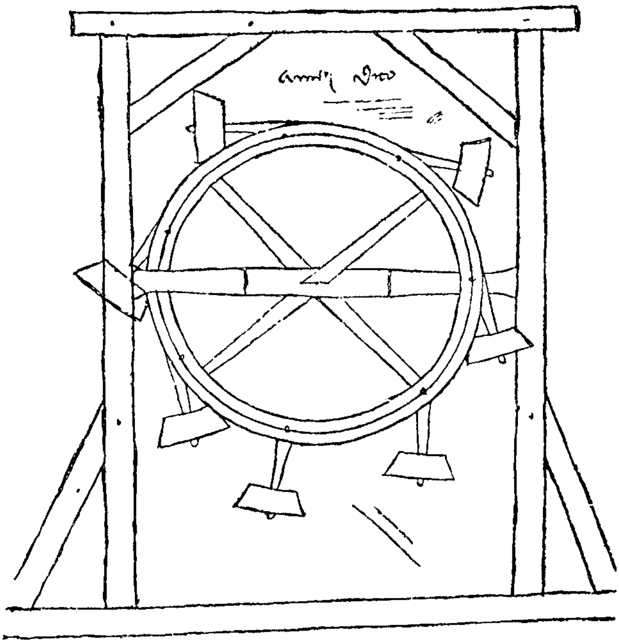
Clausius and the culture of entropy

The second law of thermodynamics has a complicated genealogy. Its first major expression is found in Carnot's *Réflexions sur la puissance motrice du feu.* Ignored at the time, its rediscovery by Clapeyron—who in 1834 published his *Mémoire sur la puissance motrice de la chaleur*—introduced the problem to scientific circles, capturing the interest, a decade later, of young William Thomson, Lord Kelvin, who was to put much effort into the matter in the late 1840s. In the course of this period Kelvin represented the school opposed to Joule's, since he was mainly concerned with irreversible phenomena. Finally, it was the German physicist Rudolf Clausius who completed and gave canonical form to the splendid edifice of thermodynamics.

By 1851, in his memoir *The Dynamical Theory of Heat*, Kelvin was able to formulate the two principles,[17] attributing the first to Joule and the second to Carnot and Clausius. Some years later, in 1865, Clausius himself was to express them in the cosmological terms by which they have come down in history:

Die Energie der Welt ist Konstant.
Die Entropie der Welt strebt einem Maximum zu.

The philosophical and scientific importance of the second principle can hardly be overestimated. Through the inevitable increase of entropy associated with any interaction of matter and energy, irreversible changes and the direction of the movement of time are introduced into a universe



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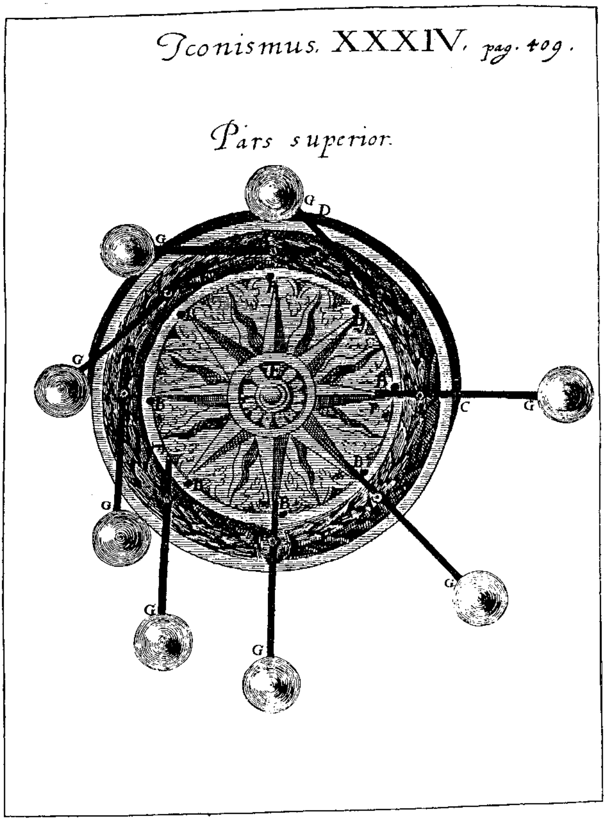
Newton had described as being reversible and without history. Moreover, the increase of entropy is greater the faster the transformations—reversibility presupposes infinitely slow transformations—and this links the speed of processes to the increase of degradation while providing a valuable tool for analyzing the relation between the acceleration of changes generated by the Industrial Revolution on one hand and the depletion of natural resources on the other.

Into the orderly, immutable, timeless, and necessary world of mechanicism, entropy introduces disorder, degradation, irreversible time, and aleatory change; into the Promethean ideology of mechanical progress, an awareness



2.8.

of degradation associated with change; into Laplace's frozen orbits, the combustion of igneous machines.

The actual creators of the notion of entropy were not ignorant of its profound cosmological and historical repercussions. Carnot early on initiated his *Réflexions* with a cosmological declaration that would lead him from the natural production of motion in geological foldings and meteorological changes to the artificial production of movement in the steam machines of the Industrial Revolution, thus situating his ideas within the broad framework of cosmological evolution.[18] In the same way, Clausius emphasized the inevitability of the thermal death of the universe that is inferred from the second principle, and Kelvin shattered an old Faustian dream when he demonstrated the impossibility of perpetual motion.

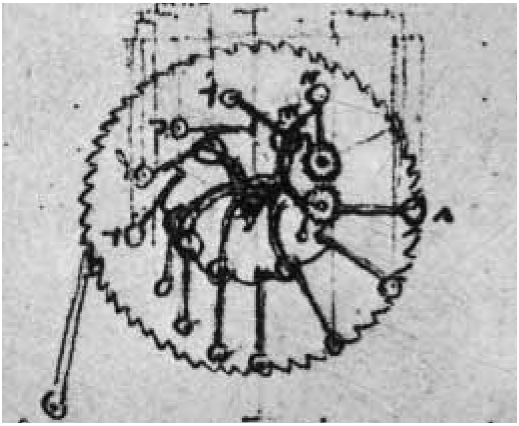
The second law of thermodynamics destroys the stable universe of mechanicism and demonstrates the impossibility of perpetual motion. That old dream, whose earliest graphic representation is Villard de Honnecourt's quicksilver Ferris wheel, gave rise to numerous designs for machines, such as that invented by a Basel artisan and reproduced in the book of the Jesuit Schott, a disciple of Athanasius Kircher. Leonardo himself took an active interest in the theme and ended up convinced that perpetual motion was impossible, concluding that the search for continuous movement was as fanciful as the search for the philosopher's stone.

2.7. *Wheel of perpetual motion in Villard de Honnecourt's* Album *(c. 1240).*

2.8. Mobile perpetuum basilense *of Jeremias Mitz, in Gaspar Schott's* Technica curiosa *(Cologne, 1643).*

2.9. *Study of continuous movement by Leonardo in the Codex Forster II, folio 90 recto.*

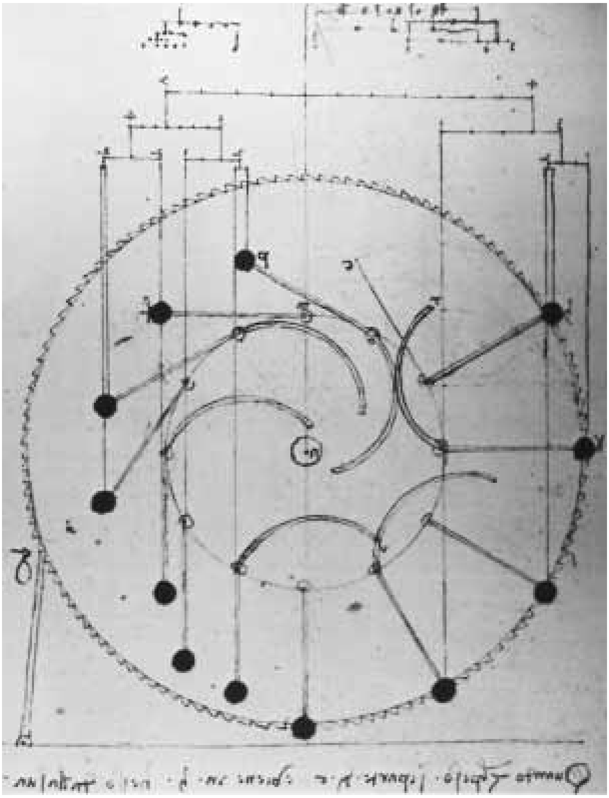
2.10. *Another version of this study, in the Codex Madrid II, folio 145 recto.*



2.9.

Entropy is therefore the true author of the demolition of the conceptually mechanistic world. Its theoretical vigor and versatility make it extraordinarily useful in numerous fields of inquiry, and its suitability for the interpretation of complex processes has led to affirmations such as the following: “The Entropy Law will soon supersede Newtonian mechanics as the ruling paradigm of science because it, and only it, adequately explains the nature of change, its direction, and the interconnectedness of all things within the change process.”[19]

Such optimism is probably justified by the increasing importance of thermodynamics in diverse fields like chemistry, biology, economics, and communication theory; however, it is necessary to note that the unanimous recognition of entropy’s profound philosophical originality and its fertility as a theoretical paradigm have not been accompanied by any similar process in the technological field, where it has been judged too abstract and general a concept to lend itself to practical uses.



2.10.

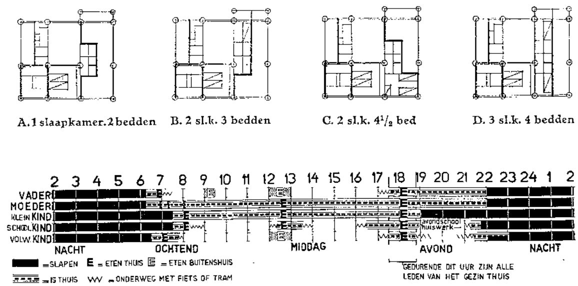
In the technological-productive field, the quantitative emphasis of Joule's and Rankine's first principle still prevails over the qualitative priorities of Carnot's, Kelvin's, and Clausius's second principle. What Cesare Maffioli has called the "culture of energy,"[20] with its obsession with the increase of production and consumption of material and energetic goods, still occupies first place in our times. Still embryonic, and heralded by signs like the theoretical ruin of mechanism, the "culture of entropy," with its qualitative preferences and concern for the conservation of resources, can be discerned in the background. Coming decades will witness the development of a struggle between them which today, a century and a half after Carnot, has just begun, and on whose outcome might depend our very survival.

Time and entropy

irreversibility and duration

If entropy has profoundly transformed our view of the world, no less has it influenced our very conception of time, which has undergone a Copernican turn under the impetus of this new theoretical paradigm.

Entropy, in effect, alters our conception of time in two ways, introducing direction in its course while marking its tempo. By associating time with becoming, events, irreversible changes, entropy establishes the orientation of time: that in which entropy increases.[21] Eddington formulated this same concept through a fortunate phrase: "Entropy is time's arrow." Unlike mechanics, where time is essentially reversible, thermodynamics puts direction into time: t and $-t$ are no longer equivalent. Prigogine thus called thermodynamics the "physics of becoming,"[22] as against the physics of being, classical and quantum mechanics.[23] The science of objects gives way to the science of events, the world of



The time of mechanisms is present in the functionalist conceptions of the modern dwelling: the house is a machine made of pieces that can be put together, inhabited by individuals subjected to the inexorable time of the clock. Space and time decompose into clockwork fragments.

2.11. *Types of workers' dwellings and time scheme for their use (Mart Stam, 1935).*

trajectories to the world of processes, and history installs itself in the bosom of nature and matter.

This renewed protagonism of history must be attributed, precisely, to the fact that its course overruns the sphere of clocks and proves itself radically irreducible to the unanimous monotony of orbits. Its time is not mechanical but thermodynamic and statistical, as Lévi-Strauss stressed when he pointed out that mechanical time is "reversible and non-cumulative," whereas "historical time is 'statistical'; it always appears as an oriented and non-reversible process."[24]

Besides establishing its direction, entropy marks the rhythm of time. Paraphrasing Eddington, we could say that entropy determines not only the direction but also the very magnitude of the temporal vector. Today it is widely accepted that astronomical time, the time of clocks, is essentially different from the time we associate with biological or cultural becoming. The latter, unlike Newtonian time which flows uniformly (*aequilabiliter fluit*, as Newton himself wrote), [25] flows with the rhythm of processes and the speed of events, in the same way that it stops if these come to a halt. Recalling Schumpeter's nomenclature for dynamic time and historical time, Georgescu-Roegen suggests naming them *t* and *T*, making mechanical laws functions of *t* and the entropy law a function of *T*.[26] Von Bertalanffy in turn has gone through the qualities that make the time of pendulums and stars different from biological time, which is associated with metabolical processes.[27] Finally, Prigogine has come to make a mathematical formulation of a thermodynamic time which, in contrast to astronomical or mechanical time, is not linear but logarithmic, dependent upon probabilities, and is not general but local, determined as it is by events at a given point.[28]

Finally it is worth noting that if mechanical time is philosophically expressed through the absolute categories of Kantian rationalism, the time of processes finds greater acceptance in vitalistic conceptions. Prigogine himself, as an antecedent of thermodynamic time, has invoked the famous Bergsonian *durée*,[29] a "duration" which, as Bergson emphasized in *L'évolution créatice*, is inseparable from the inventive process of creating forms: "The more we delve into the nature of time, the more we shall understand that duration means invention, creation of forms, continuous elaboration of the absolutely new." This absolute newness only fits into the irreversible and historical time of thermodynamics, which like Bergson's time is punctuated by singular events and moves at the speed dictated by the unrepeatable occurrences of natural and social becoming.

Entropy, order, probability, information
Darwin versus Carnot?

As we have seen, entropy determines the rhythm of time through events. Underlying this is the conception of entropy

2.12.

as a thermodynamic probability, a fruit of efforts by Boltzmann, Gibbs, and Planck to broaden the framework of classical theory. In this context it is common to speak of order when referring to improbable states, and correspondingly of disorder where probable states are involved. Entropy here is no longer the degradation of energy but a synonym of the degradation of order in general terms.

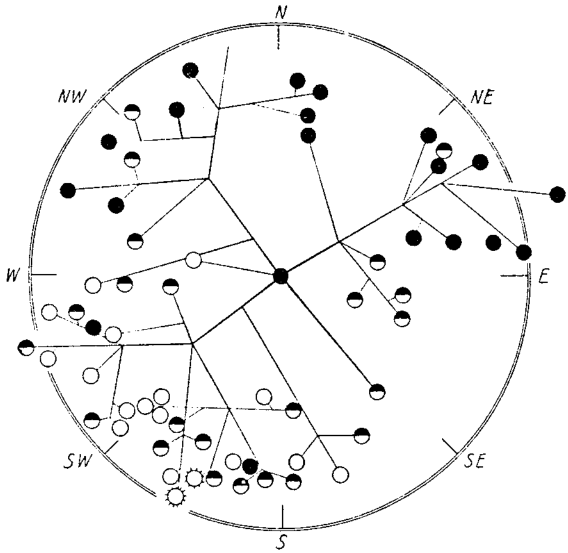
Such generic use of the word—where entropy is associated with disorder, its scope all the more broadened by the coincidence of entropy's algebraic expression and the average number of signaled messages, which led Claude Shannon to refer to the "entropy of information" in his important work of 1948—has given rise to the introduction of the concept of entropy in fields from economics to sociology, from psychology to art. However, the extended use of the concept has not been accompanied by a parallel deepening in its real sense; the original rigor has become gradually dispersed in a merely metaphorical use, when not palpably distorted and even contradictory. From Shannon himself as early as 1956 to Georgescu-Roegen and Arnheim in the 1970s,[30] many writers in diverse fields have drawn our attention to the risks involved in using the notion of entropy too freely, as well as the conflicts and paradoxes that result from its improper extension to other fields through superficial comparisons or forced analogies.[31]

Natural processes alter the homogeneity of mechanical time: flowers open and close at different hours of the day, and the branches of a tree bloom on different days, depending on their cardinal position. In designing his meteorological clock, the architect Christopher Wren endeavored to register variations of temperature and wind in order to study their effects on living beings. Though governed by circadian clocks, organisms dwell in a time that does not flow uniformly.

2.12. *Flower clock proposed by Linnaeus, 1751: each flower opens at a different hour.*

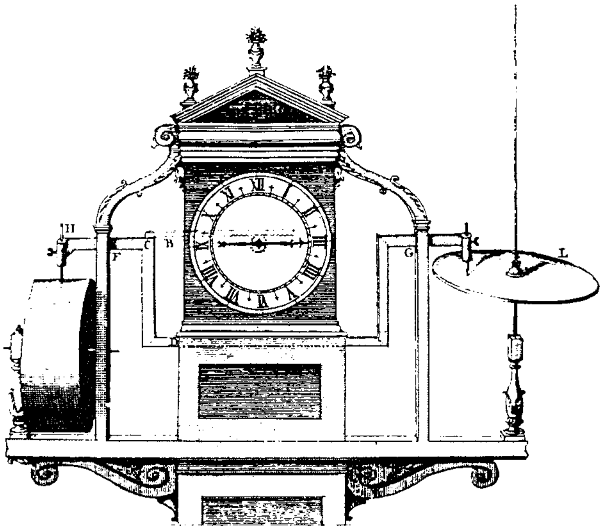
2.13. *Blooming times in a pine tree recorded by A. Scamoni in 1938; flowers first appear on the south-southwest side and last—two days later—in the branches oriented northward.*

2.14. *Wren's project for a meteorological clock, published by T. Birch in 1756.*



2.13.

Of these apparent conflicts, surely the most publicized is that between the physical and cosmological tendency toward the degradation of order and organization on one hand, and the inverse tendency—evident in the organic and social world, but present as well in crystals and molecules—toward geometric order and structural organization.[32] Bergson's phrase could be understood in this way: time, which is the "creation of forms," is not determined by the swinging of the pendulum, nor by successive increases of entropy and the subsequent degradation of form; on the contrary, it is determined by the morphogenetic creative occurrences that mark the decrease of entropy in vital processes. The opposition between these tendencies, which has caused rivers of ink to spill over an alleged contradiction between Darwin and



2.14.

Carnot, is in most cases reducible to the differences between thermodynamic behaviors expected in a closed system, where entropy does tend to increase, and in an open system, which is able to reduce its entropy if it benefits from a relationship that allows the environment to absorb the surplus entropy of the system.[33] Time, then, is associated with the "creative evolution" of the organized being, but also, necessarily, with the corresponding degradation of order in the environment.

three

Architecture, Memory, and Entropy: Amnesia or History

Morphological Persistence: Lazy Forms and Obstinate Time

Energy that accumulates as information

the memory of matter

Architecture, or, if you wish, the construction of the artificial environment, lends itself admirably to examination in thermodynamic terms. We have talked about architectural energy consumption belonging to the wider framework of exosomatic energy, so named in order to differentiate it from endosomatic or metabolic energy. We have also mentioned the importance of distinguishing between energy of construction (construction including repair and demolition) and energy of maintenance: the latter fuels the processes contained by the building; the former fuels the actual building as process. Finally, we have separated energy that comes from taking advantage of climatic variables and energy that comes from combustibles: the first uses free energies; the second, accumulated energies.

Having thus introduced the general outlines of the idea of entropy, we are ready to trace the thermodynamic features of architecture by describing in detail two concepts which, though previously referred to, have not yet been made objects of discussion. Within the framework of visualizing the building and the city as open thermodynamic systems, the idea is to understand both of them as information-bearing material structures, and to describe them as material systems subject to a simultaneous process of degradation and conformation.

These two ideas clearly spell out the relation between form,[1] matter, and energy: the capacity of matter to accumulate energy as *in-formation*, and the need for matter to receive energy to maintain its *con-formation*. Matter, hence, needs energy in order to maintain its form, and form, in turn, can be thought of as a wealth of stored energy. Let us see how.

The ecologist Ramón Margalef, to whom we owe the elaboration of the link between the material structures of nature and information, has stressed that “information and form always appear in association with historic development. In a world already endowed with a certain structure, any interaction between matter and energy—which signifies increased entropy—alters the structure and makes future changes more predictable and not less predictable than before."[2] In urban development, or in a building's construction process, every decision—tracing a roadway, situating a facility, distributing a floor plan—conditions subsequent building episodes, rendering them more predictable; the energy necessary to materialize each of these decisions is accumulated in physical structures that on one hand condition—and perhaps facilitate—future construction, and on the other hand can be used to interpret past construction. The energy stored in construction—both in the materials themselves and in the significant order in which they find themselves as a result of transport and installation—is therefore projected toward the future, which it helps form, and toward the past, which it interprets.

Therefore, as Margalef says, "the information that is inherent in present structures and which can be used to reconstruct the past can be considered to be a true reflection of the energy used and degraded in the past. This energy has not been altogether lost, since the structures it has formed or informed remain important in channeling future changes, rendering certain future states more probable than others. It is possible to discover or interpret the 'utility' of this information if we are willing to accept that accumulated structures render 'more efficient' the future degradation of more energy."[3]

In fact, a bridge or an insulating element requires energy to manufacture, transport, and install. The energy used to form the bridge or insulating element is not altogether dissipated; it persists as an organization that allows a more efficient use of the mechanical energy needed to span a gorge and the thermal energy indispensable to withstand a winter season. The lower energy cost of transportation or heating is related to the initial investment of energy in the bridge or insulation system.

At the same time, the energy used in the elaboration of a prototype of a bridge or a new insulation material can be interpreted equally as an initial investment ultimately facilitating the saving of energy in the construction of bridges or the manufacture of insulation materials: here too it can be said that the energy used has not been altogether lost, having been accumulated as useful information.

There are hence two senses in which expended energy is actually conserved: as *material* organization making for a more efficient subsequent use of energy, and as *mental* organization resulting from a process of acquiring experience, which likewise leads to increased efficiency. In fact, both senses are but manifestations of the dichotomy/identity between form and information. Used energy accumulates as *form* or *information* resulting in greater efficiency in the subsequent use of energy. The bridge, for example, is simultaneously form allowing more efficient transport and information permitting improved construction of future bridges.

This distinction does not appear in the analysis of Margalef, who refers to both indiscriminately when, as in the theme that most concerns us here, the spatial expression of the information-energy connection, he writes:

In most organisms, the organization of space can be related to a certain consumption of energy that is partly recovered as information in the form of behavior, traditions, paths, tunnels, etc. As significant information, energy is saved in the projection toward the future. . . . Space files plenty of information, not only through the localization and active or passive movements of organisms, but also through their forms of growth and the way they organize transport, as well as through all kinds of constructions external to the very biomass that results from the activity of organisms. The more spectacular examples are found in man but are not limited to this particular species.[4]

As we see, energy is stored as form (material organization of space) and as information (mental organization of space), without distinction; this accumulation of energy can increase efficiency, as much in the use of space as in its reproduction. In architecture, the accumulation of energy as form/information is expressed in phenomena such as the persistence of certain spatial organizations through time. The tenacious survival of urban schemes or building typologies, the rare consistency of some formal layouts, and the continued adherence to certain construction solutions are evidence of the existence of a morphological memory: a memory that does not rest only in the heads of builders, inhabitants, or spectators, but is present as well in the architecture itself.

After all, matter also “remembers,” also files information. The earth’s layers remember geological ages, the rings of a tree recall past springs and autumns, and the archaeological mound is a reminder of the passage of cultures. The built structure remembers living habits and processes, contains information about historic vicissitudes, and forms the material basis of collective memory.[5]

Morphological permanence is therefore justified not only by the correspondence of floor plans to certain functional uses, or of images to a number of human perceptive organs, or of building practices to given material and technological resources; on the contrary, we know only too well how form survives beyond the obsolescence of use or technique. Morphological permanence must thus also be explained in terms of the energy accumulated—as memory—in existing things. The present intervenes in the conformation of the future by energetically making continuity more efficient than rupture, and renovation more efficient than demolition, through the persistence of boundaries, foundations, perceptual habits, building traditions. The new church rising on the site of the old one, the linteled stone architecture reproducing the primitive wooden construction, and the recourse to classicism in order to express the solidness of a political, cultural, or financial institution are not functional, technical, or expressive archaisms, but manifest the economy derived from the symbolic persistence of places and forms.

From the amnesia of modernity to architecture as a support for memory

The introduction of memory into architecture entails a parallel evaluation of the persistence of the existing and the continuity of history. This double gesture contrasts dramatically with the formidable amnesia of the modern movement, which zealously condemned the previously built to a state of tabula rasa while ingenuously and splendidly emphasizing its rupture with everything that came before, to the point of expelling the teaching of history to the darkness outside. The ferocious and Promethean optimism, the luminous confidence in reason, the revolutionary and messianic sentiments that made the pioneers of the modern movement worthy and direct successors of the men of the Enlightenment were joined together, as in the latter, by a Rousseauian nostalgia for the good savage and lost paradise that fills the cultural panorama of the era from end to end, leaving a trail of primitivism in art and philosophy. And in the end it is not reason, so repeatedly simulated, that replaces memory, but a nostalgia for innocence admirably expressed by Gimferrer's accurate verse: "Si pierdo la memoria, ¡qué pureza!"

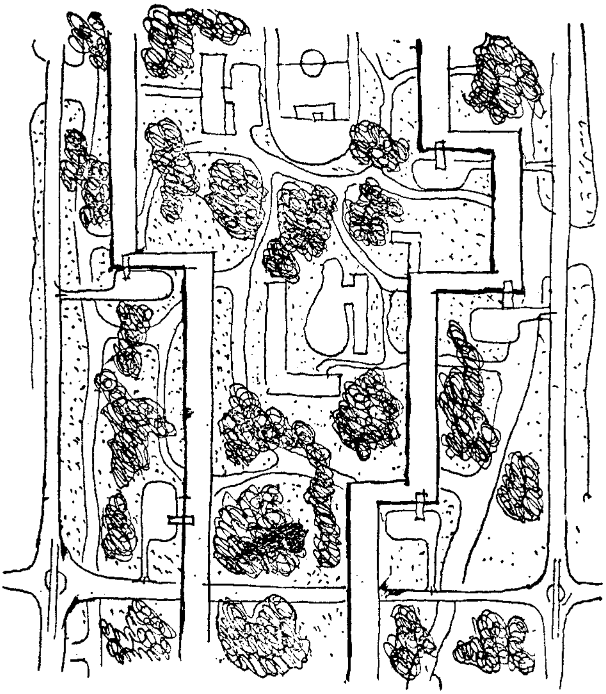
In the final analysis, it is the desire for purity through amnesia that best characterizes the emotional climate of the

3.1.

The city that remembers and the city that forgets: the urban fabric of Florence conserves the marks of its Roman amphitheater even if dwellings were built on the site during the Middle Ages; the arcade survives as cadastral parcels. In contrast, Le Corbusier's proposals for Paris adopt a tabula rasa attitude toward existing streets and property boundaries; the blocks cut through the dense urban tangle in order to build a fragment of an amnesic utopia.

3.1. *Florence, current map of the zone where the amphitheater stood.*

3.2. *Le Corbusier, distribution of green zones and residential blocks in a typical district, 1941.*



3.2.

architects of the modern movement. In this context, the recuperation of history and memory constitutes the return of the existential original sin, the loss of paradise, and, with this, the extinction of the hope of a new man and a new city.

Indeed, the irruption of irreversible time and historic flow into the landscape of architecture introduces degradation, corruption, aging, and life into the eternal universe, the frozen world, the mineral cosmos described by Newton's laws. The link between modern architecture and the Newtonian paradigm has been pointed out on several occasions;

the negation in both cases of irreversible and historic time constitutes a new factor contributing to the probability of the hypothesis.

In clear opposition to this static vision, the current conception of the history of nature[6] reminds us that "the increased entropy that accompanies the energy changes resulting in new arrangements of material elements is energy that cannot be recovered in the same form as it was put in; but the new arrangements of material elements represent the memory of the universe, and it is in relation to them that time appears to be irreversible."[7] Architecture, as an arrangement of material elements, must be understood both as a product of memory and as a physical support for it.

The transmission of information

the genetic and the cultural channels

As a physical support of memory, architecture performs an important function in cultural evolution.[8] We must underline the word "cultural," since numerous misunderstandings have their origins in the insufficient differentiation between cultural and biological evolution. The latter uses genes as a support for the memory of a species, and the genetic code as a language through which information is filed and transmitted. At the same time, as Erich Jantsch points out, "biological genetics is supplemented by other forms of genealogical communication such as tradition and laws in the social domain and books, works of art and architecture in the cultural domain. The metabolical processes become enriched by the production and distribution of energy, goods and services."[9]

So there are two[10] different channels for transmitting information:[11] the biological channel, which "remembers" by means of genetic material, and the sociocultural channel, which "remembers" by means of mental artifices like theories or laws and material artifacts like buildings or utensils.

In the case of the human species, the development of the sociocultural channel results, as Mumford writes, from the "attempt to modify the environment in such a way as to fortify and sustain the human organism: the effort is either to extend the powers of the otherwise unarmed organism, or to manufacture outside of the body a set of conditions more favorable toward maintaining its equilibrium and ensuring its survival. Instead of a physiological adaptation to the cold, like the growth of hair or the habit of hibernation, there is an environmental adaptation, such as that made possible by the use of clothes and the erection of shelters."[12]

It is not difficult to explain the predominance of the cultural channel, in our species, over the genetic channel. The reasons lie essentially in the speed and capacity of the reaction, which are far greater in the former. Both the speed of information transmission and renovation and the capacity to store messages are much higher in the cultural channel. Environmental adaptation, in Mumford's example, is much faster and much more versatile than physiological adaptation through evolutionary change.

As early as chapter 1, where architecture was described as an exosomatic artifact of man, the rigorous *biological* determination of metabolic energy consumption was contrasted with the *cultural* determination, highly variable and dynamic, of exosomatic energy consumption, within which we must include that motivated by the production and maintenance of buildings. Thus "the biological realm of necessity" is confronted with "the cultural realm of freedom," and indeed one easily sees, as Margalef points out, that freedom—understood as the existence of choice—"advances in parallel to the importance of the cultural channel, relative to that of the genetic channel, as a bearer of information."[13]

The use of energy and exosomatic artifacts (tools, books, buildings), as well as the use of symbolic artifices (etiquette, social relations, customs), substantially accelerate the rhythm of evolution and expand the scope of freedom.[14] Material objects as much as social and cultural practices are transmitted and partly modified from generation to generation. Therefore, they can all be considered supports of a permanently renewed social memory.

We have compared the speed of information transmission and renovation characterizing the cultural channel with the slow and much less flexible genetic channel. Here we must not fail to state the cultural channel's other advantage, also previously mentioned: its capacity, which is incomparably greater than that of the biological channel. Charles J. Lumsden and Edward O. Wilson have expressed this superiority through an eloquent example: "To possess a completely inborn vocabulary of 10,000 words and to speak in sentences of 10 words each would require a truly astronomical 10^{40} nucleotides, or 10^{16} kilograms of DNA, far more than the weight of the entire human species!"[15]

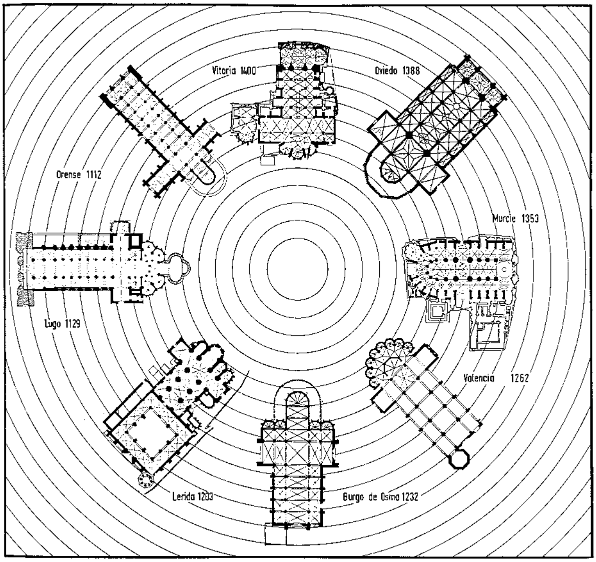
As we see, the genetic channel has the capacity to store and transmit a very small amount of information compared to that which can be channeled through such sociocultural means as language or architecture.

The Lamarckian evolution of culture and the fallacy of biological analogies

Speed and capacity, the two advantages that the cultural channel has over the genetic channel, are precisely what make it possible to speak of a Lamarckian evolution of culture—as opposed to a biological evolution, which must be interpreted in Darwinist terms.[16] As is well known, the main difference between the evolutionary theories of Darwin and Lamarck is that the latter considered possible the inheritance of characteristics acquired in the course of the life of an individual, while the former understood organic evolution as a process of natural selection operating though chance variations. In Lamarck's conception, the environment molds the organism and modifications in the organism are transmitted to its descendants, who are then better adapted to the environment. In Darwin's, the environment simply selects the best-adapted individuals, prolonging their life and increasing their ability to reproduce so that their descendants are more numerous than those of the individuals less adapted to the environment in question.

The subsequent development of genetics—especially the formulation of what Crick has called the "central dogma" of molecular genetics: that information is transmitted only from the DNA to the protein, never the other way around—has eliminated the possibility that acquired characteristics are inherited, since this would require the passage of information from the protein to the nucleic acid, and confirmed the Darwinian theory of organic evolution. But though abandoned in the biological plane, Lamarck's conception has subsequently been rescued in the sociocultural plane, whose evolution it describes remarkably well, since here the transmission of both the material objects and the social practices embodying cultural memory is patently feasible. This hereditary transmission of what has been built, fabricated, written, thought, and learned through work and experience from one generation of men and women to the next is what makes cultural evolution Lamarckian, what makes the cultural channel exceed the genetic in velocity and capacity, and what explains the extraordinary speed and breadth of human evolution.

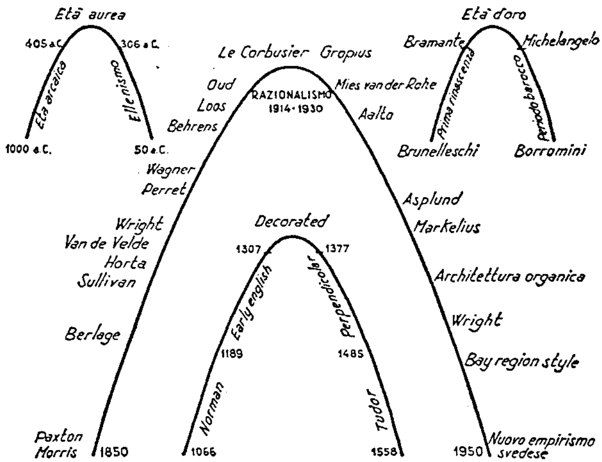
We emphasize here the difference between Darwinian evolution of organisms and Lamarckian evolution of culture



3.3.

because of the damage that confusion between the two has caused in architectural criticism. Philip Steadman has gone so far as to declare that "the central fallacy at the heart of most of the historical analogies made between architecture and biology—of which Geoffrey Scott's 'Biological Fallacy' is just one aspect—arises principally out of an improper equation of the Darwinian mechanisms of organic evolution with the 'Lamarckian' characteristics of the transmission of culture and the inheritance of material property."[17]

This compels us to be more cautious when making analogies between buildings (and other human productions) as supports of cultural memory and genetic material as the support of biological memory, or when comparing man's symbolic products, his different codes and languages—including architecture—to the genetic code.



3.4.

The evolution of architecture, like that of other cultural products, unfolds in small jumps that make it possible to track down genetic connections between buildings: there is no construction without known parents. It is nevertheless advisable not to push such biological analogies, as it is better not to establish parallelisms like those Zevi denounces, wherein the great styles are interpreted in terms of infancy, maturity, and decadence.

3.3. *George Kubler, evolutionary change through small transformations.*

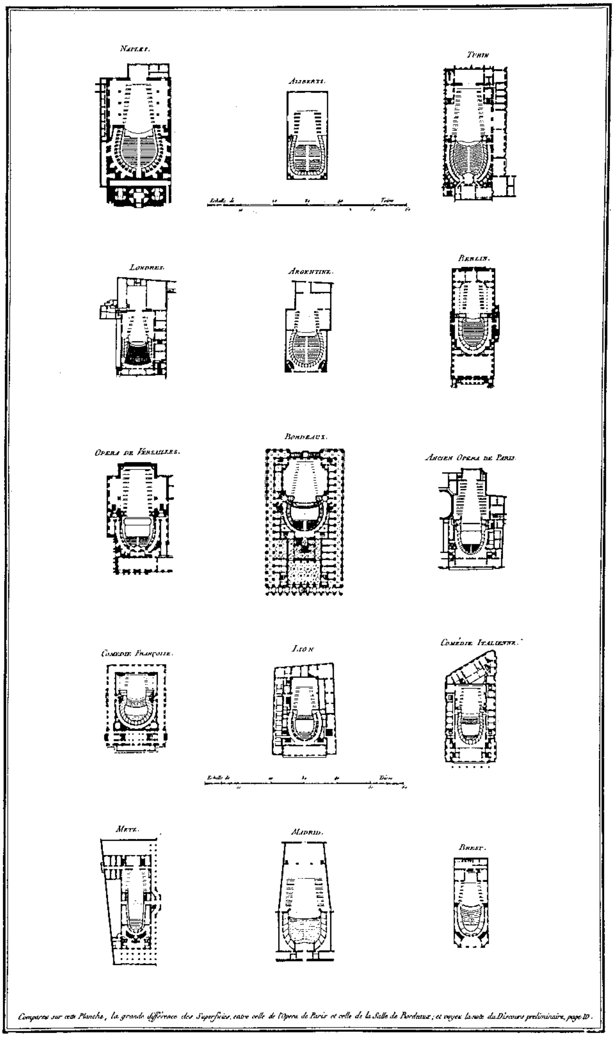
3.4. *Bruno Zevi, the evolutionary fallacy of architectural historiography.*

Nevertheless, one is tempted to sketch, albeit briefly, the metaphorical use of the biological concepts of genotype and phenotype in the field of architectural evolution. As Steadman himself has emphasized, “It is not individual artefacts which evolve. It is abstract *designs*, of which particular artefacts are concrete realisations. The distinction corresponds to that made in biology, considerably after Darwin, between the *genotype*, which is the ‘description’ of the species transmitted through biological heredity, and the *phenotype*, which is the physical embodiment of what is described in the individual organic body.”[18]

In the architectural field, the abstract designs are building typologies and the specific realizations are particular buildings. The typologies—much studied during the seventies in the context of a renewed interest in urban phenomena—could thus be the biological genotypes, and the works of architecture the corresponding phenotypes. The typology-genotypes are materialized in building-phenotypes, the conformation of which would depend as much on typological information—or *génothèque*, to use Boris Ryback's expression[19]—as on the specific circumstances of the environment—or *phénothèque*, used

Compiling a series of buildings or phenotypes makes it possible to arrive at the ideal project or genotype that all of them spring from, which is expressed differently in every case.

3.5. *Comparison of floor plans of Europe's major eighteenth-century theaters, collected by Victor Louis—designer of Bordeaux's theater—in* Salle de spectacle de Bordeaux *(1782).*


Naples.
Alberti.
Turin
Londres.
Argentine.
Berlin.
Opera de Versailles.
Bordeaux.
Ancien Opera de Paris.
Comedie Françoise.
Lion
Comédie Italienne.
Metz.
Madrid.
Brest.
Comparez sur cette Planche, la grande différence des Superficies, entre celle de l'Opera de Paris et celle de la Salle de Bordeaux; et voyez la note du Discours préliminaire, page 10.

3.5.

in its broadest sense so as to include the peculiarities of place as well as those of budget, technical means available, etc.[20]

In this light, the *Leçons d'architecture* that J. N. L. Durand published in 1819 are a taxonomic study of architectural organisms or phenotypes trying to reconstruct, for each functional category or species, the original model or genotype, with the aim of facilitating its reproduction.[21] Good examples of these architectural genotypes can be found in the repetitive building of large organizations, whether store chains, military barracks, churches, or colonial settlements. Hamburger joints, Roman encampments, temples of the Society of Jesus, and Spanish towns in America all use certain genotypes—more defined than usual in these cases, owing to the existence of a unified administration—which in interaction with the special peculiarities of each case generate particular architectural or urban phenotypes.

But the analogy must stop here. The localization of architecture in the cultural/Lamarckian framework renders it impossible to pursue this biological analogy further. At this point it is fitting to make a brief note of where we are.

Up to now we have been describing the capacity of architecture to accumulate energy as information, its role as a physical support of memory, and, through memory, as a support of morphological permanence, in contrast to the amnesic and ahistoric rupture of the modern movement. We have also discussed the information that is stored in physical structures such as buildings and stressed its importance in cultural evolution, which, unlike exclusively biological processes, allows acquired experience to be transmitted, accounting for greater speed and breadth; the transmission of information through the genetic channel, in contrast, though unable to describe architectural evolution with the same accuracy, provides stimulating analogies, as in the case of the genotype and phenotype concepts.

Having looked at the capacity of matter to accumulate energy as information, we must now look into matter's need for energy in the maintenance of its conformation—or in architectural terms, the built environment's need for a continuous flow of energy by which to conserve its form.

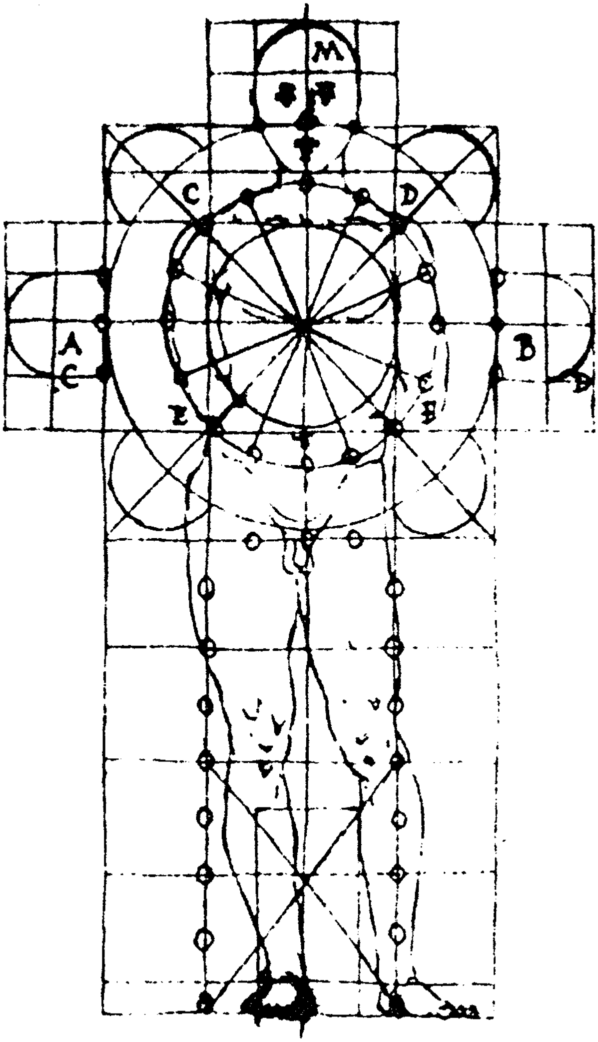
The energy that flows to maintain conformation

the heteronomy of the built domain

As open thermodynamic systems, the building and the city share the living organism's need to consume energy continuously in order to maintain the morphological organization on which its very existence is based. Repeatedly expressed in the preceding chapters, this idea can be more thoroughly developed now that the basics of the concept of entropy, which plays a key role in the matter, have been described. The view of the built environment as a thermodynamic system, as we shall later see, gains importance from this idea's function as a cornerstone of the most recent organic analogies.

The parallel insertion of living matter and man-made artifacts into energy and material flows has been eloquently described by Prigogine and Stengers. If we examine a cell or a city, we notice "that these systems are not only open but live on their openness, nourishing themselves with the flows of matter and energy reaching them from the outside world. This rules out the possibility that a city or a living cell evolves toward a state of mutual compensation, toward a balance between incoming and outgoing flows. If we decide to, we can isolate a crystal, but the city and the cell die quickly when separated from their mediums, for they are part of the worlds that nourish them and constitute a sort of local and unique incarnation of the flows they never cease to transform."[22]

Indeed, such a comparison between city and cell only expresses in contemporary language the old simile between



3.6.

3.7.

The Vitruvian story of the architect Dinocrates, which Francesco di Giorgio Martini interpreted by drawing parallelisms between the building and the human body not too different from his own anthropometric plans, was seen by Alberti and later by Fischer von Erlach as an illustration of the importance of flows for the city: the material and energy supplies necessary for the maintenance of architecture. In the realm of organic metaphors, physiology is as useful as anatomy.

3.6. *Francesco di Giorgio Martini, Latin cross floor plan of a church proportioned with the dimensions of the human body (Magliabechian Codex II, I, 141, folio 42 verso).*

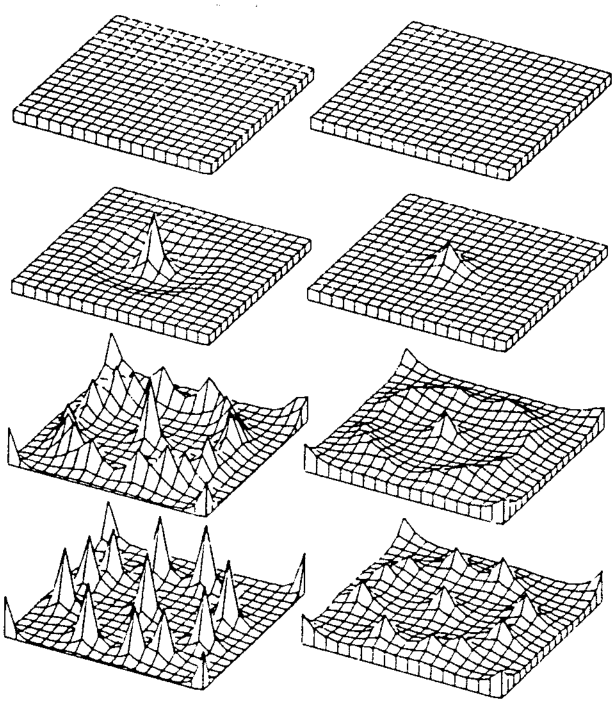
3.7. *Johann Bernhard Fischer von Erlach, Mount Athos shaped as Alexander the Great by Dinocrates, from* Entwurff einer historischen Architektur *(1721).*

the building and the human body, with the latter no longer understood in the Aristotelian manner as a harmonic assemblage of parts, but as an organism in need of a medium in which to survive. Remember Filarete's words in his *Trattato d'architettura* when he affirms that "the building is really a man. You will see that it must eat in order to live, exactly like a man. . . ."[23]

The dependence of organism on medium is, in effect, a manifestation of the same phenomenon that brings about the heteronomy of the built domain. Autonomy, as we know, is a characteristic of simplicity: all that is complex is heteronomous, or, if you wish, interdependent. A farm needs its lands; a city needs its hinterland, as countless sieges in military history have shown. The famous anecdote—first told by Vitruvius—about the architect Dinocrates proposing to build a city on Mount Athos in the image of Alexander the Great has served generations of treatise writers to exemplify the follies brought about by the ignorance of *commoditas* and *necessitas* in architectural and urban design.[24] Reminding the architect that "just as a newborn child cannot sustain itself nor begin to grow gradually without the milk of the wet nurse, so . . . a city, without fields and harvests, can neither grow nor become populous, nor can it maintain its inhabitants without abundant provisions,"[25] The replica of Alexander is not only an early biological analogy[26] but also an exemplary description of the built environment as an open system, as a receiver of nutritious matter and energy flows.

In this context it is important to note that the necessary flows increase with the scale and degree of specialization of the biological or urban organism. This has important repercussions in space, and very especially in terms of the organization of transport. As Margalef points out, "every ecosystem tends to develop its internal cycle by following a vertical axis defined by light and gravity. Horizontal transport, dependent on external energy, can be considered a disturbance, or at the least a modification imposed on the fundamental scheme of vertical movements. . . . To the extent that transport is not symmetrical . . . it leads to a local and uneven accumulation of certain chemical elements and organic matter."[27] And the other way around: the local accumulation of persons, merchandise, buildings, etc. that cities are requires the presence of horizontal transport, with the consequent demand for external energy.[28] So that we could rightly attribute the spatial organization of our societies to the availability of external energy. The mechanisms of segregation and horizontal specialization established by the Athens Charter, for example, cannot exist without the leading role played by transport, a role it did not play in the nineteenth-century city where segregation and specialization were predominantly vertical.

In nature as well as in the human organization of space, photosynthesis or production tends to spread uniformly, whereas respiration or consumption groups into clusters. Agriculture, for example, takes up all the land available, whereas consumers group together in villages or cities. Influenced perhaps by his studies in marine ecology, Margalef puts special emphasis on the vertical segregation of the ecosystem, with productive organisms and consumers occupying the upper and lower layers, respectively. But the differentiation between primary production and respiration also occurs horizontally, as Howard Odum showed in his graphic comparison of a tropical forest with farmland when seen from above: "Productive photosynthesis [is] dispersed evenly over the surface but the respiration [is] clustered in centers and linked to production through convergence of circulating pathways."[29] Such concentration of consumption takes place as much in a school of oysters in an estuary as in



3.8.

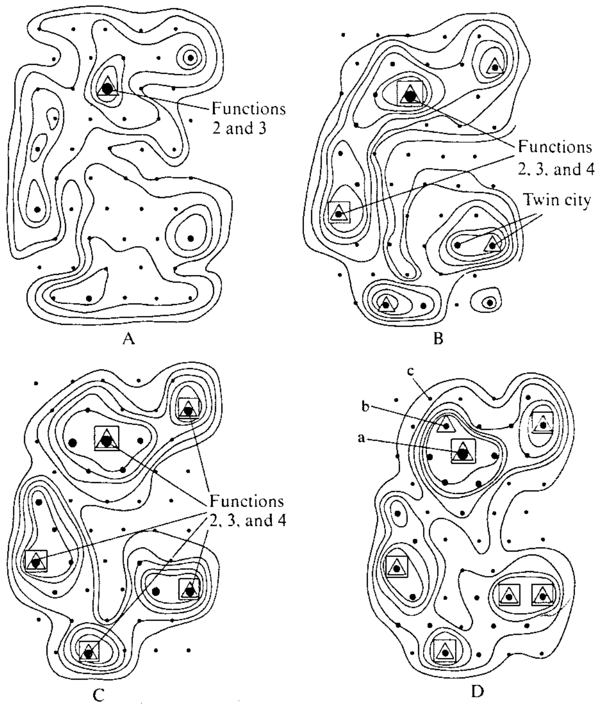
an industrialized city. Odum states that the energetic processes in both cases are similar: there is an input of energy and a release of heat and residues.[30]

The magnitude of energy flows is of course highly variable, both in production and in consumption.[31] For example, a rain forest produces around 130 kcal/m^2-day (very close to the conversion maximum of solar light, estimated at 170 kcal/m^2-day), which it subsequently consumes through respiration. Cultivated land produces about 40 kcal/m^2-day, and the average primary production for the planet as a whole is 6 kcal/m²-day. Consumption, in turn, rises to 6.1 kcal/m²-day for the entire biosphere—the excess over production must be attributed to the consumption of fossil fuels,[32] measured at 0.135 kcal/m²-day. In a village without machines (100 m²/inhabitant), consumption would be 30 kcal/m²-day, and in a big city as much as 4,000 kcal/m²-day. By way of comparison, the above-mentioned school of oysters would consume about 60 kcal/m²-day.

Two mathematical models of the genesis and maintenance of form. In the first diagram, biological morphogenesis is reproduced through changes in the concentration of a chemical activator and a chemical inhibitor; in the second, urban development is depicted through the effects in space of economic parameters. Organic form is regulated by chemical flows, urban form by economic flows, and both ultimately depend on energetic and material flows.

3.8. *Morphogenetic model: evolution through time of the concentration of an activator (left) and an inhibitor (right), which regulate biological conformation. Hermann Haken,* Synergetics *(1978), reproduction of a study by Meinhardt and Gierer.*

3.9. *Model of an urbanization process: four moments (A, B, C, and D) in the "history" of an initially uniform region where several economic functions try to operate in each of the mesh's fifty localities; by the second phase the region's five main urban cores are already clearly defined. Ilya Prigogine,* From Being to Becoming *(1980).*



3.9.

In Spain as a whole, human consumption of energy is close to 4 kcal/m^2-day.[33] If we consider that energy consumption in a city is a thousand times greater, we can imagine that the spatial distribution of global consumption must be extraordinarily uneven, and this is exactly the case, since consumption occurs mostly in urban agglomerations and industrial nuclei, the primary receivers of energy flows.

Though the preceding has paid special attention to energy flows, it must once again be noted that material flows are just as important. Chapter 1 defined architecture as both a material organization that regulates and puts order to energy flows and, simultaneously and inseparably, as an energetic organization that stabilizes and maintains material forms. In fact Margalef, following Needham, tends to uphold the view that "living systems have always been energy systems competing for materials," rather than material systems competing for energy, as one would initially imagine. "The distinction is important," he points out, "since the transmission of information is more closely related to the possibility of organizing enormous amounts of matter than to the possibility of allowing the flow of large amounts of energy."[34]

Though we acknowledge the pertinence of the ecologist's observations, the standpoint adopted here with respect to our particular organic analogy is more all-embracing. We commended the validity of both interpretations when we quoted von Bertalanffy, according to whom the organism "is a continuous process in which both construction materials and energetic substances decompose and regenerate."[35] This is the interpretation that best suits the vision of the building as an organism.

Architecture and entropy

for a theory of rehabilitation

It might be good at this point to leave aside all references to energy and material flows and introduce the concept that is the main theme of this section: entropy. After all, in the words of Nicholas Georgescu-Roegen, "however surprising it may seem to common sense, life does not feed on mere matter and energy, but—as Schrödinger explained so well—on low entropy."[36] This formulation is better than previous ones since it adjusts in all ways to architecture, which can only survive with a continuous supply of low entropy, also called negative entropy or negentropy.

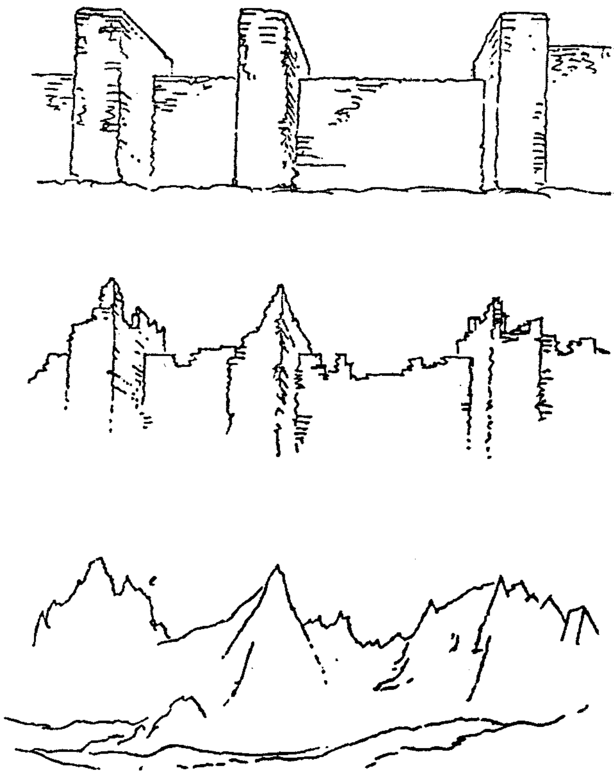
3.10.

The ruins of the Tower of Babel are the archetypal representation of the mortality of architecture: the confusion of tongues interrupts the flow of information that holds up the building; without it, entropy breaks up what has been organized. When Ruskin or Viollet-le-Duc contemplate natural forms as architectural ruins, their drawings illustrate this irreversible process of disorganization. Architectural interpretations of nature share either the hypothesis of a common mythical origin, as Werner Oechslin has pointed out, or else the conviction that architecture and nature are subject to the same laws.

3.10. *Ruins of the Tower of Babel according to Athanasius Kircher (*Turris Babel, *1679).*

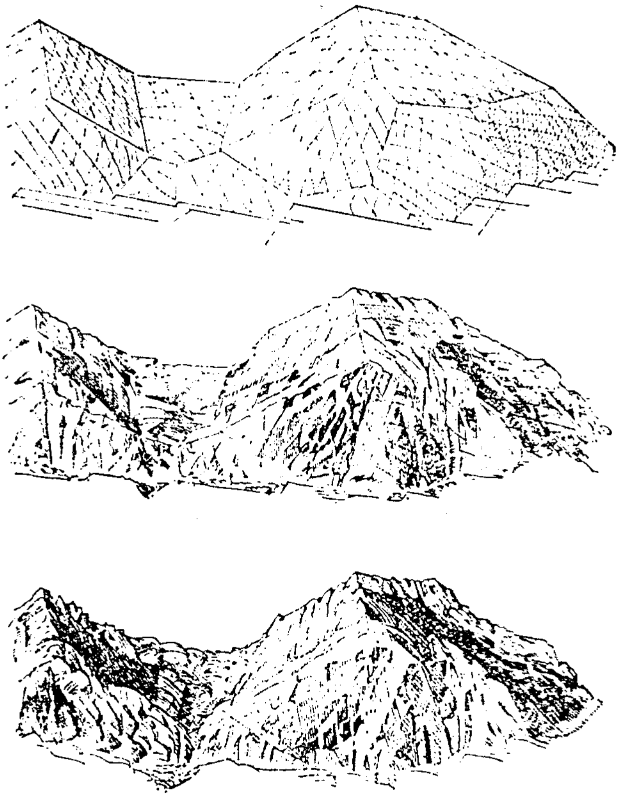
3.11. *John Ruskin, studies of the Aiguilles-de-Chamonix showing the erosion of the rampart form of the Alps.*

3.12. *Eugène-Emmanuel Viollet-le-Duc, crystalline protoforms of the Alpine mountains and their disintegration.*



3.11.

Nevertheless, matter and energy are so closely linked to one another that the formulation would not be altogether complete if we limited the meaning of entropy to that associated with the degradation of energy. We must inevitably take a further step, even at the risk of blurring the concept, to take into account the degradation of matter, which, like energy, is dissipated and irrevocably lost to man in every interaction between the two.[37]



3.12.

Georgescu-Roegen himself has proposed the formulation of a fourth law of thermodynamics—admittedly not with a very fortunate choice of wording—which may be stated either as “Unavailable matter cannot be recycled” or, in a formulation that is less ambiguous and less tautological, as “A closed system (i.e., a system that does not exchange matter with the environment) cannot perform work indefi-

The depiction of Soane's Bank of England as a ruin is more than a mere romantic fantasy: it is an anatomical dissection in which the decomposition of the architectural form reveals its constructive logic, and at the same time is a reminder about the inevitable expiration of everything organized. As in another canvas by Gandy showing a bird's-eye view of the bank ruins, the degradation simultaneously shows the subjection of architecture to the temporal laws of thermodynamics. The building is inscribed in a historical time as built nature, intelligible and perishable.

3.13. *Joseph Michael Gandy*, Perspective of the Bank of England as a Ruin.

nitely at a constant rate."[38] This law, which "proclaims for matter what the Entropy Law proclaims for energy," differs from the latter in that "an isolated system, instead of tending toward heat death [when all energy is unavailable], tends toward chaos [when all matter-energy is unavailable]."[39]

The same conception is in the mind of Edgar Morin when, in describing what he calls the message of the second principle, he goes beyond a narrow or exclusively energetic vision to refer to a much more generic cosmic panorama that includes matter and the very idea of organization:

> There is, in time, and always will be, a dimension of degradation and dispersion. No organized thing, no organized being can escape degradation, disorganization, dispersion. No living thing can escape death. Perfumes evaporate, wines sour, mountains flatten, flowers wither, living things and suns return to dust. . . . All creation, all generation, all development, and even all information must be paid for in entropy. No system, no being can regenerate itself in isolation.[40]

This, according to Morin, is the message of the second principle, a message that puts architecture in the realm of the transient and movable, in the midst of the processes of transformation and decomposition, in the heart of vital phenomena and the passage of irreversible time. It is in the context of the irreversible decomposition of the organized, the inevitable degradation of the built, the sure ruin of buildings, that the bases of a theory of rehabilitation must be established, one that takes into account the environment's need for a continuous supply of materials and energy to allow it to repair the damages of time and chance, reconstruct its form, regenerate its original conformation or adapt it to new needs.[41]

"Obstinate time" and the "restoration of buildings," according to Alberti

The figure of Alberti, an attractive one for many reasons, exemplifies the view of architecture in permanent reconstruction in the tenth and last book of his *De re aedificatoria*, that admirable treatise which, as Françoise Choay has written, "celebrates time, bearing within it life and death, creation and destruction."[42] It is difficult indeed to imagine a better description of this beautiful book than this reference to its celebration of time (Leon Battista calls it "obstinate time that upsets things"), the treatise's true protagonist. Alberti assures the reader that "time conquers all things" and that "the batteries of old age are dangerous and very powerful; the body has no defense against the laws of Nature and must succumb to old age; some think even heavens mortal, because they are a body."[43]

Observe how this paragraph, situated at the start of book X, titled "Restoration of Buildings," places the activity of architectural repair and restoration in the cosmological framework of the degradation associated with irreversible time, of old age and death, to which all things are subjected, including "even heavens." This view of the built environment in constant change, the roots of which are more Aristotelian than Heraclitan (Alberti himself quotes a few pages later: "Aristotle argued that Nature was continually changing"),[44] gives a true measure of the dialectical dimension of Leon Battista, who, as Choay stresses, "does not define the horizon of construction in purely positive terms, in the framework of a linear progression. From the outset, he situates the builder's activity in the field of degradation, trapped between error and obsolescence."[45]

And no less notable is the equally dialectical conception of time with respect to the two fundamental factors of the ruin of a construction, namely human errors and aging, which compel Alberti to close his treatise with the "restoration of works." In effect, time is simultaneously the start of degradation and a safeguard against errors; the passage of time, which is the cause of decay in the built work, ensures that painstaking reflection is carried out while the project is still on the drawing board.[46]

In any case Alberti's text describes architecture—systematically, perhaps for the first time—as in need of permanent restoration and repair, or, as it were, of a continuous flow of negative entropy, in the image and likeness of living beings, so as to maintain, like these, an independent existence.

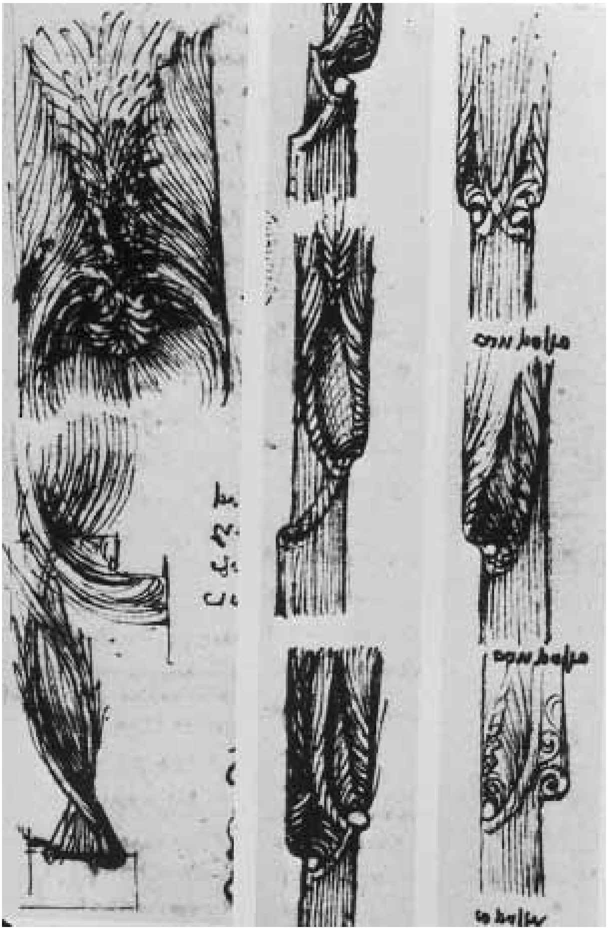
The consistence of form

homeostasis and hysteresis

The continuous process of decay and regeneration, which von Bertalanffy compared with Goethe's *Stirb und werde*, and which is characteristic of the dynamic structure of living systems at all levels of organization,[47] allows us to apply to architecture the biological nomenclature for the simultaneous and complementary existence of anabolic and catabolic processes in organisms. Thus, within this metabolic—not metabolistic—view of the building, we could speak of the need for the irremediable catabolic degradation of the built work to be complemented by the indispensable anabolic constructive action that restores, in a never-concluded process, the permanently transforming form of architecture. Rudolf Arnheim makes use of this same metaphor, for example, when he alludes to the "anabolic creation of a structural theme" in his book *Art and Entropy*.[48]

The consistency of form is thus guaranteed by the dynamic interaction of both kinds of processes, catabolic and anabolic, which relate to one another through a retroactive *curl* of a generative and organizing character, one which, in the words of Edgar Morin, "carries out the passage from the thermodynamics of disorder to the dynamics of organization."[49] As Prigogine and Stengers have reminded us, such a curl, whether inhibiting or catalytic, plays "an essential role in metabolic functioning as described by molecular biology,"[50] and can also be found in architecture, though one would have to look for it with a certain zeal.

The presence of this retroactive curl ensures morphological permanence in situations of disequilibrium, such as that of the building looked upon as an open thermodynamic system, pierced through by flows of energy and materials. The recursive organizations the curl gives rise to have been described by Morin as "organizations which, in and through



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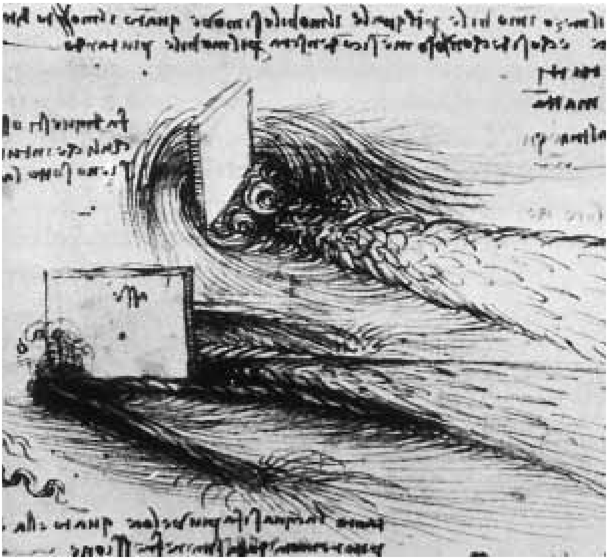


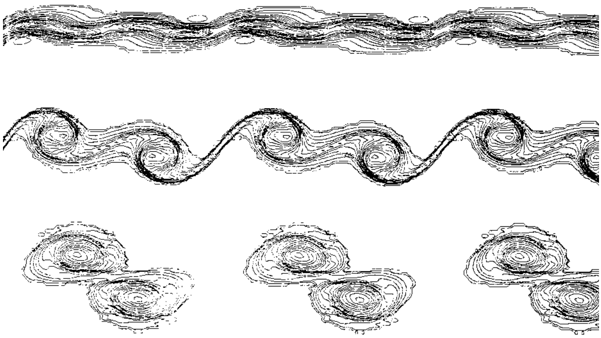
3.15.

For a form to be consistent, a thermodynamic imbalance is required. The eddies whose morphological persistence Leonardo marveled at and those now rendered by mathematical models have something in common: the existence of a flow that maintains their form; if the flow is interrupted, the system breaks down and is ruined.

3.14. *Leonardo da Vinci, studies of hydraulic fluids.*

3.15. *Leonardo da Vinci, hydraulic studies of the effect of an obstacle.*

3.16. *Mathematical simulation of the emergence of order in fluid flows. Ilya Prigogine,* From Being to Becoming *(1980).*



3.16.

disequilibrium, in and through instability, in and through the increase of entropy, produce stationary states, homeostasis, that is, a certain form of equilibrium, a certain form of stability, a certain form of consistency, a true morphostasis."[51]

Consistency of form, we must repeat, is in every way dependent on the energy flow that feeds the process. It is again Edgar Morin who has most brilliantly expressed this idea, and we must find pretexts to quote him anew. "The consistency of a candle flame, a whirlpool's shape, a star's morphology, a cell's or a living organism's homeostasis, cannot do without a certain thermodynamic disequilibrium, that is, some energy flow running through them. Rather than destroying the system, the flow feeds it, contributing to its very existence and organization. What is more, stoppage of the flow leads to the degradation and ruin of the system."[52]

This is precisely what happens in the case of architecture, which needs a flow of entropy in order to subsist, and to which can be applied, as to organisms, the concept of homeostasis that Wiener defined as the "conjunction of the processes by which we living beings resist the general trend of corruption and degeneration."[53] An architectural homeostasis that centers, by now far from the trivial example of the thermostat, on repair and rehabilitation processes, as repeatedly and convincingly suggested by Christopher Alexander beginning with his 1964 *Notes on the Synthesis of Form*.[54]

Against this point of view—which attributes the conservation of form to the presence of retroactive mechanisms that, by expending energy, are constantly correcting the rhythm and direction of the processes while renewing what has degraded—voices have been raised that assign a more relevant role to the very tendency of the form or the process to persevere in its original manifestation, in a singular contemporary expression of Spinoza's idea that all things desire to persist in their being.

One of these voices is Paul Colinvaux who, precisely in the context of a bitter critique of the applications of information theory to ecological systems, attributes the stability of these to the fact that "each species is endowed with a vital strategy oriented toward its persistence."[55] This contradicts the traditional view that associates stability with the complexity of the ecosystem, the variety of its species, and the resulting increased efficiency of its mutual regulation.

In the same way Erich Jantsch, using the term Conrad Waddington applied to the tendency of processes to continue in their original forms, even after being temporarily disarranged, has formulated his conviction that "homeorhesis is probably more important in evolution than homeostasis."[56] Margalef, in turn, speculates on the tendency of ecosystems to persist "with a sort of inertia or hysteresis, which we have tried to represent or characterize by a 'relaxation time,' this being a basis for stabilization and persistence"; he wonders if perhaps "nature is better described by its laziness or indolence than by homeostasis."[57]

Both concepts—Jantsch's homeorhesis and Margalef's hysteresis—allude to the inertia of processes, which probably rests on the same “memory of matter” that was discussed earlier in this chapter as one of the main supports of morphological permanence. The logical circle therefore closes when one considers the form a simultaneous product, as stated before, of the energy deposited in matter as information and the energy flowing through it in order to maintain its coherence; or, as it were, the energy accumulated as memory and the energy that flows as food and regulation. In sum, expressed in analogical terms, form can be understood as resulting from the joint intervention of energetic capital and profit, hysteresis and homeostasis, inertia and autoregulation, permanence and adaptive change.

four

Paradigms of Life and Thermodynamic Architectures

Heliotechnology, Bioclimatism, Rehabilitation: Between Energy and Entropy

The architecture of energy

new organicism or new functionalism?

We have discussed organisms and ecosystems, genetics and metabolism, Darwin and Lamarck; in fact, one could think that the thermodynamic analysis of architecture is but an elaborated biological metaphor. From this point of view, the opposition between thermodynamics and mechanistic thought (a theme of this book from the very start) is seen as a philosophical and scientific manifestation of the old duality between the mechanical and organic views of architecture.

Of course, the view that links thermodynamics to biology, energy to life, and contrasts them with the inanimate and mechanical universe is not unfounded; but, as we shall see, it is only true to a certain extent. At this point it becomes necessary to explore the nature of the relation between energy and life and, even more important, to clear up the true meaning of the opposition between organism and mechanism. Only through this double exploration is it possible to accurately place the thermodynamic view (whether analytical or analogical) within the framework and perspective of architectural criticism.

In the course of such a reflection we hope to back up the thesis that the thermodynamic conception of architecture, more than a contemporary expression of organicism, must be understood as a present-day manifestation of functionalism, at the core of which there is both an organic and a mechanical component. The double soul of thermodynamics—suggested metaphorically in previous pages through dualities like sun/fire, energy/entropy—is easily concealed on account of the priority given to terms indicating the break with mechanism (fire, entropy), and through it to the organic view; but we must not forget the permanent and symmetrical presence of the mechanical dimension. Both conceptions belong to a single, functionalist realm; a realm, moreover, that does not exhaust the thermodynamic view of architecture, and that has an important symbolic and expressive dimension, one closer to the classical *venustas* than to the *utilitas* discussed here.

Life and entropy

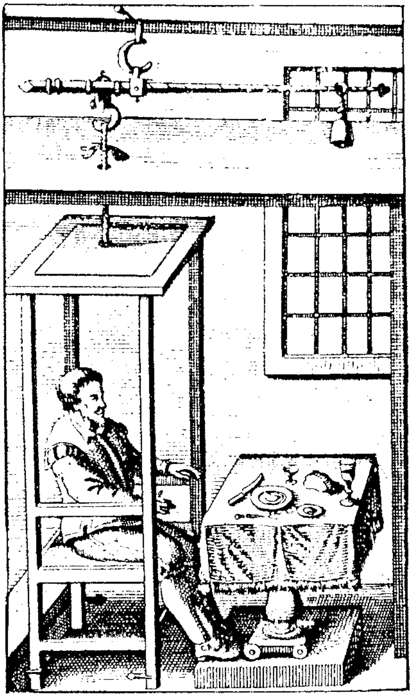
organisms as open thermodynamic systems

As Cesare Maffioli reminds us, "Thermodynamics and biology, heat and life, have in truth always been closely connected fields: the origins of the science of heat, for example, must to a great extent be searched for in the history of medicine, and conversely Lavoisier's idea that respiration is nothing but a particular form of combustion was decisive for the development of physiology."[1]

Besides these common origins are substantive bonds, the most important of which is undoubtedly the character of a thermodynamic system attributable to living beings. In fact, of the three types of systems studied by thermodynamics (adiabatic, closed, and open), living organisms can be considered a particular case of the last category, open thermodynamic systems.

As we know, classical thermodynamics preferred to deal with adiabatic systems (those which can only interchange work with the outside) and with closed systems (which can interchange work and heat, but not matter). Interest in open systems, which can interchange both matter and energy (in the form of heat or work), is more recent.

These open systems, which are characteristic of chemistry and biology, are by their very nature largely unstable, although they can achieve states of dynamic equilibrium. Consequently, they accurately describe the behavior of systems beyond equilibrium that interchange matter and energy



Thermodynamics is closely related to biology. The metabolical study of the organism thinks of it as an open thermodynamic system, one that exchanges matter and energy with its exterior; and physiology understands respiration as a form of combustion. Such a link between heat and life has historical origins.

4.1. *Santorio Santorio (1561–1636), the Italian physician and possible inventor of the thermometer, seated on his "weighing chair," where he could eat and sleep and which he used for the first experiments on metabolism.*

with the outside, such as chemical reactions and especially living beings, which Margalef, not without humor, calls "the most distinguished category" among structures beyond equilibrium in the universe.[2]

As explained in the preceding chapter, the maintenance of the form of these structures, their resistance to degradation, is made possible only through a flux of energy: the flame needs fuel; the living being, food.[3] In fact, this energy flow is a process by which more usable energy is converted into less usable energy, so one could simply say that resistance to degradation necessitates energy degradation.

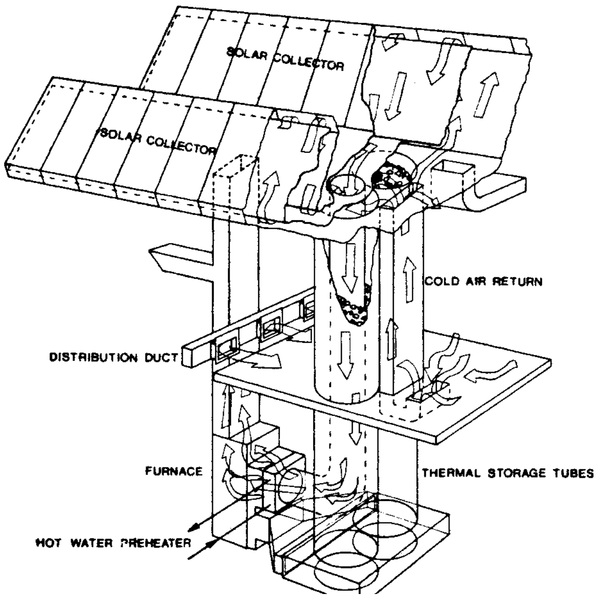
The foregoing can of course be expressed more concisely and elegantly through the concept of entropy: open thermodynamic systems—like a building or a living being—require a supply of low entropy for maintenance. Georgescu-Roegen has eloquently explained the importance of the nexus between life and entropy:

> We know that people can live even if deprived of sight, or of hearing, or of the sense of smell or taste. But we know of no one able to live without the feeling of the entropy flow, that is, of that feeling which under various forms regulates the activities directly related with the maintenance of the physical organism. . . . It is therefore no exaggeration if one argues that the entropic feeling, in its conscious and unconscious manifestations, is the fundamental aspect of life from amoeba to man.[4]

The architecture of the first principle

heliotechnical mechanicism

The close relationship between thermodynamics and biology nourishes the mistaken conviction that energy-oriented analyses of architecture inexorably lead to biologistic concepts and organic metaphors. This makes it necessary to turn once



When architecture is designed based on energy priorities, the resulting image is not always organic. Many constructions using solar energy, for example, are displays of extreme mechanicism; heliotechnology is a branch of heating and ventilation engineering that yields intricate machines full of tubes, valves, and pumps.

4.2. *System of solar heating through collectors (Watson).*

again to the hidden face of the science of heat, stressing the mechanicist character of the first principle and recalling the opposition, described in chapter 2, between the two cultures coexisting in its womb: that of energy and that of entropy.

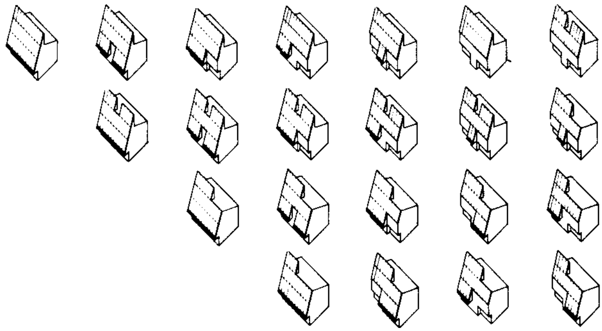
The thermodynamic vision of architecture can of course lead to organicist conceptions, but in the same way that it can lead to the practice of the most extreme mechanicism, both in design processes and the language of final products. This is palpably and eloquently demonstrated by the latest crop of heliotechnic architecture.

Indeed, the active solar architecture of helioengineering can be considered a contemporary expression of the grand mechanical-technological tradition found most recently with Norman Foster or Richard Rogers, and which many considered to have expired with the swan song of the Pompidou Center. Both the unifunctional mechanicism of the design processes—where even the inclination of the surfaces is determined by solar charts—and the machine expressivity of the blades, pipes, metal towers, and pumps make this architecture a worthy successor to the *machine à habiter.* A domestic factory of energy, any prototype of an autonomous house, with its solar collectors, wind generators, and methane digestors, has the appearance of a machine, is designed like a machine, and functions—though often rudimentarily—like a machine.

I have mentioned the *machine à habiter*; and this is not an innocent reference to Le Corbusier. It is widely known that solar architecture endeavors to be a critique on the thermal inadequacy of modern architecture, a critique whose beginnings many situate in the oil crisis of 1973–1974 but which has really existed since the years of the modern movement in the writings of Tessenow, Blomfield, and others.[6] With his determination to design "one single building for all nations and climates, the house with *respiration exacte*,"[7] Le Corbusier was to become a routine target of critics, who pointed out the thermal insensitivity of his *mur neutralisant* as well as the costly naivete of *respiration exacte* or the conflict between the sculptural power and debatable energy functionality of his *brise-soleil.* Paradoxically, the detractors of his "single building for all nations and climates" have promoted a second international architecture characterized by a single building—the solar house—for all nations and climates, such that few things resemble one another as much as a solar house in Edinburgh and one in Naples.

In its break with the uniqueness and specificity of places, modern architecture pursued both the repeatability of buildings in space and the repeatability of space in buildings, and this in many different ways. The Cartesian grids in plan and elevation were not only material but energetic; visual homogeneity went hand in hand with thermal homogeneity, and the 18°C that Le Corbusier proposed for "Russia, Paris, Suez, or Buenos Aires"[8] is not due exclusively to an individual passion for "le standard, l'invariant,"[9] but to a broader idea generalized among the architects of the modern movement which sought to bring construction into the quantitative, mechanical, and normalized world of industrial production, exchanging the creation of place for the production of a necessarily homogeneous and repeatable space. Heliotechnical architecture has the same disdain for the expressive and symbolic capacity of thermal variety.[10] The space under a solar collector does not differ too greatly from that existing behind Le Corbusier's screens or Mies's curtain walls. The inclined glass panes of heliotechnical construction, just like the sculptural, richly articulated surfaces of the *brise-soleil* or the terse facades, full of reflections, of the curtain enclosure, speak only to the eye.[11] The space they contain is indifferent to thermal perception: the coolness of a shade, the heat of a fire, the warm touch of wood, and the relief offered by a light breeze are removed from the isotropic and isothermal mechanical universe of heliotechnical construction.

Obsessed as it is with maximizing gains, minimizing losses, and optimizing output, this kind of architecture is a living example of the mechanicist, reductive, unidirectional, and monofunctional approach to design. In fact, the thermodynamic path is a road that forks both ways, toward the



4.3.

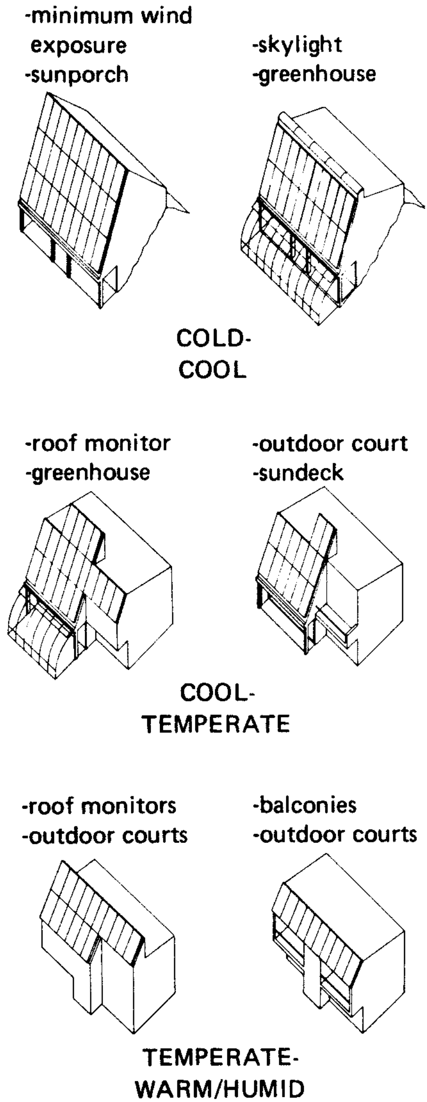
Nothing resembles a solar house more than another solar house: adapting to climate does not rule out formal homogeneity in this new International Style.

4.3. *Models of solar houses obtained by combining four alternative sets of floor plans and sections.*

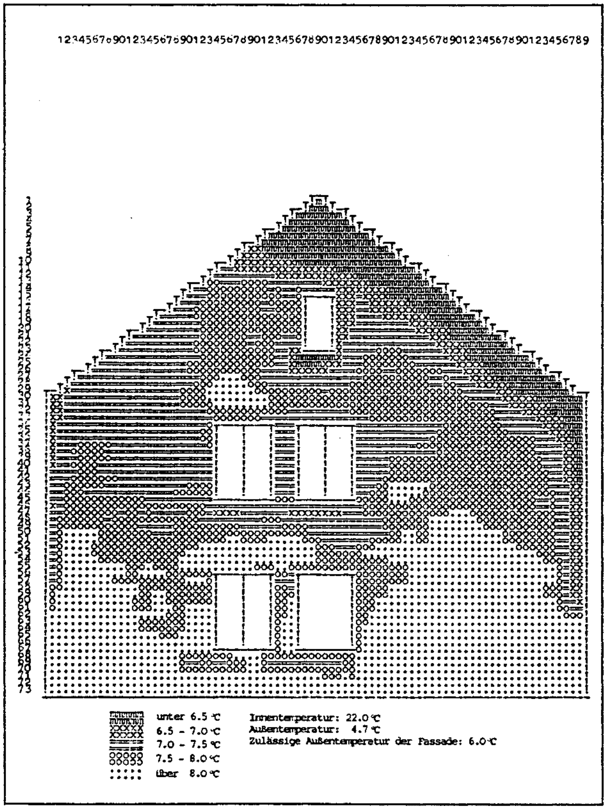
4.4. *Solar houses for three different climates (cold, temperate, and tropical).*

mechanicism of the first principle and the organicism present in the second.

Thus, heliotechnical construction is probably the clearest expression of what could be called "architecture of the first principle," with its emphasis on the quantitative aspects that characterize the "culture of energy." Yet it is not the case that this mechanical and quantitative conception associated with energy is rivaled by a monolithic, organic and qualitative conception in the bosom of the "culture of entropy." On the contrary, the latter is full of deep cracks and major divisions, which are particularly clear-cut with regard to the link


-minimum wind
exposure
-sunporch
-skylight
-greenhouse
COLD-
COOL
-roof monitor
-greenhouse
-outdoor court
-sundeck
COOL-
TEMPERATE
-roof monitors
-outdoor courts
-balconies
-outdoor courts
TEMPERATE-
WARM/HUMID

4.4.

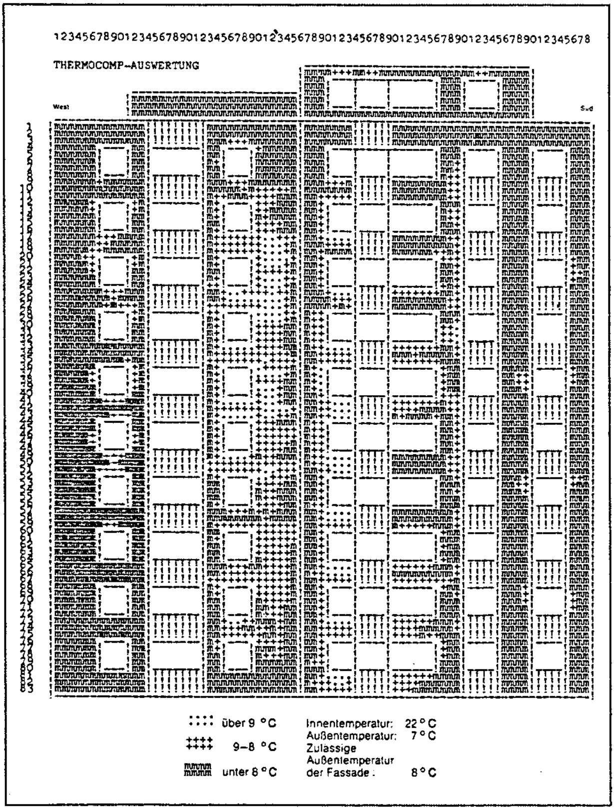


4.5.

Visual homogeneity goes hand in hand with thermal homogeneity. Mechanical calculation equates temperature and appearance: isotropic space is isothermal.

4.5. *Thermogram of a one-family house indicating different facade temperatures.*

4.6. *Thermogram of an apartment building.*


THERMOCOMP–AUSWERTUNG
West
Süd
über 9 °C
9–8 °C
unter 8 °C
Innentemperatur: 22 °C
Außentemperatur: 7 °C
Zulässige Außentemperatur der Fassade: 8 °C

4.6.

between thermodynamics and biology and whose very existence notably hinders the identification of a possible "architecture of the second principle."

Cultures of entropy

Georgescu's pessimism and Prigogine's optimism

Within the culture of entropy, the most unbridgeable gap is surely, as indicated above, the divide in the field of relations between life and thermodynamics. For some, vital phenomena occurring in the framework of thermodynamics are nevertheless irreducible to this science; for others, much of life would be explainable through nonlinear thermodynamics.

A good representative of the first school is Nicholas Georgescu-Roegen, who writes that "life is manifested by an entropic process that, without violating any natural law, cannot be completely derived from these laws—including those of thermodynamics! Between the physico-chemical domain and that of life there is, therefore, a deeper cleavage than even that between mechanics and thermodynamics."[12]

The leading spokesman of the opposite view is the chemist Ilya Prigogine, who puts prime emphasis on the rupture between mechanics and thermodynamics, stressing the continuity of the latter, through bridging elements such as dissipative structures, with the field of life.

The comparison between Carnot and Darwin discussed in chapter 2 is quite different from these two viewpoints. We recall that the "contradiction" between Carnot and Darwin made reference to the apparent paradox between the inevitable thermodynamic degradation of all existing things and the opposite movement, which manifests itself in every living being individually as well as in the evolution of life on earth as a whole. Both the development of a single organism and the evolutionary process of life in general move in the direction of greater organization, precisely the opposite of what to expect in the case of the lone action of the entropy law, which prognosticates the increase of disorder and the decomposition of organization. One could therefore say that life flows in a direction opposite that of "time's arrow," which determines the inevitable tendency of entropy to increase.

For the traditional viewpoints of the first school cited above, the question is practically settled by the verification that an organism is an open system and, in the words of Harold Blum, that "the small local decrease of entropy accompanying the construction of the organism entails a much greater increase of the entropy of the universe."[13] In this way, as Jeremy Rifkin writes, "Evolution means the creation of larger and larger islands of order at the expense of ever greater seas of disorder in the world."[14]

This interpretation, probably the most frequent, is simplistic in the eyes of Prigogine's disciples, one of whom, the philosopher Edgar Morin, has contemptuously described it as something extracted from the "thermodynamic Vulgate." In their opinion the matter is more complex, since it is not a mere matter of explaining life's compatibility *with* thermodynamic laws, an issue that might even seem banal, but of justifying the genesis and growth of that organized complexity which life is *on the basis of* thermodynamic laws. As Prigogine and Stengers ask, "How to articulate Darwinian evolution, statistical *selection* of rare occurrences, with the statistical *disappearance* of all particularities, of all infrequent configurations described by Boltzmann? . . . How to insert the evolution of living beings, of their societies, of their species, in the thermodynamic world of growing disorder?"[15]

To be sure, "linear thermodynamics does not provide for the settling of the Darwin-Carnot paradox."[16] This role is reserved for nonlinear thermodynamics, which mathematically explains the formation and maintenance of *dissipative* structures (forms of supermolecular organization requiring the continuous dissipation of energy and matter) through the increase of small initial random fluctuations.[17] The most elemental of these structures can provide intermediate links between nonorganized matter and the extremely organized matter of living beings. This leads to the idea that "organized phenomena can be born from themselves, through a thermodynamic imbalance. . . . Thus cosmogenesis, including even biogenesis, [seems] inseparable from a capricious, complex, and uneven dialectic of heat and cold."[18] In short, as Prigogine and Stengers argue, "the opposition between Carnot and Darwin has given rise to complementarity."[19]

Being open thermodynamic systems, dissipative structures include living beings, which equally require a flux of energy for their maintenance: through them the nonlinear thermodynamics of irreversible processes and molecular biology meet. Indeed, "while 'nonlinear' reactions, whose effect [the presence of the product of reaction] in turn acts upon the cause, are relatively rare in the inorganic world, molecular biology has discovered that they are practically the rule in living systems. Autocatalysis [the presence of X accelerates its own synthesis], autoinhibition [the presence of X blocks the catalysis necessary for the synthesis of X], and crossed catalysis [each of two products belonging to different chain reactions activates the synthesis of the other] are the classical mechanisms of metabolic regulation."[20]

The debate on dissipative structures as a new paradigm

The theory of dissipative structures has an extraordinary influence on numerous disciplines, so much that many consider it the new scientific paradigm for an age that contemplates the transit from a nonrenewable energy base to a renewable one, and from transformation processes based on physics to others based on molecular biology.[21] As Jeremy Rifkin points out, "the theory of dissipative structures provides a perfect rationalization for the age of bioengineering. It places a positive value on increased biological complexity and the continued reordering of living matter into new structures, which is what genetic engineering is really all about. With dissipative structures we move from viewing the world as an industrial machine to viewing it as an engineered organism."[22]

Needless to say, from the ranks of entropic pessimism, the stubborn historic optimism underlying Prigogine's theories is judged severely. Likewise criticized is the political manipulation facilitated by its approval of unpredictability, imbalance, and order through fluctuations, these being used to justify neoliberal economic policies, as against the Keynesian control mechanism.[23] Pierre Thuillier, for example, has even gone to the extent of maintaining that "the new alliance"[24] between man and nature that Prigogine advocates is but a new version of the old alliance between science and the dominant class referred to by Karl Marx.[25]

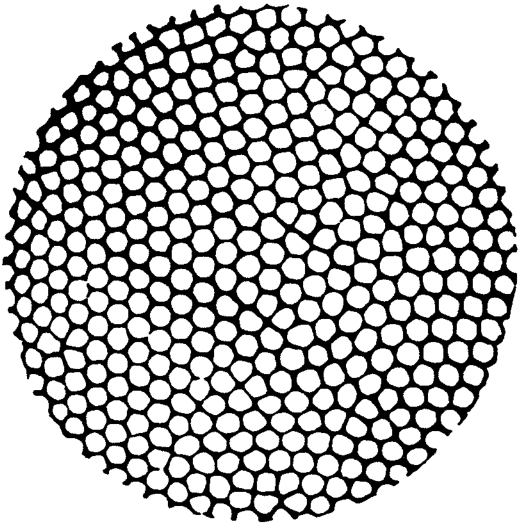
Undoubtedly many of these critiques are baseless and seem to build more upon an emotive adherence to Newtonian causality, mechanicist rationalism, and planned organization. Those objections that center on the not too convincing Promethean character of the historical predictions of this school seem more substantial. Rifkin has expressed it in these terms:

> The theory of dissipative structures, like the earlier Newtonian paradigm, completely ignores the Entropy Law, concentrating only on that part of the unfolding process that creates increasing order. By refusing to recognize that increased ordering and energy flow-through always creates ever greater disorder in the surrounding environment, those who advocate bioengineering technology as the transforming apparatus for a renewable energy environment are

THE BELOUSOV-ZHABOTINSKII REACTION: CHEMICAL SCROLL WAVES

Spiral chemical waves develop when the Belousov-Zhabotinskii reagent is allowed to stand in a shallow dish. The waves can appear spontaneously or be initiated by touching the surface with a hot filament, as in the photographs above. The small circles are bubbles of carbon dioxide evolved by the reaction (see the section on coherent structures in chemistry and biology in chapter 5). After the initial photograph was taken, subsequent ones were taken at 0.5, 1.0, 1.5, 3.5, 4.5, 5.5, 6.5, and 8.0 seconds. Photographs by Fritz Goro.

4.7.



4.8.

"Dissipative" structures are forms of organization that require the continuous dissipation of matter and energy; the most elemental of these constitute links between inert matter and living beings. As a new paradigm in many disciplines, this theory thinks of the universe not as a clockwork machine but as an artificial organism.

4.7. *Spiral chemical waves formed in the Belousov-Zhabotinskii reaction, photographed at intervals of approximately one second. Ilya Prigogine,* From Being to Becoming *(1980).*

4.8. *Spatial distribution, seen from above, of Bénard convection cells, which are formed in a liquid when its bottom part is heated.*

doomed to repeat the same folly that has led us to the final collapse of our nonrenewable energy environment and the age of physics that was built upon it.[26]

It is extremely important to verify how the contrasting views of these two ways of interpreting the second principle are manifested in the very conception of thermodynamics. For the entropic optimism of the chemist Prigogine, thermodynamics is essentially chance, fluctuations, imbalance, these being, in the final analysis, generators of order. For the entropic pessimism of the economist Georgescu-Roegen, thermodynamics is necessity, a compulsory iron law that inevitably leads to disorder.[27]

Chance generating order or necessity leading to disorder? Despite the apparent contradiction, the two viewpoints can probably be reconciled by paying heed to Rifkin's criticism of the theory of dissipative structures, quoted above, as being concerned only with a part of the process. In effect, if we keep this observation in mind, we will understand that thermodynamics is *chance generating order* in fragments of the process, while it is *necessity generating disorder* in the process as a whole.

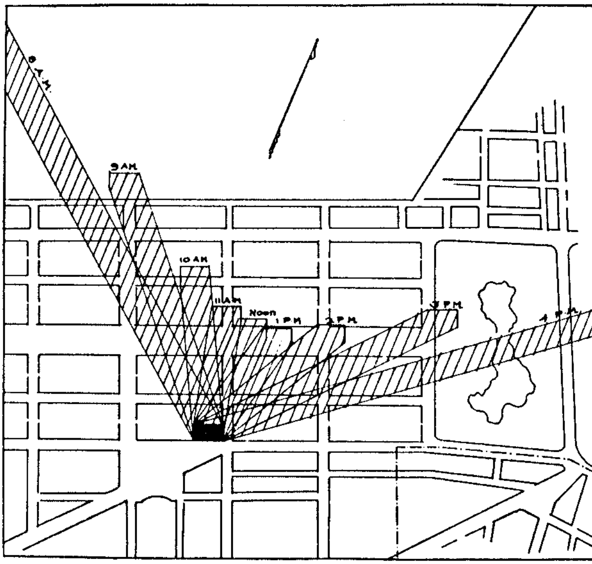
There nevertheless remains a huge gap between the two interpretations of entropy, a matter which, as previously stressed, makes it notably difficult to delimit that built version of the energy theme that we metaphorically called "architecture of the second principle." We now return to this matter, aided by this prolonged digression whose extension is justified only by the singular epistemological importance that the new paradigm of dissipative structures is acquiring, and in the hope that knowledge of its general features will help to trace the thermodynamic characterization of architecture.

Architectures of the second principle
bioclimatism and rehabilitation

What we have called "architecture of the second principle" can be seen as divided by the same gap that separates the two interpretations of entropy. On the one hand there is a passive solar architecture, more concerned with controlling than with maximizing the capture of natural energy, nourished by fluctuating energy flows, self-regulated by processes similar to metabolic ones. This architecture finds its model not in the industrial machine but in the artificial organism; this is the constructive manifestation of what we termed entropic optimism.

On the other hand there is an architecture of rehabilitation, as attentive to the process of entropic degradation of matter as to that which affects energy, dedicated to the recuperation and recycling of both the existing material support and the information it contains, and concerned first and foremost with rehabilitating what is built and degraded, recycling what is fabricated and used, recuperating what has been learned and forgotten; this architecture would in turn constitute the physical expression of entropic pessimism.

Both architectures of the second principle entail a break with the Newtonian mechanicist paradigm, though in different ways: the first puts more emphasis on the energy of maintenance, the second on the energy of construction; the former is concerned above all with the processes taking place in the building, the latter with construction as a process. Both pay close attention to information energy: in the first case as a regulator of flows, in the second as something that can be accumulated in matter. Recalling the dichotomies of chapter 3, the two architectures of the second principle differ in the priority they give to energy that flows as food and regulation and to energy that accumulates as memory; to energy profit and to energy capital; to adaptive change and to

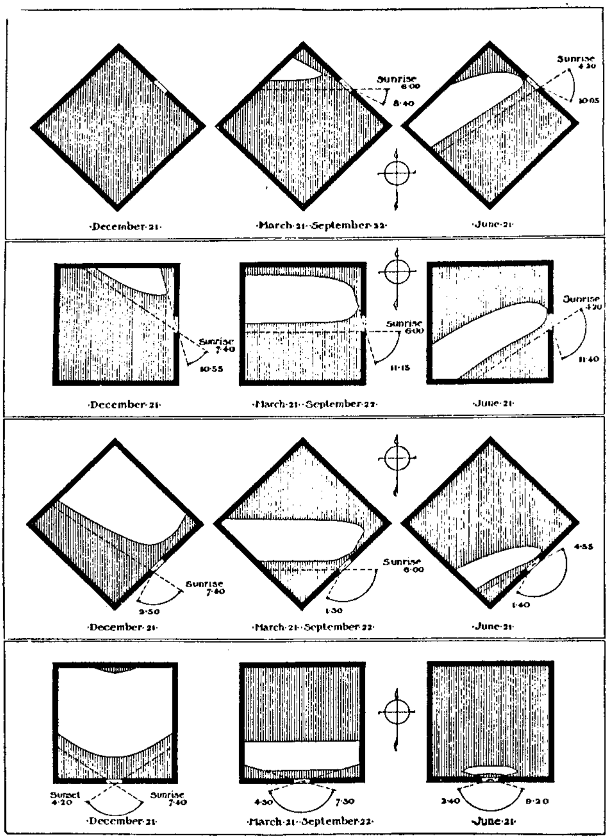


4.9.

If heliotechnology was a mechanistic thermodynamic architecture, bioclimatism is organicist. The transit from machine to organism is like the transit from active to passive solar energy: the use of climate as an energy resource through the positioning and morphology of the building is a key concept of bioclimatic architecture; studies on sunshine pioneered this approach, although there was still much of Taylorist mechanicism in the search for an "ideal orientation."

4.9. *Shadow cast by a 90-meter skyscraper at different times of the day. As a consequence of this study by Atkinson, in 1904 the city of Boston imposed limitations on the height of buildings.*

4.10. *Solar penetration at solstices and equinoxes through windows facing different directions (William Atkinson, 1894).*


Sunrise 6·00
8·40
Sunrise 4·30
10·05
·December·21·
·March·21··September·22·
·June·21·
Sunrise 7·40
10·55
Sunrise 6·00
11·15
Sunrise 4·20
11·40
·December·21·
·March·21··September·22·
·June·21·
Sunrise 7·40
2·50
Sunrise 6·00
1·30
4·55
1·40
·December·21·
·March·21··September·22·
·June·21·
Sunset 4·20
Sunrise 7·40
4·30
7·30
3·40
9·20
·December·21·
·March·21··September·22·
·June·21·

4.10.

permanence; to self-regulation and to inertia; to homeostasis and to hysteresis.

While their functional priorities clearly separate the two thermodynamic interpretations of architecture, the difference between them is no less expressive in the field of formal manifestations or in that involving the processes of typological configuration. Passive architecture is a prolongation of organic approaches, with their emphasis on climatic adaptation or on the use of materials endowed with symbolic biological connotations; integration with nature is its key concept. The architecture of rehabilitation, on the other hand, translates the adaptation of preexisting formal codes into a contemporary language, whether those of great stylistic crystallizations or those of neovernacular anonymity; integration with history is the essential concept here.

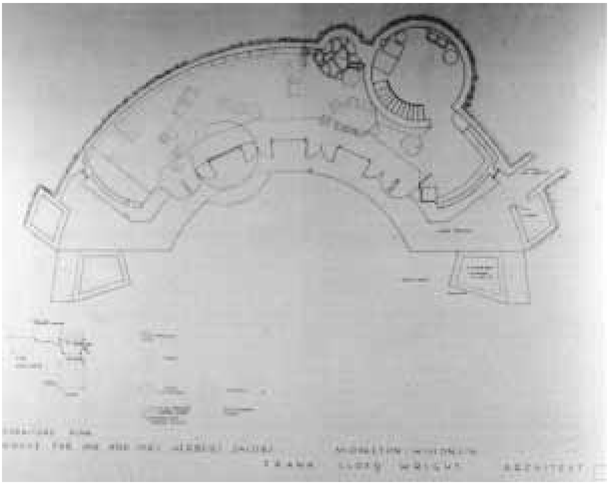
If this occurs in the field of formal expression, a similar situation arises in that of typological use. The production of types in passive architecture comes about through a random, multidimensional, combinatorial, radically novel process, one in many ways similar to that involving the creation of species in the field of genetic engineering, and threatened by an identical range of risks. The architecture of rehabilitation, in turn, comes with what could be considered—using the

Adapting to sunshine while representing its movement: facing south and recalling the traditional Indian village of the American Southwest, Wright's solar hemicycle benefits from the sun while revering it.

4.11. *Frank Lloyd Wright, solar hemicycle (second Jacobs House), 1943–1948.*

4.12. *Frank Lloyd Wright, solar hemicycle, floor plan with furniture, 1944.*

4.11.



4.12.

same metaphor—an extraordinary respect for the typological genetic pool, the product of a very long process that appeals more to memory than to genetic creativity and only accepts conservative forms of typological hybridization.

Thermodynamic architectures confronting time and function

As we have seen, there is no single architecture of energy but several, all significantly related to epistemological and scientific conceptions that differ in their estimation of the role and meaning of thermodynamics in the contemporary cultural world. We can distinguish an active, heliotechnical, mechanical architecture of energy, which we associated with the first principle; a passive, bioclimatic, organic architecture representing the optimistic side of the second principle; and finally, a rehabilitative architecture of supports and languages that is as attentive to the dissipation of energy as it is to the degradation of matter and information, and that constitutes the pessimistic face of entropy.

All three thermodynamic architectures emerged with enhanced vigor on account of the generalized economic crisis and the attendant slowdown of building activity in the early 1970s, and more specifically as a consequence of the 1973 oil crisis, with the ensuing unrest in industrialized countries. Such circumstances brought about a sudden irruption of *necessitas* into architectural thought, and it comes as no surprise that the architecture produced during the crisis is marked by an eloquent functionality.[28]

But though evident in both heliotechnical and bioclimatic architecture,[29] this functional stamp manifests itself diffusely and ambiguously in rehabilitative architecture, which can only be considered functional in a latent sense incorporating language and memory into the concept of function. A moment's reflection here will show a major difference between this third thermodynamic architecture and the other two: the architecture of rehabilitation makes the passage of time the cornerstone of its theoretical building, in contrast with the ahistorical character of heliotechnical and bioclimatic architecture. In this sense, and recalling the close relationship between time and entropy described in chapter 2 and well summed up by Eddington's phrase identifying entropy with "time's arrow," one is probably accurate in affirming that only rehabilitative architecture fully deserves to be considered "architecture of the second principle." Hence the fact that the gap between this architecture and the other two is larger and deeper than that separating these from each other: the distance between heliotechnical mechanicism and bioclimatic organicism is smaller than that separating either from the rehabilitative attitude, as already suggested by its different position along the functional spectrum.

Such polarization is further enhanced by underlying connections between the concepts of organism and mechanism,[30] connections that may not altogether eliminate but do qualify their conventional opposition, and in so doing reinforce their joint position on one end of the functional panorama, as well as their contrast with the historical dimension of rehabilitative attitudes.

Up to this point we have tried to show that, despite the abundance of biological analogies, the energetic approach to architecture leads not only to organicism but also to the most resolute mechanicism. The kinds of architecture we have called bioclimatic and heliotechnical, respectively, well exemplify these two interpretations, and in the development of this text we have discerned the existence of a third kind of thermodynamic architecture, one focused on physical and symbolic rehabilitation, in a clash with the degradation that entropy—or irreversible time—brings about in both matter and information. Comparing this third alternative with the first two allows a clearer perception of the links between them, while making it possible to situate both in the realm of functionalism. Such a common localization suggests throwing light on the nature of the relationship between organism and mechanism, a task to be undertaken in the next chapter.

five

Organisms and Mechanisms, Metaphors of Architecture

Mechanical, Thermal, and Cybernetic Machines versus the Living and the Built

On the fraternity between buildings, living beings, and machines

Biological and mechanical quotations are omnipresent in architecture, occurring, moreover, with singular simultaneity. Organisms and mechanisms frequently appear in plans or sketches of buildings, punctuating, emphasizing, offering metaphors, or suggesting comments. After all, the building is an artifact meant to shelter living beings, and there is nothing strange about the mechanical or natural universe serving as a model, a contrast, or a stimulus in the design process. Nevertheless, the extent to which they overlap and coincide is astonishing.

In what are probably the two most famous notebooks of architectural history,[1] separated by more than six centuries, living beings and machines are juxtaposed and entangled among construction sketches. The oldest known clock with an escapement device[2] and the first frame saw appear in Villard de Honnecourt's *Album* of the late thirteenth century, but so do drawings of a lion and a bear, a lobster and a swan, a dragonfly and a fly, parrots and dogs, cats and horses. . . . Organic and mechanical metaphors notoriously abound in Le Corbusier's notebooks, while skeletons and automobiles, fish and airships proliferate among his designs for buildings. Of course the two had very different approaches. Whereas the medieval builder contemplated architectural solutions and mechanical devices with the same degree of interest and drew decorative details and exotic animals with equally avid curiosity, the contemporary architect established conscious, explicit parallelisms and formulated pedagogical or polemical analogies between buildings and the mechanical or natural world. Both, notwithstanding, pursued a conception that makes architecture have a share in a world inhabited by living beings and mechanical contrivances. This said, what links are there between organisms and machines that explain their frequent and simultaneous presence in the mind and pencil of builders?

Before proceeding further, note that the idea here is not so much to explore organic and mechanical references in architecture as to reflect on the parallelisms and reciprocal relationship between the very conceptions of organisms and machines, and this from two perspectives: the fluctuations in their dialogue through history, and the opinions and works of two architects of this century who exemplify these opposed approaches.

One can rightly engage in a historical examination of the dialogue between organisms and machines because the relationship between them has suffered major modifications, as a result of the contrast between the extraordinarily slow evolution of organisms and the accelerated rate of change that the world of machines has been subjected to in the last few centuries. That is, in a reduced span of time the mechanical universe has undergone radical transformation, whereas the organic universe, in the sense used here, has remained practically unchanged. It is thus the machine, and its successive versions, that have determined the different conceptions of the relationship between organism and mechanism: mechanical, thermal, and cybernetic machines[3] have generated the views of the organism as mechanism, motor, and automaton, respectively.[4]

In each of these historically successive metaphors, energy plays a different role: whereas in the world of mechanisms energy is above all work, mechanical motion, in the world of thermal machines it is basically heat, and in that of cybernetic machines it is information. Similarly, the old analogy between artifact/building and organism/body takes on different lines, with the building considered a body composed of parts, a body that nourishes itself, and an intelligent body, respectively.

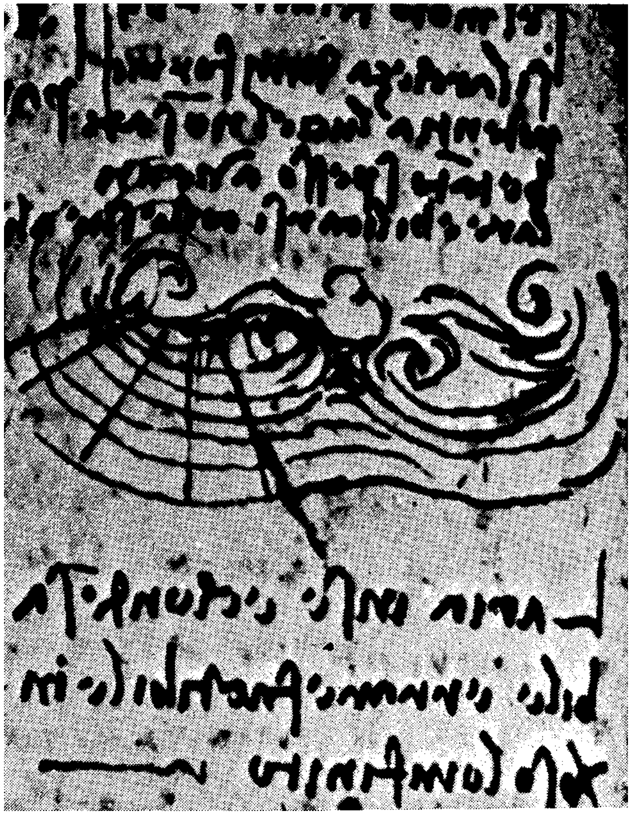
From an architectural perspective, the importance of these considerations lies in the fact that organic references are almost always influenced by the way the organism is viewed *through* the machines of the age. If the organism is contemplated through the perspective of the machine, the distance between organic and mechanical analogies of architecture can be understood to be more symbolic then functional, as will be shown in the parallel analyses of the paradigmatic cases of Frank Lloyd Wright and Le Corbusier, the theme of the second half of this chapter.

Mechanical organisms

From the bête machine *to the automaton*

The dialogue between machine and life is first manifest in the conception of the organism as a mechanical artifact, and there are few better examples of this dialogue than Leonardo's. His drawings not only juxtapose heads and machines, hygrometers and figures, Madonnas and hydraulic wheels, but also formulate detailed parallelisms between the organic and mechanical worlds, such as the famous one about fish and ships, or those expressed in flying machine designs. These parallelisms are not accidental. In fact, Leonardo's unexecuted book titled the *Elements of Machines* was to have presented the elemental parts of mechanical devices and served as a prelude to his treatise *On the Human Body*. He described the relationship between the two thus: "Do not forget that the book on the elements of machines with its beneficial functions should precede proofs relating to the motion and power of man and other animals; then on their bases, you will be able to verify your propositions."[5]

Indeed in Leonardo's opinion, as Benevolo points out, "machines were not a world of independent objects, with laws and development to be studied, but artificial extensions of



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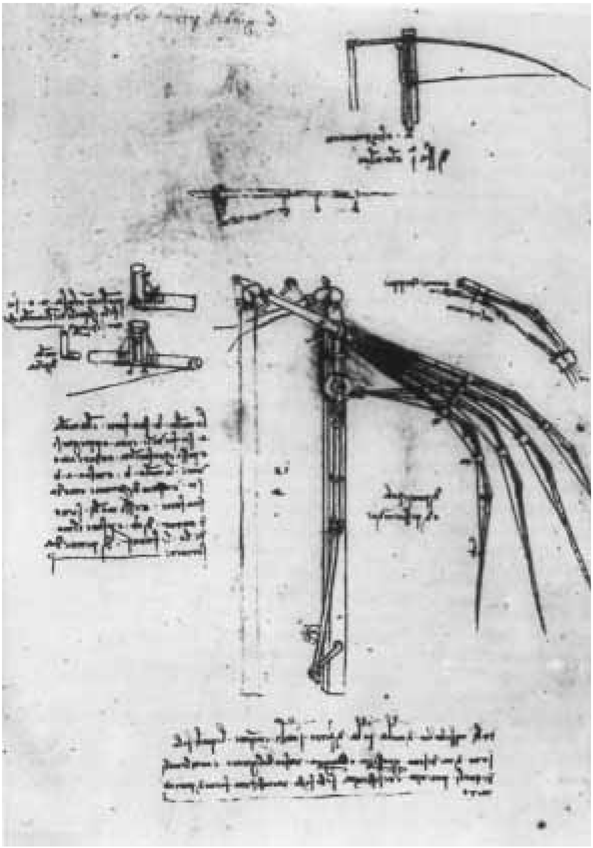

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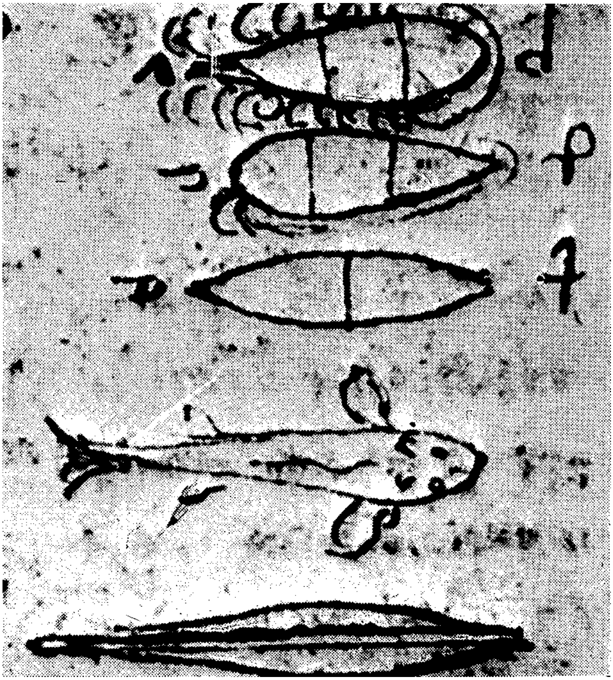
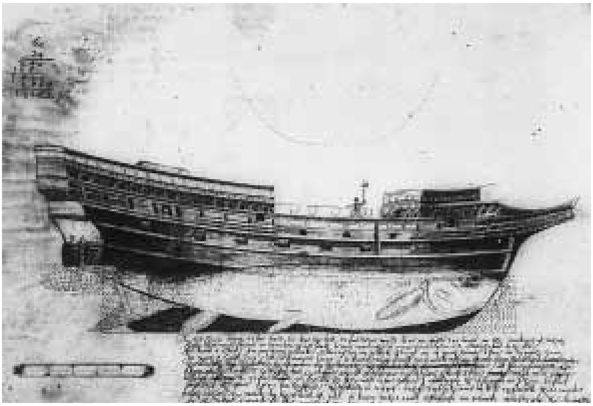


5.3.

man's capacities for movement and work, similar to the limbs of the body and reducible to the same vital principles, as the limbs, in their turn, are reducible to mechanisms which are moved directly by the 'soul.' The real objective of [his] research lay in comparing and giving a single interpretation of the biological universe and the mechanical universe."[6]

In any case, from the Leonardo who proclaims his conviction that "the bird is an instrument operating through mathematical laws"[7]or the Gómez Pereira whose *Antoniana Margarita* of 1554 defends the thesis that all creatures except



5.4.

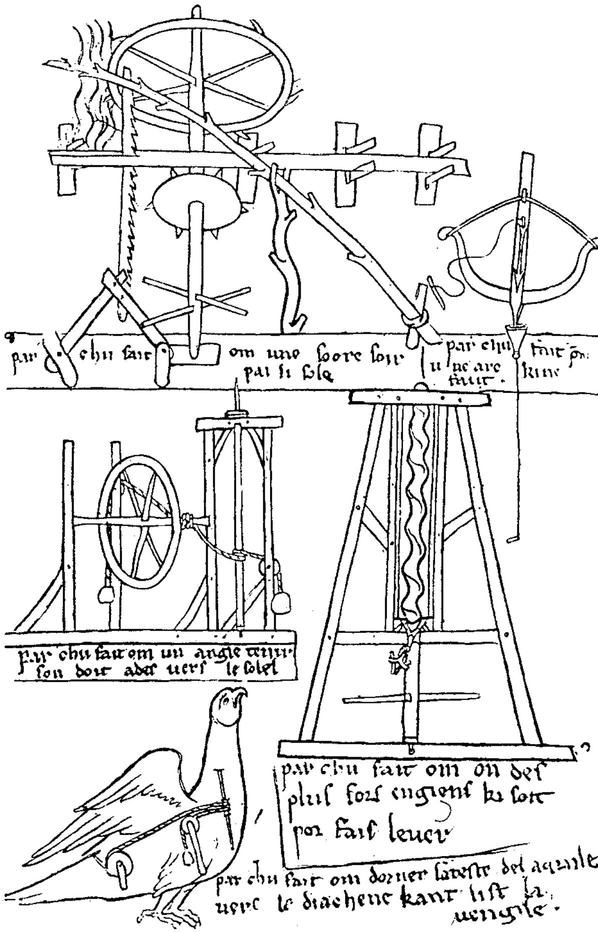
From the flight of birds to the navigation of fish. The same eye contemplates the bird as a flying machine and the navigating machine as a fish: the organic is perceived in mechanical terms, and the mechanical in organic terms. The bird is seen as a natural mechanism; the ship as a fish built in a shipyard. There is no break between the artificial wing and the swimming ship.

5.1. *Leonardo da Vinci, air compression under the wings of a bird, 1513–1514. Paris, Ms. E, folio 47 verso.*

5.2. *Leonardo da Vinci, mechanisms for moving an artificial wing. Codex Atlanticus, folio 341 recto.*

5.3. *Leonardo da Vinci, shapes of fish and ships, 1510–1515. Paris, Ms. G, folio 50 verso.*

5.4. *Comparison of the hull of a ship with the body of a fish taken from* Fragments of Ancient English Shipwrightry, *a work of the late sixteenth century partly attributed to the Elizabethan shipbuilder Matthew Baker.*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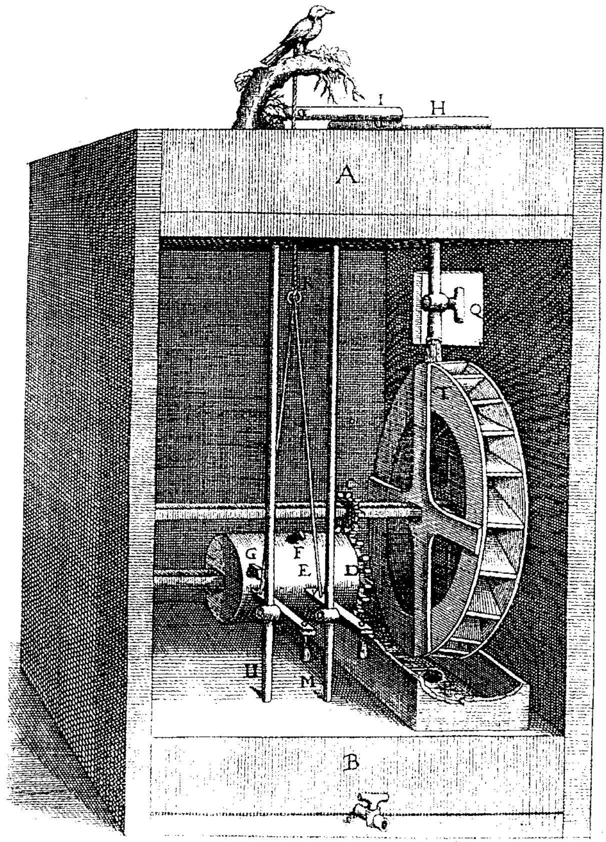


5.6.

The anatomie mouvante *of birds, from Villard's eagle to Salomon de Caus's birds. Whether a medieval marvel or a mannerist curio, the automaton helps span the gulf that separates mechanisms from organisms.*

5.5. *Eagle with an articulated head in a page of Villard de Honnecourt's* Album *(c. 1240).*

5.6. *Mechanical bird in Salomon de Caus's* Les raisons des forces mouvantes *(Frankfurt, 1615).*

man are automata without a soul, there is a long history of contemplating living nature in mechanical terms.[8] Unquestionable milestones in this history are *la bête machine* (the animal as a machine) of the *Discourse on Method* and the detailed elaboration that Julien de La Mettrie made almost a century later, in *L'homme machine* of 1748.[9]

During this long period the proliferation of rudimentary automata served as a symbolic bridge between machines and organisms;[10] the clockwork or hydraulic mechanisms of Juanelo, De Caus,[11] Kircher, or Vaucanson fascinated their contemporaries and continue to amaze us today.

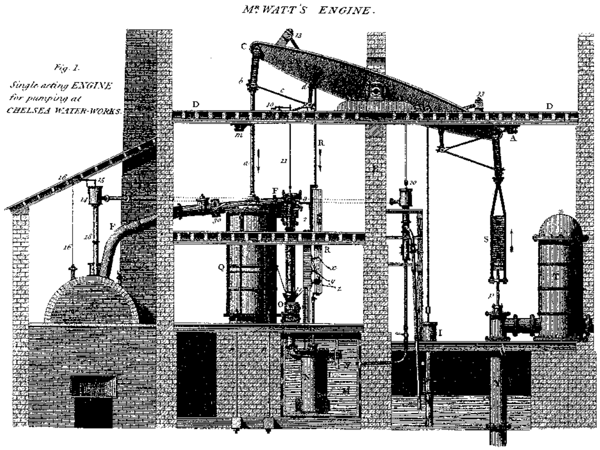
It is astonishing to see how tenaciously these makers of machines seek to create replicas of living beings. Juanelo Turriano, for example, is known for the water lifter he built for the city of Toledo[12] but probably spent more time contriving automata: flying birds, shepherdesses playing the lute, and swordsmen for the entertainment of Charles V. Jacques de Vaucanson, to mention another case, invented a new type of lathe and revolutionized textile machinery, but these technological advances cannot be separated from his work as a builder of automata, which gave him popularity and fortune. Through them, moreover, he was able to offer an admirable material illustration of Descartes's philosophical theses,[13] accurately interpreted by his *anatomie mouvante:* machines that ape the organism make it possible to think of the organism as a machine. Mumford is perhaps not altogether fair, therefore, when he says that "technology remembers Vaucanson for his loom, more than for his mechanical duck that seemed alive and could not only eat but also digest and excrete."[14] Despite their apparent frivolity, automata are technical testing grounds; even more importantly, they are eloquent ideological manifestos—more accessible than philosophical treatises—through which mechanical and clockwork views of the organism are diffused and generalized.

From the clock to the steam machine
thermodynamic Freud

The mechanical *Weltbild* underwent a deep transformation with the advent of the steam machine. While maintaining a significant continuity with the mechanical paradigm and thus confirming Lewis Mumford's opinion that "the clock, not the steam-machine, is the key-machine of the modern industrial age,"[15] the invention of this machine brought about a major shift in the functional and symbolic realm.

Prigogine and Stengers have described such shifting of emphasis thus: "Developing from an automaton nature, which is as alien to man as a clock is to a clockmaker, in the course of the nineteenth century we witness the transformation of that mechanical nature into a motor nature, with the new, distressing question regarding the exhaustion of resources and the descent into conflict with the rival perspective of progress—precisely what has allowed the transit from the clock to the igneous machine."[16] In this way, the transit from the mechanism to the engine introduces the second expression of the dialogue between the machine and life, which consists of viewing the organism as a thermal machine.

The diffusion of the steam engine, and even more so of the science of energy built on the heat of thermal machines, gave rise to a vigorous cultural shake-up as much as to a far-reaching technical and economic mutation. Thermodynamics transformed our conception of the world: man, society, nature, from then on, would be reflected in the mirror of energy. If the scientific importance of thermodynamics was great, "its cultural resonance was also immense: a new conception of man as an energy machine [Jacques Lacan, for example, has shown to what extent Freudian theory rested on this view]; a new conception of society as an engine . . . a new conception of nature itself as *energy*, that is, the creative and productive capacity of qualitative differences."[17]



The steam machine transformed the symbolic world as much as the physical world; the engine replaced the mechanism as the key metaphor. The centrifugal regulator, which Watt added to a subsequent version of his machine and which was soon to be adopted as an emblem of science, heralded the next phase, which would lead to the servoregulated automaton.

5.7. *Watt's first steam machine, patented in 1769 and manufactured beginning in 1775.*

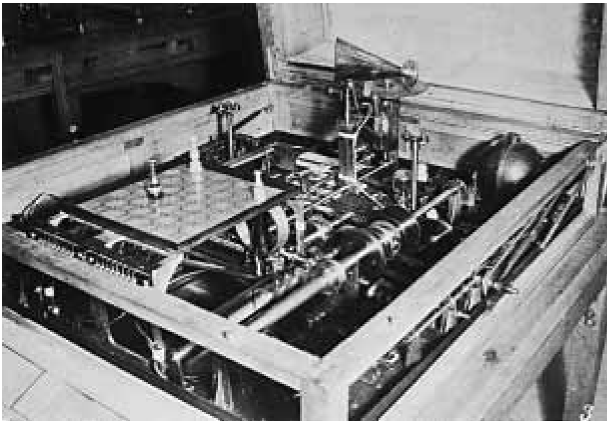
The mention of Freud in this context is not casual. His anthropology conceives the subject as a tangle of fluxes and energy drives; the role of the libido, or the relationship between the principle of pleasure and the reduction of tension, as Rudolf Arnheim has shown, establishes a direct parallel with the second thermodynamic principle.[18] Long before Lacan, this parallelism was noted by disciples of Freud like Siegfried Bernfeld, who as early as 1934 wrote that "physical systems for which the entropy principle holds behave as if they had an impulse to reduce their internal quantities of tension within the system as a whole."

In the same way, Freud's theory about irrational and unpredictable components in the mind and in human conduct creates a kinship between his work and the concept of thermodynamic causality, which substitutes chance and probability for the necessary relationships of Newtonian mechanicism. Norbert Wiener indicated the points of contact between Freud's view and Gibbs's statistical approaches, stressing that "in recognizing chance as a basic element incorporated into the very fabric of the universe, these men come close to one another, and close as well to the tradition of St. Augustine."[19]

Sigmund Freud, in any case, has only been cited as an example, especially relevant, perhaps, but by no means the only one, since the thermodynamic conception of organisms penetrates the entire cultural fabric of the nineteenth century and survives to our days. Suffice it to quote the description of a living being offered by a contemporary philosopher, Edgar Morin: "The living being is a thermo-hydraulic machine in slow combustion operating between zero and sixty degrees Celsius, eighty percent of which consists of circulating and soaking water, incessantly consuming itself and being consumed." He adds: "It is definitely a well-tempered, multi-regulated machine with a formidable informational device."[20] This last phrase already implies what would be the third expression of the dialogue between the machine and life, the contemplation of the organism as a cybernetic machine.

From the engine to the servomechanism
A cybernetic anthropology

The example of psychoanalytic theory also serves to illustrate the informational view of the organism. It was Wiener himself who induced Gregory Bateson to consider psychoanalytic practice in cybernetic terms. According to Heims, "Wiener put forward the idea that in communication



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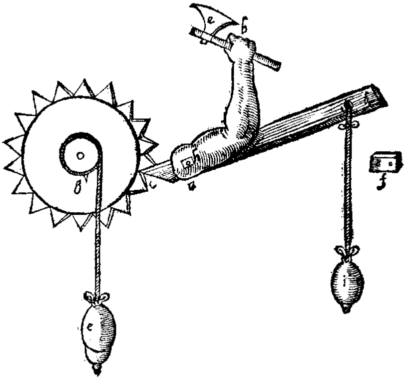


5.9.

systems the crucial concept is information rather than energy, and that therefore Freud's emphasis on libido was inappropriate."[21] Along these lines, Bateson elaborated a set of theories including that of the double link in schizophrenia, the treatment of alcoholism, and the application of family therapy, all extraordinarily influential and based on the conception of the human being as a cybernetic machine.

Indeed, this cybernetic view of organisms exceeds the anthropological limits of our example and extends to any vital phenomenon. It tends to be interpreted in terms of feedback, servomechanisms, circular processes, etc. The very popularity of these terms testifies to the diffusion of the set of theories formulated in the heat of the development of computer technology during World War II, among which we must mention—besides Wiener's cybernetics, systematically presented in 1948—the game theory of von Neumann and Morgenstern (1947) and the information theory of Shannon and Weaver (1949). Although these theoretical constructs have numerous antecedents,[22] the most relevant probably being the concept of homeostasis that was elaborated by Cannon in the late 1920s, only with them, from 1950 onward, was the conception of the organism as a servo-regulated automaton generalized.

The cybernetic automaton is the latest manifestation of the mechanical paradigm, which has been the inspiration for "living machines" since its Alexandrian origins.

5.8. *Mechanism of the second chess player of Leonardo Torres Quevedo, 1920.*

5.9. *Mechanical arm in an Italian translation of Hero's book* Automatopoietike (Gli automati; *Venice, 1601).*

As Morin has written, "the idea of the cybernetic machine moved through the track of molecular biology to become the basis of the new conception of life. . . . The incorporation of cybernetics into biology constituted an incorporation of biology into cybernetics. The living being from then on could be conceived, and was conceived, as the most complete cybernetic machine and even as the most complete automaton [von Neumann, 1966], exceeding the most modern of automatic fabrications [Rosnay, 1966] in complexity, perfection, and efficiency, even in the least of bacteria."[23]

In mentioning the transit from the clock to the steam machine, we noted that this transformation did not contradict a certain continuity of the mechanical paradigm. The same thing applies now as we consider the passage from the steam machine to the computer, from the engine to the cybernetic automaton; in this case, too, the mechanical paradigm survives, hidden but omnipresent, as the true thread of an entire age. Far from denying it, the cybernetic view confirms the persistence of the mechanism. As Ludwig von Bertalanffy has indicated, there is an evident relationship between the model of the "organism as servomechanism" and the zeitgeist of a mechanized society: "the domination of the machine, the theoretical view of living beings as machines and the mechanization of man himself" are closely related to the "mechanistic world picture."[24]

This mechanistic conception has bequeathed us a submissive, predictable, manipulable automaton nature: "a dull affair, soundless, scentless, colourless, merely the hurrying of matter, endlessly, meaninglessly," in the words of Whitehead.[25] In the final analysis, this is the very world view that underlies the analogies between the organism and mechanical, thermal, and cybernetic machines which we have described.

Note, however, that all these analogies have been put forward with the organism as the subject, or at least the image of the organism viewed through a mechanical magnifying glass, through the smoked glass of thermodynamics, or through the frosted and analytical glass of information. It is equally possible and even necessary to run the process in reverse, to scan the inside of each analogy and describe the reflections of the different categories of machines in the revealing looking glass of organic life. In this way we can understand that if there are mechanical organisms, so are there organic mechanisms; that if there is an automaton nature, so is there a natural automaton, and that the two are interrelated.

The mechanical face therefore has an organic back; the organism is perceived through the machine, but the machine is likewise perceived through the organism. The fact that both belong to the same functional realm must be understood in the context of this mutual reflection, this inextricable interweaving, this interminable dialogue of misted-up or shattered concave mirrors that distort, diffuse, and fragment—in the kaleidoscope of history—the inseparable and confronted images of mechanisms and organisms.

Organic mechanisms

mechanical machines and mechanizing machines

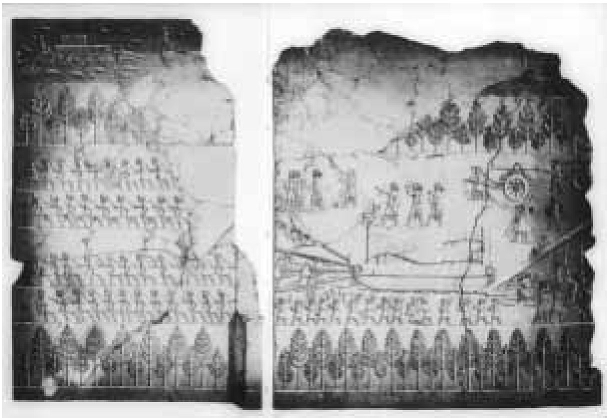
What emerges from the foregoing is that the machine can be contemplated *from* the organism and *as* an organism. Having spoken of the *bête machine*, we shall now describe the mechanism as a prolongation of the organic body and as a materialization of the organization of the social body. If we have mentioned the conception of the organism as a thermal machine, so is it possible to speak of thermal machines as organisms and extensions of the organic; finally, in the same way that we have dwelt on the contemplation of living beings as servomechanisms, so shall we on that of cybernetic automata as living machines.

Even at its very origins, the machine was indebted to the organism for at least two reasons. On one hand, as Ernst Kapp suggested more than a century ago in his *Grundlinien einer Philosophie der Technik*, it can be said that machines come about as projections of organs, so that the hammer, for instance, is an extension of the fist, and the assemblage comprising the hammer and the hand that clenches it is the equivalent of an elemental machine.[26] On the other hand, as repeatedly stressed by Lewis Mumford, the mechanism appeared as an element of social life long before the peoples of the Western world turned to the machine.[27] What he calls the "social megamachine"—the mechanical organization of the slaves who built the pyramids, the soldiers of the Macedonian phalanx, or the oarsmen of Roman galleys—entailed the creation of organic machines to precede and prepare the way for mechanical devices.

Subsequently, the artificial creation of a moving agent with the first steam engine meant a qualitative leap in the mechanical evolution and an opportunity to renew and reinforce the organic conception of the machine, as enthusiastically expressed by Bernard Forest de Belidor,[28] who contemplated one of the first Newcomen machines in France and shared his experience in *L'architecture hydraulique:*

> So here is the most marvelous of all machines; its mechanism resembles that of animals. Heat is the principle behind its movement; the circulation produced in its conduits is like that of blood in veins, with valves that open and close according to need; it nourishes itself and excretes on its own at an established rate, and extracts from its work everything it needs in order to subsist.

A century later in 1853, describing the opening of a factory in the industrial community of Saltaire, a British clergyman adopts the same fervent tone: "Finally the large steam



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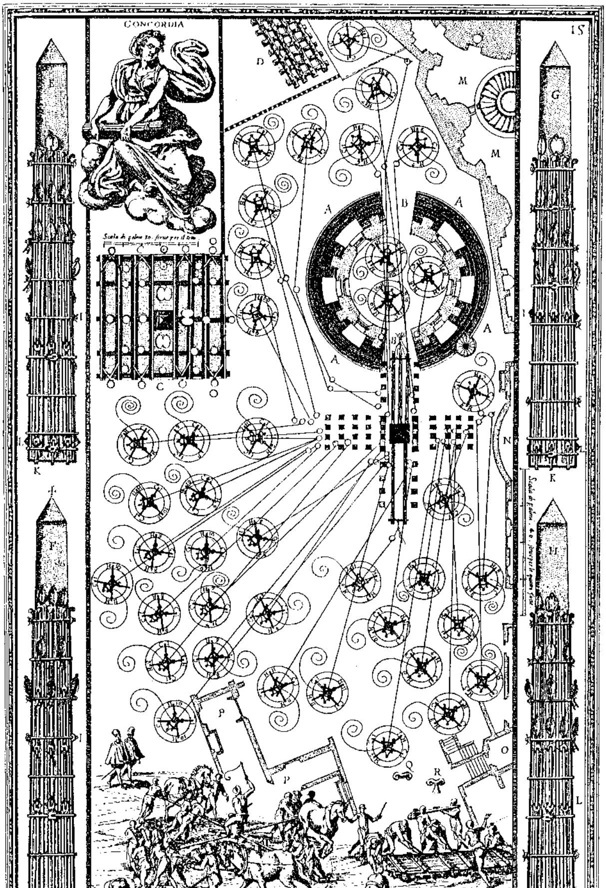
The reverse of the automaton is represented by the mechanical organization of organic motion: in the former, the mechanical pretends to be organic; in the latter, the organic anticipates, mimics, and emulates the mechanical. Transporting an Assyrian statue or the Vatican's obelisk requires an intricate social choreography, with a clockwork precision similar to that expected of a chorus line. As in Juanelo's Artificio, the "dancing machine" and the mechanical dancer join hands.

5.10. *Assyrian bas-relief depicting the transporting of a statue, seventh century B.C., British Museum.*

5.11, 5.12. *Domenico Fontana,* Della transportatione dell'obelisco vaticano *(Rome, 1590).*

5.13. *Busby Berkeley,* Footlight Parade, *1933.*



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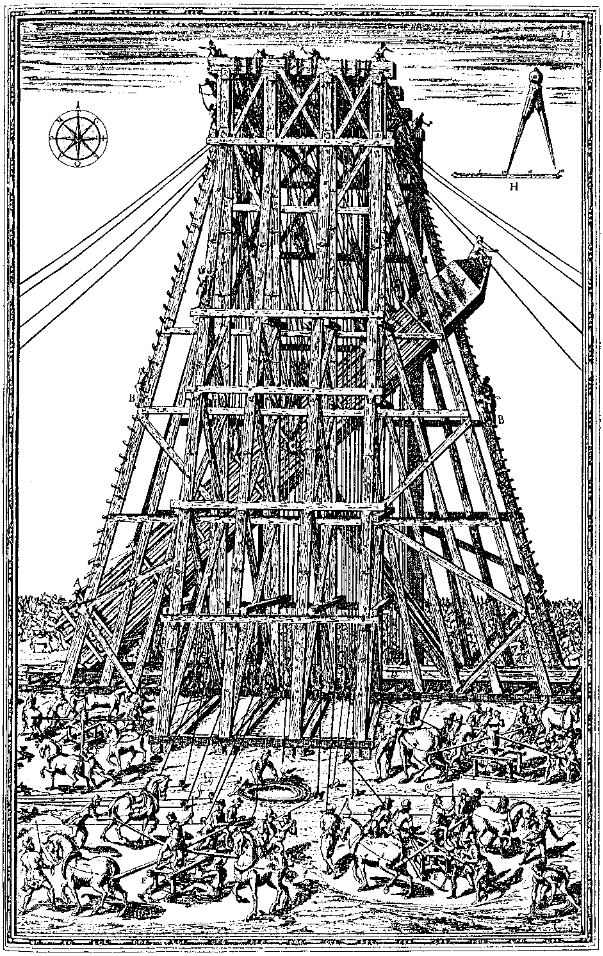

5.12.

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machines began to move, transmitting energy to all parts of the vast organism which, as if touched by a mysterious hand, woke up to life. . . . What a marvelous scene!”[29]

In both cases, in contrast to the conception of the Cartesian *bête machine* (and despite their being inscribed in the same mechanical universe), it was no longer the organism that was interpreted as a machine, but the machine that was explained in organic terms. In this context, as Mumford noted, it was perhaps more than anecdotal that Giovanni Branca’s engraving representing one of the steam machine’s antecedents should depict an anthropomorphic cauldron. Thermal machines constitute a spectacular second approximation to the organism, and it comes as no surprise that they are understood in terms of it.

Samuel Butler was keenly aware of this approximation when he put the following words in the mouth of the author of the book of machines: “The vapour-engine must be fed with food and consume it by fire even as man consumes it; it supports its combustion by air as man supports it; it has a pulse and circulation as man has. It may be granted that man’s body is as yet the more versatile of the two, but then man’s body is an older thing; give the steam-engine but half the time that man has had, give it also a continuance of our present infatuation, and what may it not ere long attain to?”[30] As we see, the phantom of the rebellion of machines already weighs over industrial culture: the shadow of the automaton hovers over a world where the line between organisms and mechanisms is progressively blurred.

Finally, the third great approximation of the machine to the organism can be associated to cybernetics and what Morin has called “the Wienerian revolution: contemplating the machine as a living being,” with a use of terms that endeavors to be more rigorous than metaphorical. This concept of Wiener and its extrapolation in the works of

Maturana, Varela, and Morin himself affirms that "today we must conceive the machine not as mechanism but as praxis, production, and *poiesis*," since "in the machine there exists not only the *mechanical* (repetitive) but also the *mechanizing* (inventive)."[31]

This organic, creative, *mechanizing* view of the cybernetic automaton tries to break what Mumford has called "the ominous bond" between the "automaton" and the "other," an irremediable consequence of the gestation of the automaton, which "is the last step in a process that began with the use of one part or another of the human body as a tool,"[32] that is, in a process of increasing alienation from the organism of man. Nevertheless, this "mechanizing machine" has no tranquilizing effect; far from making the mechanical automaton more attractive, it gives it the outlines of a nightmare.

Living machines

between the golem and the cultural fact

The growing mechanization of the organic[33] and the parallel biologization of the mechanical have preoccupied not only the apostles of vitalism—who criticize the metaphor of the automaton because, unlike the living being, it has an end that lies outside of itself—but also the creators of the latest generation of automata, the cybernetic machines, and particularly the greatest of them all, the mathematician Norbert Wiener.

Wiener indeed was aware of the risks involved in a biological interpretation of cybernetic machines, which he associated with the golem, the disturbing animated robot of Jewish legends.[34] "The machine," he said, "is the modern equivalent of the *golem* of the rabbi of Prague." And his own work "with mechanical analogies between organisms, or the nervous systems of organisms, and automata or formal or

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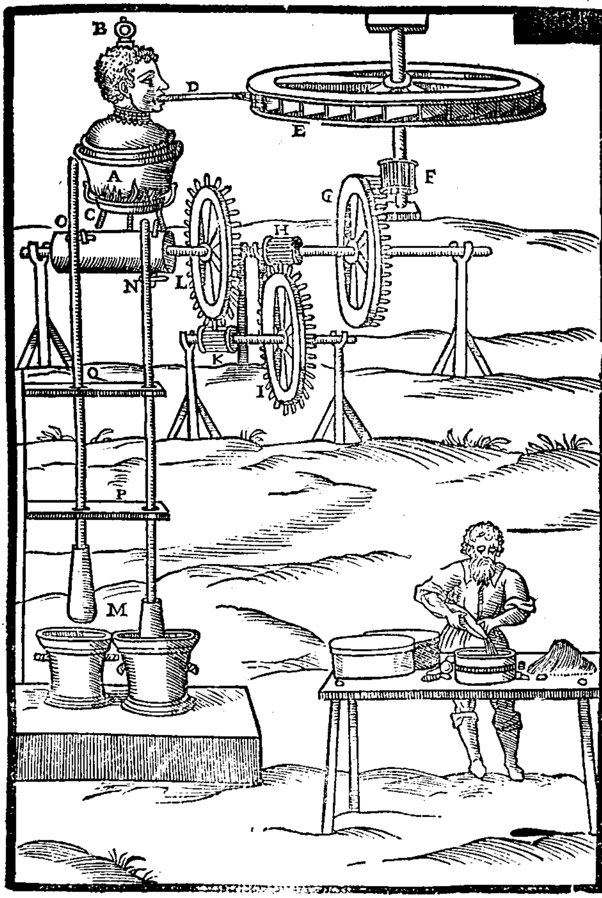

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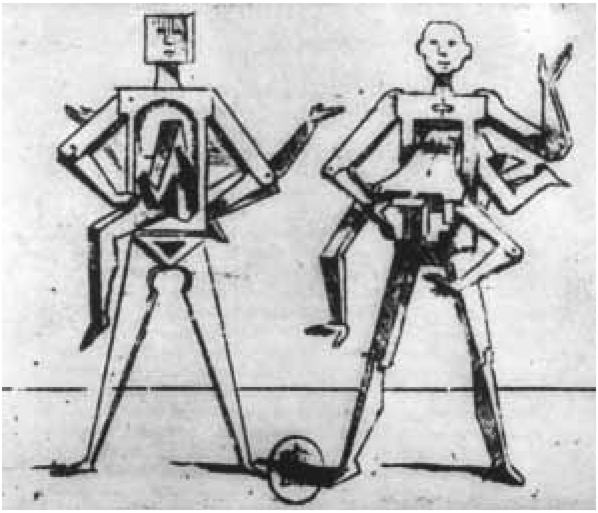

5.15.

From the naive ingenuity of the anthropomorphic boiler or the articulated mannerist doll to the disturbing golem or the perverse robot: mechanical machines have given way to mechanizing machines. The intelligent automaton threatens to supplant the organism.

5.14. *Giovanni Branca*, Le machine *(Rome, 1629).*

5.15. *G. B. Bracelli, etching, late sixteenth century.*

5.16. *Paul Wegener*, Der Golem, *1920.*

5.17. *Fritz Lang*, Metropolis, *1927.*

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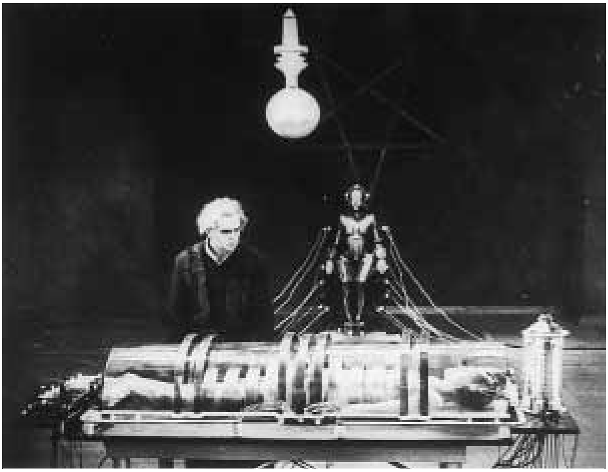


5.17

mechanical models," as Heims has observed, made him resemble "the maker of a *golem*."[35]

In this preoccupation with the supplanting of life by the mechanism, Wiener's attitude contrasts with that of another great mathematician, the creator of the theory of automata John von Neumann, whose career ran parallel to Wiener's in many ways but who accepted the protagonism of the machine. Perhaps better than anyone else, von Neumann represents the survival of the mechanical paradigm in this third cybernetic phase, as proven by his own epistemological position, since unlike Wiener, who "considered random processes and chaos fundamental, von Neumann saw the mechanism and the logic underlying it in all scientific phenomena."[36]

Live cybernetic machines are the ultimate expression of the kidnapping of life by mechanism, but they simultaneously and paradoxically present the possibility of defeating the mechanical automaton and the view of nature "as a stupid and passive mechanism, essentially alien to freedom and the aim of the human spirit,"[37] and of replacing, as Prigogine has proposed, the classical description of the world as an automaton with the Greek paradigm of the world as a work of art.

Note that the world is referred to as a work of art, a product of culture, and not as a biological organism. Up to this point we have shown that if organisms can be contemplated as machines, so machines can be interpreted as living beings. Here, following Mumford's advice, we have avoided "the false notion that the mechanism has nothing to learn from life" and "the equally false notion that life has nothing to learn from the mechanism," and tried to stress the close bond that renders the organism and the machine inseparable. In the light of this bond, it would be inconsistent to substitute a totally organic for a totally mechanical conception of the world, one being practically equivalent to the other. We ought to pay heed to Ludwig von Bertalanffy's warning: "After having overthrown the mechanistic view, we are careful not to slide into 'biologism,' that is, into considering mental, sociological and cultural phenomena from a merely biological standpoint."[38]

In architecture and urbanism it is mechanical analogies that have been worn out by overuse, but we must keep in mind that buildings, like cities, in the words of Kevin Lynch when referring to the latter, "are not machines and neither are they organisms, and perhaps resemble them even less. . . . Rather than communities of non-thinking organisms undergoing inevitable phases until they reach a certain iron limit . . . cities are the product of beings capable of learning. Culture can stabilize or alter the habitat system, and it is not clear whether we wish it to be otherwise."[39]

Such a capacity to learn and such a cultural dimension of the transformation of the environment, both of which require the protagonism of human freedom, can be said to be incorporated in that version of thermodynamic architecture which made time and memory its axis, and which we previously called rehabilitative architecture to distinguish it from heliotechnical and bioclimatic architectures, expressions of the mechanical and organic paradigms.

Mechanical Wright, organic Le Corbusier
the biotechnical unanimity

The foregoing has offered many examples of the links between organisms and mechanisms that enable us to situate the corresponding analogies in a common functional space. We can now verify the hypothesis through a parallel reading of the two architects of this century who best represent these opposed approaches: Frank Lloyd Wright and Le Corbusier.

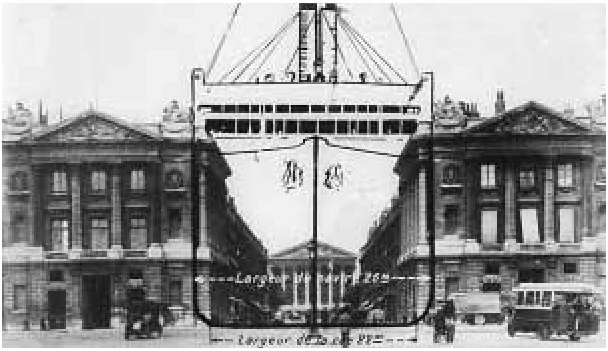
In chapter 1 a comparison between Wright and Le Corbusier was drawn to present the characteristics of igneous and solar architecture, using terms that referred us to the cosmological opposition that had taken shape between the world of combustion and that of trajectories. A similar opposition between identical poles is present in our discussion of the bond that links the conceptual pair organism/mechanism to the architectural pair bioclimatic/heliotechnical.

We say "a similar opposition" because the organic, an inevitable reference in bioclimatic architecture, is an evident expression of the aleatory and unstable world of combustion, while the mechanical, besides being a characteristic feature of heliotechnical architecture, is a necessary component of the obligatory, clockwork world of celestial orbits. And we say "identical poles" because both architectures admirably reflect the fire/sun and the organism/mechanism dialectic. These intertwined analogies are what enable us to consider Frank Lloyd Wright a representative example of the bioclimatic school and Le Corbusier a perfect paradigm of heliotechnical architecture.

The association of these names to the organic and mechanical views of architecture is of course a commonplace in architectural criticism, so we shall refrain from dwelling on it further. Suffice it to remember, in the words of Peter Collins, that "in the present century the biological analogy has been associated primarily with Frank Lloyd Wright," whereas "we are mainly familiar with the mechanical analogy as expressed by Le Corbusier in *Towards a New Architecture*,"[40] although both analogies, as Collins notes, have their roots in the last century.[41]

Nonetheless, the idea here is not so much to dwell on what is specifically organic in Wright or mechanical in Le Corbusier as to examine the points of contact between both perspectives which allow us to encapsulate them within a common field. Chapter 1 ended with a mention of the double dimension, functional and symbolic, that characterizes the relationship between architecture and energy. The examination to be undertaken must necessarily begin with a parallel verification that the lines separating organism from mechanism are as vague and blurred in the functional field as they are clear and sharp in the symbolic field.

In fact we could say that if the mechanism appears as a mediator between architecture and biology, so does the organic serve as a bridge between the building and the machine. To Wright, the mechanical imitates the organic;[42] to Le Corbusier, it is the organic that must be contemplated in mechanical terms:[43] organism and artifact intertwine and intersect, quoting each other, reflecting and explaining one another. Wright wrote that "a chair *is* a machine to sit in . . . a tree *is* a machine to bear fruit . . . they are that before they are anything else. And to violate that mechanical requirement . . . is to finish before anything of higher purpose can



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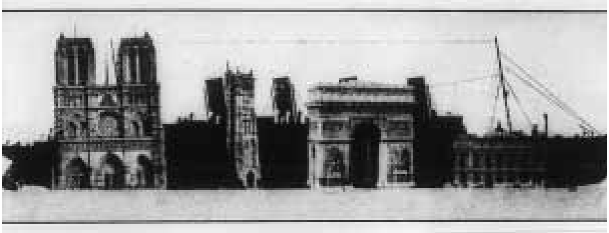

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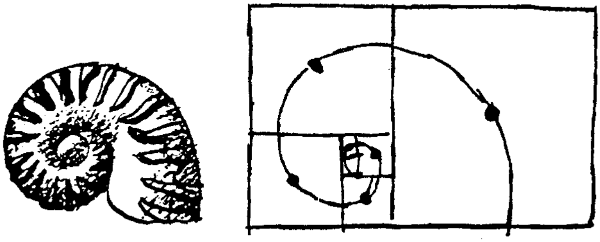
Le Corbusier's mechanical analogies contain organic echoes. Does not the beauty that contemporary architects were incapable of seeing in a ship have something to do with the way it is adapted, like a fish, to move in water? Besides competing in size with Parisian buildings, are not his ocean liners living machines that snort and puff out smoke like the buildings in Metropolis?

5.18. *Le Corbusier, ocean liner and Paris street, 1925.*

5.19. *Le Corbusier, the* Aquitaine, *from* Vers une architecture *(1923).*



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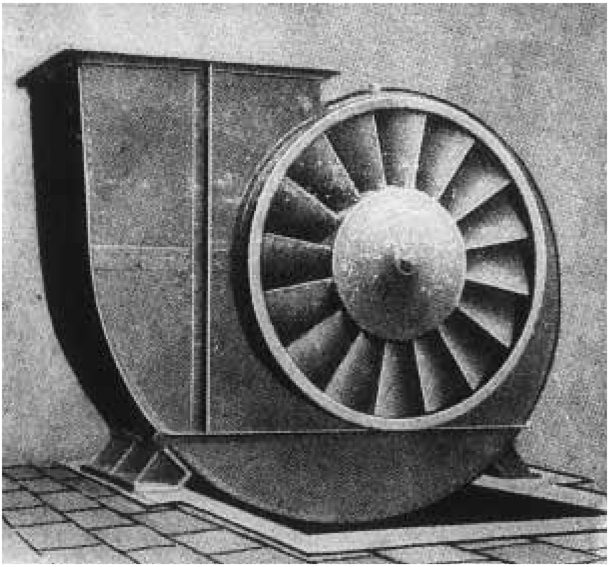


5.21.

happen."[44] Le Corbusier, in turn, did not hesitate to define the city as "biologie cimentée."[45]

Words of one could easily be taken for words of the other. The fervent organicist of Broadacre spoke of the city as a "great machine" that has been formed in "blind obedience" to the cosmic laws of a universe that in a sense is also an "obedient machine";[46] the propagandist of the *machine à habiter* described his Ville Radieuse as an "organized body" supporting a "biological organization" in an 83-page text where, according to Françoise Choay, the words *vie* and *vivre* appear 65 times (not counting verbal conjugations and derived adjectives!).[47]

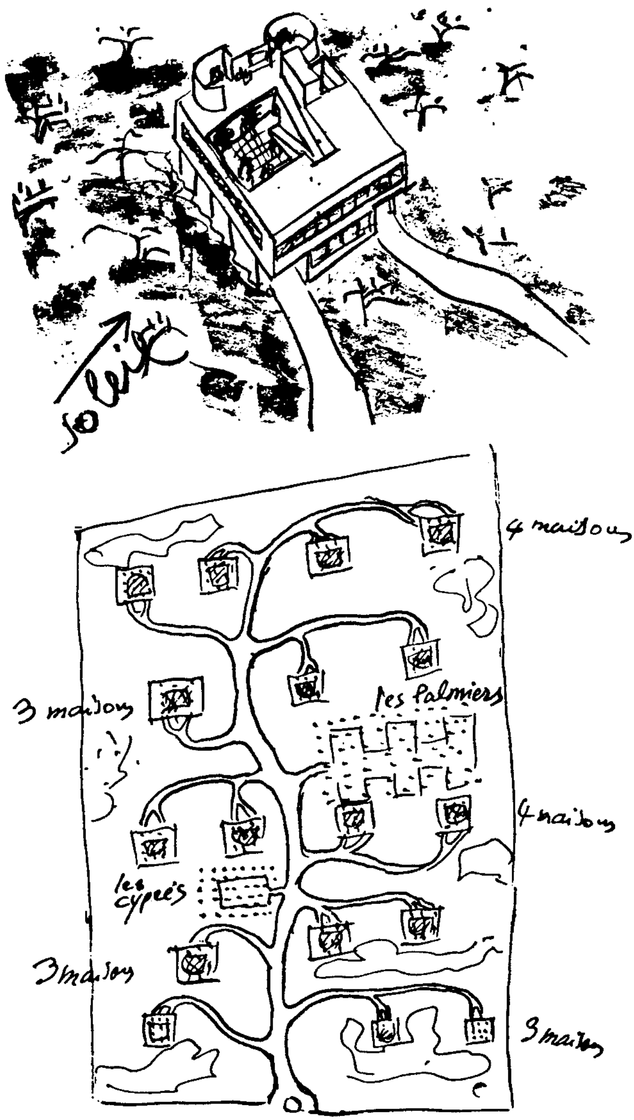
"Any house is a far too complicated, clumsy, fussy, mechanical counterfeit of the human body. Electric wiring for nervous system, plumbing for bowels, heating system and fireplaces for arteries and heart, and windows for eyes, nose, and lungs generally. The structure of the house, too, is a

Similarly, his organic analogies leave mechanical sediments. When proposing the snail as the origin of the spiral motif, was he perhaps also thinking of the fan that he reproduced in Vers une architecture? *Do not the branches or blood vessels he proposed to form the fabric of circulations in his Villa Savoye complexes link up the repeated model of one of the most eloquent symbolic manifestos of the machine age?*

5.20. *Le Corbusier, spiral motif, from* Oeuvre complète.

5.21. *Le Corbusier, low-pressure fan, from* Vers une architecture *(1923).*

5.22. *Le Corbusier, suburban complex formed by multiple Villa Savoyes, from* Précisions *(1930).*


soleil
4 maisons
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5.22.

kind of cellular tissue stack full of bones."[48] When Frank Lloyd Wright writes this, we hear echoes of Le Corbusier's biological comparisons "of the physiology of breathing with the ventilation of buildings; of the nervous system with the networks of electricity supply, communication and telephone services in a building or city, of the bowels with sewer pipes and refuse systems; and, favourite analogy of all, the circulation of the blood with the circulation of people or traffic."[49]

In fact such parallelisms obey the deeper connections that bring biological and mechanical analogies together, as we have already said, in the common functionalist stream of the modern movement,[50] always underlying which, as Alan Colquhoun and Philip Steadman have written, is "an implied belief in biotechnical determinism."[51] A biotechnical determinism, incidentally, that is present as much in heliotechnical architecture, whether the equinoxes and solstices that govern Le Corbusier's *brise-soleil* or the solar charts that define the design of solar collectors in the latest generation of autonomous houses, as it is in bioclimatic architecture, whether the influence of site and region on Wright's desert houses[52] or the microclimatic detail of the passive architecture of recent years.

Mechanical cathedrals

the functional machine and the symbolic machine

If organism and mechanism, as we have seen, interpenetrate and merge in the functional field, in the symbolic realm their respective images move away from one another and polarize into a state of permanent confrontation. It is this expressive, aesthetic, symbolic conflict that makes Wright criticize the "childish attempt to make buildings resemble steamships, flying machines, or locomotives," in what is a clear allusion to the proliferation of mechanical images in *Vers une architecture*. He writes:

Nor should we outrage the machine by trying to make dwelling places too complementary to machinery. . . . The machine . . . should build the building, if the building is such that the machine may build it naturally and therefore build it supremely well. But it is not necessary for that reason to build as though the building, too, were a machine—because, except in a very low sense, indeed, it is not a machine, nor at all like one. . . . Let us not forget that the simplicity of the universe is very different from the simplicity of a machine.[53]

Thus the polemic takes shape above all in the plane of images. Underlying either set of stylistic codes is a deep-rooted acceptance of industrial production processes and adherence to Taylorist methods.[54]

In the case of Le Corbusier, the matter is so clear that it will suffice to recall the hymn to Taylorism he intoned in some famous paragraphs after visiting the Ford assembly lines in Detroit:

When the cathedrals were white, collaboration was complete. . . . In the Ford factory, everything is collaboration, unity of views, unity of purpose, a perfect convergence of the totality of gestures and ideas. With us, in building, there is nothing but contradictions, hostilities, dispersion, divergence of views, affirmation of opposed purposes, pawing the ground. . . . Let the hitherto contradictory currents line up in a single procession. . . . Let the ghosts stop blocking the road![55]

To the architect, overwhelmed as he is by the great American dream, the dilemma can be expressed clearly: “On one side barbarism, on the other—here at the Ford plant—modern times.”[56]

Wright's case, however, is more complex. His ferocious diatribes against the machine did not preclude his occasional use of the Model T to explain what his "assembled house" would be;[57] and the same architect who warned against the machine becoming "a way of life instead of being used by life as a tool" built what is surely the most eloquent monument to the mechanical way of life, the Larkin company headquarters.

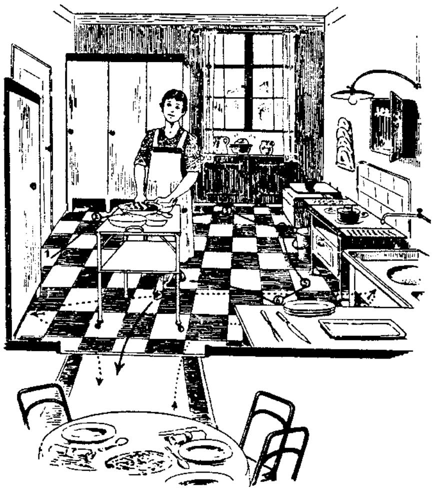
Completed in 1904, two years before the publication of Frederick Winslow Taylor's chief work, *Principles of Scientific Management*, the Larkin building is indeed the physical materialization of mechanical space. The machine is present in this huge administrative container ("a cathedral of work"), not so much as artifact but as mechanized social organization. The rigid Fordian regimentation of office employees operating in a single space, the strict arrangement of work stations, and even the furniture contribute to what Mumford called a social megamachine, the mechanical organization of human labor that historically preceded the emergence of the machine as a mechanical artifact.

Le Corbusier's mechanical cathedral. Le Corbusier found his "white cathedrals" in the Ford assembly lines of Detroit. "On one side barbarism, on the other—here at the Ford plant—modern times." A year later, Charlie Chaplin presented modern times under a different light. But the Taylorist rationalization of domestic space had already been proposed in Germanic Europe back in the 1920s.

5.23. *Charlie Chaplin*, Modern Times, *1936.*
5.24. *The Ford factory, around 1936.*
5.25. *Kitchen for rationalized movements, Erna Meyer, Stuttgart, 1926.*

5.23.

5.24.



5.25.

In this sense it could be said that the Larkin building has more merits as a product of the universe of machines than much of what we have called engineering architecture. On entering the building, the employees find themselves in a mechanical universe where their individual freedom is reduced to a minimum (despite the emphatic inscription engraved over the main entrance: “Honest labour needs no master”). They have no control over its artificially homogeneous thermal and lighting conditions; the height of the windows prevents them from having any visual contact with the outside; they may not modify the furniture arrangement, with the desks rigorously lined up in rows and the filing cabinets stuffed under the sills; there is no privacy whatsoever in the vast supervised spaces; not even the seats can be moved around as they are attached to the desks on one arm.[58]

Mechanization of work and organizational Taylorism are therefore the protagonists of this architecture: an architecture that contains a formidable social machine, but which, paradoxically or perhaps consequently, *does not express it.*

Le Corbusier deemed the industrial assembly line to be the contemporary equivalent of the building of medieval cathedrals; Wright built his work cathedral—conceived with the same reverential attitude as the contemporary Unity Temple—as a tribute to the scientific organization of administrative labor. These mechanical cathedrals are the dream shared by the two architects: the industrial factory that processes matter at the Ford plant and the administrative factory that processes information at the Larkin building[59] belong, in the final analysis, to the same material and philosophical paradigm.

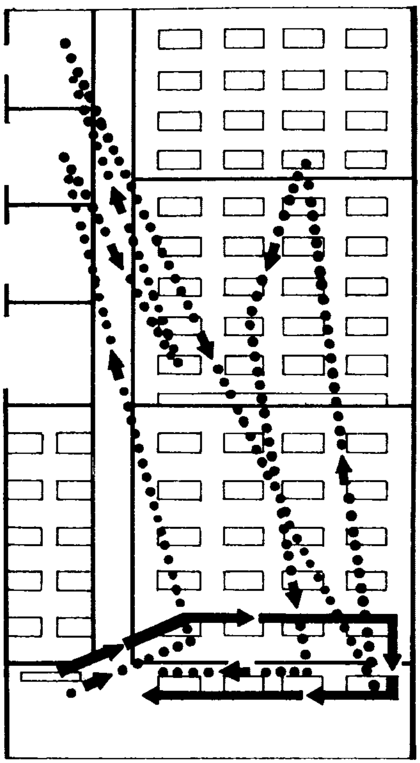
Frank Lloyd Wright's mechanical cathedral. The Larkin building was designed as a "cathedral of work": the formidable panoptic space is a monument to the supervision and control of mechanized administrative work. It would still take nearly two decades for Galloway—who in 1918 proposed Larkin as a model for the "modern office building"—to apply Taylor's methods of scientific organization of work to these information-processing factories, methods that Klein would later use in his studies on housing.

5.26. *Interior of the Larkin building, Frank Lloyd Wright, 1904.*

5.27. *Rationalization of paperwork movement in an office, Galloway, 1921.*

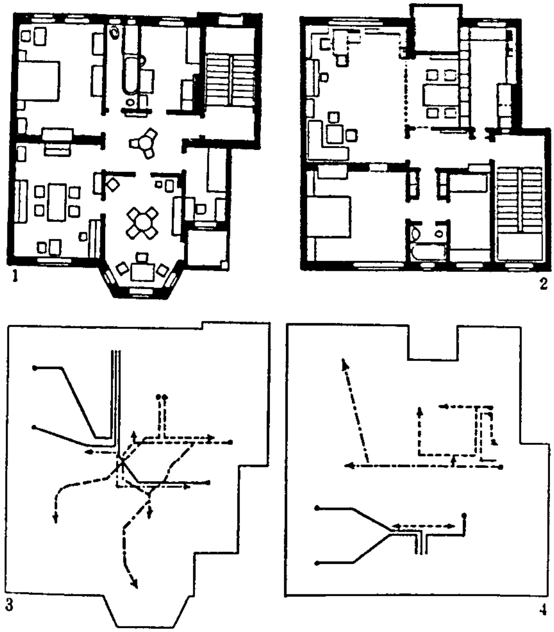
5.28. *Studies on the layout of housing, Alexander Klein, 1928.*

5.26.



5.27.

Chosen here as representatives of mechanical and organic poetics, Le Corbusier and Wright are clearly one in accepting the *functional machine*, though their attitudes continue to vary when it comes to the *symbolic machine*. Similarly, heliotechnical architecture and bioclimatic architecture—which we have associated with these two architects from the very beginning—are situated in what could be called a broad functionalist position; readily assuming functionalism, both



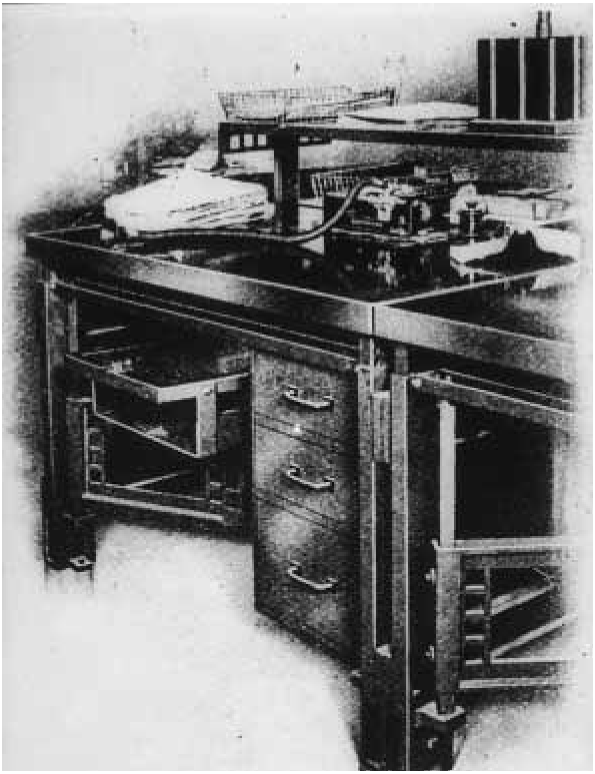
5.28.

locate the machine-life polemic in a decidedly symbolic realm. Otherwise, organism and mechanism are by all means equivalent, and the architectural analogies made about them interchangeable.

Environment and form

between tabula rasa and the memory of place

All this emphasis on the equivalence of the mechanical and organic approaches might be judged to be rather excessive. We should thus probably qualify it by recognizing, in Peter Collins's words, that "one great advantage of the biological



The Larkin building, erected at the threshold of the twentieth century, was an early and eloquent manifestation of the machine universe. Its articulated metal furniture pieces were the fruit at once of the normalization of objects and the normalization of processes, of the ergonomic rationalization of furniture and the Fordian rationalization of work.

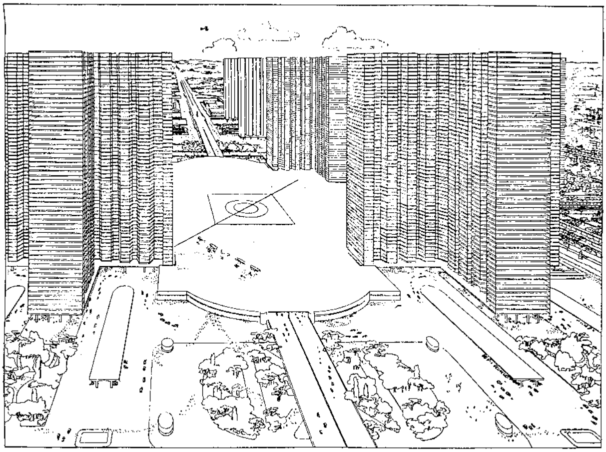
5.29. *Furniture of the Larkin building, Frank Lloyd Wright, 1904.*

[over the mechanical] analogy was that it laid particular emphasis on the importance of environment, since clearly all living organisms depend on environments for their existence, and constitute in themselves environments which influence other organisms nearby."[60] In our case, the notorious advantage of bioclimatic architecture over heliotechnical architecture rests on a similar reasoning.

But Collins himself qualifies this observation at another point of his text: "So far as [Darwin's] biological theory of the relationship of form to environment is concerned, the relevance of Darwinism to architecture has tended to decrease. Improvements in air-conditioning equipment[61] are making architectural form increasingly independent of climatic considerations."[62]

In any case, the environment that biological metaphors give importance to tends to be exclusively the natural environment, and only rarely that involving the built domain. In fact, the two architects we have used as paradigms significantly express themselves in very similar terms when calling for a "fresh start" (Le Corbusier) or a "radical elimination" (Wright) of all existing construction.[63]

Such a tabula rasa stance appears in both heliotechnical and bioclimatic architecture, which deal with an exclusive dialogue between the building and the outside world (whether that of trajectories or that of climate), ignoring its relation with other buildings. A permanent dialogue with the built domain only appears in that variant of thermodynamic architecture we have conveniently called the architecture of rehabilitation, with the priority it gives to existing things and its attention to memory, and where the term "environment" acquires all the rich historical, cultural, and collective connotations that are absent in mechanical and organic reductionisms.



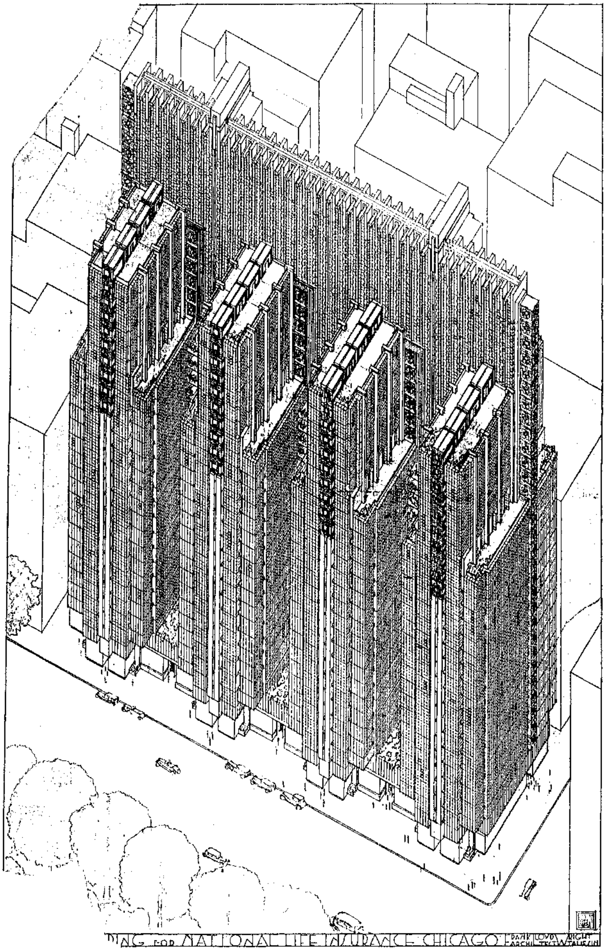
5.30.

The mention of the collective dimension here is not at all casual. On the contrary, one of the most important aspects of rehabilitative architecture is precisely the shift of emphasis from individual buildings to communities of buildings. Here we are following up on what Morin calls the superposition of a collective "macro-order" and an individual "micro-disorder,"[64] in order to approach the existing (and remembered) environment with its varied buildings, which Alberti rightly said was produced not by the diversity of uses or desires but by the diversity of people.[65]

Though so often opposed to one another, Wright and Le Corbusier worked from a common stem of visionary, radical, optimistic, and amnesic modernity.

5.30. *Ville Contemporaine, Le Corbusier, 1922.*

5.31. *National Life Insurance building, Frank Lloyd Wright, 1924.*


DING FOR NATIONAL LIFE INSURANCE CHICAGO
FRANK LLOYD WRIGHT ARCHITECT TALIESIN

5.31.

If people are diverse and buildings heterogeneous, the reconciliation of the latter's micro-disorder with the geographical and historical macro-order in which they are inserted becomes the main task of an architecture that endeavors to rehabilitate places and memories, in quest of a climatic and technical but also social and cultural genius loci.

Given their irreducible uniqueness, an energy-oriented examination of *individual buildings* would require analytical tools of a symbolic and perceptive nature far transcending the intentions and possibilities of this text. The relationship between energy and style in the context of the search for a possible thermal aesthetic; the importance of perceiving energy and embracing temperature versus the contemporary dominion of the visual that constitutes a true "dictatorship of the eye"; the influence of energy on the shape of space, from the protagonism of climate to that of fossil fuels; the shift from thermal variety to thermal homogeneity, from the space hierarchized by the central hearth and articulated by the positioning of rooms to the space/time uniformity generated by artificial light and peripheral heating; the symbolic dialectic between the transparent architecture of glass and the opaque architecture of the fireplace, between the greenhouse and the cave, lightness and thermal inertia; energy understood as a repairing *pharmakon* in the Albertian framework of a rehabilitation theory: all these themes require extensive elaboration not to be undertaken here. Chapter 7, which serves as an epilogue, simply sketches some of the issues in the context of a quick history of thermal space in architecture.

As for the energy-oriented analysis of *communities of buildings*, it introduces questions of an economic and sociological nature that are difficult to avoid. Rehabilitative architecture that endeavors to value the existing while proposing technical and symbolical alternatives involves the conservation of whatever energetic capital—physical or informational—has accumulated through time in the built domain.

Among the questions raised by such an analysis, none is as important as that concerning energy accounting. This has played a major role since the 1970s as the key to a possible technical and social alternative by which, in the context of an ecological economy, "arbitrary" monetary calculation would give way to "objective" energy computation. In the field of construction, energy accounting gave rise to hopes for the discovery of a scientific standard that would make it possible to quantitatively compare different technical options, thereby clearing the road toward an environment-conserving architecture: one that is an enemy of waste, jealous in the preservation of inherited knowledge, careful in the use of material and energy resources; an architecture reconciled with both nature and culture.

The progress that energy accounting has made in this context cannot be overstated. The next chapter will therefore tackle the historical origins of the concept.

six

Energy as the Currency of Nature: A Genealogy

From Social Energetics to the Construction of an Ecological Economy

Energy accounting, from myth to tool

The importance of energy accounting to a thermodynamic conception of architecture has been sufficiently discussed. It began to emerge at the start of the seventies in the heat of environmental concerns and shot to the center of public and professional attention with the oil crisis of 1973. But the discipline of energy accounting did not make it to the eighties in good health, debilitated not so much by its inherent frailties as by the disproportionate weight of the expectations that were placed on its shoulders. Held by many to be at once the basis of a new theory of value, the fundamental concept by which to supersede monetary fetishism, the essential tool for econometrics, social forecasting, and economic planning, and the philosopher's stone that would make it possible to reconcile technology and nature, economics and ecology, energy accounting not surprisingly tottered, to the disappointment of whoever had chosen it as a lever to move the world.

It is therefore about time that we relieved it of its exaggerated responsibilities and established the chores it can perform without abusing the concept or exhausting the instrument. Far from scornfully demoting it, to relieve the discipline of the Herculean tasks previously assigned to it is to express absolute confidence in the future of the idea and the fertility of its approach, both of which would be seriously threatened if we insisted on overwhelming it with the burden of multiple mirages: the mythical discipline must be transformed into a modest analytical tool.

The concept can best be reduced to its proper dimensions by exploring its genealogy. Though as a method it flourished only in the seventies, its roots reach back at least two centuries, intertwining all the currents that would impetuously and simultaneously rise later. At the same time, going back to origins necessarily entails untying contemporary knots and separating the threads of strengths and insufficiencies, vices and virtues. To penetrate the idea's prehistory is to illuminate its labyrinthine present, and recuperating the concept's infancy contributes to an understanding of both its sudden maturity and premature exhaustion.

Moreover, the history of energy accounting is an evocative narrative in which economics, physics, and biology engage in dialogue and competition, misunderstanding and plundering, undermining and instructing one another: a narrative, incidentally, that no one, as far as I know, has told yet.

The prehistory of calculation

Physiocrats and the tableau oeconomique

As with so many other adventures of modernity, perhaps it is not inappropriate to situate the beginning of energy accounting in the Enlightenment. The Physiocrats of Louis XV's Versailles introduced three of our narrative's key themes.

First is the central role that economic government plays in social life. François Quesnay, the leader of this early systematic school of political economy, expressed it in words that have become famous: "The small discoveries, the curious experiments of scientific academies, the small investigations, the dubious dissertations of antiquaries, are frivolities and trivialities when compared to the study of the essential objects of economic government."

Next is the quantification of fluxes as a tool of interpretation. Quesnay's *Tableau oeconomique* of 1758 is the most illustrious antecedent, with a two-century difference, of Leontief's input-output tables, which have been extremely important in the development of energy accounting.

Last is the exclusive attribution to nature of the origin of wealth. Appropriately headed by a connoisseur of the natural world (Quesnay was Louis XV's doctor), the members of the Secte des Economistes judged agriculture, based on land, to be the only really productive activity, thereby laying the foundations for a theory of value centered on nature or *physis*.

Significantly, it was a detractor of the Physiocrats—Ferdinando Galiani, who attacked their utility-based theory of value as well as their defense of the regulation of commerce—who then introduced a fourth thread in the history being narrated here: the concern about scarcity and waste, which the abbot Galiani associated with fashion, "that disease of the human mind," as he called it in his famous *Della moneta*, published in 1751.

Note that energy has not appeared yet; it is to do so later in the context of a theoretical construction, thermodynamics, and of certain practical devices, thermal machines. Though Newcomen's machine already existed, Watt's—and with it, modern industrial society based on the consumption of fossil energy—was not to be developed until the 1770s, and even then the communication between technicians, scientists, and economists that would later bear so much fruit was far from fluid. Adam Smith, for example, as Jouvenel observed, wrote his *Wealth of Nations* at the same time and in the same university where Watt perfected his steam machine, yet the only use he imagined for coal in his work was its capacity to warm the workers.[1]

Energy equivalences, from Rumford to Joule

energy, currency of physics

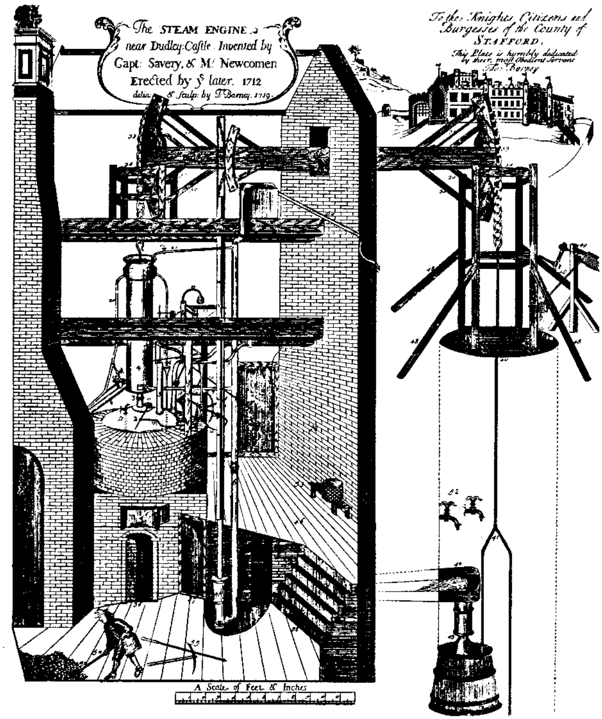
It took until the middle of the next century for the concept of energy to crystallize and for its possible use as a unit of accounting to be considered, but before the eighteenth century was over Count Rumford had performed the famous experiment that proved the existence of a link between mechanical movement and heat,[2] thereby paving the way for Joule's determination of the "mechanical equivalent of heat" and the consequent understanding of energy—in what is an early economic metaphor—as a "currency of physics" during the second half of the nineteenth century.

This was anticipated by a professor at the Ecole Polytechnique, J. N. P. Hachette,[3] when he proposed that all natural phenomena be measured in terms of the new dynamic

Watt's first machines replaced Newcomen's in the Cornwall mines, quadrupling output; the subsequent rotary model supplanted the pumps and machinery moved by animal traction at London breweries. Whereas in the former case the inventor's economic agreement with the proprietors was based on the amount of fuel saved, in the latter the power of the machine had to be determined so as to set a canon proportional to the number of horses it rendered unnecessary. Thus Watt established the horsepower of steam (the work that could be achieved by a horse) as a new unit of power, thereby facilitating energy computations.

6.1. *Steam machine of Savery and Newcomen, 1712 (engraving by Barney, 1719).*

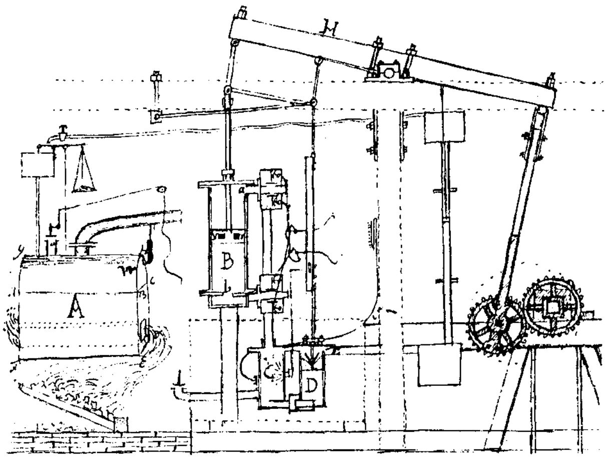
6.2. *Sketch of Watt's rotary machine in Georg von Reichenbach's notebook, 1791. With the help of his drawings, this German engineer built high-precision steam machines in his country, as would the Spanish engineer Agustín de Betancourt in France, where he reproduced by memory a machine he had briefly observed in London in 1788.*



6.1.

unit kgm (in 1811, incidentally, the same year that Jean-Joseph Fourier was awarded a prize by the Academy for his theory on the spread of heat in solids, a work that amounted to a first blow on Laplace's mechanistic system).

Founded on similar lines and even closer to the concept of energy accounting is the curious calculation formulated by the mathematician and member of Parliament Baron Dupin to compare the power of France with that of England. Through a series of scales expressing the equivalence in men



6.2.

of horses and donkeys (such as 1 horse = 7 men), Dupin came to the conclusion that France had “37 million active men, 8,400,000 being of the human race.” With coal included, France had 48.8 million men and England more than 60 million.

I owe the anecdote to Alfred Sauvy, who went on to say that “seen from the viewpoint of its time, this calculation is no more extravagant than some of our contemporary operations of national accounting. At least it has the merit of escaping the field the monetary accounting and of confirming the idea of the multiplication of human power.”[4] Nonetheless, both Hachette’s proposal and Dupin’s suggestive calculation constituted isolated initiatives of energy accounting that were not followed up on.

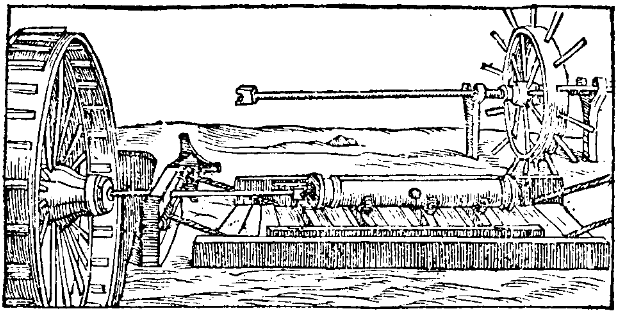
The works of Charles Babbage warrant separate mention. This pioneer in computers wrote fundamental texts about the relation between science and industry, such as the deservedly famous *On the Economy of Machinery and Manufactures*, published in 1832, two years before he founded the Royal Statistical Society. In the book Babbage refererred to Malthus and his theory of value, saying that "an estimate of the quantity of that food on which the labourer usually subsists" could perhaps be used as a unit of measurement.[5]

The contemporary study carried out by Carnot regarding the efficiency of the transformation of heat into mechanical energy in thermal machines can be hailed—following Georgescu-Roegen—as the first work in econometrics.[6] But in this case too the ideas were pursued no farther, and the publication of the *Réflexions* in 1824 went unnoticed on the whole.

Notice came, as we have said, with the second half of the century, which began with the publication of two major works that laid the bases of the first law of thermodynamics, establishing the equivalence of the different forms of energy and the possibility of using it as a general unit of measurement: *On the Mechanical Equivalent of Heat*, which Joule published in 1850, and *Outlines of the Science of Energetics* by W. M. Rankine, published five years later.

Awareness of scarcity and waste in Jevons's *Coal Question*

The importance of these books, which laid the theoretical foundations of energy accounting, should not let us forget that, in their emphasis on the necessary conservation of energy, they conceal the very motive for undertaking such calculations: an awareness of the finite character of energy resources, and the consequent concern about waste. Regarding such preoccupation with scarcity, which we previously discerned in Galiani, an obligatory reference is the *Essay on the Principle of Population* that Malthus published in 1798, and, in the context of energy, Jevons's *The Coal Question*.

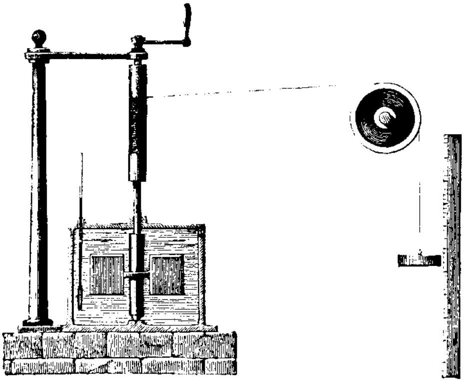


6.3.

In 1798 Count Rumford demonstrated that the mere mechanical movement of a machine for drilling holes in cannons produced heat, and half a century later Joule determined the "mechanical equivalent of heat," paving the way for the use of energy as an accounting unit: a "currency of physics" that would also be a currency for social calculation.

6.3. *Cannon-perforating machine. Vannoccio Biringuccio*, De la pirotechnia, *(1540).*

6.4. *Device designed by James Joule in 1847 to measure the mechanical equivalent of heat. The weight moves the blade, and the thermometer registers the temperature increase for a given amount of work.*



6.4.

Though the latter work is undoubtedly the best-known and most influential warning by an economist about the risks of energy exhaustion,[7] similar fears had been expressed long before by persons of different disciplines.[8] During the 1830s, in the same cradle of the first Industrial Revolution that was to produce Jevons's book, alarm about the wasteful bulk sale of coal gave rise to laws that fixed its price and corresponding duties on the basis of the weight of the mineral. The precautions were intended to prevent the burning at mine entrances of all the small coal, which brought no economic profits. It was at this time that a geologist—the Reverend William Buckland, one of the most eloquent critics of the "deplorable and almost unbelievable fact that . . . nearly a third of the best coal produced by the mines of Newcastle is condemned to be wasted in the gigantic perpetual flame that burns at the mouth of practically all the pits of the district"—warned that "a large part of the nation's current wealth being machine-based . . . its prosperity will not survive the exhaustion of coal."[9] These same arguments would be further developed a generation later by the author of *The Coal Question*.

William Stanley Jevons, whom his contemporaries called the "Malthus of energy,"[10] published his famous work drawing attention to the limits of economic development based on the availability of coal in the same year (1865) that Clausius coined his well-known cosmological expression of the second law of thermodynamics, according to which the world's entropy always tends to increase. Though one is tempted to make connections, the chronological coincidence—like that of Hachette and Fourier half a century before—does not denote a common theoretical universe. Hachette and Jevons operated within the mechanistic categories that Fourier and Clausius were beginning to demolish. In doing so they were placing the debate—on both energy accounting and resource forecasting—in the framework of what has been called culture of energy, in contrast to a possible culture of entropy that is only now beginning to be discerned.

In fact, Jevons himself announced in 1871 his intention to establish a new economics as "the mechanics of utility and self-interest," and revealed an utter fascination with the mechanistic dogma of Laplace in his *Principles of Science* of 1874,[11] which propounded that economics be raised to the category of an exact science in which even pleasure could be properly measured.[12] This of course places Jevons in the quantitative context of the energy equivalences of the first principle, which contradicts the qualitative emphasis that characterizes the second principle of thermodynamics.[13]

In the same way, his conviction that "economics, if it is to be a science at all, must be a mathematical science" led him to wrestle with the contradiction arising from the use of statistical data in his mechanical equations, a contradiction he resolved by expressing the hope that such data might in the future become "more complete and accurate . . . so that the formulae could be endowed with exact meaning."[14] That aside, his theory of value, based as it was on utility, definitively led him away from the possible development of an energy basis for economics that *The Coal Question* pointed to.[15]

Jevons must nevertheless be credited with having introduced, not so much the concept of economic forecasting—and here all allegations that he did not foresee the future with the accuracy of a fortune teller are unjustified—as what Schumacher proposed to call "exploratory calculation,"[16] an analytical tool from which are derived, albeit in exaggerated form, many of the monetary or physical macromodels that are now basic elements of economic theory, and which have been key stimuli in the development of energy accounting.

The heyday of energy theories, from Rankine to Ostwald

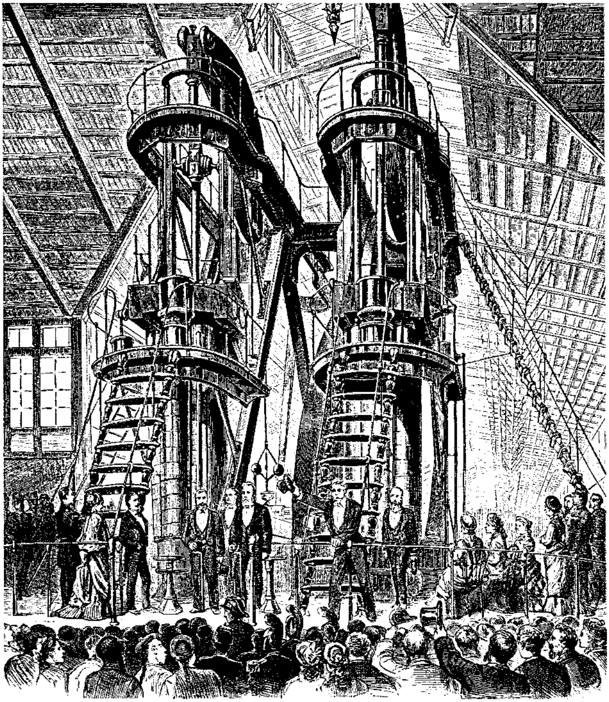
The endeavor to endow economics with a physical base, in continuity with the pioneering formulations of the Physiocrats, was notably represented in the second half of the century by the figure of the socialist Ukrainian physicist Sergei Podolinski. In an article published in 1881, Podolinski strove to reconcile the work-based theory of value with energy accounting by integrating economic cycles with natural cycles, amid the skepticism of Engels who deemed it "totally impossible to try to express economic relationships in physical terms."[17]

Engels, of course, was more sensitive to the problems of scarcity and energy waste that Jevons had brought up than to the attempts at expressing natural and economic flows in energy units. As he told Marx in a letter of 1882, "what Podolinski has completely forgotten is that the working man is not only a fixer of present solar heat, but more than that, a squanderer of past solar heat. The degree of wastage of energy reserves, coal, minerals, forests, etc., you know only too well, more than I do." And in another letter written only a few days later he concluded: "The old economic fact, therefore, that all industrial products must be based on agricultural products, on livestock, hunting, and fishing, can if you wish be translated to physical terms, but we would benefit little from it."[18]

It is not to be forgotten that such polemics thrived in the favorable breeding ground of the energy theories that had flourished thanks to Rankine's *Outlines* of 1855, and which, as Baracca points out, were much diffused through Central Europe during the last decades of the nineteenth century,[19] a century which for Marx and Engels would have been not only the century of Darwin but also that of Mayer, Joule, and Clausius.[20]

It was also in this context of the popularity of energy theories that the first analogies between money and energy were drawn. Georgescu-Roegen named the German physicist Georg Helm as a pioneer in this regard in his *Die Lehre von der Energie* of 1887. His ideas were to be expanded at the close of the century by Leone Winiarski, who affirmed that "the prices of commodities . . . represent nothing but the various conversion coefficients of the biological energy. . . . *Gold* is therefore the general social equivalent, the pure personification and incarnation of socio-biological energy."[21]

The "energetics" theory of the German chemist Wilhelm Ostwald was at its height at the time. Inscribed in the century's positivist and romantic tradition, this antimechanistic and antimaterialistic school of thought defended energy conservation as being the only principle of the natural sciences. In his famous lesson of 1895, Ostwald proposed that "the mechanistic interpretation of natural phenomena be replaced by energetic interpretation . . . [since] the only direct knowledge we have of the outside world has to do with its energetic condition."[22] Matter can only be understood in terms of energy, since only energy can impress upon the



The heyday of energy theories in the final decades of the nineteenth century coincides with a formidable leap, in terms of scope and dimension, in the development of thermal machines. Corliss's steam machine, an emblem of the United States' Centennial Exhibition held in 1876 in Philadelphia, was the largest of its era and symbolized the energy potential of the new industrial society.

6.5. *President Ulysses S. Grant and the emperor of Brazil activating Corliss's machine. Frank Leslie,* Illustrated Historical Register of the Centennial Exhibition *(1876).*

sensory organs. Curiously, the economic dimension of energy constitutes yet another argument in favor of its reality: "the most astonishing proof of the reality of energy is that it has a mercantile value," wrote Ostwald in 1910.[23]

The influence of these theories during those years was overwhelming, so much so that Boltzmann, the atomism of whose statistical mechanics openly contradicted the energetic conceptions, affirmed in 1898 that he was "aware of being only an individual weakly fighting the current of the times."[24] The science historian Stephen Brush even attributed Boltzmann's suicide in 1906 to "the depression engendered by a deep pessimism about the future of his theory."[25]

Between physical and biological economics

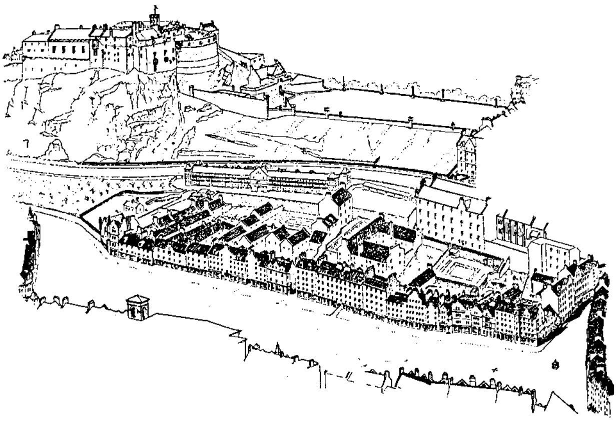
Geddes and the "vital budget"

A fruit of the popularity of energy theories was the publication during the second decade of the present century of two key works that demanded the interpretation of economics and society in terms of energy fluxes. Written by scientists with social concerns, they represent the culmination of one career and the beginning of another. *Cities in Evolution* was indeed the most important work of Patrick Geddes, an evolutionary biologist, a disciple of Huxley, and at the time a professor of botany at a Scottish university; and *Matter and Energy* is the first major publication (in this particular field, that is, since his scientific work had begun long before) of Frederick Soddy, a British chemist and collaborator of Rutherford who years later would receive a Nobel Prize for his work on isotopes.

We have already mentioned initial works of Geddes that present a sociological view of energy as early as 1881,[26] but it is in his *Cities in Evolution*, a compendium of his social and urbanistic doctrines written when the author was sixty, that his opinions about the links between economics and energy are most explicitly expressed. Here Geddes lamented the fact that "money economics" hindered one's perception of "real economics," insisted on the need for "studies of the physical realities in economic processes," and denounced "economic text-books without that elementary physical knowledge which should underlie every statement of the industrial process—save perhaps at most, a reference, and that often depreciatory, to Prof. Stanley Jevons on solar crises, or on the exhaustion of our coal supply."[27]

The world in which Geddes writes, which he calls "paleotechnic," characterized by the "dissipation of energy" and "deterioration of life," would have to give way—so the scientist predicts and the social reformer in him hopes—to a new "neotechnic" order, centered on "conserving energies" and "organizing environment toward the maintenance and evolution of life."[28] For this passage from Kakotopia to Eutopia, Geddes turns to Carlyle, Morris, or Ruskin for stimuli, for, far from being "easier to discredit . . . as 'romantic', or 'aesthetic' . . . their view of industry was already far more in accordance with the physicist's doctrine of energy than is that of the conventional economics even of to-day."[29]

In this way, the "neotechnic town" would adopt a "physical economy" where natural resources are no longer conceived in a "mere monetary sense." Money accounting would be revised, changing the money wages into a "vital budget."[30] Indeed, "Physics is not the only science which criticises the traditional paleotechnic economy with its essential resultants of dissipated energies, dust and ashes, however veiled in glittering gossamers of money statistics. Biology too has its word to say: and just as for the physicist there is no wealth save in realised and conserved energies and materials, so for the evolutionary biologist, exactly as for Ruskin before him, 'there is no Wealth but Life.'"[31]



Patrick Geddes interpreted the city in biological and energetic terms. His Cities in Evolution *opens with images of his native Edinburgh, whose medieval ecological harmony was destroyed by industrialization, and closes with a seal of the phoenix heralding the rebirth of Dublin. To the botanist and urban reformer Geddes, the medieval city must overcome the paleotechnic horrors of the industrial city and pass on to the neotechnic garden city.*

6.6. *Edinburgh's Grassmarket: the old agricultural center and marketplace at the foot of the castle hill. Patrick Geddes,* Cities in Evolution *(1915).*

The mere maintenance of life, argues Geddes, requires a minimal "vital budget" that the physiologist can determine experimentally in energy units. "This stage of biological economics once reached . . . there is of course no harm, but immediate convenience and advantage, in comparing the physiologist's minimum ration— . . . and its real and permanent statistical notation of heat and work units, 'calories'— with the fluctuating money notation of the trader and his economist. For this notation will now also serve us . . . it can no longer go on blinding us all to the physical and physiological facts behind it."[32]

The foregoing paragraphs express the contemporary view of energy accounting. The biologist, sociologist, and urbanist Geddes was not interested in the epistemological questions tackled by the Physiocrats or the classical school, nor in treatises about the economic theory of value. Rather, his use of energy as an accounting unit is in line with the search for a "real and permanent" measurement, as opposed to "fluctuating money notation." His aim is to clarify the material bases of economic life that are hidden behind the mystifying veil of monetary accounting.

Social energetics, from Soddy to Mumford

The same house (Williams and Norgate, which no longer exists) that produced *Cities in Evolution* had three years earlier (1912) published an important book, *Matter and Energy*, in which the chemist Frederick Soddy presented the first version—developed further in other works—of his ideas on the interrelation between the laws of thermodynamics and social mechanics. "The laws that express the relationship between energy and matter," he wrote, "are not only important for pure science. . . . In the final analysis, [these laws] govern the rise and fall of political systems, the freedom or servitude of nations, the movements of commerce and industry, the origins of wealth and poverty, and the general physical welfare of the race."[33]

As in Jevons, Engels, or Geddes, this opinion about the importance of energy was accompanied by a keen awareness of the problem of scarcity and the nonrenewable character of resources. "Present civilization, even in its purely physical aspects, does not constitute a continuous and self-sufficient movement. . . . It has been possible only after the accumulation of energy produced in the course of a very long period, which allows it to supplement its gains with energetic capital."[34] As he would stress in a work published ten years later, "the energy laws that govern the life of men provide the intellectual foundations of sociology and economics, and expose some of the principal causes of the failure, not only of our own but, in my opinion, of all the great civilizations that came before."[35]

Soddy's most significant contributions to the specific theme of energy accounting would not appear until 1926 with *Wealth, Virtual Wealth and Debt*, which contains one of the earliest and most detailed descriptions of the process of calculating the energetic cost of an object, for which he selects the automobile as an example. Referring to tires, he writes:

> If we go back to the origins of tires, we will discover which part of its cost must be attributed to energy expenditure. These require a flux of a given climate's solar energy, physical work in rubber plantations, coal for the railways and ships which transport the raw material from the tropics, as well as for the factories which transform it into tires. The railways and ships, in turn, and all the buildings and implements necessary for their manufacture, as well as the materials used—the iron and the metals, and the coal that must be extracted—are the result of the spending of physical energy.[36]

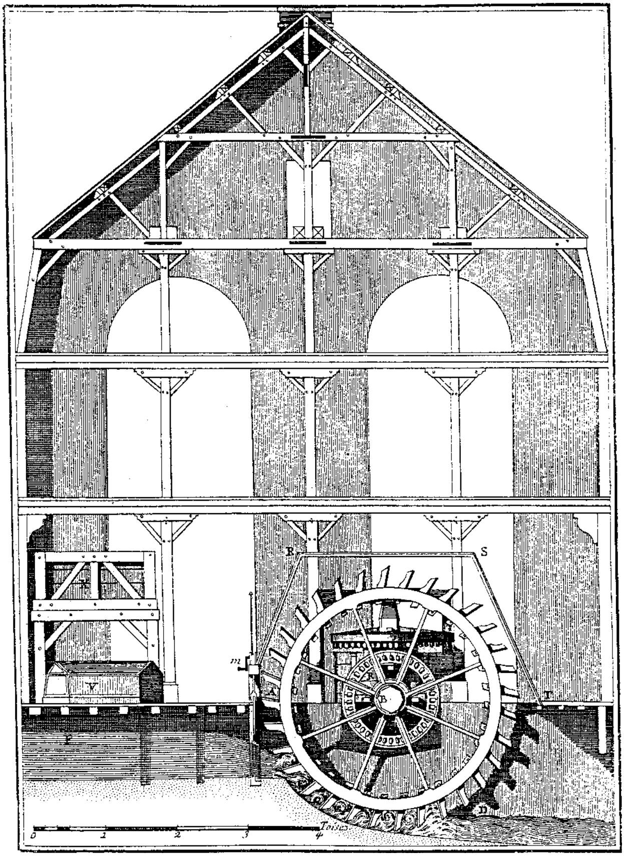
It is therefore not surprising that Soddy, after emphasizing the nonrenewable character of energy, concludes that "the flow of energy should be the fundamental object of economics,"[37] and formulates the suggestion that the relative abundance of energy in subsequent decades should contribute to its dropping into oblivion.

Geddes and Soddy put a close to a first phase in the crystallization of the concept of energy accounting. Thereafter came a parenthesis of almost half a century during which attention to these themes was superficial or nonexistent. Both the discrediting of energetic theories in the field of physics and the steadily growing availability of fuels[38] contributed to diffusing the interest in such matters.

Throughout this period, only isolated works picked up the thread left by these precursors. Worthy of special mention is Lewis Mumford's *Technics and Civilization* (1934). Mumford, a disciple of Patrick Geddes, applied the energy-related intuitions of his master and of Soddy to the historical analysis of social development, in the framework of a major publication that for the first time systematically described the interrelations between technology and culture during the last thousand years of Western civilization.

Mumford developed Geddes's concepts of the paleotechnic and neotechnic phases of culture, arriving at a division into three periods which he expressed "in terms of power and characteristic materials." Thus, "the eotechnic phase is a water-and-wood complex: the paleotechnic phase is a coal-and-iron complex, and the neotechnic phase is an electricity-and-alloy complex."[39] In this manner Mumford tried to integrate *energy* and *materials* in a global vision, these having been opposed to one another in Soddy's analysis: "Progress in the physical sphere does not come about so much through the successive control of materials . . . as through the successive control of nature's sources of energy."[40]

The volume contains frequent references to the study of economic activities from the viewpoint of energy,[41] and corresponding attacks on "pecuniary accounting": "What are called gains in capitalist economics often turn out, from the standpoint of social energetics, to be losses; while the real gains . . . [remain] outside the commercial scheme of accountancy."[42] Nevertheless, the work as a whole adds little in



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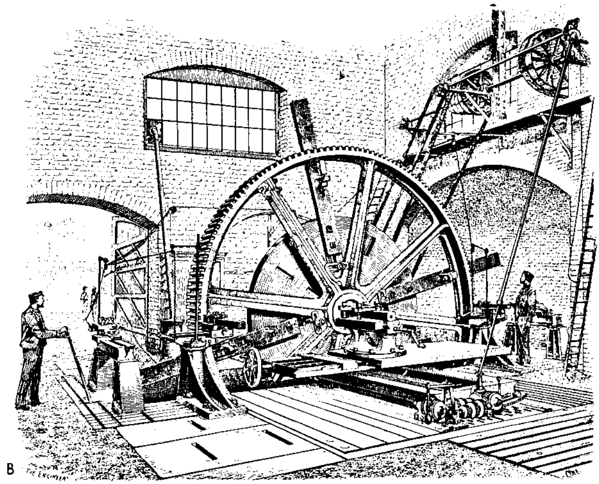


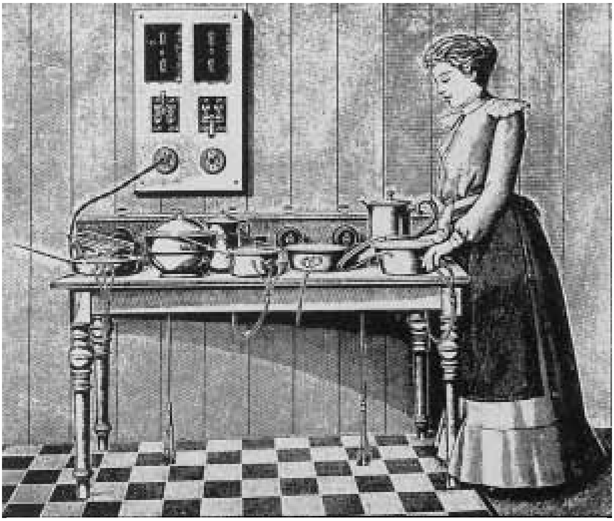
6.8.

Lewis Mumford proposed a representation of cultural evolution in terms of energy and materials: the eotechnic age is based on water and wood; the paleotechnic on coal and iron; the neotechnic on electricity and alloys.

6.7. *Section of a waterwheel (engraving in the* Encyclopédie, *1751–1780).*

6.8. *Wheel in a foundry in Soho, London, built around 1850.*

6.9. *Electric kitchen utensils manufactured in the late nineteenth century.*



6.9.

this regard to what had already been written by Geddes and Soddy (other than the historical description of social development in energy terms), and it remains an isolated effort that hardly interrupted the half-century silence in which energy accounting was immersed.

Energy flows in the ecosystem, between Lotka and Lindeman

Energy analysis recovered the limelight in the 1970s through ecology—a discipline that was celebrating its first centenary around that time and which had, precisely, come of age with the introduction of energy calculations into its arsenal of tools. Decisively instrumental for this new heyday of energy accounting were the oil crisis and the renewed validity of thermodynamics, but its link with ecology has been so close that it is difficult to understand without going through the early stages of such a fortunate encounter.

This is not the first appearance of biological preoccupations in our narrative. As a matter of fact, energy had been associated with life since the works undertaken in the mid-nineteenth century by the physiological school of Mayer, Helmholtz, and Liebig,[43] so much so that any interpretation of social or economic phenomena in energy terms almost irremediably led to a biological analysis. Still, it is true that physics had been the leading player up to this point, and considerations of a specifically biological nature, though heralded in the observations of Marshall or Geddes, began to appear in full form only with the rise of ecology.

It was around 1870 that the German zoologist Ernst Haeckel had first used this term in its contemporary sense,[44] defining it, incidentally, as the science dealing with "the economics of nature." A hundred years later Margalef would describe it as "the study of nature in terms of matter, energy, and organization."[45] His substitution of "study in terms of matter, energy, and organization" for "economics" is definitely evocative for our purposes.

In any case the important thing here is that since 1920, energy analyses—on an equal footing with the dynamics of populations—have been a priority for ecologists. Some, like the statistician,[46] demographer, and biologist Alfred J. Lotka, have been simultaneously concerned with both themes, and for this reason it is proper to begin with him.

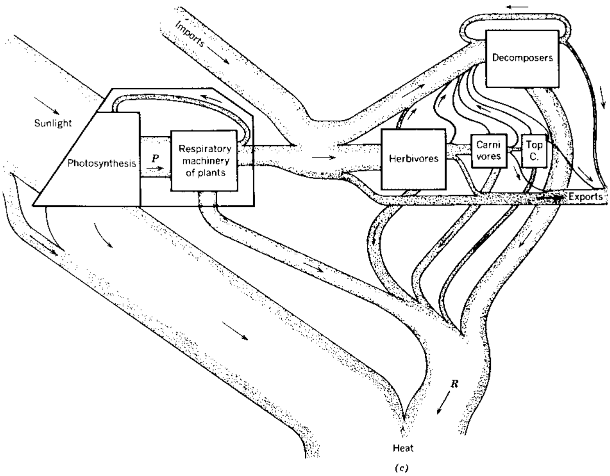
Lotka, whose differentiation between endosomatic and exosomatic tools is discussed in chapter 1, also deserves to be remembered for his contributions to the mathematical bases of the study of populations[47] and for his linking of the energy flow in organisms to biological evolution. Although the thesis he put forward in 1922, extolling the evolutionary advantage of organisms that maximize energy flow by means of the ecosystem,[48] was later qualified, there are authors who still consider it universally valid. One such is Howard T. Odum, who designates it the "Darwin-Lotka law of energy."[49]

In his *Elements of Physical Biology*, published in 1925, Lotka extended his energy concerns to the social and economic field, along the lines of Geddes and Soddy, by postulating the existence of a certain correspondence between energy and monetary accounting: "Just as one particular slot machine will always deliver a certain package of chocolate, so a certain social organization under similar conditions will render (approximately) the same amount of a selected form of energy in return for a stated sum of money."[50] Such insights of the biologist, however, are peripheral to the central thread of our present discussion, which seeks to highlight the fundamental milestones of the introduction of energy calculations into ecology. This introduction resulted in the consolidation of ecology as a scientific discipline with a solid quantitative base, and was subsequently influential in numerous fields of knowledge including economics, which would benefit from the transplanting of some of the procedures of energy accounting.

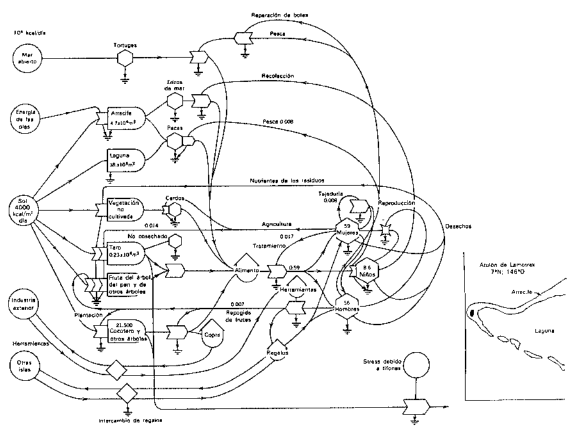
The study of energy flows in the ecosystem helps to define the bases of an ecological economy. Human systems are analyzed in terms of the circulation of energy and materials, just like natural systems.

6.10. *Flow of sunlight and food in an environmental system, with inputs and outputs of matter and energy. Howard T. Odum,* Environment, Power, and Society *(1971).*

6.11. *Flows in a stable, solar-energy-based system of low-density human population (Alkire and Odum, 1971).*


Imports
Sunlight
Photosynthesis
P
Respiratory machinery of plants
Decomposers
Herbivores
Carni vores
Top C.
Exports
R
Heat
(c)

6.10.


Reparación de botes
Pesca
Tortugas
Mar abierto
Recolección
Erizos de mar
Energía de las olas
Arrecife
Pesca 0.008
Peces
Laguna
Nutrientes de los residuos
Sol 4000 kcal/m² día
Vegetación no cultivada
Cerdos
Tejeduría 0.008
Reproducción
0.014
Agricultura
59 Mujeres
Desechos
0.017
No cosechado
Tratamiento
Taro 0.23x10⁶m²
Alimento
0.59
8.6 Niños
Fruta del árbol del pan y de otros árboles
Herramientas
Industria exterior
0.007
56 Hombres
Plantación
Recogida de frutos
21.500 Cocotero y otros árboles
Copra
Herramientas
Regalos
Otras islas
Stress debido a tifones
Intercambio de regalos
Atolón de Lamotrek 7°N; 146°O
Arrecife
Laguna

6.11.

The most important line of work in this field specifically has to do with the study of the food ladder, through which energy circulates from productive green plants to the different rungs of consuming organisms. The concept was originated in 1920 by a German biologist, August Thienemann, and developed seven years later by a British animal ecologist, Charles E. Elton, who concocted the idea of the ecological niche and that of the pyramid of numbers.[51]

It was around the same time, at Ohio State University, that Nelson Transeau first calculated the efficiency of plants in transforming energy to organic combustible,[52] and in the next decade that two American limnologists, E. Birge and C. Juday, devised the concept of primary production (the rate at which organic energy is fixed through photosynthesis) on the basis of their measurements of the energy balance in lakes.

But the discipline really came of age only in 1942, with the posthumous publication of a work by a 26-year-old American, Raymond L. Lindeman, who came up with a rigorous formulation of the current trophic-dynamic concept of ecology, centering on the quantification of energy flows through ecosystems.[53] In short, as Colinvaux graphically explained, what Lindeman did (along with George Evelyn Hutchinson, who would continue his work at Yale University) was "to think of food and bodies in terms of calories, instead of considering them organic substances. A unit of biomass represents a unit of potential energy that is measured in calories. . . . This is now known by anyone in the prosperous western countries, where people worry over the calories in their meals for fear of obesity. In the thirties and forties even illiterate chorus girls of Hollywood knew it, but biologists woke up to the idea of calories rather more slowly."[54]

The achievement of these two men of Yale was to articulate field experiences with the fundamental laws of physics, thereby endowing ecology with a quantitative rigor unknown until then: "They described the progressive degradation of energy as it circulates through the food chains, losing its capacity to do work and continuously descending toward the heat drain. The great chain of life . . . which numerous naturalists had previously intuited, now appeared clear and as a direct consequence of the second thermodynamic law."[55]

Toward an ecological economy

Georgescu's entropy and Odum's power

As we have already said, the rebirth of interest in energy accounting was to take place only in the seventies in the context of the new ecological science that had incurred so great a debt to thermodynamics. To be sure, there were isolated works during the fifties—such as those by Zimmermann, Cottrell, and White—that continued the old tradition of social energetics, but the new approaches were not to be articulated clearly until the seventies.[56] The year 1971 saw the publication of two books that became—and remain to this day—obligatory references for the economy-ecology polemic. They were also immediate precedents of the works that proliferated in the wake of the oil crisis of 1973–1974.

Written, respectively, by an economist and an ecologist who apparently never met and certainly did not quote one another,[57] both texts have been deservedly popular and singularly influential. The book by the economist, Nicholas Georgescu-Roegen, describes the economic process in thermodynamic terms; that of the ecologist, Howard T. Odum, extends the energetic conception of ecosystems that we have just described—a conception whose crystallization owes much to his teacher Hutchinson and to his brother Eugene P. Odum, chief propagator of these ideas through his 1953 *Fundamentals of Ecology*[58]—to the economic and social systems built by man. From different starting points, and in the context of the environmental concerns of the late sixties, both Georgescu-Roegen's *The Entropy Law and the Economic Process* and Odum's *Environment, Power, and Society* try to formulate an ecological economy, and agree that the road to it passes through energy.

Observe, however, that this is the word both titles are most careful to avoid: Georgescu speaks of *entropy;* Odum, of *power*. And it is in this apparently innocent choice of terms that we can best perceive the conceptual and methodological gulf that, despite so many coincidences, finally sets the two works apart. The economist's priority was finding a new groundwork for his discipline, and he decided to look for it in the law of *entropy*, the second thermodynamic principle; the ecologist tried to apply the most fruitful methods of his own field to other spheres, and for a tool chose the analysis of *power* or energy flow. Whereas the economist proposed to integrate his discipline into ecological science,[59] the ecologist expressed a desire to broaden his own so that it could absorb economic science, among others.

They therefore wrote complementary books which, in their reciprocal intention to absorb and be absorbed, were vivid testimony of the attraction that the rising star of ecology held for the declining star of economics. Pulled down by the ruin of its material fruits, the latter sought to reconstruct its theoretical structure over the same conceptual foundations that have made ecology a solid field today: energy analysis.

As no brief summary of these two fundamental books can possibly do them justice, we shall simply reproduce the words with which the authors themselves have identified the context of their works. To Georgescu-Roegen, The important fact is that the discovery of the Entropy Law brought the downfall of the mechanistic dogma of Classical physics which held that everything which happens in any phenomenal domain whatsoever consists of locomotion alone and, hence, there is no irrevocable change in nature. It is precisely because this law proclaims the existence of such a change that before too long some students perceived its intimate connection with the phenomena peculiar to living structures. By now, no one would deny that the economy of biological processes is governed by the Entropy Law, not by the laws of mechanics. The thought that the economic process, too, must be intimately connected with the Entropy Law is the origin of the inquiry that forms the subject of this book.[60]

Odum, in turn, described the purpose of his work thus:

In recent years studies of the energetics of ecological systems have suggested general means for applying basic laws of energy and matter to the complex systems of nature and man. In this book, energy language is used to consider the pressing problem of survival in our time—the partnership of man in nature. An effort is made to show that energy analysis can help answer many of the questions of economics, law, and religion.[61]

Thus, Georgescu-Roegen is of the opinion that economics, like biology, ought to endow itself with a thermodynamic base; and Odum proposes methods already being used in ecology to carry this out and build an energy-oriented social accounting.

Growing world awareness concerning the environment, resources, and population, which took hold around that time,[62] also presented the possibility of using energy accounting no longer merely to express economic magnitudes in physical terms, but also to introduce environmental externalities[63] into social computation and planning as well as the forecasting of the capacity of processes to maintain themselves durably. In this way, when the material and ideological shake-up of the oil crisis came a few years later, conditions were ripe for a torrent of works that, armed with the analytical and predictive weapon of energy accounting, endeavored to face up to the challenge of the new circumstances.

This last stretch of the history of energy analysis, during which it reached its prime through noneconomic scientists like Leach, Commoner, Lovins, and Odum himself (to name only the better-known ones), goes beyond the time scope of our narrative, but it has a rightful place in a description of the present situation of the method and of the hopes and frustrations aroused by it, as well as the ambiguity and fecundity it still possesses.

seven

Thermal Space in Architecture

Construction and Combustion, from Vitruvius to Le Corbusier

The silent place and the silent hearth
from primitive fire to thermal muteness

In this epilogue I will try to tackle two principal issues: on one hand, the idea that architecture has a material, visible dimension and an energetic, invisible one, and that these are inseparable; on the other, the notion that the process of visual homogenization that we associate with modernity has its correlate in a parallel process of thermal homogenization. The space of our times is uniform and repeatable both materially and energetically. The artificial place of construction and the artificial climate of combustion go through similar processes: the singular place becomes quantified space; the changeable climate gives way to standardized comfort.

As we mentioned in chapter 1, Vitruvius situates the origin of human society with the discovery of fire, which is the origin of man's building activity. Rooted in Epicurean evolutionism, and beyond that in the mythology of so many primitive societies, Vitruvius's idea is not as remote as it might seem. Twenty centuries later, anthropologists associate the domestication of fire with the separation of paleoanthropoids from their biological predecessors, and consider evidence of combustion the surest signs of human habitation.

Such fraternity between the origins of architecture and fire has a functional as well as a symbolic dimension. Fire warms bodies and transforms food but also symbolizes the soul of the house and the city, thus becoming a basic element in the rites of urban and domestic foundation. The material organization of space reproduces conceptions of the cosmos, and in both fields fire occupies a privileged place: the house, *imago mundi*, unites construction and combustion in pragmatic everyday use as much as in symbol and myth. The original fire burns warmly and enigmatically in the primitive hut.

The bond between architecture and fire has undergone alterations and metamorphoses in history. If the process has a guiding thread, it is perhaps the progressive erosion of the symbolic value of fire, an erosion that flows parallel to fire's quantitative multiplication. Fire reproduces and divides itself, specializes, proliferates in numbers and magnitude. But as it increases in quantity, fire suffers a slow but sure decrease of quality, losing its ritual and mythical content; it is dislodged, and then ousted altogether, from the central place it occupied in architectural space.

The fire of the hearth—ancient focus of conversation and crackling soul of the house—is first individualized and later diffused, fragmented into a mosaic of personal fires. By the time modernity comes into the picture, the silent and detached fires that warm our docile bodies are already strange and remote. The eloquent flames of bygone ages have become mute, and the visual silence of architecture finds its replica in a thermal silence: an identical paralysis of the eye and of the skin.

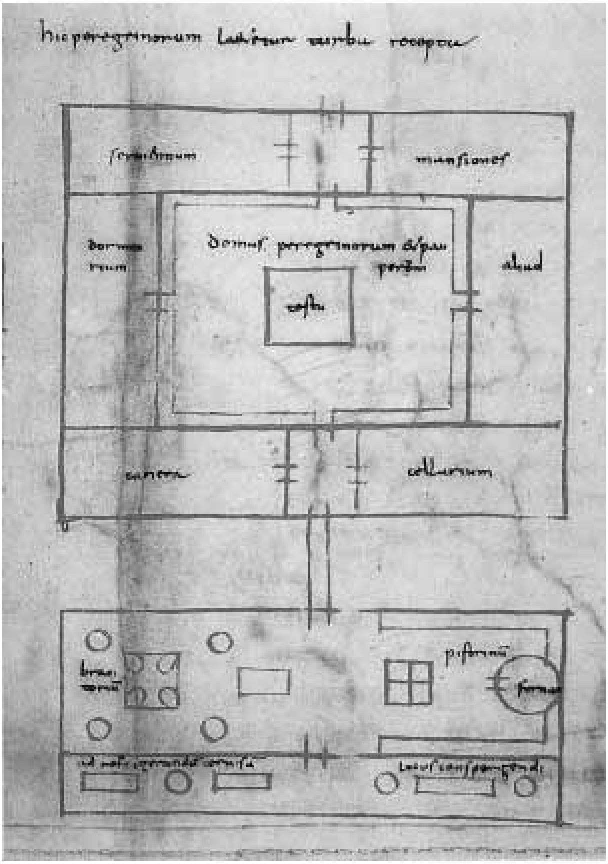
From the central hearth and the brazier to the chimney
thermal comfort and private space

In the earliest urban cultures, which sprang up in benign climates, the symbolic role of fire in the house was more important than its functional role. The ritual continuity of the flame mattered more than its heating power. The right positioning and dimensions of windows and the thermal inertia of walls sufficed to make the house habitable in summer, and during winter a vegetal coal brazier could supplement the fire that burned in the soot-stained atrium. The Roman hypocausts, the *heliocamino* or hot air ducts of Pliny's villa, were extravagant exceptions that in no way diminish the protagonism of the brazier and the sun in the world of classical antiquity.[1]

In the Middle Ages, the Carolingian period constituted the greatest effort to recover the cultural unity that had been lost among the ruins of the classical world. The plan of the Benedictine abbey of St. Gall, drawn at the beginning of the ninth century, is surely the most eloquent architectural document of that era that has come down to our days. A physical and social microcosm, the graphic representation of its utopian scheme that orders and codifies space and time has fascinated scholars since the publication of the first critical edition in 1844. One of the enigmas that challenged them even then was the presence, in the center of each service building, of a square symbol opaquely called *testu.* The solution to the mystery was to be found in one of the squares, where the scribe used the more transparent designation *locus foci:* an omnipresent central fire whose symbolic importance is proven by its graphic protagonism in an abbreviated illustration that excludes even stairs and windows.[2]

But the plan of St. Gall is mentioned here for other reasons. Here the fireplace appears for the first time, and with it the concept of individual and segregated thermal comfort. Pilgrims and the poor, servants and laymen carrying out the *opus manuum*, manual labor, congregate around the central hearth, while in the quarters of the abbot or his distinguished guests the *caminata* installed in the wall offer warmth and intimacy to those engaged in the *opus dei*, intellectual or ecclesiastical labor.

The fireplace spread throughout Europe during the twelfth, thirteenth, and fourteenth centuries, except in Spain, which remained attached—as much because of its agreeable climate as because of its shortage of wood—to the traditional braziers, for whose invention Spain is undeservedly credited by more than one historian. The early fifteenth-century painting of St. Barbara that can be contemplated at the Prado Museum shows the degree of refinement that thermal comfort in a bourgeois home had already attained by then. The glass of the window and the fire


mansiones
Domus peregrinorum & pau
perum
aliud
cellarium
pistrinum

7.1.

7.2.

Fire moves from the central hearth to the side fireplace, conserving many of its culinary functions. The heat of the fireplace is associated with sick people and women who have just delivered, with scholars and ladies; but if a healthy male warms himself beside one, chances are he is an idler. Private space is linked to thermal comfort, and the fireplace becomes an instrument of segregation.

7.1. *Plan of St. Gall, the hospice for pilgrims and the poor, with the hearth (*testu*) at the center.*

7.2. *Interior with a weaver and ladies at play (detail of frescoes by Bracciano, c. 1450).*

of the hearth indicate a thermally controllable interior that made it possible to engage in sedentary activities such as reading, although such architectural elements had to be complemented by furniture and dress. The rung that kept the feet off the floor and the articulated back support that allowed one to alternately face and look away from the fire were accompanied by ample clothing worn by women, clerics, and scholars alike.[3]

A century later, Diane de Poitiers could relish a hot bath in her chamber. The fireplace was capable of heating the water fetched by her maid, but did not suffice to warm up the air to the temperature required by the naked body, so the bath—like the bed—had to be complemented by a canopy and curtains forming a thermal niche.[4] Such a canopy is still needed in the second half of the seventeenth century for the daybed of another French courtesan, Madame de Montespan. Louis XIV's lover rests her bare foot on a cushion to protect it from the freezing floor of the gallery at the castle of Clagny, which two large braziers do little to warm. Here again, clothing and furnishings contribute to the thermal

The fireplace allows Saint Barbara to read and Diane de Poitiers to take a bath; in both cases—sedentary and hygienic activities—thermal comfort requires the participation of furniture: the bench with a foot rung and an articulated back support, the bath with a canopy. Madame de Montespan, too, needed a canopy and cushions to supplement the weak heat of braziers.

7.3. Saint Barbara, *Master of Flémalle, 1438.*

7.4. Diane de Poitiers in Her Bath, *François Clouet, c. 1535.*

7.5. Madame de Montespan Reclining on Her Divan, *Henri Gascard, c. 1680.*

7.3.

7.4.

comfort that fireplaces and braziers, noxious and inefficient, are not able to provide on their own.

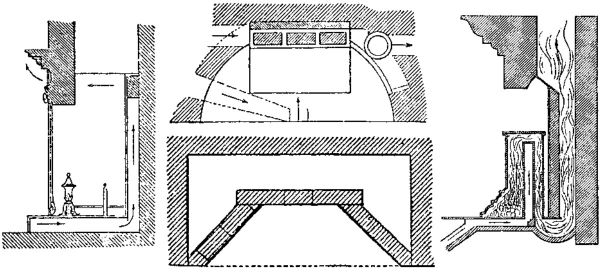
Smoke doctors and glass doctors

fireplaces, stoves, greenhouses

In the seventeenth and eighteenth centuries the fireplace underwent successive reforms and improvements carried out by the "smoke doctors," the last and greatest of these having been Count Rumford, who published his still unsurpassed

7.5.

7.6.



7.7.

design recommendations in 1796.[5] On the threshold of modernity, the fireplace had won in efficiency what it had lost in size and centrality, which it now tried to retrieve by means of elaborate ornamental frames. This was a losing battle, however, and it is difficult to believe that it was still fire that was being exalted in Piranesi's fireplaces. Removed from the center of the house, fire now multiplied and divided along the walls of different rooms.[6]

While these developments were taking place in the urban dwelling, rural houses maintained the structure of the primitive hut, with a hearth on the ground that served alike for heating, cooking, and drying. The Cinderellas attending to the fireplaces and the very sweeps sliding down the chimneys did not live too differently.

Decentralized and reduced in the name of efficiency, the next step in fire's architectural degradation was shutting it away in a stove, with the attendant disappearance from view of the flame's infinite variety. Though the stove was much employed in the cold north of Europe since the Middle Ages, its use spread elsewhere in the continent—not without

The large fireplaces common in Europe during the seventeenth century were thermally inefficient and did a poor job of expelling smoke; successive technical improvements tried to address these problems.

7.6. *Domestic interior illustrated in G. Markham,* The English House-wife *(1683).*

7.7. *Technical developments of the fireplace by Savot (1624, left), Gauger (1713, above), Franklin (1745, right), and Rumford (1796, below), redrawn by Victor Charles Joly in his* Traité pratique du chauffage *(Paris, 1869).*

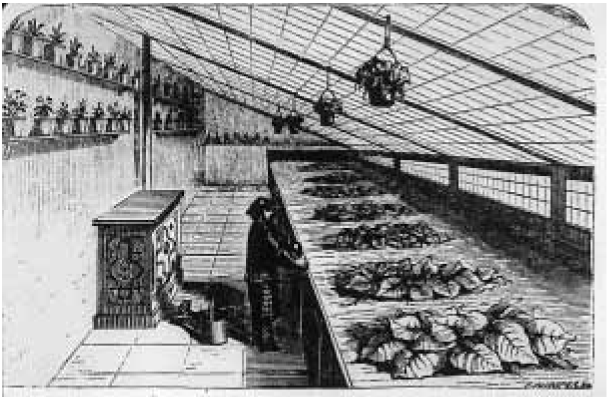
meeting emotional resistance in the process[7]—only in the eighteenth and nineteenth centuries, in the iron version popularized by Benjamin Franklin, as against the bulky brick stoves that were common in Germany or Russia. But this withdrawal of fire was only a step short of its definitive expulsion from habitable space, and no typology illustrates this process as clearly as those producers of artificial climate that we call greenhouses.[8]

The wheeled braziers of the *orangeries* and the brick stoves of the first greenhouses were quickly replaced by the iron stoves of slow combustion, which were practically standard by the end of the seventeenth century. But their uneven distribution of temperature and occasional emission of noxious gases soon made it advisable to transfer the source of heat outside the room containing plants. After a few experiments resembling the Roman hypocaust, whereby hot air was sent to a hollow space under the floor, and after a foray into steam, a system using hot water that had first been described by the Marquis de Chabannes in 1818 became the standard by the mid-nineteenth century. Fire was banished to the basement, with heat brought up and distributed evenly within the botanical space by hot water tubes hidden along the perimeter. Plants, which could now enjoy the advantages of peripheral heating and thermal homogenization, were

The solar energy captured through the glass of a greenhouse is supplemented by the heat of the stove, which is later placed outside the heated space for the sake of a more uniform distribution.

7.8. *Greenhouse with a slow-combustion iron stove, London, 1873.*

7.9. *Domestic greenhouse with a heating system using hot water, New York, 1889.*



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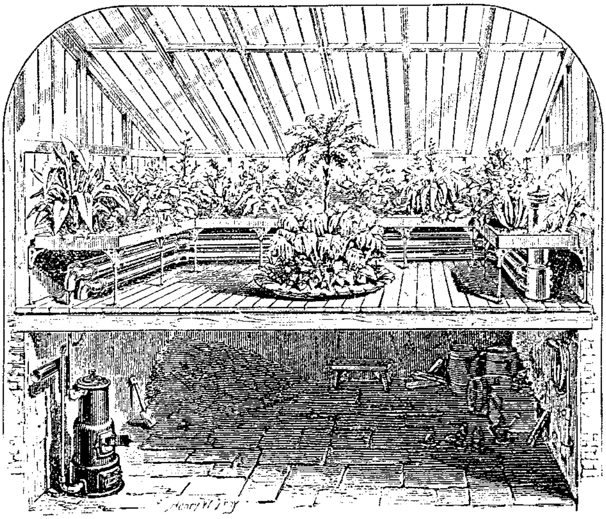


7.9.

thus the first to benefit from the inversion of the primitive central hearth and its thermal hierarchization of space. Gardeners were slightly ahead of architects in anticipating the functional rationalization and symbolic degradation of fire.

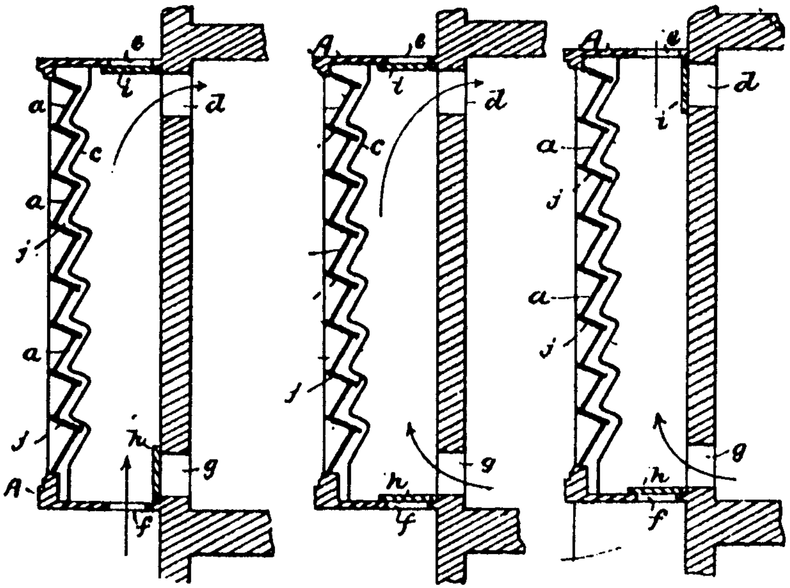
A similar process has occurred with another basic environmental element of the greenhouse: the sun shining through the glass. Like fire, the sun has been bottled up, improving its thermal efficiency at the expense of its symbolic presence. From the solar wall patented by Morse in 1881, where the rear wall of the heat-accumulating greenhouse is moved several inches from the glass, to Walker's patent of 1902 for a solar collector for heating water, the advances made in the capture and regulation of heat were accompanied by a radical symbolic transformation. With Morse's wall the architectural space of the greenhouse became an uninhabitable technical space, while in Walker's collector it was reduced to a mere slit in an apparatus. Like the fire in a burner or a stove, the sun trapped in the collector is turned into a gadget, forever exiled from habitable space.[9]

Panopticon or panthermicon

homogenization and quantification

In any case, the process involving the thermal homogenization of architectural space really made headway with the central heating and ventilation systems which, though already debated in the final decades of the eighteenth century, began to be massively installed in the next century in the large institutional buildings of the modern state: hospitals, prisons, schools, and, naturally, parliamentary halls!

In many ways Jeremy Bentham's Panopticon was a paradigm of the emerging modernity. Every point along its circular perimeter was subject to the permanent supervision of the warden installed at the center. Its simultaneously

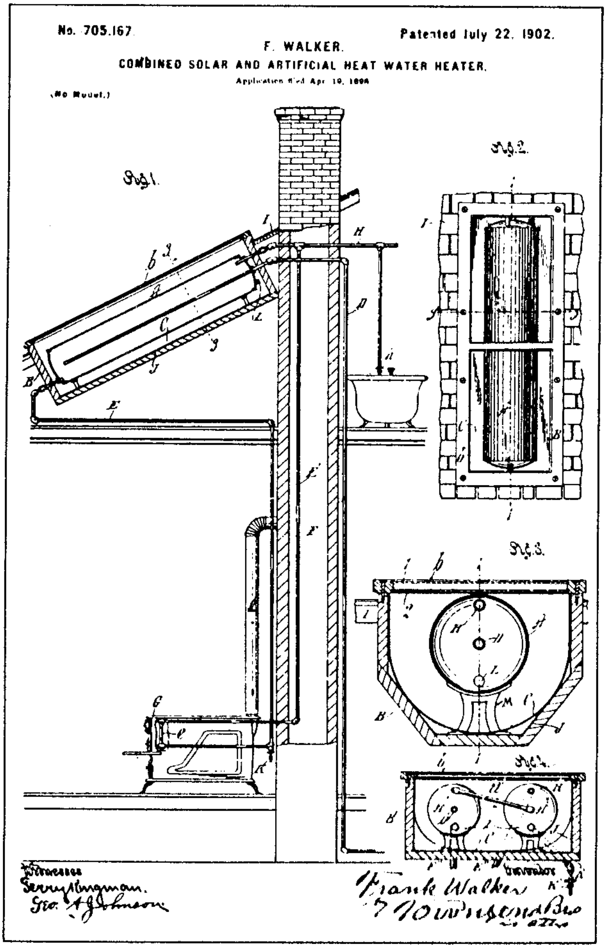


7.10.

As fire gets locked up in the transit from the hearth to the stove, so is the sun trapped when glass gives way to the collector: the capture of energy is improved at the cost of bottling solar heat in air chambers or water pipes.

7.10. *Patent of a solar wall, Edward S. Morse, 1881.*

7.11. *Patent of a solar collector, Frank Walker, 1902.*

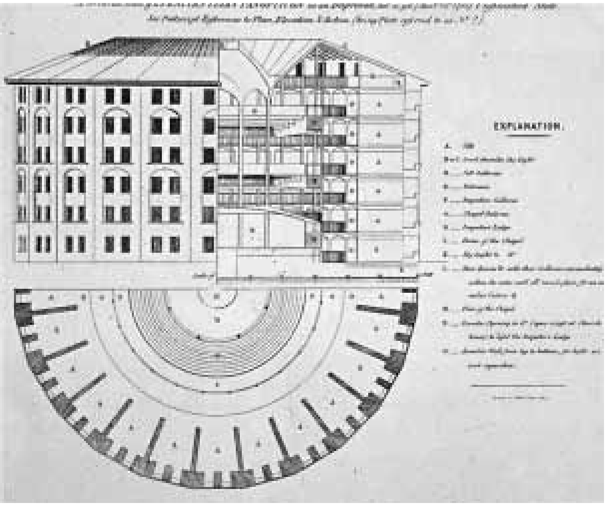

No. 705,167.
Patented July 22, 1902.
F. WALKER.
COMBINED SOLAR AND ARTIFICIAL HEAT WATER HEATER.
(No Model.)
Frank Walker

7.11.

fragmented and homogeneous space and its at once reformist and repressive character have been widely considered symptomatic of the physical and social transformations provoked by enlightened thought. It must be remembered that the author of the maxim "the greatest happiness of the greatest number" did not propose this utopian building only for the purpose of facilitating the implementation of rationalized penal reforms; besides penitentiaries, prisons, and reformatories, the Panopticon was to serve for hospitals, mental asylums, orphanages, and workshops: the collective spaces that characterized a new social and institutional structure.[10]

For his Panopticon Bentham proposed a heating and ventilation system "based on the principle of those used in greenhouses," which guaranteed homogeneous "artificial warmth" that would safeguard the health of bodies in the same way that the vigilant eye tried to reform the ways and safeguard the health of souls. The Panopticon was therefore also a panthermicon.[11]

Dating from the same year as the utilitarian philosopher's architectural artifice (1787) is Jean Baptiste Leroy's report on hospital reform (*Précis d'un ouvrage sur les hôpitaux*), as well as his design for a hospital conceived as "an authentic machine for curing the sick." Here Leroy employed "the true theory of air circulation," previously applied to "mines and fireplaces," to design uniformly ventilated and heated wards. Heir to studies undertaken by Savot in the early 1600s and Gauger a century later on the circulation of hot air in fireplaces, Leroy made full use of the experimental method and scientific approach to come up with a homogeneous and regulated atmosphere. Also stemming from the new interest in hospital architecture that was provoked by the need to reconstruct the Hôtel-Dieu (destroyed by fire in 1772), the essentially formalist proposals of Poyet and Petit also assigned ventilation a very relevant role, although in this case more



7.12.

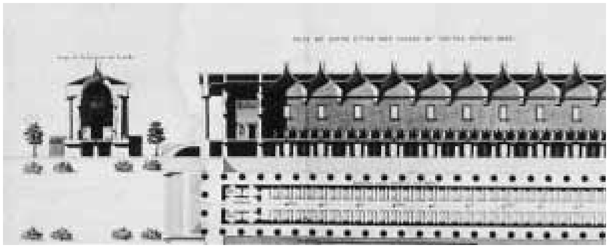
Panopticons are panthermicons; visual control goes hand in hand with thermal control as much in the ideal building designed by Bentham as in the proposals for hospitals of the same period. The homogeneity of modern space is accompanied by the homogeneity of temperature.

7.12. *Penitentiary panopticon, revised version, Bentham, 1791.*

7.13. *Project for a hospital, Leroy, 1787.*

7.14. *Project for a hospital, Poyet, 1785.*

7.15. *Project for a hospital, Petit, 1774.*



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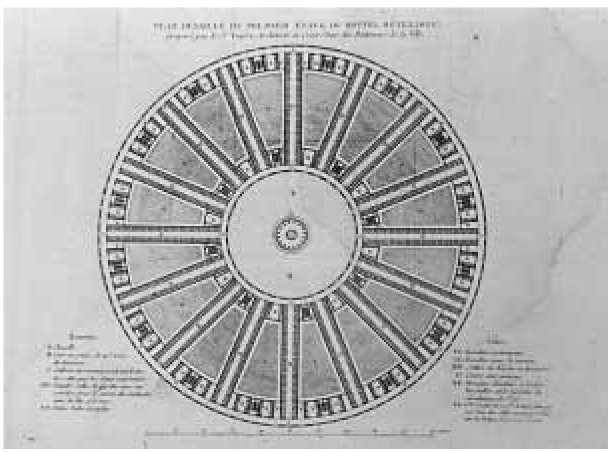

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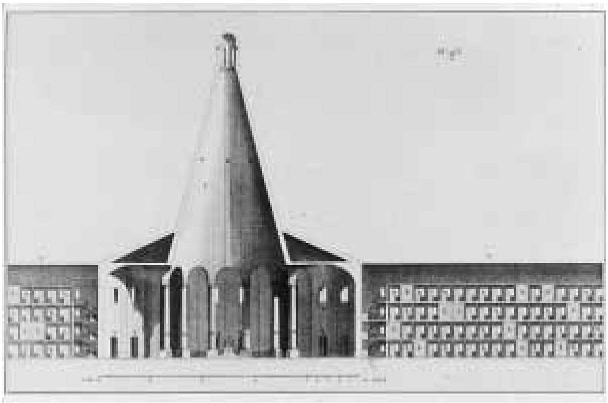


7.15.

symbolic than functional. Thermal uniformity and ventilation continued to dominate hospital design for many years.[12]

Measurement tools were indispensable in this long road to thermal homogeneity. The shift from symbolic quality to functional quantity took place with the help of quantifying instruments, especially the thermometer, which developed relatively late.

There was still none available when Savot explored thermal comfort in *L'architecture française des bâtiments particuliers*, published in 1624. Francis Bacon had some years before described a modified version of Galileo's thermoscope, but such contrivances were neither practical nor widespread, and alchemists regulated the temperature of their ovens using the four degrees of heat described in the *Philosophia reformata* of 1622, where each was defined with reference to everyday washing or cooking practices. Nevertheless the Florentine glassblowers managed to concoct hermetic thermometer tubes by midcentury, and Cardinal Polignac made much use of them in the experiments described in *La mé-*

canique du feu, which he published in 1713 under the pseudonym of Nicolas Gauger. Fahrenheit developed the first reliable thermometer a decade later, and its use was widespread by the close of the century.

By then the measurement of humidity had come a long way since Nicholas of Cusa's primitive hygroscope, first described in the late fifteenth century, and air speed could likewise be determined through accurate anemometers. The time was ripe for modern reformers to consider the criteria they imposed on visual space—repeatability and homogeneity—and apply them to thermal space. Thermal gradient, relative humidity, and air movement were gauged in the mid-nineteenth century with the aim of achieving through artificial means the environmental uniformity of which Louis Savot's convection fireplaces and Polignac's caliducts had been pioneers. The field entirely belonged to engineers and heat physicists, the Tredgolds and Péclets, for whose theoretical and practical work quantification was the fundamental tool.[13]

Prisons and parliaments

practical developments and theoretical contributions

Paradoxically, the thermal revolution of modernity underwent a singular expansion in two building typologies, both characteristic of the modern state, that accommodate very different sectors of society: prisons and parliaments.

In the prison, a space of isolation, "windows spoil discipline by transmitting sound," making it necessary to install centralized ventilation and heating systems. The very famous jail of Pentonville, described in 1844 by Jebb[14]—author of the above quote—and much imitated on the continent by General Morin, and the Mazas prison in Paris, built by the engineer Grouvelle around the same time, are archetypal examples of what Bentham had anticipated in his *Panopticon*.

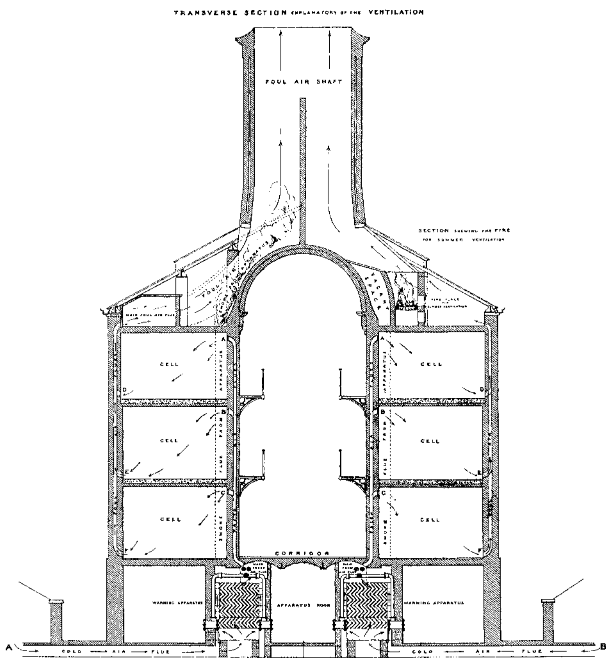
The parliamentary hall and the auditorium, spaces of communication, accommodated such large assemblies that conventional ventilation methods would not do, so here, too, there was a need to resort to elaborate systems of temperature regulation and air movement. Benjamin Latrobe's 1817 detail sketch of the Capitol in Washington—the first building, incidentally, ever to have air conditioning, later in 1928—skillfully incorporated the numerous chimney stacks in the drum of the lantern that crowns the Senate chamber. This was still far, however, from the complex systems that Reid designed hardly a decade later for the ventilation of

Few buildings are as revolutionary as prisons in terms of environmental design. Pentonville puts Bentham's thermal recommendations into practice, and Grouvelle's in Paris also has a central heating system. Penitentiary spaces are at once egalitarian and centralized, homogeneous and controllable, though not to the exclusion of individual variation, as the devices of Pentonville show.

7.16. *Prison of Pentonville. Joshua Jebb,* Report of the Surveyor-General of Prisons *(1844).*

7.17. *Mazas prison, Paris. Rinaldo Ferrini,* Tecnologia del calo*re (1876).*

7.18. *Devices for the regulation of temperature in Pentonville prison. The cell has a triple-pane glass window that allows air to circulate, and hot air tubes built into the corridor wall which the inmate can regulate to modify the temperature.*



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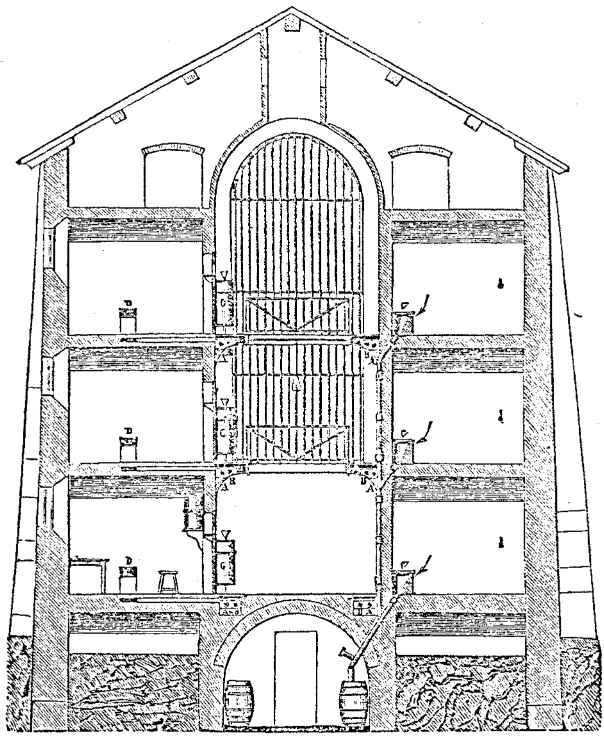
Britain's House of Commons[15] (where Desaguliers had installed a manually regulated air extractor in 1736), or the elegant auditoriums that Péclet proposed in the second edition of his *Traité de la chaleur*, published in 1843.

That same year Isabel II laid the first stone of Spain's Congress building in Madrid, a work of the architect Narciso Pascual y Colomer whose heating and ventilation system, considerably advanced for its times, was installed by the French company Duvoir. The heat producers and ventilation shafts allowed a constant temperature of 20°C and a total renewal of air every half hour. Although the French engineers



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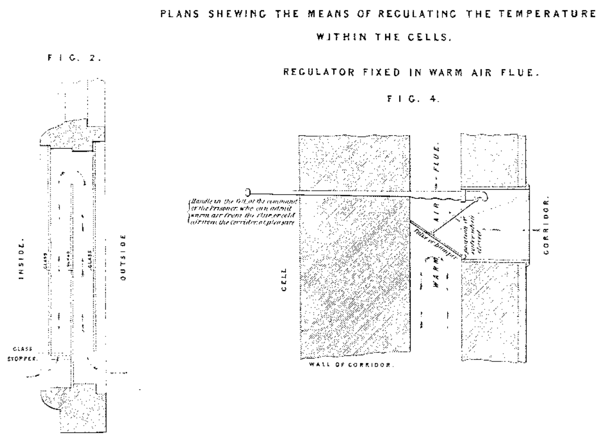
also presented a heating project using hot water, the authorities opted for an air system, considering that its capacity for quick reaction rendered it more suitable to the climate of Madrid, where the abrupt fluctuations of temperature have a range unknown in Paris or London.[16] The choice of French know-how was not surprising, despite British leadership in the field, for as late as 1867 Francisco de Paula had been distinguished by Spain's Royal Academy of Sciences for a *Memoria* about the heating and ventilation of buildings that



7.18.

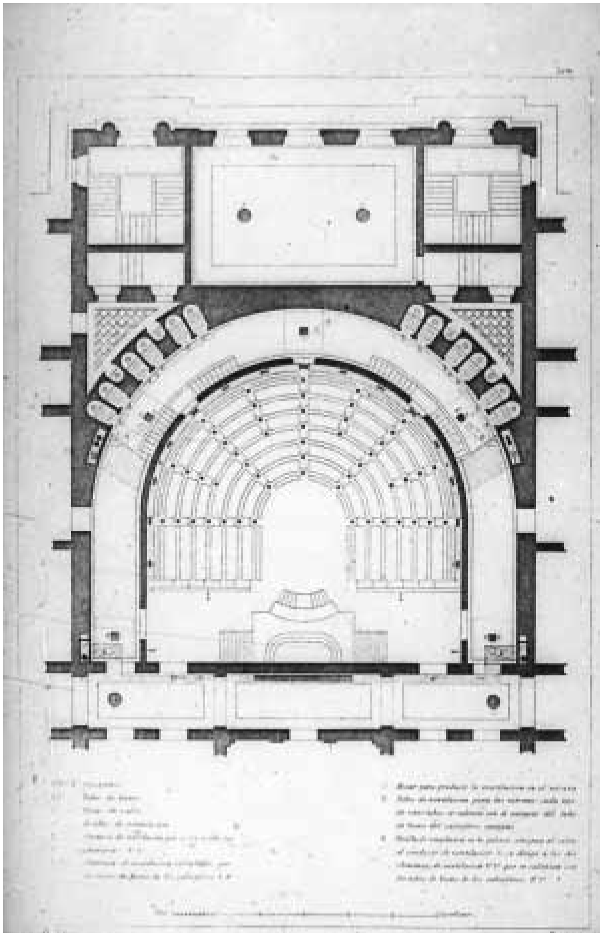
was based, as the author himself acknowledged, on the works of Péclet and Morin.[17] The greater part of heat producers set up in Madrid at that time had the name of Paris engraved on them, in reference to their place of fabrication. But the moment of France had passed; and if in 1715 Desaguliers had translated and tried to diffuse Polignac's ideas in England,[18] a century and a half later, in 1863, General Morin began his *Etudes sur la ventilation* with a detailed presentation of Reid's designs, quoted the British as authorities in the field, and acknowledged having learned much of what he knew during a trip to London.[19]

The application of centralized heating systems to houses dates back to this period, marked by a characteristic split in the method of tackling thermal problems, between the pragmatic tradition of Anglo-Saxon engineers and the more theoretical approaches of the physicists of the continent, first French and later German. In his treatise of 1869, Joly recommended learning from the British, lamenting that his theoretical French compatriots were "only concerned with the uses of heat in industry and large spaces such as hospitals, military barracks, and prisons. . . . Barracks and prisons," he said, "are interesting places, but thank God, not everybody lives there, so our modest homes should not be the object of less attention."[20] The architect Ernest Bosc, in turn, who was also French, wrote his own treatise on heating and ventilation in 1875 with the specific purpose of eliminating the theoretical formulations and protracted reasoning that were of no use to the builder, whether an engineer or an architect[21]: an opinion, incidentally, that scandalized the Italian physicist Rinaldo Ferrini, whose *Tecnologia del calore*, published only a year after Bosc's book,[22] falls in the theoretical tradition of Péclet.

It was the Germans, however, and not the Italians, who in the final decades of the century most extensively represented the continental penchant for reasoning from first principles. Thus Rietschel's treatise, published in Berlin in 1893 and for several decades the fundamental text presenting the material available in the continent, was a work built upon a solid theoretical framework, in spite of the author's reservations about its eminently practical nature.[23] So much so that when the edition revised by Brabbée was published in New York as late as 1927, the coauthor of the book and

Since large assembly spaces present numerous problems involving heating and ventilation, designing them has frequently given rise to innovations. The Congress building in Madrid has been a laboratory for important developments.

7.19, 7.20, 7.21. *Plan, basement, and section of the Congress of Deputies, Madrid, Narciso Pascual y Colomer, 1843.*



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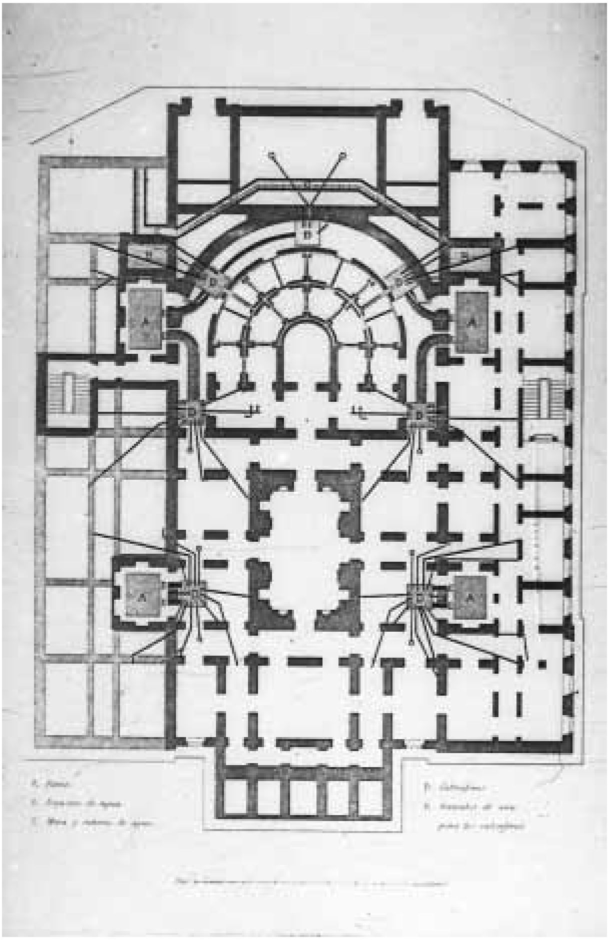

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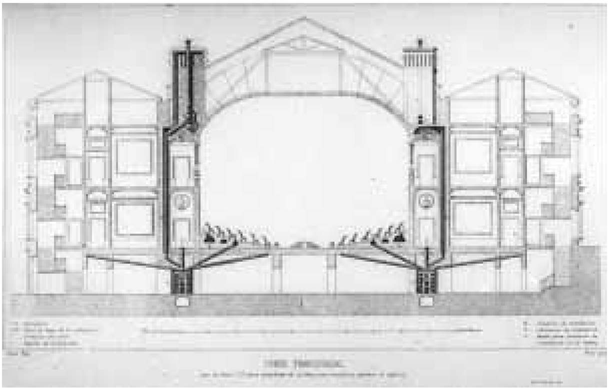


7.21.

successor of Rietschel in the Berlin chair had to warn the American public about the European habit of employing mathematical methods, and assure it that though unfamiliar on the other side of the Atlantic, these were backed by solid results obtained in practical installations.[24]

Visual homogeneity, thermal homogeneity
the age of the tube and the exile of fire

In any case the process of the rationalization and homogenization of thermal space—with the consequent symbolic downgrading of fire, which was progressively shut away in stoves and then banished to basement boilers—accelerated during the second half of the nineteenth century. Buildings became cluttered with drains, valves, and pipes, and wherever there was a fireplace, chances are that it was not used. During this period, nevertheless, heating devices endeavored to conserve some of the dignity of old fireplaces as well as the symbolic associations they still possessed, as eloquently illustrated by the picture of Burnham and Root posing in their Chicago office in front of a designer fireplace that was as intricate as it was disproportionate in size, and whose only apparent function would have been to impress clients. Hence, as if to apologize for intruding on the fire of the hearth, whose niche they frequently occupied, heating devices took on styles, whether Gothic like the radiator of 1864 or classical like the Doric heat producer of 1896, which could be used, just like traditional fireplaces, as a pedestal for a statue.

All in vain. Boilers were competing in size with habitable spaces by the first decades of the twentieth century, and installations multiplied and became increasingly complex. When Reyner Banham inverted Le Corbusier's famous aphorism "Pour Ledoux, c'était facile: pas de tubes!" in 1965 and took the trouble to convince us that the house consisted exclusively of tubes, the image he used to illustrate his statement was not too different from that of a steam heating system of 50 years before.[25]

As buildings were filled with pipes and grilles, imprisoning fire in hidden basements, heaters sought, through stylistic gestures, to reclaim the symbolic presence once had by fireplaces.

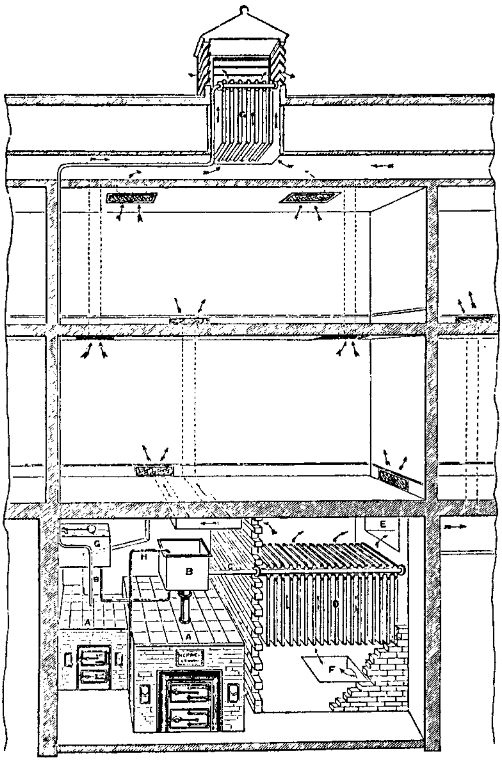
7.22. *Heating and ventilation of a school. Edward Robert Robson,* School Architecture *(1874).*

7.23. *Air distribution pipes in an apartment building of Leipzig, 1908.*

7.24. *Burnham and Root in their Chicago office, around 1880.*

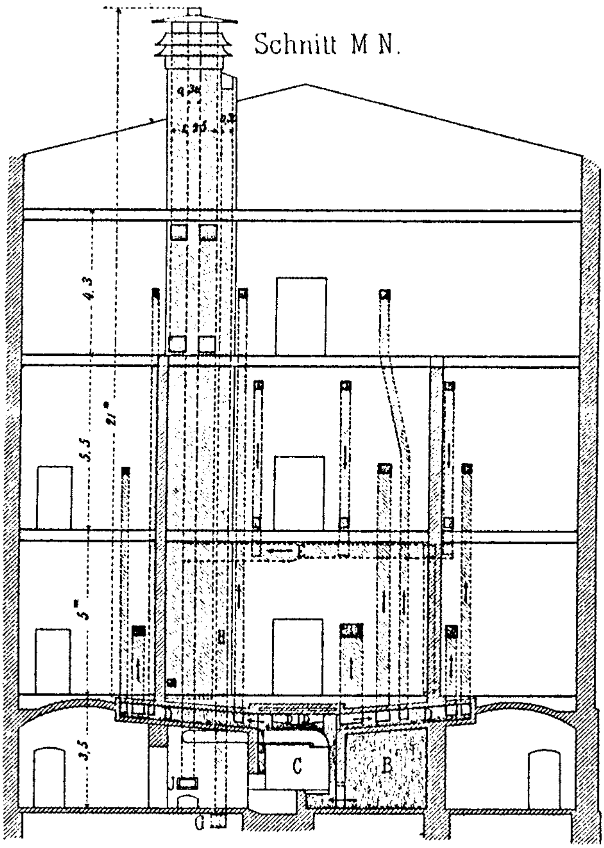
7.25. *Gothic radiator, 1864*

7.26. *Doric heat producer, 1896.*



7.22.

By the start of the modern movement, the autonomy of heating and ventilating installations was practically complete. Half a century later, the visually homogeneous, repetitive and interchangeable space of buildings was also a thermally uniform space. Both processes of homogenization had been possible thanks to the divorce between matter and energy, architecture and fire, that had been gestated in the dawn of modernity, a separation now reflected in the



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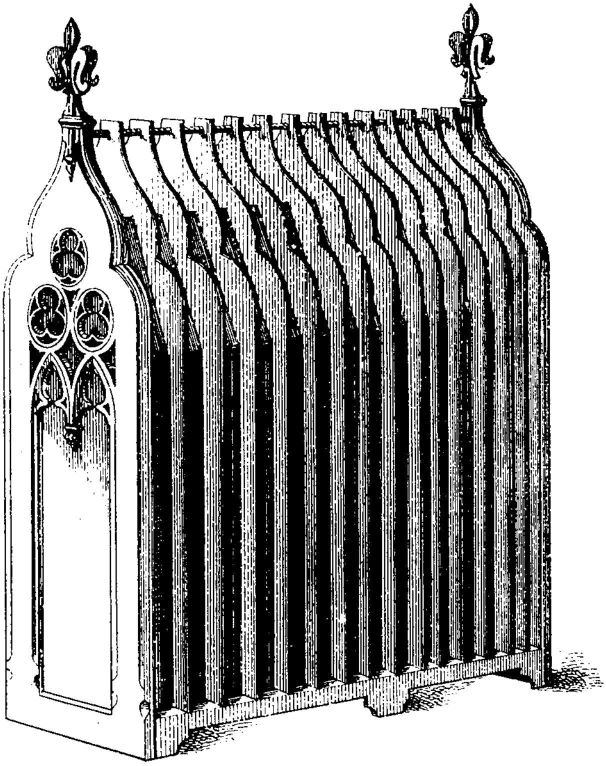

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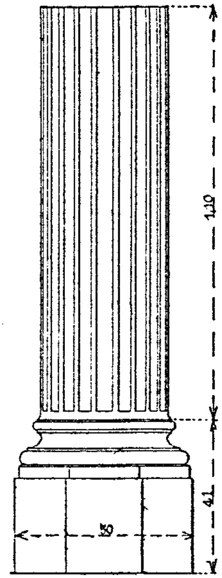
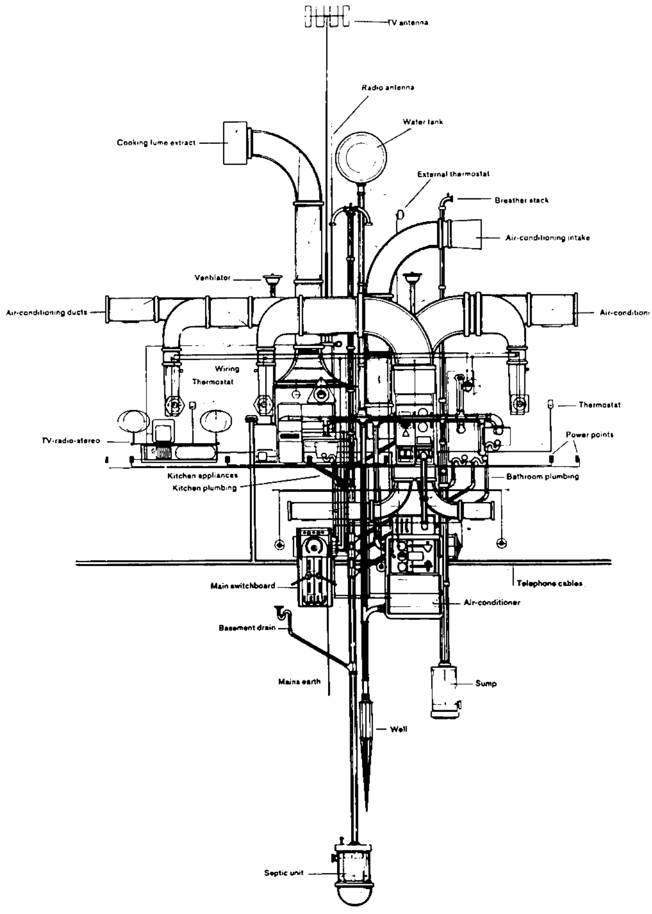


7.26.

sandwichlike alternations of space for people and space for tubes where huge material and energy costs contrast sharply with poor symbolic quality.

If it is true, as Umberto Eco's Adso affirms, that "architecture is the art that most tries, in its rhythm, to reproduce the order of the universe, which the ancients called *Kosmos*," then we will have to concede that the obsessively monotonous rhythm of the architecture of our times reproduces the view of a mechanical and meaningless world, an opaque and neutral chronology, an order of the universe that is as exact and punctual as it is unintelligible. Like the primitive hut, today's house is an *imago mundi*, but whereas the former



TV antenna
Radio antenna
Water tank
Cooking fume extract
External thermostat
Breather stack
Air-conditioning intake
Ventilator
Air-conditioning ducts
Wiring
Thermostat
Thermostat
TV-radio-stereo
Power points
Kitchen appliances
Kitchen plumbing
Bathroom plumbing
Telephone cables
Main switchboard
Air-conditioner
Basement drain
Mains earth
Sump
Well
Septic unit

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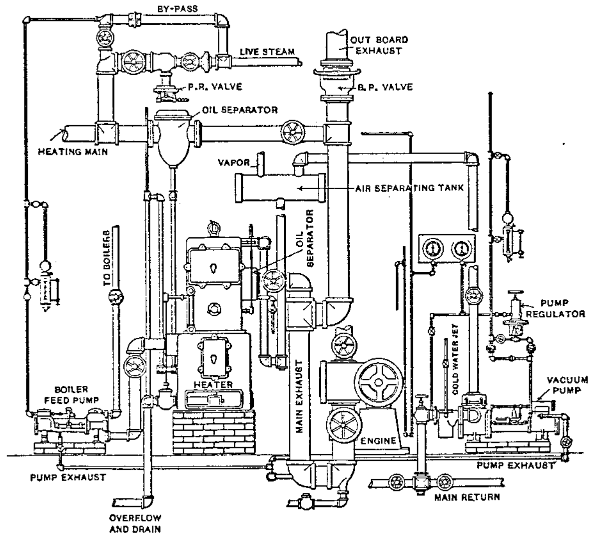

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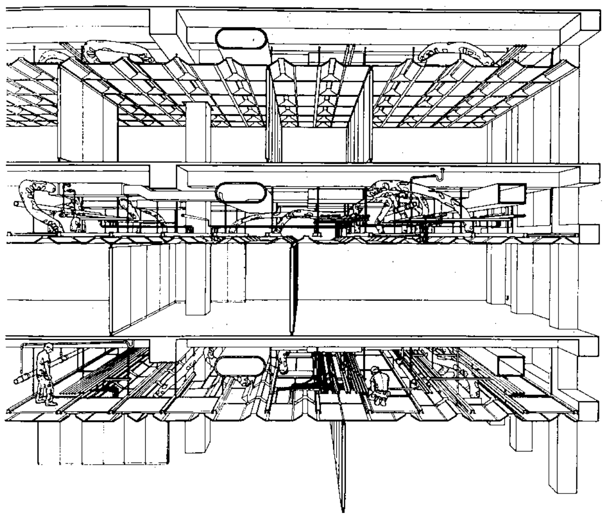
Finally, architecture goes from having installations to being an installation; the building consists of the tubes and the intricate design of their networks. The space in between, though the formal justification of their existence, is of little visual or symbolic interest.

7.27. *House reduced to installations, illustration by François Dallegret for an article by Reyner Banham, 1965.*

7.28. *Webster heating system, 1914.*

7.29. *Academic building of the University of California, 1970.*



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bespoke a world articulated by centers and limits, the latter expresses a uniform and measurable world whose only attribute is its extension.

But this is not the only bitter fruit of the rupture between construction and combustion. Such a separation, which facilitates repetition in space, also stimulates repetition in time. While seeking to abstract itself from place and become a homogeneous and thus measurable space, it aspires to abstract itself from time, historical time crystallized in memory as well as meteorological and astronomical time. Oblivious to place, it also aims to be oblivious to memory, to the flow of days and seasons, to weather and stars.

Yet its ancient soul survives in the depths of humankind's symbolic sensibility, and the greatest of modern architects have known how to inject meaning into thermally and visually homogeneous spaces, endowing them with echoes of an archaic voice, fragments of an obscure and remote discourse.

Functional neutrality and symbolic eloquence
thermal space in Wright and Le Corbusier

During one of his sojourns in Japan, Frank Lloyd Wright, who abhorred radiators, discovered a local version of the Roman hypocaust, and from then on was an ardent defender of heating systems built into the floor slab, so much so that he later considered what he called "gravity heat" his most important technical contribution to architecture. His first American experience with this was in the original Jacobs House, built in 1937, in whose foundations he installed hot water pipes; these allowed him to dispense with the radiators he had gone to so much trouble to hide in his prairie houses. The resulting warmth—homogeneous, regular, and totally invisible—made for an unmistakably modern thermal space, yet Wright felt the need to make such atmospheric regulation visible in some way, so at the center of the house rose a voluminous fireplace, which was as functionally redundant as it was symbolically indispensable: once again, the original fire inhabiting the heart of the architecture.[26]

Nine years later, in the second Jacobs House, Wright brought the sun into the picture in a gesture of welcome. Resting its back on a grassy slope, the house faced the sun and spread out in the form of a glazed semicircle. But here too Wright longed for the hearth, and the family gathered around an old-fashioned, ritual fire.

One of the most groundbreaking innovations of Le Corbusier was his famous *mur neutralisant*, a facade between

7.30.

7.31.

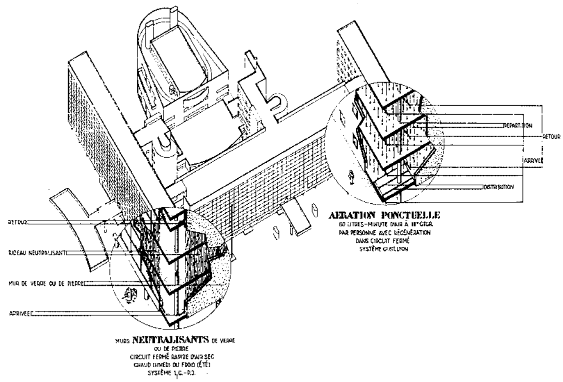
whose two panels hot or cold air could be made to circulate, through which he hoped to liberate architecture from the yoke that bound it to climate, thanks to the advantages of "international scientific techniques." This extravagant method of peripheral heating, combined with "punctual airing," was expected to yield a thermally homogeneous atmosphere in Moscow's Centrosoyuz, built between 1928 and 1934, as well as in the Cité de Refuge of 1933. Lack of funds prevented him from testing it out at the Centrosoyuz. As for the Cité de Refuge, the building was only usable during a few cold months, until summer rendered it uninhabitable.

Le Corbusier's solution to such overheating was the *brise-soleil*, which he always described as a product of astronomical and mathematical calculation. But just as important as the shade it provided was the symbolic function it performed, since it signified architecture's adaptation to the environment by linking up with the solar cycle, from *un soleil se lève* to *un soleil se lève à nouveau:* the sun and the solar cycle that he includes among the archaic signs of Chandigarh that he would engrave on the roof of the grand hyperboloid; a roof that has been compared to the Jaipur observatory, but which looks rather more like a sundial.

Great modern architecture combines thermal muteness with symbolic eloquence. Though Wright installs the heating system under the floor slab, the house is not deprived of a fireplace.

7.30. *Underground heating system in the first Jacobs House. Frank Lloyd Wright, 1937.*

7.31. *Fireplace of the first Jacobs House, Frank Lloyd Wright, 1937.*



7.32.

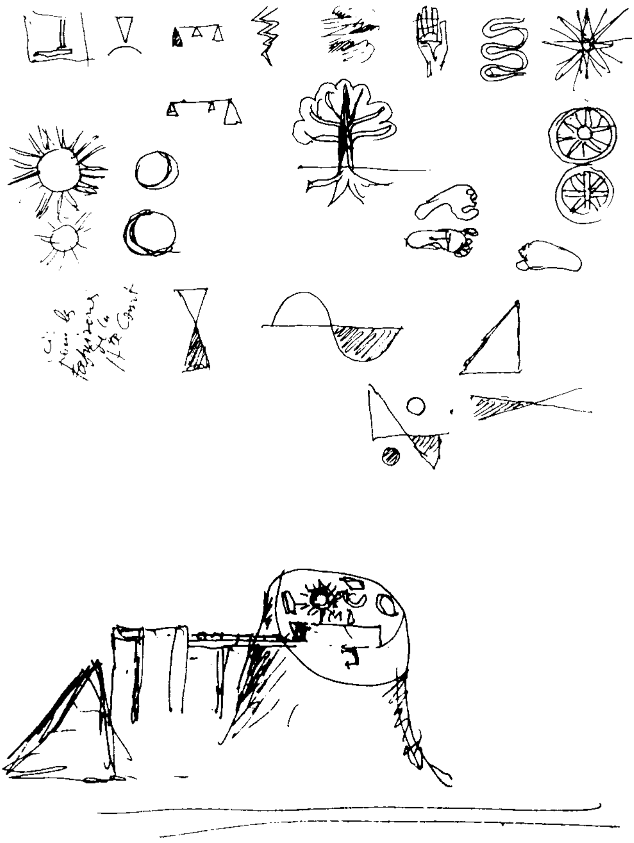
As architects of modernity, both Le Corbusier and Frank Lloyd Wright gave their buildings the homogeneity and thermal silence that characterize modern space. Simultaneously, as artists whose sensibilities reached down to deep layers of the human spirit, they introduced ancient symbols that eloquently expressed architecture's intimate relationship with fire and the sun. The result was a richer and more ambiguous architecture, a better and more truthful testimony to the dilemmas and uncertainties of our times.

Through innovations like the mur neutralisant, *Le Corbusier endeavors to free architecture from its subjection to climate; yet his buildings bear signs of ancient solar rites. Fire and sun continue to inhabit architecture.*

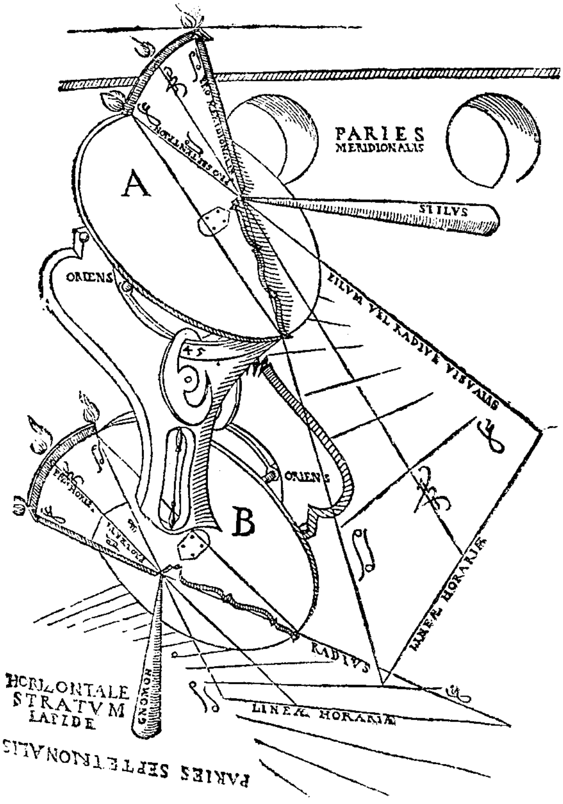
7.32. Mur neutralisant *in the Centrosoyuz project, Le Corbusier, 1928.*

7.33. *Signs and hyperboloid at Chandigarh, Le Corbusier, 1952–1956.*

7.34. *Sundial, 1599.*



7.33.


PARIES
MERIDIONALIS
A
STILVS
ORIENS
45
ORIENS
B
RADIVS
HORIZONTALE
STRATVM
LAPIDE
GNOMON
LINEÆ HORARIÆ

7.34.

The cultural crossroads

excess and entropy

The technical alternatives at our command in this age of uncertainty are social alternatives, or better still, cultural options that cannot be reduced to a mechanical scale, whether energetic or monetary. All illusions about a technology reconciled with nature in this manner must therefore be dismissed. There is no room in the quantitative and mechanistic universe of the first principle of thermodynamics for the qualitative plurality of hopes and desires, for the fears and habits that form the fabric of human existence. Only entropy can break down the limits of the narrow framework of computation and situate choices and decisions in the broader context generated by the introduction of a cultural dimension. As Georgescu-Roegen has explained:

> And paradoxical though it may seem, it is the Entropy Law, a law of elementary matter, that leaves us no choice but to recognize the role of the cultural tradition in the economic process. The dissipation of energy, as that law proclaims, goes on automatically everywhere. This is precisely why the entropy reversal as seen in every line of production bears the indelible hallmark of purposive activity. And the way this activity is planned and performed certainly depends upon the cultural matrix of the society in question. . . . The exosomatic evolution works its way through the cultural tradition, not only through technological knowledge.[27]

Such protagonism of the cultural[28] dimension runs through this book like a fine but tenacious thread. Foregoing pages have emphasized the cultural character of exosomatic energy consumption, in which we include that of buildings, as opposed to the merely biological nature of endosomatic consumption (chapter 1); stressed how entropy introduces irreversible and historical time as the support of cultural tradition (chapter 2); marked the difference between the genetic channel and the cultural channel in the transmission of information and situated architecture in the latter (chapter 3); deemed thermodynamic architecture to be that which, by giving priority to the existing domain, makes time and memory the cornerstones of its theory (chapter 4); attributed greater importance to the fact that rehabilitative architecture engages in dialogue with the cultural, and not only with the natural or technical realm (chapter 5); narrated the genesis of energy accounting between the rival poles of energy on one hand, which is quantitative and ahistoric, and entropy on the other, which is qualitative and cultural (chapter 6).

The terms "culture of energy" and "culture of entropy"[29] have been used profusely throughout. Such metaphorical denomination is faulty in the way it associates "culture" with "energy"; the energy paradigm is characterized precisely by its ignorance of a cultural heritage. Yet the formulation is helpful, as it allows us to guess that the opposition between the two paradigms takes place in a field that is wider than an exclusively natural or technological one.

Indeed, the confrontation between energy and entropy is more than a mere technical clash between waste and conservation. Energy and entropy are well-differentiated social, ethical, and intellectual options, and as options can be freely—and perhaps arbitrarily—chosen, or not. Nevertheless, there is a temptation to use models extracted from the natural sciences when defending a cultural decision, which then appears "natural" or necessary (as opposed to a "contrived" one that does not adapt to the given model). The temptation is accentuated by the fact that the thermodynamics of open systems, as Margalef points out in commenting on the works of Prigogine, predicts that "an [open] system is to evolve by decreasing the amount of energy exchanged for every unit of structure maintained." This means that living systems "are to minimize exchanges with the exterior, especially of energy, and consequently minimize the increase of entropy in relation to the maintenance of a biomass unit."[30] But attempts to apply these predictions to human societies must be abandoned, no matter how tempting it is make analogies and establish the historical inevitability of a possible "culture of entropy."[31] Ludwig von Bertalanffy writes that "a great deal of biological and human behavior is beyond the principles of utility, homeostasis and stimulus-response, and . . . it is just this which is characteristic of human and cultural activities."[32] Eric Jantsch, in turn, has attributed this uniqueness of human activities to energy consumption, arguing that since man is the only creature that uses exosomatic tools requiring much more energy than the living parts of the system, "sociocultural systems obey the laws of biological life only partially. . . . If self-organizing systems from chemical dissipative structures to ecosystems are self-limiting, technology represents a world of equilibrium structures whose growth does not limit itself."[33]

This lack of self-limitation in sociocultural systems is probably the strongest reason why we should not assume that entropy—in the energy/entropy dilemma—would necessarily be favored by our culture in the particular historic crossroads it is fast approaching. In the cycle of ecological succession, the brief initial period of waste is generally followed by a prolonged stage of "orthodox succession" governed by the predictive and economical use of resources, but we also know that human societies obey such biological patterns only partially. "Human beings tend to use and waste as quickly as the availability of resources allows. Only the pressure of necessity, competition, motivates them to use resources more cautiously and efficiently. But the regime of unpredictive exploitation reappears as soon as a new resource or external energy source is discovered. The race is resumed, precisely, in a new initial phase of maximum power use that has nothing to do with efficiency."[34]

A century and a half after Carnot's *Réflexions*,[35] the thermodynamic dilemma of power versus efficiency remains the touchstone of our at once natural and contrived culture, which debates between physical limits and the tendency to break them, between efficiency and power, conservation and waste, entropy and energy, necessity and desire. No physical or biological law can impose the entropic paradigm. If ever the latter manages to tinge the fabric of our culture, we will have to look for the cause in the gradual encroachment of a desire to persist through self-limitation.

In the field of architecture, no one has expressed this intellectual and aesthetic option as beautifully as Leon Battista Alberti: "In fashioning the members, the moderation shown by nature ought to be followed; and here, as elsewhere, we should not so much praise sobriety as condemn unruly passion for building: each part should be appropriate, and suit its purpose. For every aspect of building, if you think of it rightly, is born of necessity, nourished by convenience, dignified by use; and only in the end is pleasure provided for, while pleasure itself never fails to shun every excess."[36]

As Newton said in his *Principia*,[37] "Nature delights in simplicity." It is doubtful, however, that this statement can be applied to human nature. The loathing of "excess" mentioned by Alberti results from a voluntary and difficult choice, in which "simplicity" is not the child of the necessary and trivial simplicity of the mechanism, but the fruit of a long process of moral and intellectual decantation that is far from being consubstantial with the nature of the human mind.

Notes

1 Architecture Discovers Fire

1. Hereafter there will be numerous references to the material organization and the energy flows of a building as separate realities. Energy flows are sometimes expressed in the units appropriate to the material in question (tons or liters of this or that combustible); but more often it is matter that we translate into energy units (joules or watts necessary to produce a brick or a door). Such equivalences are mere accounting conventions and will not affect our line of reasoning. Neither have they anything to do with the relativist correspondence of mass to energy.

2. More exactly, life requires the *degradation* of energy. As a thermodynamic structure that lies outside the world's equilibrium, its continuity depends on a constant flow of *entropy.* It feeds not on energy but on *negentropy.* Note that there is no contradiction between classical mechanics and the first thermodynamic principle, which consecrates energy conservation. The conflict, as we will discuss in detail later on, is with the second principle.

3. See Angelo Baracca and Arcangelo Rossi, eds., *Materia e energia* (Milan: Feltrinelli, 1978), pp. 53 and 307–314, for original texts and critiques on Ostwald.

4. See Ramón Margalef, *Perspectivas de la teoría ecológica* (Barcelona: Blume, 1978), p. 98, for an examination of the relations between matter, energy, and organization.

5. The term "energy of maintenance" is not entirely satisfactory because it is easily associated with repair and conservation, processes we have included under "energy of construction." Both terms are ambiguous.

6. This methodological separation is not to be confused with an epistemological one. Epistemologically speaking, matter and energy

are clearly distinguishable from one another in the world of intermediate dimensions. Their ever-simultaneous presence is what allows us to see their separation as a mere methodological device dictated by convenience.

7. Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: Braziller, 1968), p. 158.

8. The use of the terms "endosomatic" and "exosomatic" to refer to the organic and extraorganic instruments of the human species was introduced by the biologist and demographer Alfred Lotka, who wished to emphasize both the continuity between biological and productive processes and the distinctive evolutionary behavior of each.

9. Ramón Margalef, *La biosfera entre la termodinámica y el juego* (Barcelona: Omega, 1980), p. 9.

10. Human beings need to consume approximately 2,500 kcal per day. The average Spaniard consumes 2,759. (This figure and the other data following are taken from Earl Cook, *Man, Energy, Society* [San Francisco: Freeman, 1976], pp. 230–231, which in turn cites 1971 statistics compiled by the United Nations.) For obvious biological reasons, the variation range is minimal: the 3,300 and 1,750 consumed by the average American and Indonesian, respectively, make a ratio of less than 2:1. Anything far beyond this narrow range means death for the organism, through either excessive or deficient nutrition. Being organically conditioned, the range of *geographic* variation coincides with the range of *historic* variation. M. J. C. Toutain's calculations for France show a steady increase from 1,750 kcal/day in 1780 to 3,320 kcal/day in 1910. Whether of a spatial, temporal, or social nature, variations cannot break out of this limited interval. (Toutain's calculations are in Alfred Sauvy, *La machine et le chômage* [Paris: Dunod, 1980], p. 79.)

11. Average daily consumption varies enormously, from the American's 223,000 down to the Ethiopian's 670 kcal (*UN Statistical Year Book*, 1973). Whereas the range of variation for endosomatic energy consumption is minimal, the ratio of maximum to minimum exosomatic energy consumption exceeds 300:1. An American has

almost a hundred times the value of metabolic energy at his disposal; an Ethiopian, less than a third.

12. Certain Spanish data eloquently illustrate what it means to situate architecture in the realm of exosomatic artifacts. In 1976, the average Spaniard's daily intake of exosomatic energy was about 49,400 kcal—twenty times his endosomatic consumption. This figure is nothing exceptional, coinciding more or less with the world average. Using a 1978 work by Hall, Jantsch proves this graphically and points out that "technology has increased the biological portion of the human world by a factor of 20" (Eric Jantsch, *The Self-Organizing Universe* [Oxford: Pergamon, 1980], p. 276). Returning to the Spanish case of 1976, further calculations of my own show that a daily 6,100 kcal was used up in the construction of the built domain, and about 9,150 went to its maintenance. All in all, the energy consumed in the creation and maintenance of the built environment rose to 15,250 kcal per day per person—six times the metabolic consumption and almost a third of total exosomatic consumption. The magnitude of these figures renders it unnecessary to comment further on the link between architecture and energy.

13. The parable appears in Reyner Banham, *The Architecture of the Well-Tempered Environment* (London: Architectural Press, 1969), p. 19. It seems paradoxical to be quoting Banham in this context, because the conclusions we arrive at here are almost diametrically opposed to those he upholds in that book, so exuberantly charged as it is with technological optimism. Nevertheless, in my opinion the value of Banham's work lies more in his undeniably innovative point of view than in the actual view he propounds, which after all is conditioned by the great expectations of the 1960s. (Although Banham remained faithful to his origins, as an expatriate in California he was the most eloquent defender of West Coast hypertechnological society and a great devotee of Los Angeles freeways.)

14. It may not be pointless to add that in their studies of the very origins of our species, archaeologists consider the remains of combustion the most revealing sign of the existence of "human habitation" (see *New Scientist*, 19 November 1981, p. 50).

15. Vitruvius, *De architectura* 2.1. Erwin Panofsky has tackled some of these themes in "The Early History of Man in Two Cycles of Paintings by Piero di Cosimo," in *Studies in Iconology: Humanistic Themes in the Art of the Renaissance* (New York: Harper and Row, 1962).

16. Leon Battista Alberti, *On the Art of Building in Ten Books*, trans. Joseph Rykwert, Neil Leach, and Robert Tavernor (Cambridge: MIT Press, 1988), pp. 3, 7–8.

17. Joseph Rykwert, *On Adam's House in Paradise* (New York: Museum of Modern Art, 1972). Rykwert nevertheless makes it clear that whereas for Vitruvius the matter of origins is seminal, for Alberti it is rather secondary.

18. Françoise Choay, *La règle et le modèle* (Paris: Seuil, 1980). At this point we have to mention Gottfried Semper and his eloquent defense of the fire of the hearth as one of the "primordial forms" (*Urformen*) of architecture, around which its three other forms or elements rise: the platform, the envelope, and the roof. The hearth is the spiritual and social hub of the home, and becomes an altar when humanity reaches the urban condition. See Gottfried Semper, *The Four Elements of Architecture and Other Writings*, trans. Harry Francis Mallgrave and Wolfgang Herrmann (Cambridge: Cambridge University Press, 1989).

19. Joseph Rykwert, *The Idea of a Town: The Anthropology of Urban Form in Rome, Italy and the Ancient World* (London: Faber and Faber, 1976), pp. 104–105.

20. Lewis Mumford, *The City in History: Its Origins, Its Transformations, and Its Prospects* (New York: Harcourt, Brace and World, 1961), p. 182.

21. Rykwert, *The Idea of a Town*, pp. 99–100.

22. Ibid., p. 104.

23. Mircea Eliade and J. G. Frazer have each written much about the presence of fire in initiation and purification rites. Especially worth mentioning are the latter's *Myths of the Origin of Fire*

(London: Macmillan, 1930) and chapters 72 and 73 of his famous *The Golden Bough* (1890; London: Macmillan, 1957).

24. Rykwert, *The Idea of a Town*, p. 59.

25. François-René, vicomte de Chateaubriand, *Voyage en Amérique* (1828), pp. 123–124, quoted in Gaston Bachelard, *The Psychoanalysis of Fire*, trans. Alan C. M. Ross (Boston: Beacon Press, 1964), p. 32.

26. Lord Raglan, *The Temple and the House* (London: Routledge and Kegan Paul, 1964), p. 78.

27. "The equation of fire and life forms the basis of the system of Paracelsus. For Paracelsus, fire is life, and whatever secretes fire truly bears the seed of life" (Bachelard, *The Psychoanalysis of Fire*, p. 73). In the final analysis, as Needham has shown, the iatrochemical movement of the sixteenth century reconciles the tradition of Hellenistic protochemistry, centered around the production of gold, with the Chinese tradition that comes to us by way of Arabian alchemy, which is more concerned with the preparation of immortality-giving elixirs. Hellenic gold-making and Chinese macrobiotics (*macros bios*, long life) merge in the elixir (*al-iksir:* "the medicine of man and metals"). It is not for nothing that Paracelsus's most famous phrase is "The objective of alchemy is not to make gold, but to prepare cures for human ailments." The transformation of substances in fire raises hopes of eliminating "the impurities and corruptions" of metals and the human body alike, those existing in the latter being the cause of disease and death. In this way alchemy is linked not only to the quest for immortality, but also to the very creation of artificial life (recall the homunculi of Paracelsus and Faust), the Arabic "science of generation," automatons, etc. See Joseph Needham, *Science in Traditional China: A Comparative Perspective* (Hong Kong: Chinese University Press, 1981), pp. 57–84.

28. Lisa Heschong, *Thermal Delight in Architecture* (Cambridge: MIT Press, 1979), p. 72.

29. Gaston Bachelard, *The Poetics of Space*, trans. Maria Jolas (New York: Orion Press, 1964), p. 72.

30. O. V. de Milosz, “Mélancholie,” quoted in Bachelard, *The Poetics of Space*, p. 45.

31. Kent C. Bloomer and Charles W. Moore, *Body, Memory, and Architecture* (New Haven: Yale University Press, 1977), p. 5.

32. Bachelard, *The Psychoanalysis of Fire*, pp. 43ff.

33. Bachelard, *The Poetics of Space*, pp. 30–31.

34. Free solar energy—in radiation, air movement, and other climatic phenomena.

35. Accumulated solar energy—in wood, coal, and petroleum, for example.

36. Michel Serres, *Feux et signaux de brume: Zola* (Paris: Grasset, 1975), p. 109.

37. Edgar Morin, *La méthode*, vol. 1: *La nature de la nature* (Paris: Seuil, 1977).

38. Robert Misrahi, *Traité du bonheur*, vol. 1: *Construction d’un château* (Paris: Seuil, 1981), p. 45.

39. Ibid., p. 77.

40. Both quotes are from volume 7 (1957–1965) of his *Oeuvre complète* (Zurich: Editions d’Architecture, 1966), pp. 216 and 91.

41. Ibid., p. 205.

42. Frank Lloyd Wright, “Some Aspects of the Past and Present of Architecture” (1937), included in *The Future of Architecture* (New York: Mentor, 1963), pp. 39–72; the three quotes are taken from pp. 43–44.

43. Wright, fourth Princeton Lecture (1930), in ibid., pp. 143–162; the quote is from p. 150.

44. Peter Prangnell, “Fallingwater: Count One for You, E.J.,” *Spazio e società* 11 (September 1980), pp. 65–75.

1. Ilya Prigogine and Isabelle Stengers, *La nouvelle alliance: Métamorphose de la science* (Paris: Gallimard, 1979), pp. 97–98.

2. Ibid., p. 16.

3. P. W. Bridgman, observing this phenomenon closely, suggests in *The Logic of Modern Physics* that "many will discover in themselves a longing for mechanical explanation which has all the tenacity of original sin," and the facts seem to confirm this. Quoted from Peter Collins, *Changing Ideals in Modern Architecture, 1750–1950*, 2d ed. (Montreal: McGill-Queen's University Press, 1998), p. 166.

4. We must note here that mechanics was reestablished at the cost of dealing a harsh blow to the concept of univocal causality, precisely one of the pillars of the mechanistic dogma. The introduction of statistics—and the attendant concepts of probability and chance—into the necessary universe of Newton and Laplace distorts the original view so much that the contradictory term "statistical mechanics" has given way to the term "statistical thermodynamics."

5. Quoting from Enrico Bellone, *Il mondo di carta: Ricerche sulla seconda rivoluzione scientifica* (Milan: Mondadori, 1976), p. 97. A not too different view was upheld by Engels, who at about the same time spoke of the "century of the theory of evolution and energy transformation." Also see chapter 6, note 18, below.

6. Edgar Morin, *La méthode*, vol. 1: *La nature de la nature* (Paris: Seuil, 1977), pp. 61–62. Morin's description is vivid and eloquent, but his mention of Kepler, Galileo, and Copernicus unjustly plays down their contribution to the establishment of modern science. In their clash with Aristotelianism, they were far from advocating a hieratic, mechanized world. Newton himself was interested in alchemy. And in his *Dialogue on the Great World Systems* Galileo expressed shock at there being people who thought the earth would have been a better, more beautiful place if it had the incorruptible toughness of jasper, or if the flood had left just a sea of ice. He went on to wish upon these people a Medusa head that would turn them into

diamond statues, hence "better" than they were. Meanwhile, we must also note that the terms "cold universe" and "warm universe" had been used before Morin did so, at least by Serge Moscovici in his *Essai sur l'histoire de la nature* (Paris: Flammarion, 1977), pp. 360–368.

7. Morin, *La nature de la nature*, p. 85.

8. Quoted in Jeremy Rifkin, *Entropy: A New World View* (New York: Viking, 1980), p. 43; slightly modified.

9. Cesare Maffioli, *Una strana scienza* (Milan: Feltrinelli, 1979), p. 145.

10. Nonavailable energy is that which, in the words of Lord Kelvin, "man has irrevocably lost . . . but not annihilated." Note the inclusion of man in a scientific definition. This is unacceptable in Newtonian dogma, the cornerstone of its epistemology being the absolute separation of subject and object.

11. Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge: Harvard University Press, 1971), p. 276.

12. P. W. Bridgman, *The Nature of Thermodynamics* (Cambridge: Harvard University Press, 1941), p. 3. Georgescu-Roegen has nevertheless convincingly argued that "locomotion, particle, wave, and equation, for example, are concepts no less anthropomorphic than the two faces of entropy, the two qualities of energy" (*The Entropy Law and the Economic Process*, p. 10). In fact, "the idea that man can think of nature in wholly nonanthropomorphic terms is a patent contradiction in terms" (ibid., pp. 276–277). In his opinion the evident uniqueness of thermodynamics lies more in its links with economic value, which could make it totally incomprehensible to a nonanthropomorphic intellect.

13. Arthur Eddington, *The Nature of the Physical World* (1953); quoted in Ilya Prigogine, *From Being to Becoming: Time and Complexity in the Physical Sciences* (San Francisco: Freeman, 1980), p. 205.

14. Bachelard even shows, in his *Psychoanalysis of Fire*, how chapters about fire get shorter and shorter in successive editions of eighteenth-century chemistry books.

15. With formidable precision, incidentally: the value hit upon by Joule differs from today's accepted value by less than 0.75 percent. This says much about his genius as an experimenter—or metrologist, some would say. Also see chapter 6.

16. Maffioli, *Una strana scienza*, p. 150.

17. There is actually a third principle, Nernst's Law, which says that minimum entropy is unattainable.

18. Michel Serres has expressed this generalist and cosmological orientation of thermodynamics most beautifully: "Carnot speaks of his machine, he speaks of the world, of meteors, seas, and suns, he speaks of human groups, of the movement of signs" (quoted in Morin, *La nature de la nature*, p. 155).

19. Rifkin, *Entropy*, p. 228. Kenneth E. Boulding, however, criticizes what he calls the "cult of entropy," which he considers to be based on the above-cited work of Georgescu-Roegen and particularly manifest in Rifkin (see Boulding's *Evolutionary Economics* [Beverly Hills: Sage Publications, 1981], p. 147). Boulding's own position with respect to "thermodynamics as a post-Newtonian paradigm" is ambiguous, sprinkled with the usual misunderstandings surrounding the relation between evolution and entropy (see this chapter's final epigraph). This prompts him to warn us of the "dangers" of the concept and stress the overall implausibility of the "religion" of entropy, a term he would prefer to replace with "negative thermodynamic potential." See chapter 5 of his *Evolutionary Economics*, "The Economics of Energy and Entropy in Evolutionary Perspective," as well as Boulding's major work, *Ecodynamics* (Beverly Hills: Sage Publications, 1978); the latter is the subject of an extensive and perceptive critique by Manuel Sacristán, "La ecodinámica de K. E. Boulding," published in issue 9 of *Mientras tanto*, pp. 47–63.

20. Maffioli, *Una strana scienza*, p. 142.

21. Assuming, of course, that the system is isolated. Vital processes, for example, can go about in the direction of greater organization and the consequent decrease of entropy, but this requires

a continuous flow of negentropy from the environment to the organism, so that overall entropy increases with time.

22. Prigogine, *From Being to Becoming*, p. xviii.

23. Note that the theory of relativity, in subverting the foundations of the Newtonian world, not only leaves the idea of reversible time intact, but even incorporates it as an additional dimension of the space-time continuum. It mathematically formulates the intuitions of d'Alembert, who in 1754 warned us that time appears in dynamics as a mere "geometric parameter," and of Lagrange, who as early as 1796 described dynamics as a four-dimensional geometry. Einstein himself, just as he always resisted the concept of chance (the famous "God does not play dice" in his letter to Max Born), was never inclined to accept irreversibility, which "does not exist in physical laws" and is but the product of the illusion of "subjective time." "To those of us who are convinced physicists," he wrote, "the distinction between the past, the present and the future is only an illusion, no matter how persistent it is." See Prigogine, *From Being to Becoming*, pp. xi, 202–203.

24. Claude Lévi-Strauss, *Structural Anthropology*, trans. Claire Jacobson and Brooke Grundfest Schoepf (New York: Basic Books, 1963), p. 286. Kenneth E. Boulding expresses a similar idea when he says that the contemporary epistemological revolution "might be more than a simple revolution. It is more like the transfer to a new continent, and the name of the new continent, perhaps, is 'time'. The science of Newton, Kepler, Dalton, Laplace and Walras was essentially timeless. Its principles had no history, nor did they need one. For that science, history was an irrelevant fact: the objects it studied were the external laws of nature. But with Carnot and thermodynamics and subsequently Darwin, Rutherford and Bohr, irreversible time—or history—introduces itself in science, undermining its epistemological foundations." Boulding, prologue to Erich Jantsch, ed., *The Evolutionary Vision: Toward a Unifying Paradigm of Physical, Biological and Sociocultural Evolution* (Boulder: Westview Press, 1981).

25. In the *Principia:* "Absolute, true and mathematical time, in itself and by its very nature, flows uniformly, with no relation to anything exterior."

26. Georgescu-Roegen, *The Entropy Law and the Economic Process*, pp. 135–136.

27. Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: Braziller, 1968), p. 231.

28. Prigogine and Stengers, *La nouvelle alliance*, pp. 257ff. This same concept of "local time" has been defended by Panofsky—albeit in relativist terms—in the realm of cultural becoming: "Two historical phenomena are simultaneous . . . only in so far as they can be related within one 'frame of reference,' in the absence of which the very concept of simultaneity would be as meaningless in history as it would in physics. If we knew by some concatenation of circumstances that a certain Negro sculpture had been executed in 1510, it would be meaningless to say that it was 'contemporaneous' with Michelangelo's Sistine ceiling." Panofsky, *Meaning in the Visual Arts: Papers in and on Art History* (Garden City: Doubleday, 1955), p. 7.

29. Prigogine and Stengers, *La nouvelle alliance*, p. 29.

30. See Georgescu-Roegen, *The Entropy Law and the Economic Process*, appendix B, pp. 388ff., and Rudolf Arnheim, *Entropy and Art: An Essay on Disorder and Order* (Berkeley: University of California Press, 1971).

31. The first part of the next chapter uses concepts of the energy/information family profusely, so some of the critiques formulated here can probably apply to the most speculative of its metaphors.

32. L. L. Whyte expressed it in these terms: "Two major opposing tendencies appear in natural processes, one toward a local order, and the other toward uniformity in a general disorder. The first is manifested in all processes in which a zone of order tends to differentiate itself from a less orderly environment. This is what we see in crystallization, in chemical combinations, and in most organic processes. The second tendency is manifested in the

processes of irradiation and diffusion and leads to uniformity in thermal disorder. The two tendencies normally proceed in opposite directions, the former producing differentiated zones of order and the latter dispersing them." Whyte, *The Unitary Principle in Physics and Biology* (1949); quoted in Morin, *La nature de la nature*, p. 79.

35. See Prigogine and Stengers, *La nouvelle alliance*, pp. 144, 153, 275; also note 21 of this chapter.

3 Architecture, Memory, and Entropy: Amnesia or History

1. The word "form" is used here in a sense slightly differing from the usual. Following Margalef, I say "information" or "form" when referring to "the manner in which energy and matter combine and extend in space": Ramón Margalef, *La biosfera entre la termodinámica y el juego* (Barcelona: Omega, 1980), p. 17. For an interesting analysis, from the viewpoint of the philosophy of science, of the road that leads from the classical concept of "form" to the contemporary one of "information," see chapter III-5 ("Matter, Energy, Information") of Carl Friedrich von Weizsäcker, *The Unity of Nature*, trans. Francis J. Zucker (New York: Farrar Straus Giroux, 1980).

2. Margalef, *La biosfera entre la termodinámica y el juego*, p. 19.

3. Ibid., p. 20.

4. Ibid., pp. 132, 134.

5. Note that this conception of architecture as a support of memory is very different from the "theaters of memory" and other architectural artifices that were the physical support of the ancient art of memory, as described by Frances Yates in *The Art of Memory* (Harmondsworth: Penguin, 1969).

6. A human history of nature, that is, following Moscovici, and therefore totally different from ancient natural history. Serge Moscovici, *Essai sur l'histoire humaine de la nature* (Paris: Flammarion, 1977).

7. Margalef, *La biosfera entre la termodinámica y el juego*, p. 40.

8. Using Lotka's terminology discussed in chapter 1 (see note 8), we could say that cultural evolution affects exosomatic instruments, and biology endosomatic ones.

9. Erich Jantsch, *The Self-Organizing Universe* (Oxford: Pergamon, 1980), p. 248.

10. Margalef adds an intermediate one, the ecological channel, "based on the interaction between different coexisting species and expressed by their relative perseverance, or on the regular changes in their respective numbers." Ramón Margalef, *Perspectivas de la teoría ecológica* (Barcelona: Blume, 1978), p. 95.

11. Of course we are only referring to the transmission of information in organic evolution. The inorganic has its own channels, which are very different from biological and cultural ones. Thus the temperature and composition of a star together transmit data about its age and history; a folding or a fault contains information about the vicissitudes of our planet. Both the star and the folding can be thought of as physical supports for the memory of the cosmos.

12. Lewis Mumford, *Technics and Civilization* (1934; New York: Harcourt, Brace and World, 1963), p. 10. Georgescu-Roegen expresses the same idea with great conceptual force when he says that "exosomatic instruments enable man to obtain the same amount of low entropy with less expenditure of his own free energy than if he used only his endosomatic organs": Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge: Harvard University Press, 1971), p. 307.

13. Margalef, *La biosfera entre la termodinámica y el juego*, p. 15.

14. Note that this evolution covers not only the body of technical and scientific knowledge available, but culture as a whole—and this in the broad sense of the term, transcending the restrictive realm of the "humanities." It is in this sense of the concept of culture—as something that, rather than opposing the scientific and technical universe, includes it—that we ought to take the term "cultural channel," or Georgescu-Roegen's affirmation that "the exosomatic evolution works its way through the cultural tradition, not only through

technological knowledge" (*The Entropy Law and the Economic Process*, p. 19).

15. Charles J. Lumsden and Edward O. Wilson, *Genes, Mind and Culture* (Cambridge: Harvard University Press, 1981), p. 337.

16. These ideas are elaborated on by Philip Steadman in *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts* (Cambridge: Cambridge University Press, 1979), p. 129.

17. Ibid., p. 5.

18. Ibid., p. 81.

19. Boris Ryback, "Logique des systèmes vivants," *Encyclopaedia universalis* (Paris, 1973), vol. 15, pp. 687–697, quoted in Edgar Morin, *La méthode*, vol. 1: *La nature de la nature* (Paris: Seuil, 1977), p. 296.

20. In its most banal version, the analogy would be reduced to the simultaneous presence, in the creative act, of two design procedures that have been differentiated since ancient times: design from inside to outside, which we can associate with genotypic information, meaning functional and formal program; and design from outside to inside, an expression of phenotypic information, having to do with the material and symbolic determinants of the environment. An exaggerated example: the open block usually shows a predominance of the *génothèque* over the *phénothèque*, whereas in the closed, perimeter block it is generally the other way around; but although the inside-out is more important in the open block and the outside-in in the city block, either typology is the object of both design procedures.

21. See Steadman, *The Evolution of Designs*, p. 31. In Rafael Moneo's opinion, "Durand, as a naturalist, classifies all the stairs, courtyards, and arcades he knows of, and presents them in a single plate for the convenience of the architect," but "he does not invent types, he simply applies schematic programs of organization to those he knows" (prologue to Durand's *Compendio de lecciones de arquitectura* [Madrid: Pronaos, 1981], pp. x and viii).

22. Ilya Prigogine and Isabelle Stengers, *La nouvelle alliance: Métamorphose de la science* (Paris: Gallimard, 1979), pp. 142–143.

23. Filarete, *Trattato d'architettura*, book I, f. 6r, quoted in Françoise Choay, *La règle et le modèle* (Paris: Seuil, 1980), p. 213.

24. History is indeed so plastically seductive that even Alberti, who in his effort to be systematic and generalist leaves most of the traditional stock of anecdotes out of *De re aedificatoria*, is unable to resist the temptation to include this particular one. As Françoise Choay rightly points out, it is the only "decorative" tale he takes from Vitruvius (Choay, *La règle et le modèle*, p. 149).

25. Vitruvius, *De architectura*, book II, preface.

26. It is clearly differentiated from the traditional metaphor of the body, although treatise writers like Francesco di Giorgio attempted to interpret it along this line, believing it to illustrate "the similarity between a city and the human body." Martin Kemp, *Leonardo da Vinci: The Marvellous Works of Nature and Man* (London: Dent, 1981), p. 117.

27. Margalef, *La biosfera entre la termodinámica y el juego*, p. 11.

28. This is Margalef's opinion (ibid., p. 15).

29. Howard T. Odum, *Environment, Power, and Society* (New York: John Wiley, 1971), p. 73.

30. Ibid., pp. 7, 8.

31. All the data offered in this paragraph are taken from Odum (ibid., p. 50).

32. According to these figures, which Odum takes from Hutchinson, the biological energy consumption is approximately fifty times the fossil energy consumption, but Jantsch (*The Self-Organizing Universe*, p. 276) cites a calculation by Hall that makes the biological energy flow only ten times that of the fossil. (Of that biological flow, only 0.5 percent corresponds to the human species.)

33. According to my calculations, in 1976 the consumption was 3.77 kcal/m^2-day, of which 3.57 was exosomatic and 0.20 endoso-

matic. Today's exosomatic consumption is somewhat higher, and endosomatic consumption appreciably the same, so that the total figure may now approach 4 kcal/m^2-day.

34. Margalef, *Perspectivas de la teoría ecológica*, p. 98.

35. Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: Braziller, 1968), p. 158; see chapter 1 above.

36. Erwin Schrödinger's expression appears in chapter 6 of his short masterpiece *What Is Life?* (Cambridge, 1944), although, as Georgescu-Roegen points out, the seed of this idea goes back to Boltzmann, who as early as 1886 wrote that free energy is the object of the struggle for life (Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 192). See Ludwig Boltzmann, *Escritos de mecánica y termodinámica* (Madrid: Alianza, 1986), p. 72.

37. Prigogine and Stengers have dwelt on the link between the production of entropy and different irreversible phenomena, including of course the diffusion of heat but also the diffusion of matter, chemical reactions, etc. (*La nouvelle alliance*, p. 145).

38. See Georgescu-Roegen's afterword to Jeremy Rifkin, *Entropy: A New World View* (New York: Viking, 1980), pp. 261–269. Much better, perhaps, is the phrase he likes to repeat: "Matter matters."

39. Ibid. We must not, however, think that the entropy of matter is measurable. As the proposer of the fourth law stresses, "the entropy of energy can be measured because it is homogeneous; matter in general is, in contrast, heterogeneous, as Mendeleyev's chart glaringly shows."

40. Morin, *La nature de la nature*, p. 73.

41. Patrick Geddes, a pioneer in so many things, also introduced the contemporary view of the physical rehabilitation of the degraded environment—for which "we need both constructive and destructive energy"—in an early thermodynamic expression of the permanent mutation of urban fabrics. Geddes, *Cities in Evolution* (1915; London: Ernest Benn, 1968), p. 102.

42. Choay, *La règle et le modèle*, p. 207.

43. Leon Battista Alberti, *On the Art of Building in Ten Books*, trans. Joseph Rykwert, Neil Leach, and Robert Tavernor (Cambridge: MIT Press, 1988), Book X, Chapter I, p. 320.

44. Ibid., Book X, Chapter XII, p. 350.

45. Choay, *La règle et le modèle*, p. 90.

46. Ibid., p. 96.

47. Von Bertalanffy, *General System Theory*, p. 145.

48. Rudolf Arnheim, *Entropy and Art: An Essay on Disorder and Order* (Berkeley: University of California Press, 1971), p. 49.

49. Morin, *La nature de la nature*, p. 185.

50. Prigogine and Stengers, *La nouvelle alliance*, p. 148.

51. Morin, *La nature de la nature*, p. 187.

52. Ibid.

53. Norbert Wiener, *The Human Use of Human Beings* (New York, 1950), p. 85, quoted in Steadman, *The Evolution of Designs*, p. 175.

54. This has been emphasized by both Steadman (*The Evolution of Designs*, pp. 169ff.) and Choay (*La règle et le modèle*, p. 129). George Kubler has explained it in a particularly graphic way: "Since it brings to light medieval architectural archaeology, the history of a building cannot be written without taking into account the disasters, the repairs and the restorations that have gradually been replacing its original exterior and interior surfaces in the course of many reconstruction campaigns, in a 'fossilization' process that perpetuates the initial form at the same time that it replaces the original visible matter with another": Kubler, *Building the Escorial* (Princeton: Princeton University Press, 1982), p. 119.

55. Paul Colinvaux, *Why Big Fierce Animals Are Rare* (Harmondsworth: Penguin, 1980), p. 185.

56. Jantsch, *The Self-Organizing Universe*, p. 273.

57. Margalef, *La biosfera entre la termodinámica y el juego*, pp. 128 and 32.

4 **Paradigms of Life and Thermodynamic Architectures**

1. Cesare Maffioli, *Una strana scienza* (Milan: Feltrinelli, 1979), p. 132.

2. Ramón Margalef, *La biosfera entre la termodinámica y el juego* (Barcelona: Omega, 1980), p. 8.

3. Which is nothing but chemical energy. In fact, as Margalef points out, one consequence of the complexity of living beings, of their wealth of heterogeneous details, is that "the miniaturized machine" that an organism is "can only function with high-quality energy. The options are few: electromagnetic energy of a relatively short wavelength, or chemical energy" (ibid., p. 3).

4. Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge: Harvard University Press, 1971), p. 10.

5. Ibid., p. 191.

6. Reginald Blomfield, for example, attacked the thermal inadequacy of the architecture of the modern movement in his *Modernismus* of 1934: "These apostles of efficiency are so amazingly inefficient" (quoted from Benton and Sharp, *Form and Function* [London: Crosby Lockwood Staples, 1975], p. 176). Opinions of this kind are more generalized in writings undertaken in the wake of the oil crisis, and a good example is the comment of Philip Steadman: "The economy of means—in the esthetic, structural or spatial field—that characterized the functionalism of the Modern Movement did not extend, curiously, to the energy field" (*Energy, Environment and Building* [Cambridge: Cambridge University Press, 1975], p. 16).

7. Le Corbusier, *Précisions* (Paris: Crès, 1930), p. 64, quoted in Reyner Banham, *The Architecture of the Well-Tempered Environment* (London: Architectural Press, 1969), p. 159.

8. Le Corbusier, *Précisions*, pp. 64ff.

9. As Reyner Banham opines (*The Architecture of the Well-Tempered Environment*, p. 160).

10. The role of variety in the thermal delight that architecture can provide has been dwelt on by Lisa Heschong in her book *Thermal Delight in Architecture* (Cambridge: MIT Press, 1979). Ramón Margalef has discussed the repercussions of thermal fluctuations on living beings, and stressed the lesser efficiency of the homeotherm (*La biosfera entre la termodinámica y el juego*, pp. 188–189). By ignoring the environmental diversity that vital phenomena require, heliotechnical architecture reveals its true mechanistic nature, one inexorably linked to spatial uniformity. (Pierre Thuillier explicitly states the relation between the construction of machines and homogeneous isotropic space in "Au commencement était la machine," *Le petit savant illustré* [Paris: Seuil, 1980], pp. 29–39.)

11. Whitehead's philosophy—significantly impregnated with a biologistic flavor—has perhaps most vehemently combated the opinion predominant among philosophers, according to which sight is the typical form of a relation. See John Passmore, *A Hundred Years of Philosophy* (Harmondsworth: Penguin, 1968), pp. 341–342.

12. Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 194.

13. Harold F. Blum, *Time's Arrow and Evolution* (Princeton: Princeton University Press, 1968), p. 94.

14. Jeremy Rifkin, *Entropy: A New World View* (New York: Viking, 1980), p. 55.

15. Ilya Prigogine and Isabelle Stengers, *La nouvelle alliance: Métamorphose de la science* (Paris: Gallimard, 1979), p. 144.

16. Ibid., p. 153.

17. This description is borrowed from Prigogine and Stengers; ibid., pp. 156ff.

18. Edgar Morin, *La méthode*, vol. 1: *La nature de la nature* (Paris: Seuil, 1977), pp. 49, 48. Morin develops this line of thought in the

second volume of *La méthode*, *La vie de la vie* (Paris: Seuil, 1980), pp. 365–371.

19. Prigogine and Stengers, *La nouvelle alliance*, p. 275.

20. Ibid., p. 159. A good elementary introduction to this new conception of biology is Marcelino Cereijido, *Orden, equilibrio y desequilibrio: Una introducción a la biología* (Mexico City: Nueva Imagen, 1978).

21. Prigogine's theory of dissipative structures may simply be the most significant part of a body of theoretical developments that were undertaken in the 1970s, and for which a better denomination would perhaps be "new paradigm." Without trying to be exhaustive, we could mention Haken's "synergy," Eigen's hypercycles, Jantsch's self-organization, Maturana and Varela's "autopoiesis," von Hayek's spontaneous social orders, Boulding's "evolutionary view" and ecodynamics, Bohm's "implied order," Lovelock and Margulis's "Gaia hypothesis," Bateson's mental ecology, the works of Waddington, Weizsäcker, Laszlo, and Capra, and even Thom's theory of catastrophes. As has been suggested, all these could converge in a *dynamic* General Systems Theory, one that studies the evolution of self-organizing dissipative systems.

22. Rifkin, *Entropy*, pp. 245–246.

23. These criticisms are of course not well grounded. Von Hayek's term "spontaneous social systems" was juxtaposed with autopoiesis and dissipative structures in the title of a symposium of the American Association for the Advancement of Science (Milan Zeleny, ed., *Autopoiesis, Dissipative Structures, and Spontaneous Social Orders* [Boulder: Westview Press, 1980]). In the preface of the publication, Kenneth E. Boulding argues that autopoiesis or self-organization is but the "invisible hand" of Adam Smith (Boulding maintains that the human brain itself is run by an "invisible hand"), exalts the idea of form-generating chaos, and worries about how astonishing this point of view must be to a generation brought up in the "uncomfortable and negative" concept of entropy. (Notwithstanding, and paradoxically, this school's appreciation of general systems leads Elise Boulding—in a subsequent AAAS symposium:

Erich Jantsch, ed., *The Evolutionary Vision: Toward a Unifying Paradigm of Physical, Biological and Sociocultural Evolution* [Boulder: Westview Press, 1981]—to cite in moderately laudatory terms the works of Samir Amin and Emanuel Wallerstein about capitalism as a world system.)

24. The title of the book in which Ilya Prigogine and his young colleague Isabelle Stengers expound on the philosophical consequences of their scientific ideas.

25. Thuillier, *Le petit savant illustré*, p. 109.

26. Rifkin, *Entropy*, p. 247.

27. Margalef would have aligned himself with Georgescu-Roegen here. In the title of his book *La biosfera entre la termodinámica y el juego*, the allusion to Monod's *Le hasard et la nécessité* is evident: chance commends itself to playing (*juego*) and necessity to thermodynamics.

28. Apart from certain architectures that managed to elude a material confrontation with the specific circumstances of the crisis, withdrawing instead into autonomous universes of their own and hence products of the crisis only to the extent that they fled from it.

29. The functional nature of bioclimatic architecture will be discussed in detail in the following chapter.

30. One of the best-known connections is through the eye, the perceptive predominance of which, as we have already said, prevents energy considerations from drawing the attention they deserve (see chapter 1). When D'Arcy Thompson analyzes the growth processes of organic forms in *On Growth and Form* (1917; Cambridge: Cambridge University Press, 1961), chapter 9, pp. 268–325, he uses the same Cartesian grid that Dürer used to subject the living thing to the objective empire of mechanical representation. The gaze of the artist through the grid mechanized the organic, transformed the subject into an object, and made the posing model a "docile body," thereby initiating a tyranny of (and through) the eye that was to have its textual crystallization in Leonardo da Vinci's and Alberti's trea-

tises on painting and its graphic paroxysm in Jeremy Bentham's Panopticon (see note 11 of this chapter).

5 Organisms and Mechanisms, Metaphors of Architecture

1. Leonardo da Vinci's manuscripts do not count here because they transcend the specific field of architectural history (although they do fall under it; we have no examples of built work by Leonardo—apart from a few models and works of uncertain authorship—but Vasari called him an "excellent architect" and his manuscripts abound with projects, sketches, and theoretical studies).

2. At least in the West, for in China the clock escapement was invented early in the eighth century by I-Hsing, a Tantric Buddhist monk who was the greatest mathematician and astronomer of his time, and Liang Ling-Tsan. Joseph Needham, *Science in Traditional China: A Comparative Perspective* (Hong Kong: Chinese University Press, 1981), p. 15.

3. Ludwig von Bertalanffy adds molecular machines, meaning the mechanical structures that operate at a molecular level (*General System Theory: Foundations*, *Development*, *Applications* [New York: Braziller, 1968], p. 140).

4. Prigogine and Stengers point out that each of these images, taken from the technology of its time, contradicts the idea of an immanent organizing intelligence. Ilya Prigogine and Isabelle Stengers, *La nouvelle alliance: Métamorphose de la science* (Paris: Gallimard, 1979), p. 171.

5. Manuscript A, 10r, quoted in Martin Kemp, *Leonardo da Vinci: The Marvellous Works of Nature and Man* (London: Dent, 1981), p. 119.

6. Leonardo Benevolo, *The Architecture of the Renaissance* (Boulder: Westview Press, 1978), p. 242.

7. Codex Atlanticus, 161ra, quoted in Kemp, *Leonardo da Vinci*, p. 122. The flight of birds is described *in extenso* in the Turin manuscript *Codice sul volo degli uccelli e varie altre materie*.

8. Interspersed, to be sure, with bits and pieces of premechanistic thought. For example, William Harvey's *De motu cordis* of 1628 mixes the evident mechanicism of the description of the heart as a pump with an amalgam of cosmological ideas derived from hermeticism, Neoplatonism, and natural magic. And Gómez Pereira bases his mechanical study of animal behavior on the natural philosophy of *calculatores* and medieval medicine.

9. There seems to be a parallel tradition, from Galileo to D'Arcy Thompson, that also uses physical and mechanical knowledge for the study of living things, but does not apply to them the analogy of the machine.

10. Automata were being constructed long before the Renaissance, to be sure. Suffice it to remember the important Alexandrine tradition and its Islamic continuation, or medieval carillons with animal figures—Villard de Honnecourt himself drew a mechanical eagle whose movements were to accompany the reading of the Scriptures in churches. Nevertheless it was in the sixteenth century that automata became popular, and too few samples dated before that have come down to our days. Moreover, only in the Renaissance did they begin to be describable as "metaphors of the organic." Previously, when not mere entertainment objects, automata had a magical or religious dimension, and sometimes, like many of the mechanisms described by Hero in his *Pneumatica*, they were made for the sole purpose of serving the "scientific production of miracles" that Farrington so vehemently denounced. Even in mannerism, as Paolo Portoghesi states in *Infanza delle macchine* (Bari: Laterza, 1981) and Marcello Fagiolo develops in *Natura e artificio* (Rome: Officina Edizioni, 1979), automata or those "blasphemous variants of the human" represented the wonder and enigma of movement, the mystery of artificial life. D'Alembert and Diderot's enthusiastic response to the androids of Vaucanson was still a long way off.

11. De Caus, incidentally, was also a pioneer of environmental technology. Early in the seventeenth century, this French engineer built one of the oldest *orangeries* we know of for the Elector Palatine in Heidelberg (see John Hix, *The Glass House* [Cambridge: MIT

Press, 1974], p. 10), in the same gardens where he had installed his famous and much-copied grottoes with moving figures, true automatic theaters along the lines of those Hero of Alexandria describes in his *Automatopoietike*.

12. Which, to be sure, had certain organic echoes, proof of which is the maker's own description of it as "a machine that dances." Seventy-five years after its construction, in 1645, a new show was presented in Madrid by the name of *El Mago* (The Magician) in which the dancers imitated the movements of Juanelo's contrivance.

13. The philosopher himself was rumored to have constructed a mechanical woman, which legend called Francine. So named was an illegitimate daughter of Descartes, and the myth has as much truth to it as the golden servants of Hephaestus, the mechanical cow of Daedalus, or the androids that Roger Bacon and Albertus Magnus are said to have fabricated (not to mention Juanelo's "stick man").

14. Giedion seems to share this opinion ("it is Vaucanson's practical activities that are historically the most interesting") when he puts emphasis on the transition "from the miraculous to the utilitarian." Nevertheless he goes on to stress the admiration Vaucanson's automata drew among the likes of Condorcet, Diderot, or D'Alembert, who described the famous duck in the *Encyclopédie*. See Sigfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History* (New York: Oxford University Press, 1948), pp. 34–36.

15. Lewis Mumford, *Technics and Civilization* (1934; New York: Harcourt, Brace and World, 1963), p. 14.

16. Prigogine and Stengers, *La nouvelle alliance*, p. 28.

17. Ibid., pp. 126–129.

18. Rudolf Arnheim, *Entropy and Art: An Essay on Disorder and Order* (Berkeley: University of California Press, 1971), p. 44. Arnheim also quotes David Riesman: "It seems clear that Freud, when he looked at love or work, understood man's physical and psychic behavior in the light of the physics of entropy and the economics of scarcity" (Riesman, *Individualism Reconsidered* [Glencoe: Free Press, 1954], p. 325).

19. Quoted in Steve J. Heims, *John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death* (Cambridge: MIT Press, 1980), p. 155.

20. Edgar Morin, *La méthode*, vol. 1: *La nature de la nature* (Paris: Seuil, 1977), pp. 229–230.

21. Heims, *John von Neumann and Norbert Wiener*, p. 304.

22. We must mention the engineer Leonardo Torres Quevedo, who deserves to be called the precursor of cybernetics, as much for his theoretical works—including *Ensayos sobre automática* (1914)—as for his practical constructions, such as the Telekino, the Electromechanic Arithmometer, and the famous Automatic Chess Players, all of which were put together during the first two decades of the century. The most complete descriptions are provided by José García Santesmases in *Obra e inventos de Torres Quevedo* (Madrid: Instituto de España, 1980).

23. Morin, *La nature de la nature*, pp. 165–166.

24. Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: Braziller, 1968), pp. 161, 259.

25. Alfred North Whitehead, *Science and the Modern World* (New York: Free Press, 1967), p. 54.

26. Quoted in Sigvard Strandh, *Machines* (London: Mitchell Beazley, 1979), pp. 3, 54. It is this same idea that Samuel Butler develops in his satire *Erewhon* (London, 1872). Jorge Luis Borges and Adolfo Bioy Casares summed it up cheerfully in a dense paragraph of their *Crónicas de Bustos Domecq* that located in Butler the roots of "functionalism" (a term now rather discredited, they nevertheless warn us, in the small world of architects). Such a conception of machines presents striking similarities to Lotka's "exosomatic instruments," as Philip Steadman shows. Steadman, too, believes that *Erewhon* contains antecedents of some key notions of functionalism, including the Lamarckian evolution of the artifacts that underlay the *objet-type* of Ozenfant and Le Corbusier—whose purist magazine *L'Esprit Nouveau*, by the way, mentioned Butler in a favorable light. See Steadman, *The Evolution of Designs: Biological Analogy in Architec-*

ture and the Applied Arts (Cambridge: Cambridge University Press, 1979), chapter 8, pp. 124–136.

27. Mumford, *Technics and Civilization*, p. 41. The search for the military origins of machines also led Mumford to reckon the cannon as the first steam engine.

28. Born in Catalonia in 1698, Bernard Forest de Belidor was a typical product of the military schools founded in France during the early decades of the eighteenth century. In 1729 he published *La science des ingénieurs*, a widely disseminated treatise that was considered an exemplary work for more than a hundred years. Both this book and *L'architecture hydraulique* (1737–1753) were republished by Navier, with updated notes, as late as 1813 and 1819, respectively—a testimony to his popularity and continued validity. See Edoardo Benvenuto, *La scienza delle costruzioni* (Florence: Sansoni, 1981), pp. 274, 418.

29. Rev. R. Balgarnie, *Sir Titus Salt*, *Baronett: His Life and Its Lessons* (London: Hadder and Stoughton, 1878), quoted by Ornella Selvafolta in "Lo spazio del lavoro 1750–1910," in *La macchina arrugginita* (Milan: Feltrinelli, 1982), p. 54. Ludwig Boltzmann himself writes in 1900: "We cannot shake off the idea that nature is something animate. Don't today's machines work like conscious beings? They puff, pant, howl, groan, they emit sounds of complaint, fear, warning, and they whistle shrilly when the force applied on them increases. To maintain their strength they take from their surroundings the necessary materials, and eliminate what is not necessary, all the while going by the same laws that our own bodies do." Boltzmann, *Escritos de mecánica y termodinámica* (Madrid: Alianza, 1986), p. 192.

30. Samuel Butler, *Erewhon* (1872; Newark: University of Delaware Press, 1981), p. 190.

31. Morin, *La nature de la nature*, pp. 160, 165, 161.

32. Mumford, *Technics and Civilization*, pp. 4, 10.

33. This includes not only the mechanization of man or the conception of organisms as machines, but also the very penetration of

mechanisms into the organic world, as attested in part III ("Mechanization Meets the Organic") of Giedion's book *Mechanization Takes Command.*

34. Legends that have to be linked to old traditions of building androids, from classical mythology to the most popular contemporary version of the theme of *Frankenstein*, the famous Gothic novel of Mary Shelley (where the leading character, by the way, the doctor who creates the humanoid monster, admits to having searched for the secret of life in Albertus Magnus and Paracelsus, two figures also said to have built artificial men).

35. Heims, *John von Neumann and Norbert Wiener*, pp. 374–375. An interesting interpretation of the golem myth can be found in André Robinet, *Le défi cybernétique* (Paris: Gallimard, 1973). This work also explores the automaton theme in Pascal, Descartes, Malebranche, and Leibniz.

36. Heims, *John von Neumann and Norbert Wiener*, p. 154.

37. Prigogine and Stengers, *La nouvelle alliance*, p. 57.

38. Von Bertalanffy, *General System Theory*, p. 88.

39. Kevin Lynch, *A Theory of Good City Form* (Cambridge: MIT Press, 1981), pp. 95, 97. The importance of the cultural dimension in artifacts—including cities and buildings—was expressed very clearly by Baudrillard in *The System of Objects:* "Our practical objects . . . are continuously fleeing from technical structurality toward secondary meanings, from the technological system to a cultural system."

40. Peter Collins, *Changing Ideals of Modern Architecture*, 2d ed. (Montreal: McGill-Queen's University Press, 1998), pp. 156 and 159.

41. In fact, in Collins's opinion they were the most significant analogies of that period: "Of the various analogies used in the last century to clarify the principles of a new architecture, probably the only one to equal in importance the biological analogy has been the analogy between buildings and machines" (ibid., p. 159). We know

that as early as 1914 Geoffrey Scott devoted two chapters of *The Architecture of Humanism* to criticizing the "mechanical fallacy" and the "biological fallacy," thereby testifying to the popularity of both analogies.

42. "This thing we call the machine, contrary to the principle of organic growth, *but imitating it.*" Frank Lloyd Wright, *The Future of Architecture* (1953; New York: Mentor, 1963), p. 90; my italics. The quote is taken from the first of the Princeton lectures of 1930.

43. As when he speaks, for instance, of "la ville vivante, totale, fonctionnante avec ses organs *qui son ceux de la société machiniste.*" Le Corbusier, *La ville radieuse* (Paris: Vincent Fréal, 1933), p. 140; my italics.

44. Wright, *The Future of Architecture*, p. 159. The quote is from the fourth of the Princeton lectures.

45. Le Corbusier, *La ville radieuse*, p. 111.

46. Wright, *The Future of Architecture*, p. 92. From the first Princeton lecture.

47. Le Corbusier, *La ville radieuse*, pp. 134, 139; Françoise Choay, *La règle et le modèle* (Paris: Seuil, 1980), p. 295.

48. Wright, *The Future of Architecture*, p. 143. From the fourth Princeton lecture.

49. Le Corbusier's biological analogies are expressed here in the words of Philip Steadman, *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts* (Cambridge: Cambridge University Press, 1979), p. 48.

50. Collins in fact puts them together under the heading "functionalism," along with analogies he names "gastronomic" and "linguistic." Also see Steadman, *The Evolution of Designs*, p. 16.

51. Alan Colquhoun, "Typology and Design Method," *Perspecta* 12 (1969), p. 72, quoted in Steadman, *The Evolution of Designs*, p. 1.

52. "The site determined the features and character of Taliesin. . . . Taliesin is now a stone house and it is a house of the

North—really built for the North. . . . Taliesin was built *to belong to the region*" (Wright's emphasis). Then, moving from Wisconsin to Arizona, "the terrain now changed absolutely. Here we came to the absolute desert. . . . Taliesin West had to be absolutely according to the desert. So Taliesin there is according to its site again, according to its environment." Wright, *The Future of Architecture*, pp. 19, 21. Indeed, on numerous occasions Wright insisted that "climate means something to man"; see Frank Lloyd Wright, *The Natural House* (New York: Horizon Press, 1954), p. 178.

53. Wright, *The Future of Architecture*, pp. 144–145, 160. From the fourth Princeton lecture.

54. An adherence that is often more rhetorical than pragmatic. The "balloon frame" or the Levitt homes, for example, are better adapted to industrial production than Le Corbusier's Dom-ino House. As for Wright, it will suffice to remember the construction fiasco in the dwellings of concrete blocks that he called Usonian Automatic, built between 1921 and 1924. Seeking "the elimination of specialized work" (Wright in his *Natural House*), he delegated all execution of building services to the factory. This proved so inefficient that the project has been compared with Wright's "loathsome furniture," where "efforts reap better results as a *plastic idea* than as a solution to a *pragmatic fact*" (James Tice in *Architectural Design*, 8–9/1981, p. 62).

55. Le Corbusier, *When the Cathedrals Were White*, trans. Francis E. Hyslop, Jr. (New York: Reynal and Hitchcock, 1947), pp. 167–170.

56. Ibid., p. 167. With those same two words for a title (*Modern Times*), a year after Le Corbusier visited America in 1935, Charlie Chaplin launched the most scathing criticism of Taylorism on the big screen, culminating a cinematographic reflection on the mechanization of life that was already present in the caustic Keaton of *The Electric House* (1922), but which had its earliest philosophical manifestation in Paul Wegener's *The Golem* (1920), antecedent of numerous Frankensteins, and its crowning expression in Fritz Lang's classic *Metropolis* (1927). Chaplin's irony in *Modern Times* and

William Cameron Menzies's disturbing images in *The Future Life* (also previewed in 1936) were ignored by the enlightened, optimistic European architect then traveling through the United States, whose prophetic redemptorism would be better represented by the phrase "The machine is saving us, long live the machine!" of Sergei Eisenstein's *The General Line* (1929) than by the cultural mood of mechanism-and-Ford America.

57. See John Sergeant, *Frank Lloyd Wright's Usonian Houses: The Case for Organic Architecture* (New York: Watson-Guptill, 1976), p. 146.

58. Francis Duffy has drawn attention to some of these conditions in "Office Buildings and Organizational Change," in Anthony D. King, ed., *Buildings and Society* (London: Routledge and Kegan Paul, 1980), pp. 266–269, whereas Kenneth Frampton, a critic normally concerned with the relation between architecture, work, and production, overlooks them completely when describing the Larkin building in *Modern Architecture: A Critical History* (London: Thames and Hudson, 1980), pp. 61–62.

59. Wright deplored the clients' ordering changes in the building that made it just "another of their factories," but this only brings to light the rhetorical component of his acceptance of industrial production processes (see note 54).

60. Collins, *Changing Ideals in Modern Architecture*, p. 166. Philip Steadman has explored in detail what he calls "ecological analogy," in reference to the way the environment has a bearing on the shape of artifacts and organisms through their functions. This is crystallized in Louis Sullivan's famous "form follows function." In Steadman's opinion, there is a thread that connects Cuvier's comparative anatomy and Darwin's theory of evolution to Greenough, Viollet-le-Duc, and Semper, and on to Sullivan and Wright (*The Evolution of Designs*, pp. 57ff.). Joseph Rykwert goes farther back in time to suggest that the idea reaches Greenough, via Milizia, from the Lodoli of Algarotti, who preached the need to unite *rappresentazione* and *funzione* ("Lodoli on Function and Representation," in Rykwert, *The Necessity of Artifice* [London: Academy Editions, 1982],

pp. 114–121). I myself would say that in the notorious functionalist slogan one even perceives echoes of the theory of signatures that Paracelsus took from Pliny, which invested plants with the curative properties that their very shapes suggested, so that one resembling a heart would be a cardiac tonic, one that suggested sexual organs an antidote to sterility, etc. There is still much research to be done on the mythical and archaic origins of a good portion of contemporary architectural thought, the fruits of which may prove far more important than we currently believe.

61. A milestone among these advances is, significantly and paradoxically, the Larkin building. Wright was never a staunch supporter of the system: "To me air conditioning is a dangerous circumstance. . . . [It] has to be done with a good deal of intelligent care. . . . I think it far better to go *with* the natural climate than try to fix a special artificial climate of your own. . . . I doubt that you can ignore climate completely, by reversal make a climate of your own and get away with it without harm to yourself." Wright, *The Natural House*, pp. 175–178.

62. Collins, *Changing Ideals in Modern Architecture*, p. 154.

63. On this point they are in agreement with one of the most illustrious fathers of functionalism, the architectural theorist and reformer Carlo Lodoli, a Franciscan friar who lived in eighteenth-century Venice and is said to have coined the terms "organic" and "functional." The portrait Alessandro Longhi did of him was accompanied by two panels with inscriptions that summed up the philosopher's thought. A quotation from the book of Jeremiah—*Ut eruas et destruas* . . .—expressed that a building is preceded by the destruction of everything preexisting (Rykwert, *The Necessity of Artifice*, p. 116).

64. Morin, *La nature de la nature*, p. 74.

65. Leon Battista Alberti, *De re aedificatoria*, Book IV, Chapter I.

6 **Energy as the Currency of Nature: A Genealogy**

1. Bertrand de Jouvenel, *La civilisation de puissance* (Paris: Fayard, 1976), p. 11.

2. For Rumford and Joule, see chapter 2.

3. J. N. P. Hachette, *Traité élémentaire des machines* (Paris, 1811), pp. xiv–xv.

4. Alfred Sauvy, *La machine et le chômage* (Paris: Dunod, 1980), p. 28. In his calculation of the multiplication of human power, Dupin anticipated Lotka's ideas on endosomatic and exosomatic energy. Nevertheless, one already finds the correspondence 1 horse = 7 men in Forest de Belidor almost a century before, in 1739 (see Fernand Braudel, *Capitalism and Material Life, 1400–1800* [New York: Harper and Row, 1973], p. 246), and it seems to have been common knowledge then. Charles Delaunay's *Cours élémentaire de mécanique* (Paris, 3d ed. 1854) mentions it in a chapter significantly titled "animated engines."

5. *The Works of Charles Babbage*, ed. Martin Campbell-Kelly, vol. 8 (London: William Pickering, 1989), pp. 113, 114. A good introduction to this social reformer and mechanical genius is Anthony Hyman, *Charles Babbage* (Oxford: Oxford University Press, 1982).

6. Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge: Harvard University Press, 1971), p. 276.

7. It must be acknowledged that Jevons had started out studying natural sciences at London's University College, and so was not altogether ignorant of nature. His book contains reasoning and quotations derived from this field, including the physiologist Justus von Liebig's phrase "civilization is the saving of energy."

8. Even prior to the use of combustible fossil fuels, crises involving the supply of wood in several European countries caused generalized concern. See Mans Lönnroth, Peter Steen, and Thomas Johansson, *Energy in Transition* (Berkeley: University of California Press, 1980), pp. xiv, 6.

9. William Buckland, *Bridgewater Treatise* (1836), quoted in *Magazine of Popular Science and Journal of the Useful Arts* 2 (1837), p. 333.

10. Earl Cook, *Man, Energy, Society* (San Francisco: Freeman, 1976), p. 450.

11. Quoted in Nicholas Georgescu-Roegen, *Energy and Economic Myths* (New York: Pergamon, 1976), p. x.

12. A proto-libidinal economics? Note that, unlike the classical economics of Smith, Ricardo, and Marx, utilitarianism has a subject/choice dimension that makes it interpretable as a philosophy of desire.

13. As Maffioli points out, however, the century had its share of attempts to evaluate the enegy efficiencies of thermal machines according to the second principle, prominent among which are G. R. Bodmer's 1890 calculations to compare the Rankine and Otto cycles. Cesare Maffioli, *Una strana scienza* (Milan: Feltrinelli, 1979), p. 198.

14. W. Stanley Jevons, *The Theory of Political Economy*, 4th ed. (London, 1924), pp. 3, 21, quoted in Georgescu-Roegen, *The Entropy Law and the Economic Process*, pp. 41, 40. It is important to note that statistical concerns are just as present in the early writings of Patrick Geddes, *The Classification of Statistics* (1881) and *An Analysis of the Principles of Economics* (1885). These, according to Lewis Mumford, contain "the first sociological application of the modern concept of energy" (Mumford, *Technics and Civilization* [1934; New York: Harcourt, Brace and World, 1963], p. 458).

15. Contemporary scholars like Georgescu-Roegen have tried to build a thermodynamic economics that does not imply an energy theory of value but puts value in the context of "the enjoyment of life," in a formulation that does not hide its being rooted in utilitarian demands. To do this they have had to make the concept of energy defer to that of entropy.

16. E. F. Schumacher, *Schumacher on Energy*, ed. Geoffrey Kirk (London: Jonathan Cape, 1982), p. 61.

17. Podolinski's ideas are discussed at length in Juan Martínez Alier and José Manuel Naredo's article "La noción de 'fuerzas productivas' y la cuestión de la energía," *Cuadernos de Ruedo Ibérico*, no. 63–66 (May-December 1979), pp. 71–90.

18. Both letters quoted in ibid. As we know, this did not prevent Marx and Engels from giving a great amount of importance to finding the quantitative equivalences of the different energy forms established by the first principle of thermodynamics (this in contrast, by the way, to their scant receptiveness, if not outright hostility, to the second principle). In his *Dialectics of Nature*, Engels mentions energy and its laws of qualitative transformation, along with the evolution of species and the discovery of the cell, as the pillars of a historical and dialectical conception of nature.

19. Angelo Baracca and Arcangelo Rossi, eds., *Materia e energia* (Milan: Feltrinelli, 1978), p. 307.

20. Martínez Alier and Naredo, "La noción de 'fuerzas productivas' y la cuestión de la energía," p. 74.

21. Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 283. Winiarski may also have read Marshall, whose major work, *Principles of Economics* (1890), maintained that "economics is a branch of biology in the broad sense of the term." In Georgescu-Roegen's opinion, "among . . . economists of distinction, only Alfred Marshall intuited that biology, not mechanics, is the true Mecca of the economist."

22. In Baracca and Rossi, eds., *Materia e energia*, p. 314.

23. Ibid., p. 310.

24. Ludwig Boltzmann, *Lectures on Gas Theory* (Berkeley: University of California Press, 1964), p. 216. Mentioned in Steve J. Heims, *John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death* (Cambridge: MIT Press, 1980), p. 65; and in Baracca and Rossi, eds., *Materia e energia*, pp. 52, 307.

25. Stephen Brush, foreword to Boltzmann, *Lectures on Gas Theory*, p. 17.

26. See note 14. In his comments on Ostwald's book *Energetische Grundlagen der Kulturwissenschaften*, published in Leipzig in 1909, Lewis Mumford points out that Geddes's *The Classification of*

Statistics preempts it by a whole generation (Mumford, *Technics and Civilization*, p. 466).

27. Patrick Geddes, *Cities in Evolution* (1915; London: Ernest Benn, 1968), pp. 66–67. At around the same time Otto Neurath was also demanding that “money economics” give way to “species economics,” that statistical information and planning no longer be expressed in money units. Through physical accounting, “the camouflage and confusion produced by terms like ‘coin’ and ‘exchange’ . . . would be eliminated in one stroke. Everything would become transparent and controllable.” Otto Neurath, “Wesen und Weg der Socialisierung” (1919), rpt. in Neurath, *Empiricism and Sociology* (Dordrecht: Reidel, 1973), pp. 135–150.

28. Geddes, *Cities in Evolution*, pp. 74, 76, 60.

29. Ibid., p. 66.

30. Ibid., p. 60.

31. Ibid., p. 109.

32. Ibid., pp. 110–111.

33. Frederick Soddy, *Matter and Energy* (London: Williams and Norgate, 1912).

34. Ibid.

35. Frederick Soddy, *Cartesian Economics* (London: Hendersons, 1922). During the years between this publication and the earlier *Matter and Energy*, Soddy taught in Aberdeen, birthplace of Geddes, who was then living in Dundee on the same Scottish east coast. Geographic proximity may have brought about some contact between the two scientists, though I have found no information to this effect.

36. Frederick Soddy, *Wealth, Virtual Wealth and Debt* (London: Allen and Unwin, 1926).

37. Ibid.

38. During the fifty years that preceded the oil crisis of 1973–1974, total world energy consumption quintupled; per capita

energy consumption increased by 2.5 times. The huge increase must essentially be attributed to petroleum and natural gas. Although coal consumption doubled, its share of the total fell from 85 percent to 30 percent, whereas the consumption of liquid and gaseous combustibles, which barely exceeded 10 percent of the total in the 1920s, accounted for two-thirds of total energy consumption at the threshold of the crisis. See Gerald Foley, *The Energy Question* (Harmondsworth: Penguin, 1976), pp. 64–65.

39. Mumford, *Technics and Civilization*, p. 110.

40. Soddy, *Wealth*, *Virtual Wealth and Debt.*

41. For example, Mumford, *Technics and Civilization*, pp. 112ff., 221ff., 373ff.

42. Ibid., p. 375.

43. For a good description see Maffioli, *Una strana scienza*, pp. 132–138.

44. Quoted in Ramón Margalef, *Ecología* (Barcelona: Planeta, 1981), p. 26. According to Mayer, it was in 1866 that Haeckel proposed the term "ecology" for the science that dealt with the "household of nature" (Ernst Mayer, *The Growth of Biological Thought* [Cambridge: Harvard University Press, 1982], p. 121).Whatever the German term, it must have referred to the Greek *oikos*, meaning house or room, and from this came both *eco*logy and *eco*nomy. Such an etymological reasoning, to be sure, is not removed from the ideas of Patrick Geddes, for whom the core of economic history is the history of the house (*Cities in Evolution*, p. 111).

45. Margalef, *Ecología*, p. 17.

46. Another statistician in the tradition of Quesnay, Babbage, Jevons, Geddes, and Neurath!

47. Most particularly for the theory he shares with Volterra about the fluctuations (abundance and scarcity) in the animal ecosystem. See Howard T. Odum, *Energy, Power, and Society* (New York: John Wiley, 1971), p. 99.

48. Alfred J. Lotka, "Contribution to the Energetics of Evolution," *Proceedings of the National Academy of Sciences* 8 (1922), pp. 147–155.

49. Odum, *Energy, Power, and Society*, p. 31.

50. Alfred J. Lotka, *Elements of Physical Biology* (Baltimore, 1925), p. 356, quoted in Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 283.

51. *Encyclopaedia Britannica*, 15th ed., vol. 6, p. 197.

52. Resulting in a modest 2 percent efficiency—disappointing perhaps, though well above the 0.13 percent that Mumford mentions a decade later (*Technics and Civilization*, p. 222). For the works of Transeau, see Paul Colinvaux, *Why Big Animals Are Rare* (Harmondsworth: Penguin, 1980), pp. 30ff.

53. R. L. Lindeman, "The Trophic-Dynamic Aspect of Ecology," *Ecology* 23 (1942), pp. 399–418. Also see Odum, *Environment, Power, and Society*, p. 67, and *New Scientist*, 19 November 1981, p. 51.

54. Colinvaux, *Why Big Animals Are Rare*, p. 21.

55. Ibid., p. 23.

56. Erich W. Zimmermann, *World Resources and Industries* (New York: Harper and Row, 1951), chapter 5; W. Fred Cottrell, *Energy and Society* (New York: McGraw-Hill, 1954); Leslie A. White, *The Evolution of Culture* (New York: McGraw-Hill, 1959). There were also those who, in the hardly favorable context of energy abundance, continued to debate the exhaustion of resources. Here we should mention Charles Galton Darwin, *The Next Million Years* (Garden City: Doubleday, 1953); Hans Thirring, *Energy for Man* (Bloomington: Indiana University Press, 1958); and the collection *Schumacher on Energy.*

57. Odum's *Systems Ecology: An Introduction* (New York: John Wiley, 1983) does list two works by Georgescu-Roegen under "Suggested Readings," namely *The Entropy Law and the Economic Process* and *Energy and Economic Myths.*

58. For nearly two decades, incidentally, this was the only general text on ecology available.

59. Georgescu-Roegen justified his intentions by invoking the greater scope of ecology. This emerged clearly in a 1972 article that discusses the hope expressed in the famous "A Blueprint for Survival" (in *The Ecologist*, January 1972, pp. 1–43) that economics and ecology will one day become one: see "Energy and Economics Myths," included in the volume of the same title that Pergamon published in 1976, on pp. 1–36.

60. Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. xiii.

61. Odum, *Energy, Power, and Society*, p. vii.

62. In the ten-year period 1972–1981, the United Nations held eight "megaconferences" on the following themes: Human Environment (1972), Population (1974), Food (1975), Human Settlements (1976), Water (1977), Desertification (1977), Science and Technology for Development (1979), and New and Renewable Energy Sources (1981).

63. From Marshall onward, "externalities" means the costs and revenues incurred outside a formally independent economic unit. See Allen V. Kneese, *Economics and the Environment* (Harmondsworth: Penguin, 1977), pp. 23ff.

7 **Thermal Space in Architecture**

1. Histories of heating are never thermal histories of architecture; concentrating on heating mechanisms, they tend to ignore matters of spatial configuration. Nevertheless, they offer interesting information. Here we must mention Walter Bernan, *On the History and Art of Warming and Ventilating Rooms and Buildings* (London: Bell, 1845), whose two octavo volumes, totaling 560 pages and 240 illustrations, are a basic reference; L. A. Shuffrey, *The English Fireplace* (London: Batsford, 1912), a classic on the history of the fireplace; Lawrence Wright, *Home Fires Burning* (London: Routledge and Kegan Paul, 1964), the best contemporary source on the history of domestic heating; and Neville S. Billington and Brian M. Roberts,

Building Services Engineering: A Review of Its Development (Oxford: Pergamon, 1982), the only current reference, reliable albeit unpolished, more than two-thirds of its 530 pages devoted to the historical development of thermal installations.

2. See Lorna Price's foreword to her book *The Plan of St. Gall in Brief* (Berkeley: University of California Press, 1982), which is based on the work of Walter Horn and Ernest Born.

3. Glass, incidentally, was not yet then considered an architectural resource; inventories of the period classify the leaden panels of windows as furniture pieces, totally independent of the buildings. Compare St. Barbara's fireplace to those that appear in the *Annunciations* of the Master of Flémalle at New York's Metropolitan and van der Weyden at the Louvre. Each is without fire (these are springtime settings), and a bench pushed up close to the fireplace faces away. In van der Weyden the hole is closed with metal plates latched together, a common practice during the warm seasons; the same system is featured in Dirk Bouts's *Last Supper* in the church of St. Peter, Louvain.

4. The canopied bath appears in many sixteenth-century representations, such as the Louvre's famous canvas of the School of Fontainebleau, *Gabrielle d'Estrées and Her Sister*, but also in works of the preceding century like Memling's *Bathsheba*, and even in very early Siena frescoes at S. Gimignano depicting scenes of conjugal life, produced at the close of the thirteenth century or the start of the fourteenth.

5. The edition I consulted is of a later date: *Essay on Chimney Fire-places*, by Benjamin, Count of Rumford (Gloucester, 1862; original ed. London, 1796 and 1802). Benjamin Thompson culminated a tradition of perfecting the fireplace which, with important contributions by the French Savot and Gauger, had its most immediate antecedent in the work of Benjamin Franklin. The latter, besides his writings of 1745, published some *Observations on Smoky Chimneys* (London, 1793), the main part of which is a letter he wrote while at sea in August 1785. Among other things, Thompson and Franklin shared a concern for saving combustible energy.

6. The ornamental importance of fireplaces is evident in any history of interior decoration. Two publications are particularly noteworthy for their erudition and sensibility: Mario Praz, *La filosofia dell'arredamento* (1964; Milan: Longanesi, 1981), and Peter Thornton, *Seventeenth-Century Interior Decoration in England, France and Holland* (New Haven: Yale University Press, 1978). Subsequent to these are Charles McCorquodale, *The History of Interior Decoration* (London: Phaidon, 1983); Renato de Fusco, *Storia dell'arredamento*, 2 vols. (Turin: UTET, 1985), and Peter Thornton, *Authentic Decor: The Domestic Interior 1620–1920* (London: Weidenfeld and Nicolson, 1984), surely the best of the three.

7. A late episode of this resistance is the efforts of the American architect J. Pickering Putnam—probably the last of the "smoke doctors"—to make the open fireplace more efficient. His book *The Open Fire-Place in All Ages*, first published in 1881, extols a radiant and convection-based fireplace designed with solar motifs, and is an attempt to reconstruct what he candidly understands to be a "natural environment." See David P. Handlin, *The American Home* (Boston: Little, Brown, 1979), pp. 481–486.

8. The best history of greenhouses, in the tradition of Reyner Banham, is written by an architect: John Hix, *The Glass House* (Cambridge: MIT Press, 1974).

9. For more on Morse and Walker see Ken Butti and John Perlin, *A Golden Thread: 2500 Years of Solar Architecture and Technology* (Palo Alto: Cheshire Books; New York: Van Nostrand Reinhold, 1980), pp. 197–200 (Morse) and 122–123 (Walker).

10. Obviously much of this discussion comes from Foucault. For more on the Panopticon see chapter 2 and note 30 of chapter 4.

11. The coincidence is so revealing and extraordinary that I cannot help transcribing here an entire quote, taken from his second letter (*Panopticon or The Inspection House* is written in epistolary form): "The most economical, and perhaps the most convenient way of *warming* the cells and area, would be by flues surrounding it, upon the principle of those in hot-houses. . . . The flues, however, and the fire-places belonging to them, instead of being on the outside, as in

hot-houses, should be in the inside. By this means, there would be less waste of heat, and the current of air that would rush in on all sides through the cells, to supply the draught made by the fires, would answer so far the purpose of ventilation." And the ending is significant: "But of this more under the head of Hospitals."

12. The transformation of the hospital during the final decades of the French eighteenth century into a "machine for curing" has been admirably studied by a team headed by Foucault: Michel Foucault et al., *Les machines à guérir* (Brussels: Mardaga, 1979).

13. Thomas Tredgold, *The Principles of Warming and Ventilating*, 3d ed. (London: Taylor, 1836; 2d ed. 1824)—both Tredgold and T. Braham, who wrote the appendix to the third edition, were civil engineers; E. Péclet, *Traité de la chaleur*, 2d ed. (Paris: Hachette, 1843; 1st ed. 1828)—Péclet was a teacher of "physics applied to the arts."

14. Joshua Jebb, *Report of the Surveyor-General of Prisons on the Construction, Ventilation, and Details of Pentonville Prison* (London: Her Majesty's Stationery Office, 1844). See especially pp. 17–24 and illustration 6.

15. David Boswell Reid is also the author of *Illustrations of the Theory and Practice of Ventilation* (London: Longman, 1844).

16. *Memoria histórico-descriptiva del nuevo Palacio del Congreso de los Diputados*, published by the parliamentary commission for internal government (Madrid: Aguado, 1856).

17. Francisco de Paula Rojas, *Calentamiento y ventilación de edificios* (Madrid: Aguado, 1868), p. 424. Péclet and Grouvelle (author of the entries on heating and ventilation in Laboulaye's *Dictionary of Arts and Manufactures*) were still the basic references in this material for Bernardo Portuondo's *Lecciones de arquitectura* (Madrid: Imprenta del Memorial de Ingenieros, 1877), as they had been twenty years before for Léonce Reynaud's *Traité d'architecture* (Paris: Victor Dalmont, 1858). José A. Rebolledo's sources, however, though occasionally citing Morin, were already mostly British, as we gather from reading chapter 8 (on hygiene of construction) of his *Tratado de construcción general* (Madrid, 1889).

18. Polignac's *Mécanique du feu* was published in English as *Fires Improv'd*, translated and extended by J. T. Desaguliers (London: Senex and Curll, 1715). Besides the usual concern about smoke, the translator's foreword significantly stresses: "What he proposes to do by his Method is . . . to disperse the *Heat* so uniformly as to take away the usual Inconveniences of being obliged to creep near, or to sit at such a Distance from the *Fire*, that we are either *roasted* before or *starved* behind." The "mechanics of fire" had given way to the "homogeneous dispersion of heat." Reverend John Theophilus Desaguliers was in any case a unique personality: a cleric of the Anglican Church, a member of the Royal Society, and a grand master of the Masonic lodge of London, he was known above all as a disciple and promoter of Newton's ideas, which he defended in lectures and public experiments and even through a leaflet in verse titled "The Newtonian System of the World, the best model for Government." See Joseph Rykwert, *The First Moderns* (Cambridge: MIT Press, 1980), pp. 159–162.

19. Arthur Morin, *Etudes sur la ventilation*, 2 vols. (Paris: Hachette, 1863).

20. Victor Charles Joly, *Traité pratique du chauffage, de la ventilation et de la distribution des eaux* (Paris: Baudry, 1869), pp. ix–x. This work includes a useful summary of the history of heating (pp. 78–100) as well as a good chronological bibliography.

21. Ernest Bosc, *Traité complet théorique et pratique du chauffage et de la ventilation* (Paris: Morel, 1875). See especially the foreword.

22. Rinaldo Ferrini, *Tecnologia del calore* (Milan: Ulrico Hoepli, 1876). I am assuming it is Bosc he has in mind when he mentions "un recentissimo libro francese che tratta della ventilazione e dello scaldamento degli ambienti."

23. H. Rietschel, *Leitfaden zum Berechnen und Entwerfen von Lüftungs- und Heizungs-Anlagen* (1893; Berlin: Springer, 1909).

24. C. W. Brabbée, *Heating and Ventilation* (New York: McGraw-Hill, 1927), translated from the 7th German edition of Rietschel.

25. Reyner Banham, "The Architecture of Wampanoag" (1965), rpt. in Charles Jencks and George Baird, eds., *Meaning in Architecture* (London: Barrie and Rockliff, 1969), pp. 101–118. The illustrations are by François Dallegret.

26. Herbert and Katherine Jacobs relate their experience in *Building with Frank Lloyd Wright* (San Francisco: Chronicle, 1978).

27. Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge: Harvard University Press, 1971), pp. 18–19.

28. Needless to say, we are referring to culture in the broad sense, as that which includes artifacts and social practices, uses and tools, objects and rites, not culture in the sense that seems to be more widespread nowadays, which hardly even embraces the arts and letters. See chapter 3, note 14.

29. Terms taken from Cesare Maffioli, *Una strana scienza* (Milan: Feltrinelli, 1979), p. 142; see chapter 2 above.

30. Ramón Margalef, *La biosfera entre la termodinámica y el juego* (Barcelona: Omega, 1980), pp. 30, 149. This prediction, says Margalef, is in accordance with his own view—maintained as well by Odum and others—that ecological succession emerges as "the materialization of a tendency to maintain the maximum mass of organized matter with a minimum change of energy in the metabolism" (p. 160).

31. Here we have profusely and emphatically warned of the danger of the theoretical ruin of mechanicism leading to an adherence to equally reductive biologistic concepts (see especially chapter 1, second section; chapter 3, fourth section; and chapter 5, sixth section).

32. Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: Braziller, 1968), p. 109. Christian O. Weber has expressed a similar idea very concisely: "Homeostatic balance makes it possible for us to live, but contributes little to our living well" (Weber, "Homeostasis and Servo-Mechanisms for What?", *Psychol. Review* 56 [1949], pp. 234–249; quoted in Rudolf

Arnheim, *Entropy and Art: An Essay on Disorder and Order* [Berkeley: University of California Press, 1971], p. 48).

33. Erich Jantsch, *The Self-Organizing Universe* (Oxford: Pergamon, 1980), p. 280; also see chapter 1, second section.

34. Margalef, *La biosfera entre la termodinámica y el juego*, p. 163. Now, says Margalef, "the amount of available energy will much determine the manner in which the interaction between man and the rest of the biosphere is to continue. With the period of waste now behind us, we will be able to return to the form of succession in which minimized energy exchange is a guarantee of persistence. This direction in the changing of systems is the only one that allows predictions, and those are not encouraging" (p. 214).

35. See Maffioli, *Una strana scienza*, p. 101.

36. Leon Battista Alberti, *On the Art of Building in Ten Books*, trans. Joseph Rykwert, Neil Leach, and Robert Tavernor (Cambridge: MIT Press, 1988), book I, chapter IX, pp. 22–23.

37. Book III, rule I.

Bibliography

The following bibliography has been prepared independently of the text. In fact the notes within the book cite many more works than have been itemized here, while some titles that do figure in the list are not actually mentioned in notes. Rather than identifying all sources, the bibliography aims to acknowledge a debt of a more general character while serving as a guide to anyone interested in delving further into the subject matter.

Considering, moreover, that very extensive bibliographies are useless, I have limited the list to a hundred. And since this arbitrary number is still too large to define what have been my basic references, I have divided the list into two groups: 25 titles as a "Core Bibliography" and the remaining 75 as a "Complementary Bibliography." The omissions are many, and frequently much to my regret. Nevertheless, I am satisfied with the result of the painstaking selection process: I feel more indebted to the hundred works enumerated here than to any of those I had to omit.

The edition mentioned in each case, both in the notes and in the bibliography, is the one I have actually handled, except in cases where an original English edition or a published English translation has been substituted for a Spanish translation used by me. In the now frequent case of a transnational publisher with offices in different locations, I have simply cited the first city listed by it as the place of publication.

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