

# HOW ENERGY MAKES A DIFFERENCE ON THE MORPHOLOGY OF SPACE

Mark Balzar  
University of Applied Arts Vienna

## Abstract:

*According to the theory of relativity, there is no essential distinction between mass and energy. Energy has mass and mass represents energy. Instead of two conservation laws, we have only one, that of mass-energy. (Calaprice, Dyson, and Einstein 2005, 390)*

In today's sciences we pay a great deal of attention to the complexity of biological form and ecological formation. Analogies in urban research refer to cities as living (eco)systems, organisms or technological artifacts, which follow the rules of an urban metabolism. All these narratives seem to suggest that all matter (acting and interacting) on earth belong to a complex whole and their physiological characteristics share common organizational physical laws, which are rather dynamic and formless by their nature. A quantitative and qualitative theory for understanding these complexities and the dynamics of such a condensed organization of urban organic and inorganic materialization remains elusive, however, its impact on our planet is explicit and evident in various forms. Currently, most of humanity lives in cities. Their organization of human society and the tendency of cities to grow put ecological pressure on the global environment.

The urban realm is an ever-unfolding amalgam of the biosphere and the techno-sphere within a dynamical system of materiality which threatens the concept of static form as an expression of physiological states. This formlessness is rather an expression (and empowering) of emerging patterns than an ambiguous loss of control. This paper argues that developing a new theoretical measure of understanding the materiality of forms, and the formation of the urban realm(s) as the effect of a complex information system of interrelations seems to be necessary. The following text will discuss the trajectory through three major approaches: The philosophical concept of (New) Materialism in relation to discursive formations (a terminology developed by Michel Foucault), the scientific concept of Systems Ecology of Howard T. Odum and the theoretical concept of *individuation* by Gilbert Simondon (1992). Systems ecology grants a view to dynamism of the physical, chemical, economic, and social forces in the field of urban morphological ensembles—the passive potentialities (energy storage) and the active transgressing forces (energy transfer) governed by the second law of thermodynamics. Odum's understanding of urban energy cycles bears the potential to unravel the information patterns of an urban organism controlled by time.

**Keywords:** Theory of urbanism, ecology, energy, individuation

## 1. THE EMERGENCE OF FORM OR HOW TO BECOME FORM: A PHILOSOPHICAL APPROACH

Every building and urban assembly, every technological machine, every artificial and biological entity, is organismic. Alfred North Whitehead's organic theory establishes an ontological framework for a philosophy of organism and the theoretical concept of process at the production of the world, which is organized through relations rather than constants and facts. He proposes actual entities (present real objects resultant from a historical process) of which potential entities evolve. In Whitehead's (1979) ontology, every real physical entity, is organismic and is a representative object of the metaphysical world.

The philosophy of organism is closely allied to Spinoza's scheme of thought. But it differs by the abandonment of the subject-predicate forms of thought, so far as concerns the presupposition that this form is a direct embodiment of the most ultimate characterization of fact. The result is that the 'substance-quality' concept is avoided, and that

morphological description is replaced by the description of the dynamic process. . . . it does not lead us to any higher grade of reality. The coherence which the system seeks to preserve, is the discovery that the process, or concrescence, of any actual entity, involves the other actual entities among its components. In this way, the obvious solidarity of the world receives its explanation. (Whitehead 1979, 7)

In philosophy, there are many concepts elaborating on the force behind the materialization of objects and form in the physical and metaphysical realm. Especially the philosophy of New Materialism finds its inspiration by the concepts of Aristotle's *entelechy*, which has been further developed by German developmental biologist Hans Driesch as the life force, Spinoza's substance, Leibniz monad, or later Bergson's *elan vital*. All these ideas are united by the anxiety to explain the very origin and force behind the becoming of things.

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In the early 19<sup>th</sup> century, the British physician Thomas Young established the term energy for the driving force behind biological life. The origin of the term energy refers to the old Greek word *energeia*, which means potentiality and actuality, which on the other hand are translations of the Greek word *dunamis*, meaning possibility or capability. The same terminology was embraced and further conjoined to thermodynamic principles behind chemical processes by the mathematician Rudolf Clausius and the scientist Josiah Willard Gibbs. Together with Hermann von Helmholtz's experiments on the relationship between mechanics, heat, light, electricity and magnetism via the manifestation of a single shared force, they paved the way for Cybernetics and System Ecology, by approaching the perception of physical material and materialization through a process of energetic transformation.

From a New Materialist point of view, the order of origin, hence the relation between different objectives is dependent on physical proof and the concepts originating in physical and mathematical scientific frameworks. A logic-based coherence on the matter of thought depends on indefinite physical properties. Materiality, therefore, can only reveal itself in relation and in correlation with other matter and its depending properties. The binding forces are the sheer expression of related forms. This translates into every event being the result of a material cause, following other causes in relation to and depending on prior events. Independent from the point of observation these events take place according to their own invisible set of relationships but can be revealed or followed up through apparent phenomena in the workings of matter and energy.

With the ontological framework of the plane of immanence, consisting of assemblages within emergent ensembles, Gilles Deleuze and Felix Guattari create a theoretical machinery of multiplicities (bodies or effects of temporary phenomena derived from diverse interrelated substances) made up of many heterogeneous forms of existence which establish relationships between them. Forms enroll within the plane of immanence (Gilman et al. 1989), a theoretical cartography of relationships. These organs or "bodies" of interiority (related to French physiologist Claude Bernard's 'Milieu intérieur', 1854) are of a contingently stable nature. They form fragile substantial parts within and among bodies, as bodies of bodies, or parts of parts—thus they form systems of relations of exteriority and interiority, establishing the appearing nature of a complex whole. For the most part, those organismic bodies are of an autarchical nature, only communicating to the outside world through its permeable system boundary. This boundary appears to the outside world as an object involved in a continuous reshaping process.

Gilbert Simondon (2017) refers to this process of becoming of an object or gaining identity as 'individuation' (1992), a continuous informative and transformative process of communication creating technological as well as biological form. The process includes the development of its own skills, abilities, perspectives, and relationships, until it reaches a permanent state. Within this context, the expression of temporary effects of permanent relations is understood as individuating forms on the plain of immanence. A designed entity is therefore not only a (active or passive) part of a larger system and the expression of the ongoing forces within its own system, but it individuates from that very same system of interrelations, operating and acting permanently within it. The resultant formation of the informed object intrinsically maps its territory, discovers its own dynamic forces and relations, as well as their relative limits through and within all scales. Transformation and change are immanent and part of that nature.

## 2. HOW MATERIALITY BECOMES AN EXPRESSION OF ENERGY STORAGE OR INFORMATION (CODE) (WHITEHEAD'S OBJECTS)

If we consider buildings as atoms of urbanism, in the realm of chemistry, the periodic table of elements defines a clear system and diagram of materiality and material performance, depending on their subatomic nucleons and electrons. In a rigorous way, all elements have been ordered and organized by their atomic number (number of protons), and electron configuration as indicators of potential chemical properties or trends. The number of protons in the nucleus of the atom and electrons play a very essential part in defining individual properties of elements given by the importance of atomic behavior within their relationship as molecules. If there is an imbalance of electrons and protons in the nucleus then this element will behave as electronically charged and therefore defined as *ion*. The energy to free the electron with the least binding force to the core from the nucleus is called *ionization energy*, which also is a measure of the strength of electron bonds in molecules. (Feynman, Leighton, and Sands 2011).

The energy to free an electron from an atom and forces it to travel across elements - the origin of the transfer and storage of (digital) information - creates energetic transfer in form of electric impulses, which leaves traces in the environment through the consequently charged elements or through energetic loss. Electric current defines the flow whereas static electricity (storage) defines the potential flow. Electricity, in this case, is the result of a chemical engine driven by energetic instability with the potential to even change the nature of elements and therefore molecules

themselves. It is also within this flow of electrons where biological and technological matter merge into an amalgam of vital materiality and the laws of physics start to shape our existence and our environment.

With a thorough and thought-provoking text, the neurologist Wolf Singer (2002) posed the question whether the physiological structure of the brain could be used as a model for urbanism. He describes the process of information transfer from the corporeal immune system to the brain and draws parallels to urban structures. The immune system is limited to the physical transfer of information via molecules given the fact that it is physiologically incapable of being active through electric charge. Here the nervous-system comes into play. Those cells are activated through key substances and via electrical impulses so complex information can be transferred over long distances to the brain. Two systems merge through interaction and, as a result, two topologically independent entities are made possible. Singer concludes that through these organized architectures it is possible to overcome the limits of cartesian space, enabling highly complex structures like the human body to be realized. Structural complexity is in direct proportion to storage capacity and the quality of information. In this sense, digital technologies and the internet merge together with the built environment to become one complex urban realm.

### 3. THE AMALGAM OF NATURE AND TECHNOLOGY AT THE LEVEL OF URBAN ECOLOGY

Considering the history of urbanism, we witness in various stages and velocities the effects of an intensifying bio-technological synthesis throughout society. Understanding chemical and physical processes inherent in both nature and technology is key, in order to reveal the genuine concepts originating in complexity science, cybernetics, and systems theory. The urban realm, therefore, is the largest bio-technological organism to observe this condition.

Across various disciplines, a new cultural paradigm in understanding and treating our environment and the humanities as distinct but interdependent entities, a major draw from the complexity sciences, has caused a shift in the perception of contemporary society and the world we live in. For example, in Luis M. A. Bettencourt's research paper on the physical laws of quantities and qualities of urban growth, he argues, that cities are consumers of energy and resources and producers of artifacts, information, and waste which have often been compared with biological entities.<sup>7</sup>

They further argue in their paper, "that many diverse properties of cities from patent production and personal income to electrical cable length are shown to be power law functions of population size with

scaling exponents,  $\beta$ , that fall into distinct universality classes. Quantities reflecting wealth creation and innovation have  $\beta \sim 1.2 > 1$  (increasing returns) whereas those accounting for infrastructure display  $\beta \sim 0.8 < 1$  (economies of scale). . . . The predominance and universality of quarter-power scaling have been understood as a manifestation of general underlying principles that constrain the dynamics and geometry of distribution networks within organisms" (Bettencourt et al. 2007, 7301-7306). What is crucial at this point is that these principles of scaling laws developed for cities do not have an equivalent in the biological realm. Social network effects, wealth, and economic systems are human centered and others like building mass and infrastructure are pure technological contributions at the overall urban scale.

Ecological efficiency and energetic optimization of organisms (e.g. the metabolic rate related to the body mass index or the bifurcation of rivers and the related volume to speed ratio depending on the surface of the river bed), are phenomena of physics (Bejan and Zane 2012) which are related to the *dynamic energy budget theory*. Accordingly, these are embedded strategies of the 'geochemical energy' flow of life in the biosphere (Vernadsky 1997). As an example, used materials, architectural forms and building typologies do influence urban environments and their immediate ecosystems. There are various studies on the phenomenon of urban heat islands causing climatic shifts and *metabolic rifts*, not only at the microscale, but also at the ecological macro scale. In Phoenix, Arizona, the specific use of building materials in combination with built form has rechanneled wind behavior and contributed to significant local temperature increase causing more regular and intense-tornados overall. In *Delirious New York* (Koolhaas 1979) Rem Koolhaas describes the intensification of the urban grid and built environment working as a social condenser, where the outright increase in numbers (buildings, population, social differences, etc.) causes a social and cultural revolution.

If we understand energy as the capacity to do work, the reverse, stored energy in matter itself, represents the history of the labor involved to create the current state, as well as the reservoir of potential energy flow. The first law of thermodynamics states that energy changes form but never completely vanishes (Schneider and Sagan 2005). The second law of thermodynamics states that the total entropy of an isolated system will never decrease over time, and is constant if and only if all processes are reversible. Isolated systems spontaneously evolve towards thermodynamic equilibrium, the state of maximum entropy. By the same token, a regular pattern emerges from the flow of energy-cycles of alternating

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intervals between high sectoral growth and intervals of relatively slow growth.

Urban formations with their increased complexity are condensers of such energetic resources and potentials.

### 4. SYSTEM THEORY, COMPLEXITY SCIENCE AND URBANISM

*According to Odum, "culture is the shared program of behavior of a population that organizes the individual, the group, and the environment into high-quality systems adapted to its energy regime and providing services to its territory." (Odum 1971, 509)*

The technological and biological amalgam of *homo urbanus* is involved in an inseparable symbiosis with the chemical and physical environment of the natural artificiality of cities, including its digital environments (e.g. the digital economy and social networks). This fusion composes a new urban condition of a spatio-dynamic complex system, which demands a reconfiguration of the inherent infrastructure and redefines its local and its global status. Both positions depend on its being perceived as an Open System (Variable Environment) or as a Closed System (Constant Environment). In mathematical and computational sciences, this rigorous differentiation leads to a simplistic concept of reality in order to gain a better understanding of biological systems. In biology the observed organisation unfolds in such complex form, where both presuppositions are only differentiated through a scalar permeable system boundary.

Variable Environments require sufficiently fast adaptation and populations where tunable error rates will adjust their quasi species to meet the environmental challenge. In constant environments, on the other hand, such species will tune their error rates to the smallest possible values in order to maximize fitness. (Langton 1995, 46)

### 5. A COMPUTATIONAL (ARTIFICIAL) APPROACH TO BIOLOGICAL SYSTEMS THROUGH THE SCIENCE OF THEORETICAL BIOLOGY - CYBERNETICS VS GENERAL SYSTEM THEORY

An open system is defined by Ludwig von Bertalanffy as a system exchanging matter with its environment, presenting import and export, building up and breaking down of its material components. A system will be referred to as 'closed' if no material enters or leaves it. This system has a boundary condition, which keeps it internally stable and organizes its behavior within a closed environment upon which it can operate.

An organism, however, is not a closed system in thermodynamic equilibrium, but an open system in a (quasi-) stationary state with another one, equifinality (Von Bertalanffy 1969). Within the concept of an open

system the term, equifinality, defines the principle of achieving a stable state or goal through various potential means.

In this-sense, the equifinal self-preservation of the organism is opposed to a physical system which tends towards a state of highest probability of maximal disorder. Hence the general tendency of all systems to reach equifinality (for each individual species), through the procedure of entropy, causes the constant adaptation of an organism leading to an interdependent global morphology. Therefore, the living organism is maintained in a continuous exchange of components called metabolism.

After certain conditions, open systems approach a time-independent state, the so-called steady state. If the phenomenon of a steady state is reached in an open system, it is independent of the initial conditions, and determined only by the system parameters. This equifinality appears therefore-as a quasi-optimized closed system.

The basis of the open system is the dynamic interaction of its components. The basis of the cybernetic model is the feedback cycle, in which, by way of feedback of information, a desired value is maintained, a target is reached.

Herein lies a clear theoretical difference between both approaches. Whereas the first system theoretically is an infinite process, the second one becomes static as it reaches the target value (Von Bertalanffy 1969).

The clear gap between the two concepts of open system versus closed systems was addressed by a theory developed by Herbert A. Simon (H. A. Simon 1969) regarding artificial systems that he calls "Near-Decomposability." His idea derives from the consideration of a modular system consisting of separable and identifiable models or components of a larger realm, like buildings within a city. He coined this approach through the term 'modularity' (H. Simon 2005), which means full decomposability or almost no interdependence between modules. A decomposable system is modular in that each component or module operates primarily according to its own, intrinsically determined principles. Each component is dependent upon inputs from other components—it influences other components only by its outputs—and has a specific intrinsic function. In the case of biological evolution, the primary function is phenotypic selection, where the genes affecting the complex character have a high degree of internal integration and a low degree of external connectivity.

Thinking of cities, the urban realm defines a model for a general theory of a spatio-dynamic formation, through information transfer within the hybridization process of technology and nature. The awareness

of these diverse modes of existence of materializing objects (through the energetic transfer of material and information) indicates the process of evolving multiplicities (a condition of being many things at once of urban form, through the permanent production and reconfiguration of multiple forms at various scales (house, area, district, ...)). Therefore, the city, like any complex form of life, concerns the problem of the becoming of form and formation of the many vibrant object[ive]s.

## **6. SYSTEMS ECOLOGY - A MATHEMATICAL CONCEPT OF THE BIOLOGICAL ENVIRONMENT THROUGH THE APPROACH OF CYBERNETICS AND GENERAL SYSTEMS THEORY**

The ecologist Howard T. Odum contributed a very complex approach, not only to perceiving the built environment, but the general biological and abiotic ecosystem at large. In the late 19th century, the Viennese geologist Eduard Suess had coined the term biosphere for the place on the surface where life prospers (Suess 2019). This new terminology was followed and further developed by the Russian ecologist Vladimir Vernadsky. Odum, who found inspiration in Vernadsky's work, states that the biosphere is the largest ecosystem, but argues further that all parts (or organisms), referring to forests, the seas, or even great cities, are ecosystems too. All these different subsystems and parts of parts (Odum 1971)<sup>2</sup> operate according to their expenditure of energy following the second law of thermodynamics.

Flows of genes, books, television communications, computer programs, human culture, art, political interactions, and religious communications are examples of information. However, these all have very large embodied energies and high ratios of calories of solar energy per calorie of information. However, these all have very large embodied energies and high ratios of calories of solar energy per calorie of information. It is still appropriate to consider the calories of potential energy in information, since this is what drives the depreciation and loss of information as with losses of other kinds of storage.

Information cannot be stored without some concentration of substance or energy fields relative to the environment. For example, words on a page are concentrations of ink, memory on a computer disk is a concentration of magnetic field, and information in biological genes is a storage of DNA form relative to the environment.

The flows of information carry the most embodied energy and also have the greatest amplifier and control effects per calorie. They are the feedbacks of highly embodied energy that provide systems with specialized services, feeding back positive actions that "repay" their webs for the energy dispersed in the development of the information.... Information pathways are energy pathways. (Crawley and Odum 1984, 19)

## **7. ODUM'S CONCEPT OF ENERGY THROUGH ENERGESE: ENERGY SYSTEMS LANGUAGE**

Odum termed "energeses" (Odum 1988) an integrated approach in ecology used to describe the natural processes of adaptation and selection, which—relied on the definition of an entity as a combination of properties keeping—some stability over time—very much like Lotka's ideas on the energetics of evolution (Lotka 1922). Odum was also inspired by the ideas of the Russian ecologist Alfred J. Lotka who argued that natural selection will occur out of an evolutionary process of energetic flux within our biosphere—energy as the worldly substance, as well as cause of change.

Joining the evolution of the complex forms of organisms and matter and unraveling the mechanisms immersed in a ceaseless stream between different entities and within one entity (which is a matter of scale, time, space and historicity), the very notion of the phenomenon called life itself was effectively the focus of Odum's scientific and theoretical oeuvre. Embedded in theoretical biology and inheriting the aforementioned concepts of general systems theory and cybernetics, Odum's research on systems ecology was a very thorough and rigorous effort in understanding ecological systems through a new geography of energy flows. All configuration of biomass and abiotic matter is describable via the significant contributions to energy flow and energy storage (including the deposit of hydrocarbons in the earth, which have fueled the social and technological revolution of the past 150 years), the energy degraded and left behind, and its inherent transfer and transformation of information. The actual form as it is perceived at the time of observation expresses and is a measure of all the energy (quality) used in its making. This temporary status quo of contained energy derived from and embedded within an evolutionary process is defined by Odum as "energy". Energy describes the qualitative difference of various forms of energy at a measured state derived throughout the history of energy. For example, fossil fuels deriving from the degradation of a biomass also inherently present the solar radiation through photosynthesis of millions of years ago, as well as the degradation and transformation of its energetic process. Energy is contained within all existing substance and its materialization and expresses the potential as free energy or energetic transformation.<sup>3</sup> Odum's ideas were conceived as an integration of cybernetic theory into the research field of ecology and informed the formulation of systems ecology. In his ecological (and biochemical) theory, all physical environments of biology and technology belong to a greater realm (or organism) subdivided into various fields or microclimates transgressing and circulating, not only

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energetic quantities, but also qualities of different sets, or set of sets, very much akin to Herbert Simon's theory of modularity.

As previously stated, energy never vanishes but is in constant circulation or otherwise stored, until it is relieved from its passive state (a temporary stable appearance of form). Materiality conforms itself to the combustion of historicity and presence in time and space, forming a unique moment of quality and potential, until energy progresses onward.

Within this thermodynamic process, the term exergy (Rant 1956)<sup>4</sup> represents the available energy (work) to be used, and describes the relationship in terms of a combination property of a system and its environment. Contrary to energy, an indicator of the history of metabolism, exergy is not transferred into another property but is destroyed during the irreversible process of transformation (biological or ecological evolution)—for example by the release or loss of heat. Energy language reduces ecosystems into system boundaries (defining open and closed states of the indicated system), forcing functions, state variables, process pathways, transgressing velocities of energy qualities, sinks, and material networks based on mathematical equations and logics.

### 8. MORPHOGENESIS

The science of systems ecology developed an understanding of the materialization of organic as well as inorganic form to be the result of interrelated physicochemical systems—interactive and entangled elements through interrelated forces—which are acting and interacting upon each other. These systems are no more than very complex energetic cycles, and autocatalytic loops of interrelated chemical substances in a constant *tour de force*, in order to achieve physical stability through the change of formation and the exchange of information. These processes master thermodynamic principles in order to achieve the ultimate balance within competing influences—also called the final equilibrium or steady state in order to succeed in evolution. This eternal stable state of a process (form), which only exists in theory, is the result of all forces resolving to zero.

Odum's model of morphogenesis derives from Einstein's Theory of Relativity. Einstein states with his minimalistic but very complex formula, that every mass that is in motion is in direct relationship to an energetic counterpart. It is an entangled pair that never drifts apart. Therefore, we can measure the value of energy transgressing through the physical realm via the velocity and the mass of all particles dancing and orchestrating in friction to the rhythms of the metabolic concert of nature.

### 9. EVOLUTION OF FORM

To understand the fundamental principles of the evolution of living and non-living matter as one concert of energetic flux, constant cycles of transgressing, degrading, and dispersing particles in one space and one time, puts this motion directly in the context of thermodynamics. As the biologist Conrad Waddington, who laid the foundations of systems biology, states, "because of their inherent analytical complexity, biological concepts in general imply a multidimensionality" (Waddington 1978; Gilbert 1991). This multidimensionality belongs to the many coexistent superimpositions in phase space which defines identity through a field of locality, instead of actual points. Phase Space maps all potential states of a dynamic system where each iteration of a process leads to a different, spontaneous outcome. It postulates that our environment is the actual result of a (thermo-)dynamic process of spontaneous events, of which the phenomenon of the urban realm consists of subdivisions of differentiated bodies within a (spatio-)dynamic form(ation) in energetic flux. These subdivisions of subdivisions are in constant relation through leaking information (leakages through the systems boundary). Buildings, infrastructure, political institutions, economic systems, or social bodies are all biodiverse organisms and organs of organisms. These different complex forms of urban aggregation are gradient static expressions of representative forms of one moment in time.

### 10. WASTEFUL LIFE OR ENERGY EFFICIENCY?

The space that labor and technical know-how open to the increased reproduction of men is not, in the proper sense, one that life has not yet populated. But human activity transforming the world augments the mass of living matter with supplementary apparatuses, composed of an immense quantity of inert matter, which considerably increases the resources of available energy. (Bataille 1991, 36)

Georges Bataille argues that all life that matters ordinarily receives more energy that is necessary for maintaining life but this leads to the excess (wealth) that contributes and is essential to the growth of all systems. Without the gainful production of surpluses, life itself stagnates and, regarding thermodynamic principles, relaxes to steady state. The urban realm is nothing else than a condensed storehouse and engine of energy production and transformation. The myriad forms of urban life and matter are an assemblage of energy of various qualities, states, and excess resources, in relation with local biomass, matter, and the climatic geological and geographic conditions. These diverse forms of an ecosystem are under constant pressure and friction with its neighbors given the limited available space on earth.

The expenditure of luxurious and exuberant energy puts pressure on the formation of matter in space and drives order into chaos, transgressing energy into various subordinate realms. For Bataille, every form of available energy must lead to some form of gainful work, or it will be otherwise destroyed through unproductive use. The ground of this operation is little more than a field of multiple destructions where the surplus energy, mainly entering the world system through solar radiation, transgress into subordinate fields of lower order forms and then disappear. It follows that the squandering of energy in every form is a principle of living matter. Every form of organism depends on the favorable contribution from others (which also is a form of destruction), in order to survive as a species. This functional activity is nothing other than the vital force behind any form of biologic life and its energetic life cycle. The excessive use of energy provides the necessary turbulence in life, in order to keep it alive. Bataille concludes that real excess does not begin until the growth of the individual, or the process of individuation has reached its limits or final state, though a more immediate limitation is given by the other individuals or groups and the available space. The physiological shape is the descriptive geometry of relationships, which represents the atmospheric boundary where the assembly of individual objects is in dialogue through different levels of feedback operations. The object circumscribes the various layers and stages of the same system.

If biology breaths through its myriad forms, an ecosystem evolves in whichever form(ation) evolution might take it, and technology proceeds within or separate with the former, then all emergent states are an expression of life and energy itself.

## CONCLUSION

By extending the scope of urbanism to the process of anthropogenic metabolism<sup>5</sup> a new “lens” of information fields can be established, where hidden causalities beneath the surface can be discovered. These potentially contribute to a holistic understanding of the ongoing mechanisms and generative resources which are immanent to the entities of objects, biomass and the heritage of information (history) at an urban scale. Architects should investigate the discrete multiplicities which make a difference, even at the smallest scale. They should take a closer look at the traits of resemblance among properties, similarities of processes of different kinds and different morphologies within the realms of energy and culture. In the Deleuzian sense, the trajectory follows the singularities, the “*implicit forms that are topological rather than geometric*” (Gilles Deleuze 1987, 408). It all leads to an understanding of form to derive from its dependencies and interdependencies of its related compounds.<sup>6</sup>

*Scale-dependent observation does not exist independent of the observer. It is particularly relevant in ecology, the science of complex systems ranging from the bacterial realm to the global Biosphere. (Vernadsky 1997, 30)*

The urban realm is a complex amalgam of infrastructure, architecture, and biology in an interplay of energetic forces. Odum’s research shows that in the biological realm an ecologic system is far healthier and superior, through “looping” (recycling and up-cycling) energy and materials and by infusing these loops at intervals with fresh external energy.

Odum had a very clear view on the substance of the reality of the spectrum of energy, as emergent properties and qualities of next order forms with different hierarchical relationships and energetic life cycles. Past, present and future are not separate entities but actors in the same field. With Odum’s approach, phenomena of the biological and urban realm could be discussed on multiple levels (political strategies, private interests, economic value, efficiency in design and materialization, ecological function of the public realm, ...) and different scales. What kind of materials do we use? How much external energy do we need to produce these building materials and which global economic pathways are involved with their various effects on a local scale?

Odum’s urban matter relates on a field of processual activity with different forces simultaneously at play. Classic theories and models of urbanism consider a reductionist view of static formations of architectural forms, but do not account for emergence and the emergent properties of its energetic evolution.

In a wider sense, systems ecology relates to the seminal works of Walter Christaller’s *Central Place Theory* (Christaller 2009; van Meeteren and Poorthuis 2018), as well as Christopher Alexanders groundbreaking work on *A Pattern Language* (Alexander, Ishikawa, and Silverstein 1977; Alexander, n.d.) and his theories on morphogenetic processes in architecture and urbanism. All these approaches opposed the static model of architecture and urban form. Systems ecology grants a view towards the dynamism of the physical, chemical, economic, and social forces in the field of urban morphological ensembles—the passive potentialities (energy storage) and the active transgressing forces. Odum’s understanding of urban energy cycles becomes even more valid in evaluating extensive datasets and the effects of technological innovation, in order to unravel the information patterns over time. Here, it is necessary to differentiate the parametric model related through quantities, from the dynamic model of qualities through emerging patterns over time. These forms are not a matter of typologies. They are transformative qualities of differences in motion—descriptive inherent properties of relations.

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### ENDNOTES

- 1 Luis M.A. Bettencourt, Lobo Jose, Dirk Helbing, Christian Kühnert, and Geoffrey West. 2007. "Growth, Innovation, Scaling, and the Pace of Life in Cities." *PNAS* Vol.104, No.104: 7301-7306
- 2 *Concepts of the structure and function of the natural world emerged as parts within parts within parts* (Odum 1971, 2).
- 3 Science distinguishes between Gibbs free energy as available energy calculated through the maximum of reversible work that may be performed by a thermodynamic system at a constant temperature and pressure or Helmholtz free energy is a thermodynamic potential that measures the useful work obtainable from a closed thermodynamic system at a constant temperature and volume [www.sciencedirect.com/topics/earth-and-planetary-sciences/free-energy]
- 4 The concept of exergy has been developed by J. Willard Gibbs, but the term was first mentioned by Zoran Rant in 1956.
- 5 Anthropogenic metabolism, also referred to as 'metabolism of the anthroposphere', is a term used in industrial ecology, material flow analysis, and waste management to describe the material and energy turnover of human society.
- 6 Manuel Delanda. 2013. *Intensive Science and Virtual Philosophy*. First Edit. London, Oxford, New York, New Dehli, Sydney: Bloomsbury Academic.

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