A Matrix of Architecture and Ecology: Mother Nature Unfurled

PETIA MOROZOV
madLab

Merging disciplines and expertise should help us grasp complex whole issues, for example, connecting micro-effects with macro-transformations, the global with the local context, the urban with the unbuilt territory.
—*Amerigo Marras*[1]

Key terms can be extracted that infer scale—micro, macro, global, local, urban, unbuilt—one wonders, how do we actually achieve the connection of which Marras speaks? This question is at the root of this paper, and it has compelled me to reconsider the rhetoric surrounding the dynamics of scale.

BEFORE THERE WAS SUSTAINABILITY

German Zoologist Ernst Haechel first coined the term *ecology* in 1873, nearly a century into the First Industrial revolution. Since then, the field has expanded at an arresting rate to include a broad constituency of disciplines. To the scientist, ecology is the study of the relationships and interactions between living organisms and their natural or developed environment. To the sociologist, it is an understanding of spatial and temporal interconnectedness between cultures.

To the industrialist, ecology is the latest brand of commerce, breathing life into obsolescent business strategies. According to an article in the September 11, 1999 Economist, ''companies with an eye on their 'triple bottom-line'—economic, environmental and social sustainability—outperform their less fastidious peers on the stock market, according to a new index from Dow Jones and Sustainable Asset Management.''[2] The call for action is piercing and timely. Led by organizations like U.S. Green Building Council—the new ''green'' regulators for sustainable building—and wildly popular[3] publications such as McDonough and Braungart's *Cradle to Cradle: Remaking the Way We Make Things,*the re-tooling of industry is already in place. Confirming the economic argument for eco-effectiveness, McDonough et al, envisions ''commerce as the engine of change, and honors its need to function quickly and productively.''[4]

But what of the architect? What meaning has architecture decided for ecology? Not surprisingly, there still exists the romanticized notion of nature. Like a muse, nature has imparted her mystique on architecture by way of her image, as if to imply servitude. Frank Lloyd Wright's quest to understand just *how* to respond to her vastness was a pre-occupation, his ongoing romance. As he put it, ''nature furnished the materials for architectural motifs out of which architectural forms as we know them today have been developed, and, although our practice for centuries has been for the most part to turn from her, seeking inspiration in books and adhering slavishly to dead formulae, her wealth of suggestion is inexhaustible; her riches greater than any man's desire.'' As the works of other disciplines suggest, however, it is not her image that mystifies, but rather her process. This notion is about to wreak a glorious havoc on architecture.

CONFESSIONAL

This paper is underpinned by two quasi-religious imperatives, one of mercy and one of deliverance. It has been architecture's fate to be the purveyors of materializing our environment, a process by which nature's resources are regrettably, yet unavoidably consumed. For this, architecture must accept its destiny and move on. It has also been architecture's weakness to circumvent ecological accountability, as has been the case for its industrialist and historicist counterparts. For this, architecture must attest to its own resilience and seek an ecological means for its redemption. The best — and perhaps, only — way to get architecture out of the limited business of form-making would seem to be greater collaboration with the fields of study that deal specifically with the larger picture.

To be sure, there are well-meaning architects who acknowledge a need for change, indeed, claiming that ecology and architecture are synonymous, or even, that "ecology is, from the beginning, a certain kind of thinking about or from architecture."[5] What is flawed here is the presupposition that both architecture and ecology arrive at compatible understandings about and manifestations of our environment. These differences will be left for the environmentalists and developers to debate. What is of interest, however, is the notion that architecture and ecology are linked by way of their *behavior.* To go one step further, their behaviors share similar degrees of complexity, of *interconnectedness.*

NATURE *AND* MAN

The goals of man and nature have long been in grave contradiction, and we have been slow to realize its consequences. This would make us believe that the state of crisis must be the motivator. I contend that this has actually weakened the role of ecological thinking in architecture. While debate over nature's meaning continues, it is prudent to concede that man's hands have been the work of thievery rather than of collaboration. It is well documented, for example, that climate change, depleted resources and energy crises are the workings of an ecological system under extreme, "unnatural" forces. What future actions protect or alter natural processes? How can it be that civilized mankind can possess such forces against the untamed and the hostile? Are we at all prepared to confront our own brutish force?

Today's ecological concerns trigger these essentially historical questions, and its history is nothing short of a tragedy. As recently as 1984, Donald Worster found "little history in the study of nature, and little nature in the study of history".[6] History was a humanistic enterprise, ecology a scientific one. Analogies abounded, "the book of nature" was a common cliché, and historical "science" was recurrently trendy. But most scholars stressed the disparate temporal horizons, subject matter, and sources of the two realms and slighted their parallels. Nature was mundane and mindless, history the sublime drama of human will. While ecologists doggedly termed nature mankind's master, devotees of advancement saw nature as mankind's servant.

REWIRING THE DISCOURSE

We now know that ecology is a robust system of complex behaviors and interconnected relationships, and its model has prompted the same interconnectedness between allied disciplines. Investigation in numerous fields of biology and mathematics has catapulted ecology to higher scientific ground. It is important to review a key development in mathematics that altered the state of ecology in the 20th century, that of chaos theory. This paradigm shift in ecology was also perhaps the most counter-intuitive — behaviors within an ecosystem could display erratic and even unpredictable behavior, but it was not *random*. This fundamental shift presented the possibility that internal, as well as external forces, were identifiable agents of change, laying new ground for the study of adaptation and deterministic chaos.[7] So, for instance, rather than assuming changes in an eco-system due to wind and rain patterns, it was conceivable — though not fully understood — that changes were self-created by the agents *within* the system. Nature could no longer be thought of as the sentinel of equilibrium, but more like a "coordinated machine" striving for diversity.[8] By crossing over the traditional boundaries of study, pioneering ecologists discovered ways of communicating this behavior with a new dialect of science. This last point is groundwork in support of the argument for multidisciplinary discourse between architecture and ecology's relevant fields of inquiry.

STAIRS OF LIFE

Ecology and architecture share a common characteristic of complexity, and I argue that scale is the corresponding framework that can help to express those complexities more systemically. As an architectural occurrence, scale can be prefixed in a number of ways — human, small, large, urban, micro, macro — as an attempt to depict a perceived spatial system. Yet, I contend that these depictions are too broad of a stroke, and are often inappropriately used to suggest a perception of, rather than an absolute, scale. To clarify the discrepancy in ecological terms, a working proposition is that scale is a field of operation. This notion from a disciplined framework already elaborated quite beautifully by biologist James Miller, originator of *systems theory.* In his seminal work *Living Systems*, he proposes a framework of seven levels of living systems, from the cell to the organ, to the organism, to the group, to the organization, to the society and finally, to the supranational system.[9] I propose here is a systemic synchronization between the scales of architecture and the scales of ecology at their most fundamental level.

In each of these levels, they carry on the same basic life processes, processing inputs, throughputs and outputs of either matter, energy or information. At every point in this evolution, if each of these processes were not continued, the system would have not continued its life. In other words, the ''boundaries'' that exist between systems act as thresholds of overload to a particular system. This notion is critical to establishing whether an **eco**-system is in a state of resilience or of crisis.

This coordination of scales synchronizes architecture with ecology at a fundamental level [see Figure 1]. Identifying where the edge of one scale ends and another begins is less important than the realization that every system impacts others in critical, dynamic ways, and that one framework exists to manage the whole. These scales are fields of operation in which part of the framework's information resonates more loudly than in other fields.

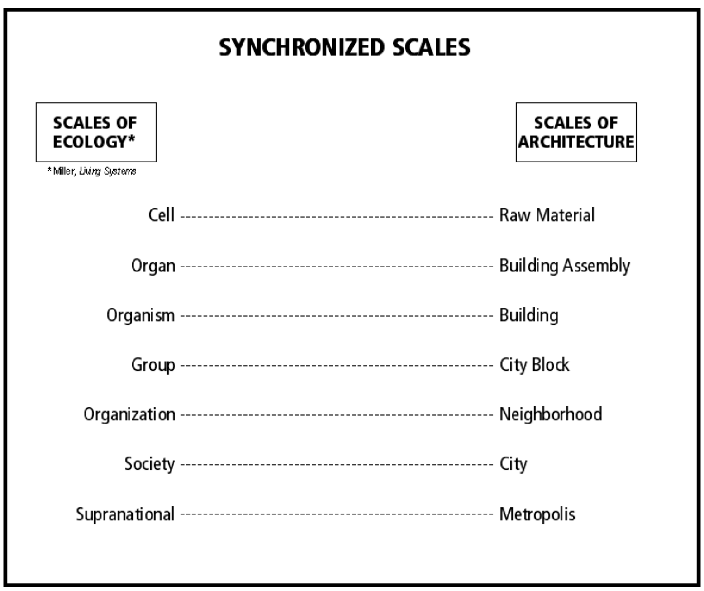


Fig. 1. Graph of Synchronized scales between ecology and architecture. Source: Author, 2003.

CONNECT THE DOT MATRIX

It has been previously illustrated that the notion of cross-cultivation among disciplines is not only a desirable mode of inquiry, it is implicit to ecology's advancement. Architecture has much to gain from such discourse, and it cannot be overestimated how positive the outcome will be for our environment. It has also been stated that systems of scale hold the potential to mitigate logistical differences between architecture and ecology. With these two operations in place, a brief review of current developments relevant to architecture and ecology is warranted. Specifically, inquiry in the fields of fractal geometry, patch dynamics, shape grammar and emergence are introduced here as agitators between fields [see Figure 2], and with the hope that similar patterns of behavior will emerge to help advance the potential of matrix complexity.

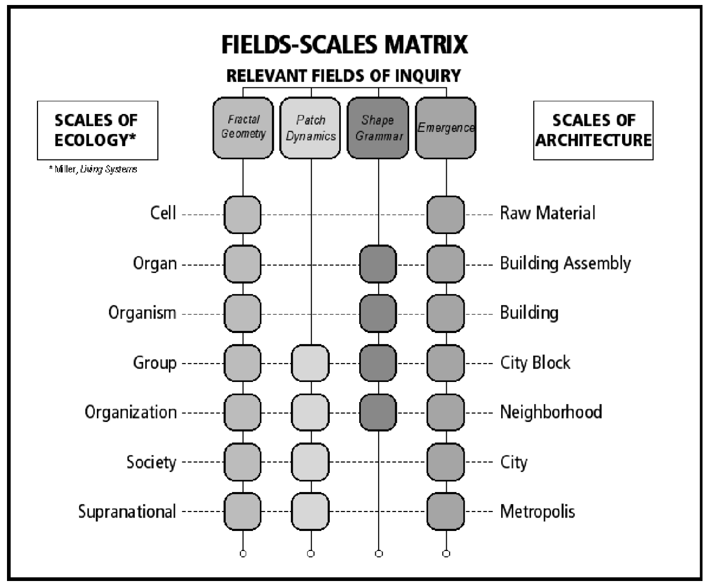


Fig. 2. Fields-Scales matrix outlining scale correlation to ecology and architecture, and their relevant fields of study. Source: Author, 2003.

A FRACTAL MIND

For almost 30 years,[10] chaos theory has been instrumental in returning science back to its state of interconnectedness and reversing ''a crisis of increasing specialization.''[11] During that time, another field has emerged out of the principles of chaos, called fractal geometry. In simplified terms, a fractal is a geometric shape that exhibits self-similarity across all scales. This holds particular relevance to the structure of the matrix [see Figure 2], since it suggests a kind of mathematical glue that has the potential to bind all of architecture and ecology's scales in a systemic pattern of complexity.

Victor Padrón urges implementation of the field: ''From the distribution of foliage on a tree, to the complex neural network of our nervous system; all of these can be better described with the help of Fractal Geometry. In the human body, the fractal design of its components like the circulatory system, nervous system, the bronchi, and the folds of the brain allow our organism, in a limited space, to greatly extend its contact surfaces in order to carry out the innumerable and complex functions of interchange that make life possible. This optimal structure must surely be motivated by evolutionary reasons.''[12] What is implicit to his statement is the idea that a synthesis operation for modeling the scalar behavior of architecture, ecology *and* fractal geometry is inevitable.

Fractal speak is still slow to enter the architectural dialogue, perhaps due to a thick scientific accent. Salingaros offers his mathematical perspective on the language barrier: ''[It] all this seems anachronistic, and even dangerous. The reason is because a closed system of knowledge lends itself to corruption and dogmatism — the opposite of the openness of the scientific method.''[13] He pleas for interconnectedness: ''Reflect for a moment on how scientific research is actually done. Someone announces the results of some investigations, and then his or her colleagues try their best to disprove them. The method by which they were obtained is scrutinized, as well as their ability to be verified by others. If they withstand this ''trial by fire', then the results are allowed to stand. When a result is verified independently by other researchers, then it enters the permanent body of scientific knowledge, at least until it is superseded by a more refined or more general result.''[14]

In Application

Theoretically, fractals are infinitesimally subdivisible, such that each part contains no less detail than the whole. In theory, then, principles of fractal geometry can inform behavior at the widest scale. In reality, at some stage of subdivision, the detail will be lost. So although true fractals cannot exist in reality, objects can possess fractal properties across a certain range of scale. Currently, architectural explorations patterned after fractal geometry occurs at the four uppermost scales: city block, neighborhood, city and metropolis [see Figure 2], while architectural explorations reside in the remaining three.

Exploration at the building scales is scant, still requiring a departure from theory. Some transition to application exists in a few architectural curricula, employing fractal geometry at more tangible scales, and building a plausible case for multidisciplinary programs. University of East London student Mark Jeffery is a candidate for a Masters of Science in Architecture for Computing and Design.[15] His portal for exploration is wider than the typical US school program, since it integrates a wider range of coursework.[16] His thesis topic is evidence of that integration: ''Fractals, Self-Similarity and Architecture.'' Recognizing the potential to bridge between disciplines his thesis aims to ''to generate built form of a fractal like nature and to investigate the form generated, … to show the possible complexities of the built form, with respect to the same fractal-like properties displayed in nature and to show how this complexity can lead to the desirable building attribute of permeability.''[17] The trend for multidisciplinary programs is on the rise, and schools responding to the pedagogical shift are pioneering the way for innovation and accountability.

Fractal Ecology

The use of fractals has been instrumental in modeling McDonough's eco-effectiveness.[18] This strategy strives to address the specific goals of ecology, equity and economy by understanding their degree of interconnectedness [see Figure 3].

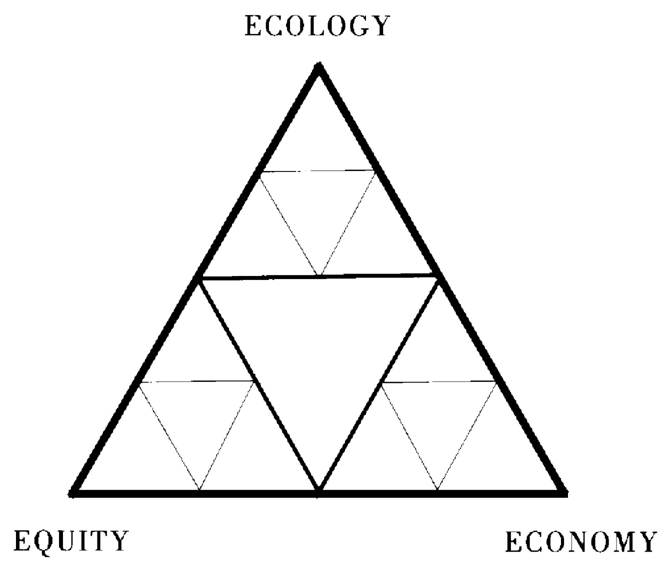


Fig. 3. Fractal for eco-effectiveness. Source: W. McDonough and M. Braungart, Cradle to cradle: ReMaking the Way We Make Things (New York, North Point Press, 2002), 150.

While highly innovative as a visualization tool, it is likely that the root of this eco-fractal model is fixed in metaphor, and fails to recognize the importance of such a framework for design as well. McDonough defends its function as ''a tool, not a symbol,''[19] but architecture is suspiciously missing. It becomes so reductive as to eliminate the role of architecture entirely; if, perhaps, architecture is embedded within the framework, it remains unclear in what corner of the fractal architecture resides. This is an important omission to illustrate, given how detrimental the absence of architecture has been in the face of ecology's concerns. To be sure, ample evidence suggests that ecology *and* architecture are suitable venues for much deeper exploration in fractal geometry.

Fractals IN Ecology

Landscape ecology, in particular, is concerned explicitly with the effect of spatial heterogeneity on ecological processes. Fractal geometry provides a multiscale quantitative approach to describing landscape patterns.[20] In ecology, fractals have been applied in analyzing animal movements, quantifying land use patterns, developing forest management schemes, estimating habitat usage, and in map renormalization procedures, such as GAP analysis. Understanding fractal principles across scales is critical to predicting the resulting changes in biodiversity, ecosystem functioning, and landscape structure.[21] Because complex systems operate on multiple scales, it should be acknowledged that a process driving a pattern at one scale might be unimportant in the bigger picture. However, the overarching concern is that these discontinuities result in heterogeneity.

PATCH DYNAMICS

Landscape ecologists have recently developed a model to study urban landscapes that takes a spatially focused approach, that of patch dynamics. This approach focuses on the creation of the spatial heterogeneity within landscapes and how that heterogeneity influences the flow of energy, matter, species and information across the landscape.[22] It recognizes without hesitation that ''the urban landscape is a mosaic of biological and physical patches within a matrix of infrastructure, social institutions, cycles and order,'' and makes the notable inclusion of both natural *and* human sources.

One useful feature of ''patchiness'' is that it can be applied to various spatial scales, specifically the nested scales of neighborhood through metropolis.[23] What is of interest here is that such nested scalar hierarchies are true for vegetation in an urban landscape as well. ''Each of these nested patch hierarchies is more than a convenient way to organize spatial heterogeneity,'' observes Zipperer et al. ''Patch hierarchies allow researchers to ask questions related to what factors influence the patterns and processes observed at each nested scale and the functional relationships within and between scales.''[24] I would go one step further to say that these hierarchies of scale for both the natural and human can be synchronized, and ultimately can inform *each other.* The critical point is that such evidence helps to disprove the myth that city is not nature and nature is not city.

Pedagogical patchiness

Brian McGrath's Urban Design studio is part of a small but growing tradition in university curricula that is crossing over into landscape ecology and instituting patch dynamics as a generator of eco-urbanism. The studio's syllabus specifically calls for a pedagogical approach where ''the activity of urban design … is seen as interdisciplinary:''[25] Outlining its mission, the studio ''must operate between the physicality and design orientation of architecture, environmental design and the abstraction of economic and political policy within the unpredictability of human behavior. Studies will also engage in intimate observation of ecological, social and cultural practices over time and as embedded within a pattern of patch dynamics.''[26] The internal workings of the studio generated intense investigation at a complexity of spatial, temporal and social scales. More interestingly, upon recognizing unifying themes between students, collaboration emerged unplanned and undetermined.

SHAPE GRAMMAR

Generally speaking, shape grammar is less concerned with the generation of behavior as it is in the pattern of behavior. In the architectural context, shape grammar is a language of generative design. It can specify a universe of design possibilities by choosing a vocabulary of shape types and some class of transformations to employ as design operators. For a given vocabulary, choosing successively more general classes of transformations will yield nested, successively more extensive universes.[27] Shape grammars enable the specification of a potentially infinite set of design objects in a finite, concise set of shape rules. As such, no formal investigations crossing between this methodology and ecology exist. It is conceivable, however, to adapt its output matrix model toward mapping complex, heterogeneous behaviors [see Figure 4]. Here exists further potential for architecture to inform another field of study toward ecology.

Terry Knight, a leading researcher of shape grammar at MIT, understands the difficulty in making this field applicable to others. She states, ''shape grammars are more than twenty-five years old, but their potential in education and practice is still far from being realized. Shape grammar theory is now far in advance of practical applications.''[28] In fact, what challenges the application of shape grammar is its computer implementation by way of its interface.[29] Future development in this field is likely to result in broader applica-

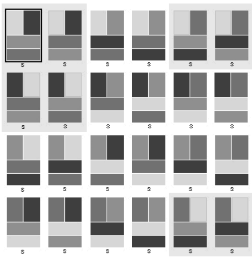


Fig. 4. 3D Shape Grammar matrix for Siza's Malagueira topology patterns. Source: Duarte website, (http://www.civil.ist.utl.pt/~jduarte/malag/Grammar/grammar_Open.html)

There must be critical mass, and the agents must be interacting. Take, for instance, the basic premise of emergence, i.e. the whole is greater than the sum of its parts, and optimize it to mean that the whole of architectural collaboration is greater than the sum of its collaborators. Emergence itself as the model of collaboration can yield a matrix of robust ecological design approaches. An example of such a model will be presented later.

BATTY'S "SUSTAINABLE TOWN CENTRE", SYNTHESIZING GEOGRAPHIC DATA WITH GEOMETRIC DATA

Fig. 5. Source: CASA website (http://www.casa.ucl.ac.uk/newtowns/papers.html)

tions, one that considers both ecological and architectural concerns.

EMERGENCE PLUS

The field of emergence is exploding with exploration across a wide array of disciplines. It is ecology's current method of information delineation for predicting future patterns in ecosystems. It is architecture's current fascination as a method of form-making. Note the difference in application. If architecture is to evolve into a body of transparent knowledge, it must revamp its characterization of emergence. It may begin by revisiting the notion of collaboration in more radical terms. To elaborate on its structure: in an architecturally emergent system, individual agents, i.e. architecture, biology, ecology, etc. can't produce the behavior. Emergent behavior can't be described in terms of the local behavior that produces the global behavior. It is the action of the parts that is controlled, not the whole. There is not a central designer to such a collaboration.

Working Models

Emergence and its graphic interface in the field of ecology has been lifted out of theory and into application. Batty's proposal for "The Sustainable Town Centre," for example, includes the development of an emergent model capable of synthesizing sustainable development at the pedestrian scale [see Figure 5].[30]

Batty states that "the most current modeling capability still resides at the macro-level with the city represented in terms of coarse zones which do not detect the finer scale geometries and infrastructures so important to questions of sustainability...We are therefore proposing a shift in scale to models which simulate sustainability at the level of land parcels and utility lines but synthesize geographic with geometric data."[31] He notes specific attention to linking macro- and micro-scales by means of an integrated model. This emergent model is the synthesis of two primary engines, TRANUS (based on fractal code), and an agent-based SWARM system (based on complexity code).[32] He argues that the task to link these two scalar models within a GIS framework is not only feasible but imperative to the larger task of synchronizing the built environment's supply with demand.

On the subject of synchronization, I propose a model that illustrates how we can conceive of scales as a non-linear operation, rather than the traditional closed-loop operation [see Figure 6].

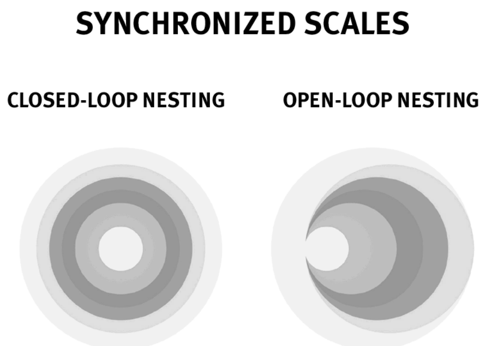


Fig. 7. Here is a condition of scalar nesting in a closed-loop, an operation that is implicitly linear. In contrast, here is a condition of scalar nesting in an open loop, wherein boundaries between fields of operation are loose and interconnected. Source: Author, 2003.

This is crucial for two reasons, the first, being a matter of resilience. Going back to Miller's model, he proposes two subsystems that define each level in a system, he calls them boundary and decider subsystems. Every level has, at its edge, a subsystem of boundaries at which point it filters out harmful substances, permits entry selectively, and protects against attack. Decider subsystems are the command and control post of a living system and help to regulate information throughout the system. Both interact within each level non-hierarchically, and both help each level to determine its rate of resilience, which in turn helps to determine an overall rate for the system.

The second reason is one of crisis: many levels within a system are subject to an overload at any given point, and because each level is fine-tuned to respond within a given capacity, it therefore cannot afford to think hierarchically but more heterogeneously. In other words, a system's ability to withstand crisis is measured by its interconnectedness.

Sharing: The Next Generation

As the prospect of multidisciplinary work is realized, it may be useful to highlight an ongoing development in computation called "EWall." Still in concept phase, this project at MIT proposes emergent processes to facilitate multi-user collaboration. It is a matrix of sharing information: how to share, what to share, when to share, where to share, and most importantly, why to share [see Figure 9]. Its environment hosts increasing complexity of interconnectedness, provides multi-scalar decision-making, democratizes disciplines and fosters evolving and emergent relationship. In other words, it behaves like

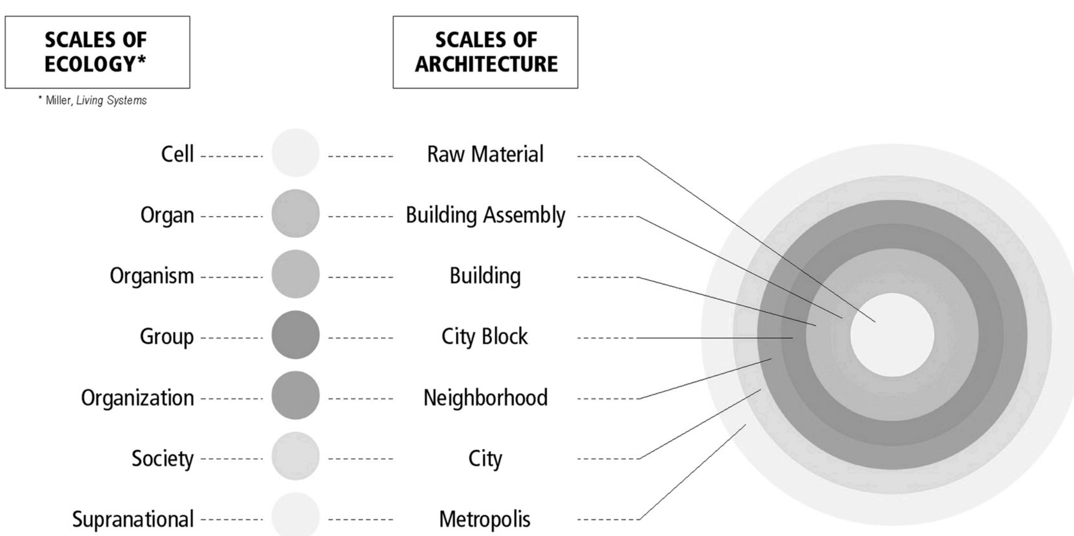
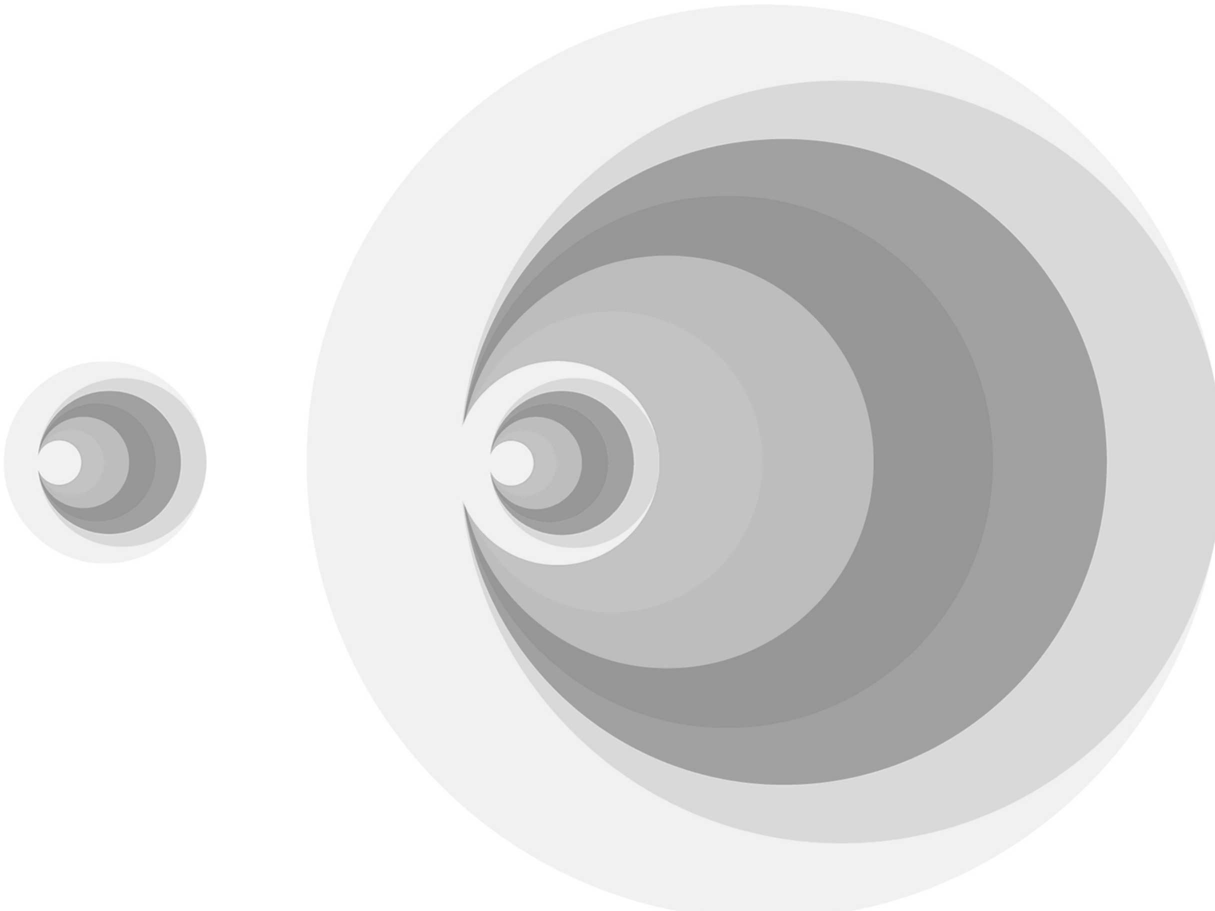


Fig. 6. Here, again, are the original seven scales in both architecture and ecology, and each scalar field of operation is color-coded. Source: Author, 2003.



SELF-SIMILAR NESTING = FRACTAL OF SCALAR OPERATIONS

Fig. 8. Now, should we monitor how the nesting persists and evolves, and we may begin to see fractal behavior emerge, and the potential for true multi-scalar behavior in architecture and urbanism. This is an inherently ecological response. Source: Author, 2003.

an ecosystem. It's time for architecture to plug in to the matrix.

MOTHER NATURE → MATRIX NATURE[33]

So then, if we are to re-conceive of this vast interconnectedness, this single ecosystem, as a new thinking in architecture about ecology, then the management of its networks, that is to say,. the manifestation of scale as a field of operation, can build layers of knowledge that evolve and interact continuously. This paper ends with a proposition to unfurl our concept of Mother Nature: As the matrix of interconnectedness grows, so will the need to map those complexities, to parse out the redundancies and the immaterial, and to invent the interface between them all. Einstein is famously quoted as saying that ''the world will not evolve past its current state of crisis by using the same thinking that created the situation''. From here, the send-off toward ecological thinking is closer than it appears, as are the impending consequences of acquiescence.

A working proposition is that the built and natural environments are not mutually exclusive conditions — one that is uniquely human, the other wild — but rather, a synthesis of both. Anthropologist James McGlade argues that there is no social system and neither is there a natural system, there are only socio-natural interactions. This linguistic re-tooling of ''nature'' invites the same for Mother Nature. That is to say, if she is, in fact, a much more complicated body of behaviors than the pop-cultural icon we so stubbornly maintain, what should we call this nature of increasing complexity into a singular system? By revisiting the meaning of the word ''matrix'' we find that it is derived from Latin, ma_ter, to mean ''mother.'' Simply, let's call it, Matrix Nature.

NOTES

[1] Amerigo Marras, ''Hybrids, Fusion, and Architecture of the In-between'' in *Eco-Tec: Architecture of the In-Between*, edited by Amerigo Marras (New York: Princeton Architectural Press, 1999), 6.

[2] Cited from ''Business This Week September 4th — September 10th 1999,'' (*http://lists.isb.sdnpk.org/pipermail/econo-list-old/1999-September/001240. html*)

[3] It this writing, Amazon.com has ranked it at #568 in sales, out of millions of titles. Its popularity is significant, since we can no longer deny the urgent state of our environment. Any positive vehicles for change are warranted.

[4] William McDonough and Michael Braungart, *Cradle to cradle: Remaking the Way We Make Things* (New York: North Point Press, 2002), 150.

[5] Mark Wigley in ''Recycling recycling,'' in *Eco-Tec: Architecture of the In-Between*, edited by Amerigo Marras (New York: Princeton Architectural Press, 1999), 42.

[6] Donald Worster, *Nature's Economy: A History of Ecological Ideas* (New York: Cambridge University Press, 1984).

[7] Richard E Leakey and Roger Lewin (Contributor), *The Sixth Extinction: Patterns of Life and the Future of Humankind* (New York: Anchor Books, 1996), 153.

[8] Ibid., 154.

[9] Victor W. Olgyay, ''Towards a Systems Ecology of Architecture,'' (*http://sundial.arch.hawaii.edu/sundial/ProPaper/SystemsEcology/SystemsEcol ogy.html*)

[10] Henri Poincaré, mathematician, first stumbled upon the notion of chaos in 1902, when he entered a contest sponsored by the king of Sweden. Advancements in the field evolved slowly, and it was finally coined ''chaos'' by James Yorke in 1975.

[11] James Gleick, *Chaos: Making A New Science* (New York: Penguin Books, 1987), 5.

[12] Victor Padrón and Nikos A. Salingaros, ''Ecology and the Fractal Mind in the New Architecture: a Conversation,''(*http://www.math.utsa.edu/sphere/salingar/Ecology.html*)

[13] Nikos A. Salingaros, *A Theory of Architecture*(*http://www.math.utsa.edu/sphere/salingar/introduction-atoa.html*)

[14] Ibid.

[15] See ''University of East London, Master of Science in Architecture: Computing and Design'' Homepage, (*http://www.uel.ac.uk/architecture/msccad.html*)

[16] It is not at all coincidence that such a program as exists in what is the epicenter of current ecological thinking and practice in architecture. The U.K., Germany and the Netherlands top the locations of exploding collaboration, and the results of such an adaptation to ecology's concerns are evident in their built environment.

[17] Michael Jeffery's Homepage, (*http://homepages.uel.ac.uk/1953r/thesis.htm*)

[18] William McDonough and Michael Braungart, *Cradle to cradle: Remaking the Way We Make Things* (New York: North Point Press, 2002), 151.

[19] Ibid.

[20] Cited from Andrew J. Kerkhoff's web page for ''Biology 576: Landscape Ecology & Macroscopic Dynamics'' course, (*http://sevilleta.unm.edu/~kerkhoff/fractals/fractals.html*)

[21] Ibid.

[22] W. C. Zipperer, J. Wu, R. V. Pouyat, and S. T. A. Pickett. ''The application of ecological principles to urban and urbanizing landscapes.'' *Ecological Applications* 2000 10(3): 685-688.

[23] Ibid.

[24] Ibid.

[25] Cited from ''Urban Design in an Expanded Field,'' Urban Design Studio, Fall 2002, Columbia University, Graduate School of Architecture, Planning and Preservation (*http://www.arch.columbia.edu/gsap/11464/*)

[26] Ibid.

[27] Cited from CECA (Centre for Environment and Computing in Architecture, University of East London School of Architecture, (*http://ceca.uel.ac.uk/~student/khudair/*)

[28] Terry W. Knight, ''Shape Grammars in Education and Practice: History and Prospects,'' *International Journal of Design Computing* (*http://www.arch.usyd.edu.au/kcdc/journal/*) vol. 2 (2000)

[29] Ibid.

[30] Michael Batty et al. (1998): *The Sustainable Town Centre*, a proposal to EPSRC, November 18, 1998, (*http://www.casa.ucl.ac.uk/newtowns/papers.html*), 4.

[31] Ibid.

[32] Ibid.

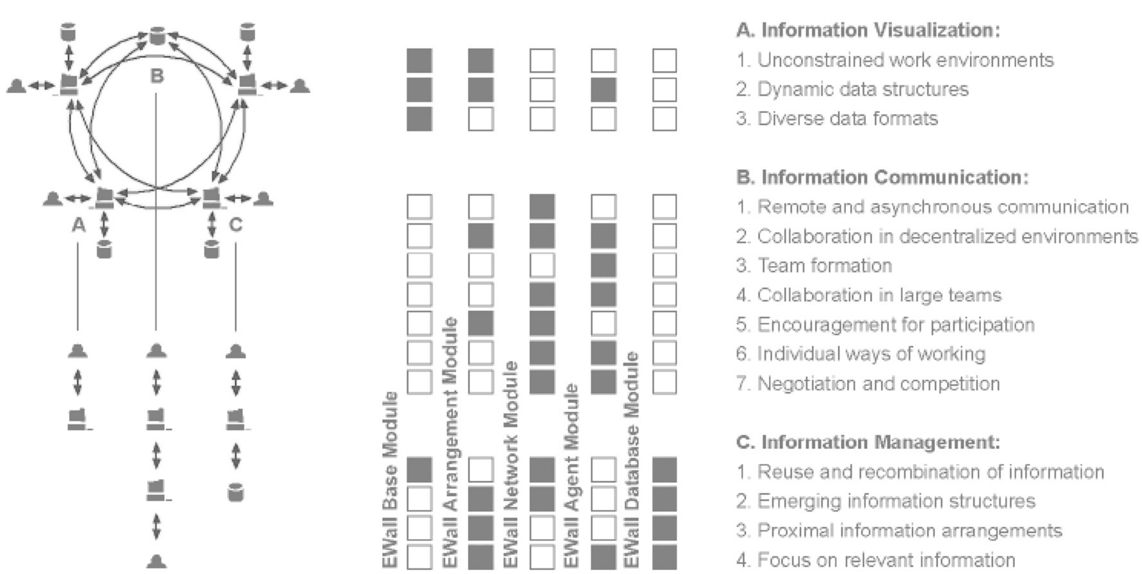


Fig. 9. EWall Matrix. Source: EWall website, (http://ewall.mit.edu/abstract/index.html)

[33] The word ''matrix'' derives from Latin: ma-ter, ma-tr-, to mean ''mother.'' The author proposes the phrase ''Matrix Nature'' as an evolutionary understanding of Mother Nature, This term embodies all of her heterogeneous complexities, i.e. spatial, scalar, etc. that could then be mapped by an elaborate matrix.