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The "*Bio*-logic" Architecture

Environmental Design Inspired by Slime Mold, Lichen and Other Natural Sources

Abstract

In *Out of Control*, Kevin Kelly argues that a range of human activities, including design and manufacturing, are increasingly defined by the "ways of biology," or what he calls "*bio*-logic." Extending Kelly's term to environmental design, the "*bio*-logic" of architecture is two-fold: (1) that the characteristics and processes of the natural environment can inspire the design of the built environment; and (2) that such a work, a "complex interweaving of living and nonliving systems," can cultivate a more intimate, responsive, and mutually-beneficial relationship between itself and the "biophilic" people, things and environmental conditions associated with it. But while Kelly envisions a future filled with "mutating buildings" and "rooms stuffed with co-evolutionary furniture," Gehry's "fish" and Calatrava's "carcasses" are indicative of an architectural avant-garde that largely fails to see beyond the traditional "*ana*-logic" of architecture, an association of buildings and natural phenomena where buildings are measured by the body or formed and decorated after flora and fauna. Towards realizing Kelly's ambitions, a *bio*-logical design project for the urban-rural interface was developed by a trans-disciplinary group of faculty and students. This paper focuses on one architectural work within the larger proposal. This particular work, inspired by the life-cycle of slime mold, is here described in two ways: with respect to the life-cycle of this living thing, and with respect to the unusual "norms and means" required to develop and communicate it. The accomplishments, shortcomings and promises of this architectural work, and of "*bio*-logical architecture" more generally, are evaluated here as well.

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> *If we are prepared, as apparently we are, for our buildings to look like animals and plants, perhaps we should be looking to make them function like them as well.* [...] *There's a latent interest in biology, but little actual knowledge.*
>
> – Hugh Aldresey-Williams, "Towards Biomimetic Architecture"[1]

Today's design avant-garde is defined, at least in part, by a tendency to conceive architectural works that look like plants and animals. Around the globe, high-profile examples of this tendency have become part of the cultural "mainstream": the many fishlike buildings by Frank Gehry, the numerous carcass-like structures by Santiago Calatrava, and the wormlike water pavilion by Nox Architects. Of course, architecture exhibiting (at one scale or another) the look of plants and animals has been around for some time, from the French Enlightenment (with Viollet-le-Duc) to the mid-twentieth century (with the elder Frank Lloyd Wright and his heir, Bruce Goff).[2] In the decades that followed the so-called "organic architecture" of Wright and Goff, interest in this plant-like and animal-like architecture waned (with the notable exception of Archigram); that is, until the 1980s, with the arrival of accessible computer technologies that facilitated the design and construction of complex forms, combined with a renewed interest in the environment, revived as "sustainability." There is no logical reason, however, why a work of architecture conceived with the aid of *NURBS* modeling software or responsive to the environment should in any way resemble a plant or an animal. This "slavish imitation of nature" is more the preoccupation of architects happier to play with shapes than to advance their practices through a serious engagement with the innovations offered by biology, bio-engineering and their allied sciences.[3]

But what if works of architecture, rather than *looking* like plants and animals, *behaved* like plants and animals? Imagine if designs for the human environment "adapted and flexed and evolved as living things do."[4] This is the challenge posed more generally to all designers and manufacturers by Kevin Kelly in his book, *Out of Control*. For Kelly, it is becoming increasingly difficult to distinguish the things of nature from the things we make. Kelly cites two trends in engineering and manufacturing that blur this distinction between the natural and the artificial: "(1) Human-made things are behaving more lifelike, and (2) Life is becoming more engineered."[5] So while "the hallmark of the industrial age has been the exaltation of mechanical design," "the hallmark of a neo-biological civilization is that it returns the designs of its creations toward the organic, again."[6] Comparing, over three time frames, how people conceive, produce and exchange things in the world reveals this curious return, today, to an older mode of making, producing and exchanging things in which nature serves as inspiration for design, and the means of production afford personalized products [Table 1].

	CLASSICAL	**MODERN**	**CONTEMPORARY**
INSPIRATION	Nature	Mechanics	Nature
PRODUCTION	Handmade (Personalized)	Mass-Produced (Serial)	Digital (Personalized)
EXCHANGE	Agrarian	Industrial	Informational

Table 1: The character of design, exchange, and production over time.

Indeed, *Out of Control* is subtitled, *The New Biology of Machines, Social Systems, and the Economic* World, inferring that the ways of biology are well-suited to thinking about a range of human activities. It is not only human production but all of "human culture" that is, for Kelly, becoming "more ecological and evolutionary."[7]

The commingling of nature and artifice that is central to Kelly's broad view of the contemporary world has only begun to emerge as an important preoccupation of architects. For one, Kelly's insightful words serve as epigraphs for two of the five chapters that comprise Richard Rogers' polemical book, *Cities for a Small Planet*.[8] In "Recycling Recycling," Mark Wigley recognizes (like Kelly, and drawing from Fuller and McHale) that the limits that distinguish the "organic" from the "technological" have "given way"; that "technology itself is an organic system" in which the communication network is a nervous system, architecture is an ecology, and the planet is a machine.[9] In an article entitled "Organic and Mechanical," Joseph Rykwert traces the co-mingling of the terms "organic" and "mechanical" in architectural thought, beginning with Vitruvius' treatise (where "the Latin *oganicus* did not mean anything very different from *machinicus*"), to Gottfried Semper, Owen Jones, and John Ruskin (all of whom cultivated "ideas about a new way of imitating nature, or relating the organism to the built form").[10] Rykwert, in conclusion, laments that while architects have long been preoccupied with nature as inspiration for decoration and form, there is not yet a "theory of architecture based on a direct appeal to…the nature that biology and chemistry study."[11] Common to the thinking of Rykwert, Rogers and Wigley – we might add David Orr and William McDonough here, too – is the recognition that our increasingly "neo-biological civilization" has deeper implications for architecture than the mere making of plant-like and animal-like forms.

Introducing the *Animated Architecture Lab*

Towards an architecture that *does* appeal to the "nature that biology and chemistry study," I established, in Fall 2003 at Clemson University's School of Architecture, the *Animated Architecture Lab* [AAL]. The AAL is defined as a multi-disciplinary research and instruction body that recognizes architecture as a living system responsive to the dynamics of life in the built and natural environments. While people generally regard architecture as a static form, the AAL envisions architecture as a dynamic and vital organ filled with and surrounded by people and things in motion.

The AAL sees beyond the traditional "analogic" of architecture, an association of buildings and natural phenomena where buildings are measured by the human body or take the form or decoration of flora and fauna. Instead, the AAL takes what Kelly calls the "*bio*-logic" (*sic*) of architecture as its premise. "*Bio*-logic," paraphrasing Kelly, involves drawing from the characteristics and processes found in the natural environment to design and manufacture things for the built environment.[12] A "*bio*-logical" architecture draws inspiration from nature, not by imitating its forms, but by understanding its behavioral traits – traits which have proven more adaptive, more flexible, and more successful in cultivating life than has our built environment. The AAL aims to demonstrate that a *bio*-logical architecture, an architecture that behaves more like living things, more like us, can better accommodate the dynamic and wide-ranging requirements of life across the built and natural environments.

***Bio*-logical Architecture for the Urban-Rural Interface**

The *Animated Architecture Lab* is an extended project which, in the 2003-4 academic year, devoted itself to designing a colony accommodating the living and working activities of a diverse group of inhabitants, located at the urban-rural interface – that threshold between farmland and new development – in what is presently the fifth most sprawling region in the United States. Located nearly at the center of the rapidly developing Atlanta-Charlotte corridor, the colony itself was envisioned as a living system that might cultivate a larger network of such live-work communities along this axis. The point of departure for our work was therefore the crisis of the region in which we live.

While this research pursuit drew in large part from Kevin Kelly's *Out of Control*, it drew more so from one of Kelly's primary sources: Ethology, the science of characterizing animal behavior.[13] What is compelling about Ethology for architecture is the fact that Ethology had already proven useful to another discipline outside of the natural sciences, that of computer science. Drawing from Ethology, computer scientists and engineers and, much later, computer animators, recognized that the logic of computers could find a parallel in the logic of living things, bringing closer the natural and the technological realms.[14]

We in the AAL did much the same as did the computer scientists, engineers and animators: we investigated the ways in which architecture might draw from the logic of animal behavior towards bringing closer the natural and the technological realms. Each of nine

M.Arch. thesis students under my supervision selected and researched a living thing that would inform the design of a *bio*-logical architecture for the urban-rural interface; and each of the nine students ultimately contributed an architectural design to the network formed by the other eight design proposals combined with the existing urban-rural conditions. Our ambition to create a *bio*-logical live-work colony was not so far-fetched, on two accounts. Firstly, rather than imposing tired and alien formulations like “new urbanism” at this critical juncture of land uses, we embodied in the architecture of the colony certain traits and processes of plants, insects, animals and other natural phenomena that have long proven to be better adapted to this given region than any human intervention. Secondly, natural traits such as healing, evolving, learning, self-governing and replicating were “traits of living things that have [already] been transported to mechanical systems” of one kind or another; so there was little reason to think that the same natural traits could not also be transported to the design of, more specifically, the built environment.[15]

“Slime Mold Architecture”

Perhaps the most compelling work of *bio*-logical architecture to come from this design research project was one that drew inspiration from slime mold [*dictyostelium discoideum*]. We discovered that, in particular, the slime mold’s life-cycle could inform our thinking about the design of live-work units at the urban-rural threshold, particularly if the architecture is designed to accommodate a rising social group that suffers from isolation in suburbia: “young nomads,” defined as single, 20-35 year-olds without allegiances to significant others in work or love, who assemble as “urban tribes” to socialize, work, travel and share accommodations.”[16]

As we were concerned with the life-cycle of a living thing, the architecture informed by it, by necessity, involves the fourth dimension: time. As such, our design research findings can only be explained by tracing the sequence of the life-cycle stages of slime mold, paired with the *bio*-logical architecture that is derived from it **[figure 1]**.

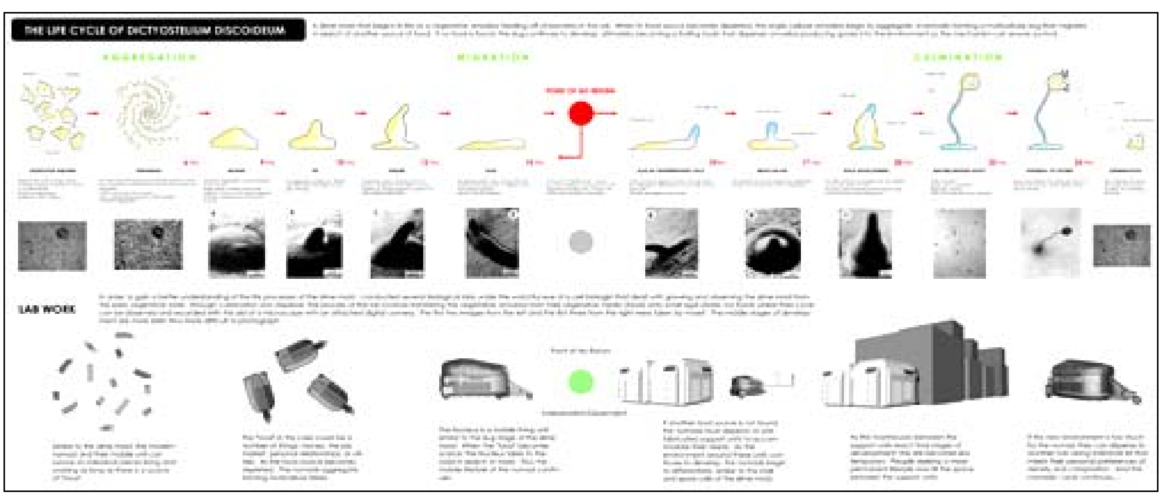

Figure 1: The Life-Cycles of both Slime Mold and “Slime Mold Architecture”

Key to understanding the slime mold's life-cycle is to recognize that it is wholly dependent on the availability of food. If food is plentiful, the slime mold can sustain itself as a single cellular organism; if food is scarce, the slime mold develops into a multi-cellular organism that, being more complex, has the capacity to migrate the distance to new food sources.

The first stage of the slime mold's life-cycle begins, then, with the slime mold as a single cellular vegetative amoeba. The food source for this amoeba is the bacteria found within soil or on dead leaves. A population of single cellular amoebae has a great degree of freedom to find food at close range, as each amoeba can move independently, finding its way to a local food source. The logic of a single cellular slime mold, free to seek nutrients, inspires the architectural design of a mobile, self-contained live-work unit that allows the young nomad the freedom to seek, in many different directions, his or her source of "sustenance," whether this be work or pleasure **[figure 2]**. As an amoeba is, by definition, a microscopic organism capable of changing shape, the mobile unit of the young nomad is comprised of parts, defined by six distinct functions (*work*, *sleep*, *relax*, *hygiene*, *food*, *utility*) that can be rearranged and reconfigured when the unit is not road-bound **[figure 3]**.

Figure 2: The Mobile Unit with "Urban Nomads"

Figure 3: The Mobile Unit with Labeled Parts

The second life-cycle stage of the slime mold is when the food source for the population of individual amoebae depletes, requiring migration to a new and more promising source of sustenance. As single cellular amoebae are unable to migrate to a new food source, they must collect or "aggregate" together to form a multi-cell living structure that, as a more complex, larger organism, does have the capacity for migration. Given the scarcity of food, the population of single cellular amoebae begin signaling and sensing one another by way of chemical secretions. The secretion of "CAMP" signals the population of individual amoeba to begin coordinating their movements, forming a living, communicative network of individuals. The coordinated movement of the single cellular amoebae, called "streaming," takes the form of a spiral. In our design research project, this network of amoebae might very well describe the network of urban nomads, each equipped with a mobile unit. As the promise for work and leisure in a given location wanes, the nomadic individuals, connected by mobile technologies and the interstate highway, mobilize to form a new collective **[figure 4]**.

Figure 4: Aggregation of mobile and base units – a multi-cellular organism

The next three life-cycle stages of the slime mold begins when individual amoeba, having aggregated towards the center of the spiral, adhere to form a multi-cellular organism enveloped by a sheath. The complexity of the aggregated multi-cellular organism – some 100,000 cells, elongated to form a slug [*Pseudoplasmodium*] – enables the slime mold to migrate to an environment that can sustain it. Returning to the architectural proposal, when urban nomads assemble to form a relatively stabilized, more communal living and working condition, the nomads aggregate their individual mobile units around one or more base units scattered along the rapidly developing Interstate-85 corridor between Atlanta and Charlotte – what is effectively the site of this design. The assembly of mobile units and some number of base units comprise a larger, multi-cellular live-work unit for the urban tribe. The pre-fabricated base units are themselves stackable and inter-lockable and provide particularized sockets for attaching the various components of the mobile units. The complexity of this assemblage of mobile units and base units affords the urban tribe expanded possibilities for collaborative living and working.

The most critical stage in the slime mold's life-cycle is the stage in which the multi-cellular organism completes its migration and seeks its bounty. At this critical stage – the "point of no return" stage – the life-cycle either reverts backwards to an earlier developmental stage or "culminates" to a more advanced stage, depending on the quantity of food found at the new location. If food is plentiful there, the multi-cellular slime mold can safely revert to a population of single cellular amoebae; if food is scarce, the multi-cellular slime mold culminates its life-cycle, transforming over several stages into a fruiting body. To secure the future existence of the slime mold, this fruiting body produces spores that are carried afar, germinating new populations of amoebae in numerous new locations, thus multiplying the prospects that the slime mold, somewhere and in some form, will survive.

At this stage in the slime mold's development, it is critical to recognize that moving forward or reverting backward results, in *both* cases, in a beneficial condition that promotes the continued existence of this organism. How different this is to conventional models of property development, where the plan of development involves projecting forward, say, five, ten, and twenty five years without much thought to contingencies. In "slime mold architecture," instead, the contingencies are planned for so that the expansion or contraction of the property development is more responsive to local, temporal conditions of the market place, the desirability of the location, and other cultural, environmental and climatic factors. If the outlook for the property turns for the worse, the slime mold architecture (base units and mobile units together) anchors the development much as did their ancestors, mobile homes, but with greatly expanded social and economic opportunities, and replete with sophisticated technologies compared with the elder model of mobile housing. If the outlook for the property turns for the better, the slime mold architecture becomes part of the developing system of relatively intensive commercial and residential development. As development intensifies, maturing members of the urban tribe have the option, like anyone else, to buy into it, purchasing more conventional homes and developing more fixed commercial bases while still maintaining a relative level of mobility offered by ownership of their mobile units **[figure 5]**.

Figure 5: Transition to a more intensively developed live-work colony.

Whatever the outlook, the land owner benefits from having the highest and best use of the site at that moment in the social and economic cycle; and the urban nomads and their tribes meanwhile maximize their potential to develop a highly responsive and adaptive network of social and economic relations along the rapidly developing Interstate corridor.

Evaluating the Work

Arguably, architects for much of human history have been developing theories of living as much as spaces for living in. To borrow the reasoning of Steven Levy, then, if architects today "are going to develop a broad theory of life," than we need to begin accepting "radically non-organic things as being alive."[17] One way of evaluating a *bio*-logical architecture inspired by "slime mold" is therefore to judge whether or not it manifests something of Fritjof Capra's three criteria of a "living system": "organization, structure and process."[18] While "organization" and "structure" are two criteria of living things shared by both the slime mold architecture and the conventional house, "process" is unique to slime mold architecture. As an "organization" the slime mold architecture, like most any house, is a configuration of functional relationships defined by the everyday needs of its inhabitants. These needs are then embodied or "structured" in the slime mold architecture as six constituent parts (not unlike the rooms of a house), with each part (or room) dedicated to particular life rituals of the inhabitant. As a "process," however, the slime mold architecture is more like a living cell than a conventional house. Unlike the conventional house, the slime mold architecture is designed explicitly to facilitate an inter-change of its six components: a new component dedicated to work, for instance, can replace an existing one and form new relationships with the other components within the design, affording new possibilities for living and working.

But while the slime mold architecture successfully embodies something of the three criteria of a living system, it clearly falls short on exhibiting one essential characteristic of living things: their capacity to manufacture their own components as replacements. But even this capacity may soon be attainable in architecture; already, components that are self-cleaning and self-healing are being developed and coming to market.

Other shortcomings of the slime mold project, shortcomings that may easily be overcome with more dedicated work, include its yet demonstrated ability to operate as a recycling center, a powerhouse, an energy carrier, a solar station, and a storage and disposal center – all characteristics of the living cell.[19] A "*bio*-logical" work of architecture is, however, not a living thing but, at best, a strange hybrid of nature and artifice – a promising, yet limiting condition that will be evaluated in broader terms at the close of this paper.

The Design and Communication of a "Poly-attentive" Architecture

> Architecture encompasses everything.[20]
> - Gio Ponti, *Amate l'architecturra*

The work of the AAL emerges not only as plans (2-D) or envelopes (3-D) but, more significantly, as inseparable webs of physical and social relationships operating within time (4-D) and across scales (from the scale of the human hand to the scale of the metropolis). The design and communication of this architecture, located at that critical, dynamic juncture of what is urban and rural, requires an expanded range of "norms and means" than do more conventional environmental design practices. As Robert Kaltenbrunner explains in "Urbanistic Strategies Today," an article appearing in *Daidalos*:

> Graphic plans and plotted layouts no longer necessarily represent the norm and means of communication for contemporary urbanism. Standardized conceptions are increasingly being replaced by dynamic value orientations that

> determine the course of action in the moments of decision – situations that are usually not predictable.[21]

In designing a four-dimensional architecture at the urban-rural interface, the attention of the architect must encompass a spectrum of related and unrelated phenomena. This capacity to attend to a spectrum of phenomena was defined by John Cage as “poly-attentiveness” and by computer scientists as “parallel architecture.”[22]

To facilitate the “poly-attentiveness” of all participants in the AAL, we employed four categories of design documents above and beyond conventional 2-D and 3-D modes of representation. These four categories are: the diagram, the prototype, the “poly-attentive drawing,” and the “design matrix.”

The diagram and the prototype are familiar enough to architects to make obvious their suitability to this investigation. The appeal of the diagram for our design research is its capacity to represent “the complex dynamics and information of the conditions that confront us, of evaluating and elucidating them.”[23] The diagrams of AAL participants represented such polyvalent, dynamic and temporal conditions of the built and natural environment as land-use, housing typology, land values, transportation and demographics.

The appeal of the prototype, meanwhile, is its capacity to demonstrate the functionality of key architectural elements of our *bio*-logical proposals on both a mechanical and aesthetical level. Our prototypes, at no less than half-scale, took inspiration in part from the research accomplished at MIT’s Media Lab – the credo there being “demo or perish.”[24] Two of the more compelling AAL prototypes were: *the hyphawall* **[figure 6]**, a building envelope drawing inspiration from lichen that actively controls the movement of moisture in and out of the building it envelopes; and *the scrambler*, a partition inspired be the wing of a butterfly that moves and displays digital images. In developing prototypes, it is important to recognize that the AAL group is consciously “not making a product but an idea.”[25]

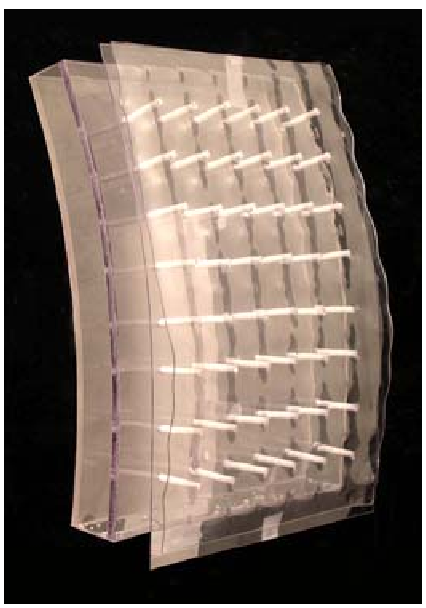

Figure 6: *Hyphawall* building envelope

The third category of design documents, what I call “poly-attentive drawing,” was useful in communicating complex aspects of each design proposal. Inspired partly by the drawings of Italian Futurists Boccioni and Severini, the “poly-attentive drawing” is comprised of words and 2-D and 3-D images over multiple time frames assembled on a single sheet of paper **[figure 7]**.

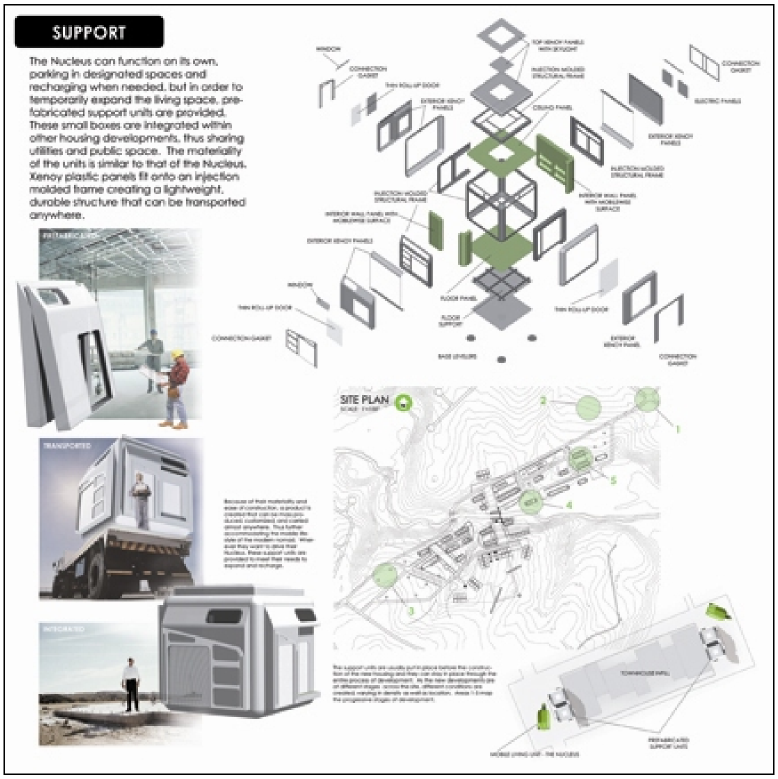

Figure 7: A “Poly-attentive drawing” of the base unit

Of the four categories of design documents employed in developing our research, what I call the “design matrix” proved most productive as a generator of architectural design. In the design matrix, characteristics and traits of the slime mold, the lichen and other natural phenomenon selected for study were demonstrated to have a corollary in environmental design at the scales of the architectural component, the building and its immediate surroundings, the live-work colony, and the metropolis. A design matrix for lichen **[figure 8]**, for example, shows that hypha, serving at once as the structure and infrastructure of lichen, appear in the architectural proposal as a network of tubes at various scales that serve the same purposes within the architectural work as they do in the work of nature. As the design matrix was that critical threshold between the logic of biology and the logic of architecture, the degree of thoroughness and thoughtfulness of each student’s design matrix was most indicative of the success of the resultant architecture.

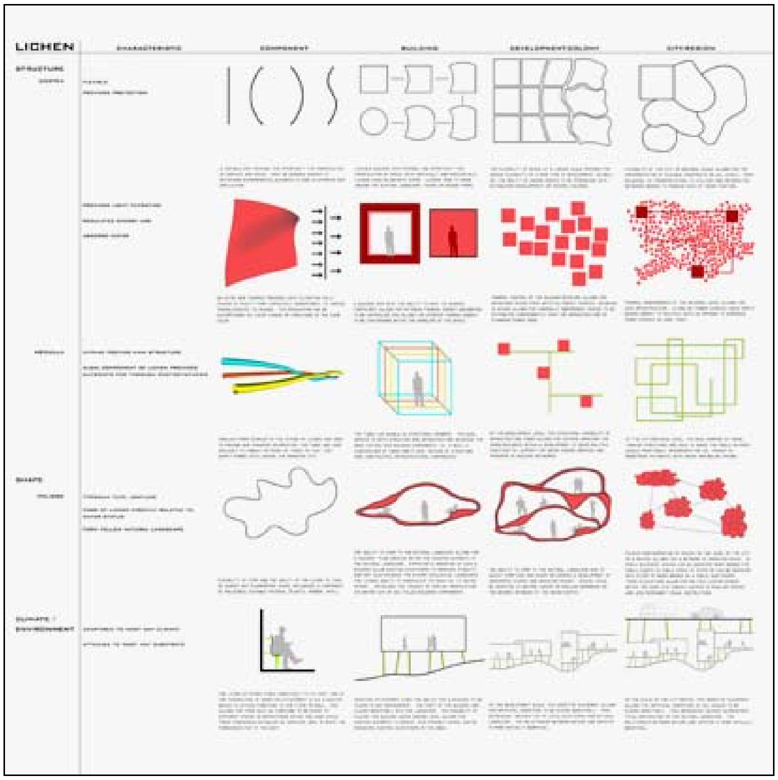

Figure 8: A "design matrix" for the lichen project

The Promise and Future of a *Bio*-logical Architecture within the Built and Natural Environments

The promise of a *bio*-logical architecture is not to equate, categorically, simple organisms like the slime mold with people and the built environment. Organisms, human societies and built environments may share certain traits but behave in different ways and by different means.[26] Instead, the promise of a *bio*-logical architecture is its "complex interweaving of living and nonliving systems."[27] Compared with more conventional models of architectural production, particularly those found at the urban-rural interface, a *bio*-logical architecture – that strange hybrid of natural and artificial behaviors, elements, and processes – has the potential to foster a more intimate, responsive, and mutually-beneficial relationship between itself and the "biophilic" people, things and its environmental surroundings.[28] The design research considered here is perhaps best viewed as one attempt to realize an "ecological design" in the way David Orr defines it in *Ecological Literacy* and *The Nature of Design*: "ecological design" as "the careful meshing of human purposes with the larger patterns and flows of the natural world and the study of those patterns and flows to inform human actions."[29]

In the not-too-distant future, writes Kevin Kelly, biology will be "the central organizing feature in our society" and architecture will be defined by "mutating buildings" and "rooms stuffed with co-evolutionary furniture,"[30] For the moment, the *Animated Architecture Lab*, a working collaborative of students and faculty from Architecture, Biology, Engineering, Computer Science and the Social Sciences, is examining the emerging physical and social configurations and patterns of our region and testing them by means of detailed design proposals for projected clients inspired by nature and following from demographic data and projections. The logic of biology is informing the way we design the environment towards sustaining and even cultivating the communicative networking, adaptation, growth and diversification of individuals, cultures, nature and technology.

Acknowledgements

Billy Zion and Shane Knight are the M.Arch. thesis students who developed, respectively, the "slime mold" and "lichen" design research projects considered here. Special thanks, in particular, to Dr. Lesly Temesvari, Professor of Biology, Clemson University, for generously participating in the "slime mold" project.

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[1] Hugh Aldersey-Williams, "Towards Biomimetic Architecture," *Nature Materials*, vol. 3 (May 2004): 278-279.

[2] We can trace this tendency back to the French Enlightenment to the writings of Viollet-le-Duc, extending, at the turn of the twentieth century, to European Art Nouveau, to works by the Catalan Gaudí, and in America, to the architecture of Louis Sullivan, Frank Furness, and particularly to the elder Frank Lloyd Wright and his heir, Bruce Goff.

[3] Hugh Aldersey-Williams, "Towards Biomimetic Architecture," p. 279.

[4] Kevin Kelly, *Out of Control: The New Biology of Machines, Social Systems, and the Economic World* (Cambridge: Perseus Books, 1994), pp. 167, 472.

[5] Ibid., p. 3.

[6] Ibid.

[7] Ibid., p. 471.

[8] See Richard Rogers, *Cities for a Small Planet* (Boulder, Colorado: Westview Press, 1997), pp. 66, 146.

[9] Mark Wigley, "Recycling Recycling" in *ECO-TEC: Architecture of the In-Between* (New York: Princeton Architectural Press, 1999) 40.

[10] Joseph Rykwert, "Organic and mechanical," *Res* 22 (Autumn 1992): 13 and 17.

[11] Ibid., p. 18.

[12] Kelly, *Out of Control*, 2. What Kelly refers to as "*bio*-logic" has been popularly defined "biomimetic" by Janine M. Benyus in *Biomimicry: Innovation Inspired by Nature* (New York: HarperCollins, 1997).

[13] Ethology was established in the 1940s with its three famous founders, Konrad Lorenz, Karl von Freisch and Niko Tinbergen, who began describing the logic of animal behavior, creating a body of work that earned them, in 1973, the Nobel Prize for pioneering scientific achievements.

[14] On Ethology as a source for Computer Scientists, see Kelly, *Out of Control*, pp. 323-324.

[15] Ibid. Indeed, biomimetic innovations such as self-cleaning glass, "smart" houses and "intelligent" networks were already a part of the architect's vocabulary at the time we were undertaking this design research project.

[16] Ethan Watters, *Urban Tribes: A Generation Redefines Friendship, Family and Commitment* (New York: Bloomsburry, 2003). "Friends," the popular television show, is a characterization of this social phenomenon.

[17] Steven Levy, *Artificial Life* (New York: Vintage, 1993), p. 9

[18] Fritjof Capra, *The Web of Life: A New Scientific Understanding of Living Systems* (New York: Anchor, 1996), pp. 157-168.

[19] Ibid., pp. 164-165.

[20] Gio Ponti, *In Praise of Architecture*, trans. G. and M. Salvadori (NY: F.W. Dodge, 1960), p. 10.

[21] Robert Kaltenbrunner, "East of Planning: Urbanistic Strategies Today," *Daidalos* 72 (1999): 8.

[22] For more about the "poly-attentiveness" of John Cage and his long-time collaborator, Merce Cunningham, see Roger Copeland, *Merce Cunningham: The Modernizing of Modern Dance* (New York: Routledge, 2004), pp. 180, 238 and 285.

[23] Gerrit Confurious, "Editorial," *Daidalos* 74, "Diagrammania" (2000): 5

[24] For more on the significance of the demonstration, see Stewart Brand, *The Media Lab: Inventing the Future at MIT* (New York: Viking, 1987), pp. 4, 40-51.

[25] Brand, *The Media Lab*, p. 50.

[26] There are two key differences between organisms and human societies: organisms communicate by chemicals and restrict the creativity of its components; human societies communicate by language and largely amplify the creativity of its components. See Fritjof Capra, *The Web of Life*, pp. 210-221.

[27] Ibid., p. 215.

[28] See Edward O. Wilson, *Biophelia* (Cambridge: Harvard University Press, 1984).

[29] David Orr, *The Nature of Design: Ecology, Culture, and Human Intervention* (Oxford: Oxford University Press, 2002), p. 20.

[30] Kelly, *Out of Control*, p. 298.