The dualities of “humanity and nature,” “organic and inorganic,” and “artificial and synthetic” are themes that have permeated architectural discourse since the beginning of the 20th century. The interplay between nature and machine can be directly related to the 19th-century discussion of nature and industrialism that was exemplified in the works of Louis Sullivan and Frank Lloyd Wright that spawned the organic architect movement. Echoes of these dichotomous themes have been resuscitated with the introduction of computational and information processing as a fundamental part of contemporary theory and critical praxis. The ability to go beyond simplistic dualities is promised by the introduction of data-informed multivariable processes that allow for complex parametric processes that introduce a range of criteria within evaluative design frameworks. The investigations detailed herein focus on surface morphology development that are explored and evaluated for their capacity to reincorporate ideas from genetic and developmental biology into an architectural discourse that has historically been dominated by the mechanistic metaphor perpetuated throughout the modern era. Biological analogs in nature suggest that the zone of decoration plays an important role in the environmental response and climate adaptability of architecture. The building envelope represents the greatest potential energetic gain or loss, as much as 50 percent; therefore, the architectural envelope plays the most significant role in the building’s energy performance. Indeed, from an environmental performance standpoint, the formal response of the envelope should tend toward complexity, as biology suggests, rather than the reduced modernist aesthetic. Information architecture coupled with environment and contextual data has the potential to return the focus of design to the rhizome, as the functional expressions of climatic performance and thermal comfort interplay within other cultural, social, and economic frameworks informing the architectural artifact. Increasing the resolution that ornament requires in terms of geometric surface articulation has a reciprocal effect on the topological relationship between surface and space; the architectural envelope can respond through geometry on the surface scale in order to more responsively interface with the natural environment. This paper responds to increasing computational opportunities in architectural design and manufacturing, first by exploring the historical trajectory of discourse on nature vs. machine in architecture, then by exploring the implications for utilizing environmental data to increase the energy performance of architecture at the building periphery, where building meets environment and creates the synthetic built ecology.

ABSTRACT

The dualities of “humanity and nature,” “organic and inorganic,” and “artificial and synthetic” are themes that have permeated architectural discourse since the beginning of the 20th century. The interplay between nature and machine can be directly related to the 19th-century discussion of nature and industrialism that was exemplified in the works of Louis Sullivan and Frank Lloyd Wright that spawned the organic architect movement. Echoes of these dichotomous themes have been resuscitated with the introduction of computational and information processing as a fundamental part of contemporary theory and critical praxis. The ability to go beyond simplistic dualities is promised by the introduction of data-informed multivariable processes that allow for complex parametric processes that introduce a range of criteria within evaluative design frameworks. The investigations detailed herein focus on surface morphology development that are explored and evaluated for their capacity to reincorporate ideas from genetic and developmental biology into an architectural discourse that has historically been dominated by the mechanistic metaphor perpetuated throughout the modern era. Biological analogs in nature suggest that the zone of decoration plays an important role in the environmental response and climate adaptability of architecture. The building envelope represents the greatest potential energetic gain or loss, as much as 50 percent; therefore, the architectural envelope plays the most significant role in the building’s energy performance. Indeed, from an environmental performance standpoint, the formal response of the envelope should tend toward complexity, as biology suggests, rather than the reduced modernist aesthetic. Information architecture coupled with environment and contextual data has the potential to return the focus of design to the rhizome, as the functional expressions of climatic performance and thermal comfort interplay within other cultural, social, and economic frameworks informing the architectural artifact. Increasing the resolution that ornament requires in terms of geometric surface articulation has a reciprocal effect on the topological relationship between surface and space; the architectural envelope can respond through geometry on the surface scale in order to more responsively interface with the natural environment. This paper responds to increasing computational opportunities in architectural design and manufacturing, first by exploring the historical trajectory of discourse on nature vs. machine in architecture, then by exploring the implications for utilizing environmental data to increase the energy performance of architecture at the building periphery, where building meets environment and creates the synthetic built ecology.

RE-FRAMING ARCHITECTURE FOR EMERGING ECOLOGICAL AND COMPUTATIONAL DESIGN TRENDS FOR THE BUILT ECOSYSTEM

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1 BACKGROUND: TRADITIONAL MODELS OF NATURE VS. MACHINE IN ARCHITECTURE

Decorative surface ornament has been largely abandoned in architectural discourse since the emergence of the international style and modernist movement in architecture, urging forward a largely mechanical paradigm for systems design. However, the strongest critique of the mechanical paradigm in architecture is its disregard for the environmental context. The emergence of the centralized mechanical system as the “one size fits all” answer to environmental control has largely removed the focus of design performance from the facade, along with ornamentation. The “organic” architects, inspired by the observations of the evolutionary biologists and naturalists of the late 19th and early 20th century, such as Ernst Haeckel and D’Arcy Wentworth Thompson (1942), sought to inform architecture with the morphological development and functional complexity of natural form. This was an early attempt of architects, following the lineage of Frank Furness, Louis Sullivan, and Frank Lloyd Wright, to recognize the symbolic importance of “natural” form to human inhabitation and embed the intelligence of nature into architectural constructions. Recently, threads of Louis Sullivan’s original principles have reemerged in contemporary trends of biological form and biophilic design. These ideas have found new outlets in digital design as the computer science theory of genetic algorithms and artificial life enter the discourse on architectural form generation. Similarly, a case can be made that the interplay between metaphors of the machine and nature continue to control the direction of architectural discourse and design today.

In contrast to the biological model, modernist metaphors of the machine sought to capture the motion of modern life through choreography. Flexible and fluid spaces were designed for efficiency, adaptability, and progression through space. The Villa Savoye (Le Corbusier) expresses this metaphor of mechanized movement, integrating all the motions of modern life from the turn radius of the owner’s automobile through the entry to the choreographed progression through the house. More adapted forms for modern life, such as Mies van der Rohe’s public and commercial buildings, exemplified the use of the free plan to allow adaptability and the rearrangement of interior spaces. This versatility of modern architecture for multiple functions continues as a common element in all areas of contemporary design. The modernization of manufacturing that followed the industrial revolution promoted the machine not only as metaphor for efficiency of design, but also as universal solution for architectural building systems, while the assembly line and mechanical production became the criteria of component design. The problem with mass production was, of course, the inability for localized adaptation to the constant flux of the local bioclimate. Climates with dramatically different environmental conditions (Figure 1) were suddenly treated uniformly, with a universal internal solution to external variability. As a result, architects were left with either highly insulated layers or grossly inadequate building systems and thus were evermore dependent on energy usage to address human comfort.

2 ORGANIC CONCEPTS OF MACHINE PRODUCTION

While it is no longer economically prohibitive to produce variable components through computer numerically controlled (CNC) production, the repetition of components on the building scale persists as the model of design efficiency. The famous mantra form follows function, often attributed to Louis Sullivan, has long been held up as an affirmation of the mechanical metaphor in design. (Turnbull refers to this as a technocratic determinism (Turnbull 2003)) However, this is largely a misrepresentation of Sullivan, whose career was dedicated to the design of highly distinctive architectural elements. Form follows function production would be a more accurate representation of the modern understanding of form follows function, which depends more closely on the efficient fabrication and assembly of architectural components than on their function as integral parts of the built environment. Though Sullivan played a seminal role in the design of the skyscraper and the modern urban skyline, his concern was the dynamic interplay of opposites (which he called parallelism) between the organic and inorganic played out in the morphological development and figuration of surface through the iterative delineation of architectural details with organic form (Figure 2) (Sullivan 1926). At the turn of the 20th century, design was grounded in its relationship to the human body, in terms of scale as well as its relationship to nature through classical canons of form and interscalar relationships. The invention of the skyscraper and the production line effectively replaced the human aspect of function with the model of the machine. Built form and mechanical production on a massive scale were no longer easily understood in relation to the human body, and suddenly the building became the object of design, a thing in and of itself. As computational design tools provide the impetus for greater flexibility in the production line, designers are once again returning to biological metaphors for design and the original intent of Sullivan’s mantra.

3 BREAKING WITH TRADITION: COMPUTATIONAL DESIGN

Computational design provides an enabling opportunity to cast off entrenched cultural practices and preconceptions of the 20th century that continue to pervade notions of utility, function, and beauty in architecture. By returning to primordial metaphors for form generation and modeling design constraints according to emerging technologies in design, materials, and fabrication, “computational” designers have sought to deconstruct contemporary design from what must now be considered anachronistic architectural genres. Historically, when the existing canons of design are discarded, the impetus for greater flexibility in the production line, designers are once again returning to biological metaphors for design and the original intent of Sullivan’s mantra.
relies on fundamental exigency for reinvention, often returning to the natural world to provide the model for novel and innovative design. Traditionally, architecture privileges metaphorical models through which design decisions can be aligned with nature, the machine, the human body, divine order—these metaphors have always driven architectural design as far back as we care to look.

However, recent innovations in computational tools for design and renewed focus on local and environmental context have begun to break these traditional models, necessitating cross-pollination and multidisciplinary design strategies. Natural and biological models provide a wealth of organizational, morphological, and performance information sets as precedents for designers to escape long-held architectural genres and dualities still prevalent in contemporary practice. Fundamental exigence in architecture develops from multiple paired frames through which organizational principles and solutions can be derived: natural-ecological, material-artificial, performance-energetic, cultural-artificial/critical, digital-synthetic. The computational design environment easily facilitates parametrically linking design criteria from multiple disciplines (Figure 4). We can argue that traditional models for design, which privilege singular metaphors that dictate decision making, fail in the computational environment, suggesting rethinking design decisions through multiple frames that are linked parametrically.

4 ANIHERARCHICAL AND OPERATIONAL CONCIOUSNESS OF COMPUTATIONAL DESIGN

The versatility of computation allows multiple design strategies to be developed concurrently through multiple frames. Design criteria can be plugged into the design process as necessary, allowing individual systems to reprocess solutions according to new information added to the sequence. As a result, the design process is allowed to develop organically while maintaining enough flexibility for specialized fine-tuning. Design solutions are then derived iteratively, such that solutions can be generated with data missing from the sequence. Iteration fills in the missing data empirically through repetition (Figure 4). The computational approach to architectural design through iteration begins building solutions more similar to genetic mutation than analytic design. In mutation, missing genetic material is temporarily replaced until a successful solution is produced in subsequent generations (Bateson 1894).

It could be argued that since organic design solutions would be generated via computational processes with enough input streams to provide for the negotiation of competing constraints and thus evolving “nature state” solutions. As in genetic mutation, missing data is merely replaced temporarily. In architectural design, temporal sequencing is necessary to the assignment of hierarchy in design criteria. Without traditional temporal constraints on design, successful solutions must be derived without hierarchy. Instead, criteria must be valued in relation to any number of opposing criteria considered, rather than in its stage in the design process (Figure 4).

5 FIVE PAIRED FRAMES OF DESIGN FOCUS

Natural-ecological frames of design focus on environmental forces and contextual influences on the built environment. Architecture exists as a system in a constant state of decay that must be externally supplied with new materials and resources to retard degradation. Alternatively, nature has always been an unattainable ideal for architecture, a system in constant renewal using available resources from the environment for growth and repair. This need for architecture to reprocess with the natural environment has received renewed interest in modern discourse, with increasing demand on energy, resources, and raw materials from the developing world. Biomimicry and biophilia represent the most recent trends in design thinking, renewing interest in biological models for design. Biomimicry looks to nature for high-performing and innovative design solutions, with the assumption that natural selection ensures the most effective fit for economical solutions (Benyus 1998). Biophilia suggests that the inherent biological and psychological links between man and nature develop through evolution in natural environments over millennia and affect human health, well-being, and happiness. By studying these inherent links to nature, biophilia looks to promote healthier built environments (Keller, Heerwagen, and Mador 2008).

Material-artificial frames represent a renewed interest in materials and material properties. The physical nature and natural quality that determine the phenomenological nature of architecture dictate design through the expression of intrinsic material properties. As Louis Kahn’s metaphor of the “skin” demonstrates, materials have agency in architectural design through the inherent strengths and limitations of matter, the ability to resist force. Material motivations are often transparent against ornamentation, whereas the virtue of form arises from material attributes thus being privileged over ornamental form from historical or cultural origins. This juxtaposition is exemplified in arguments for craft in architectural design, especially in the anti-ornamentalist writings of Adolf Loos (Loos 1998). Industrial metaphors of the machine served a similar purpose to usurp the primary of nature and biology in form generation a century earlier. Ultimately, material-artificial frames were combined with performance-energetic notions of function based on efficiencies of technology and manufacturing to produce the mechanistic model championed by the modernist movement. Through the combinatory mechanistic model, practical material-artificial design was presented as a superior to messy and unruly design based on analogical interpretations of biota. Mechanical metaphors for design offered freedom from the confusion and clutter of baroque and neoclassical ornamental design and the interpretive subjectivism that accompanied this worldview.

Performance-energetic frames represent systems in motion that are defined by activity and the transformation of energy. Since the Industrial Revolution, energy has primarily been thought of in terms of power; however, greater understanding of energy in nature has led to a more holistic understanding of economies of energy. Performance-based design has become a significant force in architectural thought since the late 1970s, when energy usage became an important focus within the discipline. Systems-based design often focuses heavily on the performance and energy consumption of mechanical systems; however, emerging trends looking at economies of energy and relationships between the environment and architecture seek to limit overall consumption of energy and natural resources through more effective and adaptable building systems. Performance-energetic design focuses on the integration of building systems and envelope to optimize performance in a dynamic environment.

Cultural-artificial/critical frames for design focus on the user experience of the built environment. Architectural scales and proportions are developed based on the anatomical and sensual relationships to the human body. It is given that human proportions are insuperable in architecture; in the absence of other measures, human proportions and, by extension, ergonomics become the obvious driver for determining architectural constraints. In classical and traditional architecture, human and social factors heavily influence architecture and ornamentation as the major impetus.
for design innovation. Architectural theorists, such as Gottfried Semper, sought to trace the origins of ornament along the lines of human civilization. In this sense, architectural ornamentation was closely related to decoration and adornment in primitive cultures (Semper 1989). The cultural-anthropocentric frame for design recognizes the importance of symbolism in architecture and seeks to control human relationships with design by manipulating culturally significant symbolism. The modernist movement exemplified design strategy that is preoccupied with the social effects of design and architectural symbolism. Similarly, the early modern movement relied heavily on symbolic transformation via physical progression through space. Farshid Moussavi discusses ornamentation as the means through which architecture relates to culture: thus an architect will seek to achieve a distinct architectural “effect,” which instills a sense of identity in the user or the viewer and suggests the intangible cultural, social, historical, environmental, or urban contextual relationships of architecture (Moussavi and Kubo 2006). The implied agency of architecture to influence an assumed audience pervades contemporary design strategy.

Digital-synthetic frames for design can be best described as organizational logics or systems derived from other frames through their interaction or synthesis. The digital-synthetic frame represents the reduction of organized systems to principles for design or quantitative relationships that can be used for innovation rather than mimesis. Genetic algorithms, parametric software, computational fluid dynamics simulation, and so forth, all exhibit traits as synthetic systems. Genetic algorithms represent organic randomization and organizational logics developed from the study of natural variation and complexity that could be adopted to the design, expression, and most importantly, performance of inorganic systems (Figure 5). Parametric software naturally enables the linking of separate and competing data sets to produce synthetic solutions. Computational fluid dynamics software simulates natural phenomena and material interactions to resolve design problems. Emerging design techniques for integrating multiple data sets through a single parametric workflow demand a wider array of competing data sets and framing to generate successful design solutions. This encourages interdisciplinary collaboration within the design process, allowing design criteria to be pulled from multiple sources.

6 DISCUSSION

Unlike holdovers from previous generations of rule-based design systems, new computational understandings of algorithms recognize that derived systems and organizational logics are in fact synthetic and do not directly translate to successful architecture. Like Mary Shelley’s Frankenstein’s monster or the replicants from Blade Runner, derivative systems exhibit not only the traits of the original model, but also new characteristics acquired through synthesis (Sennet 2008). Replication as synthesis gives substance to means and methods through experimental techne and the iterative process, unlike mimesis, which imitates or merely represents the original. Synthetic systems have the potential to benefit design; however, they must be introduced into the architectural context as derivative systems rather than representational systems that are inherently valuable through the virtues of the original. Movements such as the shape grammars or early examples of digital architecture that replicated organizational logics of natural systems, such as Lindenmayer systems for biological form generation, lacked the necessary retooling for the built environment and context to be valuable as architectural innovations. As in Koning and Eizenberg’s (1991) parametric shape
grammer study of Frank Lloyd Wright’s prairie houses, the derivative system was represented as implicit in the design of the original, when instead what was produced was a synthetic system controlled by programmatic relationships. In the context of design frames, this would be akin to limiting form generation to the digital-synthetic frame, whereas the original system would have been strongly influenced by the contextual relationships of natural-ecological framing. L-system-based structures and biological form generation exhibit a similar contextual problem resulting from dramatically shifting scales and ignoring the natural and environmental forces that influence the development of plants and organisms.

Traditions of conflicting metaphors of nature vs. the mechanical metaphors in modern design were explained in order to provide context for the current influence of natural models in digital architecture and emerging trends toward synthetic models of computation. Traditional singular models for design have proven insufficient against integrative approaches to design. The capacity for parametric linking through computation in architecture was explored, suggesting methods for framing design decisions that allow for computing and iterating criteria for design to be developed. Therefore, a system based on framing design rather than singular metaphorical models may respond to computational considerations for design. Computational design seeks innovation through synthesis of multiple streams of information from varied sources. The resulting solutions are as comprehensive as the algorithms or parametric models that calculate them. It is in this way that architecture inherently looks to external and internal sources for organizational logics and models for design. These frames for exigency in architecture provide sources for innovation and reinvention in architecture. The natural-ecological, material-artificial, performance-energetic, cultural-anthropocentric, and digital-synthetic design frames represent competing criteria for design that are readily integrated in comprehensive and multidisciplinary design [Figure 1]. The notion of computation to promote design solution through iteration is a compelling one: it is a model of evolutionary fitness that may return the focus of architecture where it belongs, as a manifestation of energetic flows whose purpose is to give us shelter; in the modern ecological crisis that may mean shelter from our own devices, while the focus of architecture where it belongs, as a manifestation of energetic flows whose purpose is to give us shelter; in the modern ecological crisis that may mean shelter from our own devices, while the focus of architecture where it belongs, as a manifestation of energetic flows whose purpose is to give us shelter; in the modern ecological crisis that may mean shelter from our own devices, while the focus of architecture where it belongs, as a manifestation of energetic flows whose purpose is to give us shelter; in the modern ecological crisis that may mean shelter from our own devices, while the focus of architecture where it belongs, as a manifestation of energetic flows whose purpose is to

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