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THROUGH THE FORMATION OF BIO-CHEMICAL INFORMATION NETWORKS NATURAL MATERIALS POSSESS EFFICIENT PROCESSES OF SELF-ORGANIZATION, ADAPTABILITY, REGENERATION AND DECOMPOSITION. This performative excellence has lead science to draw behavioral models from nature implementing biomimicry (Benyus 1998) in the pursuit of material systems optimization. Design disciplines influenced by this course are integrating living organisms as models of efficiency through bionic systems ever more into their discourse. Architecture, influenced by this tendency, is becoming progressively more aware of the vast benefits that biomimetics can yield particularly in the development of ecologically sensitive systems. Yet, the emerging incorporation of bionics into architecture is differing largely to that within the sciences by centering almost exclusively in form (geometrical pattern) generation. This paper analyzes a rising material design research methodology implementing biomimetics: matter-form parametrics based on bio-physical properties’ data. Specific study of the incorporation of broad-scalar scientific imaging into the formulation of explorative parametric grammar for the development of material systems is analyzed through a bio-synthetic polymer based wall system (SugarWall, Gensler+Gutierrez 2006b). The incorporation of broad scalar imaging and material interdependencies is propelling the emergence of new programming tactics that will affect bio-material systems architectural research.
1 Introduction

Seeing the invisible has been an object of fascination throughout history. From the optical discoveries of Grosseteste (Crombie 1953) that prompted during the medieval period the concept of acceleration to broad-scale computer simulations that enabled visualizing small scale convection patterns (Supplee 1999, 169), we have accounted continuously how the aspiration to see the "unseen" has been a catalyst for innumerous scientific innovations. Yet, it was not until the advent of Quantum Mechanics which unfolded unexpected opportunities of how we can visualize and manipulate the world that to register the unseen became substantially more feasible. Amongst the unlimited innovations originated by this scientific revolution was the viability to register and decode natural phenomena invisible to the naked eye. These new visibilities created specific opportunities to observe and control matter by design. This process enabled science to optimize material performance by the ability to meticulously manipulate atomic bonds and crystal structures. In the expanding pursuit of material optimization science turned to natural materials as inspiration for the design of efficient systems addressing biomimicry.

Biomimetic practice has advanced mostly through our capacity to gradually understand the myriad intricacies of nature. This comprehension is to a large extent the result of imaging technologies innovation which expanded our visualization capabilities. Humans see light through measurable properties of intensity and color. Intensity gives an indication of the number of light “waves” (Singh 2004, 230) or “particles” (called photons) coming from an object, whilst color is a measure of the energy contained in each photon. The latter energy range forms the visible spectrum from red (low energy photons) to violet (high energy photons) (Callister 2003, 709). Although waves span from a vast field of Gamma rays \(10^{-8}\) to long radio waves \(10^{16}\) our visible spectrum only occupies approximately 1/20 of it (Figures 1-2).

Consequently, until the continuous technological advances initiated in the nineteenth century via X-ray imaging, we had never crossed into visualizing phenomena alternatively into what has become known as visible powers of ten (Eames 1977). Infringing scalar and visual boundaries of the non-optical wavelengths became possible specifically in the latter decade due precisely to radical imaging advancements enabled by new imaging technologies and exponential computational development. We have become continually allured by the power of digital imaging as a means to see space at multiple scales in a zoom in and zoom out fashion. The incremental capacity to process and see complex data has evolved tandem to disciplinary specialization. Yet, it is precisely the advancement of information processing and imaging that creates significant opportunities of disciplinary dataset cross-pollination.

The exploration of visualizing and editing simultaneously multiple data at broad scalar wavelengths engenders informational matrices previously considered chimerical. It is precisely in this potential that the momentum to effectively address bionic material systems efficiency within architectural design exists. As designers we confront primary interrogations on this subject: How can architecture specifically implement parametric analysis to address matter-form interdependencies across multiple scales? What are the direct implications that biomimetic design research can yield for innovating design fabrication methods? How can the integration of bionics performative criteria modify existing dematerialization strategies?

2 Scalar Visualization

To unfold the former questions requires addressing directly emerging design programming ethos. Designers are increasingly developing customized scripting formulations both as theoretical and morphological constructs. Advances in digital fabrication can be counted as one of the main factors to influence this resurfacing of programming culture in archi-
tecture after its decline during the 90’s (Picon 2004, 114). This proclivity to design parametrically through customized inputs deploying few variables is directly tied to the experimentation with digital machining processes. Another crucial factor to the resurfacing of programming in architectural culture is the progressive inspiration from natural systems to articulate generative algorithmic patterns. Linguistic conformations of growth and emergence are being sought incessantly to decipher and code bio-performance consolidated into biomorphic structures. Both courses of parametric experimentation: genetic algorithms and biomorphic digital fabrication emerge as answers to design problems in the form of dimensionally driven representation. This representational process offers the benefit of yielding detailed geometrical instances with the deployment of few inputs. But
parameterization addressing material performance as a priori versus a posteriori remains largely unexplored principally due to the intrinsic complexity required decoding the associative dependencies between matter and form across scales.

To develop functional material systems, particularly deploying biomimetic strategies becomes inevitably a transdisciplinary endeavor as it involves epistemologies within and beyond disciplinary boundaries (Figure 3). The necessary dexterity to deploy creative and robust networks between disciplines is arduous and complex. This intricacy is caused partially by the conceptual and representational grammar formulated specifically to each field. The representational language of informational synthesis is thus critical to prosper in the process of developing functional biomimetic materials. This pursuit becomes particularly intricate when scientific data is to be cross-pollinated with architectural content which is represented both through precise measurements and margins of indeterminacy. While architecture design crosses multiple scales its visualization methods traditionally acknowledge the unseen through latent and rather abstract measurements. This registration of the invisible differs largely from the applied by science specially when exercised to decode natural phenomena. As designers that aim at implementing biomimetic practice to develop material efficiency we must address the opportunities presented by this representational dissociation. The transdisciplinarity of functional material systems development implementing biomimicry will conceivably transform current visualization design culture requiring it to transverse into alternative wavelength spans. The association of such visualization opportunities intertwined to emerging parametric software explorations will unfold unprecedented possibilities for material intelligibility in design ethos.

The amplification of scientific visualization processes at full scalar spectrum has catalyzed specific prospects to control materials enabling the cognition of structures and compositions. Vis-à-vis material advances have revolutionized visualization methodologies (Figure 4). So far the refinement of the analysis of matter is due mainly to three visualization techniques: chromatography, spectrometry and spectroscopic imaging. In the process of matter visualization spectroscopy advances through nuclear magnetic resonance (NMR) which involves the absorption of variable electromagnetic radiation is becoming progressively more crucial. The exact wavelengths emitted by an atom acts as a fingerprint, thus spectroscopy enables studying the wavelengths emitted by a heated substance to identify the specific atoms in it. This technique is allowing chemists to decipher more complex conditions of materials specifically due to the use of pulsed lasers enabling scientists to examine reactive events on timescales of femtoseconds ($10^{-15}$). The mapping of biological reactions in this rapid timeframe creates radically new opportunities for comprehending natural organizational systems (Atkins 2002, 205).

If, as foreseen, design culture incorporates increasingly biomimetic praxis it will inevitably develop new representational methods to register measurable contextual unseen phenomena. It is precisely the surfacing of new design representational methodologies intertwining abstract content to broader visualization of phenomena that will require extensive incorporation of parametrization. The logic behind the grammar for scripting performative criteria of material’s resistances, concessions, adaptations and self-generation intelligence is one of the most crucial factors for innovating biomimetic material systems. As designers and programmers the balance between structural speculations and performative specificity is a hard task in the pursuit of intelligent material ecologies. Expansive exposure to imaging and data processing that reveals ever more unseen phenomena will increase the understanding of the intricacies of mater-structure interdependencies and thus enable advances in the formulation of computational grammar for simulation and exploration of material systems design.

3 Interdependencies

The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not
be worth living. Of course I do not here speak of that beauty that strikes the senses, the beauty of qualities and appearances; not that I undervalue such beauty, far from it, but it has nothing to do with science: I mean that profounder beauty which comes from the harmonious order of the parts, and which a pure intelligence can grasp. POINCARÉ, 1908

Life is a network of living and inert parts that maintain a flow of energy composed by different species, subsets of organisms and their environments creating local systems or ecosystems (Wilson 1988). These ecological communities are formed by complex systems at every scale and every time. Nature’s complexity structured Poincaré’s vision that beauty in ecologies stems from the coexistence of harmonious interrelations of elements, leading him to discover a chaotic deterministic system which laid the foundations of modern chaos theory and topology. The comprehension that ecosystems behave through non-linear interdependencies has shaped the discourse of biodiversity in the latter decades, with definitions that are constantly shifting with increasing ability to process the immense data sets that contribute to the knowledge base. Acknowledging simultaneity as one of ecologies’ essential characteristics has taken course, according to Botkin, through the incorporation of computers which are revolutionizing our conception of nature (Botkin 1990, 114). Botkin conceives that computers are not only providing metaphors for understanding simultaneity but offering real opportunities for advanced parallel processing essential to analyze and visualize processes in nature. In his discussion Botkin diagnoses that the incorporation of simultaneity is particularly significant when integrated with the acceptance that nature is characterized by chance or randomness. Yet, until recent computing advances projections incorporating stochastic processes were unviable. Computers hence are providing the means to decode natural processes by enabling the inclusion of chance and simultaneity, another factor that fortifies the relevance of programming praxis for biomimetic design ethos.

The characteristic behavioral integration of bio-structures is one of the most relevant and intricate factors to address in the design of biomimetic material systems. In defiance of conventional architectural models comprised by material systems designed independently while behaving interdependently, biomimicry requires the formulation of multiple integrated design problem sets. Digital parallel processing becomes ever more necessary as a design tool for the integration of associative variables to formulate and explore performative criteria. In the explorative scripting process of grammar formulation regarding bio-material behavior Thompsian diagrams own uttermost relevance (Thompson 1951, 16). The conception of form in the Thompsian notion as a diagram of forces unfolds the notion that form itself is a combinatory pattern of multiple sources. This vision yields form as a potential combinatory diagram of the interaction of physical, cultural and economic actors positioned in a multidimensional space. And this system of forces formatted into form is inevitably manifested in our world via a material reality. Design research methodologies for bionic systems must then recognize the incorporation of these multifolded forces inclusive of materials’ properties into early performative criteria. This integration refers specifically to extrinsic and intrinsic interdependencies present in bio-material systems.

3.1 INTRINSIC INTERDEPENDENCIES

Successive levels of variable structural organization, distribution, and association constitute materials bio-performative aptitudes. The interaction between exchange processing and structure—arrangement of internal components—is responsible for defining specifically bio-functionality. From subatomic level up the omnipresent interdependency between form and matter is accountable mutually for functional and material expenditure precision.
This associative dependence or matter-form interdependencies is the formation of physical and bio-chemical networks that shape structural differentials across scales of matter in nature. Bio-materials are thus rendered with simultaneous integrative efficiency based on these multi-scalar spatial variables forming intrinsic interdependencies. Most biomaterials fall into the organic category due to their carbon based molecules frequently of polymeric structure. And when we encounter inorganic biomaterials they are generally grown within an organic matrix. This frequent phenomenon yields mineral organisms with great tensional strength distinctive to organic structures.

Organic matrices form in biominerals a template (Ball 1999, 192) that controls the shape and orientation of crystal formations (inorganic composition) extended from atomic to macroscopic scales responsible for the patterning of many skeletal and shell forms. Whether functional optimization occurs through pattern growth control or composite conformation, bio-structures consistently display structural hierarchies. Key example to these scalar hierarchies is human bone for it needs to embody compressive resistance without brittleness, needing to accomplish multiple requirements simultaneously. Its variable scalar structures enable organic and inorganic alternated distributions that perform rigidly and flexibly as necessary. The variable structural thresholds regarding form, biochemical composition and material concentration synergistically create the necessary adaptability and self-generative process that make up bio-intelligence.

Living cells display another significant aspect of natural systems: efficiency: responsiveness. Molecular complexes exhibit bio-chemical and physical alterations capable to respond and adapt constantly to environmental signals. At singular and conjunctive level cells are comprised of structures organized hierarchically from bottom-up by joining increasingly complex structures. Donald Ingber’s studies have demonstrated that cellular responsiveness stems from the physical and bio-chemical properties of their cytoskeleton. Through a process called mechanotransduction (Ingber 1997, 575) force induced modifications of biochemical assemblies add mechanical strength where stresses are most concentrated (Figure 5). Simultaneously, components are eliminated through disassembly or cleavage from low stress loci where they are no longer needed. This process is viable because the cytoskeleton is synergetically structure and catalyst. Environmental responsiveness is built in nature using tensegrity as mechnochemical adaptable constructs virtually at scales enabling flexible control systems. Combined with the multi-scalar variable structural hierarchies flexible control systems provide for integrative individual or collective local
As the comprehension of underlying design principles of cells’ formations is deepened, significant clues for assigning responsive attributes in the exploration of material systems through scripting methods will be advanced.

4 Material Syntax

Material scientists are incorporating ever more computer-aided visualization to obtain quantitative and qualitative information of material systems. Ranging from crystallography to nanostructure simulation, explorations of bio-chemical and morphological dependencies are increasingly more tangible. In fact, the examination of material data using advanced vector, tensor (continuous positional variables), and scalar visualization capabilities is enabling the manipulation of time-dependent information and complex geometries, such as computation of molecular surfaces. As designers we confront the paradigm of how to integrate these opportunities in the research and development of material systems bio-intelligence. Axel Ritter’s polycreative mechanomembrane (Figure 6) project is exemplary of the intricacy involved in the development of bionic envelopes aiming at material bio-intelligence. The weather-dependent kinetic membrane is composed of multiple functional units and subunits encompassing thermobimetals (metals composite with different thermal expansion coefficients) reactive to temperature and humidity. The multi-faceted system enables contractile and expansive membrane actions depending on the energy state emulating performative skin conditions.

Undoubtedly, the formation of multi-scalar material research strategies is a design endeavor that addresses quantitative variables with the aim to structure qualitative conditions. This methodology applied via parametric simulation exercises design logic by defining organizational variables through the intrinsic interdependencies between matter and form. Stemming from a bottom-up system that acknowledges biochemical, mechanical and geometrical conditions, structural hierarchies are assessed to formulate distinctive operations. Rising architectural research methodologies (Figure 7) are turning to address the latter conditions as a design problem when developing biomimetic material systems. The development of these studies is bound to engender material systems that can tentatively approximate bio-intelligence through bio-intelligibility.

4.1 ASSOCIATIVE GRAMMAR

The integration of emerging opportunities stemming from integrating material science’s computational imaging advances is complex. Beyond the cumbersome linguistics of conversing with architecture’s rather extraneous datasets is the specific formulation of associative raw data to structure design operations. Incorporation of early performative criteria into scripting explorations constructed through structural dependencies of physicochemical and geometrical associations can yield significant design research opportunities. An example of this research strategy is the bio-synthetic wall composite SugarWall (Gensler+Gutierrez 2006a, 2006b). This project implemented an analysis of structural thresholds of sucrose and PMMA to develop a material matrix to produce higher light diffusion, refraction and thermal efficiency than an equivalent synthetic (PMMA) wall system. With an emphasis on addressing simultaneously intrinsic and extrinsic material paradigms, this wall system sought how to associate tentatively bio-compatibility and key physicochemical factors into the scripting of performative criteria (Figure 8).

Sucrose, a plant derivate, was used as organic-grown infill due to its socio-economical benefits, bio-degradability, light refraction potential and compatibility with PMMA (McLaren et al., 2007). Scripting was probed into morphologies integrated with variable sucrose
concentration and densities to test light diffusion, transmission and weight optimization processes while retaining structural stability. Equations where constructed by associating sucrose density (g/cm$^3$) to variable PMMA volume (kg/m$^3$) and gravity (gn); (Figure 9—modular equation A; final scripting—B). Essential to this model is the incorporation of the form-material variables into the fabrication process using gravity (casting) as an explorative tool of material (infill) concentration (Figure 10—casting process).

The project yielded a wall system with higher refractive index (1.52) than equivalent standard wall system of PMMA (R.I.=1.49) at comparative flexural and compressive strength with a concentration of 66% sucrose infill. As such, it presents a wall system that is 2/3 organic-grown matter. The variable morphologies and sucrose concentration composed a system that is opaque (verso) and transparent (recto), unfolding potential opportunities for architectural phenomenal applications (Figures 11).

5 Conclusions
Visualization of unseen phenomena and comprehension of material’s scalar and structural interdependencies to shape bio-responsiveness will become increasingly more accessible in the next decades. As this unfolds, design culture will progressively assimilate the latter performative conditions into its discourse, representation, and practice formulating alternative research methodologies. Accounting for our own subjectivity when transporting natural systems’ attributes into design explorations remains inevitably as an open question. While influenced by inherent subjective decisions it is clear that architectural parametric grammar structured from explorative physico-chemical and cultural associations can originate rather than accommodate material bio-tectonics.

6 References